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A SIMULATION MODEL FOR WIND ENERGY STORAGE SYSTEMS

Volume II: Operation Manual

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16. Abstract

The effort developed a comprehensive computer program for the modeling of wind energy/storage systems utilizing any combination of five types of storage (pumped hydro, battery, thermal, flywheel and pneumatic). An acronym for the program is SIMWEST (Simulation Model for Wind Energy Storage). The level of detail of SIMWEST is consistent with a role of evaluating the economic feasibility as well as the general performance of wind energy systems.

The software package consists of two basic programs and a library of system, environmental, and load components. The first program is a precompiler which generates computer models (in Fortran) of complex wind source/storage/application systems, from user specifications using the respective library components. The second program provides the techno-economic system analysis with the respective I/O, the integration of system dynamics, and the iteration for conveyance of variables. This SIMWEST program, as described, runs on the UNIVAC 1100 series computers.

This technical report contains three volumes. Volume I gives a brief overview of the SIMWEST program and describes the two NASA defined simulation studies. Volume II, the SIMWEST operation manual, describes the usage of the SIMWEST program, the design of the library components, and a number of simple example simulations intended to familiarize the user with the program's operation. Volume II also contains a listing of each SIMWEST library subroutine. Volume III, the SIMWEST program description contains program descriptions, flow charts and program listings for the SIMWEST Model Generation Program, the Simulation program, the File Maintenance program and the Printer Plotter program. Volume III generally would not be required by SIMWEST user.

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FOREWARD

This report presents results of work conducted by Boeing Computer Services Company under NASA Contract NAS3-20385, "Wind Energy Storage Model Development." This program was conducted under the sponsorship of the Advanced Physical Methods Branch, Office of Conservation, ERDA, under the direction of Dr. G. C. Chang, and was administered by the NASA-Lewis Research Center Thermal and Mechanical Storage Section with Mr. L. H. Gordon as Project Manager. This report is in three volumes.

I. Technical Report
II. Operation Manual
III. Program Descriptions

The Boeing Program Manager for this work was R. W. Edsinger, and A. W. Warren was the principal investigator.

For completeness, the summary sections 1.1 and 1.2 of Volume I have been repeated in the Operation Manual, Volume II.

1.0 INTRODUCTION

Energy storage systems for the utilization of intermittent power sources have received increased study over the past few years. However, the type and degree of storage required for optimal utilization of wind energy and the total costs and utility of the resulting wind turbine/generator/storage system have not been thoroughly analyzed. The purpose of the SIMWEST (Simulation Model for Wind Energy Storage) program described in this document is to provide a tool for performing this needed analysis. It is a tool to aid in the design of an optimal wind energy system for a given application and to allow the resulting system to be evaluated and verified through realistic simulation.

SIMWEST consists of a library of system components and a precompiler program which allows these components to be put together in building block form. The present library contains components for five types of energy storage systems. They are pumped hydro, battery, thermal, flywheel, and pneumatic. The SIMWEST program, as described here runs on the UNIVAC 1100 series of computers.

Other computer programs exist for the simulation of wind systems and various forms of energy storage. However SIMWEST is the only program capable of simulating total wind systems containing any one or combination of the above types of storage and at the same time having the flexibility and depth required to perform thorough and meaningful parameter studies.

1.1 GENERAL APPROACH

The structure and much of the software for the SIMWEST program is based on a computer program called EASY, which was prevously developed by Boeing Computer Services, Inc. (BCS). SIMWEST consists of two basic programs, and a library of system, environmental, and load components. The first program, the Model Generation Program, is a precompiler which generates computer models (in FORTRAN) of complex wind energy generator/storage/application systems, from user specifications using SIMWEST library components. The second program exercises the resulting computer model to perform cost and potential utilization analysis. It handles input, output, integration of system dynamics, and iterates to obtain convergence of variables involved in implicit loops. The combination of these two programs provides a powerful tool for analyzing alternate storage system designs.

Figure 1-1 shows the general organization of the SIMWEST program. In addition to the two programs described above, there is a third which performs file maintenance. It is used to incorporate user supplied data for new subsystem models. Although the program is shown to be made up of a number of subprograms, it can be executed as a single batch program by supplying the model description control cards and the control cards describing the desired analysis to be performed and the desired tabular and/or plotted output.

1.2 SIMWEST LIBRARY

1.2.1 Overview

The SIMWEST library is listed in Table 1-1. It is made up of five types of components: physical, environmental, load, logical, and utility.

Physical components encompass such things as motors, generators, transmissions, flywheels, etc. These components model actual physical hardware which might be used in a wind energy system. The selection of the particular SIMWEST library set of physical components was based on the requirement that it be capable of modeling five types of energy storage systems mentioned previously: thermal, flywheel, battery, pumped hydro and pneumatic.

The degree of detail in the component models is based upon two design criteria. First, all models should contain sufficient detail to simulate all physical characteristics and constraints having significant impact on the systems overall cost effectiveness. Second, the models should be designed to minimize computer time and required user specification. It is assumed that a typical SIMWEST simulation might cover a time span of one year. Thus

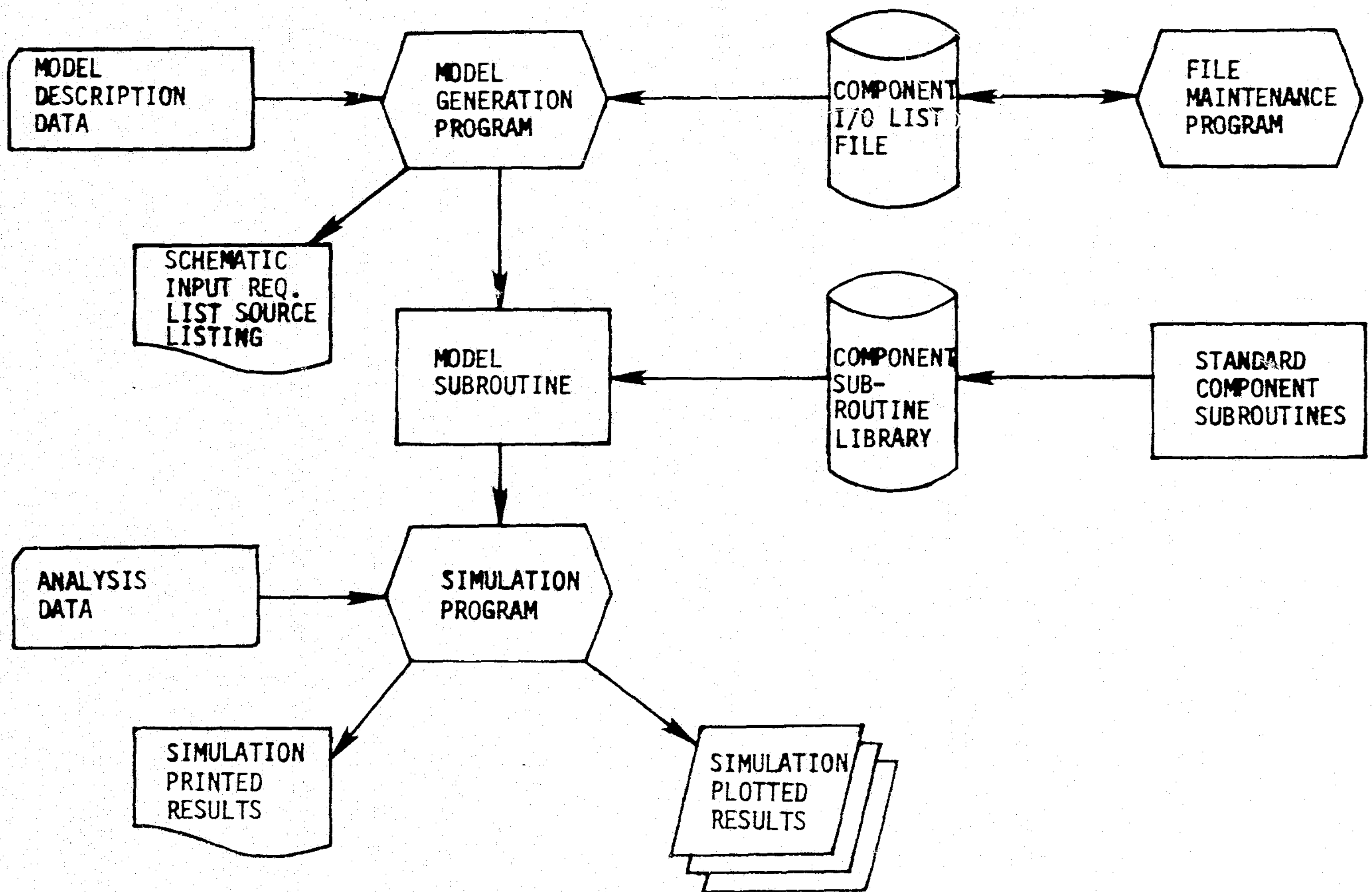

FIGURE 1-1 SIMWEST PROGRAM ORGANIZATION

TABLE 1-1 SIMWEST LIBRARY COMPONENTS

PHYSICAL

WIND TURBINE	WT
TURBINE/GENERATOR	WP
AC INDUCTION GEN.	GE
FIXED RATIO TRANSMISSION	GR
RECTIFIER	RE
BATTERY	BA
INVERTER	IV
ADMITTANCE	AD
COMPRESSOR (PNEUMATIC)	CO
ADIABATIC HEAT EXCHANGER (INPUT CYCLE)	HX
ADIABATIC HEAT EXCHANGER (OUTPUT CYCLE)	HY
PNEUMATIC STORAGE VESSEL	CS
BURNER	BN
TURBINE (PNEUMATIC)	TU
INDUCTION MOTOR	MO
VARIABLE RATIO TRANSMISSION	TR
FLYWHEEL/CLUTCH	FL
PUMP (HYDRO)	PU
TURBINE (HYDRO)	HT
HYDRO STORAGE	HS
THERMAL STORAGE	TS
UTILITY	UT

ENVIRONMENTAL

WIND	WD
AMBIENT TEMP	TP

LOAD

ELECTRICAL LOAD	LO
THERMAL LOAD	TL

LOGIC

POWER DIVIDER	PD
POWER ACCUMULATOR	PA
PRIORITY INTERRUPT	PI
SWITCH	SW,SX,SY,SZ

UTILITY

COST MONITOR	CM
SATURATION	SA
RANDOM NUMBER GENERATOR	RN
TEST FUNCTIONS	AF
TABLE LOOKUP	FU,FV
TRANSFER FUNCTION	IT,LA,LL,TF
ARITHMETIC ELEMENT	MA,MB,MC
HISTOGRAM	HG
TAPE READ	TA
TIME CONVERSION	TI

from a computer run time and economic impact point of view a simulation step size of between 15 minutes and one hour seemed reasonable.

As a result of the above two design criteria many physical components, such as the electrical components, were modeled mainly in terms of power flow and steady state response. This lack of detail is consistent with the 15 minute time step and with the concept that the important transients are on the time scale of demand curves or weather patterns, i.e. an hour or more, rather than on the time scale of electric motor transients of a few seconds. If short electric transients were to be modeled, much detail would need to be added to the component models which would greatly increase the user's task of specifying the model. Further, the simulation time step would have to be reduced to a fraction of a second so the model would not only be much larger but computer runs would be much costlier.

Environmental components are those which simulate environmental conditions. In the present SIMWEST library these conditions are wind speed and ambient temperature. These variables are generally used as inputs to physical components. Environmental component output can either be computed from measurement data provided by the user on a data tape, or from randomly generated data, based on user furnished profiles.

The load components in the SIMWEST library are used to simulate various types of power demand. They also monitor how well the system meets the simulated demand and compute the value of the energy delivered by the wind energy system to the load. Like the environmental components these components may be computed from actual measurement data or from randomly generated data based on user furnished load profiles.

The library's logical components are the power dividers, power accumulators, switches and priority interrupts. Although physical hardware could generally be built to serve the function of the logical components, they are not meant to represent any particular piece of existing hardware. Instead, they are idealized components that allow the user the flexibility of modeling the wide variety of control logic which a wind energy storage system would require. In practice, the control function might be performed by a control room operator using a predefined control strategy or by use of a minicomputer.

Finally, the utility components include such things as the tape read, the histogram and the cost monitor. These components serve only to help the user run the simulation and analyze its results.

1.2.2 Storage Subsystems

Figures 1-2 through 1-6 give example configurations of the five types of storage subsystems which can be modeled with the present SIMWEST library. For illustrative purposes the number of variables shown passed between components is limited. A description of the variables being passed is given in Table 1-2.

A total wind energy system will generally be made up of elements from a number of different subsystems (see Figure 1-8). In addition, the SIMWEST program can be used for models which include networks of storage subsystems of the same type or a network of wind generators.

1.2.3 Logic Components

The capability for modeling complex system control logic is provided by the power divider, power accumulator and priority interrupt components. Both the divider and accumulator operate on a priority basis. The priority interrupt is used by other system components to change the priority setting of the divider and accumulator.

The power divider has one input power port and four output power ports (not all output ports need be used for a given simulation). The divider also has

TABLE 1-2 PARTIAL LIST OF COMPONENT INPUTS AND OUTPUTS

SYMBOLS	
P	POWER
RE	POWER REQUEST
MP	MAXIMUM POWER
RS	ROTOR SPEED
T	TEMPERATURE
TA	AMBIENT TEMPERATURE
M	MASS FLOW RATE
H	RESERVOIR HEIGHT
LD	THERMAL LOAD DELIVERED
WV	WIND VELOCITY
GR	GEAR RATIO
EF	EFFICIENCY
INT	INTERRUPT FLAG
TSO	MINIMUM AIR TEMPERATURE
PR	PRESSURE
PS	PRIORITY SEQUENCE
WY	WEEK OF YEAR
DW	DAY OF WEEK
TD	TIME OF DAY
SP	SURPLUS POWER
VAR	FILE READ VARIABLE

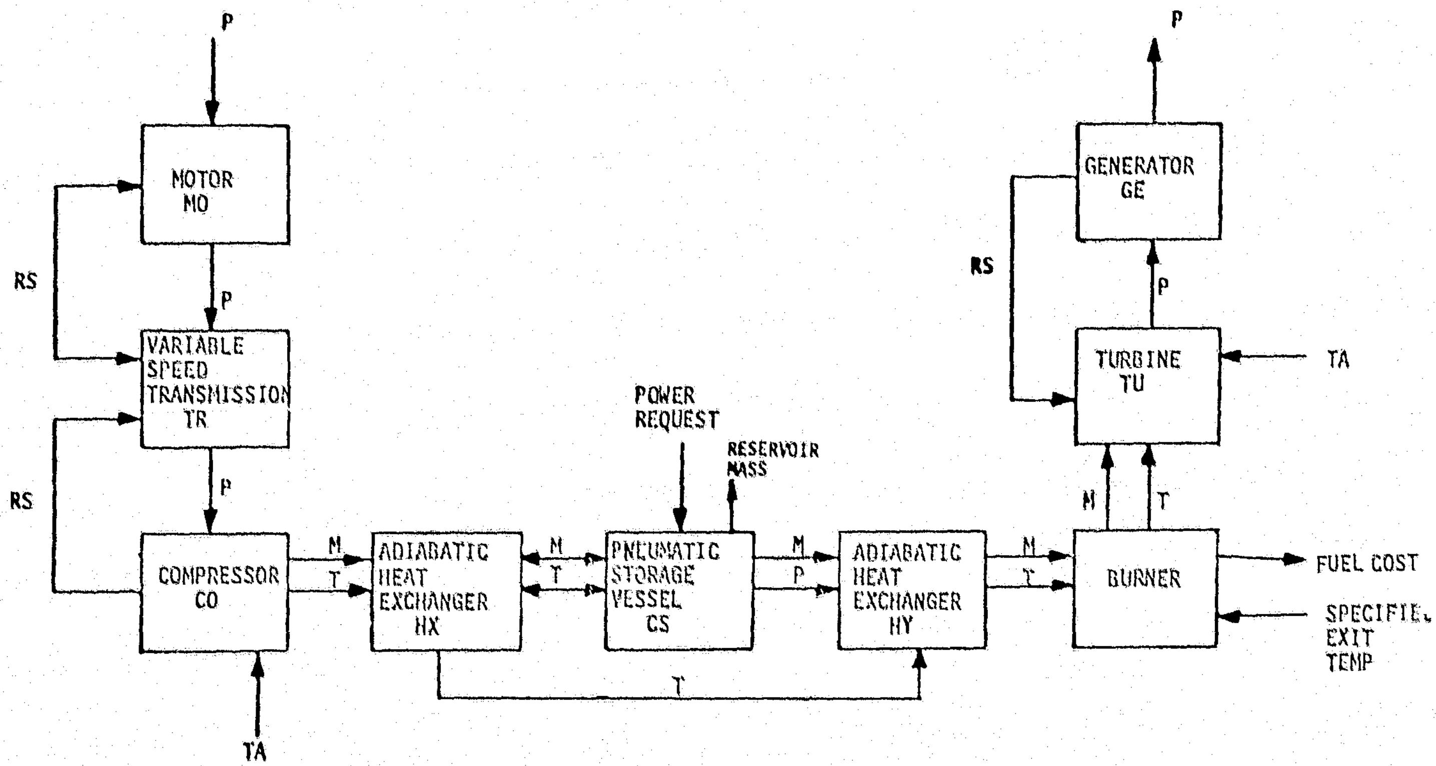

FIGURE 1-2 PNEUMATIC STORAGE SUBSYSTEM

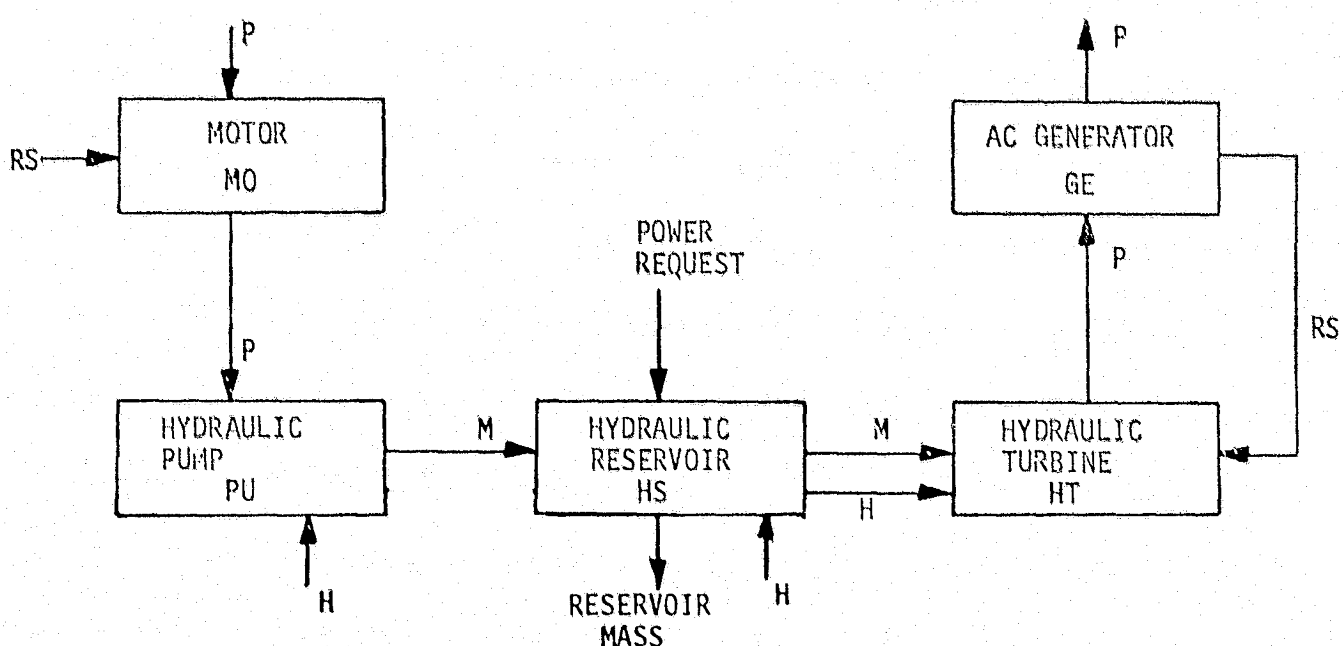

FIGURE 1-3 PUMPED HYDRO STORAGE SUBSYSTEM

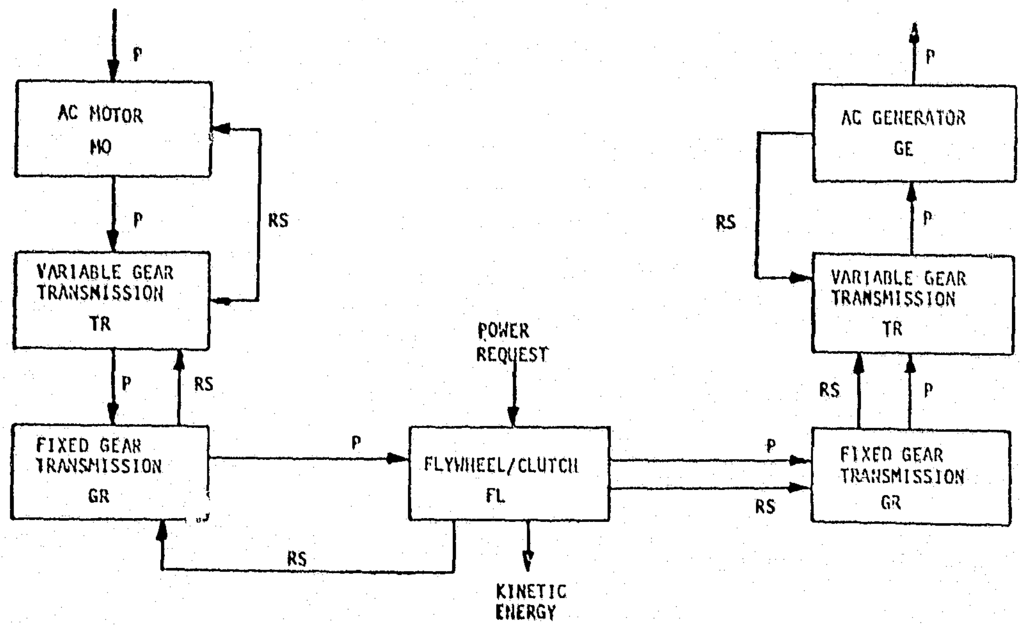

FIGURE 1-4 FLYWHEEL STORAGE

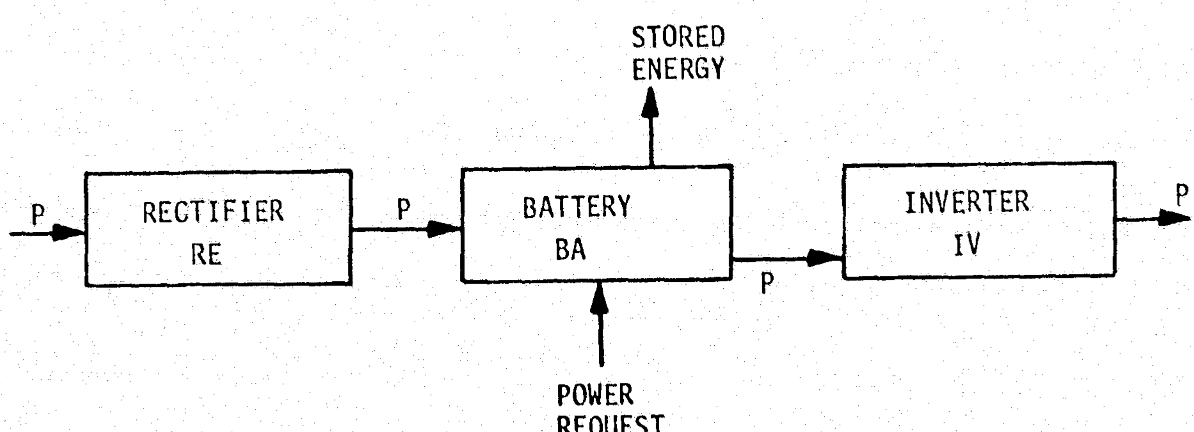

FIGURE 1-5 BATTERY STORAGE

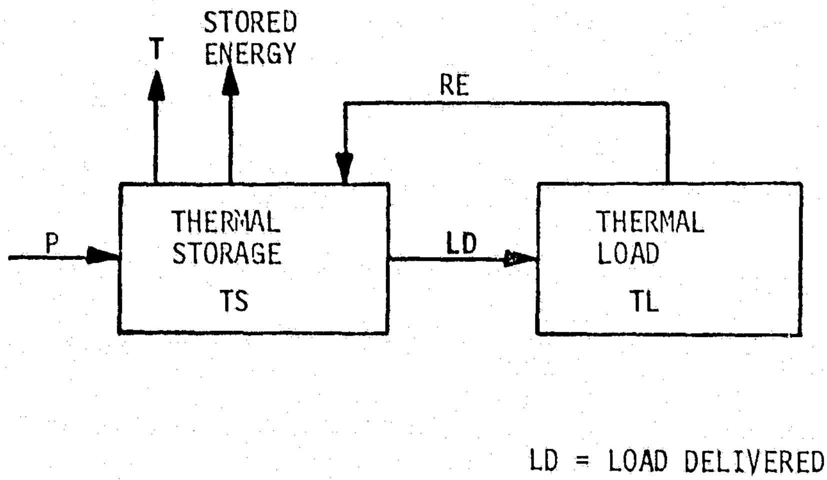

FIGURE 1-6 THERMAL STORAGE

an input request associated with each of its output power ports. These power requests generally come from a component with which the output power port is directly or indirectly connected. The user specifies priorities of either 0,1,2,3, or 4 to be associated with each of the output ports. If the input power to the power divider exceeds that requested of the port with highest priority (priority 1) then the excess power goes to the port with the next lower priority. This process continues until either all power is distributed or all requests of non-zero priority ports are met. A port with zero (0) priority will never receive power. Such ports are included so that the port may be connected to a component but transmit power only in critical situations, say, when a battery has been in discharge state for a critical amount of time. In these situations, the connected component would have to change the zero priority setting of the power divider by use of a priority interrupt.

Two or more ports may be assigned the same priority in which case the user may specify weights to be associated with each port. Then if there is not enough power available to satisfy all requests of equal priority the power is divided between them in proportion to the user specified weights.

The power accumulator is similar to the divider except that instead of distributing power from a single input port between four output ports, it accumulates power from four input ports and sends it out through a single output port. The power accumulator also accepts output power requests from the component connected to its single output power port and it outputs requests for each of its input ports in order to service the output power request.

In addition to the actual power delivered to each input port, the power accumulator also accepts information as to the maximum power that can be delivered to that port. These values are used by the accumulator to determine how to distribute its power request between its four input ports. If the input power request exceeds the maximum deliverable power for the port of highest priority, then the remainder is shifted to the port with the next lower priority. This process continues until either the power request has been completely distributed between the highest priority input ports or all input ports have requests equal to their maximum deliverable power. An example illustrative of the use of power dividers and power accumulators is given in Figure 1-7.

Here the wind turbine distributes power first to satisfy the request from load 1. If there is power left over, it then tries to satisfy the request from the battery. Finally, if the battery is full or if its charging rate is met, then the excess power goes to the flywheel. The battery is connected to the wind turbine and also has a priority zero connection to the utility. Thus, if the battery remains in a discharge state for more than a specified amount of time, it can change the utility priority (from 0 to 1) to receive the needed power.

Also in Figure 1-7, we see that load 2 prefers to draw power from the flywheel before turning to the battery. This configuration tends to keep the flywheel as discharged as possible, using it primarily as a means to absorb large influxes of power.

Figure 1-7 is a rather simple configuration used for illustrative purposes. A more complex configuration is shown in Figure 1-8.

1.2.4 SIMWEST Output

There are three basic forms of SIMWEST output to facilitate the analysis of wind energy storage systems; line printer plots, histograms of system variables and time sequenced output of variable values. To enhance the usefulness of these outputs each SIMWEST library component is associated with a number of output variables. Prior to simulating a given system the user specifies which of these variables he wants plotted. For plotted output he may select to have the independent variable be the plot time or any of the other variables. For example he may want to plot the energy of pneumatic storage as a function of time and/or as a function of storage versus temperature. If the user wants s time sequenced listing of all variable values

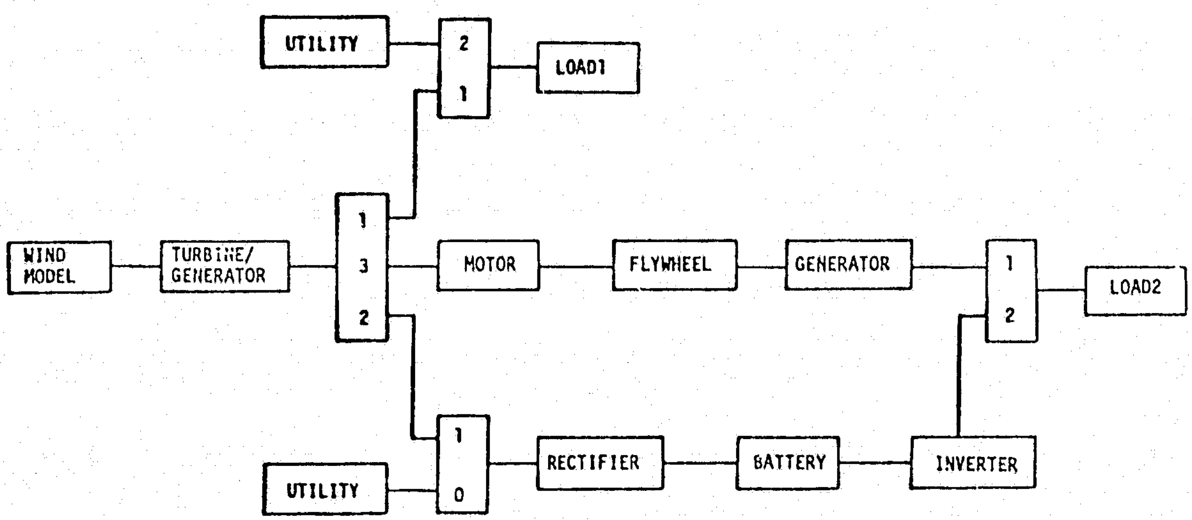

FIGURE 1-7 EXAMPLE OF POWER DIVIDER & ACCUMULATOR USE

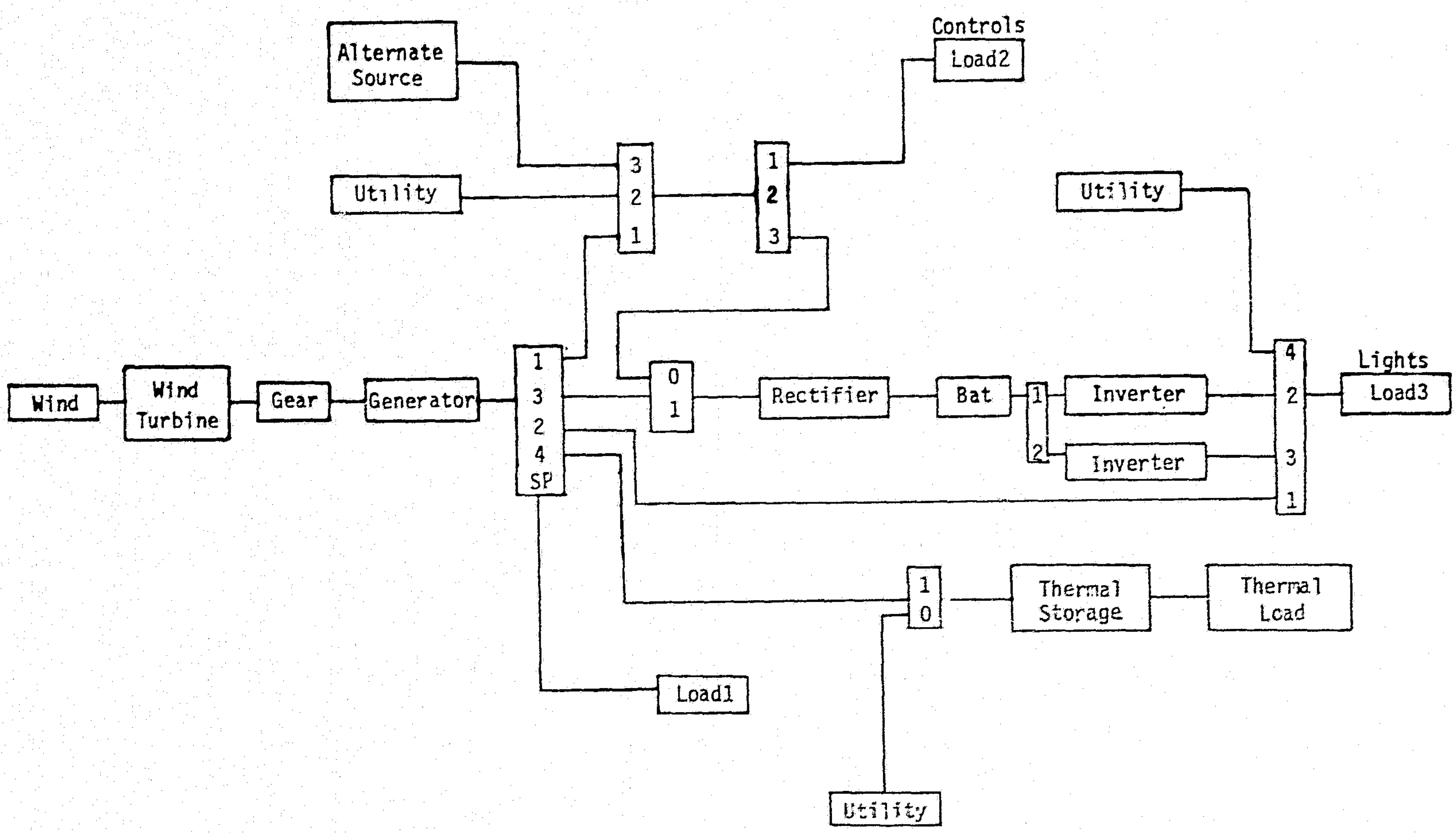

FIGURE 1-8 PLUMBROOK CONFIGURATION FOR PARAMETER STUDY

he just specifies the time step between printouts. The listing of all variables has proven to be a useful tool in understanding the performance of the storage system under consideration and a valuable aid in validating the system design.

2.0 MODEL GENERATION

The Model Generation program design is based on the assumption that the system analyst will begin by constructing a schematic diagram of the system he wishes to analyze. This schematic will be comprised primarily of standard SIMWEST library components. Standard library components include wind turbine, wind models, AC induction motors, inverters, rectifiers, etc. If a particular system cannot be modeled with existing standard components, the analyst may construct the model by including appropriate FORTRAN statements in his system description.

All interconnections between standard components are accomplished by the Model Generation program. The analyst merely specifies each standard component in the schematic diagram and all of the components that provide inputs to that component. The Model Generation program then generates names and the proper interconnections between the specified components. This is accomplished by matching the input quantities required by each standard component to the output quantities of the specified input components.

After processing the complete system model description, the Model Generation program generates a schematic diagram of the model showing the interconnections between standard components and the quantities such as power, pressure, temperature, mass flow rates, etc., that pass through each interconnection. This schematic is produced on the lineprinter to provide a rapid graphic check on the program's interpretation of the model description.

In addition, the program produces a list of input data that will be required by each component to complete the model description. Both the scalar parameters and tabular data required for the analysis are included in this list. The program assumes that any quantity not supplied by another component will be supplied as a fixed parameter by the analyst. Thus requests for non-parameter items in the input data list will reveal any connection that was omitted from the system model description.

2.1 MODEL DESCRIPTION

The Model Generation program is a precompiler program which accepts model description instructions and from these instructions generates a FORTRAN model of a system. These instructions, referred to as "program commands," are made up of one or more words. In addition, the system model description contains numeric values, standard component names, and standard input and output quantity names.

The Model Generation commands may be best introduced with a simple example of their use to describe a wind turbine system. Figure 2.1-1 shows an analyst's schematic of a wind turbine model that has been constructed using standard components on a SIMWEST schematic form. The standard component names used in this sample are:

WD - Wind Model
WT - Wind Turbine
TI - Time Conversion
HG - Histogram Generator
GR - Fixed Ratio Transmission
LO - Electrical Load
GE - AC Induction Generator

The SIMWEST description of this model would be as follows:

Example 2.1

```
LIST STANDARD COMPONENTS
MODEL DESCRIPTION        WIND TURBINE TEST CASE
LOCATION=15      TI
LOCATION=11      WD       INPUTS=TI
LOCATION=31      WT       INPUTS=WD
```

SIMWEST SCHEMATIC FORM

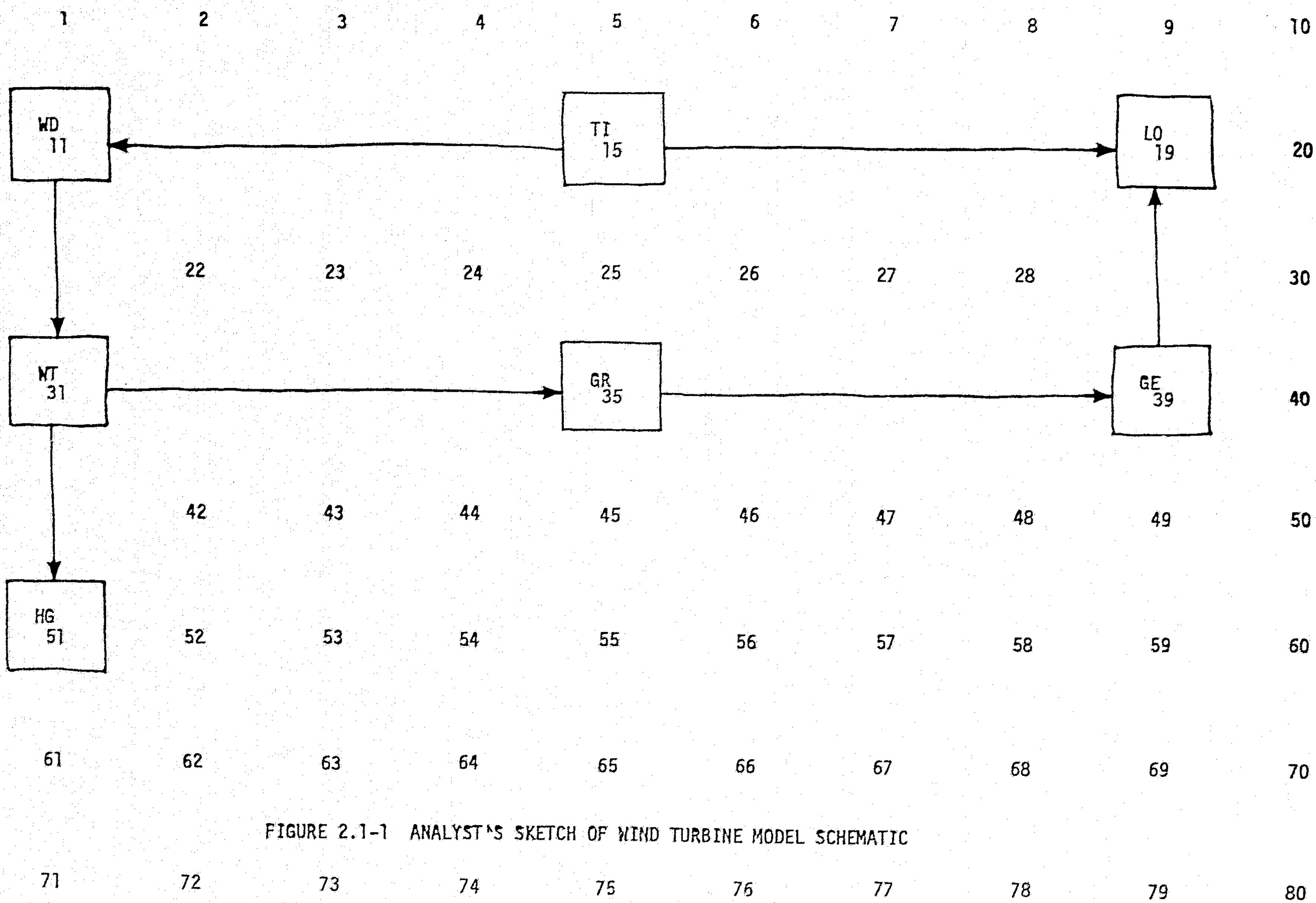

FIGURE 2.1-1 ANALYST'S SKETCH OF WIND TURBINE MODEL SCHEMATIC

Example 2.1 (Cont.)

```
LOCATION=35    GR    INPUTS=WT
LOCATION=51    HG    INPUTS=WT(P =FIN)
LOCATION=39    GE    INPUTS=GR
LOCATION=19    LO    INPUTS=GE,TI
END OF MODEL
PRINT
```

The model description consists of a statement as to the location of each component in the schematic and a list of all components that provide inputs to that component. The location of the component in the schematic is used for a line printer drawn schematic of the model, such as shown in Figure 2.1-2. In the line printer schematic the input and output quantities such as powers (P2 WT, P2 GE, P2 GR) are shown on the various connecting lines.

2.1.1 Phrases and Delimiters

The system model description is interpreted by the Model Generation program as a series of "phrases", which can appear in a free field format in any position on a data card. Phrases must be separated by any one of the delimiter symbols shown in Table 2.1-1.

Table 2.1-1

Model Generation Program Language Delimiters
= equal sign
, comma
(left parenthesis
) right parenthesis
three or more blanks

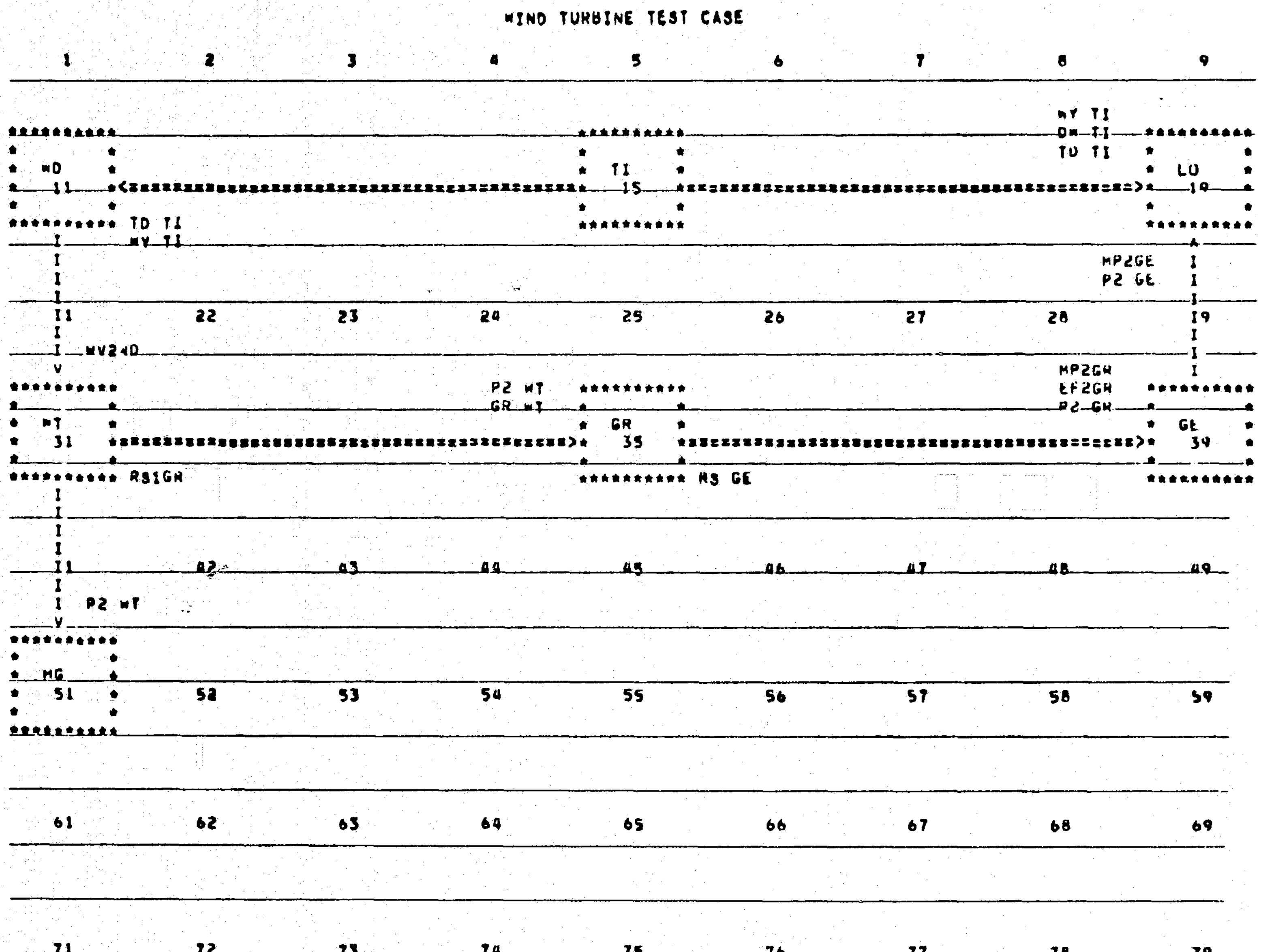

FIGURE 2.1-2 LINEPRINTER-DRAWN WIND TURBINE MODEL SCHEMATIC

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2.1.2. Command Phrases

The Model Generation command phrases are described in this section in a logical sequence similar to that in which they appear in system model descriptions.

MODEL DESCRIPTION

The MODEL DESCRIPTION command phrase indicates the start of a new system model. This phrase may be followed, (on the same card), by a title of up to 60 characters. This title will be used to identify various program output schematics, lists and program listings. In Example 2.1, the title was "Wind Turbine Test Case."

LOCATION

The LOCATION command phrase indicates the start of the description of a new component in the system model. This command must be followed by a numeric value phrase that specifies the location of the new component on the model schematic. Thus in the example of Figure 2.1-1, the location number of the wind model WD was 11 and the wind turbine WT was 31, etc. To be a valid component location, the last two digits of this number must comprise a number between 1 and 80. The hundreds column is used to specify additional pages as needed for the schematic. Thus the numbers:

1, 13, 51, 80

would be valid location numbers for components on the first page, (PAGE 0), of a system schematic. These same locations on the second page of the schematic, (PAGE 1), would be:

101, 113, 151, 180

The location number phrase is followed by the name of the component at that location. Component names are discussed in Section 2.2.

A LOCATION statement should be given only once for each component. That is, once a LOCATION statement is started for a component the complete description of all inputs to that component should be given.

INPUTS

The INPUTS command phrase indicates that the following phrases contain the names of the components that provide inputs to the component at the specified location. Thus in the example of Figure 2.1-1, the electric load at location 19 which receives inputs from generator GE and the time source TI was described as:

```
LOCATION=19     LO      INPUTS=GE,TI
```

In this example the command phrase INPUTS is followed by two component names. As many component names as are necessary to specify the inputs to a particular system component may be included in each component description.

For some system components there are multiple input and/or output ports. For example, a power divider has four input power ports. When specifying the connections between such components, it is advisable to specify which ports are to be connected. This is done by adding the port numbers to be connected after the name of the input component. Thus, the wind turbine to transmission connection could have been more explicitly described as:

```
LOCATION=35     GR      INPUTS=WT(2,1)
```

This says that port 2 of the wind turbine (WT) drives port 1 of the transmission (GR). Any quantities which have no port numbers are considered "universal ports" for input connections. Thus, the GR input of GR is connected up to GR WT, and the RS input of WT is connected up to RS|GR by the above command. If the port designations are omitted, as they were in example 2.1., the connections will be made to the first available input port starting with the minimum port number. Once a connection has been made to an input port, those input quantities that are connected are unavailable for further connections. An exception is made when the physical quantities of both input and output are specified. This method of specifying connections is described in the following paragraphs.

For certain components, such as control elements, the inputs to the component can be any physical quantity in the model. For these components, the input component names must be supplemented by the name of the particular output quantity that is to provide the input.

As an example, consider a component that represents a linear first order lag transfer function. If the transfer function component's input, FIN, was to be the rotor speed of the wind turbine WT in example 2.1, then the statement:

```
LOCATION=53     LA     INPUTS=WT(RS=FIN)
```

would indicate to the program that of the outputs of the wind turbine, the output rotor speed, RS, was to be used as the input, FIN, to the transfer function, LA.

To summarize, there are three levels of connection specification:

1. Default (only component names are specified)

   Connections are made between all unconnected inputs and outputs for the first ports for which a match of physical quantity names occurs.

2. Ports Specified

Connections are made between matching physical quantities for all unconnected inputs and outputs of the specified ports.

3. Physical Quantities Specified

Connections are made between only those quantities specified. Previous connections can be over-ridden, providing the three character physical quantity name of the previously connected variable is used. For example, the phrase

```
LOCATION=19     LO     INPUTS=GE,GE(P,2=MP2),TI
```

will replace the input parameter MP1LO by MP26E and then override the connection MP2GE and substitute P2 GE as the LO input.

END OF MODEL

The END OF MODEL command phrase indicates that model description has been completed and that the Model Generation program should proceed with the generation of the model subroutines.

PRINT

The PRINT command phrase causes the program to: (1) draw a schematic of the system model, as shown in Figure 2.1-2; (2) print a list of input requirements for the model; and (3) print a source listing of the FORTRAN subroutines that were generated for the model. The Model Generation program then terminates.

PUNCH

The PUNCH command phrase has the same effect as the PRINT command, but in addition a FORTRAN source deck of the system model is produced.

FORTRAN STATEMENTS

The FORTRAN STATEMENTS command phrase allows the system analyst to supplement the library components with FORTRAN statements. Using this feature, the analyst can introduce his own program logic, DO loops, etc., as necessary to model any system feature not obtainable with standard library components.

One of the common uses of the FORTRAN STATEMENTS command is to input large tables into the model. Two function subprograms TBLU1 and TBLU2 are provided for this use. They perform linear interpolation from one and two dimension tables, respectively. TBLU1 is in general called in the form

F = TBLU1(X,TAB(4),TAB(4+N),I,±N),

where F is the interpolated value at the desired point X, TAB is a one dimension table with dimension N, TAB(4) is the independent variable and TAB (4+N) is the dependent variable list, I = 0 for equal spaced data, I = 1 for unequal spaced data, and the dimension N is specified as the last variable if linear extrapolation is desired, and -N is specified if truncation is desired outside the table limits. Similarly, TBLU2 is in general called using the form

F = TBLU2(X,Y,TAB(4+M),TAB(4),TAB(4+M+N),IX,IY,±N,±M,N,M),

where X and Y are the values of the primary and secondary independent variables, N and M are the dimensions of the primary and secondary variable arrays, IX and IY are indicators for equal spaced or unequal spaced data as above, and the sign convention on N and M is positive for extrapolation, negative for truncation.

The FORTRAN STATEMENTS command would normally be used only when some portion of the system cannot be modeled with library components. Then using this feature of the program, the analyst must perform many of the detail connections and naming of variables, that are normally accomplished by the Model Generation program. In return for these added tasks, the analyst gains a great deal of additional freedom and flexibility in forming details of his system model. Non-executable code such as common blocks must precede the first component definition and executable code should come after a component has been defined for the iteration logic to work properly.

ADD STATES
ADD VARIABLES
ADD PARAMETERS
ADD TABLES

The ADD commands may be used in conjunction with the FORTRAN STATEMENTS to add states, variables, parameters, and tables that occur within the FORTRAN statements, to the system model. Quantities that are not specified by one of these commands cannot be accessed or manipulated by the Analysis Program.

Before discussing these commands, a few definitions of terms are in order.

States: States are those quantities in the system model that are described by first order differential equations. The state variables are the result of integrating the set of first order differential equations that comprise the dynamic system model. The number of states equals the order of the system model. The states are dynamic, time varying quantities during most simulation studies. The initial values, (initial conditions), of the states must be input as part of the system model description.

Variables: Variables are all other dynamic time varying quantities in the system model that are not states. In general, variables are related to states by algebraic relationships.

Parameters: Parameters are constant scalar quantities in the system model. Parameters can be manipulated by the analyst to alter the system model. All parameter values* should be input as part of the system model description.

Tables: Tables are constant nonscalar quantities in the system model. Tables are used to represent algebraic functional relationships with one or two independent variables. All table values must be input as part of the system model description.

The format for the ADD commands is that the command is followed by one or more phrases that contain the names of the states, variables, parameters, or tables. In addition to each table name, a number, specifying the amount of storage to be allocated for that table must be given. This number is positive if the table is two dimensional and negative if one dimensional, with absolute value determined by the formula:

$$N = 3 + I + J + D$$

N = the total storage required by the table, in words.

* For certain components, default values are provided for some parameters.

I = the number of data points in the primary independent variable table.

J = the number of data points in the secondary independent variable table. (J=0 if there is only one independent variable.)

D = the number of data points in the dependent variable table. (D=I if there is only one independent variable. D=I*J if there are two independent variables.

The following example illustrates the use of FORTRAN STATEMENTS in the parameter study model:

Example 2.2

```
          MODEL DESCRIPTION     PARAMETER STUDY
                   .
                   .
                   .
          ADD TABLES = WIND,802
          LOCATION = 41    TI
          FORTRAN STATEMENTS
          C          READ WIND VELOCITY DATA
                 WVIWD = TBLU2(TD TI,DY TI,WIND(35),WIND(4),
                1 WIND(59),0,0,24,-31,24,31)
          LOCATION = 71    WD    INPUTS = TI
                   .
                   .
                   .
```

In this model, Fortran is used to input wind velocity data. The wind table, denoted WIND, consists of up to 31 days of hourly wind speeds. Hence, as described previously, the total storage required is 3+24+31+24*31=802. The Fortran is inserted after time of day and day of the year are computed in TI. In this case, N=24, M=31, the data is equal spaced, and extrapolation is used to provide velocity data over each 24 hour period. The variable WVIWD is the name at the wind input to WD generated by the precompiler. Fortran insertion in the model ends when the LOCATION=71 ... command is read and a call to the subroutine WD is then generated.

LIST STANDARD COMPONENTS

The LIST STANDARD COMPONENTS command phrase causes the program to print a list of all standard components. For each standard component, lists of inputs, outputs, and tables for that component are provided. For each input, the physical quantity name and port number is given. For each output, the physical quantity name, port number, and the letter S, if the quantity is a state is given. For each table, the table name, the number of independent variables and the maximum amount of storage allowed is provided. This command is usually given as the first command of a model description and will result in a list of all standard component information as the first output from the Model Generation program.

2.2 NAMING CONVENTION

All standard components are given names consisting of two characters, the first of which is alphabetical. Thus we have WT for wind turbine, GE for generator, WD for wind model, etc. Where multiple components of the same type are required, the second character is used to distinguish between the different models of the same basic component type. A specific component in a model can be distinguished from other components of the same type by adding one more character to the standard component name. This character is usually numeric but can also be alphabetical or blank. Thus a given model can contain up to 37 different components of the same standard component type. For example, a model with ten different wind turbines might have these components designated as:

WT1,WT2,WT3,.....,WT8,WT9,WTA

2.2.1 Variable, Parameter, and Table Naming Conventions

All of the input, output, and tabular quantities required by each component in a system model must have unique FORTRAN names. These quantities are given names consisting of up to three characters that describe the physical quantity they represent.

Since a single component may have several inputs or outputs of the same physical quantity, the program adds the port number to the second or third character of the physical quantity name to prevent such a duplication.

The physical quantities that are outputs of a given component are identified by adding the three character name of that component to the three character name of the physical quantity. In this way, unique six character FORTRAN names are generated for all output quantities of the system model components.

Input quantities to a component that are driven by another component carry the names of the component that drives them. Any inputs that are not driven by other model components are assumed to be parameters and are assigned the name of the component for which they are an input.

If a component should require tabular data as an input, unique table names are generated just as scalar input quantity names by adding the component name to the table name. A pictorial representation of the character assignment in component, variable, and table names is given in Figure 2.2-1.

2.3 MODEL SCHEMATIC

The Model Generation program produces a schematic diagram of the system being modeled. This schematic is crude but is inexpensive and does not have the flow time delays associated with more elaborate plotting methods. Its purpose is to provide a means of rapidly locating errors in the model description.

In order to construct a schematic diagram in an efficient manner with a reasonable size program, it was necessary to establish some simple rules for symbol generation, component connection paths, and labeling. If these rules are kept in mind when laying-out a schematic for the system, the SIMWEST produced schematic will match that developed by the analyst. If the rules are violated by the analyst's schematic, the SIMWEST schematic should still be correct, but may contain some unusual component connection paths and some labeling information may be overwritten.

2.3.1 Standard Schematic Form

The SIMWEST schematic diagrams are produced on a standard 11" by 14" lineprinter page with 80 component locations per page. A standard form containing only the location numbers can be obtained by executing the Model Generation program with the single program command, PRINT. This form can then be reproduced and the copies used as forms for drawing system model schematics.

2.3.2 Input Quantity Labeling

The names of the physical quantities that are input to one component from another component are listed adjacent to the downstream component symbol.

INPUT/OUTPUT OR TABLE NAMES

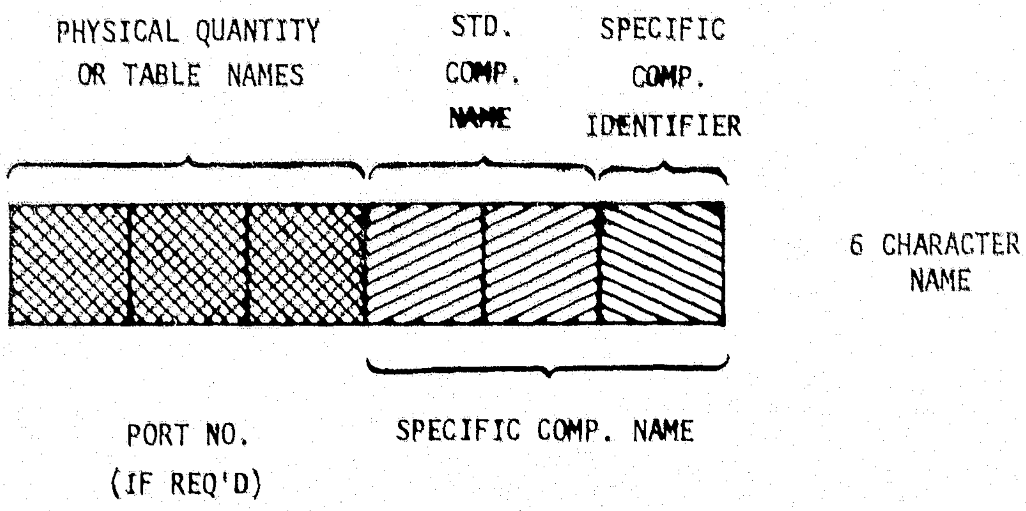


FIGURE 2.2-1 CHARACTER ASSIGNMENT INPUT/OUTPUT OR TABLE NAME

These labels are placed near the connecting line that joins the two components. Since these names are composed of the physical quantity name and the name of the component that generates the information, the source of the input is evident from the name itself. Parameter and tabular inputs to a component are not shown on the schematic. These constant inputs are described in the Input Requirements List.

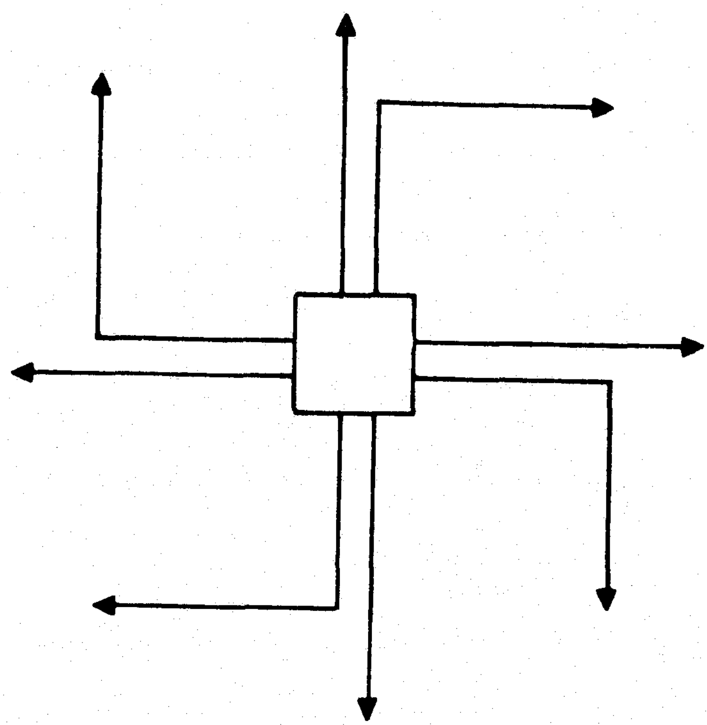
2.3.3 Component Connection Paths

In order to keep the core requirements and run time of the SIMWEST schematic drawing subroutine small, it was necessary to limit the types of connecting paths between components to a few basic routes. These paths are shown in Figure 2.3-1. Connections between components on the same horizontal or vertical line are straightforward. However, connections between components that do not share a horizontal or vertical line require at least a two segment path. These paths have been arbitrarily chosen to follow a clockwise route. It is therefore advisable that components that are on diagonal locations be placed in a clockwise sequence. If counter-clockwise flow between components is necessary, it can be accommodated by placing the components on the same horizontal or vertical lines.

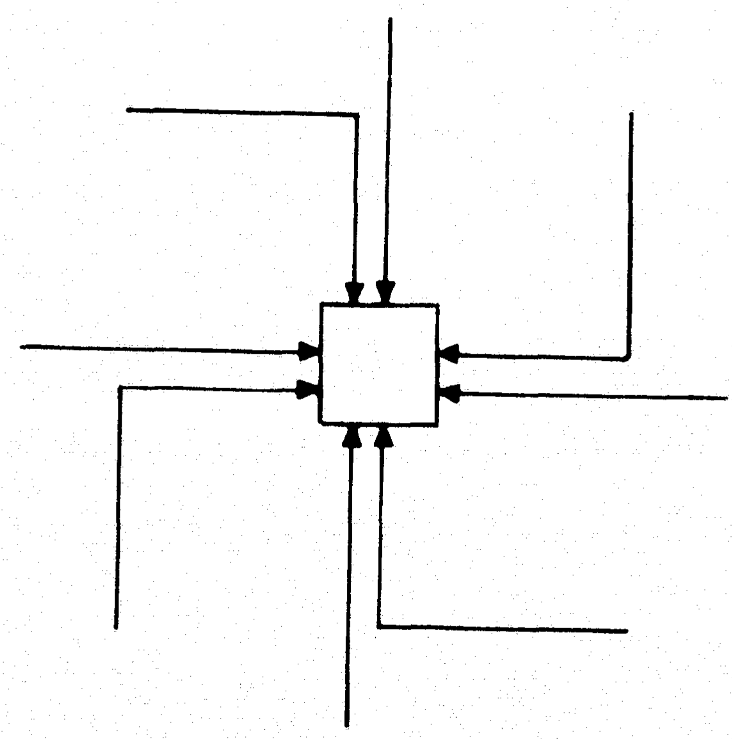
The SIMWEST schematic drawing subroutine makes no attempt to go around components that get in the way of a connection path. Such components are "run-over" by the connecting line.

2.3.4 Additional Pages

The SIMWEST schematic diagram may be broken down into as many pages as are necessary. No attempt is made to draw connecting paths between components located on different pages. It is therefore advisable to minimize the number of connecting paths between pages. This can usually be done by grouping



POSSIBLE OUTPUT PATHS



POSSIBLE INPUT PATHS

FIGURE 2.3-1 COMPONENT CONNECTION PATHS

components with many interconnections on the same page and placing page boundaries between such groups of components.

2.3.5 Guidelines for Schematic Layout

The following guidelines may help in creating schematic layouts that can be duplicated by the SIMWEST program.

1. Try to place connected components on the same horizontal or vertical line.

2. Avoid placing components on adjacent location points.

3. Place diagonal components so that flow is clockwise.

4. Group components to minimize flow paths between pages.

2.4 WARNING MESSAGES

One or more of the following warning messages will occur if the program is unable to interpret a portion of the model description or encounters problems in assembling the system model. These messages will be preceded by: *** WARNING *** or *** NOTICE ***. The symbols xxx and zzz are used to indicate phrases from the model description that are included as part of the warning message. The following messages are listed in alphabetical order:

1. CAN'T IDENTIFY xxx AS A STANDARD COMPONENT

   xxx will contain the first two characters of the phrase which cannot be identified as a command or standard component. This message will often follow other warning messages as the program makes successive attempts to interpret the given phrase.

2. CAN'T IDENTIFY xxx AS A VALID INPUT COMPONENT TO zzz

The component xxx cannot be found in the list of components for the current system model.

3. CAN'T LOCATE xxx AS AN INPUT COMPONENT TO LOCATION n

This message indicates that the component xxx, which provides inputs to location n in the schematic, has not been assigned a location number. Check for a missing LOCATION statement or misspelling of the component name.

4. COMPONENT xxx DEFINITION WASN'T COMPLETED BEFORE STARTING THE DEFINITION OF COMPONENT zzz

The command INPUTS was not given between the component names xxx and zzz. Check for proper spelling of INPUTS and a valid delimiter after the phrase xxx.

5. COMPONENT xxx HAS ALREADY BEEN DEFINED

The component xxx was defined in a previous LOCATION statement.

6. LOCATION NO. xxx FOR COMPONENT zzz HAS LAST TWO DIGITS OUTSIDE THE ALLOWABLE RANGE 1 TO 80. NO SYMBOL WILL BE PLACED IN SCHEMATIC FOR THIS COMPONENT

This message will occur at the end of the model description for a component zzz which has an invalid location number. The system model may still be valid but the schematic will not contain this component.

7. NO xxx OUTPUTS MATCH UNSATISFIED zzz INPUTS

Check that it was intended to drive component zzz with component xxx or that the inputs to zzz have been previously satisfied by other component connections.

8. TABLE NAME xxx MUST BE FOLLOWED BY A NUMERIC DIMENSION RATHER THAN zzz

When using the ADD TABLES command, it is necessary to provide the maximum amount of storage to be allocated for the table as well as the table name. This storage value must be a numeric quantity.

9. xxx IS NOT A VALID INPUT QUANTITY OR PORT DESIGNATION FOR COMPONENT zzz

The phrase xxx cannot be located as one of the input quantities or input ports of the component zzz. No connections will occur. Check the list of standard components for the proper spelling or port designations for this component.

10. xxx IS NOT A VALID LOCATION NUMBER

The LOCATION command must be followed by a numeric location number.

11. xxx IS NOT A VALID PORT DESIGNATION FOR INPUT COMPONENT zzz. ERRONEOUS CONNECTIONS MAY OCCUR.

The phrase xxx cannot be located as a valid input port for the component zzz. Connections will be attempted using the upstream output port that was identified.

2.5 MODEL GENERATION LIMITATIONS

Certain limitations exist in the Model Generation program due to array dimensions within the program. For most applications these limits should not be encountered. However, if they should be encountered they can usually be extended at the expense of larger core requirements to execute the program. The following table describes these limitations:

Limitation Description	Maximum Value
Standard components in library	150
Components per model	200
Inputs per any standard component	50
Outputs per any standard component	50
Tables per any standard component	15
Tables per model	100
Table dimension (words)	960

3.0 SIMULATION PROGRAM

Once a model has been generated as described in Section 2, the user must describe the simulation he wishes to perform. This involves specifying the various parameters detailing the model components and setting the models initial conditions. It involves defining input data tables and the type and quantities of printed output, both tabular and plotted. The user must also specify the number of iterations he wishes to perform at each time step and the maximum number of component diagnostics. This section describes in detail the commands for specifying the simulation and gives some example output.

3.1 MODEL INPUT DATA

A dynamic system model requires that the values of numerous model parameters, tables and initial conditions, be provided to complete the model description. Sections 3.1.1, 3.1.2 and 3.2 describe the methods used to specify parameter values, tables, and initial conditions.

3.1.1 Scalar Data

PARAMETER VALUES (Default values = .99999)

This program command allows the numeric values of parameters to be loaded into the system model. The PARAMETER VALUES command is followed by one or more parameter names followed by a numeric value. Each name and its value are separated by one of the standard delimiter symbols. This command is used to specify the values of all system model parameters at the beginning of an analysis. It may also be used at any point between analyses to modify the value of one or more model parameters. A default value of .99999 is provided by the Model Generation program for all parameters not so specified.

Example 3.1-1

PARAMETER VALUES = CYCLES = 6.01, TO TI = 0, EC WP = .2,
CR CM = 15, LE CM = 30, MDEHS = 4.E5, ...

3.1.2 Tabular Data

If tabular data is required by the system model, it should be loaded before any of the simulation commands described in Section 3.4 are issued. Tables may be modified between analyses by loading new values. The tables required by a SIMWEST generated model are specified in the Input Requirements List. These tables may have either one or two independent variables. All data items are in a free field format with each item separated by one of the standard delimiters: comma [,], equal sign =[,]left or right parenthesis () , or three or more consecutive blank spaces. The data items required for each table are placed on cards as follows:

Card 1	TABLE	table name	NX	NZ
Card 2*	Z table values			
Card 3*	X table values			
Card 4*	Y table values			

where:

- Table Name – The six character table name generated by the Model Generation program.
- NX – The number of points in the primary independent variable table.
- NZ** – The number of points in the secondary independent variable table.
- Z table ** – Table of NZ secondary independent variable values.
- X table – Table of NX independent table values.
- Y table – 1 or NZ tables of NX dependent variable values.

* As many cards as required may be used. Each table must start with a new card and NZ, NX, and NX*NZ points must be given per table.

** These items are omitted for tables with one independent variable.

A copy of all tabular input data is printed as it is interpreted from data cards. The following example shows the data cards for a one and a two independent variable table.

Example 3.1-2

Card 1	TABLE, TABONE, 10
Card 2	1, 2, 3, 4, 5, 6, 7, 8, 9, 10
Card 3	11, 12, 13, 14, 15, 16, 17, 18, 19, 110
Card 4	TABLE, TABTWO, 5, 4
Card 5	10.3, 20.4, 30.5, 40.6
Card 6	1, 2, 3, 4, 5
Card 7	11, 12, 13, 14, 15
Card 8	21, 22, 23, 24, 25
Card 9	31, 32, 33, 34, 35
Card 10	41, 42, 43, 44, 45

The printout of these tables would be:

```
                         TABLE TABONE
           PRIMARY INDEPENDENT VARIABLE TABLE
    1.000  2.000  3.000  4.000  5.000  6.000  7.000  8.000  9.000  10.00
               DEPENDENT VARIABLE TABLE
    11.00  12.00  13.00  14.00  15.00  16.00  17.00  18.00  19.00  110.00
                       TABLE TABTWO
           SECONDARY INDEPENDENT VARIABLE TABLE
    10.30        20.40        30.50        40.60
             PRIMARY INDEPENDENT VARIABLE TABLE
    1.000        2.000        3.000        4.000        5.000
               DEPENDENT VARIABLE TABLE
    11.00        12.00        13.00        14.00        15.00
    21.00        22.00        23.00        24.00        25.00
    31.00        32.00        33.00        34.00        35.00
    41.00        42.00        43.00        44.00        45.00
```

3.2 INITIAL CONDITION AND INTEGRATION CONTROLS

INITIAL CONDITIONS (Default value = 0)

INT CONTROLS (Default value = 1.0)

These program commands may be used to specify initial condition values and the integrator status, (either active (=1) or frozen (=0)). Default values of 0. for initial conditions and 1 for integration controls are furnished by the simulation program. However, it is strongly recommended that values appropriate to the particular system model be furnished for the initial conditions.

Each of these commands is followed by phrases of the form of a state name followed by a numeric value.

Example 3.2-1:

```
INITIAL CONDITIONS = MA HS = 1.6E6, E  TS = 600, VDELO = 0, ....
INT CONTROLS = MA HS = 0, E  TS = 1, VDELO = 1, .....
```

ALL STATES (Default Condition)

NO STATES

These program commands may be used to activate or freeze all system integrators. These commands are normally used together with the INT CONTROLS command to specify the desired integrator configuration.

3.3 INITIAL CONDITION STORAGE COMMANDS

XIC-X

XIC-XIC1

XIC-XIC2

XIC-XIC3

XIC1-XIC

XIC2-XIC

XIC3-XIC

These program commands are used to transfer data from the current state vector, X, to the initial condition vector, XIC, and between the XIC vector and three auxiliary initial condition vectors XIC1, XIC2, XIC3.

Example 3.3-1

XIC1-XIC, XIC-X, XIC2-XIC

The three program commands shown above would take the current operating point (initial condition vector) and store it in vector XIC1; then transfer the current state, X, into XIC; and then store that value of XIC in XIC2.

3.4 SIMULATION COMMANDS

SIMULATE

This program command initiates simulation operation. Associated with this command are the program values:

			Default Values:
TINC	=	time increment, hours	0.1
TMAX	=	duration of the simulation run hours	1.0
OUTRATE	=	output rate	1
PRATE	=	print rate	1
PRINT CONTROL	=	print control variable	0

These program commands specify the integration time increment, duration of simulation run, the simulation output rate, the printing rate, and the quantity of printing, at each point in time. These quantities should be specified before the first issuance of the SIMULATE command.

The Time increment, TINC, provides the integrator time step size, in hours, for the integrator. TINC also provides the report interval for which data will be available for printing or plotting. The default value for TINC is 0.1.

The duration of a simulation calculation in hours, is specified by the TMAX parameter. The default value of TMAX is 1.

The output rate parameter, OUTRATE, determines the sampling rate at which simulation data is added to plots. Thus, if OUTRATE is set equal to 10, data will be plotted every 10th time increment, TINC. The default value of OUTRATE is 1. OUTRATE should only be set to positive integer values.

The number of data samples plotted for a simulation analysis is thus given by:

$$\text{No. of Plotted Samples} = \frac{\text{TMAX}}{\text{TINC*OUTRATE}} + 1$$

For most simulation operation, the plotted output specified by the DISPLAY commands is the primary output and no line printer output is used. However, for diagnosing problems in a simulation, the line printer options provided by the PRINT CONTROL parameter allow large amounts of detailed information about the simulated system to be obtained.

The value of the PRINT CONTROL parameter controls the quantity of data printed at each print report interval as shown in Table 3.4-1. Options 1 through 4 give "snap-shots" of all states, rates, variables, and parameters of the system model at a particular point in time. Option 5 provides tabular lists of up to 10 specified quantities.* The default value for PRINT CONTROL is 0.

TABLE 3.4-1

Print Control Values

PRINT CONTROL	Resultant Lineprinter Output.
0	None (Default Condition)
1	All states, rates, and time
2	All states, rates, variables, and time
3	All states, rates, variables, and parameters at time = 0
4	All states, rates, variables, and parameters
5	Time and the quantities specified via PRINT VARIABLES command.

The PRATE parameter determines the sampling rate at which the simulation data specified by the PRINT CONTROL parameter is presented on the line-printer. Thus, if PRATE is set equal to 5, data will be printed on the line printer every 5th time it is added to the output plots. The rate of output to the lineprinter can never be greater than that to the plots. The default value of PRATE is 1. PRATE should only be set to positive integer values.

The number of data samples printed for a simulation analysis is thus given by:

$$\text{No. of Printed Samples} = \frac{\text{TMAX}}{\text{TINC*OUTRATE*PRATE}} + 1$$

*See the PRINT VARIABLES command description below.

Example 3.4-1:

```
PRINT CONTROL = 2, TINC = .01, TMAX = 10.,
OUTRATE = 10, PRATE = 10, SIMULATE
```

In the example, the simulation would run for 10 hours. Plotted output would occur every .1 hour, (10* .01), and printed output would occur every 1. hour (10* 10* .01).

PRINT VARIABLES

This program command allows up to ten variables to be specified for printing under option 5 of the PRINT CONTROL. This command is followed by from one to ten state, rate, or variable names separated by delimiters. This command wipes out all previously stored PRINT VARIABLES names.

Example 3.4-2:

```
PRINT VARIABLES = MA HS, E  TS, VDELO
```

3.5 PLOT DESIGNATION COMMANDS

DISPLAY1
DISPLAY2
DISPLAY3
DISPLAY4
DISPLAY5
DISPLAY6

These program commands may be used to define the quantities to be displayed by lineprinter plots for simulation calculations. These commands must be issued before the simulation analysis is requested. From one to five plots may be specified per display. Each plot is specified by stating the dependent variable and the independent variable separated by the letters VS. If desired, the independent and dependent axis scale ranges can also be specified. The independent scale range is specified by the word XRANGE followed by the minimum and maximum values for this scale. The dependent scale similarly is specified by the word YRANGE. If scale ranges are not specified, values will be used that span the given data.

SI MANUAL SCALES
SI AUTO SCALES (Default Condition)

The SI MANUAL SCALES command allows the plotted output requested by the DISPLAY commands to be plotted on manual scales specified by the YRANGE and XRANGE commands. The SI AUTO SCALES command can be used to return plotting to the automatic scaling mode. Auto scales are selected so that they span each plotted quantity. The auto scale option is the default used until manual scales are requested. The PRINTER PLOTS command is also required to obtain plots.

Example 3.5-1:

```
SI MANUAL SCALES, PRINTER PLOTS
DISPLAY1
WV2WD, VS, TIME, YRANGE = 10,40
P1 PD, VS, TIME, YRANGE = 0,1000
P2 PD, VS, TIME, YRANGE = 0,1000
DISPLAY2
P2 IV, VS, TIME
RE2BA, VS, TIME
RE1LO, VS, TIME
DISPLAY3
P1 PD, VS, P2 PD, YRANGE = 0,1000, XRANGE = 0,1000
```

TITLE

The TITLE command allows a title to be placed on all plotted output. Up to 74 characters may follow the delimiter that follows the TITLE command. The TITLE command may be changed before each analysis. Once defined, the title remains in effect until a new title is entered.

Example 3.5-2:

TITLE = BATTERY TEST MODEL

3.6 ITERATION AND DIAGNOSTIC CONTROL

There are three built-in parameters in any SIMWEST model : CYCLES, DLINES and RESET. These parameters are specified similar to component parameters using the PARAMETER VALUES command.

CYCLES controls the number of iterations through the model to obtain steady state. If CYCLES $\leq$ 0. then only one pass is made through the model. If CYCLES is a positive integer then the number of iterations through the model is equal to CYCLES + 1. If cycles is positive, but not an integer, then the number of iterations is equal to the smallest integer value exceeding cycles. A maximum of 20 iterations are permitted per time step. Most of the simple models of Section 8 require between four and six iterations per time step to attain steady state. A complex model with cascaded logic components may require more.

The task of finding the correct value for CYCLES is facilitated by the program printing at each time step all variables which have a greater than 5% change in value in the last iteration.

Since output statistics are only updated the last iteration, many of the variables printed indicating nonconvergence are just statistics, and as such should be ignored.

DLINES controls the amount of convergence related printout to be controlled as well as the amount of diagnostic printout put out by the library components. If DLINES >0 then the total number of diagnostic printouts is no greater than DLINES. Figure 3.6 shows a typical section of diagnostic printout using DLINES >0. If DLINES <0 then only library component diagnostics are printed with no greater than - DLINES of output. Typically, DLINES = 100 is sufficient to catch most simulation errors per run.

```
          PC3PA    NONCONVERGENCE, OLD VALUE=        4.209   NEW VALUE=        6.109
          SR UT    NONCONVERGENCE, OLD VALUE=      177.720   NEW VALUE=      264.359

          PC3PA    NONCONVERGENCE, OLD VALUE=        6.109   NEW VALUE=        7.054
          SR UT    NONCONVERGENCE, OLD VALUE=      264.359   NEW VALUE=      312.718

FLYWHEEL KINETIC ENERGY        39.875 FALLS BELOW MINIMUM REQUIREMENT         40.000

FLYWHEEL CLUTCH LOSS          1.217 EXCEEDS DELIVERABLE POWER          .400

          SP MO    NONCONVERGENCE, OLD VALUE=      553.569   NEW VALUE=      601.994
          SPCFL    NONCONVERGENCE, OLD VALUE=      543.583   NEW VALUE=      590.798
          PC3PA    NONCONVERGENCE, OLD VALUE=        7.054   NEW VALUE=        8.152
          SR UT    NONCONVERGENCE, OLD VALUE=      312.718   NEW VALUE=      370.217
```

FIGURE 3.6 TYPICAL DIAGNOSTIC OUTPUT

RESET controls the initialization value for the random number generators if several simulations are run back to back. If RESET >0 (Default) then the same random numbers are used for each simulation. If RESET $\leq$ 0 then the random numbers at the start of each simulation are obtained from the last value at the end of the previous simulation.

3.7 DEFINE COMMANDS

DEFINE STATES

DEFINE RATES

DEFINE PARAMETERS

DEFINE VARIABLES

These program commands may be used to define the alphanumeric names that will be used to refer to states, rates, parameters, and variables. All system models formed by the Model Generation program have model related names generated for all states, variables, and parameters in the model. State variable derivatives, (Rates), are generated as R1, R2,... for all models. R1, R2, ... refer to the .ates of the first, second,... states respectively. If it is desired to replace these machine generated names with other names, the DEFINE command may be used to substitute any eight character name of the analyst's choosing. These names are associated with the corresponding numeric quantities located in the labeled commons /CX/, /CXDOT/, /CP/, and /CV/. The appropriate location for each quantity is printed out along with the quantity name prior to each simulation. Each of these commands is followed by phrases containing the location numeric followed by an alphanumeric name with one to eight characters the first of which must be alphabetic.

Example 3.7:

```
DEFINE STATES
1 = PRESSURE, 2 = STROKE, 5 = VELOCITY, 7 = ANGLE

DEFINE PARAMETERS
5 = MASS, 35 = DCT AREA
DEFINE VARIABLES, 1 = T OUTLET, 2 = LIQ H20
```

Note that the program commands, numeric values and alphanumeric names must be separated by delimiters which are: comma [,], equals [=], left parentheses [(], right parenthesis [)], or three or more consecutive spaces.

3.8 EXAMPLE OUTPUT

Figure 3.8 shows a sample of the output print format generated using PRINT CONTROL = 3. This sample is taken from the Wind Turbine and File Read run

```
      TIME =   .0000                                   STATES
   1 VDELO  =  .00000

                                                       RATES
   1 R1     =   5.0009

                                                     VARIABLES
   1 I  TI  =  .00000     2 TD TI  =  .00000     3 TW TI  =  .00000     4 DW TI  =  1.0000      5 DY TI  =  1.0000
   6 WY TI  =  1.0000     7 MY TI  =  1.0000     8 VARTAW =  18.477     9 N  TAW =  446.00     10 TO TAW =  .00000
  11 M  TAW =  .25000    12 WV2WD  =  18.477    13 MV WD  =  18.477    14 AV WD  =  20.354     15 M  WD  =  58.846
  16 TIMWD  = -1.0000    17 P2 WT  =  241.84    18 TO WT  =  72080.    19 CO WT  =  .12500     20 GR WT  =  76.391
  21 MAPWT  =  795.36    22 MT WT  =  72080.    23 MPOWT  =  241.84    24 SP WT  =  30.230     25 P2 GR  =  229.65
  26 TO GR  =  895.98    27 PL GR  =  12.184    28 EF2GR  =  .94961    29 MP2GR  =  .10000+11  30 RS1GR  =  23.651
  31 SAMMG  =  1.0000    32 AV HG  =  241.84    33 SD HG  =  58485.    34 P2 GE  =  217.43     35 EE GE  =  .97710
  36 RS GE  =  1805.2    37 PL GE  =  12.224    38 EF2GE  =  .89906    39 MP2GE  =  750.00     40 MPNGE  =  .28991
  41 SP GE  =  27.179    42 VARTAL =  572.02    43 N  TAL =  446.00    44 TO TAL =  .00000     45 M  TAL =  .25000
  46 REILO  =  636.24    47 LO2LO  =  572.02    48 SRELO  =  71.502    49 SDELO  =  27.179     50 PC LO  =  38.011
  51 TIMLO  = -1.0000    52 CN LO  = -1.9575

                                                    PARAMETERS
   1 TO TI  =  .00000     2 NSTTAW =  .00000     3 ITFTAW =  1.0000     4 VO WT  =  21.000      5 VR WT  =  28.350
   6 RSGWT  =  1800.0     7 BR WT  =  80.000     8 EC WT  =  1.5000     9 AD WT  =  .23000-02  10 LAMWT  =  9.4000
  11 CPMWT  =  .41000    12 CP WT  =  .99999    13 CC WT  =  16000.    14 CM WT  =  2000.0     15 EF1GR  =  .99999
  16 MP1GR  =  .10000+11 17 CC GR  =  1000.0    18 CM GR  =  200.00    19 F1 HG  =  .00000     20 F2 HG  =  .00000
  21 F3 HG  =  .00000    22 F4 HG  =  1.0000    23 F5 HG  =  .00000    24 F6 HG  =  .00000     25 F7 HG  =  .00000
  26 F8 HG  =  .00000    27 F9 HG  =  .00000    28 F10HG  =  .00000    29 F11HG  =  .00000     30 F12HG  =  .00000
  31 F13HG  =  .00000    32 F14HG  =  .00000    33 F15HG  =  .00000    34 F16HG  =  .00000     35 FA HG  =  67.857
  36 FUPHG  =  1000.0    37 FLOHG  =  50.000    38 RAPGE  =  750.00    39 RSYGE  =  1800.0     40 RASGE  =  .10000-01
  41 DA GE  =  .20000    42 SR GE  =  .50000-02 43 VO GE  =  400.00    44 CC GE  =  1000.0     45 CM GE  =  200.00
  46 NSTTAL =  .00000    47 ITFTAL =  2.0000    48 NC LO  =  .57400-02 49 CT LO  =  4.0000     50 MN LO  =  .00000
  51 STDLO  =  6.0000    52 VE LO  =  .25000-01 53 CYCLES =  2.0100    54 DLINES =  .99999     55 RESET  =  .99999

      TIME =   12.00                                   STATES
   1 VDELO  =  97.264

                                                       RATES
   1 R1     =   .63123

                                                     VARIABLES
   1 I  TI  =  12.000     2 TD TI  =  12.000     3 TW TI  =  12.000     4 DW TI  =  1.0000      5 DY TI  =  1.0000
   6 WY TI  =  1.0000     7 MY TI  =  1.0000     8 VARTAW =  13.444     9 N  TAW =  446.00     10 TO TAW =  .00000
  11 M  TAW =  .25000    12 WV2WD  =  13.444    13 MV WD  =  39.006    14 AV WD  =  20.354     15 M  WD  =  58.846
  16 TIMWD  = -1.0000    17 P2 WT  =  36.664    18 TO WT  =  10956.    19 CO WT  =  12.125     20 GR WT  =  76.391
  21 MAPWT  =  795.36    22 MT WT  =  .23555+06 23 MPOWT  =  795.36    24 SP WT  =  4861.1     25 P2 GR  =  35.198
  26 TO GR  =  137.67    27 PL GR  =  1.4660    28 EF2GR  =  .95999    29 MP2GR  =  .10000+11  30 RS1GR  =  23.572
  31 SAMMG  =  97.000    32 AV HG  =  38889.    33 SD HG  =  .24279+08 34 P2 GE  =  27.445     35 EE GE  =  .97710
  36 RS GE  =  1800.7    37 PL GE  =  7.7533    38 EF2GE  =  .74853    39 MP2GE  =  750.00     40 MPNGE  =  .93304
  41 SP GE  =  4256.0    42 VARTAL =  1024.2    43 N  TAL =  446.00    44 TO TAL =  .00000     45 M  TAL =  .25000
  46 REILO  =  1002.0    47 LO2LO  =  1024.2    48 SRELO  =  8481.5    49 SDELO  =  4256.0     50 PC LO  =  50.180
  51 TIMLO  = -1.0000    52 CN LO  = -1.9575

      TIME =   24.00                                   STATES
   1 VDELO  =  239.65
```

FIGURE 3.8 SAMPLE PRINTER OUTPUT

described in Section 8.1, which is a very simple model. At each print time the output quantities are indexed by number and component name as they occur in the model. For example, first all the variables for component TI are printed, then all variables for component TAW, etc. The parameter values at time = 0 show both the input values and the default parameters. After T = 0 only the states, rates, and output variables are printed. Since all the model connection variables and output variables are printed, this mode is especially valuable for program debugging and analysis at a fixed time. The printer plots, samples of which are shown in Section 8, are useful for monitoring the time behavior of critical parameters such as energy in storage and percent of load delivered by storage.

4.0 JOB CONTROL PROCEDURES

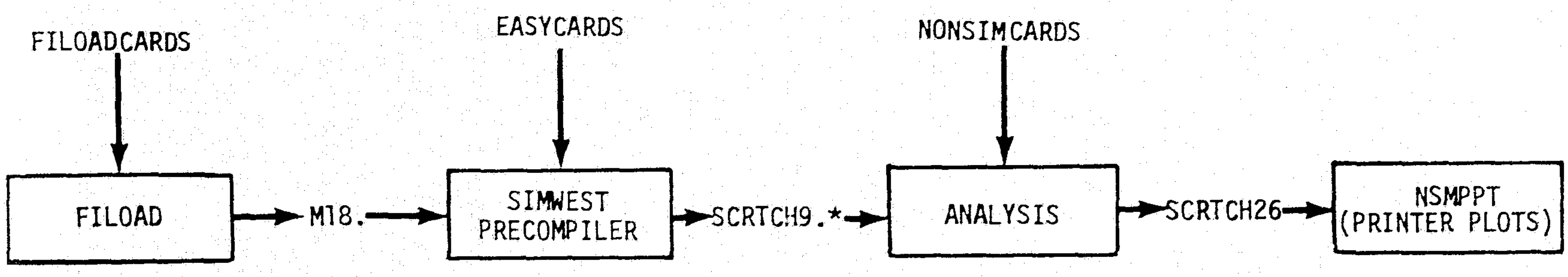
In this section, we describe job control procedures for running and maintaining the SIMWEST programs. For the convenience of the user, a number of procedure files have been set up which simplify the user control cards required. In Section 4.1, we describe the control cards for executing the model generation and analysis programs. Section 4.2 describes the procedures to maintain the programs and update the component library.

4.1 MODEL GENERATION AND ANALYSIS EXECUTION

Figure 4.1-1 shows an overview of the program structure to execute a simulation run. The program FILOAD is only executed when the component library is updated, and is thus described in the next section. The user input data for the model generation program is put on a file called EASYCARDS. A procedure file called XQTEASY is then used to generate the model Fortran and compile this model. Similarly, the user input data for the analysis program is put on a file called NONSIMCARDS, and a file called XQTANALYSIS maps the relocatable elements into absolute file elements, and executes both the simulation and printer plot programs.

A job control stream to execute these programs in a batch environment is given by:

```
@RUN ...
@DELETE,C EASYCARDS.
@ASG,UP EASYCARDS.
@DATA,IL EASYCARDS.
                .
                .
                .
      INPUT DATA DECK
         FOR MODEL
                .
                .
                .
@END
@ASG,A XQTEASY.
```



*SCRTCH9 IS FORTRAN SOURCE CODE OUTPUT

FIGURE 4.1-1 SIMWEST PROGRAM EXECUTION STRUCTURE

```
@ADD,PL XQTEASY.
@DELETE,C NONSIMCARDS.
@ASG,UP NONSIMCARDS.
@DATA,IL NONSIMCARDS.
          .
          .
          .
     INPUT DATA DECK
      FOR ANALYSIS
          .
          .
          .
@END
@ASG,A XQTANALYSIS.
@ADD,PL XQTANALYSIS.
@FIN
```

The job control procedures XQTEASY and XQTANALYSIS are shown in Figures 4.1-2 and 4.1-3. If a user is creating data inputs from a terminal, then it may be somewhat simpler to create new job control procedures similar to XQTEASY and XQTANALYSIS, but substituting his data input file names for EASYCARDS and NONSIMCARDS, respectively. If the same model is used for a series of runs, then only the analysis program is required for execution. However, it is safer and also relatively inexpensive to execute both programs when using the above job stream. Whenever the file read component is desired, the user must either substitute his file for F1 or F2, or add the following job cards to XQTANALYSIS:

```
@ASG,A MYFILE.
@USE M, MYFILE.
```

where MYFILE is the user time history file and M is a unit number between 13 and 18. (See 7.38 for a discussion of the tape/file read component.)

4.2 PROGRAM MAINTENANCE AND LIBRARY UPDATES

Whenever the component library is updated, the user must compile the Fortran code and run the FILOAD program to furnish the model generation program com-

```
@HDG  SIMWEST MODEL GENERATION
@ASG,AX MGABS.
@ASG,A  M18.
@USE 18,M18.
@ASG,T M7.
@USE 7,M7.
@ASG,T SCRTCH8.
@USE 8,SCRTCH8.
@DELETE,C SCRTCH9.
@ASG,UP SCRTCH9.
@USE 9,SCRTCH9.
@ASG,T SCRTCH1Ø.
@USE 1Ø,SCRTCH1Ø.
@ASG,T SCRTCH11.
@USE 11,SCRTCH11.
@ASG,T SCRTCH12.
@USE 12,SCRTCH12.
@ASG,A  EASYCARDS.
@USE 5,EASYCARDS.
@XQT MGABS.EASY
@ASG,AX ASRO.
@ASG,AX ASSI.
@ADD,PL 9.
@FREE 18.,7.,8.,9.,10.,11.,12.
```

FIGURE 4.1-2 XQTEASY JOB CONTROL FILE

```
@HDG  SIMWEST ANALYSIS
@ASG,AX MAPANALYSIS.
@ADD,PL MAPANALYSIS.
@ASG,AX ASABS.
@ASG,AX F1.
@USE 11,F1.
@ASG,AX F2.
@USE 12,F2.
@ASG,T SCRTCH25.
@USE 25,SCRTCH25.
@DELETE,C SCRTCH26.
@ASG,UP SCRTCH26.
@USE 26,SCRTCH26.
@ASG,AX NONSIMCARDS.
@USE 5,NONSIMCARDS.
@XQT ASABS.NONSIM
@XQT ASABS.NSMPPT
@FREE 11.,12.,25.,26.
```

FIGURE 4.1-3 XQTANALYSIS JOB CONTROL FILE ponent input and output name lists. A job control stream to compile a new component denoted DC and add it to the component library is given by:

```
@ASG,T SOURCE.
@DATA,IL SOURCE.
@FOR,IS COSI.DC,CORO.DC
          .
          .
          .
    USER FORTRAN SUBROUTINE DC
          .
          .
          .
@END
@ASG,A COSI.
@ASG,A CORO.
@ADD,PL SOURCE.
@ASG,A CMPLCO.
@ED,U CMPLCO.
ADD SOURCE.
EXIT
```

If an old component is to be updated, then one can edit the source code on CMPLCO and recompile entirely, or copy the edited subroutine including the @FOR,IS control card onto a new file and recompile. A job stream to execute the FILOAD program is given by:

```
@DELETE,C FILOADCARDS.
@ASG,UP FILOADCARDS.
@DATA,IL FILOADCARDS.
          .
          .
          .
    USER INPUT DATA
      FOR FILOAD
          .
          .
          .
@END
@ASG,A XQTFILOAD.
@ADD,PL XQTFILOAD.
```

PRECEDING PAGE BLANK NOT FILMED

```
@ASG,AX FSRO.
@PREP FSRO.
@ASG,AX MAPFSSI.
@ASG,AX FILOAD4.
@MAP,I MAPFSSI.FILOAD,FILOAD4.
 IN FSRO.FILOAD
 LIB FSRO.
END
```

FIGURE 4.2-2 MAPFILOAD PROCEDURE FILE

```
@ASG,AX MGRO.
@PREP MGRO.
@ASG,AX MAPMGSI.
@ASG,AX MGABS.
@ASG,AX FSRO.
@PREP FSRO.
@MAP,I MAPMGSI.EASY,MGABS.EASY
 IN MGRO.EASY
 LIB FSRO.,MGRO.,FSRO.
END
```

FIGURE 4.2-3 MAPEASY PROCEDURE FILE

```
@ASG,AX FSRO.
@ASG,AX ASRO.
@ASG,AX CORO.
@PREP CORO.
@PREP FSRO.
@PREP ASRO.
@ASG,AX MAPASSI.
@ASG,AX ASABS.
@MAP,I MAPASSI.NONSIM,ASABS.NONSIM
 IN ASRO.NONSIM
 IN ASRO.BLOCKDA
 IN ASRO.MODEL
 LIB  FSRO.,ASRO.,FSRO.,CORO.
 END
```

FIGURE 4.2-4 MAPANALYSIS PROCEDURE FILE

```
@ASG,AX FSRO.
@ASG,AX ASRO.
@PREP FSRO.
@PREP ASRO.
@ASG,AX MAPASSI.
@ASG,AX ASABS.
@MAP,I MAPASSI.NSMPPT,ASABS.NSMPPT
 IN ASRO.NSMPPT
 LIB FSRO.,ASRO.,FSRO.
 END
```

FIGURE 4.2-5 MAPNSMPPT PROCEDURE FILE

4. CAN'T IDENTIFY xxx VALUE WILL BE IGNORED.

This will result in not setting the quantity intended by xxx to its new value. Check for spelling of xxx or for missing delimiters.

5. CAN'T INTERPRET xxx

The phrase xxx cannot be recognized as a valid program command, program name, or program value. Check spelling of xxx or for missing delimiters.

6. nnn EXCEEDS THE ALLOWABLE INDEX RANGE FOR xxx THIS QUANTITY WILL NOT BE DEFINED

The number nnn was outside the allowable range of states, rates, variables, or parameters. Therefore, the name xxx cannot be assigned as a name for the nnnth state, rate, variable or parameter.

7. NON-ALPHA NAME ON THIS CARD --- xxx. WILL IGNORE THIS CARD.

The table inputs routine expected an alphanumeric table name but encountered a numeric value on the data card printed. Check the sequence and number of tabular data cards to assure that they match those required by the model's tables and table input formats. See Section 3.1.2 for correct formats.

8. NON-NUMERIC DATA ON THIS CARD --- xxx. WILL READ NEXT TABLE

The table input routine expected a numeric value but encountered an alphanumeric name on the data card printed. Check that the sequence and number of tabular data cards matches the model's tables and table input formats. See Section 3.1.2 for correct formats.

9. nnn PRIMARY and xxx SECONDARY INDEPENDENT VARIABLE POINTS EXCEEDS THE zzz WORD STORAGE LIMIT FOR THE FOLLOWING TABLE. SOME DATA WILL BE LOST.

The maximum amount of data allowed for each table is given In the Input Requirements List produced by the Model Generation program. Check that given data falls within this limit or for data card errors.

5.2 DIAGNOSTIC MESSAGES FOR LIBRARY COMPONENTS

A diagnostic message associated to a component is printed when a variable gets out of bounds during analysis. Adjustment of component parameters may be necessary.

In component alphabetical order, these diagnostic messages are:

AD: INPUT POWER xxxx TOO HIGH RELATIVE TO ADMITTANCE xxxx AND RATED VOLTAGE xxx
ADMITTANCE POWER LOSS xxxx EXCEEDS INPUT POWER xxxx

BA: POWER REQUEST xxxx EXCEEDS BATTERY CAPABILITY. CHECK VC, VO, AND RT.

BN: BN INLET AIR MASS FLOW RATE xxxx GREATER THAN MAXIMUM ALLOWABLE xxxx

CO: MAX ITERATIONS FOR COMPRESSOR EFFICIENCY. NP, XNP, RS = xxxx, xxxx, xxxx

CS: CS STORAGE TEMPERATURE xxxx GREATER THAN ALLOWABLE xxxx
CS MASS OF AIR IN STORAGE xxxx BELOW MINIMUM ALLOWABLE xxxx
CS MASS OF AIR IN STORAGE xxxx EXCEEDS MAXIMUM ALLOWABLE xxxx

FL: FLYWHEEL POWER LOSS xxxx EXCEEDS CHARGING POWER xxxx
FLYWHEEL LOSS xxxx EXCEEDS DISCHARGING POWER xxxx
FLYWHEEL CLUTCH LOSS xxxx EXCEEDS MAXIMUM INPUT POWER xxxx
FLYWHEEL CLUTCH LOSS xxxx EXCEEDS DELIVERABLE POWER xxxx

FLYWHEEL KINETIC ENERGY xxxx EXCEEDS CAPACITY xxxx
FLYWHEEL KINETIC ENERGY xxxx FALLS BELOW MINIMUM REQUIREMENT xxxx

GE: GENERATOR OUTPUT EXCEEDS RATED POWER

HS: HS INLET MASS FLOW RATE xxxx OR OUTLET MASS FLOW RATE xxxx IS GREATER THAN MAXIMUM xxxx
HS RESERVOIR VOLUME xxxx EXCEEDED MAXIMUM ALLOWABLE xxxx
HS RESERVOIR VOLUME xxxx DROPPED BELOW MINIMUM xxxx

HT: HT TURBINE CHARACTERISTIC PARAMETER OUT OF RANGE
HT INLET MASS FLOW RATE xxxx GREATER THAN MAXIMUM DESIGN VALUE

HX: HX EXIT TEMPERATURE xxxx GREATER THAN MAXIMUM ALLOWABLE xxxx

IV: IV POWER LOSS xxxx EXCEEDS INPUT POWER xxxx CHECK RATED DC VOLTAGE VDC

MB: WARNING-DIVISOR IN MB EQUALS 0., HAS BEEN SET = 1.

MO: MOTOR INPUT POWER xxxx .GT. RATED INPUT POWER xxxx
MOTOR SLIP xxxx EXCEEDS RATED POWER SLIP xxxx
STATOR RESISTANCE xxxx OR DAMPING xxxx TOO HIGH FOR MOTOR

RE: RE POWER LOSS xxxx EXCEEDS INPUT POWER xxxx
RE, AC INPUT POWER xxxx TOO LARGE IN RELATION TO TRANSFORMER REACTANCE xxxx AND RATED AC VOLTAGE xxxx

TA: FILE DATA OUT OF RANGE. INITIAL VALUE = xxxx ON UNIT xx
TIME POINT PAST TABLE RANGE. LAST VALUE = xxxx ON UNIT xx
READ ERROR OR END OF FILE ON UNIT xx

TR: TRANSMISSION POWER LOSS xxxx EXCEEDS INPUT xxxx
TRANSMISSION POWER LOSS xxxx EXCEEDS MAXIMUM INPUT POWER

TS: TS WORKING FLUID FLOW RATE xxxx GREATER THAN MAXIMUM ALLOWED xxxx
TS INPUT POWER xxxx GREATER THAN MAXIMUM ALLOWED CHARGE RATE xxxx
TS STORAGE TEMPERATURE xxxx OUTSIDE MINIMUM xxxx OR MAXIMUM xxxx

TU: TURBINE BACK PRESSURE xxxx GREATER THAN STORAGE VESSEL PRESSURE xxxx

6.0 CREATION OF NEW LIBRARY COMPONENTS

The addition of new standard components to the SIMWEST library involves two steps. The first is the design of the component. This design must conform to certain design conventions if the new component is to be compatible with existing components. Section 6.1 discusses these design conventions and the addition of the component subroutine to the SIMWEST library. The second step involves the addition of the new component's input and output description to the SIMWEST file M18. File M18 is used by the precompiller to generate subroutine calling sequences for the library components. Section 6.2 discusses the use of the FILOAD program to accomplish this task.

6.1 LIBRARY COMPONENT CODING

6.1.1 Component Call Sequence

The items in the component subroutine call sequence must be arranged in the following order:

1. Tables
2. Output Quantities
3. Input Quantities

Tables or inputs may not be present in the subroutine call sequence. However those items that are present must follow the sequence given above.

Dummy argument names for the call sequence quantities that are used within each subroutine should be chosen to match the physical quantity names placed in the input, output, and table name lists. Exceptions to this policy may be made when integer names (names starting with I through N) must be avoided or when additional letters will clarify the name.

The subroutine name must contain only two characters and must not duplicate the name of an existing standard component.

Tables

The table arrays must be dimensioned within the component subroutine. They must be dimensioned with only one subscript; e.g. DIMENSION TABLE (1). When table data is passed to the component subroutine, the first word in the array contains the name of the table. The second word contains the number of values given for the primary independent variable. The third word contains the number of values given for the secondary independent variable. Both of these numbers are stored as REAL quantities and must be converted to INTEGER before they can be used as a subscript. This can be done by a statement such as:

NX = TABLE (2) - number of primary independent variables
NZ = TABLE (3) - number of secondary independent variables

If there is a secondary independent variable, the secondary independent variable array will begin with the fourth word in the array. Thus if this array is designated as z(1), z(2),...., then:

z(1) = TABLE (4)
z(2) = TABLE (5)
z(3) = TABLE (6)
. .
. .
. .

The primary independent variable array begins with word NZ + 4. Thus if this array is designated as X (1), X(2), ... , then:

X(1) = TABLE (NZ + 4)
X(2) = TABLE (NZ + 5)
. .
. .
. .

The dependent variable array begins with word NX + 4 if there is no secondary independent variable. Thus if this array is designated as Y(1), Y(2),...., then:

Y(1) = TABLE (NX + 4)
Y(2) = TABLE (NX + 5)
.   .
.   .
.   .

If there is a secondary independent variable array and this array was designated Y (I,J), with $1 \leq I \leq NX$ and $1 \leq J \leq NZ$, then Y(I,J) would be related to the table array as:

Y(I,J) = TABLE(NX+NZ+3+I+(J-1)*NX)

Normally the individual elements in the table are not used directly but are passed to a table look-up routine. In this case the starting address of the X, Y, and Z tables would be referred to as:

Z(1) = TABLE (4)	secondary independent variable table
X(1) = TABLE (NZ+4)	primary independent variable table
Y(1,1) = TABLE (NX+NZ+4)	dependent variable table

If more than one table is used by a component subroutine, the table names must appear in the same sequence in the table name list stored in M18 file as in the subroutine call sequence.

Example 6.1: Given a component, HA, that requires the tables TPH and TPC as an inputs. The call sequence of this subroutine would appear as:

```
SUBROUTINE HA(TPH,TPC,...
```

Output Quantities

The term "output quantity" refers to information that is calculated and then "output" by a particular component subroutine. This is not to be confused with the "outlet quantities" of the component. The outlet quantities are associated with a particular component port as a result of assigning a positive direction of power or information flow through the component. Some outlet quantities may be calculated by the component subroutine and thus become output quantities of that component. While other outlet quantities may be furnished to the component subroutine and thus become input quantities to that subroutine.

The output quantities should be grouped together by port. That is, all outlet, (port two quantities), then all inlet, (port one quantities), etc. If a component has multiple outlet ports, the output quantities associated with each outlet port should be grouped together and listed before any inlet port output quantities.

Certain output quantities may be internal to the component and not associated with any port. In other cases the same output quantity may be associated with several ports. In such cases, no port designation is assigned to the output quantity. Such quantities are referred to as "universal port" quantities. As such, they are allowed to connect to any other similar physical quantity regardless of the input quantities port number. This is not the case for quantities with specified port numbers. Once a connection has been made between an input and output quantity with given port numbers, only connections of matching physical quantities with those port numbers occur. Manual override of this provision can be made by specifying particular physical quantity connections.

Three quantities are required for each state variable output. The first is the state variable, the second is the state variable derivative, (rate), and the third is an integer quantity, the integrator control variable.

Example: Given a component, HA, with the following outputs:

Physical Quantity	Port No.		
T	3	Outlet Ports	
T	4		
P	1 (State Variable)		Inlet Ports
P	2 (State Variable)		

The call sequence arguments for these outputs would be:

```
SUBROUTINE HA(TPH,TPC,T3,T4,P1,P1DOT,IP1,P2,P2DOT,IP2,...
```

Input Quantities

The term "input quantity" refers to information that is provided to a particular component subroutine. This is not be be confused with the "inlet quantities" of the component. The inlet quantities are associated with a particular component port as a result of assigning a positive direction of power or information, through the component. Some inlet quantities may be calculated by the component subroutine and thus become output quantities of that component, while other inlet quantities may be furnished to the component subroutine and thus become input quantities to that subroutine.

The input quantities should be grouped together by port. That is, all inlet, (port one quantities), then all outlet, (port two quantities), etc. Port designations for two port components which have the same physical quantity on both inlet and outlet will be: port 1 for upstream or inlet port and port 2 for downstream or outlet port. It is important that the inlet port quantities be listed before any outlet port quantities. If a component has multiple inlet ports, the input quantities associated with each inlet port should be grouped together and listed before any outlet port quantities.

Certain input quantities may be internal to the component and not associated with any port. In other cases the same input quantity may be associated with several ports. In such cases, no port designation is assigned to the input quantity. Such quantities are referred to as "universal port" quantities. As such, they are allowed to connect to any other similar physical quantity regardless of the output quantities port number. This is not the case for quantities with specified port numbers. Once a connection has been made between an input and output quantity with given port numbers, only connections of matching physical quantities with those port numbers occur. Manual override of this provision can be made by specifying particular physical quantity connections.

Example: Given the component HA described in the above example, with the following inputs:

Physical Quantity	Port No.	
T	1	Inlet Ports
T	2	
P	3	Outlet Ports
P	4	
AKH	(universal port quantity)	

The call sequence for these inputs would follow the output arguments, giving the complete call sequence:

```
SUBROUTINE HA(TPH,TPC,T3,T4,P1,P1DOT,IP1,P2,P2DOT,IP2,T1,T2,P3,P4,AKH)
```

The call sequence for standard component subroutines should follow the order shown in Table 6.1-1.

6.1.2 Additions and Modifications to Component Library

Section 4.2 describes the job control procedures to add a new component to the component library, compile the source code that describes the new component and add the relocatable binaries to the component library CORO.

TABLE 6.1-1

COMPONENT SUBROUTINE
CALL SEQUENCE ORDER

1. Tables

2. Output Quantities
   - 2.1 All Outlet Port Quantities*
   - 2.2 All Inlet Port Quantities* (feedback variables)
   - 2.3 All Other Output Quantities

3. Input Quantities
   - 3.1 All Inlet Port Quantities*
   - 3.2 All Outlet Port Quantities* (feedback variables)
   - 3.3 All Other Input Quantities

* Group quantities with the same port number together. If multiple inlet or outlet ports exist, arrange port quantities in order of increasing port numbers.

6.1.3 Coding Conventions

There are several coding rules which apply to any component coded. First of all, the calling sequence must be ordered so that it agrees with that constructed from the Fiload program. Hence the calling sequence begins with table arrays, is followed by output variables, and then by input parameters. State variables require three sequential parameters in the calling sequence: the state variable, the state derivative, and an integer valued integration control. With the exception of the latter, all parameters in the calling sequence are real valued. In general one cannot use any local variables or arrays to store information from call to call since there may be several components in the model which call a given subroutine. In other words, local variables can only be used for scratch calculations, unless the computed information is based on COMMON block inputs.

Most of the coding conventions and techniques used are illustrated in Figures 6.1-1 and 6.1-2. Figure 6.1-1 shows the code for the simple power curve component WP. Following the call sequence are a number of comment cards including the component purpose and calling sequence. The table PW is treated as a single dimension Fortran array. Power output is obtained from the table interpolation subroutine TBLU1. (Use of the table interpolation routines TBLU1 and TBLU2 is explained in Section 2.1). The rest of the code shows the conventions used to compute output statistics and add costs for the cost summary. IMPL is an integer variable which indicates the iteration control status:

IMPL = 0 the first time in a simulation that the model (EQMO) is called
= 1 if more iterations and hence subroutine calls are expected at a given time step
>1 the final iteration through the model.

Hence when IMPL = 0, subroutine variables are initialized, default values are assigned, etc. The statistics are only updated at the final iteration

```
CWP
      SUBROUTINE WP ( PW,BI,PO,AMI,AMP,SP,CO,VO,WVO,WV1,WV,CCI,CMI,EC)
C
C   PURPOSE     MODEL THE WIND TURBINE AND GENERATOR USING A POWER CURVE
C
C   WRITTEN BY A.W. WARREN                             VERSION 1, MARCH 3 1977
C
C   CALL SEQUENCE
C         TABLES
C                PW   = WIND GENERATION POWER IN KW VERSUS WIND VELOCITY IN MPH
C
C         OUTPUTS
C                BI   = OUTPUT BUS CURRENT, AMPS
C                PO   = POWER OUTPUT, KW
C                AMI  = MAX. OBSERVED CURRENT, AMPS
C                AMP  = MAX. OBSERVED POWER, KW
C                SP   = TOTAL OUTPUT ENERGY,KWH
C                CO   = OPERATING COST, $
C
C         INPUTS
C                VO   = RATED BUS VOLTAGE, VOLTS
C                WVO  = POWER CUTIN VELOCITY, MPH
C                WV1  = POWER CUTOUT VELOCITY, MPH
C                WV   = WIND VELOCITY, MPH
C                CCI  = CAPITOL COST / YEAR, $
C                CMI  = MAINTENANCE COST / YEAR, $
C                EC   = CONTROL ENERGY RATE, $/HR
C
      DIMENSION PW(1)
      COMMON / CIMPL / IMPL
      COMMON/COST/ CC,CM,COP /CTIME/ TIME /CSIMUL/ DUM(6),TINC,TMAX
C
C                                    POWER OUTPUT CALCULATIONS
C
      PO = 0.
      IF(WV.LT.WVO .OR. WV.GT.WV1) GO TO 10
      N = PW(2)
      PO = TBLU1(WV,PW(4),PW(4+N),1,-N)
   10 BI = PO*1000/VO
C                                 STATISTICS
C
      IF(IMPL.GT.0) GO TO 20
      CO= 0.
      AMI = 0.
      AMP = 0.
      SP = 0.
      TMAX1=TMAX*.99999
   20 IF(IMPL.LE.1) RETURN
      AMI = AMAX1(AMI,BI)
      AMP = AMAX1(AMP,PO)
      SP = SP + PO*.5*TINC
      CO= CO + EC*.5*TINC
C                                 COST SUMMATION
      IF( TIME.LT.TMAX1) RETURN
      CC = CC + CCI
      CM = CM + CMI
      COP= COP +.CO
      RETURN
      END
END FOR
```

FIGURE 6.1-1 SAMPLE COMPONENT CODE

ORIGINAL PAGE IS
OF POOR QUALITY

```
00100   CGE
00101        SUBROUTINE GE(P2,EE,RS,PL,EF2,PM2,PMN,SP,P1,RAP,RSY,RAS,DA,SR,VO,                000000
00101       1 EF1,PM1,CCI,CMI)                                                                  000000
00101   C                                                                                       000000
00101   C    PURPOSE     MODEL AC INDUCTION GENERATOR                                           000000
00101   C                                                                                       000000
00101   C    METHOD      MECHANICAL AND ELECTRICAL EFFICIENCIES ARE USED TO COMPUTE             000000
00101   C                OUTPUT POWER.  ROTOR SPEED IS COMPUTED ASSUMING POWER IS               000000
00101   C                PROPORTIONAL TO SLIP.                                                  000000
00101   C                                                                                       000000
00101   C    WRITTEN BY A.W. WARREN                           VERSION 1, MARCH 16 1977          000000
00101   C                                                                                       000000
00101   C    CALL SEQUENCE                                                                      000000
00101   C         OUTPUTS                                                                       000000
00101   C                P2  - OUTPUT POWER, KW                                                 000000
00101   C                EE  - ELECTRICAL EFFICIENCY                                            000000
00101   C                RS  - ROTOR SPEED, RPM                                                 000000
00101   C                PL  - POWER LOSS, KW                                                   000000
00101   C                EF2 - OUTPUT PRODUCT EFFICIENCY                                        000000
00101   C                PM2 - MAXIMUM OUTPUT POWER, KW                                         000000
00101   C                PMN - MAX. OBSERVED OUTPUT POWER / RATED POWER                         000000
00101   C                SP  - TOTAL OUTPUT ENERGY, KWH                                         000000
00101   C                                                                                       000000
00101   C         INPUTS                                                                        000000
00101   C                P1  - INPUT POWER, KW                                                  000000
00101   C                RAP - RATED OUTPUT POWER, KW                                           000000
00101   C                RSY - SYNCHRONOUS ROTOR SPEED, RPMN                                    000000
00101   C                RAS - RATED POWER SLIP (DEFAULT = .05)                                 000000
00101   C                DA  - MECHANICAL DAMPING, JOULE-SEC                                    000000
00101   C                SR  - STATOR RESISTANCE, OHMS                                          000000
00101   C                VO  - RATED BUS VOLTAGE, VOLTS                                         000000
00101   C                EF1 - INPUT PRODUCT EFFICIENCY                                         000000
00101   C                PM1 - MAXIMUM INPUT POWER, KW                                          000000
00101   C                CCI - CAPITAL COST/YEAR, $                                             000000
00101   C                CMI - MAINTENANCE COST/YEAR, $                                         000000
00101   C                                                                                       000000
00103         COMMON /CIMPL/ IMPL,ICNT /CTIME/ TIME                                             000000
00104         COMMON /COST/ CC,CM,CO,CV /CSIMUL/ DUM(6),TINC,TMAX                               000000
00104   C                          INITIALIZATION                                               000000
00104   C                                                                                       000000
00105         IF( IMPL.GT.0) GO TO 10                                                           000000
00107         EFF = 1.                                                                          000000
00110         TMAX1 = TMAX* .99999                                                              000002
00111         IF(RSY.EQ. .99999) RSY = 1800.                                                    000004
00113         IF(RAS.EQ. .99999) RAS = .05                                                      000007
00115         IF(DA .EQ. .99999) DA = 0.                                                        000014
00117         IF(SR .EQ. .99999) SR = 6.4/RAP                                                   000021
00121         IF(VO .EQ. .99999) VO = 400.                                                      000025
00123         IF(PM1.EQ. .99999) PM1 = 1.E10                                                    000033
00125         PMN =0.0                                                                          000040
00126         SP  =0.0                                                                          000045
00127         RATI = RAP*1000./VO                                                               000046
00130         EE  = RAP/(RAP + SR*.001*RATI**2)                                                 000047
00130   C                                                                                       000053
00130   C                        COMPUTE ROTOR SPEED AND OUTPUT POWER                           000053
00130   C                                                                                       000053
00131      10 IF( P1.GT. 0.) GO TO 20                                                           000053
00133         P2 =0.0                                                                           000064
00134         PL =0.0                                                                           000066
00135         RS = RSY                                                                          000067
00136         GO TO 30                                                                          000070
00136   C                                                                                       000072
00137      20 A = RAP/(EE*RAS)                                                                  000072
00140         B = RSY/( A + RSY**2*DA*1.0966E-5)                                                000074
00141         RS = B*(A + P1)                                                                   000100
00142         P2 = RAP*(RS/RSY -1.)/RAS                                                         000110
00143         IF (P2.GT.RAP.AND.IMPL.EQ.2) WRITE(6,100)                                         000114
00146     100 FORMAT(1H0, 40X,37HGENERATOR OUTPUT EXCEEDS RATED POWER /)                        000121
00146   C                                                                                       000143
00147         IF(P2.GT.RAP .AND. IMPL.EQ.2)ICNT=ICNT+1                                          000143
00151         PL = P1 - P2                                                                      000143
00152         EFF = P2/P1                                                                       000165
00153      30 EF2 = EF1*EFF                                                                     000166
00154         PM2 = AMIN1(RAP, PM1*EFF)                                                         000172
00154   C                                                                                       000174
00154   C                          STATISTICS                                                   000174
00155         IF(IMPL.LE.1) RETURN                                                              000174
00157         PMN = AMAX1(PMN, P2/RAP)                                                          000203
00160         SP = SP + P2*.5*TINC                                                              000212
00160   C                                                                                       000221
00160   C                          COST SUMMATION                                               000221
00161         IF( TIME.LT.TMAX1) RETURN                                                         000221
00163         CC = CC + CCI                                                                     000226
00164         CM = CM + CMI                                                                     000235
00164   C                                                                                       000240
00165         RETURN                                                                            000240
00166         END                                                                               000243
END FOR                                                                                         000362
```

FIGURE 6.1-2 SAMPLE COMPONENT CODE

when the model has presumably attained steady state values. Finally, the costs are added up when the simulation has reached the maximum time point. Capital costs, maintenance costs, and operating costs are stored in the first three locations of common block COST.

Figure 6.1-2 shows the code for the generator component GE. The program automatically assigns default parameters = .99999. Hence, when IMPL = 0 component dependent default values are assigned whenever the .99999 default is assumed. The code near Format statement 100 shows a typical diagnostic printout. The diagnostic is only printed if IMPL = 2 since we need only diagnose errors at the final iteration. Note that a counter ICNT is updated each time a diagnostic is printed. It is stored in the second location of common block CIMPL and is monitored to see if diagnostic print lines exceeds DLINES. If so, IMPL is set to 3 the final iteration, so that no further diagnostics are printed. The last convention observed here concerns the use of the maximum power and product efficiency variables denoted PM1, EF1, PM2, EF2. These variables are used to communicate information to the logic components PD and PA. The efficiency variable EFF is defined as the ratio of output power to input power except when P1 = 0. In this case the old EFF value is used, but in any case EFF = 0 must be avoided since this would communicate a zero efficiency to a logic device which would then generate an infinite request. It is seen that EF2 and PM2 represent the joint efficiency and maximum power at the output port as a consequence of the rated generator power and computed input/output efficiency.

Storage devices have in addition to the above, certain conventions to communicate with the logic components. An input parameter RE1 for port 1 request is used to initiate power discharge from storage. An output variable RE2 for port 2 request is used to communicate a maximum charge rate request and is usually computed by

RE2 = MIN (MP1, RAP)/EF1

where MP1 and EF1 are the input maximum power and input product efficiency, and RAP denotes the maximum storage charging rate. A priority interrupt INT should also be defined so that INT = 1. when storage is empty or at a minimum, INT = 0. If no interrupt is required, and INT = -1. at full storage capacity. The state of storage is normally a state variable so that the code computes the state derivative at each time point and lets the integrator update the state at each time point.

6.2 FILOAD PROGRAM

In addition to placing the subroutine representing the new standard component in the component library, descriptions of the inputs, outputs, and tables required by the new component must be added to the permanent file, M18. These lists are used by the Model Generation program to direct the connection of component inputs and outputs. The program FILOAD is provided to perform any of the following tasks:

1. Add new input, output, or table name lists.
2. Replace existing input, output or table name lists.
3. Remove all name lists for specified components.
4. Dump contents of M18 file onto Tape 9 in input format.

6.2.1 FILOAD Program Commands

The FILOAD program will recognize the following commands.

LIST STANDARD COMPONENTS

The LIST COMPONENTS command causes the program to print the input, output, and table lists for all components modified or added to the M18 file. If this command is not given the program will merely give a message stating the name of the new components being added to the file.

PURGE

The PURGE command can be used to remove a component from the M18 file. The PURGE command is followed by the names of the components to be purged. The command and the component names must be separated by one of the standard delimiters; i.e. [ ] three or more blanks, [,] comma, [=] equal sign, [()] left or right parentheses.

Example 6.3: PURGE = CM, TB, OB

This command would remove all lists for the CM, TB, and OB components from the name list file.

SYMBOL

The SYMBOL command may be used to designate the type of symbol that is to appear for each standard component in the lineprinter drawn model schematic diagram. The SYMBOL command is followed by the names of the components each followed by a symbol number. The symbol numbers and their associated symbols are shown in Figure 6.2-1. The SYMBOL command, component names, and symbol numbers are separated by standard delimiters.

Example: SYMBOL, CO = 100, SH = 200, TU = 300, OC = 400

If a symbol number is not specified for a component the default symbol of a square box will be used.

DUMP FILE

The DUMP FILE command causes the FILOAD program to dump the contents of the M18 file onto DUMPF9, in the input format of the FILOAD program. Thus for each standard component, a list of inputs, outputs, and tables will be produced. This data will be preceded by the command NEW FILE described below. This file may be edited to modify the input, output or tables description of any existing standard component or to derive a new standard component

STANDARD SCHEMATIC SYMBOLS

```
  4             5             6             7             8

             **
             *  *
             *    *                       000000000
             *      *                   0          0
             *  CO    *                 0   OC     0
  14         *   15   *       16        0    17    0      18
             *      *                   0          0
             *    *                      000000000
             *  *
             **  SYMBOL = 100                    SYMBOL = 400

  24            25            26            27            28


              ******                    **********
             *      *                   *        *
            *  SH    *                  *  ME    *
  34        *   35   *        36        *   37   *        38
             *      *                   *        *
              ******                    **********
                 SYMBOL = 200           SYMBOL = ANY OTHER NUMBER

  44            45            46            47            48
                    **
                  *  *
                *    *
              *      *
            *  TU    *
  54        *   55   *        56            57            58
              *      *
                *    *
                  *  *   SYMBOL = 300
                    **

  64            65            66            67            68
```

FIGURE 6.2-1 LIST OF STANDARD COMPONENT SYMBOLS description from an existing one. The results of such an editing would then serve as input data to a subsequent run of the FILOAD program. Unless it is intended to purge the M18 file and start anew, the NEW FILE command at the beginning of DUMPF9 should be removed before the subsequent run of the FILOAD program.

NEW FILE

The NEW FILE command instructs the FILOAD program to construct a new M18 file. This command must occur as the first card in a set of data describing a completely new M18 file. Any previous components that may have existed on the M18 file are purged by this command. It is therefore only used when installing a complete new M18 file.

FILE NAME

This command is used to load the file name to be associated with the M18 file. The current M18 file name is WINDENERGY. This command is used as:

FILE NAME = WINDENERGY

6.2.2 Input Name Lists

Input name lists are identified by the letters INPT following the component name. Thus, the input name list for a component DC would be introduced with the phrase, DCINPT. This must be followed by a phrase that contains the number of names in the input name list.

The input names are contained on the following data cards, 8 names per card. The names must be left adjusted in fields, 10 characters wide. The names are placed in Columns 1 through 3 of each field. Column 9 of each field can be used to indicate a port number which can be attached to the name to distinguish it from other quantities of the same name that occur with the given component. Thus, to indicate that temperature, T, is an input to port 1, the input name list would be:

Column:	1	2	3	4	5	6	7	8	9	10
Item:	T								1	

This quantity would then be referred to as T1.

Example 6.4:

SWINPT = 3
IN......1.IN......2.CNT

(The dots are used here to indicate blank spaces and would not be included in an actual data card).

These two data cards would indicate that the component SW had 3 input quantity names. A quantity IN appears at port 1, and is to be referred to as IN1. A quantity IN appears at port 2, and is to be referred to as IN2. A third input quantity CNT has no port designation. Note that if a port number is to be attached to a quantity name, that name should contain no more than 2 characters.

The sequence of names in the input name list must match the sequence of input arguments in the component call sequence.

6.2.3 Output Name Lists

Output name lists are identified by the letters OUTP following the component name. Thus, the output name list for a component DC would be introduced with the phrase, DCOUTP. This must be followed by a phrase that contains the number of names in the output name list.

The output names are contained on the following data cards, 8 names per card. The names must be left adjusted in fields 10 characters wide. The names are placed in Columns 1 through 3 of each field. Column 9 of each field can be used to introduce a port number which can be attached to the name to distinguish it from other quantities of the same name that occur with the given component. If the output quantity is a state variable, this must be indicated by placing S in Column 10 of the field. Thus, if power P is a state variable output quantity at port 2, the output name list would be:

Column:	1	2	3	4	5	6	7	8	9	10
Item:	P								2	S

This quantity would then be referred to as P2.

Example 6.5:

```
TZOUTP = 3
X.......1SX.......2SOUT
```

(The dots are used here to indicate blank spaces, and would not be included on an actual data card).

These two data cards would indicate that the component TZ had 3 output quantity names. A quantity X appears at port 1. This is a state variable, and will be referred to as X1. A quantity X is also a state variable that appears at port 2. It will be referred to as X2. The quantity OUT is an output variable, not a state variable, and does not have a port number associated with it. Note, that if a port number is to be attached to a quantity name that name should contain no more than 2 characters. These two characters plus the port number will reach the maximum number of 3 characters in a quantity name.

The sequence of names in the output name list must match the sequence of output arguments in the component call sequence. However, whereas three arguments are provided for each state in the subroutine call sequence, only one name is included in the output name list.

6.2.4 Table Name Lists

Table name lists are identified by the letters TABS, following the component name. Thus, the table name list for a component CM would be introduced with the phrase CMTABS. This must be followed by a phrase containing the number of names in the table name list. The table names are contained in the following cards, one table name per card. The name is located in the first 3 columns of the card. It must be accompanied by the maximum dimension that is to be provided for this table. This number must be given in columns 4 through 10 and should have a decimal point given. For single independent variable tables this number must be negative. For tables with two independent variables, this number must be positive.

Example:

```
CMTABS = 3
TAM      53.
TAB      43.
TCM     -27.
```

These four data cards would indicate that the component CM had 3 tables. The first two tables TAM and TAB have two independent variables each, as indicated by the positive dimension numbers. The table TCM has only one independent variable, as indicated by the negative dimension number. 53, 43, and 27 words of storage are to be provided for tables TAM, TAB, and TCM respectively. The maximum storage is related to the maximum number of primary, NX, and secondary, NZ, independent variables by:

MAX = 3 + NX+NZ+NX*NZ for tables with two independent variables

MAX = 3 + 2*NX for tables with one independent variable

7.0 LIBRARY COMPONENT DESCRIPTIONS

This section describes the mathematical algorithms and input/output structure of the SIMWEST library components. Each component writeup contains a brief textual description of the algorithms, a mathematical expression summarizing its function, a list of input and output variables, and a description of the calculation sequence and logic used in the model. A figure is provided which shows the nominal input and output connections, and the state variables of each component.

There are a number of features and conventions in the component descriptions which require some elaboration. These are briefly summarized below.

7a. INPUT/OUTPUT NAME LISTS

A potentially confusing factor is the way port numbers on input parameters and output variables are designated. On the model generation input cards the name of the physical quantity and the port number is separated by a comma. For example, the power variable with port designation 1 is denoted P,1. In defining input to the simulation program, this same variable would be denoted P1. To emphasize the distinction between the physical quantities and port numbers, they are listed separately in the name lists of the component write-ups. For example, P 1 in the name list denotes the power variable (or parameter) with port designation 1 even though in other parts of the text it may simply be denoted P1.

Another convention in the name lists is that the alphabetic symbol 'O' is shown as Ø to distinguish this symbol from a zero. Elsewhere in the text symbols such as VØ may be referred to as VO.

7b. INPUT PARAMETER SPECIFICATION

All input parameters are associated with default values. Many of the parameters have default values denoted in the parameter description by the letter D. For example in the Battery component the default value for terminal resistance, RT, is D = .001 ohms. All input parameters for which a default value is not so specified has a default value of .99999. Default values are intended to enable users to put models together quickly by specifying a minimum of input data. Users need only specify detailed parameter values for those components of current interest. One must be careful using this approach since the operating characteristics and efficiency of a 10kw rated device may for example be quite different than for a 100kw device.

Any user specified input parameter can be driven by one or two dimension table lookups using the FU and FV components. This enables the user to build more detailed models using time or other output variables to drive the tables. For example, if one needs to specify cost of peak load generation to the utility component as a function of peak load request, then one adds FU as an input to UT and specifies load request as an input connection to FU. The desired function table is then input to FU.

It may be noted that not all of the components have maintenance or operating cost inputs. Thus, whenever these costs are important, one can aggregate such costs and input lumped costs to the model. For example, the maintenance cost of the hydro storage system may include maintenance costs for the pump and turbine.

7c. COMPONENT LOGIC

In constructing SIMWEST components, we have adopted several conventions to aid communication with the logic components. All physical components distributing power are given two input parameters EF and MP (port 1) and two output variables EF and MP (port 2). The output EF is the product efficiency of all components in the distribution subsystem up to and including the given component, and MP is the maximum power deliverable at the output of the component. Each storage component has in addition a power request input denoted RE (port 1), a power request output denoted RE (port 2), and a priority interrupt flag denoted INT.

Figure 7.0 shows the logic and physical variable connections for power flow in and out of a hydro reservoir. Power flows from the power divider to the pump at a rate not to exceed the request RE from HS. The HS request is computed by dividing the input maximum power by the input (or pump) efficiency EF. Hence, the maximum power flowing to HS cannot exceed RE*EF = MP. Similarly, the input request to HS is computed by the PA component so as not to exceed the maximum input power MP divided by EF (turbine efficiency). Hence, the power that flows to PA cannot exceed RE*EF = input maximum power.

When the hydro reservoir is empty, the interrupt flag is turned on and the priority sequence is changed to 1 so that the reservoir is given access to power flowing into the divider.

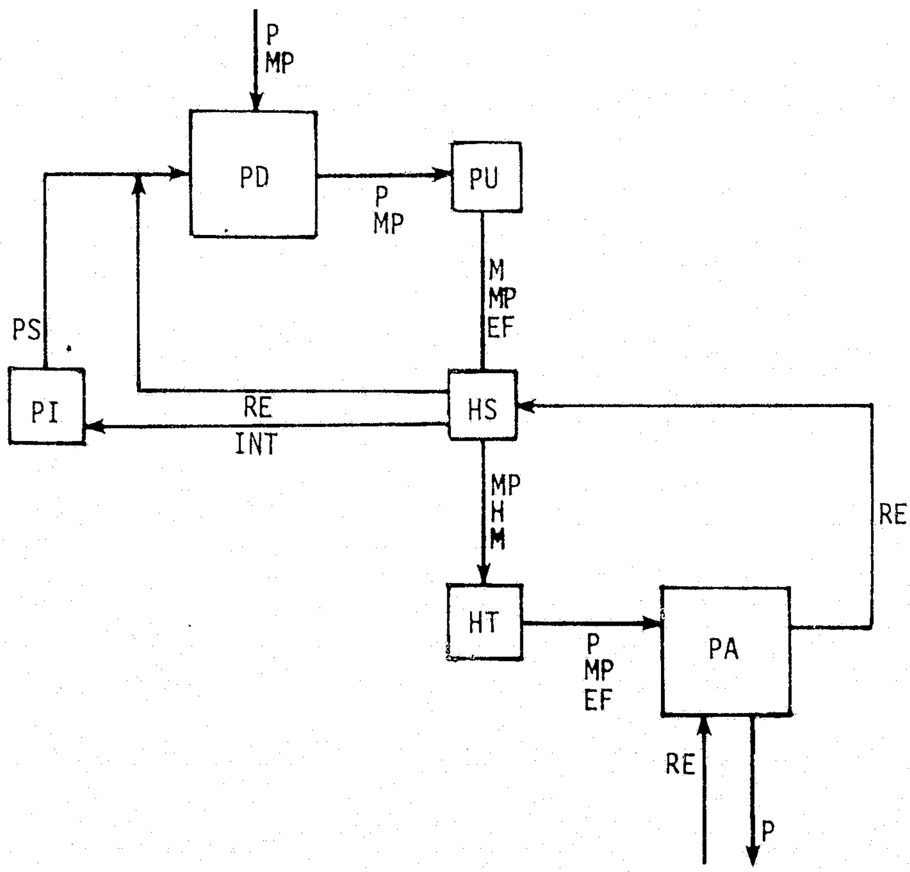
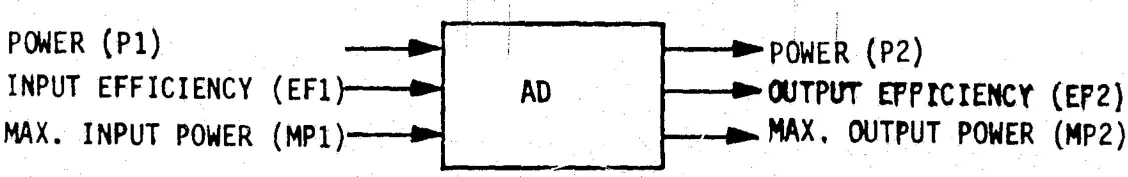


FIGURE 7.0 SAMPLE CONNECTIONS FOR LOGIC COMPONENTS

7.1 ADMITTANCE



The admittance model can be used to model transmission lines, transformers, capacitors or impedance power flows. A primary assumption is that the reactive parameters dominate the real parameters so that power transfer angle is solely based on reactive values, and power losses are based on the real admittance parameters and on power angle. The equation for power loss is based upon the following model:

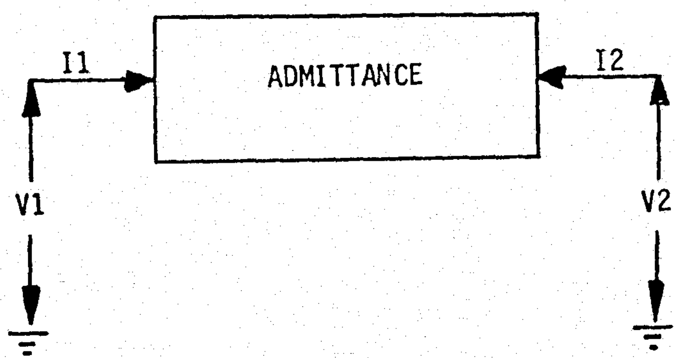


FIGURE 7.1 ADMITTANCE NETWORK MODEL

$$\begin{pmatrix} I1 \\ I2 \end{pmatrix} = \begin{pmatrix} G1 + jB1 & GM + jBM \\ GM + jBM & G2 + jB2 \end{pmatrix} \begin{pmatrix} V1 \\ V2 \end{pmatrix}$$

Where the reactive parameters B_1 and B_2 do not enter into the power loss calculations.

AD

Inputs

Parameter/Port		Description	Units
G1,GM,G2		Real admittance parameters *	mho
BM		Reactive admittance parameter *(≠0)	mho
VØ		Rated voltage magnitude	volts
P	1	Input power	kw
EF	1	Input product efficiency	–
MP	1	Maximum input power	kw
CC		Capital cost/year	$

Outputs

Variable/Port			
P	2	Output power	kw
PL		Power loss	kw
PA		Power angle	deg
EF	2	Output product efficiency	–
MP	2	Maximum output power	kw

* – See next page for User Input to Model Transmission lines, Transformers and Impedances.

Transmission Line Input:

$G1 = G2 = g*\ell$

$GM = -g*\ell$

$BM = 1/(\omega*L*\ell)$

where g = line conductance per unit length

ℓ = length of line

ω = frequency in radians/sec = 120π

L = line inductance per unit length

Transformer Input:

$G1 = G2 = GM = 0$

$BM = 1/X*h$

where X = reactance in ohms

h = turns ratio

(No power loss modeled with a transformer)

Impedance Input: (Includes capacitors and inductors)

$G1 = G2 = -GM = R/(R^2+X^2)$

$BM = X/(R^2+X^2)$

where R = resistance in ohms

X = reactance in ohms

$$= \begin{pmatrix} \omega L & \text{for an inductance } L \\ -\frac{1}{\omega C} & \text{for a capacitance } C \end{pmatrix}$$

Calculation Sequence

If $P1 \leq 0$ $P2 = PL = PA = 0$ and Return

1) Compute power angle

If $P1*1000 > BM*V\emptyset^2$, $COS\ \theta = 0$ and write DIAGNOSTIC

$\theta = -SIN^{-1}(P1*1000/BM*V\emptyset^2)$

$PA = \theta*180/\pi$

$$COS\ \theta = \sqrt{1 - (P1*1000/BM*V\emptyset^2)^2}$$

2) Compute power loss and output power

$PL = V\emptyset^2*(G1+G2+2*GM*COS\ \theta)/1000$

$P2 = P1 - PL$

$EFF = P2/P1$

If $P2 > 0$ go to 3)

write DIAGNOSTIC

$EFF = 1.$

3) Efficiency and maximum output power

$EF2 = EF1*EFF$

$MP2 = MIN(MP1, |BM| *V\emptyset^2/1000) * EFF$

4) Compute costs

```
SUBROUTINE AD        ENTRY POINT 000212

STORAGE USED  CODE(1) 000264; DATA(0) 000072; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL   000002
 0004   CTIME   000001
 0005   CSIMUL  000010
 0006   COST    000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   NWDU$
 0010   NIO2$
 0011   ASIN
 0012   SQRT
 0013   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000017 10L        0001   000060 100L      0000   000006 108F      0001   000076 200L      0001   000140 300L
 0000   000027 308F       0001   000162 400L      0006 R 000000 CCI       0005   000000 DUM       0000 R 000005 EFF
 0003 I 000001 ICNT       0003 I 000000 IMPL      0000   000054 INJP$     0000 R 000001 RR        0000 R 000003 RPC
 0000 R 000002 RR2        0000 R 000004 THETA     0004 R 000000 TIME      0005 R 000007 TMAX      0000 R 000000 TMAX1


00100     CAD                                                                                000000
00101           SUBROUTINE AD(P2,PL,PA,EF2,MP2,  G1,GM,G2,BM,VO,P1,EF1,MP1,CC)                000000
00101     C                                                                                  000000
00101     C                PURPOSE   MODEL OF TRANSMISSION LINES,TRANSFORMERS,                000000
00101     C                          CAPACITORS, OR IMPEDANCE POWER LOSS                      000000
00101     C                                                                                  000000
00101     C                METHOD    OUTPUT POWER AND POWER LOSS COMPUTED FROM                000000
00101     C                          INPUT POWER                                              000000
00101     C                                                                                  000000
00101     C                WRITTEN BY Y.K.CHAN      VERSION 1, JULY,1977                      000000
00101     C                                                                                  000000
00101     C  CALL SEQUENCE                                                                   000000
00101     C         OUTPUTS                                                                  000000
00101     C                P2  -OUTPUT POWER,KW                                               000000
00101     C                PL  -POWER LOSS,KW                                                 000000
00101     C                PA  -POWER ANGLE,DEG                                               000000
00101     C                EF2 -OUTPUT PRODUCT EFFICIENCY                                     000000
00101     C                MP2 -MAXIMUM OUTPUT POWER,KW                                       000000
00101     C         INPUTS                                                                   000000
00101     C                G1,GM,G2   -REAL ADMITTANCE PARAMETERS,MHO                         000000
00101     C                BM  -REACTIVE ADMITTANCE PARAMETERS (.NE.0.),MHO                   000000
```

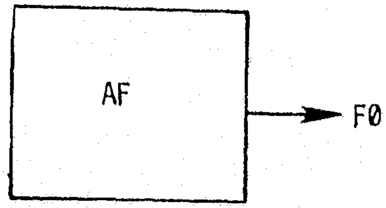
AD

```
00101   C               VO  -RATED VOLTAGE MAGNITUDE,VOLTS                000000
00101   C               P1  -INPUT POWER,KW                               000000
00101   C               EF1 -INPUT PRODUCT EFFICIENCY                     000000
00101   C               MP1 -MAXIMUM INPUT POWER,KW                       000000
00101   C               CC  -CAPITAL COST/YEAR,$                          000000
00101   C                                                                 000000
00103         COMMON /CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX       000000
00103        X        /COST/CCI                                           000000
00104         REAL MP2,MP1                                                000000
00104   C                                                                 000000
00105         P2=0.                                                       000000
00106                                                                     000000
00106         TMAX1=TMAX*.99999                                           000000
00107         IF(P1.GT.C.)GO TO 10                                        000003
00111         P2=0.                                                       000006
00112         PL=C.                                                       000007
00113         PA=C.                                                       000010
00114         MP2=MP1                                                     000011
00115         EF2=EF1                                                     000013
00116         GO TO 400                                                   000015
00116   C                                                                 000015
00116   C               COMPUTE POWER ANGLE                               000015
00116   C                                                                 000015
00117      10 RR=P1*1000./(BM*VO*VO)                                      000017
00120         RR2=RR*RR                                                   000025
00121         IF(RR2.LE.1.)GO TO 100                                      000027
00123         PA=-90.                                                     000032
00124         RRC=0.                                                      000034
00125         IF(IMPL.EQ.2)WRITE(6,108)P1,BM,VO                           000035
00133     108 FORMAT(1H0,13H INPUT POWER ,F12.3,33H TOO HIGH RELATIVE TO ADMITTA   000050
00133        XNCE ,F12.3,19H AND RATED VOLTAGE ,F12.3)                   000050
00134         IF(IMPL.EQ.2)ICNT=ICNT+1                                    000050
00136         GO TO 200                                                   000056
00137     100 THETA=-ASIN(RR)                                             000060
00140         PA=THETA*180./3.14159                                       000063
00141         RRC=SQRT(1.-RR2)                                            000066
00141   C                                                                 000066
00141   C               COMPUTE POWER LOSS AND OUTPUT POWER               000066
00141   C                                                                 000066
00142     200 PL=VO*VO*(G1+G2+2.*GM*RRC)/1000.                            000076
00143         P2=P1-PL                                                    000110
00144         EFF= P2/P1                                                  000112
00145         IF(P2.GE.0.)GO TO 300                                       000114
00147         P2=0.                                                       000117
00150         EFF=1.                                                      000120
00151         IF(IMPL.NE.2)GO TO 300                                      000122
00153         WRITE(6,308)PL,P1                                           000125
00157     308 FORMAT(1H0,24H ADMITTANCE POWER LOSS ,F12.3,21H EXCEEDS INPUT POWE   000134
00157        XR   ,F12.3)                                                 000134
00160         ICNT=ICNT+1                                                 000134
00160   C                                                                 000134
00161     300 EF2=EF1                                                     000140
00162         IF(P2.GT.0.)EF2=EF1*EFF                                     000141
00164         MP2=AMIN1(MP1,ABS(BM)*VO*VO/1000.)*EFF                      000147
00164   C                                                                 000147
00165     400 IF(IMPL.LE.1)RETURN                                         000162
00167         IF(TIME.LT.TMAX1)RETURN                                     000170
```

```
00171      79*          CCI=CCI+CC                                              000177
00171      80*     C                                                            000177
00172      81*          RETURN                                                  000202
00173      82*          END                                                     000263
```

AD

7.2 TEST FUNCTION GENERATOR



Inputs

Parameter/Port	Description
CØD	Specifies which analytic function is calculated. (See equations below for use of these inputs)
C1	
C2	
C3	
C4	
C5	

Outputs

Variable/Port	
FØ	Output variable

Calculation Sequence

```
CØD = 1   FØ = C1 + C2*SIN(C3*T + C4)
      2   FØ = C1 + C2*COS(C3*T + C4)
      3   FØ = C1 + exp(-C5*T) * SIN(C3*T + C4)
      4   FØ = C1 + exp(-C5*T) * COS(C3*T + C4)
      5   FØ = C1 + C2*T
      6   FØ = C1 + C2*exp(-C3*T)
          where: T = TIME
```

```
SUBROUTINE AF        ENTRY POINT 000143

STORAGE USED  CODE(1) 000166; DATA(0) 000014; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CTIME  000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0004   NERR2$
 0005   SIN
 0006   COS
 0007   EXP
 0010   NERR3$

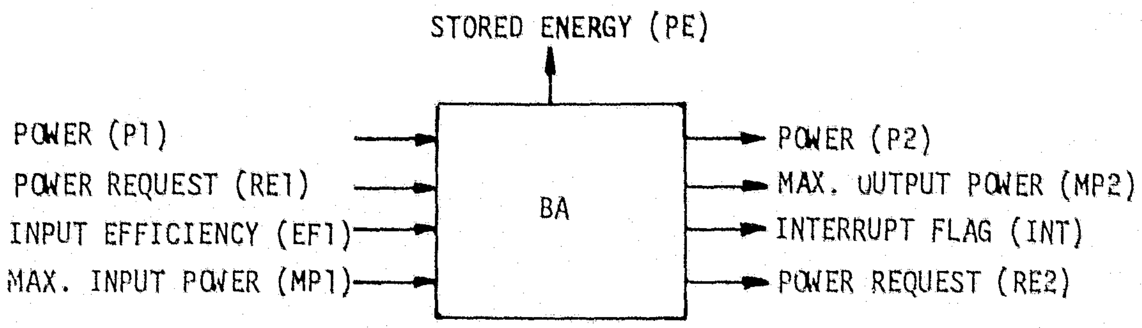
STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000022 10L      0001   000130 100L     0001   000035 20L      0001   000050 30L      0001   000073 40L
 0001   000116 50L      0001   000123 60L      0000   000001 INJP$    0000 I 000000 NCODE    0003 R 000000 TIME


00100     CAF                                                                              000000
00101           SUBROUTINE AF(FO,COD,C1,C2,C3,C4,C5)                                       000000
00101     C                                                                                000000
00101     C    PURPOSE - TO SIMULATE ANALYTICAL FUNCTIONS                                  000000
00101     C                                                                                000000
00101     C                                                                                000000
00101     C    METHOD  - SEE CODING                                                        000000
00101     C                                                                                000000
00101     C                                                                                000000
00101     C    WRITTEN BY  -  ADAM LLOYD               LATEST REVISION    FEB 76           000000
00101     C                                                                                000000
00101     C                                                                                000000
00101     C    LIMITATIONS -  NONE                                                         000000
00101     C                                                                                000000
00101     C                                                                                000000
00101     C    INPUT/OUTPUT LIST                                                           000000
00101     C                                                                                000000
00101     C    FO        OUTPUT VARIABLE                          ANY    OUTPUT VAR        000000
00101     C    COD       CODE IDENTIFYING ANALYTICAL FUNCTION     ---    INPUT  PARAM      000000
00101     C              CODE=    FO                                                   000000
00101     C                1      C1+C2*SIN(C3*TIME+C4)                                   000000
00101     C                2      C1+C2*COS(C3*TIME+C4)                                   000000
00101     C                3      C1+C2*EXP(-C5*TIME)*SIN(C3*TIME+C4)                     000000
00101     C                4      C1+C2*EXP(-C5*TIME)*COS(C3*TIME+C4)                     000000
00101     C                5      C1+C2*TIME                                              000000
00101     C                6      C1+C2*EXP(-C5*TIME)                                     000000
```

```
00101      27*     C   C1        CONSTANT INPUTS FOR ABOVE EQNS      ---    INPUT  PARAM        000000
00101      28*     C   C2        CONSTANT INPUTS FOR ABOVE EQNS      ---    INPUT  PARAM        000000
00101      29*     C   C3        CONSTANT INPUTS FOR ABOVE EQNS      ---    INPUT  PARAM        000000
00101      30*     C   C4        CONSTANT INPUTS FOR ABOVE EQNS      ---    INPUT  PARAM        000000
00101      31*     C   C5        CONSTANT INPUTS FOR ABOVE EQNS      ---    INPUT  PARAM        000000
00103      32*             COMMON/CTIME/TIME                                                     000000
00104      33*             NCODE=COD                                                             000000
00105      34*             GO TO (10,20,30,40,50,60),NCODE                                       000006
00106      35*       10    FO=C1+C2*SIN(C3*TIME+C4)                                              000022
00107      36*             GO TO 100                                                             000033
00110      37*       20    FO=C1+C2*COS(C3*TIME+C4)                                              000035
00111      38*             GO TO 100                                                             000046
00112      39*       30    FO=C1+C2*EXP(-C5*TIME)*SIN(C3*TIME+C4)                                000050
00113      40*             GO TO 100                                                             000071
00114      41*       40    FO=C1+C2*EXP(-C5*TIME)*COS(C3*TIME+C4)                                000073
00115      42*             GO TO 100                                                             000114
00116      43*       50    FO=C1+C2*TIME                                                         000116
00117      44*             GO TO 100                                                             000121
00120      45*       60    FO=C1+C2*EXP(-C5*TIME)                                                000123
00121      46*      100    RETURN                                                                000134
00122      47*             END                                                                   000165
```

7.3 BATTERY



The battery model is based on the circuit diagram shown below. Current flow is determined by the output power request minus input power. Battery leakage is proportional to stored energy. Priority interrupt logic is activated when a minimum or maximum capacity level is attained.

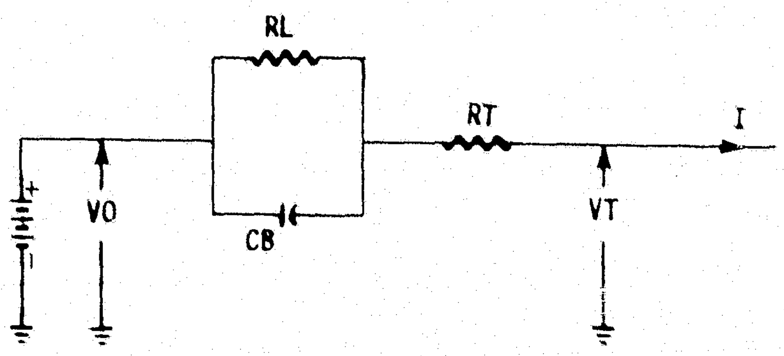


FIGURE 7.3 BATTERY CIRCUIT DIAGRAM

Basic Equations

The output power P2, stored energy PE, terminal current I, and capacitor voltage VC is computed using the following equations:

$$P2 = RE1$$

$$PE = (VC^2 + 2*V\emptyset*VC)*CB/7.2X10^6$$

$$(P2-P1)*1000 = (V\emptyset+VC)I - I^2*RT$$

$$\dot{PE} = -(I+VC/RL)(VC+V\emptyset)/1000$$

BA

Inputs

Parameter/Port		Description	Units
P	1	Input power	kw
VØ		Internal voltage	volts
RT		Terminal resistance (D = 0.001)	ohms
CB[1]		Battery capacitance (D = 2.88×10^8)	farads
RL[1]		Leakage resistance (D = 0.05)	ohms
RAP		Rated input power	kw
EF	1	Input product efficiency	–
MP	1	Maximum input power	kw
E1		Maximum energy storage	kwh
RE	1	Power request	kw
EDE		Energy deadband for priority resequencing	kwh
DT		Down time for priority resequencing	h
CC		Capital cost/year	$
CM		Maintenance cost/year	$

Outputs

Variable/Port		Description	Units
P	2	Output power (=RE1)	kw
PE		Stored energy (state of charge)	kwh
I		Terminal current (+=out,-=in)	amps
VC		Capacitor voltage	volts
VT		Terminal voltage	volts
PL		Power loss	kw
TØ		Time when battery was discharged	h
MP	2	Maximum output power	kw
INT		Priority interrupt flag	–
RE	2	Maximum charging rate request	kw

D – Default values supplied
1 – Battery leakage time constant in hours = CB*RL/3600

Statistics

Variable/Port	Description	Units
MPE	Maximum stored energy	kwh
SPC	Sum of charging energy	kwh
SPD	Sum of discharging energy	kwh

Calculation Sequence

1) Compute VC

$$VC = \sqrt{7.2X10^6 * PE/CB + VØ^2} - VØ$$

2) Solve for terminal current I

If $(P2-P1)*1000 \geq (VC+VØ)^2/4*RT$, GO TO 2'

$$I = \frac{(VC+VØ) - \sqrt{(VC+VØ)^2 - 4*RT*(P2-P1)*1000}}{2*RT}$$

Go to 3)

2)' I = (VC+VØ)/2*RT and write DIAGNOSTIC

3) Compute VT

VT = VC+VØ−I*RT

4) Potential energy balance and power loss

$$\dot{PE} = -(I+VC/RL)(VC+VØ)/1000.$$

$$PL = (I^2*RT + VC^2/RL)/1000.$$

5) Maximum charging and discharging rates

RE2 = MIN(MP1,RAP,(E1−PE)/TINC)/EF1

$MP2 = MIN(RAP,(VC+VØ)^2/(4000*RT),(PE-EDE)/TINC)$

where TINC = integration step size

Calculation Sequence Cont.

6) Priority interrupt logic

If PE $\leq$ EDE and T$\emptyset$ = 10^6, T$\emptyset$ = TIME

If PE $\leq$ EDE and TIME - T$\emptyset$ $\geq$ DT, INT = 1 and go to 7)

T$\emptyset$ = 10^6

If PE > 2*EDE and INT = 1, INT = 0

If PE $\geq$ E1, INT = -1

If PE < E1 - EDE and INT = -1, INT = 0

7) Compute Statistics and Costs

BCS 40180-2

```
SUBROUTINE BA         ENTRY POINT 000372

STORAGE USED  CODE(1) 000537; DATA(0) 000105; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000002
 0004   CTIME  000001
 0005   CSIMUL 000010
 0006   COST   000002

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   SQRT
 0010   DSQRT
 0011   NWDU$
 0012   NI02$
 0013   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000036 100L      0001   000111 200L      0000   000015 208F      0001   000136 300L      0001   000316 400L
 0001   000274 401L      0001   000314 403L      0000 D 000000 AA        0000 R 000010 AP1       0000 R 000011 AP2
 0000 D 000002 B         0000 D 000004 B2        0000 R 000012 C         0006 R 000000 CCI       0006 R 000001 CMI
 0005 R 000000 DUM       0000 R 000013 ED2       0003 I 000001 ICNT      0003 I 000000 IMPL      0000   000053 INJP$
 0004 R 000000 TIME      0000 R 000006 TINC1     0005 R 000007 TMAX      0000 R 000007 TMAX1     0000 R 000014 WAIT


00100      CBA                                                                              000000
00101            SUBROUTINE BA(P2,PE,PED,IPE,I,VC,VT,PL,TO,MP2,INT,RE2,MPE,SPC,SPD,         000000
00101          1      P1,VO,RT,CB,RL,RAP,EF1,MP1,E1,RE1,EDE,DT,CC,CM)                       000000
00101      C                                                                                000000
00101      C                 PURPOSE   BATTERY MODEL                                        000000
00101      C                                                                                000000
00101      C                 METHOD    COMPUTE STORED ENERGY AND POWER OUTPUT AS            000000
00101      C                           FUNCTIONS OF POWER INPUT AND POWER REQUEST.          000000
00101      C                           A RESISTOR/CAPACITOR NETWORK IS USED TO              000000
00101      C                           MODEL BATTERY STORAGE.                               000000
00101      C                                                                                000000
00101      C                 WRITTEN BY Y.K.CHAN                VERSION 1, JUNE 3,1977      000000
00101      C                                                                                000000
00101      C    CALL SEQUENCE                                                               000000
00101      C          OUTPUTS                                                               000000
00101      C                 P2  -OUTPUT POWER, KW                                          000000
00101      C                 PE  -STORED ENERGY (STATE),KWH                                 000000
00101      C                 PED -STORED ENERGY DERIVATIVE                                  000000
00101      C                 IPE -INTEGRATOR CONTROL                                        000000
00101      C                 I   -TERMINAL CURRENT (+=OUT,-=IN),AMPS                        000000
```

BA

```
00101   C            VC  -CAPACITOR VOLTAGE, VOLTS                           000000
00101   C            VT  -TERMINAL VOLTAGE, VOLTS                            000000
00101   C            PL  -POWER LOSS, KW                                     000000
00101   C            TO  TIME WHEN BATTERY WAS DISCHARGED, HR                000000
00101   C            MP2 -MAXIMUM OUTPUT POWER, KW                           000000
00101   C            INT -PRIORITY INTERRUPT FLAG                            000000
00101   C            RE2 -MAXIMUM CHARGING RATE REQUEST, KW                  000000
00101   C        STATISTICS                                                  000000
00101   C            SPC -SUM OF CHARGING ENERGY, KWH                        000000
00101   C            MPE -MAXIMUM STORED ENERGY,KWH                          000000
00101   C            SPD -SUM OF DISCHARGING ENERGY, KHW                     000000
00101   C        INPUTS                                                      000000
00101   C            P1  -INPUT POWER, KW                                    000000
00101   C            VO  -INTERNAL VOLTAGE, VOLTS                            000000
00101   C            PT  -TERMINAL RESISTANCE, OHMS                          000000
00101   C            CB  -BATTERY CAPACITANCE, FARADS                        000000
00101   C            RL  -LEAKAGE RESISTANCE, OHMS                           000000
00101   C            RAP -RATED INPUT POWER, KW                              000000
00101   C            EF1 -INPUT PRODUCT EFFICIENCY                           000000
00101   C            MP1 -MAXIMUM INPUT POWER, KW                            000000
00101   C            E1  -MAXIMUM ENERGY STORAGE, KWH                        000000
00101   C            RE1 -POWER REQUEST, KW                                  000000
00101   C            EDE -ENERGY DEADBAND FOR PRIORITY RESEQUENCING, KWH     000000
00101   C            DT  -DOWNTIME FOR PRIORITY RESEQUENCING, HR             000000
00101   C            CC  -CAPITAL COST/YEAR, $                               000000
00101   C            CM  -MAINTENANCE COST/YEAR, $                           000000
00101   C                                                                    000000
00103         COMMON /CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX/COST/CCI,CMI   000000
00104         REAL I,MP2,MPE,MP1,INT                                         000000
00105         DOUBLE PRECISION AA,B,B2                                       000000
00106         TINC1=DUM(7)*.5                                                000000
00106   C                                                                    000000
00107         IF(IMPL.GT.0) GO TO 100                                        000002
00111         IF(RT.EQ..99999)RT=.001                                        000005
00113         IF(CB.EQ..99999)CB=2.88E8                                      000012
00115         IF(PL.EQ..99999)RL=.05                                         000017
00117         TO=1000000.                                                    000024
00120         INT=0                                                          000026
00121         TMAX1=TMAX*.99999                                              000027
00122                                                                        000032
00122         MPE=0.                                                         000032
00123         SPC=0.                                                         000033
00124         SPD=0.                                                         000034
00124   C                                                                    000034
00124   C            CAPACITOR VOLTAGE                                       000034
00124   C                                                                    000034
00125     100 VC=SQRT((7.2E6)*PE/CB + VO**2) -VO                             000036
00125   C                                                                    000036
00125   C            TERMINAL CURRENT                                        000036
00125   C                                                                    000036
00126         P2=RE1                                                         000051
00127         AA=(P2-P1)*4000.*RT                                            000053
00130         B=VC+VO                                                        000062
00131         B2=B*B                                                         000066
00132         IF(AA.GT.B2) GO TO 200                                         000070
00134         I= B-DSQRT(B2-AA)                                              000073
00135         I=I/(2.*RT)                                                    000103
```

BA

```
00136            GO TO 300                                                   000107
00136      C                                                                 000107
00137        200 I=B/(2.*RT)                                                 000111
00143            IF(IMPL.EQ.2)WRITE(6,208)P2                                 000116
00144        208 FORMAT(1H0,15H POWER REQUEST ,F12.3,50H EXCEEDS BATTERY CAPABILITY 000127
00144          1. CHECK VC,VO, AND RT. )                                     000127
00145            IF (IMPL.EQ.2)ICNT=ICNT+1                                   000127
00145      C                                                                 000127
00145      C              TERMINAL VOLTAGE                                   000127
00145      C                                                                 000127
00147        300 VT=VC+VO-I*RT                                               000136
00147      C                                                                 000136
00147      C              POTENTIAL ENERGY BALANCE AND ENERGY LOSS           000136
00147      C                                                                 000136
00150            IF(IPE.NE.0)PEO=(-I-VC/RL)*(VC+VO)/1000.                    000144
00152            PL=(I*I*RT+VC*VC/RL)/1000.                                  000154
00152      C                                                                 000154
00152      C              MAXIMUM CHARGING AND DISCHARGING RATES             000154
00152      C                                                                 000154
00153            AP1= AMAX1(0.,(E1-PE)/DUM(7))                               000165
00154            RE2=AMIN1(MP1,RAP,AP1)                                      000175
00155            RE2=RE2/EF1                                                 000207
00156            AP2= AMAX1(0.,(PE-EDE)/DUM(7))                              000211
00157            MP2=AMIN1(RAP,B2/(4000.*RT),AP2)                            000221
00157      C                                                                 000221
00157      C              PRIORITY INTERRUPT                                 000221
00157      C                                                                 000221
00160            C=E1-EDE                                                    000241
00161            ED2=EDE+EDE                                                 000244
00162            IF(PE.GT.EDE)GO TO 401                                      000247
00164            IF(TO.GT.999999.)TO=TIME                                    000253
00166            WAIT=TIME-TO                                                000261
00167            IF (WAIT.GT.DT)INT=1                                        000264
00171            GO TO 400                                                   000272
00172        401 TO=1000000                                                  000274
00173            IF(PE.LE.ED2)GO TO 400                                      000275
00175            IF(PE.GT.E1)GO TO 403                                       000301
00177            IF(PE.GT.C)GO TO 400                                        000305
00201            INT=0                                                       000311
00202            GO TO 400                                                   000312
00203        403 INT=-1                                                      000314
00204        400 CONTINUE                                                    000316
00204      C                                                                 000316
00205            IF(IMPL.LE.1)RETURN                                         000316
00205      C                                                                 000316
00205      C              STATISTICS                                         000316
00205      C                                                                 000316
00207            MPE=AMAX1(MPE,PE)                                           000324
00210            SPC=SPC+TINC1*P1                                            000332
00211            SPD=SPD+TINC1*P2                                            000336
00211      C                                                                 000336
00212            IF(TIME.LT.TMAX1)RETURN                                     000342
00214            CCI=CCI+CC                                                  000351
00215            CMI=CMI+CM                                                  000354
00215      C                                                                 000354
00216            RETURN                                                      000357
00217            END                                                         000536
```

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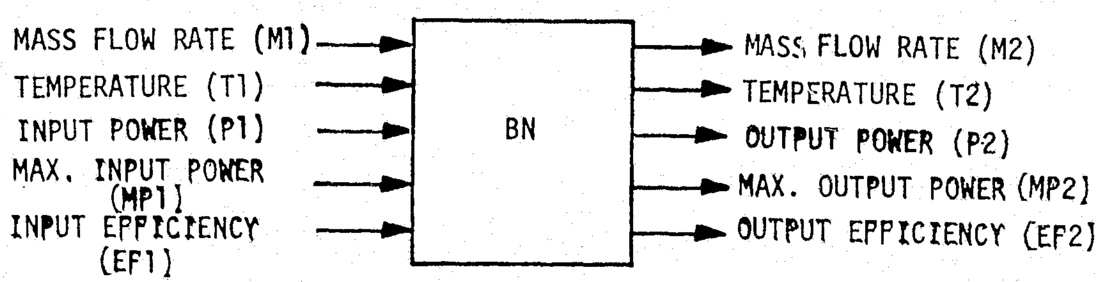
7.4 BURNER



The burner model computes the amount of fuel required to be burned in the inlet airstream to raise the air temperature from the given inlet temperature to the specified outlet temperature. The fuel mass flow rate when integrated over time allows calculation of the cost of burner fuel.

Basic Equation

The mass of fuel consumed, F, is computed from the equation:

$$\dot{F} = \frac{M1*CP*(T2-T1)}{NU*HF}$$

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Inputs

Parameter/Port		Description	Units
M	1	Inlet air mass flow rate	lb/h
CP		Air heat capacity (D = $72X10^{-6}$)	kwh/lb-^{o}F
T	1	Inlet air temperature	^{o}F
T	3	Outlet air temperature (specified)	^{o}F
NU		Combustor efficiency (D = 0.98)	–
HF		Fuel heating value (D = 5.56)	kwh/lb
CF		Specific fuel cost (D = 0.094)	$/lb
FDM		Maximum allowable fuel mass flow rate (D=17800)	lb/h
CB		Burner cost coefficient (D = 1.683)	$/lb/h
LE		Burner life expectancy	years
MDM		Maximum allowable air mass flow rate (D=27000)	lb/h
EF	1	Input product efficiency	–
MP	1	Maximum input power	kw
P	1	Input power	kw

Outputs

Variable/Port		Description	Units
F		Fuel mass consumed (state)	lb
EF	2	Output product efficiency	–
MP	2	Maximum output power	kw
T	2	Outlet air temperature	^{o}F
FD		Fuel mass flow rate	lb/h
CCØ		Burner capital cost/year	$
CØ		Fuel cost	$
M	2	Outlet mass flow rate (= M1)	lb/h
P	2	Output power	kw

Statistics

FDU		Maximum fuel mass flow rate	lb/h

D – Default values supplied

The calculation sequence and default values are based on a burner sized using first principles to maintain the outlet temperature at 600°F assuming an inlet temperature of 120°F and a mass flowrate of 2.7×10^4 lb/h. These conditions represent the extreme conditions expected and should satisfy all burner requirements. No. 6 fuel oil is assumed to be the fuel type. Cost and heating values were obtained from References 1 and 2. Cost estimates for the burner were estimated from the results of Reference 1.

Calculation Sequence

1) Capital Cost

CCØ = CB*MDM/LE

2) Maximum air mass flow rate allowed

If M1 = 0 set EFF = 1, MP2 = MP1 and go to 3)

$$M1M = \min \left\{ \frac{NU*HF*FDM}{CP*(T3-T1)} , MDM \right\}$$

If T1 > T3, M1M = MDM

3) Efficiency and maximum discharge power

EFF = 1 + M1*CP*(T2-T1)/P1 (if P1 > 0)

EF2 = EF1*EFF

MP2 = min {MP1*EFF, P1 * M1M/M1} (if M1 > 0)

P2 = P1*EFF

---

1. "Preliminary Feasibility Evaluation of Compressed Air Storage Power Systems," United Technologies AER 74-00242, December 1976.

2. Steam, Its Generation and Use, Babcock and Wilcox, New York, NY, 1972.

Calculation Sequence Cont.

4) Fuel mass flow rate

$$\dot{F} = \frac{M1*CP*(T2-T1)}{NU*HF}$$

T2 = MAX(T1, T3)

If M1 > M1M write DIAGNOSTIC

5) Compute Staticrics and Costs

CØ = CF * F

```
SUBROUTINE BN        ENTRY POINT 000270

STORAGE USED  CODE(1) 000411; DATA(0) 000052; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000002
 0004   CTIME  000001
 0005   CSIMUL 000010
 0006   COST   000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   NWDUS
 0010   NI02$
 0011   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000056 100L      0001     000237 1000L     0000     000003 1010F     0001     000121 200L      0001     000107 300L
 0006 R 000000 CCI       0006     000001 CMI       0006 R 000002 COP       0005     000000 DUM       0000 R 000002 EFF
 0003 I 000001 ICNT      0003 I 000000 IMPL      0000     000034 INJP$     0000 R 000000 M1M       0004 R 000000 TIME
 0005 R 000007 TMAX      0000 R 000001 TMAX1
```

```
00100     CBN                                                                          000000
00101          SUBROUTINE BN(F,DF,IF,EF2,MP2,T3,FD,CC,CO,M2,P2,FDU,M1,CP,T1,T2         000000
00101        1              ,NU,HF,CF,FDM,CB,LE,MDM,EF1,MP1,P1)                        000000
00101     C                                                                            000000
00101     C    PURPOSE    COMPUTE FUEL REQUIRED TO RAISE THE AIRSTREAM                 000000
00101     C                                                                            000000
00101     C               TEMPERATURE A GIVEN INCREMENT.                               000000
00101     C                                                                            000000
00101     C    METHOD     INTEGRATE THE FUEL MASS FLOW RATE OVER TIME                  000000
00101     C                                                                            000000
00101     C    WRITTEN BY F.O. MAHONY                    VERSION 1, MARCH 22 1977      000000
00101     C                                                                            000000
00101     C    CALL SEQUENCE                                                           000000
00101     C                                                                            000000
00101     C          OUTPUTS                                                           000000
00101     C               F    - FUEL MASS CONSUMED SINCE TIME=0 (STATE), LB           000000
00101     C               DF   - FUEL MASS DERIVATIVE                                  000000
00101     C               IF   - STATUS INDICATOR                                      000000
00101     C               EF2  - OUTPUT PRODUCT EFFICIENCY                             000000
00101     C               MP2  - MAXIMUM OUTPUT POWER, KW                              000000
00101     C               T3   - OUTLET AIR TEMPERATURE, DEG F                         000000
00101     C               FD   - FUEL MASS FLOW RATE, LB/HR                            000000
00101     C               CC   - BURNER CAPITAL COST/YEAR, $                           000000
```

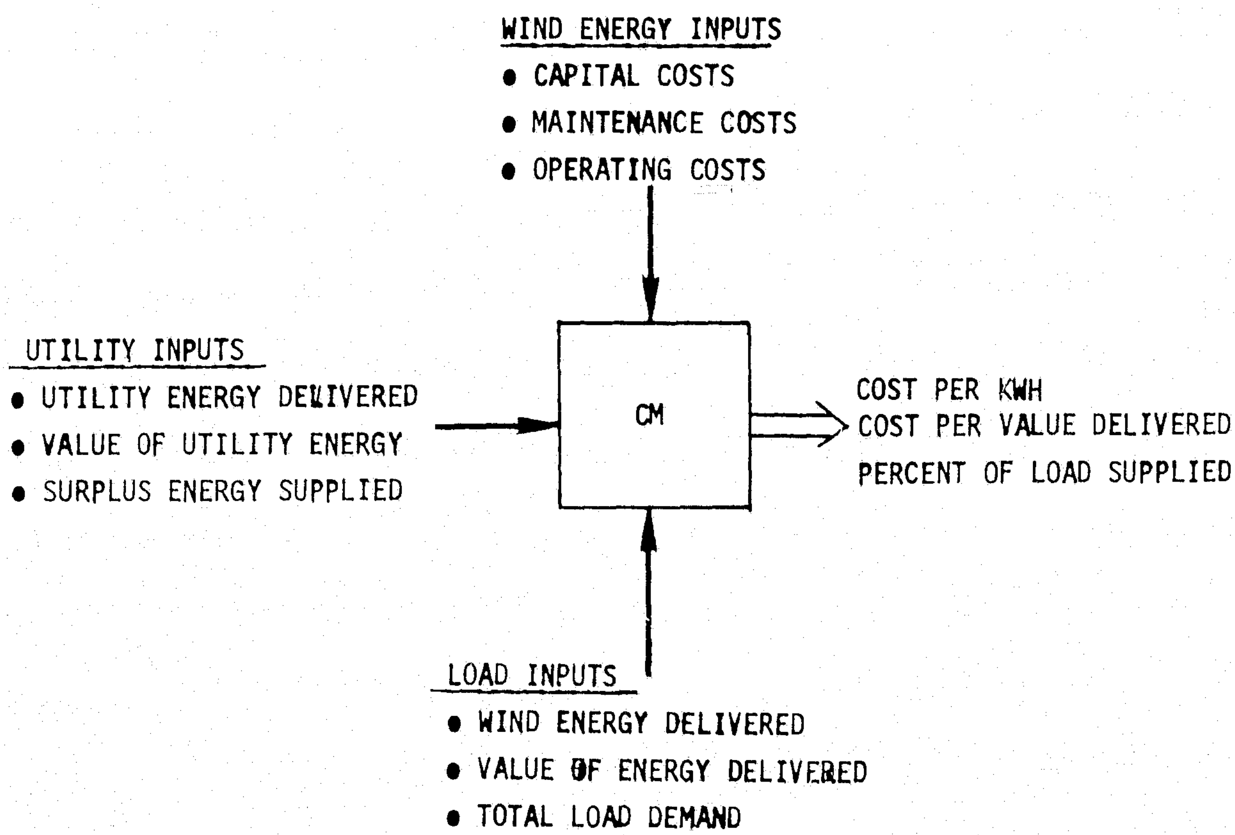
BN

```
00101      C              CO  - FUEL COST, $                                      000000
00101      C              M2  - OUTLET MASS FLOW RATE, LB/HR                      000000
00101      C              P2  - OUTPUT POWER, KW                                  000000
00101      C              FDU - OBSERVED MAXIMUM FUEL MASS FLOW RATE, LB/HR       000000
00101      C                                                                      000000
00101      C          INPUTS                                                      000000
00101      C              M1  - INLET AIR MASS FLOW RATE, LB/HR                   000000
00101      C              CP  - AIR HEAT CAPACITY, KWH/LB-DEG F                   000000
00101      C              T1  - INLET AIR TEMPERATURE, DEG F                      000000
00101      C              T2  - OUTLET AIR TEMPERATURE, DEG F                     000000
00101      C              NU  - COMBUSTER EFFICIENCY                              000000
00101      C              HF  - FUEL HEATING VALUE, KWH/LB-DEG F                  000000
00101      C              CF  - SPECIFIC FUEL COST                                000000
00101      C              FDM - MAXIMUM ALLOWABLE FUEL MASS FLOW RATE, LB/HR      000000
00101      C              CB  - BURNER COST COEFFICIENT                           000000
00101      C              LE  - BURNER LIFE EXPECTANCY, YEARS                     000000
00101      C              MDM - MAXIMUM ALLOWABLE AIR MASS FLOW RATE, LB/HR       000000
00101      C              EF1 - INPUT PRODUCT EFFICIENCY                          000000
00101      C              MP1 - MAXIMUM INPUT POWER, KW                           000000
00101      C              P1  - INPUT POWER, KW                                   000000
00101      C                                                                      000000
00103            COMMON/CIMPL/IMPL,ICNT /CTIME/TIME /CSIMUL/DUM(7),TMAX           000000
00104            COMMON/COST/CCI,CMI,COP                                          000000
00105            REAL MP2,M2,M1,NU,LE,MDM,MP1,M1M                                 000000
00105      C                                                                      000000
00106            IF(IMPL.GT.0) GO TO 100                                          000000
00110            TMAX1 =TMAX*.99999                                               000002
00111            IF(CP .EQ. .99999) CP = 72.0E-6                                  000005
00113            IF(NU .EQ. .99999) NU = 0.98                                     000012
00115            IF(HF .EQ. .99999) HF = 5.56                                     000017
00117            IF(CF .EQ. .99999) CF = 0.094                                    000024
00121            IF(FDM.EQ. .99999) FDM=1.78E+4                                   000031
00123            IF(CB .EQ. .99999) CB =1.683                                     000036
00125            IF(MDM.EQ. .99999) MDM=2.7E+4                                    000043
00125      C                                                                      000043
00127            FDU = 0.0                                                        000050
00130            CC =CB*MDM/LE                                                    000051
00131        100 EFF=1.0                                                          000056
00132            IF(M1.EQ.0.0)GO TO 200                                           000057
00134            M1M=MDM                                                          000061
00135            IF(T1.GT.T2) GO TO 200                                           000063
00135      C                                                                      000063
00135      C              MAXIMUM ALLOWABLE AIR FLOW RATE                         000063
00135      C                                                                      000063
00137            M1M=AMIN1(NU*HF*FDM/CP/(T2-T1),MDM)                              000067
00137      C                                                                      000067
00140            IF(M1.GT.M1M) GO TO 1000                                         000103
00142        300 CONTINUE                                                         000107
00142      C                                                                      000107
00142      C              EFFICIENCY AND MAXIMUM DISCHARGE POWER                  000107
00143            IF(P1.EQ.0.0)GO TO 200                                           000107
00143      C                                                                      000107
00143      C                                                                      000107
00145            EFF = 1.0+M1*CP*(T2-T1)/P1                                       000110
00145      C                                                                      000110
00146        200 EF2 = EF1*EFF                                                    000121
00147            MP2=MP1                                                          000123
```

```
00150          IF(M1.GT.0.) MP2=AMIN1(MP1*EFF,P1*M1M/M1)                      000125
00152          P2=P1*EFF                                                      000142
00152    C                                                                    000142
00152    C              FUEL FLOW RATE                                        000142
00152    C                                                                    000142
00153          IF(IF.NE.0) DF= M1*CP*(T2-T1)/NU/HF                            000145
00155          IF(T1.GT.T2) DF=0.0                                            000157
00157          FD=DF                                                          000164
00157    C                                                                    000164
00157    C             COSTS                                                  000164
00160          CO = CF*F                                                      000166
00161          T3= AMAX1(T1,T2)                                               000171
00162          M2=M1                                                          000177
00162    C                                                                    000177
00162    C             STATISTICS                                             000177
00163          IF(IMPL.LE.1) RETURN                                           000201
00163    C                                                                    000201
00165          FDU = AMAX1(FD,FDU)                                            000210
00165    C                                                                    000210
00166          IF(TIME.LT.TMAX1) RETURN                                       000216
00170          CCI= CCI + CC                                                  000225
00171          COP= COP + CO                                                  000230
00172          RETURN                                                         000233
00172    C                                                                    000233
00173     1000 IF(IMPL.EQ.2)WRITE(6,1010) M1,M1M                              000237
00200     1010 FORMAT(1H0,28HBN INLET AIR MASS FLOW RATE ,F12.3,              000250
00200         1            36H    GREATER THAN MAXIMUM ALLOWABLE ,F12.3)      000250
00201          IF(IMPL.EQ.2)ICNT=ICNT+1                                       000250
00203          GO TO 300                                                      000256
00204          END                                                            000410
```


BN

7.5 COST MONITOR[1]



This component sums the capital, operating and maintenance costs of all system components. The total yearly cost TC is then computed using a fixed charge rate factor which represents depreciation, cost of money, insurance and taxes.

[1] This component must be placed last in the model generation input file, i.e., just prior to the END OF MODEL command.

The total wind energy delivered to the loads plus surplus energy is then summed and yearly energy delivered TED computed. Cost of operation in mills is then given by

Wind system cost/kwh = TC * 1000./TED

Similarly, the value of energy delivered to the loads is summed minus the utility energy value and including the value of surplus energy, and factored to give yearly energy value delivered VED. Energy value in mills is given by

Load value/kwh = VED * 1000./TED.

Cost per value delivered is the ratio of the above two equations.

In addition to the above cost calculations, percent of total load supplied by wind storage PCW, percent of load supplied by utilities PCU and, percent of wind energy surplused to the utilities PCS is computed. The total cost in mills to meet the load is then given by

Load cost/kwh = (wind system cost/kwh * PCW + utility cost/kwh * PCU)/100.,

where

Utility cost/kwh = value of utility energy * 1000./utility energy delivered.

Inputs

Parameter/Port	Description	Units
CR	Capital charge rate	%/year
LE	System life expectancy	years

Common Block Inputs

CC	Total yearly capital costs	$
CM	Total yearly maintenance costs	$
CO	Operating and fuel costs over TMAX	$
TMAX	Simulation time interval	hr
VDE	Value of energy delivered (including surplus)	$
TDE	Wind energy delivered (including surplus)	kwh
TLD	Total load demand	kwh
UTV	Value of utility energy	$
UTD	Utility energy delivered	kwh
SPD	Surplus wind energy supplied	kwh

Outputs [1]

	Total yearly costs (TC)	$
	Yearly energy delivered (TED)	kwh
	Cost of energy per kwh	mills
	Yearly value delivered (VED)	$
	Cost per value delivered	–
	Percent of load supplied by	
	Wind Storage (PCW)	–
	Utility (PCU)	–
	Surplus energy load factor (PCS)	–
	Total load cost per kwh	mills

[1] Printout only occurs when simulation is completed. Thus no output variable symbol is required.

```
SUBROUTINE CM        ENTRY POINT 000213

STORAGE USED  CODE(1) 000226; DATA(0) 000330; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   COST    000011
 0004   CIMPL   000001
 0005   CTIME   000001
 0006   CSIMUL  000010

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   NWDU$
 0010   NI02$
 0011   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000020 100L     0000     000016 200F     0000     000034 300F     0000     000105 400F     0000     000210 500F
 0003 R 000000 CC       0000 R 000003 CCY      0003 R 000001 CMA      0003 R 000002 CO       0000 R 000002 COY
 0000 R 000015 CPKWH    0000 R 000011 CPV      0006     000000 DUM      0000 R 000005 EDE      0004 I 000000 IMPL
 0000     000313 INJP$    0000 I 000006 IVDE     0000 I 000001 LLE      0000 R 000012 PCD      0000 R 000014 PCS
 0000 R 000013 PCU      0003 R 000010 SPD      0003 R 000004 TDE      0005 R 000000 TIME     0003 R 000005 TLD
 0006 R 000007 TMAX     0000 R 000000 TMAX1    0000 R 000004 TOY      0000 R 000007 TOYN     0003 R 000007 UTD
 0003 R 000006 UTV      0003 R 000003 VDE      0000 R 000010 VDEN


00100       COST                                                                          000000
00101               SUBROUTINE CM(DUMM,FCR,LE)                                             000000
00101       C                                                                             000000
00101       C   PURPOSE     SUMMARIZE WIND ENERGE STORAGE COSTS AND LEVELIZED                 000000
00101       C               ENERGY COSTS PER KWH.                                             000000
00101       C                                                                             000000
00101       C   WRITTEN BY A.W. WARREN                          VERSION 1, MAY 1977           000000
00101       C                                                                             000000
00101       C   INPUT PARAMETERS                                                              000000
00101       C                                                                             000000
00101       C               FCR  - FIXED CHARGE RATE FACTOR INCLUDING DEPRECIATION,           000000
00101       C                      MONEY COST, INSURANCE, AND TAXES,  PER YEAR                000000
00101       C               LE   - SYSTEM LIFE EXPECTANCY , YEARS                             000000
00101       C               TMAX - SIMULATION TIME, HR                                        000000
00101       C               CC   - TOTAL YEARLY CAPITAL COSTS, $                              000000
00101       C               CM   - TOTAL YEARLY MAINTENANCE COSTS, $                          000000
00101       C               CO   - TOTAL OPERATING AND FUEL COSTS OVER TMAX, $                000000
00101       C               VDE  - VALUE OF ENERGY DELIVERED OVER TMAX, $                     000000
00101       C               TDE  - TOTAL ENERGY DELIVERED OVER TMAX, KWH                      000000
00101       C               TLD  - TOTAL LOAD DEMAND OVER TMAX, KWH                           000000
```

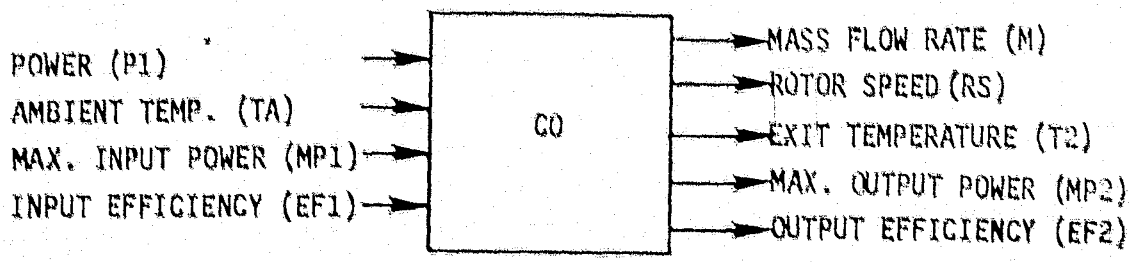
CM

```
00101    C           UTV  - VALUE OF UTILITY ENERGY SUPPLIED LESS SURPLUS VALUE, $      000000
00101    C           UTD  - TOTAL UTILITY ENERGY DELIVERED, KWH                         000000
00101    C           SPD  - TOTAL SURPLUS ENERGY SUPPLIED TO UTILITY, $                 000000
00101    C                                                                              000000
00103          COMMON /COST/ CC, CMA,CO,VDE,TDE,TLD,UTV,UTD ,SPD                        000000
00104          COMMON /CIMPL/IMPL  /CTIME/ TIME /CSIMUL/ DUM(7),TMAX                    000000
00105          REAL LE                                                                  000000
00105    C                            INITIALIZATION                                    000000
00105    C                                                                              000000
00106          IF(IMPL.GT.0)GO TO 100                                                   000000
00110          DUMM=0.0                                                                 000002
00111          CC = 0 .                                                                 000003
00112          CMA = 0.                                                                 000004
00113          CO = 0.                                                                  000005
00114          VDE= 0.                                                                  000006
00115          TDE= 0.                                                                  000007
00116          TLD= 0.                                                                  000010
00117          UTV=0.                                                                   000011
00120          UTD=0.                                                                   000012
00121          SPD=0.                                                                   000013
00122          TMAX1= TMAX*.99999                                                       000014
00122    C                                                                              000014
00123      100 IF(TIME.LT.TMAX1)RETURN                                                  000020
00125          IF(IMPL.LE.1)RETURN                                                      000026
00125    C                                                                              000026
00125    C                            COST SUMMARY OUTPUT                               000026
00125    C                                                                              000026
00127          LLE = LE                                                                 000040
00133          WRITE(6,200)LLE                                                          000047
00133      200 FORMAT(1H1,35X,33H WIND ENERGY STORAGE COST SUMMARY // 1H ,40X,I2,       000055
00133         1 17H  YEAR LIFE CYCLE )                                                  000055
00133    C                                                                              000055
00134          COY = CO*8760./TMAX                                                      000055
00135          CCY = CC*LE*FCR*.01                                                      000061
00136          TOY = COY + CMA + CCY                                                    000066
00137          WRITE(6,300)CCY,CMA,COY,TOY                                              000071
00145      300 FORMAT(//// 30X,22H0  YEARLY SYSTEM COSTS/ 1H+,29X,1H+/ 1H-,42X,          000102
00145         1 12HCAPITAL COST,12X,F8.0,2H $ / 1H ,42X, 17H(INCLUDING FIXED ,          000102
00145         2  8HCHARGES) / 1H0,42X,16HFIXED O + M COST, 8X,F8.0,2H $ /1H0 ,          000102
00145         3 42X,21HOPERATING + FUEL COST, 3X,F8.0,2H $ / 1H0,42X,5HTOTAL,          000102
00145         4 19X,F8.0,2H $ )                                                         000102
00145    C                                                                              000102
00146          EDE  = TDE * 8760./TMAX                                                  000102
00147          IVDE = VDE * 8760./TMAX                                                  000106
00150          TOYN = TOY*1000./ EDE                                                    000120
00151          VDEN = VDE*1000./ TDE                                                    000124
00152          CPV  = TOYN / VDEN                                                       000130
00152    C                                                                              000130
00153          WRITE(6,400)EDE,TOYN,IVDE,VDEN,CPV                                       000132
00162      400 FORMAT(//// 30X,26H0  ENERGY DELIVERED         / 1H+,29X,1H+ / 1H-,      000144
00162         1 42X,16HENERGY DELIVERED, 7X,F9.0,4H KWH / 1H0,33X,50(1H*) /             000144
00162         1  1H ,33X,1H*,48X,1H* /                                                  000144
00162         2 1H ,33X,1H*, 8X,19HENERGY COST PER KWH, 7X,F6.1,9H MILLS  * /           000144
00162         2  1H ,33X,1H*,48X,1H* / 1H ,                                             000144
00162         3 33X,10(5H*****) / 1H0,42X,25HVALUE OF ENERGY DELIVERED,I7,              000144
00162         4 2H $ / 1H ,42X,22H(VALUE OF FUEL SAVED) / 1H0,42X,20HENERGY VALUE       000144
00162         5 PER KWH, 6X,F6.1,6H MILLS / 1H0,42X,24HCOST PER VALUE DELIVERED,         000144
```


CM

```
00162         6 2X,F6.2)                                                          000144
00162      C                                                                      000144
00163         PCD= (TDE-SPD)*100./TLD                                             000144
00164         PCU= UTD*100./TLD                                                   000150
00165         PCS= SPD*100./TLD                                                   000154
00166         CPKWH= (TOYH*(TDE-SPD) + UTV*1000.)/TLD                             000160
00167         WRITE(6,500)PCD ,PCU,PCS,CPKWH                                      000167
00175     500 FORMAT(//// 30X,31H0  LOAD FACTOR                  / 1H+,29X,       000200
00175        1  1H+ / 1H-,42X,                                                    000200
00175        1 26HPERCENT OF LOAD SUPPLIED  , F6.1, 2H  / 1H ,42X,22HBY TOTAL WIN 000200
00175        2ND SYSTEM      / 1H0,42X,24HPERCENT OF LOAD SUPPLIED,2X,F6.1 /      000200
00175        2 1H ,41X,11H BY UTILITY  /                                          000200
00175        3  1H0,42X,26HPERCENT OF WIND ENERGY    , F6.1 /                     000200
00175        3 1H ,42X,9HSURPLUSED  /                                             000200
00175        4  1H0,42X,23HCOST TO MEET LOAD       , 3X,F6.1,6H MILLS/            000200
00175        5 1H ,42X,27H(WIND + UTILITY)            / 1H1)                      000200
00175      C                                                                      000200
00176         RETURN                                                              000200
00177         END                                                                 000225
```

7.6 COMPRESSOR (PNEUMATIC)



The compressor model represents the off-design performance of a typical axial flow compressor. The compressor is assumed designed for a specified set of design operating conditions and performance requirements. The mass flow rate is assumed directly proportional to angular velocity and independent of the pressure ratio across the compressor. This is expected to hold for ±15% of the design mass flow rate. The polytropic efficiency of the compres[illegible] is assumed to be a weak function of the angular velocity. Initial calculations are made with the design polytropic efficiency, and refinements made after the off-design parameters are calculated.

<u>Basic Equations</u>

The expression for the angular velocity is

$$RS = P1 * \frac{RSD}{MD} \; \frac{EFF}{CP*(TA+460)*\left[(PR2/PA)**A - 1\right]}$$

where:

$$EFF = ((PR2/PA)**(A*NP) - 1.)/((PR2/PA)**A - 1.)$$

$$A = (GAM - 1)/GAM*NP)$$

Inputs

Parameter/Port		Description	Units
P	1	Input power	kw
RSD		Design angular velocity (D = 3600)	rpm
MD		Design mass flow rate (D = 3000)	lb/h
CP		Heat capacity of air (D = $7.2X10^{-5}$)	kwh/lb^{o}F
TA		Inlet air temperature (ambient) (D = 70)	^{o}F
PR	2	Exit pressure (D = 147)	psi
PA		Inlet pressure (ambient) (D = 14.7)	psi
GAM		Heat capacity ratio (D = 1.4)	–
EF	1	Input product efficiency	–
MP	1	Maximum input power	kw
NPD		Design polytropic efficiency (D = 0.88)	–
PID		Design inlet pressure (ambient) (D = 14.7)	psi
PØD		Design outlet pressure (D = 147)	psi
TID		Design inlet air temp (ambient) (D = 70)	^{o}F
CK		Compressor capacity cost coefficient[1] (D = 1.0)	–
FØ		Compressor exponent for cost calculations (D = 0.75)	–

Outputs

Variable/Port		Description	Units
NP		Polytropic efficiency	–
EF	2	Output product efficiency	–
MP	2	Maximum output power	kw
TØ		Torque	ft-lb
M		Mass flow rate	lb/h
T	2	Exit temperature	^{o}F
RS		Angular velocity	rpm
CCØ		Cost of compressor/year	$

[1] CK = capital cost (known unit)/(design point mass flow rate)^{FO}* LN (outlet/inlet pressure ratio)*(life expectancy of unit)

D – Default values supplied

Statistics	Description	Units
MT	Maximum temperature	°F
MF	Maximum mass flow rate	lb/h

The calculation sequence and the default values are based on the assumption of an axial flow compressor, nominally rated at 125kw, and a pressure ratio of 10. The equations used relate first order effects among the various physical quantities and were derived from first principles originally to support the research work of Reference 1. Cost scaling was also developed in that reference based on cost estimates obtained from turbomachinery manufacturers.

Calculation Sequence

1) Costs (First pass only)

$$CC\emptyset = CK * (MD)**F\emptyset * LN\left(\frac{P\emptyset D}{PID}\right)$$

If P1 > 0 go to 2)

A = (GAM-1)/(GAM*NPD)

RAT = (PØD/PID)**A

EFF = 1, RS = 0, go to 3)

1. "Closed Cycle High Temperature Central Receiver Concept for Solar Electric Power," BEC/EPRI RP 377-1, June 1976.

CO

Calculation Sequence Cont.

2) Angular velocity iteration

$$A = (GAM-1)/(GAM*NP) \quad \text{(Initially } NP = NPD\text{)}$$

$$RAT = (PR2/PA)^{A}$$

$$EFF = (RAT^{NP}-1)/(RAT-1)$$

$$\frac{RS}{RSD} = \frac{P1}{MD} \; \frac{EFF}{CP*(TA+460)*(RAT-1)}$$

Polytropic efficiency

$$NP = 1 - (1 - NPD)*\left[2.0 - \left(\frac{P1D}{PA} * \frac{(TA+460)}{(T1D+460)} * \frac{RSD}{RS}\right)^{0.2}\right]$$

Iterate until NP and RS are consistent

(If iteration doesn't converge, then write DIAGNOSTIC and exit)

3) Mass flow rate

$$M = MD*RS/RSD$$

4) Exit temperature

$$T2 = (TA+460)*RAT - 460$$

5) Torque

If $P1 \leq 0$, set $T0 = 0$ and go to 6)

$$T0 = P1*737.6/(RS*2\pi/60)$$

6) Efficiency and maximum power

$$EF2 = EF1*EFF$$

$$MP2 = MIN(MP1*EFF,\ 1.5*MD*CP*(T2-TA))$$

7) Compute Statistics and Costs

```
SURROUTINE CO        ENTRY POINT 000420

STORAGE USED  CODE(1) 000613; DATA(0) 000066; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL   000001
 0004   CTIME   000001
 0005   CSTMUL  000010
 0006   COST    000031

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   XPRR
 0010   ALOG
 0011   NWDUS
 0012   NI02$
 0013   NSTOP$
 0014   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000136 100L      0001   000375 1000L     0000   000010 101CF     0001   000166 200L      0001   000271 300L
 0001   000315 400L      0000 R 000005 A         0006 R 000000 CCI       0005   000000 DUM       0000 R 000003 EFF
 0003 I 000000 IMPL      0000   000052 INJP$     0000 I 000002 ISP       0000 R 000000 PI        0000 R 000004 RAT
 0000 R 000006 RSNO      0004 R 000000 TIME      0005 R 000007 TMAX      0000 R 000001 TMAX1     0000 R 000007 XNP


00100      CCO                                                                          000000
00101            SUBROUTINE CO(NP,EF2,MP2,TO,M,T2,RS,CC,MT,MF,P1,RSD,MD,CP,TA,PR2,      000000
00101           1          PR1,GAM,EF1,MP1,NPD,PID,POD,TID,CK,FO)                        000000
00101      C                                                                            000000
00101      C    PURPOSE    PERFORMANCE MODEL OF AXIAL FLOW COMPRESSOR                   000000
00101      C                                                                            000000
00101      C    METHOD     COMPRESSOR IS SIZED FROM INPUT OPERATING REQUIREMENTS.       000000
00101      C                                                                            000000
00101      C               MASS FLOW IS ASSUMED PROPORTIONAL TO ANGULAR VELOCITY        000000
00101      C                                                                            000000
00101      C               AND INDEPENDENT OF PRESSURE RATIO.                           000000
00101      C                                                                            000000
00101      C    WRITTEN BY F.O. MAHONY                  VERSION 1, MARCH 22 1977        000000
00101      C                                                                            000000
00101      C    CALL SEQUENCE                                                           000000
00101      C          OUTPUTS                                                           000000
00101      C               NP  - POLYTROPIC EFFICIENCY                                  000000
00101      C               EF2 - OUTPUT PRODUCT EFFICIENCY                              000000
00101      C               MP2 - MAXIMUM OUTPUT POWER, KW                               000000
00101      C               TO  - TORQUE, FT-LB                                          000000
```

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CO

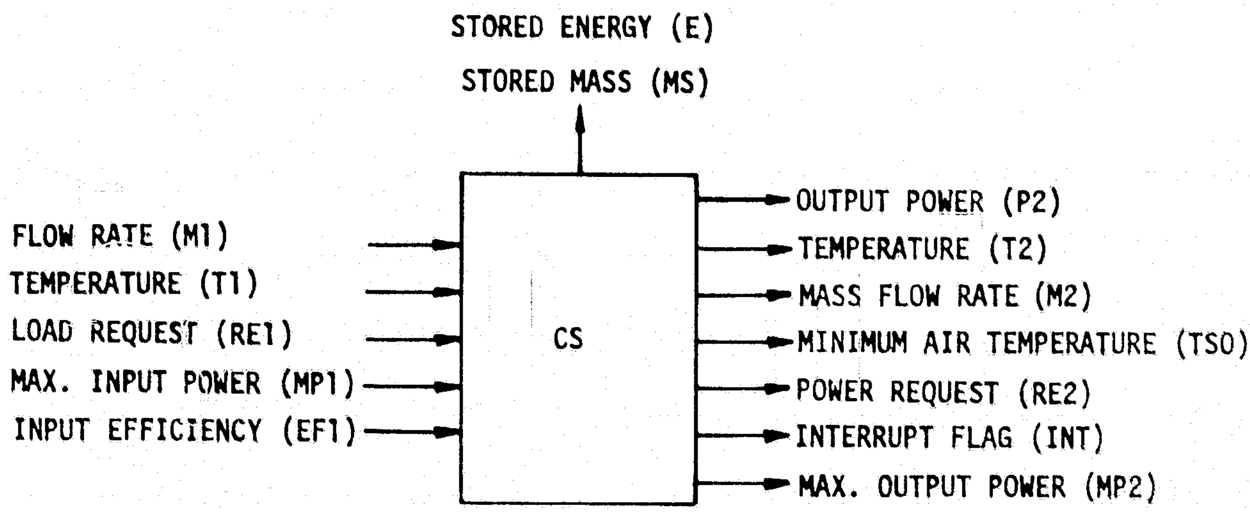
```
00101    C              M    - MASS FLOW RATE, LB/HR                                  000000
00101    C              T2   - EXIT TEMPERATURE, DEG F                                000000
00101    C              RS   - ANGULAR VELOCITY, RPM                                  000000
00101    C              CC   - COST OF COMPRESSOR PER YEAR, $/YEAR                    000000
00101    C              MT   - MAXIMUM TEMPERATURE OBSERVED, DEG F                    000000
00101    C              MF   - MAXIMUM MASS FLOW RATE, LB/HR                          000000
00101    C                                                                            000000
00101    C          INPUTS                                                            000000
00101    C              P1   - INPUT POWER, KW                                        000000
00101    C              RSD  - DESIGN ANGULAR VELOCITY, RPM                           000000
00101    C              MD   - DESIGN MASS FLOW RATE, LB/HR                           000000
00101    C              CP   - HEAT CAPACITY OF AIR, KWH/LB-DEG F                     000000
00101    C              TA   - INLET AIR TEMPERATURE (AMBIENT), DEG F                 000000
00101    C              PR2  - EXIT PRESSURE, PSI                                     000000
00101    C              PR1  - INLET PRESSURE (AMBIENT), PSI                          000000
00101    C              GAM  - HEAT CAPACITY RATIO                                    000000
00101    C              EF1  - INPUT PRODUCT EFFICIENCY                               000000
00101    C              MP1  - INPUT MAXIMUM DISCHARGE POWER, KW                      000000
00101    C              NPD  - DESIGN POLYTROPIC EFFICIENCY                           000000
00101    C              PID  - DESIGN INLET PRESSURE (AMBIENT),PSI                    000000
00101    C              POD  - DESIGN OUTLET PRESSURE (AMBIENT), PSI                  000000
00101    C              TID  - DESIGN INLET TEMPERATURE (AMBIENT), DEG F              000000
00101    C              CK   - COMPPESSOR CAPCITY COST COEFFICIENT                    000000
00101    C              FO  - COMPRESSOR EXPONENT FOR COST CALCULATION                000000
00101    C                                                                            000000
00103          COMMON /CIMPL/ IMPL /CTIME/ TIME /CSIMUL/DUM(7),TMAX /COST/CCI         000000
00104          REAL MD,MP1,NPD,NP,MP2,M,MT,MF                                         000000
00105          DATA PI  /3.14159/                                                     000000
00105    C                         INITIALIZATION                                     000000
00105    C                                                                            000000
00107          IF(IMPL.GT.0) GO TO 100                                                000000
00111          MT = 0.0                                                               000002
00112          MF = 0.0                                                               000003
00112    C                                                                            000003
00113          IF (RSD.EQ. .99999) RSD = 3600.0                                       000004
00115          IF (MD .EQ. .99999)MD = 3.0E3                                          000011
00117          IF(MP1.EQ. .99999) MP1= 1.E8                                           000016
00121          IF (CP .EQ. .99999)CP = 72.0E-6                                        000023
00123          IF (TA .EQ. .99999)TA = 70.0                                           000030
00125          IF (PR2.EQ. .99999)PR2 = 147.0                                         000035
00127          IF (PR1.EQ. .99999)PR1 = 14.7                                          000042
00131          IF (GAM.EQ. .99999)GAM = 1.4                                           000047
00133          IF (NPD.EQ. .99999)NPD = 0.88                                          000054
00135          IF (PID.EQ. .99999)PID = 14.7                                          000061
00137          IF (POD.EQ. .99999)POD = 147.0                                         000066
00141          IF (TID.EQ. .99999)TID = 70.0                                          000073
00143          IF (CK .EQ. .99999)CK = 1.0                                            000100
00145          IF (FO .EQ. .99999)FO = 0.75                                           000105
00147          NP = NPD                                                               000112
00147    C                                                                            000112
00147    C                         COST                                               000112
00147    C                                                                            000112
00150          CC = CK*MD**FO*ALOG(POD/PID)                                           000114
00151          TMAX1 = TMAX*.99999                                                    000132
00152      100 CONTINUE                                                               000136
00152    C                                                                            000136
00152    C                         SOLVE FOR POLYTROPIC EFFICIENCY                    000136
```

```
00152      C                      AND ANGULAR VELOCITY                 000136
00152      C                                                           000136
00153            ISP = 0                                               000136
00153      C                                                           000136
00154            EFF=1.0                                               000136
00155            IF(P1.GT.0.0)GO TO 200                                000140
00155      C                                                           000140
00157            RAT= (POD/PID)**((GAM-1.0)/(GAM*NPD))                 000143
00160            TO =0.0                                               000160
00161            RS=0.0                                                000161
00162            NP=NPD                                                000162
00163            GO TO 300                                             000164
00163      C                                                           000164
00164        200 A = (GAM-1.0)/(GAM*NP)                                000166
00165            RAT= (PR2/PP1)**A                                     000173
00166            EFF=(RAT**NP - 1.)/(RAT - 1.)                         000203
00166      C                                                           000203
00167            RSNO = EFF*P1/MD*1.0/CP/(TA+460.0)/(RAT-1.0)          000214
00167      C                                                           000214
00170            XNP = NP                                              000224
00170      C                                                           000224
00171            NP = 1.0-(1.0-NPD)*(2.0-(PID/PR1*(TA+460.0)/(TID+460.0)/RSNO)  000226
00171           1                    **0.2)                            000226
00171      C                                                           000226
00172            IF(ISP.GT.10) GO TO 1000                              000250
00172      C                                                           000250
00174            ISP = ISP+1                                           000254
00174      C                                                           000254
00175            IF(ABS((NP-XNP)/NP).GT.0.001) GO TO 200               000257
00177            RS= RSD*RSNO                                          000265
00177      C                                                           000265
00177      C                      MASS FLOW RATE                       000265
00177      C                                                           000265
00200        300 M = MD*RS/RSD                                         000271
00200      C                                                           000271
00200      C                      EXIT TEMPERATURE                     000271
00200      C                                                           000271
00201            T2 = (TA+460.0)*RAT-460.0                             000274
00202            IF(P1.LE.0.0)GO TO 400                                000301
00202      C                                                           000301
00202      C                      TORQUE                               000301
00202      C                                                           000301
00204            TO = P1*737.6/(RS*2.0*PI/60.0)                        000304
00204      C                                                           000304
00204      C                      EFFICIENCY AND MAXIMUM POWER         000304
00204      C                                                           000304
00204      C                                                           000304
00204      C                                                           000304
00205        400 EF2 = EF1*EFF                                         000315
00205      C                                                           000315
00206            MP2 = AMIN1(MP1*EFF,1.5*MD*CP*(T2-TA))                000317
00206      C                      STATISTICS AND COST SUMMATION        000317
00206      C                                                           000317
00207            IF (IMPL.LE.1) RETURN                                 000334
00211            MT = AMAX1(MT, T2)                                    000343
00212            MF = AMAX1(MF, M)                                     000351
00213            IF(TIME.LT.TMAX1) RETURN                              000357
```

C0

```
00215        CCI = CCT + CC                                              000366
00215   C                                                                000366
00216        RETURN                                                      000371
00216   C                                                                000371
00217    1000 WRITE (6,1010) NP,XNP,RS                                   000375
00224    1010 FORMAT (1H0,40HMAX ITERATIONS FOR COMPRESSOR EFFICIENCY,   000404
00224       1             15H - NP,XNP,RS = ,3F12.6)                     000404
00225        STOP                                                        000404
00226        END                                                         000612
```

7.7 PNEUMATIC STORAGE VESSEL (CONSTANT PRESSURE)



The pneumatic storage vessel is based on a constant pressure underground cavern design as represented in Figure 7.7. A surface pressure-compensation pond via a water shaft is assumed to maintain the vessel pressure at a constant value. This model is assumed to be used in conjunction with a heat exchanger. The energy is calculated as a function of the stored gas mass, the inlet/storage air temperature, and a leakage function proportional to the stored energy.

<u>Basic Equation</u>

The rate of energy storage is computed from the equation

$$\dot{E} = M1*CP*(T1-TO) - NU*E, \text{ charging}$$

$$\dot{E} = -M2*CP*(T2-TO) - NU*E, \text{ discharging}$$

where M1 = mass flow rate during charge

M2 = mass flow rate during discharge

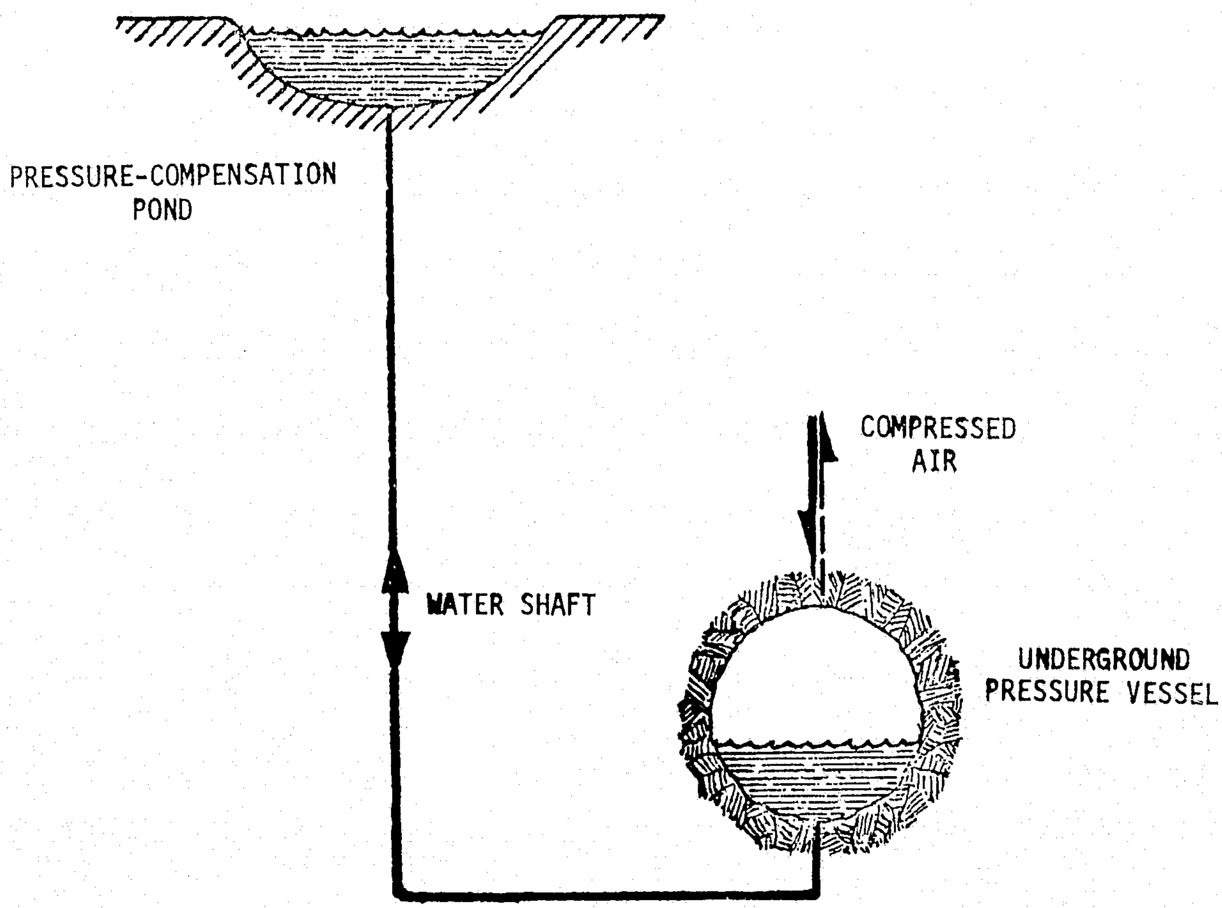


FIGURE 7.7 CONSTANT PRESSURE AIR STORAGE

Inputs

Parameter/Port		Description	Units
M	1	Inlet air mass flow rate	lb/h
CP		Air heat capacity (D = 7.2×10^{-5})	kwh/lb^{o}F
T	1	Inlet air temperature	^{o}F
TØ		Minimum air temperature (D = 60)	^{o}F
NU		Leakage coefficient (D = 0.0008)	h^{-1}
R		Gas constant (D = 2.009×10^{-5})	kwh/lb
VM		Maximum storage capacity (D = 1.2×10^{6})	ft^3
PR	1	Vessel pressure (D = 147)	psi
LE		Life expectancy of vessel	years
CV		Vessel capacity cost (D = 0.22)	$/$ft^3$
RE	1	Load request	kw
EF	1	Input product efficiency	–
MP	1	Input maximum power	kw
MDE		Mass threshold for priority resequencing	lb
MD		Maximum charge or discharge mass flow rate	lb
TM		Maximum allowable air temperature (D = 120)	^{o}F
TEM		Maximum allowable inlet temperature	^{o}F
CM		Maintenance cost/year	$

Outputs

Variable/Port		Description	Units
E		Stored energy (state)	kwh
M	2	Outlet mass flowrate	lb/hr
T	2	Storage temperature	^{o}F
V		Storage volume	ft^3
CCØ		Cost of vessel/year	$
MS		Mass of air in storage (state)	lb
MP	2	Maximum output power	kw
RE	2	Maximum charging rate	kw
INT		Interrupt priority flag	–
TSØ		Minimum air temperature (=TO)	^{o}F

D – Default values supplied

Outputs Cont.

Variable/Port

PR	2	Vessel pressure (=PR1)	psi
P	2	Output power (discharge)	kw
MDM		Maximum allowable mass flow rate (=MD)	

Statistics

EU	Maximum stored energy	kwh
VU	Maximum storage volume	ft^3

The pneumatic storage vessel calculation sequence and default values assume a 10atm cavern approximately 340 ft. below ground and sized for storage of 120kw for 24 hours. A maximum cavern wall temperature of 120°F is assumed. Cost estimates for the vessel were estimated from the results of Reference 1, with cost scaling by .05 to account for plant size differences.

---

1. "Preliminary Feasibility Evaluation of Compressed Air Storage Power Systems," United Technologies AER 74-00242, December 1976.

Calculation Sequence

TINC = integration step size, hr

C1 = conversion constant = 5.43×10^{-5} $\frac{kwh/ft^3}{psi}$

1) Vessel Cost

$$CC\emptyset = CV*VM/LE$$

2) Storage temperature

$$T2 = \frac{E}{CP*MS} + T\emptyset$$

3) Storage volume

$$V = MS* \frac{R*(T2+460)}{PR1*C1}$$

4) Maximum Mass and charging rate

$$MSM = VM* \frac{(PR1*C1)}{R*(T2+460)}$$

$$MD1 = MIN(MDM,(MSM-MS)/TINC)$$

$$RE2 = \min\left\{MP1,\ MD1*CP*(TEM-T\emptyset)\right\}/EF1$$

5) Mass flow out (discharge mode)

$$M2 = \frac{RE1}{CP*(T2-T\emptyset)}$$

$$P2 = RE1$$

6) Maximum discharge rate

$$MD = MIN(MDM,(MS-MDE)/TINC)$$

$$MP2 = CP*(T2-T\emptyset)*MD$$

Calculation Sequence Cont.

7) Stored energy rate

$$\dot{E} = CP*(T1-T0)*M1 - NU*E - RE1$$

8) Stored mass rate

$$\dot{MS} = M1 - M2$$

9) Priority interrupt

If MS $\leq$ MDE, INT = 1

If MS > 2*MDE and INT = 1, INT = 0

If MS $\geq$ MSM, INT = -1

If MS < MSM-MDE and INT = -1, INT = 0

If T2>TM write diagnostic and set INT = -1

If MS < MDE or MS >MSM write diagnostic

10) Compute Statistics and Costs

```
SUBROUTINE CS        ENTRY POINT 000427

STORAGE USED  CODE(1) 000637; DATA(0) 000125; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL   000002
 0004   CTIME   000001
 0005   CSIMUL  000010
 0006   COST    000002

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   NWDU$
 0010   NI02$
 0011   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000326 10L       0001    000074 100L     0000    000004 1000F     0000    000021 1010F     0000    000036 1020F
 0001    000344 20L       0001    000362 200L     0006 R 000000 CCI       0006 R 000001 CMI       0000 R 000003 C1
 0005 R 000000 DUM       0003 I 000001 ICNT     0003 I 000000 IMPL      0000    000072 INJP$     0000 R 000001 MD1
 0000 R 000000 MSM       0004 R 000000 TIME     0005 R 000007 TMAX      0000 R 000002 TMAX1


00100      CCS                                                                              000000
00101            SUBROUTINE CS( E,DE,IE,MS,DMS,IMS,M2,T2,V,CC,MP2,RE2,INT,TSO,PR2           000000
00101          1 ,P,MDM,EU,VU,M1,CP,T,TO,R,VM,PR1,LE,NU,CV,RE1,EF1,MP1,MDE,MD,TM            000000
00101          2 ,TEM,CM)                                                                   000000
00101      C                                                                                000000
00101      C   PURPOSE    PERFORMANCE MODEL OF CONSTANT PRESSURE STORAGE VESSEL             000000
00101      C                                                                                000000
00101      C   METHOD     ENERGY IN STORAGE COMPUTED AS A FUNCTION MASS AND                 000000
00101      C                                                                                000000
00101      C              INLET TEMPERATURE.                                                000000
00101      C                                                                                000000
00101      C   WRITTEN BY F.O. MAHONY                    VERSION 1, MARCH 23 1977           000000
00101      C                                                                                000000
00101      C  CALL SEQUENCE                                                                 000000
00101      C                                                                                000000
00101      C         OUTPUTS                                                                000000
00101      C              E    - STORED ENERGY (STATE VARIABLE), KWH                        000000
00101      C              DE   - STORED ENERGY DERIVATIVE, KW                               000000
00101      C              IE   - STATUS INDICATOR FOR E                                     000000
00101      C              MS   - MASS OF AIR IN STORAGE (STATE VARIABLE), LB                000000
00101      C              DMS  - AIR FLOW RATE, LB/HR                                       000000
00101      C              IMS  - STATUS INDICATOR FOR MS                                    000000
00101      C              M2   - OUTLET MASS FLOWRATE, LB/HR                                000000
```

CS

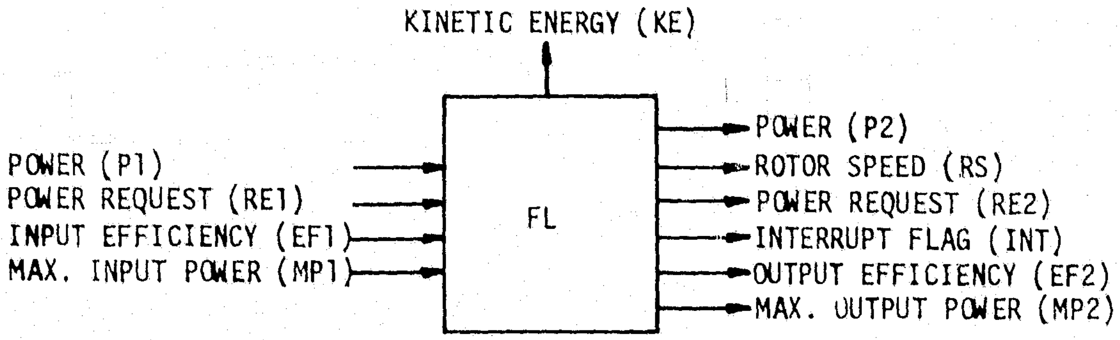
```
00101   C              T2  - STORAGE TEMPERATURE, DEG F                              000000
00101   C              V   - STORAGE VOLUME, FT**3                                   000000
00101   C              CC  - COST OF VESSEL/YEAP, $                                  000000
00101   C              MP2 - MAXIMUM OUTPUT POWER, KW                                000000
00101   C              RE2 - MAXIMUM CHARGING RATE, KW                               000000
00101   C              INT - INTERRUPT PRIORITY FLAG                                 000000
00101   C              TSO - MINIMUM AIR TEMPERATURE, DEG F                          000000
00101   C              PR2 - VESSEL PRESSURE, PSI                                    000000
00101   C              P   - OUTPUT POWER (DISCHARGE), KW                            000000
00101   C              MDM - MAXIMUM ALLOWABLE MASS FLOW RATE, LB/HR                 000000
00101   C              EU  - MAXIMUM STORED ENERGY, KWH                              000000
00101   C              VU  - MAXIMUM STORAGE VOLUME, FT**3                           000000
00101   C                                                                            000000
00101   C          INPUTS                                                            000000
00101   C              M1  - INLET AIR MASS FLOW RATE, LB/HR                         000000
00101   C              CP  - AIR HEAT CAPACITY, KWH/LB-DEG F                         000000
00101   C              T   - INLET AIR TEMPERATURE, DEG F                            000000
00101   C              TO  - MINIMUM AIR TEMPERATURE, DEG F                          000000
00101   C              R   - GAS CONSTANT, KWH/LB-DEG R                              000000
00101   C              VM  - MAXIMUM STORAGE CAPACITY, FT**3                         000000
00101   C              PR1 - VESSEL PRESSURE, PSI                                    000000
00101   C              LE  - LIFE EXPECTANCY OF VESSEL, YEARS                        000000
00101   C              NU  - LEAKAGE COEFFICIENT . , 1/HR                            000000
00101   C              CV  - VESSEL CAPACITY COST  , $/FT**3                         000000
00101   C              RE1 - LOAD REQUEST, KW                                        000000
00101   C              EF1 - INPUT PRODUCT EFFICIENCY                                000000
00101   C              MP1 - INPUT MAXIMUM POWER, KW                                 000000
00101   C              MDE - RESERVOIR THRESHOLD MASS FOR PRIORITY                   000000
00101   C                    RESEQUENCING, LB                                        000000
00101   C              MD  - MAXIMUM CHARGE / DISCHARGE MASS FLOW RATE, LB/HR        000000
00101   C              TM  - MAXIMUM ALLOWAELE STORAGE TEMPERATURE, DEG F            000000
00101   C              TEM - MAXIMUM ALLOWABLE INLET TEMPERATURE, DEG F              000000
00101   C              CM  - MAINTENANCE COST / YEAR , $                             000000
00101   C                                                                            000000
00101   C                                                                            000000
00103         COMMON /CIMPL/IMPL,ICNT/CTIME/ TIME /CSIMUL/DUM(7),TMAX                000000
00104         COMMON /COST/ CCI,CMI                                                  000000
00105         REAL NU,MS,MP2,INT,MDM,M1,LE,MP1,MDE,MD,M2,MSM,MD1                     000000
00105   C                                                                            000000
00105   C                                                                            000000
00106         IF(IMPL.GT.0) GO TO 100                                                000000
00106   C                                                                            000000
00110         IF(CP .EQ. .99999) CP = 72.0E-6                                        000002
00112         IF(TM .EQ. .99999) TM= 120.0                                           000007
00114         IF(TO .EQ. .99999) TO = 60.0                                           000014
00116         IF(NU .EQ. .99999) NU = 0.0008                                         000021
00120         IF(R  .EQ. .99999) R   = 2.009E-5                                      000026
00122         IF(VM .EQ. .99999) VM = 1.2E+6                                         000033
00124         IF(PR1.EQ. .99999) PR1 = 147.0                                         000040
00126         IF(CV .EQ. .99999) CV  = 0.22                                          000045
00130         RE1=0.0                                                                000052
00130   C                                                                            000052
00131         TMAX1 = TMAX*0.99999                                                   000053
00132         TSO=TO                                                                 000056
00132   C                                                                            000056
00133         CC = CV*VM/LE                                                          000060
00134         C1 = 5.43E-5                                                           000064
```


CS

```
00134        C                                                              000064
00135                INT = 0.                                               000066
00136                PR2=PR1                                                000067
00137                EU= 0.                                                 000071
00140                VU= 0.                                                 000072
00141          100 CONTINUE                                                 000074
00141        C                                                              000074
00141        C                                                              000074
00141        C                                                              000074
00141        C                      STORAGE TEMPERATURE                     000074
00141        C                                                              000074
00142                T2 = E/CP/MS+TO                                        000074
00142        C                                                              000074
00142        C                      STORAGE VOLUME                          000074
00142        C                                                              000074
00143                V = MS*R*(T2+460.0)/PR1/C1                             000100
00143        C                                                              000100
00143        C                      MAXIMUM MASS AND  CHARGING RATE         000100
00143        C                                                              000100
00144                MSM = VM*PR1*C1/R/(T2+460.0)                           000110
00145                MDM=MD                                                 000116
00146                MD1= AMIN1(MDM,AMAX1(0.,(MSM-MS)/DUM(7)))              000120
00147                RE2 = AMIN1(MP1,MD1*CP*(TEM-TO))/EF1                   000133
00147        C                                                              000133
00147        C                      MASS FLOW OUT (DISCHARGE)               000133
00147        C                                                              000133
00150                M2 = RE1/CP/(T2-TO)                                    000145
00151                P = RE1                                                000153
00151        C                                                              000153
00151        C                      MAXIMUM DISCHARGE RATE                  000153
00151        C                                                              000153
00152                MDM= AMIN1(MDM,AMAX1(0.,(MS-MDE)/DUM(7)))              000155
00153                MP2 = CP*(T2-TO)*MDM                                   000171
00153        C                                                              000171
00153        C                      STORED ENERGY RATE                      000171
00153        C                                                              000171
00154                IF(IE.NE.0) DE=CP*(T-TO)*M1 - NU*E -RE1                000174
00154        C                                                              000174
00154        C                      STORED MASS RATE                        000174
00154        C                                                              000174
00156                IF(IMS.NE.0) DMS=M1-M2                                 000207
00156        C                                                              000207
00156        C                             PRIORITY INTERRUPT LOGIC         000207
00160                IF(MS .LE. MDE) INT=1.                                 000214
00162                IF(MS.GT. 2.*MDE .AND. INT.EQ.1.) INT=0.               000222
00164                IF(MS .GE.MSM) INT = -1.                               000241
00166                IF(MS.LT. MSM-MDE .AND. INT.EQ.-1.) INT=0.             000247
00170                IF(T2 .GT. TM) INT= -1.                                000266
00173        C                                                              000266
00172                IF(IMPL.LE.1) RETURN                                   000274
00174                IF(IMPL.GT.2)GO TO 200                                 000303
00176                IF(T2.LT.TM) GO TO 10                                  000307
00200                WRITE(6,1000) T2,TM                                    000313
00204                ICNT=ICNT+1                                            000322
00205           10 IF(MS.GT.MDE) GO TO 20                                   000326
00207                WRITE(6,1010)MS,MDE                                    000331
00213                ICNT=ICNT+1                                            000340
```

```
00214            20 IF(MS.LT.MSM) GO TO 200                                      000344
00216               WRITE(6,1020) MS,MSM                                         000347
00222               ICNT=ICNT+1                                                  000356
00222         C                                                                  000356
00222         C                    STATISTICS                                    000356
00222         C                                                                  000356
00223           200 EU = AMAX1(EU,E)                                             000362
00224               VU = AMAX1(VU,V)                                             000367
00224         C                                                                  000367
00225               IF(TIME.LT.TMAX1) RETURN                                     000375
00227               CCI = CCI+CC                                                 000404
00230               CMI=CMI+CM                                                   000407
00230         C                                                                  000407
00231               RETURN                                                       000412
00232          1000 FORMAT(1H0,23HCS STORAGE TEMPERATURE,F12.3,18HGREATER THAN ALLOW,   000636
00232             1 5HABLE ,   F12.3)                                            000636
00233          1010 FORMAT(1H0,25HCS MASS OF AIR IN STORAGE,F12.3,               000636
00233             1 26H   BELOW MINIMUM ALLOWABLE,F12.3)                         000636
00234          1020 FORMAT(1H0,25HCS MASS OF AIR IN STORAGE,F12.3,               000636
00234             1 28H   EXCEEDS MAXIMUM ALLOWABLE,F12.3)                       000636
00235               END                                                          000636
```

7.8 FLYWHEEL/CLUTCH



The flywheel model is a first order differential equation for kinetic energy which is driven by input power when charging and by a load request when discharging. Power losses include clutch losses versus shaft speed and torque, windage losses, and friction losses due to bearing and seals. Shaft speed is determined analytically from kinetic energy. Priority interrupt logic is activated if minimum or maximum capacity levels are reached.

Basic Equations

$$KE = k * \omega^2$$

$$\dot{KE} = P_{IN} - P_{OUT} - C_1 * \omega - C_2 * \omega^{2.8},$$

where k, C_1, C_2 are flywheel constants

ω = rotor speed in rad/sec

P_{IN} = input power - clutch losses

P_{OUT} = output load request

Tables		Description	Units
CLØ		Clutch losses versus rotor speed (rpm) and torque (ft-lb), when engaged (Table dimension = 90)	kw
CL1		Clutch losses versus rotor speed (rpm) when disengaged (Table dimension = 17)	kw

Inputs

Parameter/Port			
PR		Pressure in vacuum housing	psi
HM		Moment of inertia[1]	$slug\text{-}ft^2$
RF		Radius of flywheel	ft
SR		Shaft radius	ft
WT		Flywheel weight	lb
KF		Coefficient of friction	–
ZE		Width of flywheel at tip	ft
C2		Windage loss coefficient (analytic default)	–
P	1	Input power	kw
EF	1	Input product efficiency	–
MP	1	Input maximum charging rate	kw
RAP		Rated power, charge or discharge	kw
RE	1	Discharge load request	kw
EØ		Minimum allowable storage capacity	kwh
E1		Maximum allowable storage capacity	kwh
EDE		Energy deadband for priority resequencing	kwh
CM		Maintenance cost/year	$
CC		Capital cost/year	$

Outputs

Variable/Port			
RS		Rotor speed	rpm
KE		Kinetic energy (state)	kwh

[1] Includes physical drive system.

Outputs Cont.

Variable/Port		Description	Units
TØ		Input torque (charging)	ft-lb
T1		Output torque (discharging)	ft-lb
P	2	Output power	kw
PLØ		Clutch losses (charging)	kw
PL1		Clutch losses (discharging)	kw
EF	2	Output efficiency	-
MP	2	Maximum output power	kw
INT		Priority interrupt flag	-
RE	2	Maximum charging power request	kw

Statistics

ME	Maximum stored energy	kwh
MPC	Maximum charge rate	kw
MPD	Maximum discharge rate	kw
SPC	Sum of charging energy	kwh
SPD	Sum of discharging energy	kwh

Calculation Sequence

1) Compute flywheel constants

$$k = \frac{1}{2} * HM * / 3.76616 * 10^{-7}$$

$$C_1 = KF * WT * SR * / 1.3558 * 10^{-3}$$

$$C_2 = C_o * PR^{0.8} * RF^{4.6} * (1 + 2.3 * ZE/RF) \quad \text{(DEFAULT)}$$

$$C_o = 1.0946 * 10^{-7}$$

If KE < E0 or KE > E1 write diagnostic

2) Compute rotor speed

$$\omega = \sqrt{KE/k}$$

$$RS = \omega * (60/2\pi)$$

$$P_{IN} = 0$$

3) Compute power losses and net power when charging

If P1 = 0, set TØ = PLØ = P_{IN} = 0 and go to 4)

$$T0 = P1 * 737.6/\omega$$

$$PL0 = CLØ(RS, TØ)$$

$$P_{IN} = P1 - PLØ$$

If $P_{IN} < 0$, write diagnostic

4) Compute power losses and output power when discharging

If RE1 = 0, set T1 = PL1 = P2 = P_{OUT} = 0 and go to 5)

$$T1 = RE1 * 737.6/\omega$$

$$PL1 = CLØ(RS, -T1)$$

Calculation Sequence

4) Cont.

$$P2 = RE1 - PL1$$

$$P_{OUT} = RE1$$

If P2 < 0, set P2 = 0. and write diagnostic

5) Compute power losses when disengaged

If P1 > 0 or RE1 > 0, go to 6)

$$P_{OUT} = CL1(RS)$$

6) Flywheel kinetic energy rate

$$\dot{KE} = P_{IN} - P_{OUT} - C_1 * \omega - C_2 * \omega^{2.8}$$

7) Maximum input (charging power)

$$TM = MP1*737.6/\omega$$

$$MP\emptyset = MP1 - CL\emptyset(RS,TM)$$

If MPØ ≤ 0, write diagnostic and go to 8)

$$EF\emptyset = EF1*MP\emptyset/MP1$$

$$RE2 = MIN(MP\emptyset,RAP),(EI-KE)/TINC)/EF\emptyset$$

8) Output efficiency and maximum power

$$RAP1 = MIN(RAP,(KE-E\emptyset)/TINC), \quad TINC = \text{integration step}$$

$$TM = RAP1*737.6/\omega$$

$$MP2 = RAP1 - CL\emptyset(RS,-TM)$$

Calculation Sequence

8) Cont.

If MP2 < 0 write diagnostic

$$EF2 = MP2/RAP1$$

If RE1 > 0, EF2 = P2/RE1

9) Priority interrupt logic

If KE $\leq$ EØ , INT = 1

If KE > EØ + EDE and INT=1, INT=0

If KE $\geq$ E1 , INT = -1

If KE < E1 - EDE and INT= -1, INT=0

10) Compute Statistics and Costs

```
SUBROUTINE FL          ENTRY POINT 001125

STORAGE USED  CODE(1) 001333; DATA(0) 000231; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000002
 0004    CTIME   000001
 0005    CSIMUL  000010
 0006    COST    000002

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    TBLU2
 0010    TBLU1
 0011    XPRR
 0012    NWDU$
 0013    NI02$
 0014    SQRT
 0015    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000060 10L       0000    000042 108F      0000    000026 109F      0001    000147 20L       0001    000315 200L
 0000    000060 208F      0001    000412 300L      0000    000074 308F      0001    000440 400L      0001    000544 500L
 0000    000110 508F      0001    000574 600L      0001    000705 700L      0000    000125 708F      0000  R 000005 AK
 0000  R 000022 APC       0006  R 000000 CCI       0006  R 000001 CMI       0000  R 000006 C1        0005  R 000000 DUM
 0000  R 000025 EC0       0000  R 000024 EC1       0000  R 000021 EF0       0003  I 000001 ICNT      0003  I 000000 IMPL
 0000    000166 INJP$     0000  I 000012 MN4       0000  R 000001 MPA       0000  R 000002 MPB       0000  R 000000 MPO
 0000  I 000011 M4        0000  I 000013 NNNRS     0000  I 000014 NNNRS4    0000  I 000007 NNRS      0000  I 000010 NNT
 0000  R 000015 OMEGA     0000  R 000016 PIN       0000  R 000017 POUT      0000  R 000023 RAPT      0010  R 000000 TBLU1
 0007  R 000000 TBLU2     0004  R 000000 TIME      0000  R 000003 TINC      0000  R 000020 TM        0005  R 000007 TMAX
 0000  R 000004 TMAX1


00100          CFL                                                                              000007
00101                SUBROUTINE FL(CL0,CL1,RS,KE,KED,IKE,T0,T1,P2,PL0,PL1,EF2,MP2,INT,          000007
00101               1   RE2,ME,MPC,MPD,SPC,SPD,  PR,HM,RF,SR,WT,KF,ZE,C2,P1,EF1,MP1,RAP          000007
00101               2   ,RE1,E0,E1,EDE,CM,CC)                                                   000007
00101          C                                                                                000007
00101          C                 PURPOSE   MODEL OF FLYWHEEL CAPABLE OF ABSORBING POWER         000007
00101          C                           AND OF DELIVERING POWER ON REQUEST                   000007
00101          C                                                                                000007
00101          C                 METHOD    OUTPUT POWER AND KINETIC ENERGY COMPUTED FROM        000007
00103                                                                                           000007
00103          C                           POWER REQUEST AND INPUT POWER                        000007
00103          C                                                                                000007
00103                                                                                           000007
```


FL

```
00103            C                                                              000007
00103            C           WRITTEN BY Y.K.CHAN          VERSION 1, JUNE 17, 1977  000007
00103            C                                                              000007
00103            C   CALL SEQUENCE                                              000007
00103            C        TABLES                                                000007
00103            C           CLO -CLUTCH LOSSES VS ROTOR SPEED(RPM) AND TORQUE(FT-LB),KW  000007
00103            C           CL1 -CLUTCH LOSSES VS ROTOR SPEED(RPM) WHEN DISENGAGED,KW    000007
00103            C        OUTPUTS                                               000007
00103            C           RS  -ROTOR SPEED, RPM                              000007
00103            C           KE  -KINETIC ENERGY(STATE),KWH                     000007
00103            C           KED -KINETIC ENERGY INCREASE RATE,KW               000007
00103            C           IKE -INTEGRATOR CONTROL                            000007
00103            C           TO  -INPUT TORQUE (CHARGING), FT-LB                000007
00103            C           T1  -OUTPUT TORQUE (DISCHARGING),FT-LB             000007
00103            C           P2  -OUTPUT POWER,KW                               000007
00103            C           PLO -CLUTCH LOSSES (CHARGING),KW                   000007
00103            C           PL1 -CLUTCH LOSSES (DISCHARGING),KW                000007
00103            C           EF2 -OUTPUT EFFICIENCY                             000007
00103            C           MP2 -MAXIMUM OUTPUT POWER,KW                       000007
00103            C           INT -PRIORITY INTERRUPT FLAG                       000007
00103            C           RE2 -MAXIMUM CHARGING POWER REQUEST                000007
00103            C        STATISTICS                                            000007
00103            C           ME   MAXIMUM STORED ENERGY,KWH                     000007
00103            C           MPC -MAXIMUM CHARGE RATE,KW                        000007
00103            C           MPD -MAXIMUM DISCHARGE RATE,KW                     000007
00103            C           SPC -SUM OF CHARGING POWER,KWH                     000007
00103            C           SPD -SUM OF DISCHARGING POWER,KWH                  000007
00103            C        INPUTS                                                000007
00103            C           PR  -PRESSURE IN VACUUM HOUSING,PSI                000007
00103            C           MM  -MOMENT OF INERTIA,SLUG-FT2                    000007
00103            C           RF  -RADIUS OF FLYWHEEL,FT                         000007
00103            C           SR  -SHAFT RADIUS,FT                               000007
00103            C           WT  -FLYWHEEL WEIGHT,LB                            000007
00103            C           KF  -COEFFICIENT OF FRICTION                       000007
00103            C           ZE  -WIDTH OF FLYWHEEL AT TIP,FT                   000007
00103            C           C2  -WINDAGE COEFFICIENT (ANALYTIC DEFAULT)        000007
00103            C           P1  -INPUT POWER,KW                                000007
00103            C           EF1 -INPUT PRODUCT EFFICIENCY                      000007
00103            C           MP1 -INPUT MAXIMUM CHARGING RATE,KW                000007
00103            C           RAP -RATED POWER, CHARGE OR DISCHARGE,KW           000007
00103            C           RE1 -DISCHARGE LOAD REQUEST,KW                     000007
00103            C           EO  -MINIMUM ALLOWABLE STORAGE CAPACITY,KWH        000007
00103            C           E1  -MAXIMUM ALLOWABLE STORAGE CAPACITY,KWH        000007
00103            C           EDE -ENERGY DEADBAND FOR PRIORITY RESQUENCING,KWH  000007
00103            C           CM  -MAINTENANCE COST/YEAR,$                       000007
00103            C           CC  -CAPITAL COST/YEAR,$                           000007
00103            C                                                              000007
00103                  COMMON /CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX    000007
00103                 X       /COST/CCI,CMI                                     000007
00104                  REAL KE,KED,MP2,INT,ME,MPC,MPD,KF,MP1,MPO,MPA,MPB        000007
00105                  DIMENSION CLO(1),CL1(1)                                  000007
00105            C                                                              000007
00106                  IF(IMPL.GT.0)GO TO 10                                    000007
00110                  TINC=DUM(7)*.5                                           000012
00111                  IF(C2.EQ..99999)C2=(1.0946E-7)*(PR**.8)*(RF**4.6+2.3*ZE*(RF**3.6))  000015
00113                  INT=0.                                                   000045
00114                  TMAX1=TMAX*.99999                                        000046
```

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00114      C                                                              000046
00115            MF=0.                                                    000051
00116            REI=0.                                                   000052
00117            MPC=0.                                                   000053
00120            MPD=0.                                                   000054
00121            SPC=0.                                                   000055
00122            SPD=0.                                                   000056
00123         10 CONTINUE                                                 000060
00124            AK=.5*HM*3.76616E-7                                      000060
00125            CI=KF*WT*SR*1.3558E-3                                    000063
00126            IF(((KE.GT.EO).AND.(KE.LT.EI)).OR.(IMPL.NE.2))GO TO 20   000070
00130            IF(KE.LE.EO)WRITE(6,108)KE,EO                            000115
00135            IF(KE.GE.EI)WRITE(6,109)KE,EI                            000130
00142        109 FORMAT(1H0,26H FLYWHEEL KINETIC ENERGY ,F12.3,           000143
00142           X 18H EXCEEDS CAPACITY ,F12.3)                            000143
00143        108 FORMAT(1H0,24H FLYWHEEL KINETIC ENERGY,F12.3,            000143
00143           X 33H FALLS BELOW MINIMUM REQUIREMENT ,F12.3)             000143
00144            ICNT=ICNT+1                                              000143
00145         20 CONTINUE                                                 000147
00146            NNRS=CLO(2)                                              000147
00147            NNT=CLO(3)                                               000155
00150            M4=NNT+4                                                 000164
00151            MN4=M4+NNRS                                              000166
00152            NNNRS=CL1(2)                                             000170
00153            NNNRS4=NNNRS+4                                           000177
00154            TO=0.                                                    000201
00155            TI=0.                                                    000202
00156            P2=0.                                                    000203
00157            PLO=0.                                                   000204
00160            PL1=0.                                                   000205
00161            RE2=0.                                                   000206
00161      C                                                              000206
00161      C                COMPUTE ROTOR SPEED                           000206
00161      C                                                              000206
00162        100 OMEGA=1.E-6                                              000207
00163            IF(KE.GT.0.)OMEGA=SQRT(KE/AK)                            000211
00165            RS= OMEGA*30./3.14159                                    000223
00166            PIN=0.                                                   000227
00166      C                                                              000227
00166      C                COMPUTE POWER LOSSES AND NET POWER WHEN CHARGING   000227
00166      C                                                              000227
00167            IF(P1.EQ.0.)GO TO 200                                    000230
00171            TO=P1*737.6/OMEGA                                        000236
00172            PLO=TPLU2(RS,TO,CLO(M4),CLO(4),CLO(MN4),1,1,-NNRS,-NNT,NNRS,NNT)   000242
00173            PIN=P1-PLO                                               000272
00174            POUT=0.                                                  000274
00174      C                                                              000274
00175            IF(PIN.GE.0.)GO TO 200                                   000275
00177            IF(IMPL.NE.2)GO TO 200                                   000277
00201            WRITE(6,208)PLO,P1                                       000302
00205        208 FORMAT(1H0,21H FLYWHEEL POWER LOSS ,F12.3,               000311
00205           X24H EXCEEDS CHARGING POWER ,F12.3)                       000311
00206            ICNT=ICNT+1                                              000311
00206      C                                                              000311
00206      C                 COMPUTE POWER LOSSES AND OUTPUT POWER WHEN DISCHARGING   000311
00206      C                                                              000311
00207        200 IF(REI.EQ.0.)GO TO 300                                   000315
```


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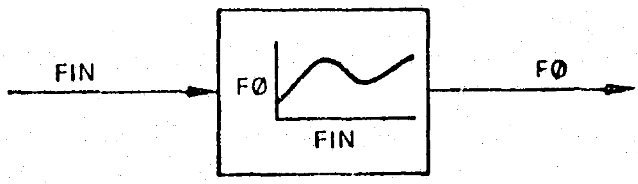
```
00211        T1=RE1*737.6/OMEGA                                                      000316
00212        PL1=TBLU2(RS,-T1,CLO(M4),CLO(4),CLO(MN4),1,1,-NNRS,-NNT,NNRS,NNT)       000322
00213        P2=RE1-PL1                                                              000357
00214        POUT=RE1                                                                000361
00215        IF(P2.GT.0..OR.IMPL.NE.2)GO TO 300                                      000363
00217         WRITE(6,308)PL1,RE1                                                    000376
00223    308 FORMAT(1H0,16H  FLYWHEEL LOSS ,F12.3,                                   000405
00223       X27H EXCEEDS DISCHARGING POWER ,F12.3)                                   000405
00224        ICNT=ICNT+1                                                             000405
00225        P2=0.                                                                   000410
00225  C                                                                             000410
00225  C              COMPUTE POWER LOSSES WHEN DISENGAGED                           000410
00225  C                                                                             000410
00226                                                                                000412
00226                                                                                000412
00226    300 IF(P1.GT.0.)GO TO 400                                                   000412
00230        IF(RE1.GT.0.)GO TO 400                                                  000414
00232        POUT=TBLU1(RS,CL1(4),CL1(NNNRS4),1,-NNNRS)                              000421
00232  C                                                                             000421
00232  C              FLYWHEEL KINETIC ENERGY BALANCE                                000421
00232  C                                                                             000421
00233    400 IF(IKE.NE.0)KED=PIN-POUT-C1*OMEGA-C2*(OMEGA**2.8)                       000440
00233  C                                                                             000440
00233  C              MAXIMUM CHARGING POWER REQUEST                                 000440
00233  C                                                                             000440
00235        TM=MP1*737.6/OMEGA                                                      000456
00236        MPA=TBLU2(RS,TM,CLO(M4),CLO(4),CLO(MN4),1,1,-NNRS,-NNT,                 000462
00236       X    NNRS,NNT)                                                           000462
00237        MPO=MP1-MPA                                                             000516
00240        IF(MPO.GT.0.)GO TO 500                                                  000520
00242        IF(IMPL.EQ.2)WRITE(6,508)MPA,MP1                                        000522
00247    508 FORMAT(1H0,22H FLYWHEEL CLUTCH LOSS  ,F12.3,                            000534
00247       X 31H EXCEEDS MAXIMUM INPUT POWER  ,F12.3)                               000534
00250        IF(IMPL.EQ.2)ICNT=ICNT+1                                                000534
00252        GO TO 600                                                               000542
00253    500 EFO=EF1*MPO/MP1                                                         000544
00254         APC= AMAX1(0.,(EI-KE)/DUM(7))                                          000547
00255        RE2=AMIN1(MPO,RAP,APC)                                                  000557
00256        RE2=RE2/EFO                                                             000571
00256  C                                                                             000571
00256  C              OUTPUT EFFICIENCY AND MAXIMUM POWER                            000571
00256  C                                                                             000571
00257    600 RAPT=(KE-EO)/(TINC*2.)                                                  000574
00260        RAPT=AMIN1(RAPT,RAP)                                                    000601
00261        RAPT=AMAX1(RAPT,RAP/1000.)                                              000606
00262        TM=RAPT*737.6/OMEGA                                                     000615
00263        MPB=TBLU2(RS,-TM,CLO(M4),CLO(4),CLO(MN4),1,1,-NNRS,-NNT,                000620
00263       X   NNRS,NNT)                                                            000620
00264        MP2=RAPT-MPB                                                            000655
00265        IF(MP2.GT.0..OR.IMPL.NE.2)GO TO 700                                     000657
00267    708 FORMAT(1H0,22H FLYWHEEL CLUTCH LOSS ,F12.3,                             000672
00267       X27H EXCEEDS DELIVERABLE POWER  ,F12.3)                                  000672
00270        WRITE(6,708)MPB,RAPT                                                    000672
00274        ICNT=ICNT+1                                                             000701
00275    700 MP2=AMAX1(MP2,RAP/1000.)                                                000705
00276        EF2=MP2/RAPT                                                            000713
00277        IF(RE1.GT.0..AND.P2.GT.0.)EF2=P2/RE1                                    000715
```

```
00277    C                                           000715
00277    C           PRIORITY INTERRUPT              000715
00277    C                                           000715
00301          EC1=E1-EDE                            000734
00302          EC0=E0+EDE                            000737
00303          IF((KE.GT.EC0).AND.(INT.EQ.1.))INT=0.  000742
00305          IF((KE.LT.EC1).AND.(INT.EQ.-1.))INT=0. 000760
00307                                                000776
00307          IF(KE.LE.E0)INT=1.                    000776
00311          IF(KE.GT.E1)INT=-1.                   001004
00313          IF((KE.GT.EC0).AND.(KE.LT.EC1))INT=0.  001012
00315          IF(IMPL.LE.1)RETURN                   001031
00315    C                                           001031
00315    C           STATISTICS                      001031
00315    C                                           001031
00317          ME=AMAX1(ME,KE)                       001040
00320          MPC=AMAX1(MPC,KED)                    001046
00321          MPD=AMAX1(MPD,-KED)                   001054
00322          SPC=SPC+TINC*P1                       001062
00323          SPD=SPD+TINC*P2                       001066
00323    C                                           001066
00324          IF(TIME.LT.TMAX1)RETURN               001072
00326          CCI=CCI+CC                            001101
00327          CMI=CMI+CM                            001104
00327    C                                           001104
00330                                                001107
00330          RETURN                                001107
00331          END                                   001332
```

7.9 ONE DIMENSION TABLE LOOKUP



Tables	Description
FTA	Tabular values of function

Inputs

Parameter/Port	
FIN	Input quantity
AN	ABS(AN) ≤ 0.5 for equispaced interpolation (AN < 0 prevents extrapolation)

Outputs

Variable/Port	
FØ	Output quantity

Calculation Sequence

FØ = FTA(FIN)

NOTE: A maximum of 18 points is allowed in the table.

```
SUBROUTINE FU        ENTRY POINT 000065

STORAGE USED  CODE(1) 000075; DATA(0) 000014; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

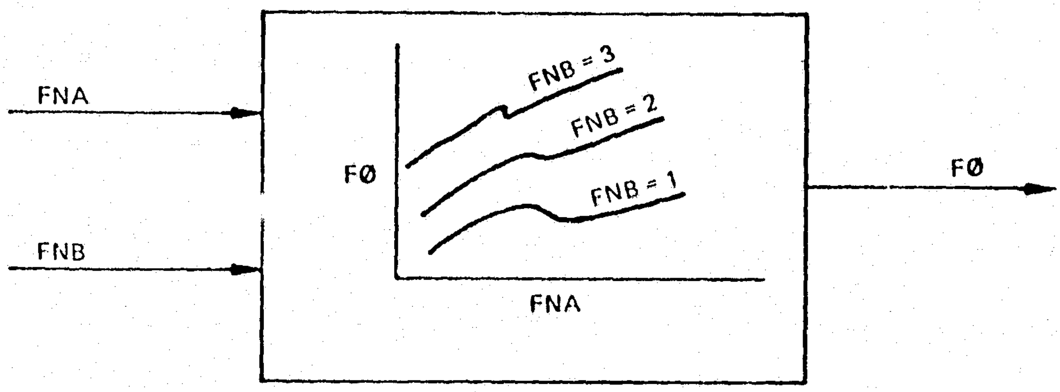
 0003   TBLU1
 0004   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0000   000005 INJP$     0000 I 000002 N        0000 I 000000 NA       0000 I 000001 NB       0003 R 000000 TBLU1


00100     CFU                                                                          000003
00101           SUBROUTINE FU(FTA,FO,FIN,AN)                                           000003
00101     C                                                                            000003
00101     C   PURPOSE - TO CALCULATE OUTPUT FO AS AN ARBITRARY FUNCTION OF             000003
00101     C             INPUT FIN USING TABULAR INPUT FTA GIVING FO=F(FIN)             000003
00101     C                                                                            000003
00101     C   METHOD  - SELF EXPLANATORY                                               000003
00101     C                                                                            000003
00101     C                                                                            000003
00101     C   LIMITATIONS - MAXIMUM ARRAY SIZE IS 18                                   000003
00101     C                                                                            000003
00101     C                                                                            000003
00101     C   WRITTEN BY - ADAM LLOYD           LATEST REVISION     APRIL  77           000003
00101     C                                                                            000003
00101     C                                                                            000003
00101     C   INPUT/OUTPUT LIST                                                        000003
00101     C                                                                            000003
00101     C   FTA      TABULAR INPUT FO=F(FIN)       ANY          INPUT  TABLE         000003
00101     C   FO       OUTPUT                        ANY          OUTPUT VAR           000003
00101     C   FIN      INPUT                         ANY          INPUT  VAR           000003
00101     C   AN       SET ABS(AN).GT.0.5 FOR UNEQUAL SPACED TABLE DATA---INPUT        000003
00101     C            SET ABS(AN).LE.0.5 FOR EQUI-SPACED TABLE DATA                   000003
00101     C            A NEGATIVE VALUE OF AN WILL                                     000003
00101     C            PREVENT EXTRAPOLATION BEYOND                                    000003
00101     C            TABLE LIMITS                                                    000003
00101     C                                                                            000003
00103           DIMENSION FTA(1)                                                       000003
00104           NA= SIGN(FTA(2),AN)                                                    000003
00105           NB=FTA(2)+4                                                            000015
00106           N=1                                                                    000026
00107           IF(ABS(AN).LE.0.5) N=0                                                 000030
00111           FO=TBLU1(FIN,FTA(4),FTA(NB),N,NA)                                      000035
00112           RETURN                                                                 000053
00113           END                                                                    000074
```

7.10 TWO DIMENSION TABLE LOOKUP



Tables	Description
FTA	Table of functional relationships (maximum number of table values = 144)

Inputs

Parameter/Port	
FNA	Input quantity (primary)
FNB	Input quantity (secondary)
AN	ABS(AN) ≤ 0.5 for equal spaced FNA data*
BN	ABS(BN) ≤ 0.5 for equal spaced FNB data*

Outputs

Variable/Port	
FØ	Output quantity

Calculation Sequence

FØ = FTA(FNA,FNB)

---

* A negative value for AN or BN prevents extrapolation beyond the table boundaries.

```
SUBROUTINE FV        ENTRY POINT 000161

STORAGE USED  CODE(1) 000204; DATA(0) 000036; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

 0003    TBLU2
 0004    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0000    000012 INJP$     0000 I 000006 NAN     0000 I 000007 NBN     0000 I 000000 N1     0000 I 000001 N2
 0000 I 000002 N3         0000 I 000003 N4      0000 I 000004 N5      0000 I 000005 N6     0003 R 000000 TBLU2


00100     1*     CFV                                                                          000003
00101     2*           SUBROUTINE FV(FTA,FO,FNA,FNB,AN,BN)                                    000003
00101     3*     C                                                                            000003
00101     4*     C    PURPOSE - TO CALCULATE OUTPUT FO AS AN ARBITRARY FUNCTION OF INPUT      000003
00101     5*     C              VARIABLES FNA AND FNB. INPUT TABLE FTA IS USED GIVING         000003
00101     6*     C              FO=F(FNA,FNB)                                                 000003
00101     7*     C                                                                            000003
00101     8*     C    METHOD  - TWO DIMENSIONAL TABLE LOOKUP                                  000003
00101     9*     C                                                                            000003
00101    10*     C                                                                            000003
00101    11*     C    LIMITATIONS - MAX ALLOWABLE SIZE OF TABULAR ARRAY IS 12X12.             000003
00101    12*     C                                                                            000003
00101    13*     C                                                                            000003
00101    14*     C    WRITTEN BY   - GEORGE DULEBA                  LATEST REVISION   MAY 76  000003
00101    15*     C                                                                            000003
00101    16*     C                                                                            000003
00101    17*     C    INPUT/OUTPUT LIST                                                       000003
00101    18*     C                                                                            000003
00101    19*     C    FTA       TABULAR INPUT                    ---        INPUT TABLE       000003
00101    20*     C    FO        OUTPUT                           ANY        OUTPUT VAR        000003
00101    21*     C    FNA       INPUT A                          ANY        INPUT  VAR        000003
00101    22*     C    FNB       INPUT B                          ANY        INPUT  VAR        000003
00101    23*     C    AN        SET ABS(AN) .GT. 0.5 FOR UNEQUAL SPACED FNA DATA- INPUT PARM  000003
00101    24*     C                 A NEGATIVE VALUE INDICATES THAT THE NEAREST END            000003
00101    25*     C                 POINT IS TO BE USED UPON EXTRAPOLATION.                    000003
00101    26*     C    BN        SET ABS(BN) .GT. 0.5 FOR UNEQUAL SPACED FNB DATA- INPUT PARM  000003
00101    27*     C                 A NEGATIVE VALUE INDICATES THAT THE NEAREST END            000003
00101    28*     C                 POINT IS TO BE USED UPON EXTRAPOLATION.                    000003
00101    29*     C                                                                            000003
00103    30*           DIMENSION FTA(1)                                                       000003
00104    31*           N1=FTA(3)+4                                                            000003
00105    32*           N2=FTA(2)+FTA(3)+4                                                     000014
00106    33*           N3=FTA(2)                                                              000026
```

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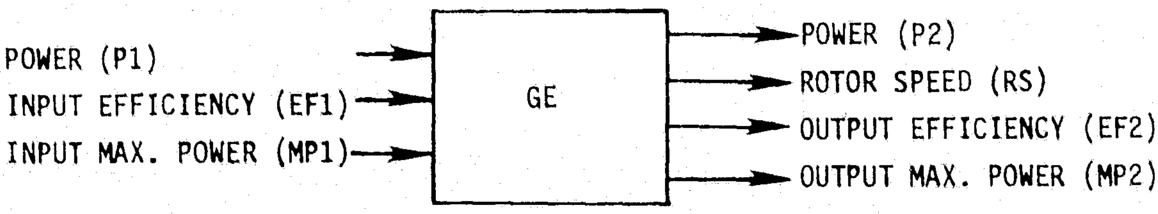
FV

```
00107    N4=FTA(3)                                                      000035
00110    N5= SIGN(FTA(2),AN)                                            000044
00111    N6= SIGN(FTA(3),BN)                                            000056
00112    NAN=1                                                          000070
00113    IF(ABS(AN).LE.0.5) NAN=0                                       000072
00115    NBN=1                                                          000077
00116    IF(ABS(BN).LE.0.5) NBN=0                                       000101
00120    FO=TBLU2(FNA,FNB,FTA(N1),FTA(4),FTA(N2),NAN,NBN,N5,N6,N3,N4)   000114
00121    RETURN                                                         000142
00122    END                                                            000203
```


FV

7.11 AC INDUCTION GENERATOR



The induction generator produces electrical power proportional to rotor slip, i.e. difference between rotor speed and synchronous speed. This relationship is used to compute rotor speed given input power and the generator parameters. Two power losses are modeled: a constant multiplicative term due to resistive heating and an additive term due to mechanical friction. Default parameters are based on a conventional squirrel-cage induction motor/generator machine. This component can also be used as a synchronous generator with RAS$\leq$.01.

<u>Basic Equations</u>

Output power P2 and rotor speed RS are computed from the following equations:

$$P2 = EE*(P1-C*RS^2)$$

$$\frac{P2}{RAP} = \frac{(RS/RSY-1)}{RAS} \qquad \text{(Power is proportional to slip)}$$

where EE = electrical efficiency

C = constant of conversion

GE

Inputs

Parameter/Port		Description	Units
P	1	Input power	kw
RAP		Rated output power	kw
RSY		Synchronous rotor speed (D = 1800)	rpm
RAS		Rated power slip (D = 0.05)	–
DA		Mechanical damping (D = 0.0)	joule–sec
SR		Internal stator resistance (D = 6.4/RAP)	ohms
VØ		Rated bus voltage (D = 400)	volts
EF	1	Input product efficiency	–
MP	1	Maximum input discharge rate (D = 1×10^8)	kw
CC		Capital cost/year	$
CM		Maintenance cost/year	$

Outputs

Variable/Port			
P	2	Output power	kw
EL		Electrical efficiency	–
RS		Rotor speed	rpm
PL		Power loss	kw
EF	2	Output product efficiency	–
MP	2	Maximum output discharge rate	kw

Statistics

MPN	Maximum output power/rated power	kw
SP	Total output energy	kwh

D – Default values supplied.

Calculation Sequence

1) First pass only

$$EFF = 1$$

$$I_{RAT} = RAP*1000/V\emptyset$$

$$EE = \frac{RAP}{RAP+SR*I^2_{RAT}/1000}$$

2) If P1 = 0 set P2 = 0, RS = RSY and go to 4)

Compute rotor speed ω in rad/sec using

$$\frac{EE(P1*1000 - \omega^2*DA\ )}{RAP*1000} = \frac{(\omega/\omega_o - 1)}{RAS}$$

with $\omega_o = RSY*(2\pi/60)$

3) Compute RS and output power

$$RS = \omega*(60/2\pi)$$

$$P2 = RAP(RS/RSY-1)/RAS$$

P2 > RAP ⇨ DIAGNOSTIC

$$EFF = P2/P1$$

4) Compute loss, efficiency terms

$$PL = P1-P2$$

$$EF2 = EF1*EFF$$

5) Compute maximum output rate

$$MP2 = MIN(RAP,MP1*EFF)$$

6) Compute Statistics and Costs

SUBROUTINE GE   ENTRY POINT 000253

STORAGE USED CODE(1) 000363; DATA(0) 000043; BLANK COMMON(2) 000000

COMMON BLOCKS

```
0003   CIMPL   000002
0004   CTIME   000001
0005   COST    000004
0006   CSIMUL  000010
```

EXTERNAL REFERENCES (BLOCK, NAME)

```
0007   NWDUS
0010   NI02$
0011   NERR3$
```

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

```
0001     000064 10L      0000     000005 100F     0001     000074 20L      0001     000172 30L      0000 R 000003 A
0000 R 000004 B        0005 R 000000 CC       0005 R 000001 CM       0005     000003 CV       0005     000002 CO
0006     000000 DUM      0000 R 000000 EFF      0003 I 000001 ICNT     0003 I 000000 IMPL     0000     000032 INJP$
0000 R 000002 RATI     0004 R 000000 TIME     0006 R 000006 TINC     0006 R 000007 TMAX     0000 R 000001 TMAX1
```

```
00100     CGE                                                                        000000
00101           SUBROUTINE GE(P2,EE,RS,PL,EF2,PM2,PMN,SP,P1,RAP,RSY,RAS,DA,SR,VO,    000000
00101          1 EF1,PM1,CCI,CMI)                                                    000000
00101     C                                                                          000000
00101     C   PURPOSE    MODEL AC INDUCTION GENERATOR                                000000
00101     C                                                                          000000
00101     C   METHOD     MECHANICAL AND ELECTRICAL EFFICIENCIES ARE USED TO COMPUTE  000000
00101     C              OUTPUT POWER.  ROTOR SPEED IS COMPUTED ASSUMING POWER IS    000000
00101     C              PROPORTIONAL TO SLIP.                                       000000
00101     C                                                                          000000
00101     C   WRITTEN BY A.W. WARREN                      VERSION 1, MARCH 16 1977   000000
00101     C                                                                          000000
00101     C   CALL SEQUENCE                                                          000000
00101     C         OUTPUTS                                                          000000
00101     C              P2  - OUTPUT POWER, KW                                      000000
00101     C              EE  - ELECTRICAL EFFICIENCY                                 000000
00101     C              RS  - ROTOR SPEED, RPM                                      000000
00101     C              PL  - POWER LOSS, KW                                        000000
00101     C              EF2 - OUTPUT PRODUCT EFFICIENCY                             000000
00101     C              PM2 - MAXIMUM OUTPUT POWER, KW                              000000
00101     C              PMN - MAX. OBSERVED OUTPUT POWER / RATED POWER              000000
00101     C              SP  - TOTAL OUTPUT ENERGY, KWH                              000000
00101     C                                                                          000000
```


GE

```
00101      C            INPUTS                                                                    000000
00101      C                  P1   - INPUT POWER, KW                                              000000
00101      C                  RAP  - RATED OUTPUT POWER, KW                                       000000
00101      C                  RSY  - SYNCHRONOUS ROTOR SPEED, RPMN                                000000
00101      C                  RAS  - RATED POWER SLIP (DEFAULT = .05)                             000000
00101      C                  DA   - MECHANICAL DAMPING, JOULE-SEC                                000000
00101      C                  SR   - STATOR RESISTANCE, OHMS                                      000000
00101      C                  VO   - RATED BUS VOLTAGE, VOLTS                                     000000
00101      C                  EF1  - INPUT PRODUCT EFFICIENCY                                     000000
00101      C                  PM1  - MAXIMUM INPUT POWER, KW                                      000000
00101      C                  CCI  - CAPITAL COST/YEAR, $                                         000000
00101      C                  CMI  - MAINTENANCE COST/YEAR, $                                     000000
00101      C                                                                                      000000
00103            COMMON /CIMPL/ IMPL,ICNT /CTIME/ TIME                                            000000
00104            COMMON /COST/ CC,CM,CO,CV /CSIMUL/ DUM(6),TINC,TMAX                              000000
00104      C                        INITIALIZATION                                                000000
00104      C                                                                                      000000
00105            IF( IMPL.GT.0) GO TO 10                                                          000000
00107            EFF = 1.                                                                         000002
00110            TMAX1 = TMAX* .99999                                                             000004
00111            IF(RSY.EQ. .99999) RSY = 1800.                                                   000007
00113            IF(RAS.EQ. .99999) RAS = .05                                                     000014
00115            IF(DA .EQ. .99999) DA = 0.                                                       000021
00117            IF(SR .EQ. .99999) SR = 6.4/RAP                                                  000025
00121            IF(VO .EQ. .99999) VO = 480.                                                     000033
00123            IF(PM1.EQ. .99999) PM1 = 1.E10                                                   000040
00125            PMN =0.0                                                                         000045
00126            SP  =0.0                                                                         000046
00127            RATI = RAP*1000./VO                                                              000047
00130            EE  = RAP/(RAP + SR*.001*RATI**2)                                                000053
00130      C                                                                                      000053
00130      C                        COMPUTE ROTOR SPEED AND OUTPUT POWER                          000053
00130      C                                                                                      000053
00131         10 IF( P1.GT. 0.) GO TO 20                                                          000064
00133            P2 =0.0                                                                          000066
00134            PL =0.0                                                                          000067
00135            RS = RSY                                                                         000070
00136            GO TO 30                                                                         000072
00136      C                                                                                      000072
00137         20 A = RAP/(EE*RAS)                                                                 000074
00140            B = RSY/( A + RSY**2*DA*1.0966E-5)                                               000100
00141            RS = B*(A + P1)                                                                  000110
00142            P2 = RAP*(RS/RSY -1.)/RAS                                                        000114
00143            IF (P2.GT.RAP.AND.IMPL.EQ.2) WRITE(6,100)                                        000121
00146        100 FORMAT(1H0, 40X,37HGENERATOR OUTPUT EXCEEDS RATED POWER /)                       000143
00146      C                                                                                      000143
00147            IF(P2.GT.RAP .AND. IMPL.EQ.2)ICNT=ICNT+1                                         000143
00151            PL = P1 - P2                                                                     000163
00152            EFF = P2/P1                                                                      000166
00153         30 EF2 = EF1*EFF                                                                    000172
00154            PM2 = AMIN1(RAP, PM1*EFF)                                                        000174
00154      C                                                                                      000174
00154      C                        STATISTICS                                                    000174
00155            IF(IMPL.LE.1) RETURN                                                             000203
00157            PMN = AMAX1(PMN, P2/RAP)                                                         000212
00160            SP = SP + P2*.5*TINC                                                             000221
00160      C                                                                                      000221
```

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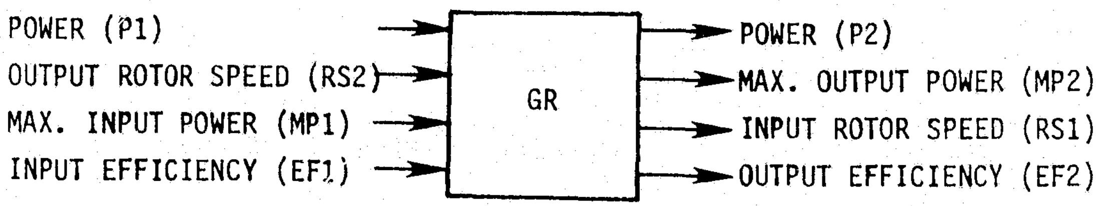
GE

```
00160    C                          COST SUMMATION             000221
00161          IF( TIME.LT.TMAX1) RETURN                       000226
00163          CC = CC + CCI                                   000235
00164          CM = CM + CMI                                   000240
00164    C                                                     000240
00165          RETURN                                          000243
00166          END                                             000362
```

7.12 FIXED RATIO TRANSMISSION



This component models a fixed gear ratio transmission. Power losses are modeled by a table lookup depending on input power. Rotor input speed is used as a feedback variable.

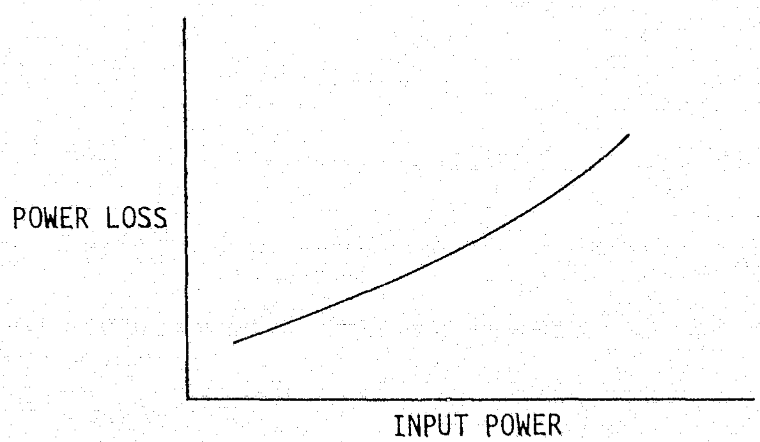


FIGURE 7.12: FIXED GEAR POWER LOSS

Tables		Description	Units
PLØ		Power loss versus input power	kw

Inputs

Parameter/Port			
GR		Gear ratio	–
RS	2	Output rotor speed	rpm
P	1	Input power	kw
EF	1	Input product efficiency	–
MP	1	Maximum input power (Default = 1×10^{8})	kw
CC		Capital cost/year	$
CM		Maintenance cost/year	$

Outputs

Variable/Port			
P	2	Output power	kw
TO		Output torque	ft-lb
PL		Power loss	kw
EF	2	Output product efficiency	–
MP	2	Maximum output power	kw
RS	1	Input rotor speed	rpm

Calculation Sequence

1) MP2 = MP1 - PLØ(MP1) (First Pass Only)

If P1 ≤ 0, set PL = P2 = 0 and go to 2)

PL = PLØ(P1)

P2 = P1 - PL

RS1 = RS2/GR

EF2 = EF1*P2/P1

2) TØ = P2*737.6/(RS2*2π/60)

3) Compute Costs

```
SUBROUTINE GR        ENTRY POINT 000157

STORAGE USED  CODE(1) 000237; DATA(0) 000023; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000001
 0004   CTIME  000001
 0005   COST   000004
 0006   CSIMUL 000010

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   TBLU1
 0010   NEPR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000057 10L      0001    000113 20L      0005 R 000000 CC      0005 R 000001 CM      0005   000002 CO
 0005    000003 CV       0006    000000 DUM      0003 I 000000 IMPL    0000   000007 INJP$   0000 I 000000 NP
 0007 R 000000 TBLU1     0004 R 000000 TIME      0006 R 000007 TMAX    0000 R 000001 TMAX1

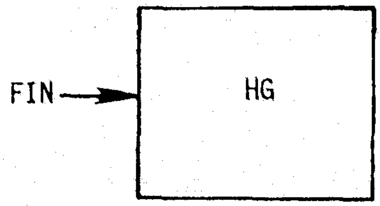

00100      CGR                                                                             000000
00101           SUBROUTINE GR(PLO,P2,TO,PL,EF2,PM2,RS1,GRA,RS2,P1,EF1,PM1,CCI,CMI)        000000
00101      C                                                                               000000
00101      C    PURPOSE   MODEL A FIXED GEAR RATIO TRANSMISSION                            000000
00101      C                                                                               000000
00101      C    METHOD    POWER LOSSES ARE INPUT AS A FUNCTION OF INPUT POWER P1.          000000
00101      C                                                                               000000
00101      C    WRITTEN BY A.W. WARREN                      VERSION 1, MARCH 16 1977       000000
00101      C                                                                               000000
00101      C    CALL SEQUENCE                                                              000000
00101      C         TABLES                                                                000000
00101      C              PLO - POWER LOSS IN KW VERSUS INPUT POWER IN KW                  000000
00101      C                                                                               000000
00101      C         OUTPUTS                                                               000000
00101      C              P2  - OUTPUT POWER, KW                                           000000
00101      C              TO  - OUTPUT TORQUE, FT-LB                                       000000
00101      C              PL  - POWER LOSS, KW                                             000000
00101      C              EF2 - OUTPUT PRODUCT EFFICIENCY                                  000000
00101      C              PM2 - MAXIMUM OUTPUT POWER, KW                                   000000
00101      C              RS1 - INPUT ROTOR SPEED, RPM                                     000000
00101      C                                                                               000000
00101      C         INPUTS                                                                000000
00101      C              GRA - GEAR RATIO                                                 000000
00101      C              RS2 - OUTPUT ROTOR SPEED, RPM                                    000000
00101      C              P1  - INPUT POWER, KW                                            000000
```

GR

```
00101      C               EF1 - INPUT PRODUCT EFFICIENCY                         000000
00101      C               PM1 - MAXIMUM INPUT POWER, KW                          000000
00101      C               CCI - CAPITAL COST / YEAR, $                           000000
00101      C               CMI - MAINTENANCE COST / YEAR, $                       000000
00101      C                                                                      000000
00103            DIMENSION PLO(1)                                                 000000
00104            COMMON /CIMPL/IMPL /CTIME/ TIME                                  000000
00105            COMMON /COST/CC,CM,CO,CV /CSIMUL/ DUM(7),TMAX                    000000
00105      C                                                                      000000
00105      C                          INITIALIZATION                              000000
00105      C                                                                      000000
00106            NP = PLO(2)                                                      000000
00107            IF( IMPL.GT.0) GO TO 10                                          000007
00111            EF2= 1.                                                          000012
00112            TMAX1 = .99999*TMAX                                              000014
00113            RS2=1.                                                           000021
00114            IF(PM1.EQ. .99999) PM1=1.E10                                     000023
00116            PM2 = PM1                                                        000030
00117            IF(PM1.LE. PLO(3+NP) ) PM2 = PM1-TBLU1(PM1,PLO(4),PLO(4+NP),1,-NP)  000032
00117      C                                                                      000032
00117      C                  POWER LOSS AND ROTOR SPEED CALUCATIONS              000032
00121         10 PL=0.                                                            000057
00122            P2=0.                                                            000057
00123            IF(P1 .EQ. 0.) GO TO 20                                          000060
00125            PL = TBLU1(P1,PLO(4),PLO(4+NP),1,-NP)                            000062
00126            P2 = P1 - PL                                                     000102
00127            EF2 = EF1*P2/ P1                                                 000104
00130            RS1 = RS2/GPA                                                    000107
00131         20 IF(RS2 .GT. 0.) TO = P2*7043./RS2                                000113
00131      C                                                                      000113
00131      C                          COST SUMMATION                              000113
00133            IF(IMPL.LE.1) RETURN                                             000121
00135            IF(TIME.LE.TMAX1) RETURN                                         000130
00137            CC = CC + CCI                                                    000137
00140            CM = CM + CMI                                                    000142
00141            RETURN                                                           000145
00142            END                                                              000236
```


GR

7.13 HISTOGRAM



The input quantity is monitored during a SIMULATE analysis. When time reaches TMAX a plotted histogram is produced with 16 intervals that span the range from FLO to FUP.

Inputs

Variable/Port	Description
FIN	Input quantity to be monitored
FUP	Upper limit for histogram
FLØ	Lower limit for histogram
F1,...F16[1]	Array containing histogram data
FA[1]	Measurement interval

Outputs

Variable/Port	
AV	Mean value (running sum during simulation)
SD	Standard deviation (running sum squared)
SAM	Number of samples

---

[1] These quantities do not require data input values.

```
SUBROUTINE HG        ENTRY POINT 000430

STORAGE USED  CODE(1) 000506; DATA(0) 000166; BLANK COMMON(2) 012174

 COMMON BLOCKS

 0003   CTIME  000001
 0004   CSIMUL 000010
 0005   COVRLY 000004
 0006   CIMPL  000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   SQRT
 0010   NWDUS
 0011   NIO3$
 0012   NIO2$
 0013   NIO1$
 0014   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000023 100L     0000    000052 100DF    0000    000056 1100F    0001    000012 120G     0000    000062 1200F
 0000    000067 1300F    0001    000034 134G     0000    000073 1400F    0001    000111 154G     0001    000154 166G
 0001    000175 177G     0001    000203 205G     0001    000211 213G     0001    000216 220G     0001    000223 225G
 0001    000224 230G     0001    000234 236G     0001    000257 24 G     0001    000272 246G     0001    000306 255G
 0001    000314 262G     0001    000053 300L     0001    000364 303G     0001    000364 305G     0000    000047 900F
 0000 R  000010 AX1      0000 R  000030 BLANK    0005    000003 CPUSEC   0004    000000 DUM      0005    000000 DUMM
 0000 R  000036 FAX      0002 R  000000 GRAPH    0000 R  000032 HORIZ    0000 R  000041 HX       0000 I  000034 I
 0000 I  000043 IC       0006 I  000000 IMPL     0000    000135 INJP$    0000 I  000037 ISAMP    0000 I  000042 J
 0000 I  000044 J1       0000 I  000045 J2       0000 I  000046 J3       0000 I  000035 L        0000 R  000033 POINT
 0000 R  000000 TD1      0003 R  000000 TIME     0004 R  000007 TMAX     0000 R  000031 VERT     0000 R  000040 XMAX


00100        CHG                                                                          000003
00101              SUBROUTINE HG(SAMP,AV,SD,F1,F2,F3,F4,F5,F6,F7,F8,F9,F10,F11,          000003
00101            1 F12,F13,F14,F15,F16,FA, FIN,FUP,FLO )                                  000003
00101        C        VERSION 2.          REVISED   MARCH  1977                          000003
00101        C  PURPOSE - DEVELOP A RUNNING HISTOGRAM OF AN INPUT SEQUENCE                000003
00101        C  CALL SEQUENCE                                                             000003
00101        C               SAMP- OUTPUT NUMBER OF SAMPLES                               000003
00101        C                AV  - OUTPUT AVERAGE (RUNNING SUM)                          000003
00101        C                SD  - OUTPUT STANDARD DEVIATION (RUNNING SUM SQUARED)       000003
00101        C            F1-F16  -  ARRAY WITH NUMBER OF OCCURENCES IN EACH INTERVAL     000003
00101        C               FA   - OUTPUT CONTAINING MEASUREMENT INTERVAL                000003
00101        C               FUP  - INPUT SPECIFYING UPPER MEASUREMENT LIMIT              000003
00101        C               FLO  - INPUT SPECIFYING LOWER MEASUREMENT LIMIT              000003
00101        C               FIN  - INPUT MEASUREMENT                                     000003
```

HG

```
00103          DIMENSION FI(16),TD1(8),AX1(16)                      000003
00104          DIMENSION GRAPH(114,46)                              000003
00105          COMMON GRAPH                                         000003
00106          COMMON/CTIME/TIME/CSIMUL/DUM(7),TMAX                 000003
00107          COMMON/COVRLY/DUMM(3),CPUSEC /CIMPL/IMPL             000003
00110          DATA BLANK,VERT,HORIZ,POINT/1H ,1HI,1H-,1H*/         000003
00115          IF(IMPL.GT.0) GO TO 100                              000003
00117          DO 50 I=1,16                                         000012
00122     50   FI(I)=0.                                             000012
00124          FA=(FUP-FLO)/14.                                     000013
00125          SD=0.                                                000017
00126          AV =0.0                                              000020
00127          SAMP=0.0                                             000021
00130    100   CONTINUE                                             000023
00131          IF(IMPL.LT.2) RETURN                                 000023
00133          DO 200 I=1,16                                        000034
00136          L=I                                                  000034
00137          FAX=FLO+(I-1)*FA                                     000036
00140          IF(FIN.LE.FAX) GO TO 300                             000045
00142    200   CONTINUE                                             000053
00144    300   FI(L)=FI(L)+1.                                       000053
00145          SAMP=SAMP+1.                                         000057
00146          AV=AV+FIN                                            000062
00147          SD=SD+FIN*FIN                                        000065
00150          IF(TIME.LT.TMAX*.99999)RETURN                        000071
00152          SAMP=0.                                              000104
00153          DO 350 I=1,16                                        000111
00156    350   SAMP=SAMP+FI(I)                                      000111
00160          ISAMP=SAMP                                           000114
00161          ISAMP=MAX0(1,ISAMP)                                  000123
00162          AV=AV/ISAMP                                          000130
00163          SD=SQRT(SD/ISAMP-AV*AV)                              000135
00164          XMAX=FI(1)                                           000147
00165          DO 360 I=1,16                                        000154
00170    360   IF(FI(I).GE.XMAX) XMAX=FI(I)                         000154
00173          IF(XMAX.EQ.0.) XMAX=10.                              000163
00175          HX=XMAX/44.                                          000167
00176          DO 370 I=1,46                                        000175
00201          GRAPH(1,I)=VERT                                      000175
00202    370   GRAPH(114,I)=VERT                                    000176
00204          DO 380 I=2,113                                       000203
00207          GRAPH(I,1)=HORIZ                                     000203
00210    380   GRAPH(I,46)=HORIZ                                    000204
00212          DO 400 I=5,103,14                                    000211
00215    400   GRAPH(I,46)=VERT                                     000211
00217          DO 450 I=8,106,7                                     000216
00222    450   GRAPH(I,1)=VERT                                      000216
00224          DO 500 I=2,45                                        000224
00227          DO 500 J=2,113                                       000224
00232    500   GRAPH(J,I)=BLANK                                     000224
00235          DO 600 IC=1,16                                       000234
00240          J=IFIX(45.5-FI(IC)/HX)                               000240
00241          DO 600 J1=1,7                                        000252
00244          J2=(IC-1)*7+J1+1                                     000257
00245          DO 600 J3=J,45                                       000263
00250                                                               000272
00250    600   GRAPH(J2,J3)=POINT                                   000272
```

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```
00254            DO 700 I=1,16                                      000306
00257                                                               000306
00257        700 AX1(I)=F1(I)/ISAMP                                 000306
00261            DO 800 I=1,8                                       000314
00264                                                               000314
00264        800 TD1(I)=FLO+(I-1)*2.*FA-FA/2.                        000314
00266                                                               000330
00266            WRITE(6,900)(GRAPH(I,1),I=1,114)                   000330
00271        900 FORMAT(1H1,9X,114A1/)                              000340
00272            WRITE(6,1000)(AX1(I),I=1,16)                       000340
00275       1000 FORMAT(1H+,9X,1HI,16F7.5,1HI/)                     000350
00276            WRITE(6,1100)                                      000350
00300       1100 FORMAT(1H+,9X,1HI,112X,1HI/)                       000355
00301            WRITE(6,1200)((GRAPH(I,J),I=1,114),J=2,46)          000355
00312       1200 FORMAT(1H+,9X,114A1/45(10X,114A1/))                000367
00313            WRITE(6,1300)(TD1(I),I=1,8)                        000367
00316       1300 FORMAT (1H+,9X,8(F13.5,1X)//)                      000377
00317            WRITE(6,1400) ISAMP,AV,SD                          000377
00324       1400 FORMAT(1H+,10X,14HHISTOGRAM FOR ,I7,8H SAMPLES,    000407
00324           19H   MEAN= ,F13.5,18H   STANDARD DEV.= ,F13.5/)   000407
00325            RETURN                                             000407
00326            END                                                000505
```

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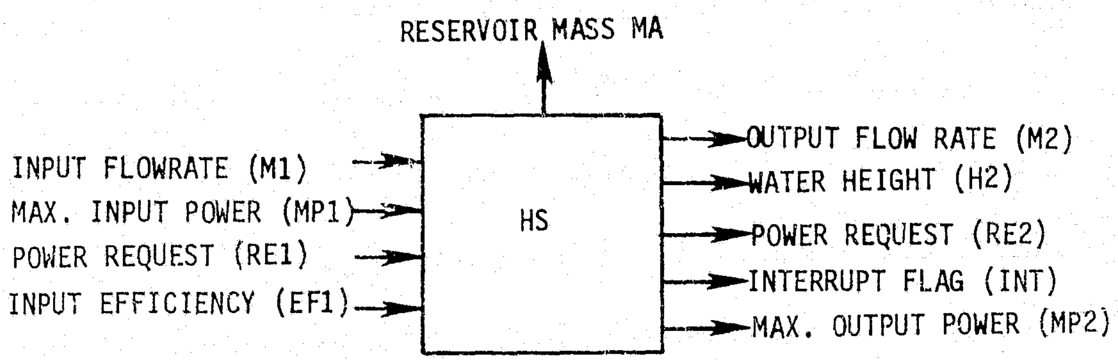
7.14 HYDRO STORAGE VESSEL



The hydro storage vessel is modeled as an above ground reservoir with a large and constant surface area. The change in reservoir height between maximum and minimum levels is assumed small in comparison to the height of the water above the turbine. Hence, reservoir height is assumed constant. The reservoir has specified evaporation and leakage rates. Average input flow gained by rainfall is also specified. Energy storage is calculated based on the potential energy of the water in the reservoir relative to the turbine inlet.

Basic Equation

$$MA = M1 - M2 - NE*AS - NL + MDR*AS/14052$$

HS

Inputs

Parameter/Port		Description	Units
M	1	Input water mass flow rate	gal/h
NE		Evaporation coefficient (D = 0.03)	gal/ft^2-h
AS		Reservoir surface area	ft^2
NL		Leakage coefficient (D = 8.0)	gal/h
MDR		Rainfall rate	inches/year
MDM		Maximum allowable mass flow rate (D = $4X10^5$)	gal/h
MM		Maximum allowable reservoir capacity (D=$5X10^6$)	gal
MØ		Minimum allowable reservoir capacity	gal
H	1	Reservoir height above turbine	ft
MDE		Reservoir deadband for priority resequence	gal
RE	1	Power request (discharge)	kw
CR		Reservoir cost coefficient (D = 0.025)	$/gal
EF	1	Input product efficiency	-
MP	1	Maximum input charging rate	kw
LE		Reservoir life expectancy	years
CM		Maintenance cost/year	$

Outputs

Variable/Port		Description	Units
M	2	Outlet water mass flow rate	gal/hr
E		Energy stored	kwh
H	2	Reservoir height above turbine (=H1)	ft
MA		Reservoir mass (state)	gal
CCØ		Reservoir cost/year	$
MP	2	Maximum discharge rate allowable	kw
INT		Priority interrupt flag	-
RE	2	Maximum charging rate request	kw

D - Default values supplied

Statistics	Description	Units
MDU	Maximum mass flow rate	gal/hr
MU	Maximum reservoir mass	gal
ML	Minimum reservoir mass	gal

The calculation sequence and default values assume a pond sized for 120kw storage for 24 hours (5×10^6 gallons of water 200 ft. above turbine inlet). The evaporation coefficient NE assures the pond drops ½" in height per 10 hours. To obtain a more accurate value for this parameter requires knowledge of local conditions. The leakage coefficient NL is based on the assumption of a loss of 0.1% of the maximum reservoir capacity in the rated storage time of 24 hours. The reservoir cost estimates are based on the compensation reservoir given in Reference 1.

---

1. "Preliminary Feasibility Evaluation of Compressed Air Storage Power Systems," United Technologies AER 74-00242, December 1976.

Calculation Sequence

C1 = conversion constant = $0.377 \times 10^{-6} \frac{kwh}{ft-lb}$

C2 = conversion constant = 8.3398 lb/gal

A = C1*C2*H1

1) Reservoir cost

CC = CR*MM/LE

2) Volume of water discharged

M2 = RE1/A

3) Reservoir water volume

$\dot{M}A$ = M1 - M2 - NE*AS-NL +(MDR*AS/14052.)

4) Energy stored

E = A*M

5) Checks

M1 > MDM or M2 > MDM ⇨ DIAGNOSTIC

M>MM, ⇨ DIAGNOSTIC

M<MØ ⇨ DIAGNOSTIC

6) Priority interrupt

If M≤MØ, INT = 1

IF M>MØ+MDE and INT=1, INT = 0

If M≥MM, INT = -1

If M<MM-DME and INT = -1, INT = 0

<u>Calculation Sequence Cont</u>.

7) Maximum charging rate request

$$MD1 = MIN\ (MDM,(MM-M)/TINC)$$

$$RE2 = MIN\ (MP1,MD1*A)/EF1$$

Maximum discharge rate

$$MP2 = A * MIN\ (MDM,(M-M\emptyset)/TINC)$$

where TINC = integration step size in hrs

8) Compute Statistics and Costs

```
SUBROUTINE HS          ENTRY POINT 000405

STORAGE USED  CODE(1) 000551; DATA(0) 000117; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000002
 0004    CTIME   000001
 0005    CSIMUL  000010
 0006    COST    000002

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    NWDU$
 0010    N102$
 0011    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000055 100L      0000    000005 1010F     0000    000030 1020F     0000    000045 1030F     0001    000144 200L
 0001    000171 300L      0001    000215 400L      0000 R 000004 A         0006 R 000000 CCI       0006 R 000001 CMI
 0000 R 000003 C1        0005 R 000000 DUM       0003 I 000001 ICNT      0003 I 000000 IMPL      0000    000076 INJP$
 0000 R 000001 MDM1      0000 R 000000 MD1       0004 R 000000 TIME      0005 R 000007 TMAX      0000 R 000002 TMAX1


00100      CHS                                                                             000000
00101            SUBROUTINE HS(M,DM,IM,M2,E,H2,CC,MP2,INT,RE2,MDU,MU,ML,M1,NE              000000
00101           1            ,AS,NL,MDR,MDM,MM,MO,H1,MDE,RE1,CR,EF1,MP1,LE,CH)             000000
00101      C                                                                               000000
00101      C   PURPOSE    PERFORMANCE OF A LARGE RESERVOIR AS AN ENERGY STORAGE            000000
00101      C                                                                               000000
00101      C              DEVICE.                                                          000000
00101      C                                                                               000000
00101      C   METHOD     ENERGY IN STORAGE IS CALCULATED FROM THE POTENTIAL               000000
00101      C                                                                               000000
00101      C              BETWEEN THE RESERVOIR AND THE TURBINE INLET.                     000000
00101      C                                                                               000000
00101      C   WRITTEN BY F. O. MAHONY                   VERSION 1, MARCH 30 1977          000000
00101      C                                                                               000000
00101      C   CALL SEQUENCE                                                               000000
00101      C          OUTPUTS                                                              000000
00101      C               M    - RESERVOIR MASS (STATE VARIABLE), GAL                     000000
00101      C               DM   - RESERVOIR MASS FLOWRATE, GAL/HR                          000000
00101      C               IM   - STATUS INDICATOR                                         000000
00101      C               M2   - OUTLET WATER MASS FLOW RATE, GAL/HR                      000000
00101      C               E    - ENERGY STORED, KWH                                       000000
00101      C               H2   - RESERVOIR HEIGHT ABOVE TURBINE (=H1), FT                 000000
00101      C               CC   - RESERVOIR COST/YEAR, $                                   000000
```

HS

```
00101      C              MP2 - MAXIMUM DISCHARGE RATE ALLOWABLE, KW                         000000
00101      C              INT - PRIORITY INTERUPT FLAG                                       000000
00101      C              RE2 - MAXIMUM CHARGING RATE REQUEST, KW                            000000
00101      C              MDU - MAXIMUM MASS FLOW RATE, GAL/HR                               000000
00101      C              MU  - MAXIMUM RESERVOIR MASS, GAL                                  000000
00101      C              ML  - MINIMUM RESERVOIR MASS, GAL                                  000000
00101      C                                                                                 000000
00101      C          INPUTS                                                                 000000
00101      C              MI  - INPUT WATER MASS FLOW RATE, GAL/HR                           000000
00101      C              NE  - EVAPORATION COEFFICIENT, GAL/FT**2-HR                        000000
00101      C              AS  - RESERVOIR SURFACE AREA, FT**2                                000000
00101      C              NL  - LEAKAGE COEFFICIENT                                          000000
00101      C              MDR - RAINFALL RATE, INCHES/YEAR                                   000000
00101      C              MDM - MAXIMUM ALLOWABLF MASS FLOW RATE, GAL/HR                     000000
00101      C              MM  - MAXIMUM ALLOWABLE RESERVOIR CAPACITY, GAL                    000000
00101      C              MO  - MINIMUM ALLOWABLE RESERVOIR CAPACITY, GAL                    000000
00101      C              HI  - RESERVOIR HEIGHT ABOVE TURBINE, FT                           000000
00101      C              MDE - RESERVOIR DEADBAND FOR PRIORITY RESEQUENCE, GAL              000000
00101      C              RE1 - POWER REQUEST (DISCHARGE), KW                                000000
00101      C              CR  - RESERVOIR COST COEFFICIENT                                   000000
00101      C              EF1 - INPUT PRODUCT EFFICIENCY                                     000000
00101      C              MP1 - MAXIMUM INPUT CHARGING RATE, KW                              000000
00101      C              LE  - RESERVOIR LIFE EXPECTANCY, YEARS                             000000
00101      C              CM  - MAINTENANCE COST/YEAR, $                                     000000
00101      C                                                                                 000000
00103            COMMON/CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX                        000000
00104            COMMON/COST/CCI,CMI                                                         000000
00105            REAL M2,MP2,MDU,MU,ML,MI,NE,NL,MDR,MDM,MM,MO,MDE,MP1,LE,INT,M               000000
00106            REAL MD1,MDM1                                                               000000
00106      C                                                                                 000000
00107            IF(IMPL.GT.0)GO TO 100                                                      000000
00107      C                                                                                 000000
00111            RF1=0.0                                                                     000002
00112            H2=H1                                                                       000003
00113            TMAX1=TMAX*0.99999                                                          000005
00114            C1 = 3.1441E-6                                                              000010
00114      C                                                                                 000010
00115            INT=0.0                                                                     000012
00116            MDU=0.0                                                                     000013
00117            MU =0.0                                                                     000014
00120            ML =1.0E10                                                                  000015
00121            IF(NE .EQ. .99999)NE =0.03                                                  000017
00123            IF(NL .EQ. .99999)NL =8.0                                                   000024
00125            IF(MDM.EQ. .99999)MDM=4.0E5                                                 000031
00127            IF(MM .EQ. .99999)MM =5.0E6                                                 000036
00131            IF(CR .EQ. .99999)CR =0.025                                                 000043
00131      C                                                                                 000043
00131      C                                                                                 000043
00131      C                       RESERVOIR COST                                            000043
00131      C                                                                                 000043
00133            CC =CR*MM/LE                                                                000050
00133      C                                                                                 000050
00133      C                       VOLUME OF WATER DISCHARGED                                000050
00133      C                                                                                 000050
00134        100 A=C1*H1                                                                     000055
00135            M2 =RE1/A                                                                   000057
00135      C                                                                                 000057
```

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```
00135     C                    RESERVOIR MASS FLOW RATE                                  000057
00135     C                                                                              000057
00136           IF(IM.NE.0)DM=M1-M2-NE*AS-NL+MDR*AS/14052.0                              000062
00136     C                                                                              000062
00136     C                    ENERGY STORED                                             000062
00136     C                                                                              000062
00140           E =A*M                                                                   000077
00140     C                                                                              000077
00141           MDM1=MDM/.9999                                                           000102
00142           IF(M1.LT.MDM1.AND.                                                       000105
00142          1  M2.LT.MDM1)GO TO 200                                                   000105
00142     C                                                                              000105
00144           IF(IMPL.EQ.2)WRITE(6,1010)M1,M2,MDM                                      000122
00152           IF(IMPL.EQ.2) ICNT=ICNT+1                                                000135
00152     C                                                                              000135
00154       200 IF(M .LT.MM+MDE)GO TO 300                                                000144
00154     C                                                                              000144
00156           IF(IMPL.EQ.2)WRITE(6,1020)M,MM                                           000150
00163           IF(IMPL.EQ.2)ICNT=ICNT+1                                                 000162
00163     C                                                                              000162
00165       300 IF(M .GT.MO)GO TO 400                                                    000171
00165     C                                                                              000171
00167           IF(IMPL.EQ.2)WRITE(6,1030)M,MO                                           000174
00174           IF(IMPL.EQ.2) ICNT=ICNT+1                                                000206
00174     C                                                                              000206
00174     C                    PRIORITY INTERRUPT                                        000206
00174     C                                                                              000206
00176       400 IF(M .LE.MO)INT=1.0                                                      000215
00200           IF(M .GT.(MO+MDE).AND.                                                   000222
00200          1  INT.EQ.1.0)INT=0.0                                                     000222
00202           IF(M .GT.MM)INT=-1.0                                                     000241
00204           IF(M .LT.(MM-MDE).AND.                                                   000247
00204          1   INT.EQ.-1.0)INT=0.0                                                   000247
00204     C                                                                              000247
00204     C                    MAXIMUM CHARGE RATE REQUEST AND DISCHARGE RATE            000247
00204     C                                                                              000247
00206           MD1= AMIN1(MDM,AMAX1(0.,(MM-M)/DUM(7)))                                  000266
00207           RE2=AMIN1(MP1,MD1*A)/EF1                                                 000302
00210           MP2=AMIN1(MDM,AMAX1(0.,(M-MO)/DUM(7)))*A                                 000311
00210     C                                                                              000311
00211           IF(IMPL.LE.1)RETURN                                                      000326
00211     C                                                                              000326
00211     C                    STATISTICS                                                000326
00211     C                                                                              000326
00213           MDU=AMAX1(DM,MDU)                                                        000335
00214           MU =AMAX1(M ,MU )                                                        000343
00215           ML =AMIN1(M ,ML )                                                        000351
00215     C                                                                              000351
00216           IF(TIME.LT.TMAX1)RETURN                                                  000357
00216     C                                                                              000357
00220           CCI=CCI+CC                                                               000366
00221           CMI=CMI+CM                                                               000371
00221     C                                                                              000371
00222           RETURN                                                                   000374
00222     C                                                                              000374
00223      1010 FORMAT(1H0,23HHS INLET MASS FLOW RATE,F12.3, 5H  OR ,                    000550
00223          1              21HOULET MASS FLOW RATE,F12.3,                             000550
```

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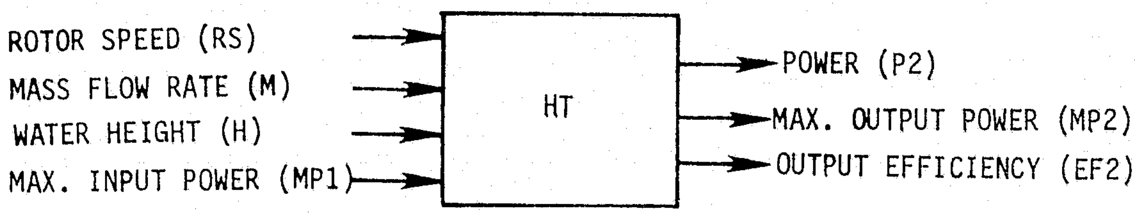
HS

```
00223          2            26H   IS GREATER THAN MAXIMUM,F12.3)                000550
00224      1020 FORMAT(1H0,19HHS RESERVOIR VOLUME,F12.3,                        C00550
00224          1            30H    EXCEEDED MAXIMUM ALLOWABLE,F12.3)            000550
00225      1030 FORMAT(1H0,19HHS RESERVOIR VOLUME,F12.3,                        000550
C0225          1            24H    DROPED BELOW MINIMUM,F12.3)                  000550
00225     C                                                                     C00550
C0226           END                                                             C00550
```

7.15 HYDRAULIC TURBINE



The hydraulic turbine model is based on a constant speed design and is typical of a reaction/Francis type turbine. The turbine is assumed to be designed to a specified operating point and output power.

For off design performance the pump efficiency is assumed to be functionally related to the first power of the mass flow rate. The equations are assumed to be valid over a specified range of values for the turbine parameter.

Basic Equations

$$P = EFF*M*C1*C2*H$$

$$EFF = 1-(1-EFD)*MD/M$$

where C1, C2 are conversion constants.

Inputs

Parameter/Port		Description	Units
M		Inlet mass flow rate	gal/h
H		Height of reservoir above turbine inlet	ft
EFD		Design pt. turbine efficiency (D = 0.90)	–
MD		Design pt. mass flow rate (D = $2X10^5$)	gal/h
MM		Maximum mass flow rate (D = $3X10^5$)	gal/h
EF	1	Input product efficiency	–
MP	1	Input maximum discharge rate	kw
CK		Turbine capacity cost coefficient[1] (D = 0.011)	–
FØ		Turbine exponent for cost calculations (D = 0.5)	–
RS		Angular velocity	rpm
X		Turbine head exponent for cost calculations (D = 0.25)	–

Outputs

Variable/Port		Description	Units
CCØ		Turbine cost/year	$
EFF		Turbine efficiency	–
P	2	Output power	kw
EF	2	Output product efficiency	–
MP	2	Output maximum discharge rate	kw
CP		Turbine characteristic parameter	–

Statistics

CPU	Maximum CP	–
CPL	Minimum CP	–
PU	Maximum output power	kw

D – Default values

[1] CK = Capital cost (known unit)/((MD*481.2)**FO*H**X*life expectancy)

HT

The calculation sequence and default values assume a constant speed reaction type hydraulic turbine nominally rated for 120kw and located 200 ft. below the reservoir. The equations relating the various physical parameters are assumed to be valid for the indicated range of the characteristic turbine parameter, CP. The equations and cost estimates are based on the data given in Reference 1, and the cost estimates on data from Reference 2.

Calculation Sequence

$$C1 = 0.377\times10^{-6}\ \frac{\text{kwh}}{\text{ft-lb}}$$

$$C2 = 8.3398\ \text{lb/gal}$$

$$A = C1*C2*H$$

1) Costs

CCØ = CK* (MD*481.2)**FØ*H**X

2) Efficiency

If $M \le 0$ set EFF = 1 and go to 3)

EFF = 1-(1-EFD)*MD/M

EFF = MAX(EFF, 0.6)

---

1. L. Marks and T. Baumeister, "Mechanical Engineers Handbook", McGraw Hill, N.Y., 1958, Section 9, p. 207.

2. Carson and Fogleman, "Comparison of Methods for Converting Existing Power Plants to Pumped Storage Facilities", International Engineering Company, Inc., 1974.

Calculation Sequence Cont.

3) Output Power

P2 = EFF*A*M

4) Product Efficiency

EF2 = EF1*EFF

EFM = MM -(1-EFD)*MD

5) Maximum Discharge Rate

MP2 = Min{ MP1*EFD, EFM*A}

6) Turbine Characteristic Parameter

(If P2 ≤ 0 go to 7)

CP = RS*SQRT (P2*0.746)/H**1.25

If CP>100 write DIAGNOSTIC

If M> MM write DIAGNOSTIC

7) Compute Statistics and Costs

SUBROUTINE HT   ENTRY POINT 000305

STORAGE USED CODE(1) 000430; DATA(0) 000075; BLANK COMMON(2) 000000

COMMON BLOCKS

```
0003   CIMPL   000002
0004   CTIME   000001
0005   CSIMUL  000010
0006   COST    000001
```

EXTERNAL REFERENCES (BLOCK, NAME)

```
0007   XPRR
0010   SQRT
0011   NWDU$
0012   NI02$
0013   NERR3$
```

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

```
0001     000073 100L      0000     000003 1010F     0000     000016 1020F     0001     000205 200L      0001     000231 300L
0001     000113 400L      0006 R 000000 CCI       0000 R 000001 CI        0005     000000 DUM       0000 R 000002 EFM
0003 I 000001 ICNT      0003 I 000000 IMPL      0000     000057 INJP$     0004 R 000000 TIME      0005 R 000007 TMAX
0000 R 000000 TMAX1
```

```
00100      CHT                                                                        000000
00101            SUBROUTINE HT(CC,EFF,P,EF2,MP2,CP,CPU,CPL,PU,H,H,EFD,MD,MM           000000
00101           1              ,EF1,MP1,CK,FO,RS,X)                                   000000
00101      C                                                                          000000
00101      C   PURPOSE     PERFORMANCE OF A HYDRAULIC TURBINE                             000000
00101      C                                                                          000000
00101      C   METHOD      OFF DESIGN PERFORMANCE IS ASSUMED PROPORTIONAL TO              000000
00101      C                                                                          000000
00101      C               MASS FLOW RATE                                                 000000
00101      C                                                                          000000
00101      C      WRITTEN BY F. O. MAHONY                  VERSION 1, MARCH 30 1977       000000
00101      C                                                                          000000
00101      C   CALL SEQUENCE                                                              000000
00101      C         OUTPUTS                                                              000000
00101      C              CC  - TURBINE COST/YEAR, $                                      000000
00101      C              EFF - TURBINE EFFICIENCY                                        000000
00101      C              P   - OUTPUT POWER, KW                                          000000
00101      C              EF2 - OUTPUT PRODUCT EFFICIENCY                                 000000
00101      C              MP2 - OUTPUT MAXIMUM DISCHARGE RATE, KW                         000000
00101      C              CP  - TURBINE CHARACTERISTIC PARAMETER                          000000
00101      C              CPU - MAXIMUM CP                                                000000
```

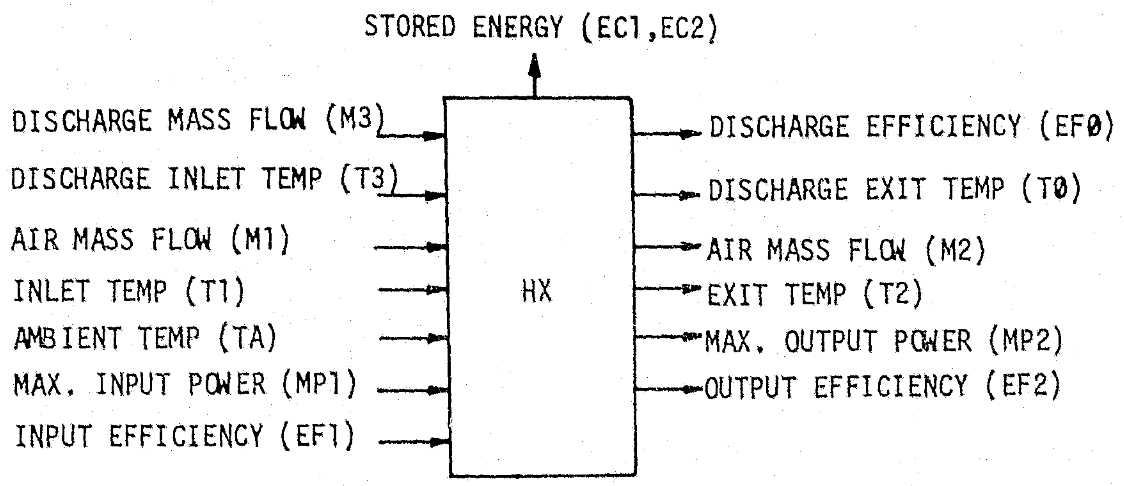
HT

```
00101   C              CPL - MINIMUM CP                                          000000
00101   C              PU  - MAXIMUM OUTPUT POWER, KW                            000000
00101   C                                                                        000000
00101   C          INPUTS                                                        000000
00101   C              M   - INLET MASS FLOW RATE, GAL/HR                        000000
00101   C              H   - HEIGHT OF RESERVOIR ABOVE TURBINE INLET, FT         000000
00101   C              EFD - DESIGN POINT TURBINE EFFICIENCY                     000000
00101   C              MD  - DESIGN POINT MASS FLOW RATE, GAL/HR                 000000
00101   C              MM  - MAXIMUM MASS FLOW RATE, GAL/HR                      000000
00101   C              EF1 - INPUT PRODUCT EFFICIENCY                            000000
00101   C              MP1 - INPUT MAXIMUM DISCHARGE RATE                        000000
00101   C              CK  - TURBINE CAPACITY COST COEFFICIENT                   000000
00101   C              FO  - TURBINE EXPONENT FOR COST CALCULATIONS              000000
00101   C              RS  - ANGULAR VELOCITY, RPM                               000000
00101   C              X   - TURBINE HEAD EXPONENT FOR COST CALCULATIONS         000000
00101   C                                                                        000000
00103         COMMON/CIMPL/IMPL,ICNT/CTIME/TIME /CSIMUL/DUM(7),TMAX /COST/ CCI   000000
00104         REAL MP2,M,MD,MM,MP1                                               000000
00104   C                                                                        000000
00105         IF(IMPL.GT.0)GO TO 100                                             000000
00105   C                                                                        000000
00107         TMAX1=TMAX*0.99999                                                 000002
00110         RS =3600.0                                                         000005
00110   C                                                                        000005
00111         IF(EFD.EQ. .99999)EFD=0.9                                          000007
00113         IF(MD .EQ. .99999)MD =2.0E5                                        000014
00115         IF(MM .EQ. .99999)MM =3.0E5                                        000021
00117         IF(CK .EQ. .99999)CK =0.011                                        000026
00121         IF(FO .EQ. .99999)FO =0.5                                          000033
00123         IF(X  .EQ. .99999)X  =0.25                                         000040
00123   C                                                                        000040
00125         CPL=1.0E10                                                         000045
00126         CPU=0.0                                                            000047
00127         PU =0.0                                                            000050
00127   C                                                                        000050
00130         C1 = 3.1441E-6                                                     000051
00131         CC =CK*(MD*481.2)**FO*H**X                                         000053
00131   C                                                                        000053
00131   C                     EFFICIENCY                                         000053
00132     100 EFF =1.0                                                           000073
00132   C                                                                        000073
00133         IF(M.LE.0.0)GO TO 400                                              000074
00133   C                                                                        000074
00135         EFF=1.0-(1.0-EFD)*MD/M                                             000077
00136         IF(EFF.LT.0.6) EFF=0.6                                             000104
00136   C                                                                        000104
00136   C                     OUTPUT POWER                                       000104
00136   C                                                                        000104
00140     400 P  =EFF*M*H*C1                                                     000113
00140   C                                                                        000113
00140   C                     PRODUCT EFFICIENCY                                 000113
00140   C                                                                        000113
00141         EF2=EF1*EFF                                                        000117
00141   C                                                                        000117
00141   C                     MAXIMUM DISCHARGE RATE                             000117
00141   C                                                                        000117
00142         EFM =MM*.9999-(1.0-EFD)*MD                                         000122
```

```
00142    C                                                                            000122
00143         MP2=AMIN1(MP1*EFD,EFM*H*C1)                                             000131
00143    C                                                                            000131
00143    C                     TURBINE CHARACTERISTIC PARAMETER                       000131
00143    C                                                                            000131
00144         IF(P .LE. 0.0) GO TO 300                                                000142
00146         CP =RS*SQRT(P*0.746)/H**1.25                                            000144
00146    C                                                                            000144
00147         IF(CP.LT.100.0)GO TO 200                                                000162
00147    C                                                                            000162
00151         IF(IMPL.EQ.2)WRITE(6,1010)CP                                            000165
00155         IF(IMPL.EQ.2) ICNT=ICNT+1                                               000176
00155    C                                                                            000176
00157     200 IF(M.LT.MM)GO TO 300                                                    000205
00157    C                                                                            000205
00161         IF(IMPL.EQ.2)WRITE(6,1020)M,MM                                          000210
00166         IF(IMPL.EQ.2) ICNT=ICNT+1                                               000222
00166    C                                                                            000222
00170     300 IF(IMPL.LE.1)RETURN                                                     000231
00170    C                                                                            000231
00170    C                     STATISTICS                                             000231
00170    C                                                                            000231
00172         CPU=AMAX1(CPU,CP)                                                       000237
00173         CPL=AMIN1(CPL,CP)                                                       000245
00174         PU =AMAX1(PU ,P )                                                       000253
00174    C                                                                            000253
00175         IF(TIME.LT.TMAX1)RETURN                                                 000261
00175    C                                                                            000261
00175    C                     COST                                                   000261
00175    C                                                                            000261
00177         CCI=CCI+CC                                                              000270
00177    C                                                                            000270
00200         RETURN                                                                  000273
00200    C                                                                            000273
00201    1010 FORMAT(1H0,48HHT TURBINE CHARACTERISTIC PARAMETER OUT OF RANGE          000427
00201        1 F12.3)                                                                 000427
00202    1020 FORMAT(1H0,23HHT INLET MASS FLOW RATE,F12.3                             000427
00202        1            ,37H    GREATER THAN MAXIMUM DESIGN VALUE,F12.3)            000427
00202    C                                                                            000427
00203         END                                                                     000427
```

HT

7.16 ADIABATIC HEAT EXCHANGER



The purpose of the adiabatic heat exchanger is to recover a portion of the heat of compression from the high pressure, high temperature air exiting from the compressor. Figure 7.16-1 shows an adiabatic heat exchanger used in an underground, constant pressure compressed air energy storage system. The adiabatic heat exchanger operates in a manner similar to the high temperature thermal energy storage systems currently conceived for solar thermal power plants[1]. In the storage charging mode, high pressure, high temperature air enters the top of the heat exchanger and deposits a portion of its thermal energy in the storage media as either sensible heat or latent heat of fusion. The exiting high pressure air is stored in an appropriate vessel, e.g., underground cavern. In the discharge cycle (HY), high pressure, low temperature air enters the bottom of the heat exchanger, recovers thermal energy from the storage media and exits to the turbine.

The adiabatic heat exchanger model is based on a two cell storage model. Given the stored energy in both cells, a linear temperature profile is computed

[1] BEC/EPRI RP 788-1, "Advanced Thermal Energy Storage Systems," November 1976.

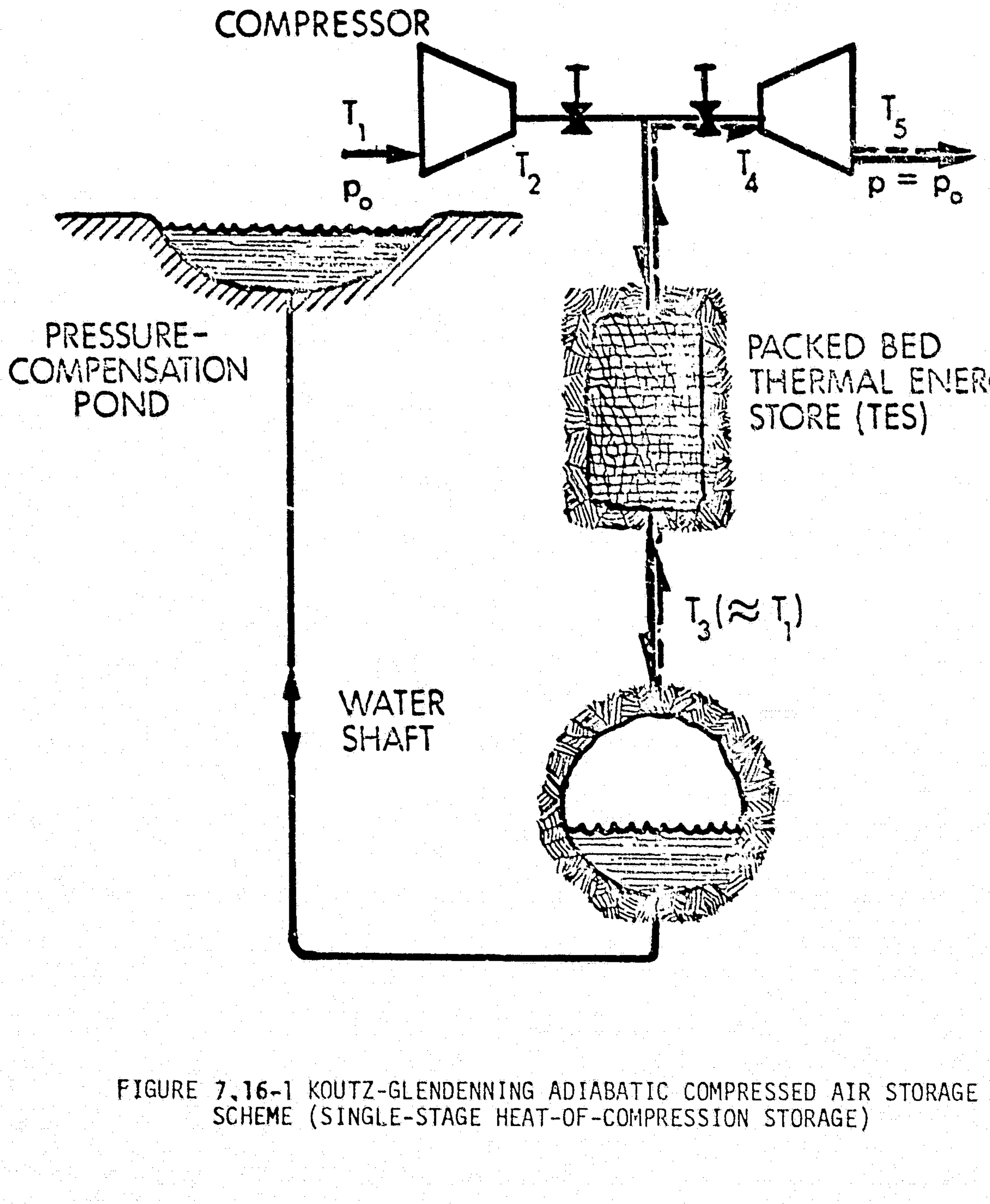


FIGURE 7.16-1 KOUTZ-GLENDENNING ADIABATIC COMPRESSED AIR STORAGE SCHEME (SINGLE-STAGE HEAT-OF-COMPRESSION STORAGE)

for the media mass. Based on a given inlet mass flow rate, the convective film coefficient, unit thermal conductance, and heat exchanger exit temperature are calculated.

The rate of energy deposited (or withdrawn) is calculated and integrated to yield the stored energy state. For a phase change media, the temperature profile is approximated in the following way: Average cell temperatures TS1 and TS2 are determined from the enthalpy diagram (Figure 7.16-2) using average cell entropy EC1/MA and EC2/MA, respectively. Then a linear temperature profile is constructed as shown in Figure 7.16-3.

Basic Equations

$$\dot{EC1} = PX - PY - NU * EC1 - BE * (EC1 - EC2)$$

$$\dot{EC2} = (P2 - PX) - (P0 - PY) - NU*EC2 + BE * (EC1 - EC2)$$

where

EC1, EC2 = storage power in cells 1 and 2, respectively

PX = charging power in cell 1

PY = discharging power in cell 1

P2 - PX = charging power in cell 2

P0 - PY = discharging power in cell 2

NU = storage media leakage constant

BE = storage media mixing constant

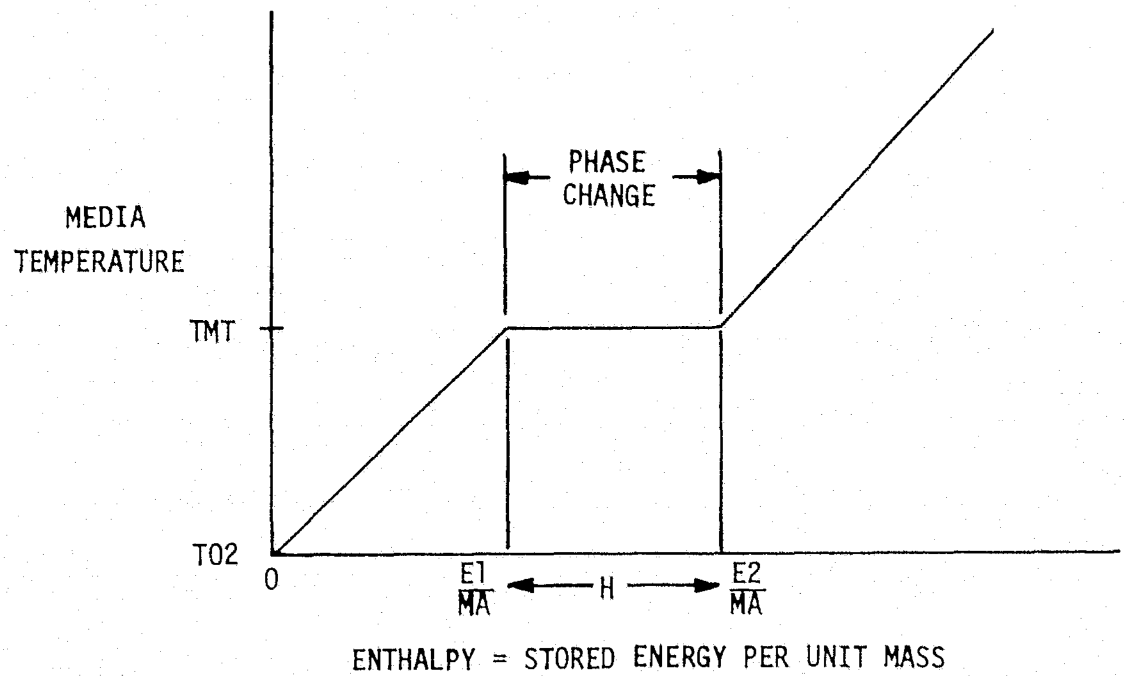


FIGURE 7.16-2: ENTHALPY-TEMPERATURE DIAGRAM FOR HX

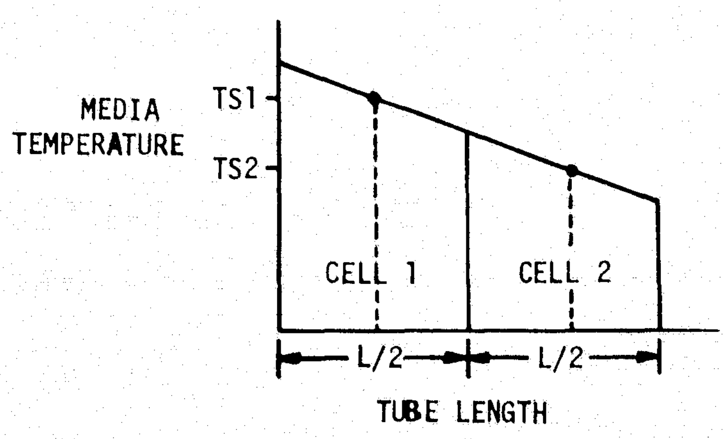


FIGURE 7.16-3: STORAGE TEMPERATURE VERSUS TUBE LENGTH

HX

Inputs

Parameter/Port		Description	Units
NU		Storage energy loss coefficient (D = 0.002)	$(h)^{-1}$
ST		Rated storage time[1]	h
BE		Storage energy mixing coefficient (D = 0.0)	h^{-1}
TØ1		Minimum allowable storage temperature (D = 60)	°F
DTD		Media temperature swing[1] (D = 400)	°F
PD		Rated storage thermal power	kw
TEM		Maximum allowable exit temperature (D = 240)	°F
XD		Design point fraction of molten media mass (D = 0.8)	-
EF	1	Input product efficiency	-
MP	1	Maximum input charging rate	kw
CP1		Storage media heat capacity (D = $2.93X10^{-4}$)	kwh/lb °F
H		Storage media heat of fusion[2] (D = 0.0219)	kwh/lb
TMT		Storage media melt temperature[2] (D = 147)	°F
CPF		Air heat capacity (D = $7.6X10^{-5}$)	kwh/lb°F
KF		Air thermal conductivity (D = $1.03X10^{-4}$)	kw/ft°F
MU		Air viscosity (D = 0.055)	lb/ft-h
NT		Number of tubes (D = 200)	-
D		Tube diameter (D = 0.03)	ft
L		Tube length (D = 4)	ft
DEL		Tube half spacing (D = 0.085)	ft
K		Storage media thermal conductivity (D = 0.0078)	kw/ft-°F
T	1	Inlet air temperature	°F
M	1	Inlet mass flow rate	lb/h
CM		Storage device yearly maintenance cost (D = 0.6)	$/kw
CSA		Storage device capacity cost (D = 50)	$/kw
CSB		Storage device energy cost (D = 15.6)	$/kwh
LE		Unit life expectancy	years

D - Default values specified
1 - Design point conditions
2 - Used for phase change media, H = 0 for sensible heat

Inputs

Parameter/Port		Description	Units
M	3	Discharge cycle mass flow rate from storage	lb/hr
T	3	Discharge cycle temperature from storage	^oF
TA		Ambient temperature	^oF
TSØ		Storage vessel minimum temperature	^oF

Outputs

Variable/Port		Description	Units
EC1		Stored energy (state) for cell 1 (hot side)	kwh
EC2		Stored energy (state) for cell 2 (cold side)	kwh
M	2	Outlet mass flow rate (=M1)	lb/hr
MP	2	Maximum discharge rate	kw
TS1,TS2		Average temperatures for cells 1 and 2	^oF
T	2	Air exit temperature	^oF
MA		Required storage media mass	lb
CCØ		Storage device capital cost/year	$
HF		Convective heat transfer coefficient	kwh/ft^2-^oF
U		Unit thermal conductance	kwh/ft^2-^oF
P	2	Charge rate into heat exchanger	kw
E1,E2		Energy stored at start and end of melt	kwh
PM		Maximum allowable charge rate	kw
EF	2	Output product efficiency	–
RT		Thermal resistance	$^oF/kw$
PØ		Discharge power taken from heat exchanger	kw
TØ		Discharge cycle output temperature	^oF
EFØ		Discharge cycle efficiency	–

Statistics

TSU	Maximum storage temperature	^oF
TSL	Minimum storage temperature	^oF
ME	Maximum stored energy	kwh
MT	Maximum exit temperature	^oF

The default values assume use of paraffin wax as the phase change storage medium. (In reality, paraffin wax may not be applicable to temperatures as high as 600°F. The selection of a phase change medium involves careful consideration of a number of factors [see Reference 1]). The heat exchanger geometric parameters, i.e., tube number, diameter, etc., and heat exchanger cost estimates are based on the baseline phase change storage device developed in Reference 1, but scaled down to reflect expected mass flow rates and required media mass. Although these data were developed for a different application (50 MWe, 6 hour storage, average temperature = 786°C), they can be considered representative until detail design data is available.

1. "Advanced Thermal Energy Storage," BEC/EPRI RP 788-1, July 1976.

Calculation Sequence

1) Initial Calculations

$$MA = \frac{PD*ST*0.5}{XD*H+CP1*DTD}$$

CC0 = (CSA+CSB*ST)*PD/LE

E1 = MA*CP1*(TMT-T01)

E2 = MA*[H+CP1*(TMT-T01)]

T3 = TS0=TA

A = (D*DEL+DEL**2)/5.

RB(1) = D/2, RB(I+1) = SQRT(RB(I)**2+A)   I=1,5

RN(I) = SQRT((RB(I+1)**2+RB(I)**2)/2)

$$RT = \frac{D}{2*K} \sum_{I=1}^{4} LN\left(\frac{RN(I+1)}{RN(I)}\right)$$

2) Storage Temperature (see Figure 7.16-2)

$$TS = \begin{cases} T01 + \dfrac{E}{MA*CP1} & \text{if } E < E_1 \\ TMT & \text{if } E_1 \le E \le E_2 \\ T01 + \dfrac{\left(\dfrac{E}{MA} - H\right)}{CP1} & \text{if } E > E_2 \end{cases}$$

where TS = TS1 and E = EC1 for storage cell 1 and similarly for cell 2.

3) HX Exit Temperature Calculations

M2 = M1

P2 = 0

PX = 0

3) Cont.

T2 = TS2 - (TS1-TS2)/2

ΔT = TS1-TS2

If M1 = 0, GO TO 7)

4) Convective Heat Transfer Coefficient[1]

$$HF = \frac{KF}{D}\left[0.0215 * \left(\frac{M1}{NT} * \frac{4}{MU*PI*D}\right)^{0.8} * \left(\frac{CPF*MU}{KF}\right)^{0.6}\right]$$

5) Thermal Conductance

$$U = \left\{\frac{1}{HF} + RT\right\}^{-1}$$

UA = U*PI*D*L*NT/(CPF*M1*2)

6) Exit Temperature and Charge Rate (See Equation A2. in Appendix)

TX = T1 - ΔT -(1. - EXP(-UA))*(T1 - TS1 - ΔT/2 - ΔT/UA)

T2 = TX - ΔT - (1.-EXP(-UA))*(TX - (TS1+TS2)/2-ΔT/UA)

P2 = M1*CPF*(T1-T2)

PX = M1*CPF*(T1-TX)

7) HY Exit Temperature Calculations

TØ = TS1 + ΔT/2

PØ = 0.

PY = 0.

If M3 = 0 GO TO 11)

---

[1] Kays, W. M., Convective Heat and Mass Transfer, McGraw Hill, N.Y., 1966, p. 173.

8) Convective Heat Transfer Coefficient

$$HF\emptyset = \frac{KF}{D}\left(.0215 * \left(\frac{M3}{NT} * \frac{4}{MU*PI*D} \right)^{0.8} * \left(\frac{CPF*MU}{KF} \right)^{0.6} \right)$$

9) Thermal Conductance

$$U\emptyset = \left(\frac{1}{HF\emptyset} + RT \right)^{-1}$$

$$UA = U\emptyset*PI*D*L*NT/(CPF*M3*2)$$

10) Exit Temperature and Discharge Rate (See Equation A3. in Appendix)

$$TY = T3 + \Delta T - (1.-EXP(-UA))*(T3 - TS2 + \Delta T/2 + \Delta T/UA)$$

$$T\emptyset = TY + \Delta T - (1.-EXP(-UA))*(TY - (TS1 + TS2)/2 + \Delta T/UA)$$

$$P\emptyset = M3*CPF*(T\emptyset-T3)$$

$$PY = M3*CPF*(T\emptyset-TY)$$

11) Energy Deposited

$$\dot{EC1} = PX - NU * EC1 - PY - BE * (EC1 - EC2)$$

$$\dot{EC2} = (P2-PX) - NU * EC2 - (P\emptyset - PY) + BE* (EC1 - EC2)$$

If T2 ≥ TEM, WRITE DIAGNOSTIC

12) Maximum Allowable Mass Flow Rate

$$MDM = PD/(CPF*DTD)$$

13) Maximum Allowable Charge Rate

$$PM = MDM * CPF * (T1-TA)$$

14) Charging and Discharging Efficiency

$$EFF = 1$$

If $T2 > TS\emptyset$ $\quad EFF = \frac{T2 - TS\emptyset}{T1 - TA}$

$$EF\emptyset = 1$$

If $T3 > TS\emptyset$ $\quad EF\emptyset = \frac{T\emptyset - TA}{T3 - TS\emptyset}$

$$MP2 = MIN\ (MP1,\ PM) * EFF$$

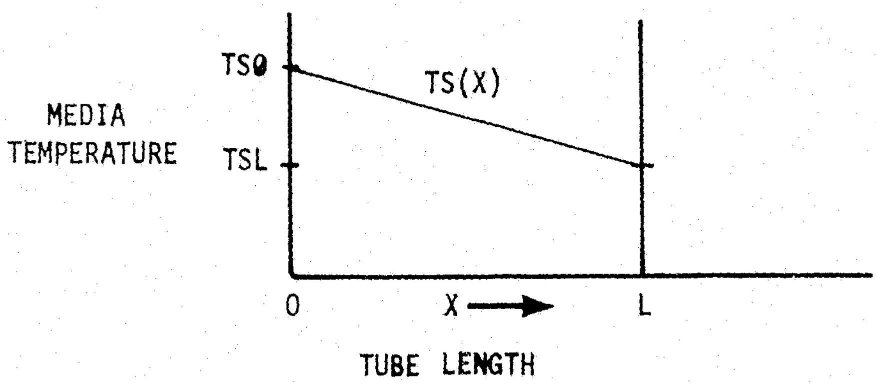
$$EF2 = EF1 * EFF$$

15) Compute Statistics and Cost Summation

Appendix: Temperature Equations for a Media with Constant Gradient

Assumptions

1) Constant Gradient Media Temperature:



2) Working Fluid Differential Equation:

A1. $$\frac{\partial Tf}{\partial X} = \frac{UA}{L}(TS - Tf) \qquad 0 < x < L$$

Main Results: Exit temperature in the charging and discharging cycles are given by

A2. $$Tf(L) = Tf(0) + \Delta TS - (1-\exp(-UA))*\left(Tf(0)-TS\emptyset + \frac{\Delta TS}{UA}\right)$$

A3. $$Tf(0) = Tf(L) - \Delta TS - (1-\exp(-UA))*\left(Tf(L)-TSL - \frac{\Delta TS}{US}\right)$$

where $\Delta TS = TSL - TS\emptyset$.

Proof: Multiplying A1. by exp(UA·X/L) and recombining terms yields:

A4. $$\frac{\partial}{\partial X}\left(\exp(UA*X/L)*Tf\right) = \frac{UA}{L}*\exp(UA*X/L)*TS(X).$$

Integrating A4. and subsituting $TS(X) = TS\emptyset + \frac{\Delta TS}{L} * X$ yields

A5. $$Tf(X) = \exp(-UA*X/L)*Tf(0) + \frac{UA}{L}\int_0^X \exp(-UA(x-y)/L)*TS(y)dy$$

$$= \exp(-UA*X/L)Tf(0) + (1-\exp(-UA*X/L))*(TS\emptyset - \Delta TS/UA)$$

$$+ \frac{\Delta TS}{L} * X$$

Recombining terms in A5. and letting X=L yields A2. Equation A3. follows from A2. by symmetry, i.e., substitute in A2:

Tf(0) for Tf(L)

Tf(L) for Tf(0)

TSL for TSØ

TSØ for TSL.

```
SUBROUTINE HX          ENTRY POINT 001065

STORAGE USED  CODE(1) 001517; DATA(0) 000143; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000002
 0004    CTIME   000001
 0005    CSIMUL  000010
 0006    COST    000002

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    SQRT
 0010    ALOG
 0011    XPRR
 0012    EXP
 0013    NWDU$
 0014    NI02$
 0015    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000301 100L       0000     000034 1010F      0001     000514 200L       0001     000236 205G       0001     000264 214G
 0001     000637 300L       0001     000714 500L       0000 R 000016 A          0006 R 000000 CCI        0006 R 000001 CMI
 0000 R 000020 DELT       0005     000000 DUM        0000 R 000033 EFF        0000 R 000030 HFO        0000 I 000017 I
 0003 I 000001 ICNT       0003 I 000000 IMPL       0000     000107 INJP$      0000 R 000000 MDM        0000 R 000014 PI
 0000 R 000023 PX         0000 R 000027 PY         0000 R 000001 RB         0000 R 000007 RN         0000 R 000025 TEMP
 0004 R 000000 TIME       0005 R 000007 TMAX       0000 R 000015 TMAX1      0000 R 000022 TSC        0000 R 000021 TSH
 0000 R 000026 TX         0000 R 000032 TY         0000 R 000024 UA         0000 R 000031 UO


00100        1*      CHX                                                                                      000000
00101        2*             SUBROUTINE HX(EC1,DE1,IE1,EC2,DE2,IE2,M2,MP2,TS1,TS2,T2,MA,                       000000
00101        3*            1CC,HF,U,P,E1,E2,PM,EF2,PO,TO,EFO,R,TSU,TSL,ME,MT,NU,ST,BE,TO1,DTD                000000
00101        4*            2          ,PD,TEM,XD,EF1,MP1,CP1,H,TMT,CPF,KF,MU,NT,D,L,DEL,K,T1                  000000
00101        5*            3             ,M1,CM,CSA,CSB,LE,M3,T3,TA,TSO)                                      000000
00101        6*      C                                                                                        000000
00101        7*      C     PURPOSE   PERFORMANCE OF ADIABATIC HEAT EXCHANGER DURING CHARGE                    000000
00101        8*      C                                                                                        000000
00101        9*      C               CYCLE                                                                    000000
00101       10*      C                                                                                        000000
00101       11*      C    METHOD     HEAT STORAGE MEDIA ASSUMED TO CONTAIN NO TEMPERATURE                     000000
00101       12*      C                                                                                        000000
00101       13*      C               GRADIENTS. ENERGY DEPOSITED IS A FUNCTION OF TEMPERATURE                 000000
00101       14*      C                                                                                        000000
00101       15*      C               AND THERMAL CONDUCTANCE                                                  000000
00101       16*      C                                                                                        000000
```

```
00101   C   WRITTEN BF F. O. MAHONY                  VERSION 2, JUNE 1977               000000
00101   C                                                                                000000
00101   C   CALL SEQUENCE                                                                000000
00101   C         OUTPUTS                                                                000000
00101   C              EC1 - STORED ENERGY (STATE ) FOR STORAGE CELL 1, KWH               000000
00101   C              DE1 - ENERGY RATE FOR EC1, KW                                      000000
00101   C              IE1 - STATUS INDICATOR FOR EC1                                     000000
00101   C              EC2 - STORED ENERGY STATE FOR STORAGE CELL 2, KWH                  000000
00101   C              DE2 - ENERGY RATE FOR EC2, KW                                      000000
00101   C              IE2 - STATUS INDICATOR FOR EC2                                     000000
00101   C              M2  - OUTLET MASS FLOW RATE, LB/HR                                 000000
00101   C              MP2 - MAXIMUM DISCHARGE RATE ALLOWABLE, KW                         000000
00101   C              TS1 - STORAGE TEMPERATURE IN CELL 1, DEG F                         000000
00101   C              TS2 - STORAGE TEMPERATURE IN CELL 2, DEG F                         000000
00101   C              T2  - AIR EXIT TEMPERATURE, DEG F                                  000000
00101   C              MA  - REQUIRED STORAGE MEDIA MASS  LB                              000000
00101   C              CC  - STORAGE DEVICE CAPITAL COST/YEAR, $                          000000
00101   C              HF  - CONVECTIVE HEAT TRANSFER COEFFICIENT, KWH/FT2-F              000000
00101   C              U   - UNIT THERMAL CONDUCTANCE, KWH/FT2-F                          000000
00101   C              P   - CHARGE RATE OF HEAT EXCHANGER                                000000
00101   C              E1  - ENERGY STORED AT STAPT OF MELT PHASE, KWH                    000000
00101   C              E2  - ENERGY STORED AT END OF MELT PHASE, KWH                      000000
00101   C              PM  - MAXIMUM ALLOWABLE CHARGE RATE, KW                            000000
00101   C              EF2 - OUTPUT PRODUCT EFFICIENCY                                    000000
00101   C              PO  - DISCHARGE POWER TAKEN FROM HEAT EXCHANGER, KW                000000
00101   C              TO  - DISCHARGE CYCLE OUTPUT TEMPERATURE, DEG F                    000000
00101   C              EFO - DISCHARGE CYCLE EFFICIENCY                                   000000
00101   C              R   - THERMAL RESISTANCE, DEG F/KW                                 000000
00101   C                                                                                000000
00101   C         STATISTICS                                                             000000
00101   C              TSU - MAXIMUM STORAGE TEMPERATURE, DEG F                           000000
00101   C              TSL - MINIMUM STORAGE TEMPERATURE, DEG F                           000000
00101   C              ME  - MAXIMUM STORED ENERGY, KWH                                   000000
00101   C              MT  - MAXIMUM EXIT TEMPERATURE, DEG F                              000000
00101   C                                                                                000000
00101   C         INPUTS                                                                 000000
00101   C              NU  - STORAGE ENERGY LOSS COEFFICIENT                              000000
00101   C              ST  - RATED STORAGE TIME, HR                                       000000
00101   C              BE  - STORAGE ENERGY MIXING COEFFICIENT, 1/HR                      000000
00101   C              TO1 - MINIMUM ALLOWABLE STORAGE TEMPERATURE, DEG F                 000000
00101   C              DTD - MEDIA TEMPERATURE SWING, DEG F                               000000
00101   C              PD  - RATED THERMAL STORAGE POWER, KW                              000000
00101   C              TEM - MAXIMUM ALLOWABLE EXIT TEMPERATURE, DEG F                    000000
00101   C              XD  - DESIGN POINT FRACTION OF MOLTEN MEDIA MASS                   000000
00101   C              EF1 - INPUT PRODUCT EFFICIENCY                                     000000
00101   C              MP1 - MAXIMUM INPUT CHARGING RATE                                  000000
00101   C              CP1 - STORAGE MEDIA HEAT CAPACITY, KWH/LB-F                        000000
00101   C              H   - STORAGE MEDIA HEAT OF FUSION, KWH/LB                         000000
00101   C              TMT - STORAGE MEDIA MELT TEMPERATURE, DEG F                        000000
00101   C              CPF - AIR HEAT CAPACITY, KWH/LB-F                                  000000
00101   C              KF  - AIR THERMAL CONDUCTIVITY, KWH/FT-F                           000000
00101   C              MU  - AIR VISCOSITY, LB/FT-HR                                      000000
00101   C              NT  - NUMBER OF H/X TUBES                                          000000
00101   C              D   - TUBE DIAMETER, FT                                            000000
00101   C              L   - TUBE LENGTH, FT                                              000000
00101   C              DEL - TUBE HALF SPACING, FT                                        000000
00101   C              K   - STORAGE MEDIA THERMAL CONDUCTIVITY                           000000
```

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```
00101        C              T1   - INLET AIR TEMPERATURE, DEG F                               000000
00101        C              M1   - INLET MASS FLOW RATE, LB/HR                                000000
00101        C              CM   - STORAGE DEVICE YEARLY MAINTENANCE COST $/KW                000000
00101        C              CSA  - STORAGE DEVICE CAPACITY COST, $/KW                         000000
00101        C              CSB  - STORAGE DEVICE ENERGY COST, $/KWH                          000000
00101        C              LE   - UNIT LIFE EXPECTANCY, YEARS                                000000
00101        C              M3   - DISCHARGE CYCLE MASS FLOW RATE FROM CS, LB/HR              000000
00101        C              T3   - DISCHARGE CYCLE TEMPERATURE FROM CS, DEG F                 000000
00101        C              TA   - AMBIENT TEMPERATURE, DEG F                                 000000
00101        C              TSO  - STORAGE VESSEL MINIMUM TEMPERATURE FROM CS, DEG F          000000
00101        C                                                                            000000
00103              COMMON /CIMPL/IMPL,ICNT/CTIME/TIME /CSIMUL/DUM(7),TMAX                 000000
00104              COMMON /COST/ CCI,CMI                                                  000000
00105              REAL M3,MDM,NU,M2,MP2,MA,ME,MT,MP1,MU,NT,M1,LE,KF,K,L                  000000
00106              DIMENSION RB(6),RN(5)                                                  000000
00107              DATA PI/3.14159/                                                       000000
00107        C                                                                            000000
00111              IF(IMPL.GT.0)GO TO 100                                                 000000
00111        C                                                                            000000
00113              IF(NU .EQ. .99999)NU =0.002                                            000002
00115              IF(BE .EQ. .99999)BE = 0.0                                             000007
00117              IF(T01.EQ. .99999)T01=60.0                                             000013
00121              IF(DTO.EQ. .99999)DTO=400.0                                            000020
00123              IF(TEM.EQ. .99999)TEM=240.0                                            000025
00125              IF(CP1.EQ. .99999)CP1=2.93E-4                                          000032
00127              IF(H   .EQ. .99999)H  =2.188E-2                                        000037
00131              IF(XD .EQ. .99999)XD =0.8                                              000044
00133              IF(TMT.EQ. .99999)TMT=147.0                                            000051
00135              IF(CPF.EQ. .99999)CPF=7.6E-5                                           000056
00137              IF(KF .EQ. .99999)KF =1.03E-4                                          000066
00141              IF(MU .EQ. .99999)MU =0.055                                            000073
00143              IF(NT .EQ. .99999)NT =200.0                                            000100
00145              IF(D   .EQ. .99999)D  =3.0E-2                                          000105
00147              IF(L   .EQ. .99999)L  =4.0                                             000112
00151              IF(DEL.EQ. .99999)DEL=8.5E-2                                           000117
00153              IF(K   .EQ. .99999)K  =7.8E-3                                          000124
00155              IF(CM .EQ. .99999)CM =0.6                                              000131
00157              IF(CSA.EQ. .99999)CSA=50.0                                             000136
00161              IF(CSB.EQ. .99999)CSB=15.6                                             000143
00161        C                                                                            000143
00163              TSL=1.0E8                                                              000150
00164              PO=0.0                                                                 000152
00165              PM= 0.0                                                                000153
00166              TSU=0.0                                                                000154
00167              ME=0.0                                                                 000155
00170              MT=0.0                                                                 000156
00171              M3=0.0                                                                 000157
00172              T3=TA                                                                  000160
00173              TSO=TA                                                                 000162
00174              MA =PD*0.5*ST/(XD*H+CP1*DTO)                                           000163
00175              CC =(CSA+CSB*ST)*PD/LE                                                 000175
00176              CM= CM*PD                                                              000203
00177              E1 =MA*CP1*(TMT-T01)                                                   000206
00200              E2 =MA*(H+CP1*(TMT-T01))                                               000211
00201              TMAX1=TMAX*0.99999                                                     000216
00202              A   =(D*DEL+DEL**2)/5.0                                                000221
00202        C                                                                            000221
```

ORIGINAL PAGE IS
OF POOR QUALITY

HX

```
00202      C                   COMPUTE THERMAL RESISTANCE OF MEDIA              000221
00202      C                                                                    000221
00203            RB(1)=D/2.0                                                    000230
00203      C                                                                    000230
00204            DO 20 I=1,5                                                    000236
00207            RB(I+1)=SQRT(RB(I)**2+A)                                       000236
00210         20 RN(I)=SQRT((RB(I+1)**2+RB(I)**2)/2.0)                          000245
00210      C                                                                    000245
00212            R=0.0                                                          000260
00212      C                                                                    000260
00213            DO 30 I=1,4                                                    000264
00216         30 R=R+ALOG(RN(I+1)/RN(I))                                        000264
00216      C                                                                    000264
00220            R=R*D/2.0/K                                                    000274
00220      C                                                                    000274
00220      C                   STORAGE TEMPERATURES                             000274
00220      C                                                                    000274
00221        100 TS1=TMT                                                        000301
00221      C                                                                    000301
00222            IF(EC1.LT.E1) TS1= TO1+ EC1/(MA*CP1)                           000302
00224            IF(EC1.GT.E2) TS1= TO1+ (EC1/MA - H)/CP1                       000315
00226            TS2=TMT                                                        000327
00227            IF(EC2.LT.E1)TS2= TO1+ EC2/(MA*CP1)                            000331
00231            IF(EC2.GT.E2) TS2= TO1+ (EC2/MA - H)/CP1                       000341
00231      C                                                                    000341
00233            DELT= TS1 - TS2                                                000353
00234            TSH= TS1+ .5*DELT                                              000356
00235            TSC= TS2 - .5*DELT                                             000362
00235      C                                                                    000362
00236            T2= TSC                                                        000365
00237            M2=M1                                                          000366
00240            P =0.0                                                         000370
00241            PX=0.0                                                         000371
00242            U=1.0/R                                                        000372
00242      C                                                                    000372
00243            IF(M1.LT.0.001)GO TO 200                                       000375
00243      C                                                                    000375
00243      C                   CONVECTIVE HEAT TRANSFER COEFFICIENT             000375
00243      C                                                                    000375
00245            HF =KF/D*(0.0215*(M1/NT*4.0/MU/PI/D)**0.8*(CPF*MU/KF)**0.6)    000400
00245      C                                                                    000400
00245      C                   UNIT THERMAL CONDUCTANCE                         000400
00245      C                                                                    000400
00246            U = 1.0/(1.0/HF+R)                                             000432
00247            UA= U*PI*D*L*NT/(M1*CPF*2.)                                    000440
00250            TEMP= DELT/UA                                                  000452
00251            UA= 1. - EXP(-UA)                                              000455
00251      C                                                                    000455
00251      C                   EXIT TEMPERATURE                                 000455
00251      C                                                                    000455
00252            TX= T1 - DELT - UA*(T1-TSH-TEMP)                               000463
00253            T2= TX- DELT - UA*(TX-(TS1+TS2)*.5-TEMP)                       000473
00253      C                                                                    000473
00253      C                   CHARGE RATE                                      000473
00253      C                                                                    000473
00254            P =M1*CPF*(T1-T2)                                              000504
00255            PX = M1*CPF*(T1-TX)                                            000507
```


HX

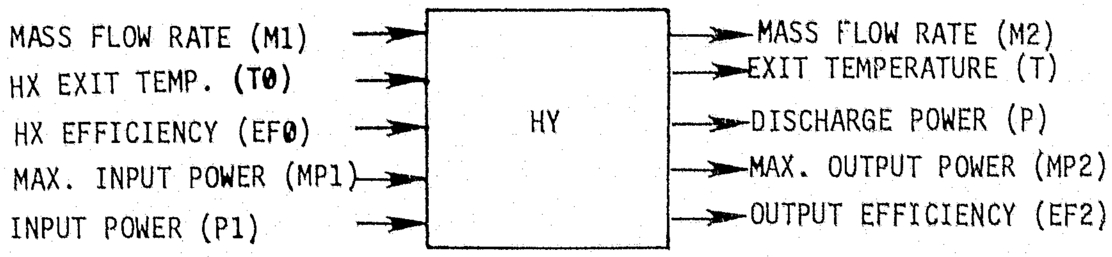
```
00255      C                                                                        000507
00255      C               HY EXIT TEMPERATURE CALCULATIONS                          000507
00255      C                                                                        000507
00256        200 TO = TSH                                                           000514
00257            PO =0.0                                                            000515
00260            PY=0.0                                                             000516
00261            IF(M3.LT. .001)GO TO 300                                           000517
00261      C                                                                        000517
00261      C               CONVECTIVE HEAT TRANSFER COEFFICIENT                      000517
00261      C                                                                        000517
00263            HFO =KF/D*(0.0215*(M3/NT*4.0/MU/PI/D)**0.8*(CPF*MU/KF)**0.6)       000523
00263      C                                                                        000523
00263      C               UNIT THERMAL CONDUCTANCE                                  000523
00263      C                                                                        000523
00264            UO=1.0/(1.0/HFO+R)                                                 000555
00265            UA= UO*PI*D*L*NT/(M3*CPF*2.)                                       000563
00266            TEMP= DELT/UA                                                      000575
00267            UA= EXP(-UA) - 1.                                                  000600
00267      C                                                                        000600
00267      C               EXIT TEMPERATURE AND DISCHARGE RATE                       000600
00267      C                                                                        000600
00270            TY= T3+ DELT+ UA*(T3-TSC+TEMP)                                     000606
00271            TO= TY+ DELT + UA*(TY-(TS1+TS2)*.5+TEMP)                           000616
00272            PO =M3*CPF*(TO-T3)                                                 000627
00273            PY= M3*CPF*(TO-TY)                                                 000632
00273      C                                                                        000632
00273      C               ENERGY DEPOSITED                                          000632
00273      C                                                                        000632
00273      C                                                                        000632
00274        300 IF(IE1.NE.0) DE1= PX- PY -NU*EC1 -BE*(EC1-EC2)                     000637
00276            IF(IE2.NE.0) DE2= P-PX - (PO-PY) -NU*EC2 +BE*(EC1-EC2)             000653
00276      C                                                                        000653
00300            IF (T2.LT.TEM) GO TO 500                                           000667
00300      C                                                                        000667
00302            IF(IMPL.EQ.2)WRITE(6,1010)T2,TEM                                   000673
00307            IF(IMPL.EQ.2)ICNT=ICNT+1                                           000705
00307      C                                                                        000705
00307      C               MAXIMUM ALLOWABLE CHARGE AND FLOW RATES                   000705
00307      C                                                                        000705
00311        500 MDM= PO/(CPF*DTD)                                                  000714
00311      C                                                                        000714
00312            PM =MDM*CPF*(T1-TA)                                                000720
00312      C                                                                        000720
00312      C                 CHARGING AND DISCHARGING EFFICIENCY                     000720
00312      C                                                                        000720
00313            EFF=1.0                                                            000726
00313      C                                                                        000726
00314            IF(T2.GE.TSO)EFF=(T2-TSO)/(T1-TA)                                  000730
00314      C                                                                        000730
00316            EFO =1.0                                                           000740
00316      C                                                                        000740
00317            IF(T3.GT.TSO)EFO=(TO-TA)/(T3-TSO)                                  000742
00317      C                                                                        000742
00321            MP2=AMIN1(MP1,PM)*EFF                                              000754
00321      C                                                                        000754
00322            EF2=EF1*EFF                                                        000763
00322      C                                                                        000763
```

```
00322        C
00322        C                    STATISTICS                                  000763
00322        C                                                                000763
00323              IF(IMPL.LE.1)RETURN                                        000766
00323        C                                                                000766
00325              TSU =AMAX1(TSU,TS1)                                        000775
00326              TSL =AMIN1(TSL,TS2)                                        001003
00327              ME = AMAX1(ME, EC1+EC2)                                    001011
00330              MT  =AMAX1(MT ,T2)                                         001020
00330        C                                                                001020
00331              IF(TIME.LT.TMAX1)RETURN                                    001026
00331        C                                                                001026
00333              CCI =CCI+CC                                                001035
00334              CMI=CMI+CM                                                 001040
00335              CM= CM/PD                                                  001043
00335        C                                                                001043
00336              RETURN                                                     001046
00336        C                                                                001046
00337         1010 FORMAT(1H0,22HHX   EXIT TEMPERATURE ,F12.3                 001516
00337             1          ,35H   GREATER THAN MAXIMUM ALLOWABLE   ,F12.3)  001516
00337        C                                                                001516
00340              END                                                        001516
```

RCS 40180-

HX

7.17 ADIABATIC HEAT EXCHANGER - DISCHARGING CYCLE



HY is the discharge cycle complement to HX. All the calculations to obtain the exit temperature and heat exchange power deposited or withdrawn are done in HX. The results are then passed to HY for summary.

Inputs

Parameter/Port		Description	Units
M	1	Air mass flow rate from storage	lb/hr
TØ		Exit temperature from HX	°F
P	1	Discharge power from storage	kw
EFØ		Discharge cycle efficiency from HX	–
MP	1	Maximum power from storage	kw

Outputs

Variable/Port			
M	2	Exit air mass flow rate (=M1)	lb/hr
T		Exit temperature (=TØ)	°F
P	2	Discharge power	kw
MP	2	Maximum discharge power	kw
EF	2	Output product efficiency	–

Statistics

TL	Minimum exit temperature	°F
TU	Maximum exit temperature	°F
SP	Total energy discharged	kwh

Calculation Sequence

1) M2 = M1

   T = TØ

   MP2 = MP1*EFØ

   EF2 = EFØ

   P2 = P1*EFØ

2) Compute Statistics

```
SUBROUTINE HY        ENTRY POINT 000064

STORAGE USED  CODE(1) 000135; DATA(0) 000017; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000001
 0004   CSIMUL 000007

EXTERNAL REFERENCES (BLOCK, NAME)

 0005   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000007 100L     0004   000000 DUM      0003 I 000000 IMPL     0000   000002 INJP$     0004 R 000006 TINC

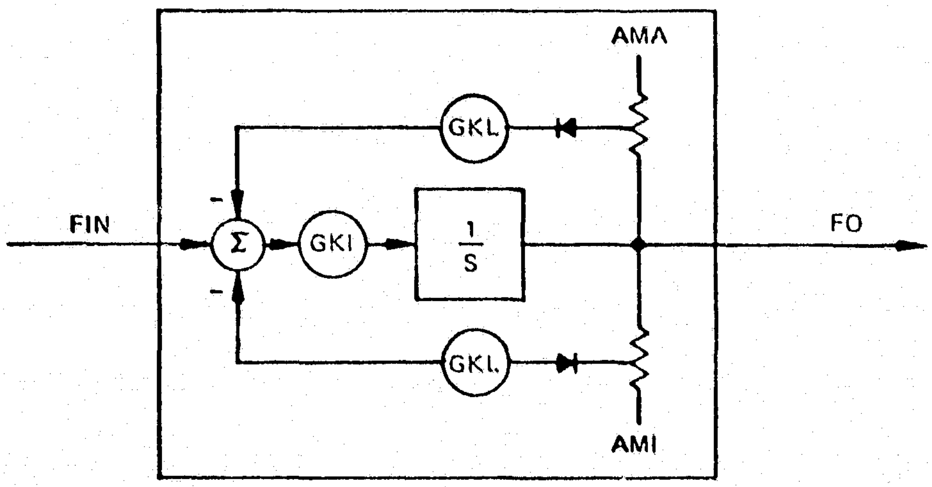

00100     CHY                                                                        000000
00101           SUBROUTINE HY(M2,T,P2,MP2,EF2,TL,TU,SP,M1,TO,P1,EF0,MP1)             000000
00101     C                                                                          000000
00101     C    PURPOSE   PERFORMANCE OF ADIABATIC HEAT EXCHANGER DURING DISCHARGE    000000
00101     C                                                                          000000
00101     C              CYCLE                                                       000000
00101     C                                                                          000000
00101     C    METHOD    COMPUTE EXIT CONDITIONS USING HEAT EXCHANGER STATE          000000
00101     C                                                                          000000
00101     C              DETERMINED IN HX                                            000000
00101     C                                                                          000000
00101     C    WRITEN BY F. O. MAHONY                 VERSION 1, MARCH 27 1977       000000
00101     C                                                                          000000
00101     C    CALL SEQUENCE                                                         000000
00101     C         OUTPUTS                                                          000000
00101     C              M2  - EXIT AIR MASS FLOW RATE (=M1), LB/HR                  000000
00101     C              T   - EXIT TEMPERATURE (=TO), DEG F                         000000
00101     C              P2  - TOTAL DISCHARGE POWER, KW                             000000
00101     C              MP2 - MAXIMUM DISCHARGE POWER, KW                           000000
00101     C              EF2 - OUTPUT PRODUCT EFFICIENCY                             000000
00101     C                                                                          000000
00101     C         STATISTICS                                                       000000
00101     C              TL  - MINIMUM EXIT TEMPEPATURE, DEG F                       000000
00101     C              TU  - MAXIMUM EXIT TEMPERATURE, DEG F                       000000
00101     C              SP  - TOTAL ENERGY DISCHARGED, KWH                          000000
00101     C                                                                          000000
00101     C         INPUTS                                                           000000
00101     C              M1  - AIR MASS FLOW RATE FROM STORAGE, LB/HR                000000
00101     C              TO  - EXIT TEMPERATURE FROM HX, DEG F                       000000
00101     C              P1  - DISCHARGE POWER FROM STORAGE, KW                      000000
```

HY

```
00101      C                EFO - DISCHARGE CYCLE EFFICIENCY                    000000
00101      C                MP1 - MAXIMUM POWER FROM STORAGE, KW                000000
00101      C                                                                    000000
00103            COMMON /CIMPL/IMPL /CSIMUL/DUM(6),TINC                         000000
00103      C                                                                    000000
00104            REAL M2,MP2,M1,MP1                                             000000
00104      C                                                                    000000
00105            IF(IMPL.GT.0)GO TO 100                                         000000
00105      C                                                                    000000
00107            TU =0.0                                                        000002
00110            SP =0.0                                                        000003
00110      C                                                                    000003
00111            TL =1.0E10                                                     000004
00112        100 M2 =M1                                                         000007
00113            T  =T0                                                         000010
00114            P2 =P1*EFO                                                     000012
00115            MP2=MP1*EFO                                                    000015
00116            EF2=EFO                                                        000020
00116      C                                                                    000020
00117            IF(IMPL.LE.1)RETURN                                            000022
00117      C                                                                    000022
00121            TL =AMIN1(TL ,T )                                              000031
00122            TU =AMAX1(TU ,T )                                              000037
00122      C                                                                    000037
00123            SP =SP +P2*TINC/2.0                                            000045
00123      C                                                                    000045
00124            RETURN                                                         000052
00125            END                                                            000134
```

HY

7.18 INTEGRATOR WITH SATURATION



Inputs

Parameter/Port	Description
FIN	Input
GKI	Integration gain
GKL	Saturation limiter gain
AMA	Upper limit of output (Default = 10^{36})
AMI	Lower limit of output (Default = -10^{36})

Outputs

Variable/Port	
FØ	Output (state)

Calculation Sequence

$$\dot{F\emptyset} = GKI*[FIN-GKL*(F\emptyset-AMA)] \quad \text{if} \quad F\emptyset > AMA$$

$$\dot{F\emptyset} = GKI * FIN \quad \text{if} \quad AMI \le F\emptyset \le AMA$$

$$\dot{F\emptyset} = GKI*[FIN-GKL*(F\emptyset-AMI)] \quad \text{if} \quad F\emptyset < AMI$$

```
SUBROUTINE IT        ENTRY POINT 000051

STORAGE USED  CODE(1) 000067; DATA(0) 000007; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   NEPR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

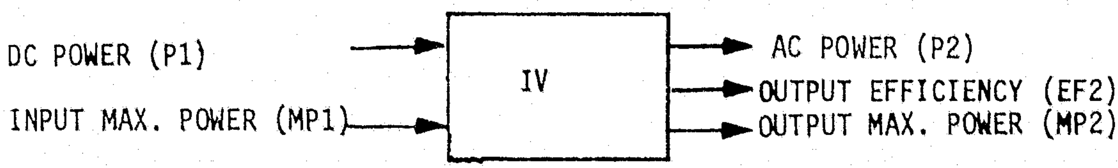
 0000 R 000000 EPS        0000   000003 INJP$


00100    CIT                                                                            000000
00101          SUBROUTINE IT(FO,FODOT,IFO,FIN,GKI,GKL,AMA,AMI)                          000000
00101    C  VERSION 2.                          REVISED  OCT 8 1976                     000000
00101    C                                                                              000000
00101    C  PURPOSE - SIMULATION OF AN INTEGRATOR WITH SATURATION                       000000
00101    C                                                                              000000
00101    C                                                                              000000
00101    C  METHOD  - SEE CODING                                                        000000
00101    C                                                                              000000
00101    C                                                                              000000
00101    C  LIMITATIONS - EXCESSIVELY HIGH VALUES OF GKL MAY RESULT IN POOR             000000
00101    C                STEADY STATE CONVERGENCE                                      000000
00101    C                                                                              000000
00101    C                                                                              000000
00101    C  WRITTEN BY  - ADAM LLOYD                 LATEST REVISION - NOV 75           000000
00101    C                                                                              000000
00101    C                                                                              000000
00101    C  INPUT/OUTPUT LIST                                                           000000
00101    C                                                                              000000
00101    C  FO         INTEGRATOR OUTPUT             ANY          OUTPUT STATE          000000
00101    C  FODOT      OUTPUT DERIVATIVE             ANY          OUTPUT DERIV          000000
00101    C  IFO        INTEGRATOR CONTROL            ---          PROGRAM VAR           000000
00101    C  FIN        FUNCTION INPUT                ANY          INPUT  VAR            000000
00101    C  GKI        INTEGRATOR GAIN               ANY          INPUT  PARAM          000000
00101    C  GKL        DERIVATIVE LIMITER GAIN       ANY          INPUT  PARAM          000000
00101    C  AMA        UPPER LIMIT OF OUTPUT         ANY          INPUT  PARAM          000000
00101    C             WHERE DERIV. LIMITER STARTS                                      000000
00101    C  AMI        LOWER LIMIT OF OUTPUT         ANY          INPUT  PARAM          000000
00101    C             WHERE DERIV. LIMITER STARTS                                      000000
00103          EPS=FIN                                                                  000000
00103    C ------------ PROVIDE DEFAULTS THAT ELLIMINATE SATURATION                     000000
00104          IF(AMA.EQ..99999)AMA=1.E36                                               000001
00106          IF(AMI.EQ..99999)AMI=-1.E36                                              000006
00110          IF(FO.GT.AMA)EPS = FIN - GKL*(FO-AMA)                                    000013
00112          IF(FO.LT.AMI)EPS = FIN - GKL*(FO-AMI)                                    000024
```

IT

```
00114    IF(IFO.NE.0)FODOT=GKI*EPS    000035
00116    RETURN                       000042
00117    END                          000066
```

7.19 DC-AC INVERTER



This component models a solid state inverter/transformer. Power losses due to resistive heating and contact potential loss are modeled. A step-up transformer may also be needed to boost output voltage up to that of the bus. Default parameter values are based on rated power = 200 kw.

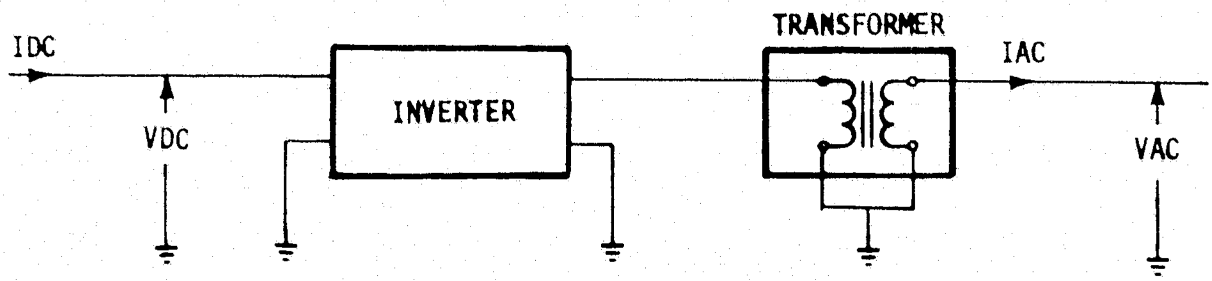


FIGURE 7.19 INVERTER FUNCTIONAL DIAGRAM

Inputs

Parameter/Port		Description	Units
P	1	DC input power	kw
RT		Transformer resistance (D = 0)	ohms
VDC		Rated DC voltage (D = 100)	volts
OI		Inverter contact potential (D = 0)	volts
RI		Inverter resistance (D = 0.005)	ohms
RAP		Rated input power	kw
EF	1	Input product efficiency	–
MP	1	Maximum input power	kw
CC		Inverter cost/year	$

Outputs

Variable/Port			
P	2	AC output power	kw
IDC		DC input current	amps
PL		Power loss	kw
EF	2	Output product efficiency	–
MP	2	Maximum output power	kw

D – Default values supplied.

Calculation Sequence

If P1 ≤ 0,   P2 = IDC = PL = 0,   EFF = 1 and go to 3)

1) Input and output current

$$IDC = P1*1000/VDC$$

$$IAC = \sqrt{6}*IDC/\pi$$

2) Power loss and output power

$$PL = (IDC*(DI+RI*IDC) + \sqrt{3}*RT*IAC^2)/1000$$

$$P2 = P1 - PL$$

$$EFF = P2/P1$$

$P2 \leq 0$ ⇨ Diagnostic, EFF = 1

3) Efficiency and maximum power

$$EF2 = EF1*EFF$$

$$MP2 = MIN(MP1,RAP)*EFF$$

4) Compute Costs

```
SUBROUTINE IV        ENTRY POINT 000175

STORAGE USED  CODE(1) 000261; DATA(0) 000046; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000002
 0004    CTIME   000001
 0005    CSIMUL  000010
 0006    COST    000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    SQRT
 0010    NWDU$
 0011    NIO2$
 0012    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000030 100L      0001    000047 200L      0000    000004 208F      0001    000145 400L      0006 R 000000 CCI
 0005    000000 DUM       0000 R 000003 EFF       0000 R 000000 IAC       0003 I 000001 ICNT      0003 I 000000 IMPL
 0000    000034 INJP$     0000 R 000001 PI        0004 R 000000 TIME      0005 R 000007 TMAX      0000 R 000002 TMAX1

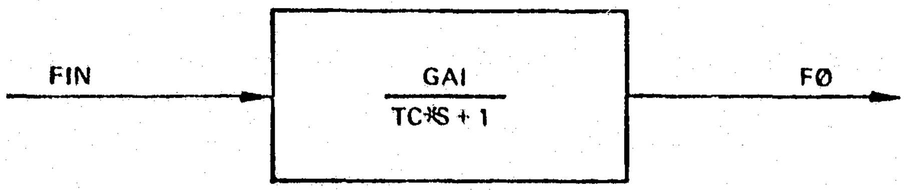

00100     CIV                                                                   000000
00101           SUBROUTINE IV(P2,IDC,PL,EF2,MP2,P1,RT,VDC,DI,RI,RAP,EF1,MP1,CC)  000000
00101     C                                                                     000000
00101     C                  PURPOSE   SOLID STATE INVERTER/TRANSFORMER MODEL   000000
00101     C                                                                     000000
00101     C                  METHOD    COMPUTE AC POWER AS A FUNCTION OF        000000
00101     C                            INPUT DC POWER                           000000
00101     C                                                                     000000
00101     C                  WRITTEN BY  Y.K.CHAN     VERSION 1, JUNE 2, 1977   000000
00101     C                                                                     000000
00101     C   CALL SEQUENCE                                                     000000
00101     C                  OUTPUTS                                            000000
00101     C                  P2  -AC OUTPUT POWER, KW                           000000
00101     C                  IDC -DC INPUT CURRENT, AMPS                        000000
00101     C                  PL  -POWER LOSS, KW                                000000
00101     C                  EF2 -OUTPUT POWER EFFICIENCY                       000000
00101     C                  MP2 -MAXIMUM OUTPUT POWER, KW                      000000
00101     C              INPUTS                                                 000000
00101     C                  P1  -DC INPUT POWER, KW                            000000
00101     C                  RT  -TRANSFORMER RESISTANCE, OHMS                  000000
00101     C                  VDC -RATED DC VOLTAGE, VOLTS                       000000
00101     C                  DI  -INVERTER CONTACT POTENTIAL, VOLTS             000000
00101     C                  RI  -INVERTER RESISTANCE, OHMS                     000000
```

IV

```
00101       C              RAP -RATED OUTPUT POWER, KW                                    000000
00101       C              EF1 -INPUT PRODUCT EFFICIENCY                                  000000
00101       C              MP1 -MAXIMUM INPUT POWER, KW                                   000000
00101       C              CC  -INVERTER COST/YEAR                                        000000
00101       C                                                                             000000
00103             COMMON /CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX/COST/CCI          000000
00104             REAL IDC,MP2,MP1,IAC                                                    000000
00105             DATA PI/3.14159/                                                        000000
00105       C                                                                             000000
00107             IF(IMPL.GT.0) GO TO 100                                                 000000
00111             IF(RT.EQ..99999)RT=0.                                                   000002
00113             IF(VDC.EQ..99999)VDC=100.                                               000006
00115             IF(DI.EQ..99999)DI=0.                                                   000013
00117             IF(RI.EQ..99999)RI=.005                                                 000017
00121             TMAX1=TMAX*.99999                                                       000024
00121       C                                                                             000024
00121       C              COMPUTE INPUT AND OUTPUT CURRENT                               000024
00121       C                                                                             000024
00122         100 IF(P1.GT.0.)GO TO 200                                                   000030
00124              P2=0.                                                                  000032
00125              IDC=0.                                                                 000033
00126              PL=0.                                                                  000034
00127              EF2=EF1                                                                000035
00130              MP2=AMIN1(MP1,RAP)                                                     000037
00131              GO TO 400                                                              000045
00132         200 IDC=P1*1000./VDC                                                        000047
00133             IAC=SQRT(6.)*IDC/PI                                                     000052
00133       C                                                                             000052
00133       C              POWER LOSS AND OUTPUT POWER                                    000052
00133       C                                                                             000052
00134             PL=(IDC*(DI+RI*IDC)+SQRT(3.)*RT*IAC*IAC)/1000.                          000060
00135             P2=P1-PL                                                                000075
00136             EFF=P2/P1                                                               000077
00136       C                                                                             000077
00136       C              EFFICIENCY AND MAXIMUM POWER                                   000077
00136       C                                                                             000077
00137             EF2=EF1*EFF                                                             000101
00140             MP2=AMIN1(MP1,RAP)                                                      000103
00141             MP2=MP2*EFF                                                             000111
00142             IF(P2.GT.0.)GO TO 400                                                   000114
00142       C                                                                             000114
00144             EF2=EF1                                                                 000117
00145             MP2=AMIN1(MP1,RAP)                                                      000121
00146             IF(IMPL.EQ.2)WRITE(6,208)PL,P1                                          000123
00153         208 FORMAT(1H0,14HIV POWER LOSS ,F12.3,21H EXCEEDS INPUT POWER ,F12.3,      000135
00153            128H CHECK RATED DC VOLTAGE VDC   )                                      000135
00154             IF(IMPL.EQ.2)ICNT=ICNT+1                                                000135
00156             P2=0.                                                                   000143
00156       C                                                                             000143
00157         400 IF(IMPL.LE.1)RETURN                                                     000145
00161             IF(TIME.LT.TMAX1)RETURN                                                 000153
00163             CCI=CCI+CC                                                              000162
00164             RETURN                                                                  000165
00165             END                                                                     000260
```


IV

7.20 FIRST ORDER LAG



Inputs

Parameter/Port	Description
FIN	Input quantity
GAI	Gain
TC	Time constant[1] (hours)
FØ	Output variable (state)

Calculation Sequence

$$\dot{F\O} = (GAI * FIN - F\O)/TC$$

NOTE: d.c. gain = GAI; time constant = TC

infinite frequency gain = 0

pole location = $\frac{1}{TC}$ rad/sec.

---

[1] If TC = 0, then FØ = FIN*GAI

```
SUBROUTINE LA         ENTRY POINT 000026

STORAGE USED  CODE(1) 000045; DATA(0) 000010; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIO     000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0004   NERR3$

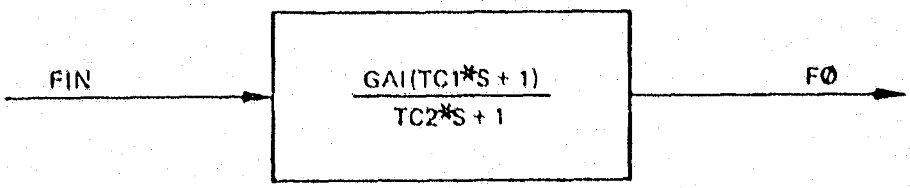
STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000010 10L      0003   000002 IDIAG     0000   000000 INJP$     0003   000000 IREAD     0003   000001 IWRITE


00100     CLA                                                                                  000000
00101           SUBROUTINE LA(FO,FODOT,IFO,FIN,GAI,TC)                                         000000
00101     C                                                                                    000000
00101     C   PURPOSE - TO SIMULATE FIRST ORDER LAG      FO        GAI                         000000
00101     C                                             ---- = ----------                      000000
00101     C                                             FIN    (1.+TC*S)                       000000
00101     C                                                                                    000000
00101     C                                                                                    000000
00101     C   METHOD  - SEE CODING                                                             000000
00101     C                                                                                    000000
00101     C                                                                                    000000
00101     C   WRITTEN BY  -   ADAM LLOYD        LATEST REVISION     NOV 75                     000000
00101     C                                                                                    000000
00101     C                                                                                    000000
00101     C   INPUT/OUTPUT LIST                                                                000000
00101     C                                                                                    000000
00101     C   FO         TRANSFER FUNCTION OUTPUT           ANY      OUTPUT STATE              000000
00101     C   FODOT      TRANSFER FUNCTION OUTPUT           ANY      OUTPUT STATE              000000
00101     C   IFO        INTEGERATOR CONTROL                ---      PROGRAM VAR               000000
00101     C   FIN        TRANSFER FUNCTION INPUT            ANY      INPUT  VAR                000000
00101     C   GAI        TRANSFER FUNCTION GAIN             ---      INPUT  PARAM              000000
00101     C   TC         TIME CONSTANT                      SECS     INPUT  PARAM              000000
00103           COMMON/CIO/IREAD,IWRITE,IDIAG                                                  000000
00104           IF(TC.NE.0.) GO TO 10                                                          000000
00106           FO= GAI*FIN                                                                    000001
00107           RETURN                                                                         000004
00110        10 IF(IFO.NE.0) FODOT=(GAI*FIN-FO)/TC                                             000010
00112           RETURN                                                                         000016
00113           END                                                                            000044
```

LA

7.21 LEAD LAG



Inputs

Parameter/Port	Description
FIN	Input quantity
TC1	Numerator time constant (hours)
TC2	Denominator time constant (hours)
GAI	Gain

Outputs

Variable/Port	
X1	Intermediate quantity (state)
FØ	Output quantity (variable)

Calculation Sequence

$$FØ = (X1 + FIN*TC1*GAI)/TC2$$

$$\dot{X1} = GAI*FIN-FØ$$

NOTE: d.c. gain = GAI

$$\text{infinite gain} = \frac{GAI*TC1}{TC2}$$

$$\text{zero location} = -\frac{1}{TC1}\text{, rad/sec}$$

$$\text{pole location} = -\frac{1}{TC2}\text{, rad/sec}$$

```
SUBROUTINE LL        ENTRY POINT 000022

STORAGE USED  CODE(1) 000031; DATA(0) 000004; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIO    000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0004   NERR3$

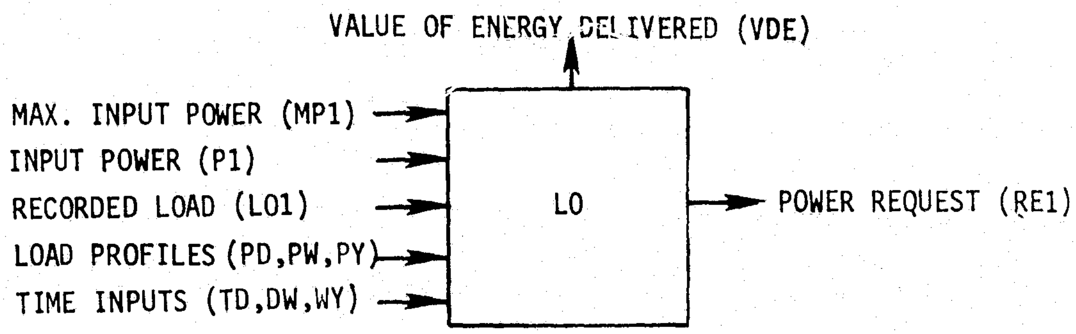
STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0003   000002 IDIAG     0000   000000 INJP$     0003   000000 IREAD     0003   000001 IWRITE


00100        CLL                                                                          000000
00101              SUBROUTINE LL(X1,X1DOT,IX1,FO,FIN,TC1,TC2,GAI)                         000000
00101        C                                                                            000000
00101        C   PURPOSE - TO SIMULATE LEAD LAG TRANSFER FUNCTION                         000000
00101        C                                                                            000000
00101        C                          FO      GAI*(1.+TC1*S)                            000000
00101        C                         ----- = ---------------                            000000
00101        C                          FIN      (1.+TC2*S)                               000000
00101        C                                                                            000000
00101        C                                                                            000000
00101        C   METHOD  - SELF EXPLANATORY                                               000000
00101        C                                                                            000000
00101        C                                                                            000000
00101        C   LIMITATIONS -   NONE                                                     000000
00101        C                                                                            000000
00101        C                                                                            000000
00101        C   WRITTEN BY  -   ADAM LLOYD          LATEST REVISION  NOV 75              000000
00101        C                                                                            000000
00101        C                                                                            000000
00101        C   INPUT/OUTPUT LIST                                                        000000
00101        C                                                                            000000
00101        C   X1        STATE VARIABLE                     ANY      OUTPUT STATE       000000
00101        C   X1DOT     STATE VARIABLE DERIVATIVE          ANY      OUTPUT STATE       000000
00101        C   IX1       INTEGRATOR CONTROL                 ---      PROGRAM VAR        000000
00101        C   FO        TRANSFER FUNCTION OUTPUT           ANY      OUTPUT VAR         000000
00101        C   FIN       TRANSFER FUNCTION INPUT            ANY      INPUT  VAR         000000
00101        C   TC1       TIME CONSTANT (NUMERATOR)          SECS     INPUT  PARAM       000000
00101        C   TC2       TIME CONSTANT (DENOMINATOR)        SECS     INPUT  PARAM       000000
00101        C   GAI       TRANSFER FUNCTION GAIN             ---      INPUT  PARAM       000000
00103              COMMON/CIO/IREAD,IWRITE,IDIAG                                          000000
00104              FO=(X1+FIN*TC1*GAI)/TC2                                                000000
```

```
00105          IF(IX1.NE.0)X1DOT= GAI*FIN-FO          000005
00107          RETURN                                 000013
00110          END                                    000030
```

7.22 ELECTRICAL LOAD



This component represents electrical load either by a user-specified data file time history or by a set of random numbers with user-specified daily, weekly, and yearly average profiles and user-specified random variation. It also computes the value of the power delivered to the load by the system. This value delivered is determined from a user-specified value per kwh. This value may be input in tabular form as a function of time of day, time of year, or any other system parameter.

If the user selects to have the electrical load represented by random numbers, then the load (L02) is generated from the following equation:

Basic Equation

$$L\emptyset 2 = \left[PD(TD) + CN(t) \right] * PW(DW) * PY(WY) * NC$$

where

PD, PW, PY are the daily, weekly, and yearly profiles, respectively, and TD, DW, WY are the time of day, day of the week, and week of the year, respectively. NC is a normalizing constant.

CN is a colored noise term with user-specified correlation time, standard deviation and mean.

Tables		Description	Units
PD		Daily profile (tabular with TD)	kw
PW		Weekly profile (tabular with DW)	arbitrary
PY		Yearly profile (tabular with WY)	arbitrary

Inputs

Parameter/Port			
P	1	Power delivered	kw
MP	1	Maximum Input Power deliverable (D = $1X10^{10}$)	kw
NC		Normalizing constant	
VE		Value of Electrical Energy	$/kwh
LØ	1	Electrical load data file input	kw
TD		Time of day	–
DW		Day of week	–
WY		Week of year	–
CT		Correlation time of random noise	hr
MN,STD		Mean (D = 0) and std. deviation of random noise	kw
EF	1	Input Power Efficiency	–

Outputs

Variable/Port			
RE	1	Power request	kw
VDE		Value of energy delivered (state)	$
LØ	2	Electrical load	kw
TIM		Last time a random sample was used	hr
CN		Colored noise sample	kw

Statistics

SRE	Total energy requested	kwh
SDE	Total energy delivered	kwh
PC	Percentage of load met	–

D – Default values supplied

Calculation Sequence

1) Initialize CN(0) (first pass)

2) Check for data file input

If LØ1 = .99999 go to 3)

LØ2 = LØ1 and go to 5)

3) Generate colored noise CN

If TIM = TIME go to 5)

$$A = \begin{cases} \exp(-\Delta/CT), & CT > 0,\ \Delta = \text{integration step size, hr} \\ 0. & CT = 0 \end{cases}$$

CN = A*CN+W,

Where W is white noise generated by RN with

Mean = MN * (1-A) and standard deviation = STD * $\sqrt{1-A^2}$

4) Compute LØ2

LØ2 = (PD(TD) + CN) * PW(DW) * PY (WY) * NC

TIM = TIME

5) Power request and value delivered

RE = MIN(MP,LØ2)/EF1

6) Statistics

VDE = P1*VE

SRE = SRE + LØ2* Δ/2

SDE = SDE + P1* Δ/2

PC = 100.* SDE/SRE

```
SUBROUTINE LO          ENTRY POINT 000344

STORAGE USED  CODE(1) 000471; DATA(0) 000055; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000001
 0004    CSIMUL  000010
 0005    CTIME   000001
 0006    COST    000006

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    RN
 0010    TBLU1
 0011    EXP
 0012    SQRT
 0013    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000062 10L        0001    000070 100L       0001    000233 150L       0000 R 000005 A          0000 R 000000 AX
 0006    000000 CC         0006 R 000004 CDE         0006    000001 CM         0006    000002 CO         0006 R 000005 CRE
 0006 R 000003 CV          0000 R 000011 DLO         0004    000000 DUM        0003 I 000000 IMPL        0000    000022 INJP$
 0000 I 000001 ND          0000 I 000002 NW          0000 I 000003 NY          0010 R 000000 TBLU1       0005 R 000000 TIME
 0004 R 000006 TINC        0004 R 000007 TMAX        0000 R 000004 TMAX1       0000 R 000010 W           0000 R 000012 WLO
 0000 R 000006 WMN         0000 R 000007 WSD         0000 R 000013 YLO


 00100        CLO                                                                                  000002
 00101           SUBROUTINE LO (PD,PW,PY,VDE,DVD,IVD,RE,LO2,SRE,SDE,PC,TIMO,XN,                   000002
 00101          1 TD,DW,WY,XNC,CT,XMN,STD,VE,LO1,PMAX,PO,EF)                                       000002
 00101        C                                                                                    000002
 00101        C   PURPOSE    GENERATE ELECTRICAL LOAD FROM DAILY, WEEKLY, YEARLY AND               000002
 00101        C              RANDOM PROFILE DATA AND EVALUATE PERFORMANCE STATISTICS               000002
 00101        C                                                                                    000002
 00101        C   METHOD     COLORED NOISE IS ADDED TO A MEAN DAILY PROFILE AND MULTIPLIED         000002
 00101        C              BY WEEKLY AND YEARLY WEIGHTING FCNS. POWER REQUESTED IS EITHER        000002
 00101        C              THE GENERATED LOAD OR THE MAX. POWER DELIVERABLE.                     000002
 00101        C                                                                                    000002
 00101        C   WRITTEN BY A.W.WARREN                           VERSION 1, MARCH 9 1977          000002
 00101        C                                                                                    000002
 00101        C   CALL SEQUENCE                                                                    000002
 00101        C         TABLES                                                                     000002
 00101        C              PD  - MEAN DAILY PROFILE, KW                                          000002
 00101        C              PW  - MEAN WEEKLY PROFILE, -                                          000002
 00101        C              PY  - MEAN YEARLY PROFILE, -                                          000002
 00101        C                                                                                    000002
```

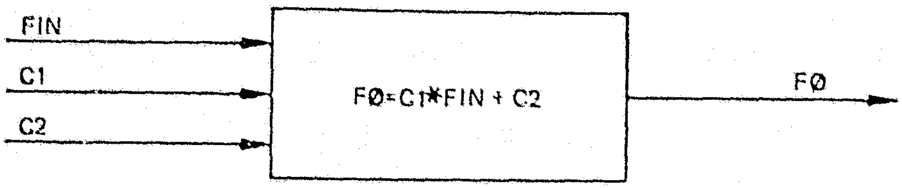
LO

```
00101    C          OUTPUTS                                                    000002
00101    C               VDE - VALUE OF ENERGY DELIVERED (STATE), $            000002
00101    C               DVD - DERIVATIVE OF VDE                               000002
00101    C               IVD - INDICATOR FOR VDE                               000002
00101    C               RE  - POWER REQUEST, KW                               000002
00101    C               LO2 - ELECTRICAL LOAD DEMAND, KW                      000002
00101    C               SRE - SUM OF ENERGY DESIRED, KWH                      000002
00101    C               SDE - SUM OF ENERGY DELIVERED, KWH                    000002
00101    C               PC  - CUMULATIVE PERCENT OF LOAD DELIVERED, -         000002
00101    C               TIMO- LAST TIME A RANDOM SAMPLE WAS USED, HR          000002
00101    C               XN  - COLORED NOISE SAMPLE, KW                        000002
00101    C                                                                     000002
00101    C          INPUTS                                                     000002
00101    C               TD  - TIME OF DAY, HR                                 000002
00101    C               DW  - DAY OF WEEK (1-7)                               000002
00101    C               WY  - WEEK OF YEAR (1-52)                             000002
00101    C               XNC - NORMALIZING CONSTANT, -                         000002
00101    C               CT  - CORRELATION TIME OF RANDOM NOISE, HR            000002
00101    C               XMN - MEAN OF RANDOM NOISE, KW                        000002
00101    C               STD - STANDARD DEVIATION OF RANDOM NOISE, KW          000002
00101    C               VE  - VALUE OF ELECTRICAL ENERGY, $/KWH               000002
00101    C               LO1 - ELECTRICAL LOAD DATA FILE INPUT, KW             000002
00101    C               PMAX- MAX. INPUT POWER DELIVERABLE, KW                000002
00101    C               PO  - POWER DELIVERED TO LOAD, KW                     000002
00101    C               EF  - INPUT POWER EFFICIENCY                          000002
00101    C                                                                     000002
00103           DIMENSION PD(1),PW(1),PY(1)                                    000002
00104           REAL LO1,LO2                                                   000002
00105           COMMON /CIMPL/ IMPL /CSIMUL/ DUM(6),TINC,TMAX/CTIME/TIME       000002
00106           COMMON /COST/CC,CM,CO,CV,CDE,CRE                               000002
00107           DATA AX/.99999/                                                000002
00107    C                                                                     000002
00107    C                         INITIALIZATION                              000002
00107    C                                                                     000002
00111           ND = PD(2)                                                     000002
00112           NW = PW(2)                                                     000011
00113           NY = PY(2)                                                     000020
00114           IF(IMPL.GT.0) GO TO 10                                         000027
00116           IF(XMN.EQ. .99999)XMN=0.                                       000032
00120           THAX1 = TMAX*.99999                                            000036
00121           TIMO=-1.                                                       000041
00122           SRE =0.0                                                       000043
00123           SDE =0.0                                                       000044
00124           PC  =0.0                                                       000045
00125           CALL RN(XN,AX,STD,XMN)                                         000046
00126           IF(PMAX.EQ. .99999) PMAX = 1.E10                               000054
00126    C                                                                     000054
00126    C                         CHECK FOR DATA FILE INPUT                   000054
00126    C                                                                     000054
00130        10 IF(LO1.EQ. .99999) GO TO 100                                   000062
00132           LO2 = LO1                                                      000064
00133           GO TO 150                                                      000066
00133    C                                                                     000066
00133    C                         GENERATE COLORED NOISE SAMPLE XN            000066
00133    C                                                                     000066
00134       100 IF(   TIMO.EQ.TIME) GO TO 150                                  000070
00136           A=0.                                                           000072
```


LO

```
00137          IF(CT.GT.0.) A = EXP(-TINC/CT)                    000073
00141          WMN = XMN*(1.-A)                                  000116
00142          WSD = STD*SQRT(1.-A*A)                            000122
00143          CALL RN(W,AX,WSD,WMN)                             000133
00144          XN = XN*A + W                                     000141
00144    C                   COMPUTE ELECTRICAL LOAD DEMAND      000141
00144    C                                                       000141
00145          DLO = TBLU1(TD,PD(4),PD(ND+4),1,-ND)              000145
00146          WLO = TBLU1(DW,PW(4),PW(NW+4),1,-NW)              000164
00147          YLO = TBLU1(WY,PY(4),PY(NY+4),1,-NY)              000203
00150          LO2 = (DLO+XN)*WLO + YLO*XNC                      000222
00151          TIMO = TIME                                       000230
00152      150 RE = AMIN1(PMAX,LO2)/EF                           000233
00152    C                   PERFORMANCE STATISTICS              000233
00152    C                                                       000233
00153          IF(IMPL.LE.1) RETURN                              000241
00155          IF(IVD.NE. 0) DVD = PO*VE                         000250
00157          SRE = SRE + LO2*0.5*TINC                          000261
00160          SDE = SDE + PO*0.5*TINC                           000266
00161          IF(SRE.GT.0.) PC = 100.*SDE/SRE                   000271
00161    C                                                       000271
00163          IF(TIME.LT.TMAX1) RETURN                          000300
00165          CV = CV + VDE                                     000307
00166          CDE= CDE + SDE- PO*0.5*TINC                       000312
00167          CRE= CRE + SRE- LO2*0.5*TINC                      000316
00170          RETURN                                            000325
00171          END                                               000470
```

7.23 MULTIPLY AND ADD



Inputs

Parameter/Port	Description
FIN	Input quantity
C1	Input quantity
C2	Input quantity

Outputs

Variable/Port	
FØ	Output quantity

Calculation Sequence

FØ = C1*FIN + C2

```
SUBROUTINE MA          ENTRY POINT 000012

STORAGE USED  CODE(1) 000016; DATA(0) 000004; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

 0003   NERR3$

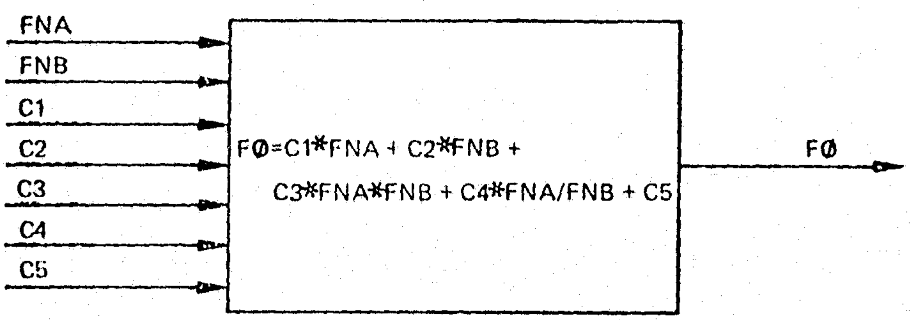
STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0000   000000 INJP$


00100       1*     CMA                                                                          000000
00101       2*           SUBROUTINE MA(FO,FIN,C1,C2)                                            000000
00101       3*     C                                                                            000000
00101       4*     C   PURPOSE - TO SIMULATE THE EQUATION   OUTPUT=C1*INPUT + C2                000000
00101       5*     C                                                                            000000
00101       6*     C                                                                            000000
00101       7*     C   METHOD  - SEE CODING                                                     000000
00101       8*     C                                                                            000000
00101       9*     C                                                                            000000
00101      10*     C   WRITTEN BY  -  ADAM LLOYD          LATEST REVISION     NOV 75            000000
00101      11*     C                                                                            000000
00101      12*     C                                                                            000000
00101      13*     C   LIMITATIONS - NONE                                                       000000
00101      14*     C                                                                            000000
00101      15*     C                                                                            000000
00101      16*     C   INPUT/OUTPUT LIST                                                        000000
00101      17*     C                                                                            000000
00101      18*     C   FO         OUTPUT VARIABLE             ANY            OUTPUT VAR         000000
00101      19*     C   FIN        INPUT  VARIABLE             ANY            INPUT  VAR         000000
00101      20*     C   C1         CONSTANT MULTIPLIER         ---            INPUT  PARAM       000000
00101      21*     C   C2         CONSTANT ADDITION           ---            INPUT  PARAM       000000
00103      22*           FO=C1*FIN + C2                                                         000000
00104      23*           RETURN                                                                 000003
00105      24*           END                                                                    000015
```

MA

7.24 MULTIPLY, DIVIDE, AND ADD



Inputs

Parameter/Port	Description
FNA	Input quantity
FNB	Input quantity
C1	Input quantity
C2	Input quantity
C3	Input quantity
C4	Input quantity
C5	Input quantity.

Outputs

Variable/Port	
FØ	Output quantity

Calculation Sequence

FØ = C1*FNA+C2*FNB+C3*FNA*FNB+C4*FNA/FNB+C5

```
SUBROUTINE MB        ENTRY POINT 000051

STORAGE USED  CODE(1) 000064; DATA(0) 000023; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   ERMESS 000002
 0004   CIO    000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0005   NWDUS
 0006   NIO2$
 0007   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

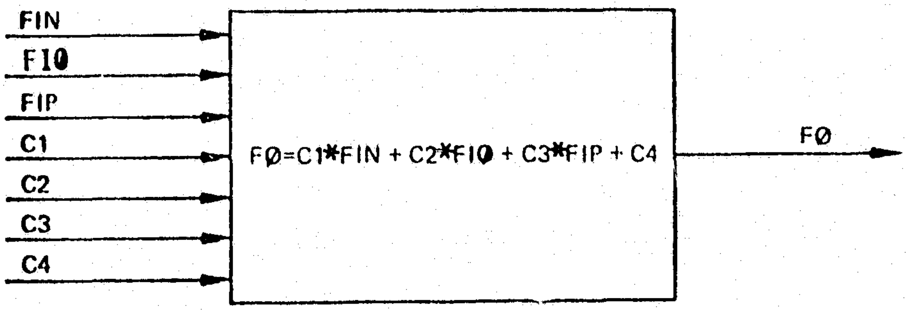
 0001   000030 10L        0000   000000 20F       0001   000042 30L       0004   000002 IDIAG      0003   000001 IERR
 0003   000000 IFATAL     0000   000015 INJP$     0004   000000 IREAD     0004 I 000001 IWRITE


00100      CMB                                                                          000000
00101            SUBROUTINE MB(FO,FNA,FNB,C1,C2,C3,C4,C5)                               000000
00101      C                                                                            000000
00101      C    PURPOSE - TO SIMULATE THE EQUATION   Y=C1*XA+C2*XB+C3*XA*XB+C4*XA/XB+C5     000000
00101      C                                                                            000000
00101      C                                                                            000000
00101      C    WRITTEN BY - GEORGE DULEBA                       LATEST REVISION   MAY 76   000000
00101      C                                                                            000000
00101      C                                                                            000000
00101      C    LIMITATIONS - IF FNB=0 DURING DIVISION, FNB IS SET TO E-20.             000000
00101      C                  DIAGNOSTIC MESSAGE IS GIVEN.                              000000
00101      C                                                                            000000
00101      C                                                                            000000
00101      C    INPUT/OUTPUT LIST                                                       000000
00101      C                                                                            000000
00101      C    FO         OUTPUT VARIABLE              ANY          OUTPUT VAR         000000
00101      C    FNA        INPUT VARIABLE A             ANY          INPUT  VAR         000000
00101      C    FNB        INPUT VARIABLE B             ANY          INPUT  VA          000000
00101      C    C1         MULTIPLIER 1                 ANY          INPUT  VAR         000000
00101      C    C2         MULTIPLIER 2                 ANY          INPUT  VAR         000000
00101      C    C3         MULTIPLIER 3                 ANY          INPUT  VAR         000000
00101      C    C4         MULTIPLIER 4                 ANY          INPUT  VAR         000000
00101      C    C5         ADDITIVE VARIABLE            ANY          INPUT  VAR         000000
00101      C                                                                            000000
00101      C                                                                            000000
00103            COMMON/ERMESS/IFATAL,IERR                                              000000
00104            COMMON/CIO/IREAD,IWRITE,IDIAG                                          000000
```

MB

```
00105            FO= C1*FNA + C2*FNB + C3*FNA*FNB + C5                      000000
00106            IF(C4.EQ.0.99999) GO TO 30                                 000012
00110            IF(FNB.EQ.0.) GO TO 10                                     000015
00112            FO= FO + C4*FNA/FNB                                        000017
00113            RETURN                                                     000024
00114       10   WRITE(IWRITE,20)                                           000030
00116       20   FORMAT(/,30X, 53HWARNING- DIVISOR IN MB EQUALS 0., HAS BEEN SET=1.   000034
00116           2E-20)                                                      000034
00117            FO= FO + C4*FNA*1.E+20                                     000034
00120       30   RETURN                                                     000042
00121            END                                                        000063
```

7.25 MULTIPLY AND ADD



Inputs

Parameter/Port	Description
FIN	Input quantity
FIØ	Input quantity
FIP	Input quantity
C1	Input quantity
C2	Input quantity
C3	Input quantity
C4	Input quantity

Outputs

Variable/Port	
FØ	Output quantity

Calculation Sequence

FØ = C1*FIN + C2*FIØ + C3*FIP + C4

```
SUBROUTINE MC        ENTRY POINT 000020

STORAGE USED  CODE(1) 000024; DATA(0) 000004; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

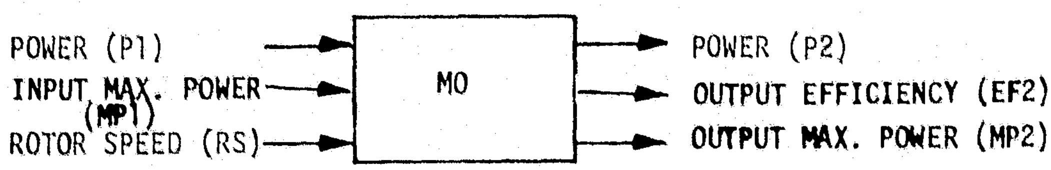
 0003   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0000   000000 INJP$


00100      CMC                                                                     000000
00101           SUBROUTINE MC(FO,FIN,FIO,FIP,C1,C2,C3,C4)                          000000
00101      C                                                                       000000
00101      C    PURPOSE - TO SIMULATE THE EQUATION  FO=C1*FIN+C2*FIO+C3*FIP+C4     000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C    METHOD  - SEE CODING                                               000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C    WRITTEN BY  -  ADAM LLOYD          LATEST REVISION   NOV 75        000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C    LIMITATIONS - NONE                                                 000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C    INPUT/OUTPUT LIST                                                  000000
00101      C                                                                       000000
00101      C    FO         OUTPUT VARIABLE            ANY          OUTPUT VAR      000000
00101      C    FIN        INPUT  VARIABLE            ANY          INPUT  VAR      000000
00101      C    FIO        INPUT  VARIABLE            ANY          INPUT  VAR      000000
00101      C    FIP        INPUT  VARIABLE            ANY          INPUT  VAR      000000
00101      C    C1         CONSTANT MULTIPLIER        ---          INPUT  PARAM    000000
00101      C    C2         CONSTANT MULTIPLIER        ---          INPUT  PARAM    000000
00101      C    C3         CONSTANT MULTIPLIER        ---          INPUT  PARAM    000000
00101      C    C4         CONSTANT ADDITION          ---          INPUT  PARAM    000000
00103           FO=C1*FIN+C2*FIO+C3*FIP+C4                                         000000
00104           RETURN                                                             000011
00105           END                                                                000023
```

7.26 AC INDUCTION MOTOR



The induction motor produces mechanical power and torque proportional to slip speed, i.e. power and torque approach zero as the rotor approaches synchronous speed. Two power losses are modeled: a constant multiplicative term due to resistive heating and an additive term due to mechanical friction. Default parameters are based on a conventional squirrel-cage induction motor/generator machine.

Basic Equations

$$P2 = EE*P1 + DA*RS^2*C$$

where

P1,P2 = input and output power

EE = electrical efficiency

DA = mechanical damping

C = conversion constant

MO

Inputs

Parameter/Port		Description	Units
P	1	Input power	kw
DA		Mechanical damping (D = 0)	joule-sec
RS		Rotor speed	rpm
RSY		Synchronous rotor speed (D = 1800)	rpm
SR		Stator resistance (D = 8/RAP)	ohms
VØ		Rated input voltage (D = 400)	volts
RAP		Rated input power	kw
RAS		Rated power slip (D = 0.05)	–
EF	1	Input product efficiency	–
MP	1	Maximum input power (D = $1x10^8$)	kw
CC		Capital cost/year	$
CM		Maintenance cost/year	$

Outputs

Variable/Port		Description	Units
P	2	Output mechanical power	kw
EE		Electrical efficiency	–
TØ		Mechanical torque	ft-lb
PL		Power loss	kw
EF	2	Output product efficiency	–
MP	2	Output maximum power	kw

Statistics

MT		Maximum torque	ft-lb
MPN		Maximum output power/rated power	–
SP		Output energy sum	kwh

D – Default values supplied.

Calculation Sequence

1) Compute electrical efficiency (first pass only)

$$I_{RAT} = RAP*1000/VO$$

$$EE = 1 - SR*I^2_{RAT}/RAP*1000$$

2) Diagnostics

P1 > RAP ⇨ DIAGNOSTIC

SLIP = 1 - RS/RSY > RAS ⇨ DIAGNOSTIC

3) Output power and power loss

$$\omega = RS*(2\pi/60)$$

$$P2 = EE*P1 - DA*\omega^2/1000$$

$$PL = P1 - P2$$

4) If P2 > 0 go to 5)

P1 > 0 ⇨ DIAGNOSTIC

EF2 = EF1, MP2 = MIN(MP1,RAP)

Go to 7)

5) Compute torque

$$T\emptyset = P2*1000/\omega*k$$

k = 1.3558 joules/ft-lb

Calculation Sequence Cont.

6) Efficiency and maximum output power

EF2 = EF1*(P2/P1)

MP2 = MIN(MP1,RAP)*(P2/P1)

7) Compute Statistics and Costs

```
SUBROUTINE MO          ENTRY POINT 000312

STORAGE USED  CODE(1) 000434; DATA(0) 000102; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL   000002
 0004   CTIME   000001
 0005   CSIMUL  000010
 0006   COST    000010

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   NWDU$
 0010   N102$
 0011   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000062 100L      0001    000106 200L      0000    000004 208F      0001    000135 300L      0000    000017 308F
 0001    000213 400L      0000    000032 408F      0001    000201 409L      0001    000235 500L      0006 R 000000 CCI
 0006 R 000001 CMI        0006    000002 COP       0005 R 000000 DUM        0003 I 000001 ICNT       0003 I 000000 IMPL
 0000    000066 INJP$     0000 R 000003 OMEGA      0000 R 000002 SLIP       0006    000004 TDE       0004 R 000000 TIME
 0000 R 000001 TINC       0006    000005 TLD       0005 R 000007 TMAX       0000 R 000000 TMAX1      0006    000007 UTD
 0006    000006 UTV       0006    000003 VDE


00100      CMO                                                                          000000
00101            SUBROUTINE MO(P2,EE,TO,PL,EF2,MP2,MT,MPN,SP,                           000000
00101           1                 P1,DA,RS,RSY,SR,VO,RAP,RAS,EF1,MP1,CC,CM)             000000
00101      C                                                                            000000
00101      C                  PURPOSE   AC INDUCTION MOTOR MODEL                        000000
00101      C                                                                            000000
00101      C                  METHOD    MECHANICAL POWER AND TORQUE CALCULATED          000000
00101      C                            FROM INPUT AC POWER AND ROTOR SPEED             000000
00101      C                                                                            000000
00101      C                  WRITTEN BY Y.K.CHAN         VERSION 1, JUNE 13, 1977      000000
00101      C                                                                            000000
00101      C   CALL SEQUENCE                                                            000000
00101      C          OUTPUTS                                                           000000
00101      C                  P2   -OUTPUT MECHANICAL POWER,KW                          000000
00101      C                  EE   -ELECTRICAL EFFICIENCY                               000000
00101      C                  TO   -MECHANICAL TORQUE,FT-LB                             000000
00101      C                  PL   -POWER LOSS,KW                                       000000
00101      C                  EF2  -OUTPUT POWER EFFICIENCY                             000000
00101      C                  MP2  -OUTPUT MAXIMUM POWER,KW                             000000
00101      C          STATISTICS                                                        000000
00101      C                  MT   -MAXIMUM TORQUE,FT-LB                                000000
```

MO

```
00101   C              MPN -MAXIMUM OUTPUT POWER/RATED POWER                    000000
00101   C              SP-OUTPUT POWER SUM                                      000000
00101   C          INPUTS                                                       000000
00101   C              P1   -INPUT POWER,KW                                     000000
00101   C              DA   -MECHANICAL DAMPING,JOULE-SEC                       000000
00101   C              RS   -ROTOR SPEED,RPM                                    000000
00101   C              RSY -SYNCHRONOUS ROTOR SPEED,RPM                         000000
00101   C              SR   -STATOR RESISTANCE,OHMS                             000000
00101   C              VO   -RATED INPUT VOLTAGE,VOLTS                          000000
00101   C              RAP -RATED INPUT POWER,KW                                000000
00101   C              RAS -RATED PWER SLIP                                     000000
00101   C              EFI -INPUT PRODUCT EFFICIENCY                            000000
00101   C              MPI -MAXIMUM INPUT POWE,KW                               000000
00101   C              CC   -CAPITAL COST/YEAR,$                                000000
00101   C              CM   -MAINTENANCE COST/YEAR,$                            000000
00101   C                                                                       000000
00103         COMMON /CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX             000000
00103        X     /COST/CCI,CMI,COP,VDE,TDE,TLD,UTV,UTD                        000000
00104         REAL MP2,MT,MPN,MP1                                               000000
00104   C                                                                       000000
00105         IF(IMPL.GT.0)GO TO 100                                            000000
00107         IF(DA.EQ..99999)DA=0.                                             000002
00111         IF(RSY.EQ..99999)RSY=1800.                                        000006
00113         IF(SR.EQ..99999)SR=8./RAP                                         000013
00115         IF(VO.EQ..99999)VO=400.                                           000021
00117         IF(MP1.EQ..99999)MP1=1.E8                                         000026
00121         IF(RAS.EQ..99999)RAS=.05                                          000033
00123         TMAX1=TMAX*.99999                                                 000040
00124         MT=0.                                                             000043
00125         MPN=0.                                                            000044
00126         SP=0.                                                             000045
00127         TINC=DUM(7)*.5                                                    000046
00127   C                                                                       000046
00127   C              COMPUTE ELECTRICAL EFFICIENCY                            000046
00127   C                                                                       000046
00130         EE=1.-SR*RAP*1000./(VO*VO)                                        000051
00131     100 IF(P1.LE.RAP)GO TO 200                                            000062
00133         IF(IMPL.EQ.2)WRITE(6,208)P1,RAP                                   000065
00140     208 FORMAT(1H0,18H MOTOR INPUT POWER,F12.3,23H .GT.RATED INPUT POWER ,  000077
00140        1  F12.3)                                                          000077
00141         IF(IMPL.EQ.2)ICNT=ICNT+1                                          000077
00143     200 SLIP=1.-(RS/RSY)                                                  000106
00144         IF(SLIP.LE.RAS)GO TO 300                                          000111
00146         IF(IMPL.EQ.2)WRITE(6,308)SLIP,RAS                                 000114
00153     308 FORMAT(1H0,11H MOTOR SLIP,F12.3,25H EXCEEDS RATED POWER SLIP,     000126
00153        1  F12.3)                                                          000126
00154         IF(IMPL.EQ.2)ICNT=ICNT+1                                          000126
00154   C                                                                       000126
00154   C              COMPUTE POWER AND POWER LOSS                             000126
00154   C                                                                       000126
00156     300 OMEGA=RS*3.14159/30.                                              000135
00157         P2=EE*P1-DA*OMEGA*OMEGA/1000.                                     000140
00160         PL=P1-P2                                                          000147
00161         TO=0.                                                             000151
00162         IF(P2.GT.0.)GO TO 400                                             000152
00164         IF(P1.LE.0.)GO TO 409                                             000155
00166         IF(IMPL.EQ.2)WRITE(6,408)SR,DA                                    000160
```

```
C0173        408 FORMAT(1H0,19H STATOR RESISTANCE  ,F12.3,12H OR DAMPING ,          000172
00173           XF12.3,20H TOO HIGH FOR MOTOR  )                                   000172
00174             IF(IMPL.EQ.2)ICNT=ICNT+1                                          000172
00174        C                                                                      000172
00174        C                 EFFICIENCY AND MAXIMUM OUTPUT POWER                  000172
C0174        C                                                                      000172
00176        409  CONTINUE                                                          000201
00177             P2=0.                                                             000201
00200             EF2=EF1                                                           000201
00201             MP2=AMIN1(MP1,RAP)                                                000203
00202             GO TO 500                                                         000211
00203        400  EF2=EF1*P2/P1                                                     000213
00204             MP2=AMIN1(MP1,RAP)*P2/P1                                          000216
00205             IF(RS.NE.0.)TO=P2*737.6/OMEGA                                     000226
00205        C                                                                      000226
00207        500  IF(IMPL.LE.1)RETURN                                               000235
00207        C                                                                      000235
00207        C                 STATISTICS                                           000235
00207        C                                                                      000235
00211             MT=AMAX1(TO,MT)                                                   000243
00212             MPN=AMAX1(P2/RAP,MPN)                                             000251
00213             SP=SP+P2*TINC                                                     000260
00213        C                                                                      000260
00214             IF(TIME.LT.TMAX1)RETURN                                           000264
00216             CCI=CCI+CC                                                        000273
00217             CMI=CMI+CM                                                        000276
00217        C                                                                      000276
00220             RETURN                                                            000301
00221             END                                                               000433
```

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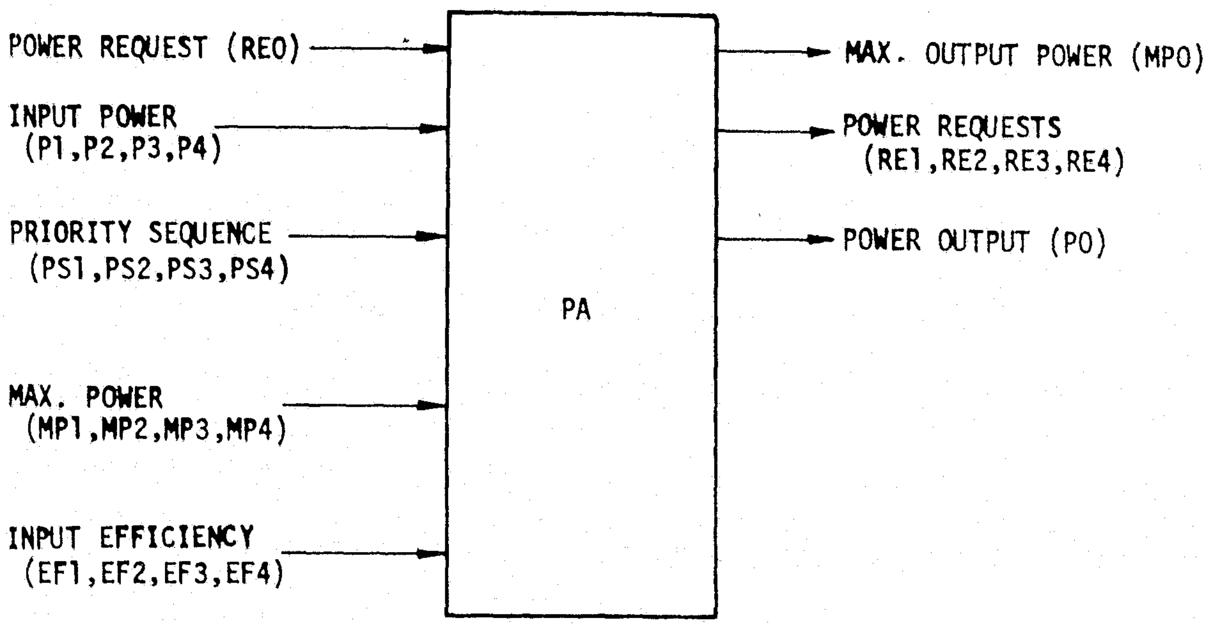
7.27 POWER ACCUMULATOR



This component sums power from four input ports and allocates power requests to each port's source of power generation. If an input power request (load) exceeds the maximum power that can be delivered by the port of highest priority, then the remaining load is allocated according to weight within priority, and then allocated to the next priority ports. (See 1.2.3 for further discussion.)

Inputs[1]

Parameter/Port		Description	Units
RE	0	Load request	kw
EF	1,2,3,4	Input efficiency from port i	-
P	1,2,3,4	Input power from port i (default = 0.)	kw
PS	1,2,3,4	Priority sequence (default=1,2,3,4)	-
F	1,2,3,4	Allocation weight (for equal priorities)	-
MP	1,2,3,4	Maximum power (default = 1×10^8)	kw

Outputs

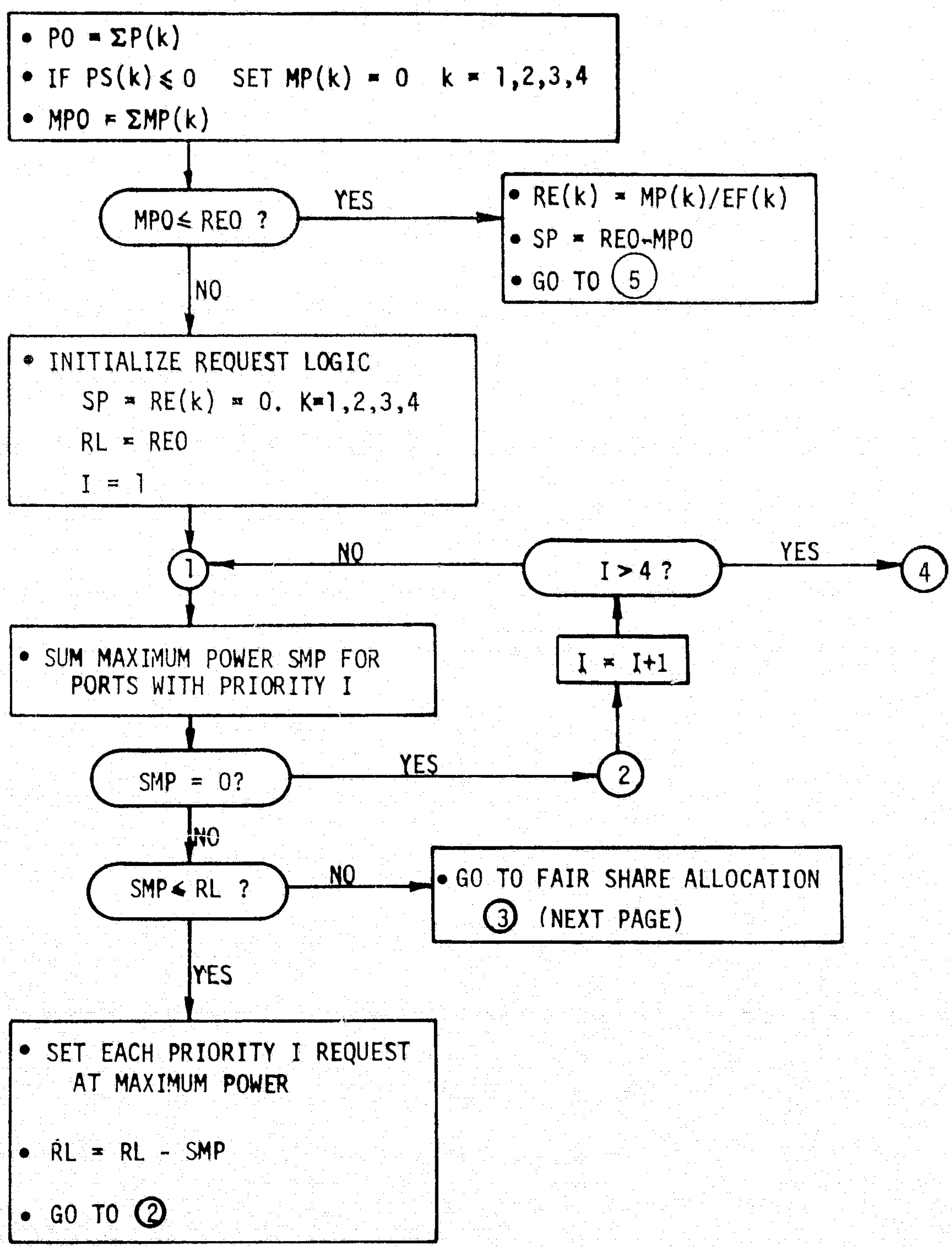
Variable/Port			
MP	0	Maximum deliverable power ($\Sigma MP(i)$)	kw
RE	1,2,3,4	Power request for port i	kw
P	0	Power output	kw
SP		Supplemental power request to meet load (Power deficit) = $RE_0 - \Sigma MP_i$	kw

Statistics

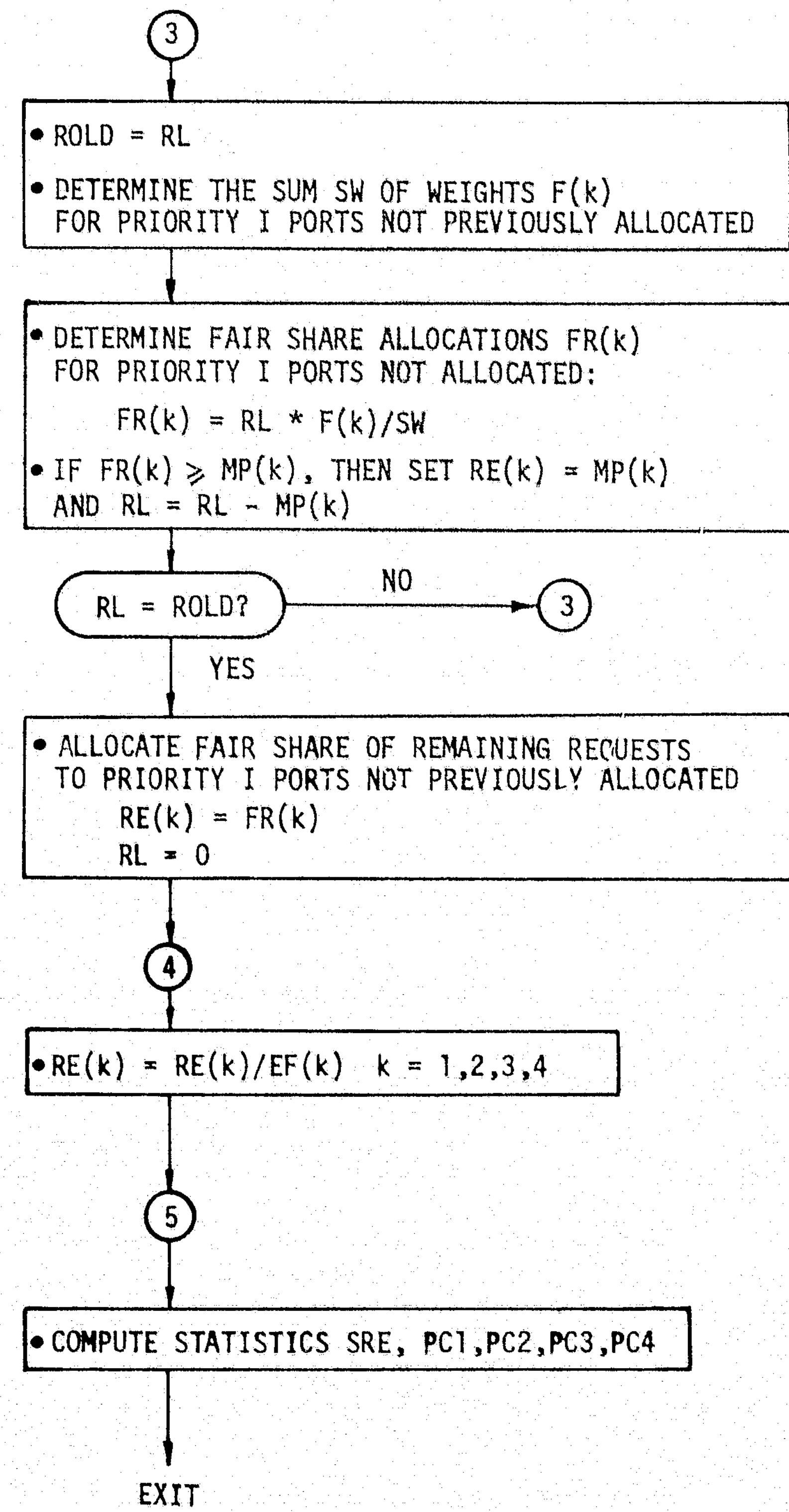
SRE		Sum of energy requested	kwh
PC	1,2,3,4	Percent of cumulative load request delivered by port i	%

1 No capital costs assigned since this is an allocation component, not a physical device.

CALCULATION LOGIC



PA FAIR SHARE ALLOCATION



```
SUBROUTINE PA          ENTRY POINT 000520

STORAGE USED  CODE(1) 000752; DATA(0) 000110; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000001
 0004   CSIMUL 000010

EXTERNAL REFERENCES (BLOCK, NAME)

 0005   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000376 1000L      0001   000401 2000L      0001   000235 234G       0001   000244 241G       0001   000264 254G
 0001   000306 273G       0001   000325 305G       0001   000363 325G       0001   000104 40L        0001   000301 400L
 0001   000417 500L       0001   000301 600L       0001   000316 700L       0001   000161 80L        0001   000353 800L
 0001   000372 900L       0004   000000 DUM        0000 R 000030 FR         0000 R 000042 FRU        0000 I 000037 I
 0003 I 000000 IMPL       0000   000055 INJP$      0000 I 000041 K          0000 R 000034 LL         0000 R 000035 LOLD
 0000 R 000014 MP         0000 R 000004 PR         0000 R 000000 R          0000 R 000024 SMP        0000 R 000044 SRI
 0000 R 000043 SRO        0000 R 000020 SW         0004 R 000006 TINC       0000 R 000036 TINC1      0004   000007 TMAX
 0000 R 000010 W          0000 R 000040 XI


00100      CPA                                                             000000
00101            SUBROUTINE PA(MPO,                                        000000
00101           1        R1, R2, R3, R4,                                   000000
00101           2        PO,SP,                                            000000
00101           3        SR,PC1,PC2,PC3,PC4,                               000000
00101           4        RO,                                               000000
00101           4        EF1, EF2, EF3, EF4,                               000000
00101           5        P1, P2, P3, P4,                                   000000
00101           6        PR1, PR2, PR3, PR4,                               000000
00101           7        W1, W2, W3, W4,                                   000000
00101           8        MP1, MP2, MP3, MP4)                               000000
00101      C                                                               000000
00101      C    PURPOSE.   MODEL POWER ACCUMULATOR                         000000
00101      C                                                               000000
00101      C    METHOD.  PRIMARY REQUEST ALLOCATION RESULTING FROM PRIORITY    000000
00101      C    ASSIGNMENTS.  SECONDARY REQUEST ALLOCATION RESULTING       000000
00101      C    FROM WEIGHT ASSIGNMENTS.                                   000000
00101      C    THAT IS, REQUESTS ARE ALLOCATED ACCORDING TO                000000
00101      C      *  PORT PRIORITY (HIGHEST PRIORITY = 1)                  000000
00101      C      *  PORT WEIGHTS (IN CASE OF EQUAL PRIORTIES.  )          000000
00101      C                                                               000000
00101      C    FORMAL ARGUMENT DEFINITION.                                000000
00101      C    R1,...., R4      POWER REQUESTS IN KW      (OUTPUTS)       000000
```

PA

```
00101      C     HPO              TOTAL MAXIMUM POWER       (OUTPUT)             000000
00101      C     SP               SURPLUS REQUEST           (OUTPUT)             000000
00101      C     PO               TOTAL LOAD IN KW          (OUTPUT)             000000
00101      C     SR               SUM OF ENERGY REQUESTED, KWH (OUTPUT)          000000
00101      C     PC1,...,PC4      PERCENT OF CUM LOAD DELIVERED (OUTPUT)         000000
00101      C     RO               TOTAL POWER REQUESTED,KW (INPUT)               000000
00101      C     P1,..., P4       INPUT POWER IN KW         (INPUTS)             000000
00101      C     PR1,..., PR4     PORT PRIORITIES           (INPUTS)             000000
00101      C     W1,..., W4       PORT WEIGHTS              (INPUTS)             000000
00101      C     MP1, ..., MP4      MAXIMUM POWERS          (INPUTS)             000000
00101      C     EF1, ..., EF4      EFFICIENCIES            (INPUTS)             000000
00101      C      COMMON STORAGE                                                 000000
00103             COMMON/ CIMPL / IMPL                                           000000
00104             COMMON / CSIMUL / DUM(6), TINC, TMAX                           000000
00105            REAL MPO,MP1,MP2,MP3,MP4                                        000000
00105      C                                                                     000000
00105      C     LOCAL VARIABLES                                                 000000
00105      C                                                                     000000
00105      C                                                                     000000
00105      C     R(K) IS THE POWER REQUEST AT PORT K                             000000
00106            REAL R(4)                                                       000000
00106      C                                                                     000000
00106      C     PR(K) IS THE PRIORITY ASSIGNED TO PORT K                        000000
00107            REAL PR(4)                                                      000000
00107      C                                                                     000000
00107      C     W(K) IS THE WEIGHT ASSIGNED TO PORT K                           000000
00110            REAL W(4)                                                       000000
00110      C                                                                     000000
00110      C     MP(K) IS MAXIMUM POWER TO BE ALLOCATED TO PORT K                000000
00111            REAL MP(4)                                                      000000
00111      C                                                                     000000
00111      C     SW(I) IS THE SUM OF THE WEIGHTS ASSIGNED TO PRIORITY-I PORTS    000000
00112            REAL SW(4)                                                      000000
00112      C                                                                     000000
00112      C     SMP(I) IS THE SUM OF THE MAXIMUM POWER AT PRIORITY-I PORTS      000000
00113            REAL SMP(4)                                                     000000
00113      C                                                                     000000
00113      C     FRU IS "FAIR SHARE" UNIT FOR PRIORITY-I PORTS                   000000
00113      C                                                                     000000
00113      C     FR(K) IS THE COMPUTED "FAIR SHARE" REQUEST FOR PORT K           000000
00114            REAL FR(4)                                                      000000
00114      C                                                                     000000
00114      C     LL IS THE LOAD LEFT AT EACH POINT IN THE ITERATION              000000
00115            REAL LL,LOLD                                                    000000
00115      C                                                                     000000
00115      C     IF IMPL IS ZERO, THEN ASSIGN DEFAULT VALUES                     000000
00116            IF (IMPL .GT. 0) GO TO 40                                       000000
00120            RO = 0.0                                                        000002
00121            IF (PR1 .EQ. 0.99999) PR1 = 1.0                                 000003
00123            IF (PR2 .EQ. 0.99999) PR2 = 2.0                                 000010
00125            IF (PR3 .EQ. 0.99999) PR3 = 3.0                                 000015
00127            IF (PR4 .EQ. 0.99999) PP4 = 4.0                                 000022
00131            IF (MP1 .EQ. 0.99999) MP1 = 1.0E8                               000027
00133            IF (MP2 .EQ. 0.99999) MP2 = 1.0E8                               000034
00135            IF (MP3 .EQ. 0.99999) MP3 = 1.0E8                               000041
00137            IF (MP4 .EQ. 0.99999) MP4 = 1.0E8                               000046
00141            IF(P1  .EQ. .99999) P1=0.0                                      000053
```


PA

```
00143              IF(P2  .EQ. .99999) P2=0.0                                    000057
00145              IF(P3  .EQ. .99999) P3= 0.0                                   000063
00147              IF(P4  .EQ. .99999) P4=0.0                                    000067
00151              SR=0.                                                         000073
00152              PC1=0.                                                        000074
00153              PC2=0.                                                        000075
00154              PC3=0.                                                        000076
00155              PC4=0.                                                        000077
00156              TINC1= 0.5*TINC                                               000100
00157           40 CONTINUE                                                      000104
00157        C                                                                   000104
00157        C     IF THE TOTAL MAXIMUM POWER IS .LE. TOTAL POWER                000104
00157        C     REQUESTED, THEN SUBMIT REQUESTS AT MAX-POWER, SET REQUEST     000104
00157        C     SURPLUS EQUAL TO THE DIFFERENCE, AND RETURN                   000104
00160              PC = P1 + P2 + P3 + P4                                        000104
00161              IF(PR1.LE.0.0) MP1=0.                                         000110
00163              IF(PR2.LE.0.0) MP2=0.                                         000114
00165              IF(PR3.LE.0.0) MP3=0.                                         000120
00167              IF(PR4.LE.0.0) MP4=0.                                         000124
00171              MPO = MP1 + MP2 + MP3 + MP4                                   000130
00172              IF (MPO .GT. RO) GO TO 80                                     000135
00174              R1 = MP1/EF1                                                  000140
00175              R2 = MP2/EF2                                                  000143
00176              R3 = MP3/EF3                                                  000146
00177              R4 = MP4/EF4                                                  000151
00200              SP = RO - MPO                                                 000154
00201              GO TO 500                                                     000157
00202           80 CONTINUE                                                      000161
00202        C                                                                   000161
00202        C     PROCEED WITH ALLOCATION ALGORITHM SINCE THE SUM OF            000161
00202        C     ALL MAXIMUM POWER INPUTS EXCEEDS THE TOTAL REQUEST RO         000161
00202        C                                                                   000161
00202        C     INITIALIZATION                                                000161
00203              LL = RO                                                       000161
00204              R1 = 0.0                                                      000162
00205              R2 = 0.0                                                      000163
00206              R3 = 0.0                                                      000164
00207              R4 = 0.0                                                      000165
00210              SP = 0.0                                                      000166
00210        C                                                                   000166
00210        C     IF THE TOTAL REQUEST (OR LOAD) IS ZERO, THEN RETURN           000166
00211              IF (RO .LE. 0.0) GO TO 500                                    000167
00213              R(1)=R1                                                       000171
00214              R(2)=R2                                                       000173
00215              R(3)=R3                                                       000175
00216              R(4)=R4                                                       000177
00217              PR(1) = PR1                                                   000201
00220              PR(2) = PR2                                                   000203
00221              PR(3) = PR3                                                   000205
00222              PR(4) = PR4                                                   000207
00223              W(1) = W1                                                     000211
00224              W(2) = W2                                                     000213
00225              W(3) = W3                                                     000215
00226              W(4) = W4                                                     000217
00227              MP(1) = MP1                                                   000221
00230              MP(2) = MP2                                                   000223
00231              MP(3) = MP3                                                   000225
```

```
00232         MP(4) = MP4                                               000227
00232   C                                                               000227
00232   C                                                               000227
00232   C     ITERATE ON PRIORITY I FOR I = 1, 2, 3, 4                  000227
00232   C                                                               000227
00233         DO 1000 I = 1, 4                                          000235
00233   C                                                               000235
00236         XI = I                                                    000235
00236   C     OBTAIN SUM OF MAXIMUM POWER FOR PORTS WITH PRIORITY I     000235
00237         SMP(I) = 0.0                                              000240
00240         DO 100 K = 1, 4                                           000244
00243         IF (PR(K) .EQ. XI) SMP(I) = SMP(I) + MP(K)                000244
00245     100 CONTINUE                                                  000253
00245   C                                                               000253
00245   C     IF NO PRIORITY-I MAXIMUM POWER EXISTS, THEN PROCEED WITH  000253
00245   C     THE NEXT HIGHER PRIORITY                                  000253
00247         IF (SMP(I) .EQ. 0.0) GO TO 1000                           000253
00247   C                                                               000253
00247   C     IF THE SUM OF ALL PRIORITY-I MAXIMUM POWER .GT. LOAD      000253
00247   C     LEFT, THEN GO AROUND                                      000253
00251         IF (SMP(I) .GT. LL) GO TO 400                             000255
00251   C                                                               000255
00251   C     THE SUM OF ALL PRIORITY-I MAXIMUM POWER .LE. LOAD         000255
00251   C     LEFT, SO SUBMIT EACH PRIORITY-I REQUEST                   000255
00253         DO 200 K = 1, 4                                           000264
00256         IF (PR(K) .EQ. XI) R(K) = MP(K)                           000264
00260     200 CONTINUE                                                  000272
00260   C                                                               000272
00260   C     UPDATE LOAD LEFT                                          000272
00262         LL = LL - SMP(I)                                          000272
00262   C                                                               000272
00262   C     IF THE REMAINING LOAD IS ZERO, THEN EXIT THE ITERATION    000272
00263         IF (LL .LE. 0.0) GO TO 2000                               000275
00263   C                                                               000275
00263   C     OTHERWISE, PROCEED WITH NEXT HIGHER PRIORITY              000275
00265         GO TO 1000                                                000277
00265   C                                                               000277
00266     400 CONTINUE                                                  000301
00266   C                                                               000301
00266   C     THE SUM OF THE PRIORITY-I MAXIMUM POWER EXCEEDS THE       000301
00266   C     LOAD LEFT, SO COMPUTE AND SUBMIT FAIR SHARE REQUESTS      000301
00266   C      TO EACH PRIORITY-I PORT                                  000301
00266   C                                                               000301
00267     600 CONTINUE                                                  000301
00267   C                                                               000301
00267   C     SAVE LL FOR LATER REFERENCE                               000301
00270         LOLD = LL                                                 000301
00270   C                                                               000301
00270   C     DETERMINE FAIR SHARE UNITS FOR ALL PRIORITY-I             000301
00270   C     PORTS TO WHICH NO REQUEST HAS BEEN SUBMITTED              000301
00271         SW(I) = 0.0                                               000302
00272         DO 700 K = 1, 4                                           000306
00275         IF (R(K) .NE. 0.0) GO TO 700                              000306
00277         IF (PR(K) .EQ. XI) SW(I) = SW(I) + W(K)                   000307
00301     700 CONTINUE                                                  000317
00303         FRU = 1.0 / SW(I)                                         000317
00303   C                                                               000317
```

PA

```
00303   C      FIRST, SUBMIT FAIR SHARE REQUESTS TO PORTS FOR WHICH THE          000317
00303   C      FAIR SHARE REQUEST EXCEEDS THE MAXIMUM POWER.  CONSIDER ONLY      000317
00303   C      PORTS TO WHICH NO REQUEST HAS BEEN SUBMITTED                      000317
00304          DO 800 K = 1, 4                                                   000325
00307          IF (R(K) .NE. 0.0) GO TO 800                                      000325
00311          IF (PR(K) .NE. XI) GO TO 800                                      000326
00311   C                                                                        000326
00311   C      COMPUTE FAIR SHARE                                                000326
00313          FR(K) = (W(K) * FRU) * LL                                         000331
00313   C                                                                        000331
00313   C      IF FAIR SHARE EXCEEDS MAXIMUM POWER, THEN SUBMIT REQUEST          000331
00314          IF (FR(K) .GE. MP(K)) R(K) = MP(K)                                000335
00314   C      - - - AND REDUCE LOAD LEFT TALLY                                  000335
00316          IF (FR(K) .GE. MP(K)) LL = LL - MP(K)                             000343
00320      800 CONTINUE                                                          000354
00320   C                                                                        000354
00320   C      IF LL .NE. LOLD, THEN LL WAS REDUCED DURING THE                   000354
00320   C      PROCESSING IN THE "DO 800" LOOP ABOVE.  THIS CHANGES              000354
00320   C      THE FAIR SHARE COMPUTATION.  IT IS THEREFORE                      000354
00320   C      NECESSARY TO GO BACK THROUGH THE "DO 800" LOOP IN                 000354
00320   C      ORDER TO RECONSIDER ANY PORT WHICH MAY NOW                        000354
00320   C      SATISFY THE REQUIREMENT THAT FR(K) .GE. MP(K).  ONLY              000354
00320   C      PRIORITY-I PORTS TO WHICH NO REQUEST HAS BEEN                     000354
00320   C      MADE ARE ELIGIBLE FOR RECONSIDERATION                             000354
00322          IF (LL .LT. LOLD) GO TO 600                                       000354
00322   C                                                                        000354
00322   C      FINALLY, SUBMIT REQUESTS TO THOSE PORTS FOR WHICH THE FAIR SHARE  000354
00322   C      .LT. THAN THEIR MAXIMUM POWER.  CONSIDER ONLY                     000354
00322   C      PRIORITY-I PORTS TO WHICH NO REQUEST HAS BEEN SUBMITTED           000354
00324          DO 900 K = 1, 4                                                   000363
00327          IF (R(K) .NE. 0.0) GO TO 900                                      000363
00331          IF (PR(K) .NE. XI) GO TO 900                                      000364
00333          R(K) = FR(K)                                                      000367
00334      900 CONTINUE                                                          000373
00336          LL=0.0                                                            000373
00337          GO TO 2000                                                        000374
00337   C                                                                        000374
00340     1000 CONTINUE                                                          000401
00340   C                                                                        000401
00342     2000 CONTINUE                                                          000401
00342   C                                                                        000401
00342   C      FINALLY, ASSIGN OUTPUTS TO NON-SUBSCRIPTED FORMAL PARAMETERS.     000401
00342   C      ALSO, MODIFY ALL REQUESTS ACCORDING TO THE INPUT EFFICIENCIES     000401
00343          R1 = R(1) / EF1                                                   000401
00344          R2 = R(2) / EF2                                                   000403
00345          R3 = R(3) / EF3                                                   000406
00346          R4 = R(4) / EF4                                                   000411
00347          SP = LL                                                           000414
00350      500 IF(IMPL.LE.1) RETURN                                              000417
00352          SPO= SR                                                           000425
00353          SR=SR+ RO*TINC1                                                   000427
00354          IF(SR.LE.0.) RETURN                                               000433
00356          SRO=SRO/SR                                                        000441
00357          SRI= TINC1*100./SR                                                000444
00360          PC1= PC1*SRO + P1*SRI                                             000450
00361          PC2= PC2*SRO + P2*SRI                                             000454
00362          PC3= PC3*SRO + P3*SRI                                             000462
```

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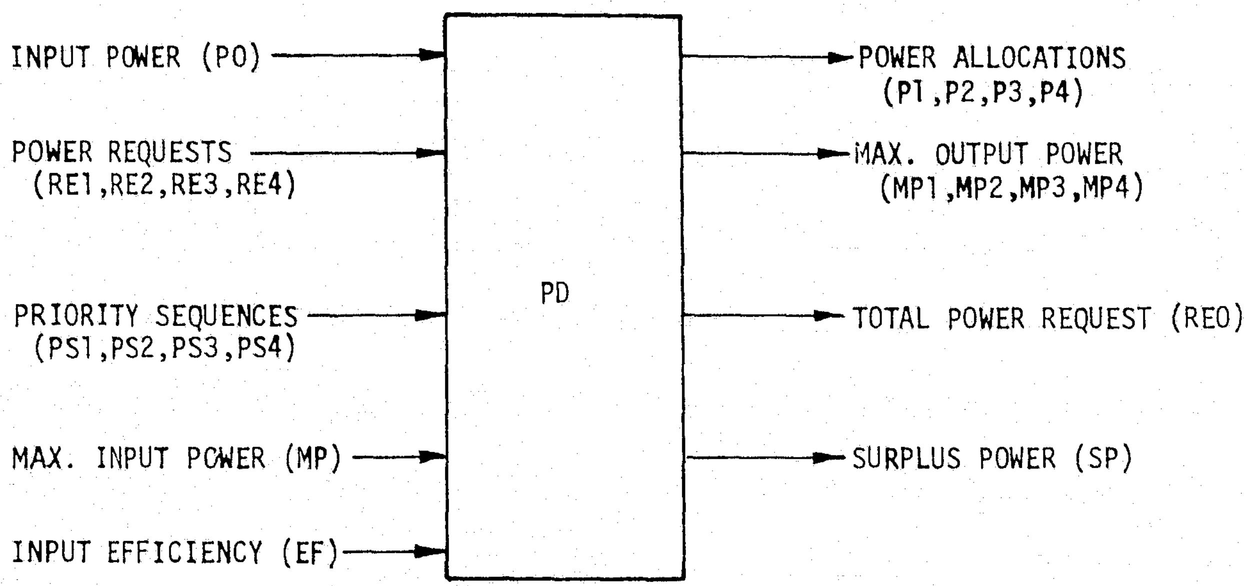
```
00363     252*          PC4= PC4*SRO + P4*SRI                                  000470
00364     253*          RETURN                                                 000476
00365     254*          END                                                    000751
```

7.28 POWER DIVIDER



This component allocates power to four ports plus surplus based on priority, port requests, and allocation weights for equal priority ports. Each port is assigned a priority sequence from 1 to 4, and a weighting $F_i>0$, i=1,2,3,4 for proportional allocation among equal priority ports. If power available exceeds the power requested for a set of ports of equal priority, then the remaining power is allocated to ports having the next highest priority. If power available is less than the power requested for ports of equal priority then power is allocated between them in proportion to their respective allocation weights.

The total power request is the sum of the port requests divided by input efficiency. The maximum power outputs MP1,...MP4 are necessary for direct connections to a power accumulator PA. These variables may be used as maximum power inputs to other components, although such connections are not required. (See 1.2.3 for further discussion.)

PD

Inputs[1]

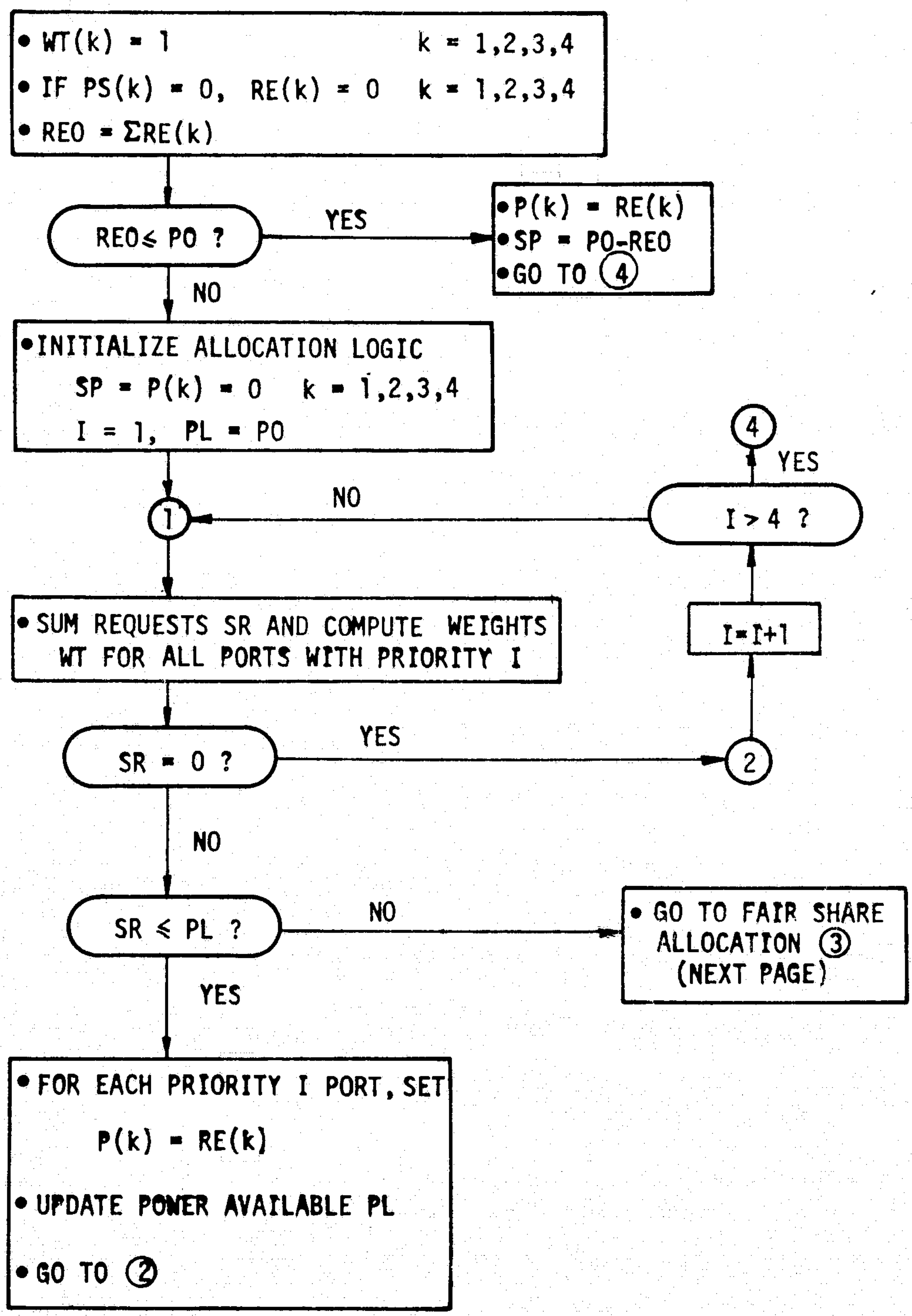
Parameter/Port		Description	Units
P	0	Input power	kw
RE	1,2,3,4	Power requests of output ports	kw
PS	1,2,3,4	Priority sequence (default = 1,2,3,4)	–
F	1,2,3,4	Allocation weight (for equal priorities)	–
MP		Maximum input power (default = 1×10^8)	kw
EF		Input efficiency	–

Outputs

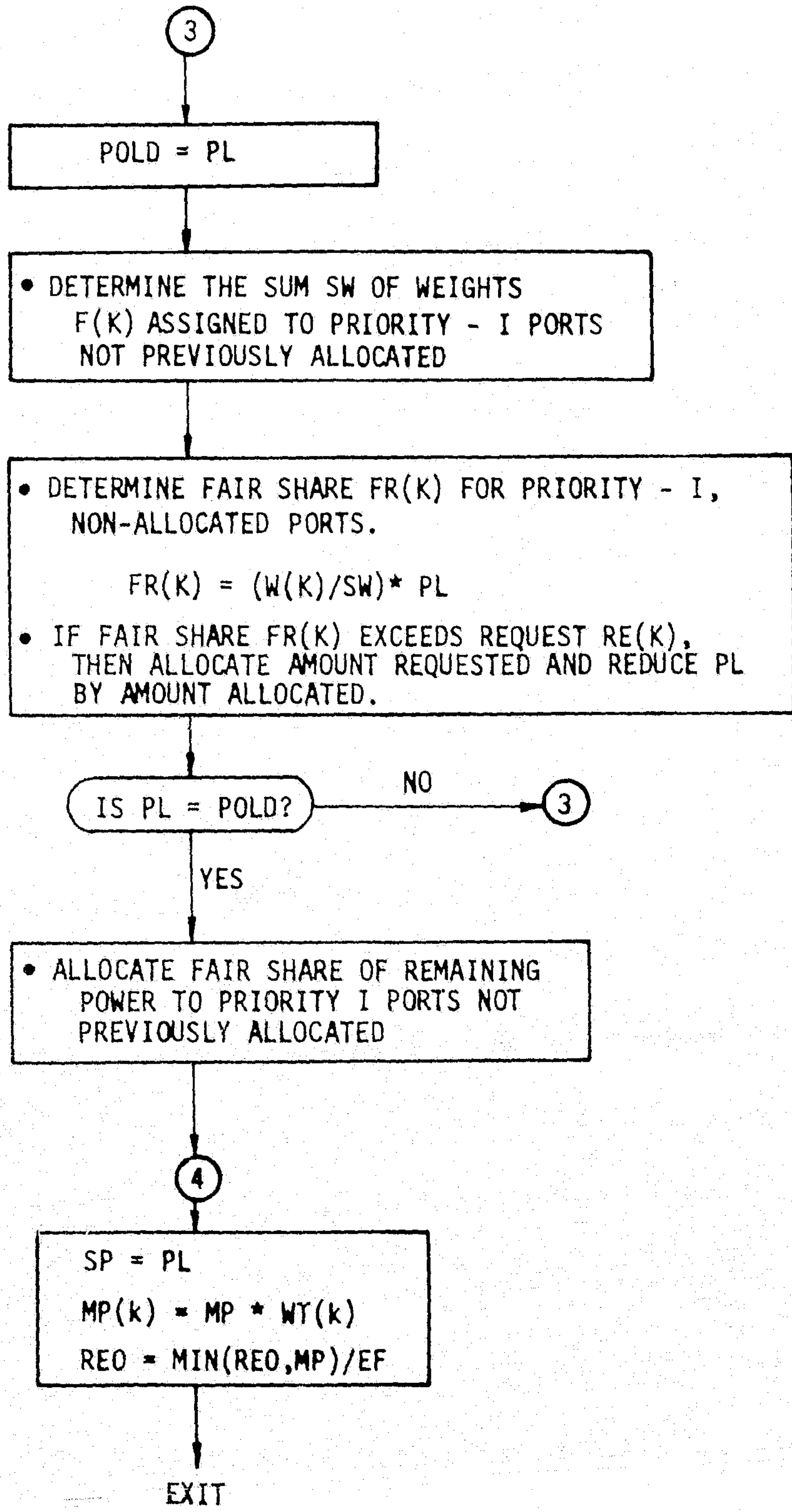
Variable/Port			
P	1,2,3,4	Output power for port i	kw
RE	0	Output power request	kw
SP		Surplus power	kw
MP	1,2,3,4	Output maximum power based on MP	kw

1 No capital costs assigned since this is an allocation component, not a physical device.

CALCULATION LOGIC



PD FAIR SHARE ALLOCATION



```
SUBROUTINE PD          ENTRY POINT 000452

STORAGE USED  CODE(1) 000642; DATA(0) 000106; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0004   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000371 100L     0001     000172 216G     0001     000202 224G     0001     000263 253G     0001     000303 270G
 0001     000406 300L     0001     000322 302G     0001     000357 322G     0001     000045 40L      0001     000276 [illegible]
 0001     000276 600L     0001     000313 750L     0001     000116 80L      0001     000350 800L     0001     000366 900L
 0000 R   000030 FR       0000 R   000046 FRU      0000 R   000035 F1       0000 R   000036 F2       0000 R   000037 F3
 0000 R   000040 FR       0000 I   000041 I        0003 I   000000 IMPL     0000     000055 INJP$    0000 I   000044 K
 0000 R   000000 P        0000 R   000034 PL       0000 R   000045 POLD     0000 R   000010 PR       0000 R   000004 R
 0000 R   000024 SR       0000 R   000020 SW       0000 R   000014 W        0000 R   000043 WT       0000 R   000042 XI
```

```
00100     CPD                                                              000000
00101           SUBROUTINE PD(                                             000000
00101          1     P1, P2, P3, P4,                                       000000
00101          2     R0,                                                   000000
00101          3     SP,PM1,PM2,PM3,PM4,                                   000000
00101          4     P0,                                                   000000
00101          5     R1, R2, R3, R4,                                       000000
00101          6     PR1, PR2, PR3, PR4,                                   000000
00101          7     W1, W2, W3, W4, PM, EF)                               000000
00101     C                                                                000000
00101     C     PURPOSE.   MODEL POWER DIVIDER                             000000
00101     C                                                                000000
00101     C     METHOD.   PRIMARY FLOW ALLOCATION RESULTING FROM PRIORITY  000000
00101     C     ASSIGNMENTS.   SECONDARY FLOW ALLOCATION RESULTING         000000
00101     C     FROM WEIGHT ASSIGNMENTS.                                   000000
00101     C     THAT IS, TOTAL AVAILABLE POWER IS ALLOCATED                000000
00101     C     ACCORDING TO                                               000000
00101     C       *  PORT REQUESTS                                         000000
00101     C       *  PORT PRIORITY (HIGHEST PRIORITY = 1)                  000000
00101     C       *  PORT WEIGHTS (IN CASE OF EQUAL PRIORTIES)             000000
00101     C                                                                000000
00101     C     ALLOCATION SCHEME.                                         000000
00101     C     IS SUM OF ALL REQUESTS .LT. POWER AVAILABLE PO             000000
00101     C     YES.                                                       000000
00101     C       FULFILL EACH PEQUEST                                     000000
```


PD

```
00101     C         UPDATE POWER AVAILABLE                                   000000
00101     C         EXIT                                                     000000
00101     C       NO.                                                        000000
00101     C         IS SUM OF ALL PRIORITY-1 REQUESTS .LT. PD                000000
00101     C         YES.                                                     00000C
00101     C           FULFILL EACH PRIORITY-1 REQUEST                        000000
00101     C           UPDATE POWER AVAILABLE (TO PL)                         000000
00101     C           GO ON TO PRIORITY-2 REQUESTS                           000000
00101     C         NO.                                                      000000
00101     C           ALLOCATE "FAIR SHARE" TO EACH PRIORITY-1 PORT          000000
00101     C           EXIT.                                                  000000
00101     C           IS SUM OF ALL PRIORITY-2 REQUESTS .LT. PL              00000C
00101     C                                                                  000000
00101     C        AND SO ON AND SO FORTH                                    000000
00101     C                                                                  00000C
00101     C       FORMAL ARGUMENT DEFINITION.                                000000
00101     C       P1,..., P4      POWER ALLOCATIONS IN KW  (OUTPUTS)         000000
00101     C       RC             TOTAL POWER REQUESTED    (OUTPUT)           000000
00101     C       SP              SURPLUS POWER            (OUTPUT)          000000
00101     C       PM1,...,PM4   PORT MAXIMUM OUTPUT POWER IN KW      (OUTPUT) 000000
00101     C       PO              TOTAL POWER INPUT IN KW  (INPUT)           000000
00101     C       R1,..., R4      PORT REQUESTS IN KW      (INPUTS)          000000
00101     C       PR1,...., PR4   PORT PRIORITIES          (INPUTS)          000000
00101     C       W1,..., W4      PORT WEIGHTS            (INPUTS)           000000
00101     C       PM              MAXIMUM INPUT POWER IN KW  (INPUT)         000000
00101     C       EF              INPUT EFFICIENCY      (INPUT)              000000
00101     C                                                                  000000
00101     C        COMMON STORAGE                                            000000
00103              COMMON/ CIMPL / IMPL                                      000000
00103     C                                                                  000000
00103     C       LOCAL VARIABLES                                            000000
00103     C                                                                  000000
00103     C       P(K) IS THE POWER ALLOCATED TO PORT K                      000000
00104             REAL P(4)                                                  00000C
00104     C                                                                  000000
00104     C       R(K) IS THE POWER REQUEST AT PORT K                        000000
00105             REAL R(4)                                                  000000
00105     C                                                                  000000
00105     C       PR(K) IS THE PRIORITY ASSIGNED TO PORT K                   000000
00106             REAL PR(4)                                                 000000
00106     C                                                                  000000
00106     C       W(K) IS THE WEIGHT ASSIGNED TO PORT K                      000000
00107             REAL W(4)                                                  000000
00107     C                                                                  000000
00107     C       SW(I) IS THE SUM OF THE WEIGHTS ASSIGNED TO PRIORITY-I PORTS 00000C
00110             REAL SW(4)                                                 000000
00110     C                                                                  000000
00110     C       SR(I) IS THE SUM OF THE REQUESTS AT PRIORITY-I PORTS       000000
00111             REAL SR(4)                                                 000000
00111     C                                                                  000000
00111     C       FRU IS "FAIR SHARE" UNIT FOR PRIORITY-I PORTS              000000
00111     C                                                                  000000
00111     C       FR(K) IS THE COMPUTED "FAIR SHARE" ALLOCATION TO PORT K    000000
00112             REAL FR(4)                                                 000000
00112     C                                                                  000000
00112     C       PL IS THE POWER LEFT AT EACH POINT IN THE ITERATION        00000C
00113             REAL PL                                                    000000
```

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00113  C                                                            000000
00113  C     IF IMPL IS ZERO, THEN ASSIGN DEFAULT VALUES            000000
00114        IF (IMPL .GT. 0) GO TO 40                              000000
00116        R1 = 0.0                                               000002
00117        R2 = 0.0                                               000003
00120        R3 = 0.0                                               000004
00121        R4 = 0.0                                               000005
00122        IF(PM.EQ. .99999) PM=1.E8                              000036
00124        IF (PR1 .EQ. 0.99999) PR1 = 1.0                        000013
00126        IF (PR2 .EQ. 0.99999) PR2 = 2.0                        000020
00130        IF (PR3 .EQ. 0.99999) PR3 = 3.0                        000025
00132        IF (PR4 .EQ. 0.99999) PR4 = 4.0                        000032
00134        IF(PM .EQ. .99999) PM= 1.E8                            000037
00134  C                   INITIALIZATION OF F"S                    000037
00134  C                                                            000037
00136     40 CONTINUE                                               000045
00137        F1= 1.                                                 000045
00140        F2= 1.                                                 000046
00141        F3= 1.                                                 000047
00142        F4= 1.                                                 000050
00142  C                                                            000050
00142  C     IF THE TOTAL POWER REQUESTED IS .LE. TOTAL POWER       000050
00142  C     INPUT, THEN SATISFY REQUESTS, SET POWER SURPLUS        000050
00142  C     EQUAL TO THE DIFFERENCE, AND RETURN                    000050
00143        IF(PR1.LE.0.0) R1=0.0                                  000051
 0145        IF(PR2.LE.0.0) R2=0.0                                  000055
00147        IF(PR3.LE.0.0) R3=0.0                                  000061
00151        IF(PR4.LE.0.0) R4=0.0                                  000065
00153        RO = R1 + R2 + R3 + R4                                 000071
00154        IF (RO .GT. PO) GO TO 80                               000076
00156        P1 = R1                                                000101
00157        P2 = R2                                                000103
00160        P3 = R3                                                000105
00161        P4 = R4                                                000107
00162        SP = PO - RO                                           000111
00163        GO TO 3000                                             000114
00164     80 CONTINUE                                               000116
00164  C                                                            000116
00164  C     PROCEED WITH ALLOCATION ALGORITHM SINCE THE SUM OF     000116
00164  C     ALL REQUESTS EXCEEDS THE TOTAL AVAILABLE POWER PO      000116
00164  C                                                            000116
00164  C     INITIALIZATION                                         000116
00165        PL = PO                                                000116
00166        P1 = 0.0                                               000117
00167        P2 = 0.0                                               000120
00170        P3 = 0.0                                               000121
00171        P4 = 0.0                                               000122
00172        SP = 0.0                                               000123
00172  C                                                            000123
00172  C     IF THE TOTAL POWER IS ZERO, THEN RETURN                000123
00173        IF (PO .EQ. 0.0) GO TO 3000                            000124
00175        P(1) = P1                                              000126
00176        P(2) = P2                                              000130
00177        P(3) = P3                                              000132
00200        P(4) = P4                                              000134
00201        R(1) = R1                                              000136
00202        R(2) = R2                                              000140
```


PD

```
00203          R(3) = R3                                          000142
00204          R(4) = R4                                          000144
00205          PR(1) = PR1                                        000146
00206          PR(2) = PR2                                        000150
00207          PR(3) = PR3                                        000152
00210          PR(4) = PR4                                        000154
00211          W(1) = W1                                          000156
00212          W(2) = W2                                          000160
00213          W(3) = W3                                          000162
00214          W(4) = W4                                          000164
00214    C                                                        000164
00214    C                                                        000164
00214    C     ITERATE ON PRIORITY I FOR I = 1, 2, 3, 4           000164
00214    C                                                        000164
00215          DO 1000 I = 1, 4                                   000172
00215    C                                                        000172
00220          XI = I                                             000172
00220    C     OBTAIN SUM OF REQUESTS FROM PORTS WITH PRIORITY I  000172
00221          SR(I) = 0.0                                        000175
00222          WT=0.0                                             000176
00223          DO 100 K = 1, 4                                    000202
00226          IF (PR(K) .EQ. XI) SR(I) = SR(I) + R(K)            000202
00230          IF(PR(K) .EQ. XI) WT= WT+ W(K)                     000207
00232      100 CONTINUE                                           000217
00232    C                                                        000217
00234          IF(PR1 .EQ. XI) F1= W1/WT                          000217
00236          IF( PR2.EQ. XI) F2 =W2/WT                          000225
00240          IF(PR3 .EQ. XI) F3= W3/WT                          000233
00242          IF(PR4 .EQ. XI) F4= W4/WT                          000241
00244          IF(PL.LE.0.0) GO TO 1000                           000247
00244    C                                                        000247
00244    C     IF NO PRIORITY-I REQUESTS EXIST, THEN PROCEED WITH 000247
00244    C     THE NEXT HIGHER PRIORITY                           000247
00246          IF (SR(I) .EQ. 0.0) GO TO 1000                     000252
00246    C                                                        000252
00246    C     IF THE SUM OF ALL PRIORITY-I REQUESTS .GT. POWER   000252
00246    C     AVAILABLE, THEN GO AROUND                          000252
00250          IF (SR(I) .GT. PL) GO TO 400                       000254
00250    C                                                        000254
00250    C     THE SUM OF ALL PRIORITY-I REQUESTS .LE. POWER      000254
00250    C     AVAILABLE, SO FULFILL EACH PRIORITY-I REQUEST      000254
00252          DO 200 K = 1, 4                                    000263
00255          IF (PR(K) .EQ. XI) P(K) = R(K)                     000263
00257      200 CONTINUE                                           000271
00257    C                                                        000271
00257    C     UPDATE POWER AVAILABLE                             000271
00261          PL = PL - SR(I)                                    000271
00262          GO TO 1000                                         000274
00262    C                                                        000274
00263      400 CONTINUE                                           000276
00263    C                                                        000276
00263    C     THE SUM OF THE PRIORITY-I REQUESTS EXCEEDS THE     000276
00263    C     POWER AVAILABLE, SO COMPUTE AND ALLOCATE FAIR      000276
00263    C     SHARE TO EACH PRIORITY-I PORT                      000276
00263    C                                                        000276
00264      600 CONTINUE                                           000276
00264    C                                                        000276
```

PD

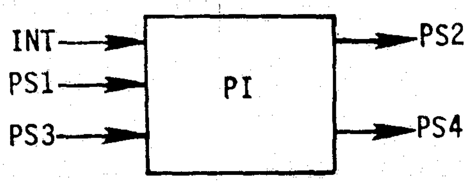
```
00264   C     SAVE PL FOR LATER REFERENCE                                   000276
00265         POLD = PL                                                     000276
00265   C                                                                   000276
00265   C     DETERMINE FAIR SHARE UNITS FOR ALL PRIORITY-I                 000276
00265   C     PORTS FOR WHICH NO ALLOCATION HAS BEEN MADE                   000276
00266         SW(I) = 0.0                                                   000277
00267         DO 700 K = 1, 4                                               000303
00272         IF (P(K) .NE. 0.0) GO TO 700                                  000303
00274         IF (PR(K) .EQ. XI) SW(I) = SW(I) + W(K)                       000304
00276     700 CONTINUE                                                      000314
00300         FRU = 1.0 / SW(I)                                             000314
00303   C                                                                   000314
00303   C     FIRST, ALLOCATE FAIR SHARE TO PORTS FOR WHICH THE             000314
00303   C     FAIR SHARE EXCEEDS THE REQUEST.  CONSIDER ONLY PRIORITY-I     000314
00303   C     PORTS, AND CONSIDER ONLY PORTS TO WHICH NO ALLOCATION         000314
00303   C     HAS YET BEEN MADE                                             000314
00301         DO 800 K = 1, 4                                               000322
00304         IF (P(K) .NE. 0.0) GO TO 800                                  000322
00306         IF (PR(K) .NE. XI) GO TO 800                                  000323
00306   C                                                                   000323
00306   C     COMPUTE FAIR SHARE                                            000323
00310         FR(K) = (W(K) * FRU) * PL                                     000326
00310   C                                                                   000326
00310   C     IF FAIR SHARE EXCEEDS REQUEST, THEN FULFILL REQUEST           000326
00311         IF (FR(K) .GE. R(K)) P(K) = R(K)                              000332
00311   C     - - - AND REDUCE AVAILABLE POWER                              000332
00313         IF (FR(K) .GE. R(K)) PL = PL - P(K)                           000340
00315     800 CONTINUE                                                      000351
00315   C                                                                   000351
00315   C     IF PL .NE. POLD, THEN PL WAS REDUCED DURING THE               000351
00315   C     PROCESSING IN THE "DO 800" LOOP ABOVE.  THIS CHANGES          000351
00315   C     THE FAIR SHARE COMPUTATION.  IT IS THEREFORE                  000351
00315   C     NECESSARY TO GO BACK THROUGH THE "DO 800" LOOP IN             000351
00315   C     ORDER TO RECONSIDER ANY PORT WHICH MAY NOW                    000351
00315   C     SATISFY THE REQUIREMENT THAT FR(K) .GE. R(K).  ONLY           000351
00315   C     PRIORITY-I PORTS FOR WHICH NO ALLOCATION HAS BEEN             000351
00315   C     MADE ARE ELIGIBLE FOR RECONSIDERATION                         000351
00317         IF (PL .NE. POLD) GO TO 600                                   000351
00317   C                                                                   000351
00317   C     FINALLY, ALLOCATE POWER TO THOSE PORTS REQUESTING             000351
00317   C     MORE THAN THEIR FAIR SHARE.  CONSIDER ONLY                    000351
00317   C     PRIORITY-I PORTS FOR WHICH NO ALLOCATION HAS BEEN MADE        000351
00321         DO 900 K = 1, 4                                               000357
00324         IF (P(K) .NE. 0.0) GO TO 900                                  000357
00326         IF (PR(K) .NE. XI) GO TO 900                                  000360
00330         P(K) = FR(K)                                                  000363
00331     900 CONTINUE                                                      000367
00333         PL = 0.0                                                      000367
00333   C                                                                   000367
00334    1000 CONTINUE                                                      000373
00334   C                                                                   000373
00334   C                                                                   000373
00334   C     FINALLY, ASSIGN OUTPUTS TO NON-SUBSCRIPTED                    000373
00334   C     FORMAL PARAMETERS                                             000373
00336         P1 = P(1)                                                     000373
00337         P2 = P(2)                                                     000375
                                                                            000377
```

PD

```
00341     254*          P4 = P(4)                         000401
00342     255*          SP = PL                           000403
00343     256*     3000 PM1=PM*F1                         000406
00344     257*          PM2=PM*F2                         000410
00345     258*          PM3=PM*F3                         000413
00346     259*          PM4=PM*F4                         000416
00347     260*           RO= AMIN1(RO,PM)/EF              000421
00350     261*          RETURN                            000430
00351     262*          END                               000641
```


PD

7.29 PRIORITY INTERRUPT



This component is used by the storage components to change priority of the power requests when minimum or maximum capacity is approached.

Inputs

Parameter/Port		Description
PS	1	Input priority for PS4 output
PS	3	Input priority for PS2 output (default=PS1)
INT		Interrupt flag

Outputs

Variable/Port		
PS	2	Output priority for charge cycle
PS	4	Output priority for discharge cycle

Equations

$$PS2 = PS1 \quad \text{if } INT=0$$

$$PS2 = 1 \quad \text{if } INT > 0$$

$$PS2 = 0 \quad \text{if } INT < 0$$

$$PS4 = PS3 \quad \text{if } INT \leq 0$$

$$PS4 = 0 \quad \text{if } INT > 0$$

```
SUBROUTINE PI        ENTRY POINT 000040

STORAGE USED  CODE(1) 000061; DATA(0) 000010; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0004   NERR3$

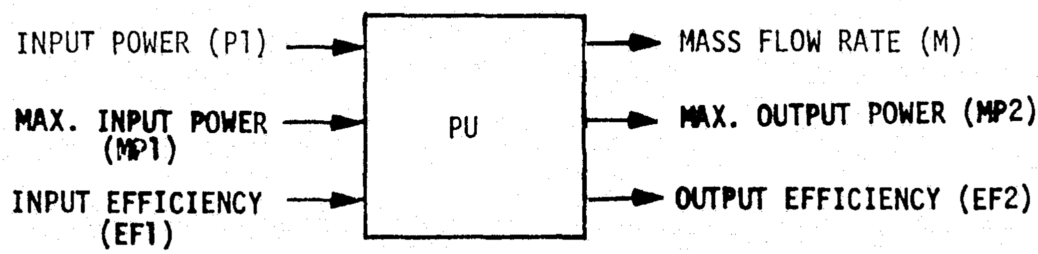
STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000010 10L        0003 I 000000 IMPL      0000   000002 INJP$


00100   CPI                                                                          000000
00101         SUBROUTINE PI(PS2,PS4,PS1,PS3,INT)                                     000000
00101   C                                                                            000000
00101   C   PURPOSE    CHANGE PRIORITY OF POWER ALLOCATION TO STORAGE COMPONENTS     000000
00101   C                                                                            000000
00101   C   WRITTEN BY A.W.WARREN                          VERSION 1, APRIL 14 1977  000000
00101   C                                                                            000000
00101   C   CALL SEQUENCE                                                            000000
00101   C             PS2 - OUTPUT PRIORITY (0 TO 4)                                 000000
00101   C             PS4 - OUTPUT PRIORITY (COMPLEMENT TO PS2)                      000000
00101   C             PS1 - INPUT PRIORITY FOR PS2                                   000000
00101   C             PS3 - INPUT PRIORITY FOR PS4                                   000000
00101   C             INT - INTERRUPT FLAG                                           000000
00101   C                   0= NO INTERRUPT                                          000000
00101   C                   1= INCREASE ALLOCATION PRIORITY                          000000
00101   C                  -1= DECREASE ALLOCATION PRIORITY                          000000
00101   C                                                                            000000
00103         REAL INT                                                               000000
00104         COMMON /CIMPL/IMPL                                                     000000
00105         IF(IMPL.GT.0) GO TO 10                                                 000000
00107         IF(PS3.EQ. .99999) PS3=PS1                                             000002
00107   C                                                                            000002
00111      10 PS2=PS1                                                                000010
00112         PS4=PS3                                                                000011
00113         IF(INT.GT.0.) PS2=1.                                                   000013
00115         IF(INT.LT.0.) PS2=0.                                                   000020
00117         IF(INT.GT.0) PS4= 0.                                                   000024
00121         RETURN                                                                 000030
00122         END                                                                    000060
```

PI

7.30 HYDRAULIC PUMP



The hydraulic pump model is based on a constant speed design. The pump is assumed to be designed to a nominal operating point and input power. For off-design performance the pump efficiency is assumed to be functionally related to the square root of the mass flow rate.

Basic Equations

The output mass flow rate is based on the equations

M = P1*EFF/(C1*C2*H1)

EFF = 1 - (1-EFD)*SQRT(MD/M)

where C1, C2 are conversion constants

Inputs

Parameter/Port		Description	Units
P	1	Input power	kw
H	1	Height of water above inlet	ft
EFD		Pump efficiency at design pt. (D = 0.90)	-
MD		Mass flow rate at design pt. (D = $2X10^5$)	gal/h
EF	1	Input product efficiency	-
MP	1	Input maximum charging rate	kw
MM		Maximum allowable mass flow rate (D = $3X10^5$)	gal/h
CK		Pump capacity cost coefficient[1] (D = 0.011)	
FØ		Pump exponent for cost calculations (D = 0.5)	-
Y		Pumphead exponent for cost calculations (D=0.25)	-

Outputs

Variable/Port		Description	Units
M		Output mass flow rate	gal/h
EFF		Pump efficiency	-
CCØ		Pump cost/year	$
EF	2	Output product efficiency	-
MP	2	Maximum output power	kw

Statistics

M2U		Maximum output mass flow rate	gal/h

D - default values

[1] CK = capital cost (known unit)/((MD*481.2)**FØ*H1 **Y * expected life time)

The calculation sequence and default values assume a constant speed hydraulic pump nominally rated for 120KW and located 200 ft. below a reservoir. The equations relating the various physical quantities and the cost estimates are based on first principles and the data presented in Reference 1, and the cost estimates on Reference 2.

Calculation Sequence

$$C1 = 0.377*10^{-6} \quad \frac{kwh}{ft-lb}$$

$$C2 = 8.3398 \text{ lb/gal}$$

1) Costs (first pass only)

$$CC = CK*(MD*481.2)^{FØ}*H1**Y$$

1. L. Marks and T. Baumeister, "Mechanical Engineers Handbook", McGraw Hill, N.Y., 1958, Section 14, p. 19.
2. Carson and Fogleman, "Comparison of Methods for Converting Existing Power Plants to Pumped Storage Facilities", International Engineering Company, Inc., 1974.

Calculation Sequence Cont.

2) Mass flow rate and pump efficiency

If P1 $\leq$ 0, set EFF = 1, M = 0 and go to 3)

Solve the basic equations for M and EFF using:

$$X^3 - XA + B = 0$$

where

A = P1/(C1*C2*H1)

B = A*(1-EFD)* $\sqrt{MD}$

M = X^2

EFF = 1-(1-EFD)* $\sqrt{MD}$/X

3) Product efficiency and maximum charge rate

EF2 = EF1*EFF

MP2 = MIN(MP1*EFF, MM*C1*C2*H1)

4) Compute Statistics and Costs

SUBROUTINE PU   ENTRY POINT 000216

STORAGE USED CODE(1) 000313; DATA(0) 000033; BLANK COMMON(2) 000000

COMMON BLOCKS

```
0003   CIMPL   000001
0004   CTIME   000001
0005   CSIMUL  000010
0006   COST    000001
```

EXTERNAL REFERENCES (BLOCK, NAME)

```
0007   CURIC
0010   XPRR
0011   SQRT
0012   NERR3$
```

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

```
0001     000073 100L      0001     000142 200L      0000 R 000004 ANS      0000 R 000002 A3      0000 R 000003 A4
0006 R 000000 CCI        0000 R 000001 C1        0005     000000 DUM      0003 I 000000 IMPL    0000    000020 INJP$
0004 R 000000 TIME       0005 R 000007 TMAX      0000 R 000000 TMAX1
```

```
00100      CPU                                                                 000000
00101            SUBROUTINE PU(M,EFF,CC,EF2,MP2,M2U,P1,H1,EFD,MD,EF1,MP1,MM    000000
00101           1             ,CK,FO,Y)                                        000000
00101      C                                                                   000000
00101      C   PURPOSE    PERFORMANCE OF HYDRAULIC PUMP                        000000
00101      C                                                                   000000
00101      C   METHOD     COMPUTE PUMP FLOW RATES ASSUMING CONSTANT SPEED WITH 000000
00101      C                                                                   000000
00101      C              EFFICIENCY A FUNCTION OF SQRT(FLOW RATE)             000000
00101      C                                                                   000000
00101      C   WRITTEN BF F. O. MAHONY               VERSION 1, MARCH 29 1977  000000
00101      C                                                                   000000
00101      C   CALL SEQUENCE                                                   000000
00101      C        OUTPUTS                                                    000000
00101      C             M    - OUTPUT MASS FLOW RATE, GAL/HR                  000000
00101      C             EFF- PUMP EFFICIENCY                                  000000
00101      C             CC   - PUMP COST/YEAR, $                              000000
00101      C             EF2 - OUTPUT PRODUCT EFFICIENCY                       000000
00101      C             MP2 - MAXIMUM OUTPUT CHARGE RATE, KW                  000000
00101      C             M2U - MAXIMUM OUTPUT MASS FLOW RATE, GAL/HR           000000
00101      C                                                                   000000
00101      C        INPUTS                                                     000000
           C             P1   - INPUT POWER, KW                                000000
```

PU

```
00101      C            H1  - HEIGHT OF WATER ABOVE INLET, FT                       000000
00101      C            EFD - PUMP EFFICIENCY AT DESIGN POINT                       000000
00101      C            MD  - MASS FLOW RATE AT DESIGN POINT, GAL/HR                000000
00101      C            EF1 - INPUT PRODUCT EFFICIENCY                              000000
00101      C            MP1 - INPUT MAXIMUM CHARGING RATE, KW                       000000
00101      C            MM  - MAXIMUM ALLOWABLE MASS FLOW RATE, GAL/HR              000000
00101      C            CK  - PUMP CAPACITY COST COEFFICIENT                        000000
00101      C            FO  - PUMP EXPONENT FOR COST CALCULATIONS                   000000
00101      C            Y   - PUMP HEAD EXPONENT FOR COST CALCULATIONS              000000
00101      C                                                                        000000
00103            COMMON /CIMPL/IMPL /CTIME/TIME/CSIMUL/DUM(7),TMAX /COST/CCI        000000
00103      C                                                                        000000
00104            REAL M,MP2,M2U,MD,MP1,MM                                           000000
00104      C                                                                        000000
00105            IF(IMPL.GT.0)GO TO 100                                             000000
00105      C                                                                        000000
00107            TMAX1=TMAX*.99999                                                  000002
00107      C                                                                        000002
00110            C1= 3.1441E-6                                                      000005
00110      C                                                                        000005
00111            IF(EFD.EQ. .99999)EFD=0.9                                          000007
00113            IF(MD .EQ. .99999)MD =2.0E5                                        000014
00115            IF(MP1.EQ. .99999)MP1=1.E8                                         000021
00117            IF(MM .EQ. .99999)MM =3.0E5                                        000026
00121            IF(CK .EQ. .99999)CK =0.011                                        000033
00123            IF(FO .EQ. .99999)FO =0.5                                          000040
00125            IF(Y   .EQ. .99999)Y  =0.25                                        000045
00127            CC =CK*(MD*481.2)**FO*H1**Y                                        000052
00127      C                                                                        000052
00130            M2U =0.0                                                           000071
00131        100 EFF= 1.0                                                           000073
00132            M= 0.0                                                             000074
00133            IF(P1 .LE. 0.0) GO TO 200                                          000075
00133      C                                                                        000075
00133      C                      SOLVE CUBIC EQUATION FOR M AND EFF                000075
00133      C                                                                        000075
00135            A3= -P1/(C1*H1)                                                    000100
00136            A4 =-A3*(1.0-EFD)*SQRT(MD)                                         000105
00136      C                                                                        000105
00137            CALL CUBIC(A3,A4,ANS)                                              000115
00140            IF(ANS.LE.0.) GO TO 200                                            000122
00140      C                                                                        000122
00142            M  =ANS**2                                                         000125
00143            EFF=1.0-(1.0-EFD)*SQRT(MD)/ANS                                     000130
00143      C                                                                        000130
00143      C                      PRODUCT EFFICIENCY AND CHARGE RATE                000130
00143      C                                                                        000130
00144        200 EF2=EF1*EFF                                                        000142
00145            MP2=AMIN1(MP1*EFF,MM*H1*C1)                                        000144
00145      C                                                                        000144
00146            IF(IMPL.LE.1)RETURN                                                000156
00146      C                                                                        000156
00146      C                      STATISTICS                                        000156
00146      C                                                                        000156
00150            M2U=AMAX1(M2U,M )                                                  000165
00150      C                                                                        000165
00151            IF(TIME.LT.TMAX1)RETURN                                            000173
```

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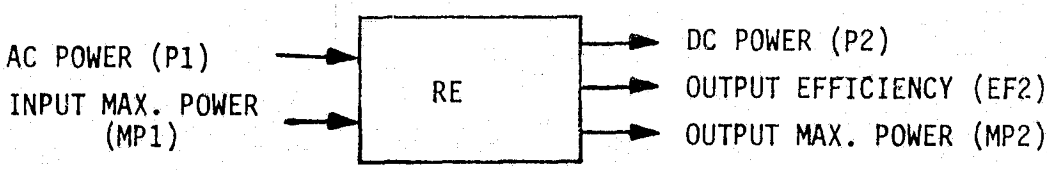
PU

```
00151     81*     C                          000173
00153     82*           CCI=CCI+CC           000202
00153     83*     C                          000202
00154     84*           RETURN               000205
00155     85*           END                  000312
```


PU

7.31 AC-DC RECTIFIER



This component models a solid-state rectifier/transformer. Power losses due to resistive heating and contact potential loss are modeled. Default parameter values determining power losses are based on 200 kw rated power.

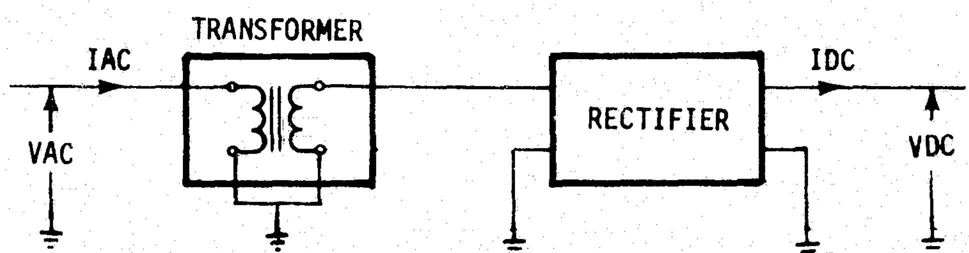


FIGURE 7.31: RECTIFIER FUNCTIONAL DIAGRAM

Inputs

Parameter/Port		Description	Units
P	1	AC input power	kw
RT		Transformer resistance (D = 0)	ohms
XT		Transformer reactance (D = 0.03)	ohms
VAC		Rated AC voltage (D = 440)	volts
DR		Rectifier contact potential (D = 0)	volts
RR		Rectifier resistance (D = 0.02)	ohms
RAP		Rated input power	kw
EF	1	Input product efficiency	–
MP	1	Maximum input power (D = $1.\times10^{8}$)	kw
CC		Rectifier cost/year	$

Outputs

Variable/Port			
P	2	DC output power	kw
IAC		AC input current	amps
PL		Power loss	kw
EF	2	Output product efficiency	–
MP	2	Maximum output power	kw

D – Default values supplied.

Calculation Sequence

1) Compute transformer power angles

$$Y = SIN(\theta) = \sqrt{3}*XT*P1*1000/VAC^2$$

$$ABS(Y) > 1 \Rightarrow \text{DIAGNOSTIC}$$

2) Input and output current

If P1 $\leq$ 0 set P2 = IAC = PL = 0., EFF = 1 and go to 4)

$$IAC = VAC \sqrt{2-2COS(\theta)} \; / \; (\sqrt{3}*XT)$$

$$" \; = VAC \sqrt{2-2*\sqrt{1-Y^2}} \; / \; (\sqrt{3}*XT)$$

$$IDC = \pi*IAC \; / \; \sqrt{6}$$

3) Power loss and output power

$$PL = (\sqrt{3}*RT*IAC^2 + IDC*(DR+IDC*RR))/1000$$

$$P2 = P1 - PL$$

$$EFF = P2/P1$$

$$P2 \leq 0 \Rightarrow \text{DIAGNOSTIC, } EFF = 1$$

4) Efficiency and maximum power

$$EF2 = EF1*EFF$$

$$MP2 = MIN(MP1,RAP)*EFF$$

5) Compute Costs

```
SUBROUTINE RE        ENTRY POINT 000257

STORAGE USED  CODE(1) 000352; DATA(0) 000073; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000002
 0004   CTIME  000001
 0005   CSTMUL 000010
 0006   COST   000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   NWDUS
 0010   NIO2$
 0011   SQRT
 0012   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000042 100L     0000   000307 108F     0001   000100 200L     0001   000117 300L     0000   000034 308F
 0001    000214 400L     0006 R 000000 CCI      0005   000000 DUM      0000 R 000006 EFF      0003 I 000001 ICNT
 0000 R  000000 IDC      0003 I 000000 IMPL     0000   000061 INJP$    0000 R 000001 PI       0000 R 000002 ROOT3
 0004 R  000000 TIME     0005 R 000007 TMAX     0000 R 000003 TMAX1    0000 R 000004 Y        0000 R 000005 YY


00100     CRE                                                                              000000
00101           SUBROUTINE RE(P2,IAC,PL,EF2,MP2,P1,RT,XT,VAC,DR,RR,RAP,EF1,MP1,CC)          000000
00101     C                                                                                000000
00101     C              PURPOSE        SOLID STATE RECTIFIER/TRANSFORMER MODEL            000000
00101     C                                                                                000000
00101     C              METHOD          COMPUTE OUTPUT DC POWER AS A FUNCTION             000000
00101     C                              OF INPUT AC POWER                                 000000
00101     C                                                                                000000
00101     C              WRITTEN BY Y.K.CHAN          VERSION 1, JUNE 1, 1977              000000
00101     C                                                                                000000
00101     C   CALL SEQUENCE                                                                000000
00101     C       OUTPUTS                                                                  000000
00101     C              P2  -DC OUTPUT POWER, KW                                          000000
00101     C              IAC -AC INPUT CURRENT, AMPS                                       000000
00101     C              PL  -POWER LOSS, KW                                               000000
00101     C              EF2 -OUTPUT PRODUCT EFFICIENCY                                    000000
00101     C              MP2 -MAXIMUM OUTPUT POWER, KW                                     000000
00101     C       INPUTS                                                                   000000
00101     C              P1  -AC INPUT POWER, KW                                           000000
00101     C              RT  -TRANSFORMWR RESISTANCE, OHMS                                 000000
00101     C              XT  -TRANSFORMER REACTANCE, OHMS                                  000000
                         VAC -RATED AC VOLTAGE, VOLTS                                      000000
```

RE

```
00101   C             DR  -RECTIFIER CONTACT POTENTIAL, VOLTS                000000
00101   C             RR  -RECTIFIER RESISTANCE, OHMS                        000000
00101   C             RAP -RATED INPUT POWER, KW                             000000
00101   C             EF1 -INPUT PRODUCT EFFICIENCY                          000000
00101   C             MP1 -MAXIMUM INPUT POWER, KW                           000000
00101   C             CC  -RECTIFIER COST/YEAR, $                            000000
00101   C                                                                    000000
00103         COMMON /CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX/COST/CCI 000000
00104         REAL IAC,MP2,MP1,IDC                                           000000
00105         DATA PI/3.14159/                                               000000
00107         DATA ROOT3/1.73205/                                            000000
00107   C                                                                    000000
00111         IF(IMPL.GT.0) GO TO 100                                        000000
00113         IF(MP1.EQ..99999)MP1=1.E8                                      000002
00115         IF(RT.EQ..99999) RT=0.                                         000007
00117         IF(XT.EQ..99999) XT=.03                                        000013
00121         IF(VAC.EQ..99999) VAC=440.                                     000020
00123         IF(DR.EQ..99999) DR=0.                                         000025
00125         IF(RR.EQ..99999) RR=.02                                        000031
00127         TMAX1=TMAX*.99999                                              000036
00127   C                                                                    000036
00127   C             COMPUTE TRANSFORMER POWER ANGLES                       000036
00127   C                                                                    000036
00130     100 Y=ROOT3*XT*P1*1000./(VAC*VAC)                                  000042
00131         YY=Y*Y                                                         000051
00132         IF(YY.LE.1.)GO TO 200                                          000053
00134         IF(IMPL.EQ.2)WRITE(6,108)P1,XT,VAC                             000056
00142     108 FORMAT(1H0,19HRE, AC INPUT POWER ,F12.3,49H TOO LARGE IN RELATION  000071
00142        1TO TRANSFORMER REACTANCE ,F12.3,22H AND RATED AC VOLTAGE  ,F12.3)  000071
00143         IF(IMPL.EQ.2)ICNT=ICNT+1                                       000071
00145     200 YY=AMIN1(1.,YY)                                                000100
00145   C                                                                    000100
00145   C             INPUT AND OUTPUT CURRENT                               000100
00145   C                                                                    000100
00146         IF(P1.GT.0.)GO TO 300                                          000105
00150         P2=0.                                                          000110
00151         IAC=0.                                                         000111
00152         PL=0.                                                          000112
00153         EFF=1.                                                         000113
00154         GO TO 400                                                      000115
00154   C                                                                    000115
00155     300 IAC=VAC*SQRT(2.-2.*SQRT(1.-YY))/(ROOT3*XT)                     000117
00156         IDC=PI*IAC/SQRT(6.)                                            000140
00156   C                                                                    000140
00156   C             POWER LOSS AND OUTPUT POWER                            000140
00156   C                                                                    000140
00157         PL=(ROOT3*RT*IAC*IAC+IDC*(DR+IDC*RR))/1000.                    000147
00160         P2=P1-PL                                                       000161
00161         EFF=P2/P1                                                      000163
00162         IF(P2.GT.0.) GO TO 400                                         000165
00164         IF(IMPL.EQ.2)WRITE(6,308)PL,P1                                 000170
00171     308 FORMAT(1H0,14HRE POWER LOSS ,F12.3,21H EXCEEDS INPUT POWER ,F12.3)  000202
00172         IF(IMPL.EQ.2)ICNT=ICNT+1                                       000202
00174         P2=0.                                                          000210
00175         EFF=1.                                                         000211
00175   C                                                                    000211
00175   C             EFFICIENCY AND MAXIMUM POWER                           000211
```

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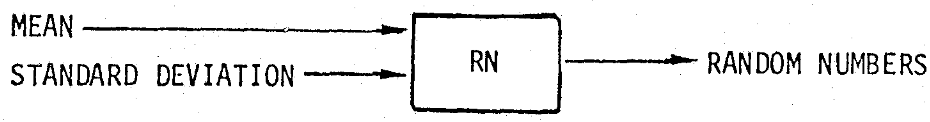
```
00175     80*      C                                                                000211
00176     81*        400 EF2=EF1*EFF                                                000214
00177     82*            MP2=AMIN1(MP1,RAP)                                         000216
00200     83*            MP2=MP2*EFF                                                000224
00201     84*            IF(IMPL.LE.1)RETURN                                        000226
00203     85*            IF(TIME.LT.TMAX1)RETURN                                    000235
00205     86*            CCI=CCI+CC                                                 000244
00205     87*      C                                                                000244
00206     88*            RETURN                                                     000247
00207     89*            END                                                        000351
```


RE

7.32 RANDOM NUMBERS



This component generates an uncorrelated sequence of normally distributed random numbers with a specified mean and standard deviation.

Inputs

Parameter/Port	Description
MN	Mean value of sequence
SIG	Standard deviation of sequence
NST[1]	Start parameter. (Use any odd integer greater than 1). Default supplied.

Outputs

Variable/Port	
FØ	Random number output

---

1 If RESET parameter > 0 then succeeding simulations use NST to start random sequence.

```
SUBROUTINE RN        ENTRY POINT 000065

STORAGE USED  CODE(1) 000105; DATA(0) 000033; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0004   NEPR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

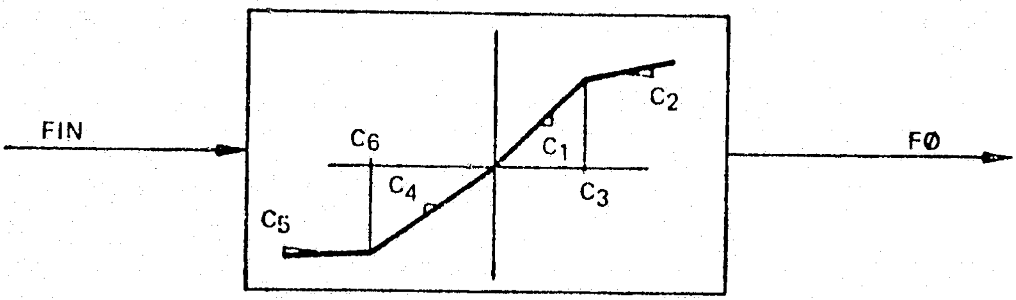
 0001   000026 123G       0001   000021 5L        0000 R 000006 AXO       0000 I 000007 I         0003   000001 ICNT
 0003 I 000000 IMPL       0000   000024 INJP$     0003 I 000002 ITEST     0000 D 000004 SUM       0000 D 000000 X
 0000 D 000002 Y


00100      CRN                                                                              000000
00101            SUBROUTINE RN(U,AX,SIG,AMN)                                                000000
00101      C    VERSION 2.              '       REVISED  MAY 1977                           000000
00101      C    PURPOSE -  GENERATES A NORMALLY DISTRIBUTED RANDOM NUMBER                   000000
00101      C    CALL SEQUENCE                                                               000000
00101      C                 U - RANDOM NUMBER OUTPUT                                       000000
00101      C                 AX- A START PARAMETER WHICH CONTROLS THE BEGINNING POINT       000000
00101      C                     OF THE OUTPUT SEQUENCE.  AX SHOULD BE ANY ODD INTEGER      000000
00101      C                     GREATER THAN ONE.  THE DEFAULT VALUE OF AX IS 431469.      000000
00101      C                     AX IS UPDATED FOR NEW CALLS TO THE SUBROUTINE.             000000
00101      C                SIG- THE DESIRED STANDARD DEVIATION OF THE SEQUENCE             000000
00101      C                AMN- THE DESIRED MEAN OF THE SEQUENCE                           000000
00101      C                                                                                000000
00101      C    DESIGNED BY         ROGER W. CALL              SEPT 1976                    000000
00103            COMMON /CIMPL/IMPL,ICNT,ITEST                                              000000
00104            DOUBLE PRECISION X,Y,SUM                                                   000000
00105            DATA Y /253967.D0/ AXO/0./                                                 000000
00110            IF(IMPL.GT.0)GO TO 5                                                       000000
00112            IF(AX.EQ..99999) AX=431469.                                                000002
00114            IF(AXO.EQ.0.) AXO= AX                                                      000007
00116            IF(ITEST.EQ.1) AX= AXO                                                     000013
00120          5 X =AX                                                                      000021
00121            SUM=0.D0                                                                   000022
00122            DO 1 I=1,12                                                                000026
00125            X= DMOD(X*Y,16777216.D0)                                                   000026
00126          1 SUM= SUM+ X/16777215.D0                                                    000036
00130            AX= X                                                                      000043
00131            U=(SUM-6.0)*SIG+AMN                                                        000045
00132            RETURN                                                                     000054
00133            END                                                                        000104
```


RN

SA

7.33 SATURATION FUNCTION



Inputs

Parameter/Port	Description
FIN	Input quantity
C1	Slope 0 < FIN < C3
C2	Slope FIN > C3
C3	Positive saturation intercept
C4	Slope 0 > FIN > C6
C5	Slope FIN < C6
C6	Negative saturation intercept

Outputs

Variable/Port	
FØ	Output quantity

Calculation Sequence

```
FØ = C1*C3 + C2*(FIN-C3)   if FIN > C3
FØ = C1*FIN                if 0 < FIN < C3
FØ ≠ C4*FIN                if 0 > FIN > C6
FØ = C4*C6 + C5*(FIN-C6)   if FIN < C6
```

```
SUBROUTINE SA        ENTRY POINT 000051

STORAGE USED  CODE(1) 000076; DATA(0) 000013; BLANK COMMON(2) 000000

EXTERNAL REFERENCES (BLOCK, NAME)

 0003    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

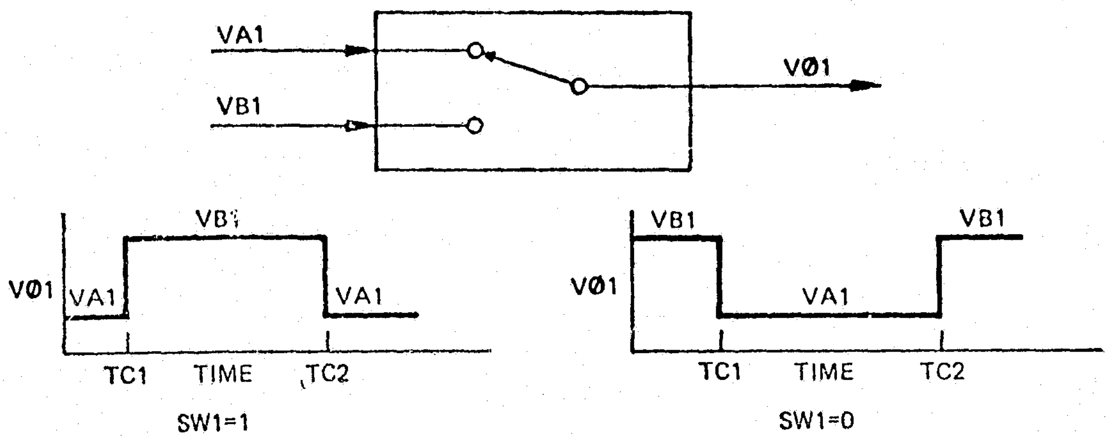
 0001   000017 10L       0001   000042 100L      0001   000027 20L       0001   000037 30L       0000   000000 INJP$


00100      CSA                                                                          000000
00101            SUBROUTINE SA(FO,FIN,C1,C2,C3,C4,C5,C6)                                000000
00101      C                                                                            000000
00101      C   PURPOSE - TO SIMULATE SATURATION                                         000000
00101      C                                                                            000000
00101      C                                                                            000000
00101      C   METHOD - SEE CODING. C3 AND C6 ARE VALUES OF THE INPUT AT WHICH          000000
00101      C            SATURATION OCCURS.  C3 IS GREATER THAN C6. THE ROUTINE          000000
00101      C            CAN SIMULATE A CHANGE OF SLOPE AT THE ORIGIN (C1.NE.C4)         000000
00101      C            PROVIDED C6 IS LESS THAN ZERO. SIMILARLY THE SLOPES             000000
00101      C            IN THE SATURATION REGION (C2 AND C5)CAN DIFFER.                 000000
00101      C            THE SLOPES CAN BE POSITIVE OR NEGATIVE                          000000
00101      C                                                                            000000
00101      C                                                                            000000
00101      C   WRITTEN BY  -  ADAM LLOYD              LATEST REVISION - NOV 75          000000
00101      C                                                                            000000
00101      C   LIMITATIONS - USE OF ZERO SLOPES (C2=0 OR C5=0) IN THE SATURATION        000000
00101      C                 REGION SHOULD BE AVOIDED. IT IS DESIRABLE THAT THE         000000
00101      C                 SLOPE RATIOS C1/C2 AND C4/C5 SHOULD NOT EXCEED 100.        000000
00101      C                 EXCESSIVE SLOPE RATIOS MAY RESULT IN VERY SLOW             000000
00101      C                 CONVERGENCE                                                000000
00101      C                                                                            000000
00101      C                                                                            000000
00101      C   INPUT/OUTPUT LIST                                                        000000
00101      C                                                                            000000
00101      C   FO       OUTPUT VARIABLE                  ANY        OUTPUT VAR          000000
00101      C   FIN      INPUT  VARIABLE                  ANY        INPUT  VAR          000000
00101      C   C1       SLOPE               ) FIRST      ANY        INPUT  PARAM        000000
00101      C   C2       SATURATION SLOPE    ) SLOPE      ANY        INPUT  PARAM        000000
00101      C   C3       SATURATION INTERCEPT)            ANY        INPUT  PARAM        000000
00101      C   C4       SLOPE               ) SECOND     ANY        INPUT  PARAM        000000
00101      C   C5       SATURATION SLOPE    ) SLOPE      ANY        INPUT  PARAM        000000
00101      C   C6       SATURATION INTERCEPT)            ANY        INPUT  PARAM        000000
00101      C                                                                            000000
00103            IF(FIN.GT.C3)GO TO 10                                                  000000
```

SA

```
00105              IF(FIN.LT.C6)GO TO 20                 000003
00107              IF(FIN.LT.0.)GO TO 30                 000007
00111              FO=C1*FIN                             000012
00112              GO TO 100                             000015
00112        C   POSITIVE SATURATION                     000015
00113         10   FO=C1*C3+C2*(FIN-C3)                  000017
00114              GO TO 100                             000025
00114        C   NEGATIVE SATURATION                     000025
00115         20   FO=C4*C6+C5*(FIN-C6)                  000027
00116              GO TO 100                             000035
00116        C   NEGATIVE UNSATURATED                    000035
00117         30   FO=C4*FIN                             000037
00120        100   RETURN                                000042
00121              END                                   000075
```

7.34 SINGLE POLE SWITCH



THE SWITCHING OPERATION MAY BE CONTROLLED BY EITHER TIME OR THE INPUT PARAMETER SW1. THE TIME DEPENDENCE MAY BE ELIMINATED BY SETTING TC1 = 10^{36}

Inputs

Parameter/Port	Description
VA1	Input to switch
VB1	Input to switch
SW1	Switch control parameter
TC1	Time for first switching (hours)
TC2	Time for second switching (hours)

Outputs

Variable/Port	
VØ1	Switch output

Calculation Sequence

If SW1 = 0 then

$$VØ1 = \begin{pmatrix} VA1 & TC1 < TIME < TC2 \\ VB1 & \text{otherwise} \end{pmatrix}$$

If SW1 = 1 then

$$VØ1 = \begin{pmatrix} VB1 & TC1 < TIME < TC2 \\ VA1 & \text{otherwise} \end{pmatrix}$$

```
SUBROUTINE SW        ENTRY POINT 000042

STORAGE USED  CODE(1) 000047; DATA(0) 000007; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CTIME   000001
 0004   CIO     000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0005   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

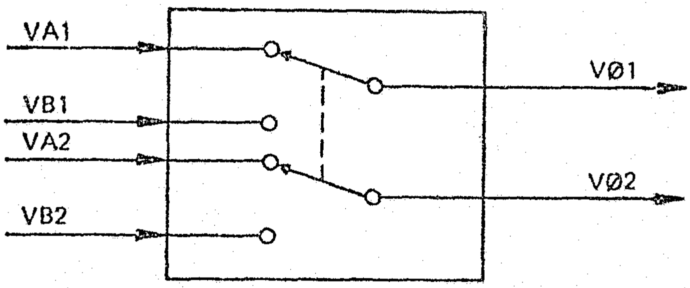
 0004   000002 IDIAG     0000    000003 INJPS     0004    000000 IREAD     0004    000001 IWRITE    0000 R 000000 SX
 0003 R 000000 TIME


00100      CSW                                                                     000000
00101            SUBROUTINE SW(VO1,VA1,VB1,SW1,TC1,TC2)                            000000
00101      C                                                                       000000
00101      C   PURPOSE - TO PROVIDE SWITCH CONTROL FOR ONE VARIABLE                000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C   METHOD  - SEE CODING                                                000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C   WRITTEN BY  - ADAM LLOYD          LATEST REVISION    NOV 75         000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C   LIMITATIONS - NOT MORE THAN TWO SWITCHINGS AT TIMES TC1 AND TC2     000000
00101      C                                                                       000000
00101      C                                                                       000000
00101      C   INPUT/OUTPUT LIST                                                   000000
00101      C                                                                       000000
00101      C   VO1       OUTPUT VARIABLE NO 1          ANY     OUTPUT VAR          000000
00101      C   VA1       INPUT VARIABLE NO A1          ANY     INPUT  VAR          000000
00101      C   VB1       INPUT VARIABLE NO B1          ANY     INPUT  VAR          000000
00101      C   SW1       SWITCH CONTROL INITIAL VALUE  ---     INPUT  PARAM        000000
00101      C                 =1.   VO=VB                                           000000
00101      C                 =0.   VO=VA                                           000000
00101      C   TC1       TIME FOR FIRST SWITCH         SECS    INPUT  PARAM        000000
00101      C   TC2       TIME FOR SECOND SWITCH        SECS    INPUT  PARAM        000000
00101      C                 (TC2.GT.TC1)                                          000000
00103           COMMON/CTIME/TIME                                                  000000
00104           COMMON/CIO/IREAD,IWRITE,IDIAG                                      000000
00105           SX=SW1                                                             000000
```

```
00106     30*          IF(TIME.GT.TC1.AND.TIME.LT.TC2)SX=ABS(SW1-1.)          000001
00110     31*          V01=VA1                                                000023
00111     32*          IF(SX.GT.0.5)V01=VB1                                   000025
00113     33*          RETURN                                                 000033
00114     34*          END                                                    000046
```


SW

7.35 TWO POLE SWITCH



SEE SW FOR SWITCH CONTROL LOGIC

Inputs

Parameter/Port	Description
VA1	Input to switch 1
VA2	Input to switch 2
VB1	Input to switch 1
VB2	Input to switch 2
SW1	Switch control parameter
TC1	Time for first switching (hours)
TC2	Time for second switching (hours)

Outputs

Variable/Port	
VØ1	Output from switch 1
VØ2	Output from switch 2

```
SUBROUTINE SX        ENTRY POINT 000052

STORAGE USED  CODE(1) 000062; DATA(0) 000007; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CTIME   000001
 0004   CIO     000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0005   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0004   000002 IDIAG      0000   000003 INJPS     0004   000000 IREAD     0004   000001 IWRITE    0000 R 000000 SW
 0003 R 000000 TIME

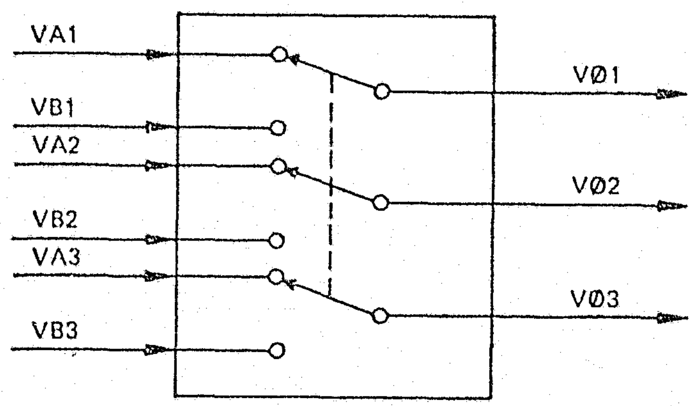

00100     CSX                                                                    000000
00101           SUBROUTINE SX(VO1,VO2,VA1,VA2,VB1,VB2,SW1,TC1,TC2)               000000
00101     C                                                                      000000
00101     C   PURPOSE - TO PROVIDE A SWITCH COMPONENT FOR TWO VARIABLES          000000
00101     C                                                                      000000
00101     C                                                                      000000
00101     C   METHOD  - SEE CODING                                               000000
00101     C                                                                      000000
00101     C                                                                      000000
00101     C   WRITTEN BY  - ADAM LLOYD           LATEST REVISION    NOV 75       000000
00101     C                                                                      000000
00101     C                                                                      000000
00101     C   LIMITATIONS - NOT MORE THAN TWO SWITCHINGS AT TIMES TC1 AND TC2    000000
00101     C                                                                      000000
00101     C                                                                      000000
00101     C   INPUT/OUTPUT LIST                                                  000000
00101     C                                                                      000000
00101     C   VO1        OUTPUT VARIABLE NO 1          ANY      OUTPUT VAR       000000
00101     C   VO2        OUTPUT VARIABLE NO 2          ANY      OUTPUT VAR       000000
00101     C   VA1        INPUT VARIABLE NO A1          ANY      INPUT  VAR       000000
00101     C   VA2        INPUT VARIABLE NO A2          ANY      INPUT  VAR       000000
00101     C   VB1        INPUT VARIABLE NO B1          ANY      INPUT  VAR       000000
00101     C   VB2        INPUT VARIABLE NO B2          ANY      INPUT  VAR       000000
00101     C   SW1        SWITCH CONTROL INITIAL VALUE  ---      INPUT  PARAM     000000
00101     C                 =1.   VO=VB                                          000000
00101     C                 =C.   VO=VA                                          000000
00101     C   TC1        TIME FOR FIRST SWITCH         SECS     INPUT  PARAM     000000
00101     C   TC2        TIME FOR SECOND SWITCH        SECS     INPUT  PARAM     000000
00101     C                 (TC2.GT.TC1)                                         000000
```

SX

```
00103      COMMON/CTIME/TIME                                   C00000
00104      COMMON/CIO/IREAD,IWRITE,IDIAS                       C00000
00105      SW=SW1                                              C00000
00106      IF(TIME.GT.TC1.AND.TIME.LT.TC2)SW=ABS(SW1-1.)       C00001
00110      VO1=VA1                                             C00023
00111      VO2=VA2                                             C00025
00112      IF(SW.GT.0.5)VO1=VB1                                C00027
00114      IF(SW.GT.0.5)VO2=VB2                                C00035
00116      RETURN                                              C00043
00117      END                                                 C00061
```


SX

7.36 THREE POLE SWITCH



SEE SW FOR SWITCH CONTROL LOGIC

Inputs

Parameter/Port	Description
VA1	Input to switch 1
VA2	Input to switch 2
VA3	Input to switch 3
VB1	Input to switch 1
VB2	Input to switch 2
VB3	Input to switch 3
SW1	Switch control parameter
TC1	Time for first switching (hours)
TC2	Time for second switching (hours)

Outputs

Variable/Port	
VØ1	Output from switch 1
VØ2	Output from switch 2
VØ3	Output from switch 3

```
SUBROUTINE SY          ENTRY POINT 000063

STORAGE USED  CODE(1) 000077; DATA(0) 000011; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CTIME   000001
 0004    CIO     000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0005    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

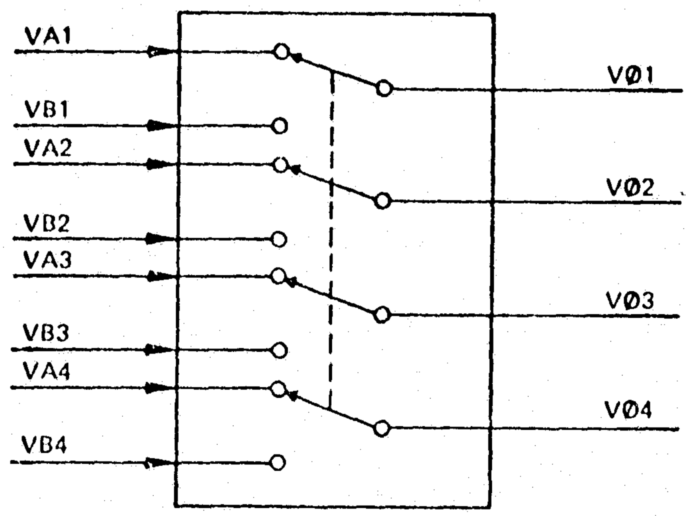
 0004    000002 IDIAG      0000    000003 INJPS     0004    000000 IREAD     0004    000001 IWRITE    0000 R 000000 SW
 0003 R 000000 TIME


00100      CSY                                                                                  000000
00101            SUBROUTINE SY(VO1,VO2,VO3,VA1,VA2,VA3,VB1,VB2,VB3,SW1,TC1,TC2)                  000000
00101      C                                                                                    000000
00101      C   PURPOSE - TO PROVIDE A SWITCH COMPONENT FOR THREE VARIABLES                      000000
00101      C                                                                                    000000
00101      C                                                                                    000000
00101      C   METHOD  - SEE CODING                                                             000000
00101      C                                                                                    000000
00101      C                                                                                    000000
00101      C   WRITTEN BY  - ADAM LLOYD            LATEST REVISION     NOV 75                   000000
00101      C                                                                                    000000
00101      C                                                                                    000000
00101      C   LIMITATIONS - NOT MORE THAN TWO SWITCHINGS AT TIMES TC1 AND TC2                  000000
00101      C                                                                                    000000
00101      C                                                                                    000000
00101      C   INPUT/OUTPUT LIST                                                                000000
00101      C                                                                                    000000
00101      C   VO1        OUTPUT VARIABLE NO 1              ANY       OUTPUT VAR                000000
00101      C   VO2        OUTPUT VARIABLE NO 2              ANY       OUTPUT VAR                000000
00101      C   VO3        OUTPUT VARIABLE NO 3              ANY       OUTPUT VAR                000000
00101      C   VA1        INPUT VARIABLE NO A1              ANY       INPUT  VAR                000000
00101      C   VA2        INPUT VARIABLE NO A2              ANY       INPUT  VAR                000000
00101      C   VA3        INPUT VARIABLE NO A3              ANY       INPUT  VAR                000000
00101      C   VB1        INPUT VARIABLE NO B1              ANY       INPUT  VAR                000000
00101      C   VB2        INPUT VARIABLE NO B2              ANY       INPUT  VAR                000000
00101      C   VB3        INPUT VARIABLE NO B3              ANY       INPUT  VAR                000000
00101      C   SW1        SWITCH CONTROL INITIAL VALUE      ---       INPUT  PARAM              000000
00101      C                   =1.    VO=VB                                                     000000
00101      C                   =0.    VO=VA                                                     000000
```

SY

```
C0101      C    TC1         TIME FOR FIRST SWITCH          SECS      INPUT   PARAM       000000
C0101      C    TC2         TIME FOR SECOND SWITCH         SECS      INPUT   PARAM       000000
C0101      C                    (TC2.GT.TC1)                                             000000
00103              COMMON/CTIME/TIME                                                     000000
00104              COMMON/CIO/IREAD,IWRITE,IDIAG                                         000000
00105              SW=SW1                                                                00000C
00106              V01=VA1                                                               000001
00107              V02=VA2                                                               000003
00110              V03=VA3                                                               000005
00111              IF(TIME.GT.TC1.AND.TIME.LT.TC2)SW=ABS(SW1-1.)                         000007
00113              IF(SW.GT.0.5)V01=VB1                                                  000031
00115              IF(SW.GT.0.5)V02=VB2                                                  000037
00117              IF(SW.GT.0.5)V03=VB3                                                  000045
00121              RETURN                                                                000053
00122              END                                                                   000076
```

7.37 FOUR POLE SWITCH



SEE SW FOR SWITCH CONTROL LOGIC

Inputs

Parameter/Port	Description
VA1	Input to switch 1
VA2	Input to switch 2
VA3	Input to switch 3
VA4	Input to switch 4
VB1	Input to switch 1
VB2	Input to switch 2
VB3	Input to switch 3
VB4	Input to switch 4
SW1	Switch control parameter
TC1	Time for first switching (hours)
TC2	Time for second switching (hours)

Outputs

Variable/Port	
VØ1	Output from switch 1
VØ2	Output from switch 2
VØ3	Output from switch 3
VØ4	Output from switch 4

```
SUBROUTINE SZ          ENTRY POINT 000073

STORAGE USED  CODE(1) 000112; DATA(0) 000011; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CTIME  000001
 0004   CIO    000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0005   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0004   000002 INDIAG     0000   000003 INJPS     0004   000000 IREAD     0004   000001 IWRITE    0000 R 000000 SW
 0003 R 000000 TIME

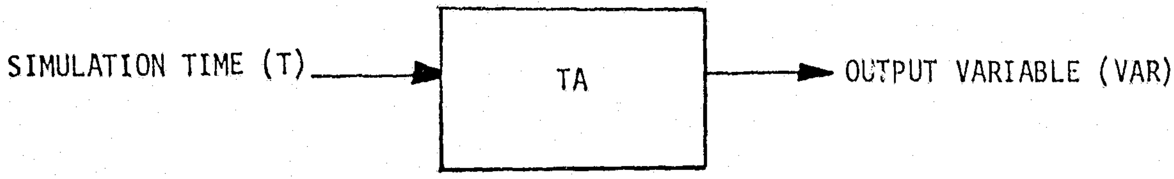

00100     CSZ                                                                000000
00101           SUBROUTINE SZ(VO1,VO2,VO3,VO4,VA1,VA2,VA3,VA4,VB1,VB2,VB3,VB4,  000000
00101          1 SW1,TC1,TC2)                                                000000
00101     C                                                                  000000
00101     C    PURPOSE - TO PROVIDE A SWITCH COMPONENT FOR FOUR VARIABLES    000000
00101     C                                                                  000000
00101     C                                                                  000000
00101     C    METHOD  - SEE CODING                                          000000
00101     C                                                                  000000
00101     C                                                                  000000
00101     C    WRITTEN BY  - ADAM LLOYD          LATEST REVISION    NOV 75   000000
00101     C                                                                  000000
00101     C    LIMITATIONS - NOT MORE THAN TWO SWITCHINGS AT TIMES TC1 AND TC2  000000
00101     C                                                                  000000
00101     C                                                                  000000
00101     C    INPUT/OUTPUT LIST                                             000000
00101     C                                                                  000000
00101     C    VO1      OUTPUT VARIABLE NO 1          ANY      OUTPUT  VAR    000000
00101     C    VO2      OUTPUT VARIABLE NO 2          ANY      OUTPUT  VAR    000000
00101     C    VO3      OUTPUT VARIABLE NO 3          ANY      OUTPUT  VAR    000000
00101     C    VO4      OUTPUT VARIABLE NO 4          ANY      OUTPUT  VAR    000000
00101     C    VA1      INPUT VARIABLE NO A1          ANY      INPUT   VAR    000000
00101     C    VA2      INPUT VARIABLE NO A2          ANY      INPUT   VAR    000000
00101     C    VA3      INPUT VARIABLE NO A3          ANY      INPUT   VAR    000000
00101     C    VA4      INPUT VARIABLE NO A4          ANY      INPUT   VAR    000000
00101     C    VB1      INPUT VARIABLE NO B1          ANY      INPUT   VAR    000000
00101     C    VB2      INPUT VARIABLE NO B2          ANY      INPUT   VAR    000000
```

SZ

```
00101   C   VB4       INPUT VARIABLE NO B4           ANY     INPUT  VAR         000000
00101   C   SW1       SWITCH CONTROL INITIAL VALUE   ---     INPUT  PARAM       000000
00101   C                 =1.   VO=VB                                           000000
00101   C                 =0.   VO=VA                                           000000
00101   C   TC1       TIME FOR FIRST SWITCH          SECS    INPUT  PARAM       000000
00101   C   TC2       TIME FOR SECOND SWITCH         SECS    INPUT  PARAM       000000
00101   C                 (TC2.GT.TC1)                                          000000
00103         COMMON/CTIME/TIME                                                 000000
00104         COMMON/CIO/IREAD,IWRITE,IDIAG                                     000000
00105         SW=SW1                                                            000000
00106         IF(TIME.GT.TC1.AND.TIME.LT.TC2)SW=ABS(SW1-1.)                     000001
00110         VO1=VA1                                                           000023
00111         VO2=VA2                                                           000025
00112         VO3=VA3                                                           000027
00113         VO4=VA4                                                           000031
00114         IF(SW.GT.0.5)VO1=VB1                                              000033
00116         IF(SW.GT.0.5)VO2=VB2                                              000041
00120         IF(SW.GT.0.5)VO3=VB3                                              000047
00122         IF(SW.GT.0.5)VO4=VB4                                              000055
00124         RETURN                                                            000063
00125         END                                                               000111
```


SZ

7.38 TAPE/FILE READ



This component reads a data file containing a single output variable time history. The file structure is specified below, and assumes equal increment data. Linear interpolation is used to obtain the output value. No more than eight TA components are allowed per model. The component TI is used to supply the time input T. The data files must be catalogued using the names F1, F2, or the JCL procedure file XQTANALYSIS modified appropriately. If tape data is used, it must be read into permanent storage files in a prior job step.

Inputs

Parameter/Port	Description	Units
NST	Number of records to skip at start[1]	
T	Simulation time referenced to start of year	hr
ITF	Indicator function: 0 = no read J = read data into Jth array ($J \leq 8$)	

[1] NST = (start time of simulation-start time of file)/(data increment x 446)

Outputs

Variable/Port	Description	Units
VAR	Output variable at time T	
N	Length of file record	
TØ	Time of first data value in current record	hr
H	Time increment between data values	hr

Record Structure

1st record = identification header, 28 words

Nth record (N > 1): 448 words

first word = time of first data value in hours (TØ)

second word = time increment between data values (H)

J+2 word = data value at time = TØ + (J-1)H

(J=1,...,446)

If the useful data ends in the middle of a record, then an end value = .99999 is used to signal end of information.

Calculation Sequence

If ITF = 0 RETURN

1) Initialization. (First Pass Only)

- o Read 1st record and write out identification header data and unit number. (Error exit to 6))

- o Read past NST data records. Go to 4)

Calculation Sequence Cont.

2) File location incorrect; use initial value

o If T ≥ TØ GO TO 3)
  Write diagnostic
  VAR = A(1,J)   (J=ITF)
  Return

3) Table Interpolation for Output

o If T ≥ TØ + N * H GO TO 4)
  XT(1) = TØ
  XT(2) = TØ+H
  VAR = TBLU1(T,XT,A(1,J),0,N)
  Return

4) Read Next Data Record

If end has been encountered previously go to 5)
Read next record into array A(·,J). If end encountered, set
N = last value. (Error exit to 6))
  TØ = A(1,J)
  H = A(2,J)
  GO TO 3)

5) End of File. Use last value.

VAR = A(N,J)
Write Diagnostic
Return

6) Read Error Encountered

Write Diagnostic and STOP

```
SUBROUTINE TA          ENTRY POINT 000343

STORAGE USED  CODE(1) 000403; DATA(0) 007132; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL  000002
 0004    DATARD 000700

EXTERNAL REFERENCES (BLOCK, NAME)

 0005    NTRAN
 0006    TBLU1
 0007    NWDU$
 0010    NIO3$
 0011    NIO2$
 0012    NSTOP$
 0013    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000321 10L      0001     000102 100L     0001     000231 167G     0000     007035 20F      0001     000135 200L
 0000     007046 30F      0001     000176 300L     0001     000262 400L     0001     000244 60L      0000     007062 80F
 0000     007076 90F      0000 R 000000 A          0000 R 006760 B          0000 I 007034 I          0003 I 000001 ICNT
 0003 I 000000 IMPL       0000 I 007014 IND        0000     007121 INJP$    0000 I 007030 IUN        0000 I 007027 J
 0000 I 007031 L1         0000 I 007033 N          0000 I 007032 NO         0006 R 000000 TBLU1      0004 R 000000 TEMP
 0000 R 007026 X          0000 R 007024 XT


00100     CTAPE                                                                  000000
00101           SUBROUTINE TA(VAR,NOUT,TO,H,NST,T,ITF)                           000000
00101     C                                                                      000000
00101     C     PURPOSE     READ TIME HISTORY DATA ON STORAGE DEVICE             000000
00101     C                                                                      000000
00101     C                                                                      000000
00101     C     METHOD      USE NTRAN SEQENTIAL BLOCK READ FROM MASS STORAGE     000000
00101     C                 INTO CORE.  LINEAR INTERPOLATION IS USED TO OBTAIN   000000
00101     C                 VALUE AT SPECIFIED TIME T.                           000000
00101     C                                                                      000000
00101     C    WRITTEN BY A.W. WARREN                 JUNE 1977                  000000
00101     C                                                                      000000
00101     C    CALL SEQUENCE                                                     000000
00101     C            OUTPUTS                                                   000000
00101     C                VAR  - OUTPUT VARIABLE AT TIME T                      000000
00101     C                NOUT - LENGTH OF DATA BLOCK LAST READ                 000000
00101     C                TO   - TIME OF FIRST DATA VALUE IN CORE, HR           000000
00101     C                H    - TIME INCREMENT BETWEEN DATA VALUES, HR         000000
00101     C            INPUTS                                                    000000
```

TA

```
00101  C                    NST  - NUMBER OF BLOCKS TO SKIP AT START                 000000
00101  C                    T    - SIMULATION TIME REFERENCED TO START OF YEAR, HR   000000
00101  C                    ITF  - INDICATOR FOR LOGICAL UNIT TO READ                000000
00101  C                             = 0   NO READ                                   000000
00101  C                             = 1,...8 FOR LOGICAL UNITS 11,...18, RESP.     000000
00101  C                                                                             000000
00103        DIMENSION A(446,8),B(28),IND(8),XT(2)                                   000000
00104        COMMON /CIMPL/ IMPL,ICNT /DATARD/ TEMP(448)                             000000
00105        REAL NST,NOUT,ITF                                                       000000
00106        DATA X/.99999/                                                          000000
00106  C                                                                             000000
00106  C                       INITIALIZE AND POSITION THE FILE                     000000
00106  C                                                                             000000
00110        VAR=X                                                                   000000
00111        J=ITF+.001                                                              000001
00112        IF(J.EQ.0) RETURN                                                       000012
00114        IUN= J+10                                                               000017
00115        IF(IMPL.GT.0) GO TO 100                                                 000022
00115  C                                                                             000022
00117        CALL NTRAN(IUN,10)                                                      000026
00120        CALL NTRAN(IUN,2,28,B,L1,22)                                            000032
00121        IF(L1.LT.0)GO TO 10                                                     000042
00123        WRITE(6,20) IUN,B                                                       000045
00127     20 FORMAT(1H0,30HIDENTIFICATION HEADER FOR UNIT,I3/(1H ,10A6))             000056
00130        NO= NST*16.+.001                                                        000056
00131        CALL NTRAN(IUN,6,NO,22)                                                 000070
00132        IND(J)= L1                                                              000076
00133        GO TO 300                                                               000100
00133  C                                                                             000100
00133  C                       TOO MANY BLOCKS READ                                  000100
00133  C                                                                             000100
00134    100 IF(T.GE.T0) GO TO 200                                                   000102
00136        VAR= A(1,J)                                                             000105
00137        IF(IMPL.EQ.2) WRITE(6,30) VAR,IUN                                       000111
00144     30 FORMAT(1H0,39HFILE DATA OUT OF RANGE. INITIAL VALUE= ,                  000123
00144       1  F12.5,9H  ON UNIT,I4)                                                 000123
00145        IF(IMPL.EQ.2)ICNT=ICNT+1                                                000123
00147        RETURN                                                                  000131
00147  C                                                                             000131
00147  C                       TABLE INTERPOLATION FOR OUTPUT                        000131
00147  C                                                                             000131
00150    200 IF(T.GE.T0+NOUT*H) GO TO 300                                            000135
00152        XT(1)= T0                                                               000142
00153        XT(2)= T0+H                                                             000144
00154        N=NOUT                                                                  000146
00155        VAR = TBLU1(T,XT,A(1,J),0,N)                                            000155
00156        RETURN                                                                  000172
00156  C                                                                             000172
00156  C                       READ NEXT DATA BLOCK                                  000172
00156  C                                                                             000172
00157    300 IF(IND(J).EQ.0)GO TO 400                                                000176
00161        CALL NTRAN(IUN,2,448,TEMP,IND(J),22)                                    000200
00162        IF(IND(J).LT.0)GO TO 10                                                 000212
00164        T0= TEMP(1)                                                             000220
00165        H= TEMP(2)                                                              000222
00165  C                                                                             000222
```

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```
00171          IF(TEMP(I+2).EQ.X)GO TO 60                              000231
00173       50 A(I,J)= TEMP(I+2)                                       000234
00175          I=I+1                                                   000240
00176       60 NCUT= I-1                                               000244
00177          IF(I.LT.447)IND(J)=0                                    000250
00201          GO TO 200                                               000260
00201    C                                                             000260
00201    C                    END OF USEFUL DATA REACHED               000260
00201    C                    (.99999 DATA VALUE ENCOUNTERED.)         000260
00201    C                                                             000260
00202      400 N= NCUT                                                 000262
00203          VAR=A(N,J)                                              000270
00204          IF(IMPL.EQ.2)WRITE(6,80)VAR,IUN                         000275
00211       80 FORMAT(1H0,41HTIME POINT PAST TABLE RANGE. LAST VALUE=  ,   000307
00211         1 F12.5,9H  ON UNIT,I4)                                  000307
00212          IF(IMPL.EQ.2)ICNT=ICNT+1                                000307
00214          RETURN                                                  000315
00214    C                                                             000315
00214    C                    READ ERROR OR END OF FILE REACHED        000315
00214    C                                                             000315
00215       10 WRITE(6,90)IUN                                          000321
00220       90 FORMAT(1H0,33HREAD ERROR OR END OF FILE ON UNIT,I4)     000326
00221          STOP                                                    000326
00222          END @ SUBROUTINE TA                                     000402
```

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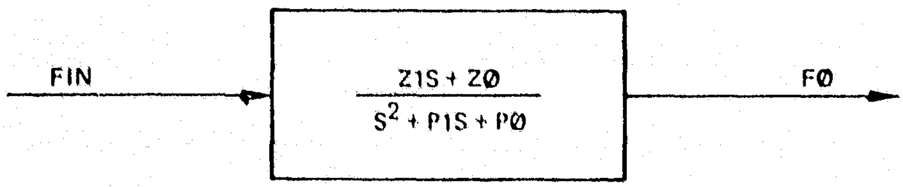
TA

7.39 SECOND ORDER TRANSFER FUNCTION



Inputs

Parameter/Port	Description
FIN	Input quantity
ZØ	Numerator coefficient
Z1	Numerator coefficient
PØ	Denominator coefficient
P1	Denominator coefficient

Outputs

Variable/Port	
X1	Intermediate state
FØ	Output quantity (state)

Calculation Sequence

$$\dot{\text{X1}} = \text{ZØ*FIN} - \text{PØ*FØ}$$

$$\dot{\text{FØ}} = \text{X1} + \text{Z1*FIN} - \text{P1*FØ}$$

NOTE: d.c. gain = $\frac{\text{ZØ}}{\text{PØ}}$; infinite frequency gain = 0.

SUBROUTINE TF   ENTRY POINT 000027

STORAGE USED CODE(1) 000035; DATA(0) 000004; BLANK COMMON(2) 000000

COMMON BLOCKS

0003   CIO   000003

EXTERNAL REFERENCES (BLOCK, NAME)

0004   NERR3$

STORAGE ASSIGNMENT (BLOCK, TYPE, RELATIVE LOCATION, NAME)

0003   000002 IDIAG   0000   000000 INJP$ 0003   000000 IREAD   0003   000001 IWRITE

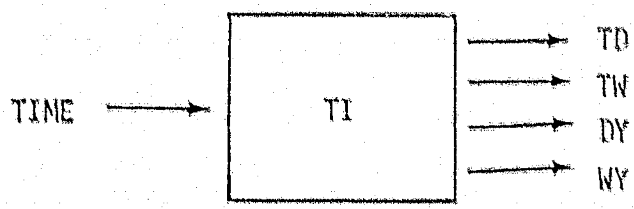
```
00100      CTF                                                              000000
00101         SUBROUTINE TF(X1,X1DOT,IX1,FO,FODOT,IFO,FIN,Z0,Z1,P0,P1)      000000
00101      C                                                                000000
00101      C   PURPOSE - TO SIMULATE A SECOND ORDER TRANSFER FUNCTION WITH  000000
00101      C             FIRST ORDER NUMERATOR                              000000
00101      C                                                                000000
00101      C                         FO       Z1*S + Z0                     000000
00101      C                        ----- = -----------                     000000
00101      C                         FIN       2                            000000
00101      C                                S + P1*S*P0                     000000
00101      C                                                                000000
00101      C   METHOD  - SELF EXPLANATORY                                   000000
00101      C                                                                000000
00101      C                                                                000000
00101      C   LIMITATIONS  -  NONE                                         000000
00101      C                                                                000000
00101      C                                                                000000
00101      C   WRITTEN BY      ADAM LLOYD          LATEST REVISION  NOV 75  000000
00101      C                                                                000000
00101      C                                                                000000
00101      C   INPUT/OUTPUT LIST                                            000000
00101      C                                                                000000
00101      C   X1       INTERMEDIATE STATE VARIABLE        ANY    OUTPUT STATE   000000
00101      C   X1DOT    STATE VARIABLE DERIVATIVE          ANY    OUTPUT STATE   000000
00101      C   IX1      INTEGRATOR CONTROL                 ---    PROGRAM VAR    000000
00101      C   FO       TRANSFER FUNCTION OUTPUT           ANY    OUTPUT STATE   000000
00101      C   FODOT    TRANSFER FUNCTION OUTPUT DERIV.    ANY    OUTPUT STATE   000000
00101      C   IFO      INTEGRATOR CONTROL                 ---    PROGRAM VAR    000000
00101      C   FIN      TRANSFER FUNCTION INPUT            ANY    INPUT  VAR     000000
00101      C   Z0       NUMERATOR COEFFICIENT              ANY    INPUT  VAR     000000
00101      C   Z1       NUMERATOR COEFFICIENT              ANY    INPUT  VAR     000000
```

TF

```
00101   C   P0          DENOMINATOR COEFFICIENT          1/SEC2    INPUT   VAR          000000
00101   C   P1          DENOMINATOR COEFFICIENT          1/SEC     INPUT   VAR          000000
00103         COMMON/CIO/IREAD,IWRITE,IDIAG                                              000000
00104         IF(IX1.NE.0)X1DOT=Z0*FIN-P0*F0                                             000000
00106         IF(IF0.NE.0)F0DOT=X1+Z1*FIN-P1*F0                                          000007
00110         RETURN                                                                     000020
00111         END                                                                        000034
```


TF

7.40 TIME CONVERSION



Converts simulation running time in hours to time referenced to start of day and start of week, and computes number of days and weeks elapsed since start of year.

Inputs

Parameter/Port	Description	Units
TO	Initial time of simulation from start of year	hrs
TIME	Running time (input via common/CTIME)	hrs

Outputs

Variable/Port		
TW	Time since start of week	hrs
TD	Time since start of day	hrs
WY	Number of weeks	-
DY	Number of days	-
MY	Number of months (approx.)	-
T	Running time from start of year	hrs
DW	Day of week	-

Calculation Sequence

T = AMOD(TO+TIME,8760)

WY = T/168+1

DY = T/24+1

MY = T/730+1

TW = AMOD(T,168)

TD = AMOD(T,24)

DW = TW/24+1

```
SUBROUTINE TI        ENTRY POINT 000122

STORAGE USED  CODE(1) 000155; DATA(0) 000031; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CTIME  000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0004   NERR3$

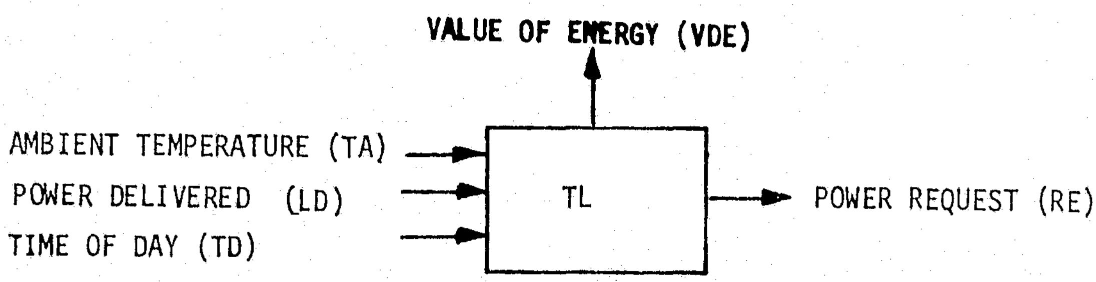
STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0000   000013 INJP$     0000 I 000002 MY       0000 I 000000 ND       0000 I 000001 NW       0003 R 000000 TIME


00100     CTI                                                                                   000000
00101           SUBROUTINE TI(T,TD,TW,DW,DY,WY,AMY,TO)                                          000000
00101     C                                                                                     000000
00101     C   PURPOSE    CONVERT SIMULATION TIME TO DAILY, WEEKLY, MONTHLY UNITS                    000000
00101     C                                                                                     000000
00101     C   WRITTEN BY  A.W. WARREN                           VERSION 1, MARCH 3 1977            000000
00101     C                                                                                     000000
00101     C   CALL SEQUENCE                                                                     000000
00101     C             T    - SIMULATION TIME FROM START OF YEAR, HR         OUTPUT VAR.         000000
00101     C             TD   - TIME OF DAY, HR                               OUTPUT VAR.         000000
00101     C             TW   - TIME SINCE START OF WEEK, HR                  OUTPUT VAR.         000000
00101     C             DW   - DAY OF WEEK                                   OUTPUT VAR.         000000
00101     C             DY   - DAY OF YEAR                                   OUTPUT VAR.         000000
00101     C             WY   - WEEK OF YEAR                                  OUTPUT VAR.         000000
00101     C             AMY  - MONTH OF YEAR (APPROX.)                       OUTPUT VAR.         000000
00101     C             TO   - SIMULATION INITIAL TIME FROM START OF YEAR, HR  INPUT PARM         000000
00101     C                                                                                     000000
00103           COMMON / CTIME / TIME                                                           000000
00104           T = AMOD(TO + TIME,8760.)                                                       000000
00105           TD = AMOD(T,24.)                                                                000007
00106           TW = AMOD(T,168.)                                                               000015
00107           ND = TW/24.+1.001                                                               000023
00110           DW = ND                                                                         000034
00111           ND = T/24.+1.001                                                                000037
00112           DY = ND                                                                         000050
00113           NW = T/168.+1.001                                                               000053
00114           WY = NW                                                                         000065
00115           MY = T/730.+1.001                                                               000070
00116           AMY = MY                                                                        000102
00116     C                                                                                     000102
00117           RETURN                                                                          000105
```

```
00120     32*          END                                                    000154
```

7.41 THERMAL LOAD



Thermal load is computed as a user specified function of ambient temperature and time of day. The actual load delivered is either the load requested or the maximum discharge rate of the thermal storage chamber. The value of the thermal energy delivered and % of total load actually delivered are also computed.

Basic Equation

RE = TLØ(TA)*TWT(TD)*NC

where

TLØ = Thermal load versus temperature table

TWT = Daily profile weighting function

NC = Normalizing constant

TL

Tables	Description	Units
TLØ	Thermal load versus ambient temperature	kw
TWT	Daily profile weighting function (tabular with time of day)	

Inputs

Parameter/Port		
TA	Ambient temperature	^oF
LD	Power delivered	kw
TD	Time of day (0-24)	h
VE	Value of thermal energy	$/kwh
NC	Normalizing constant	

Outputs

Variable/Port		
RE	Load request	kw
VDE	Total value of energy delivered (state)	$

Statistics		
PC	Cumulative percent of load delivered	-
SLD	Total energy delivered	kwh
SRE	Total energy requested	kwh

<u>Calculation Sequence</u>

1) Compute load request

RE = TLØ(TA)*TWT(TD)*NC

2) Value of energy dynamics

$\dot{V}$DE = LD*VE

3) Statistics

SLD = SLD+LD* Δ/2

SRE = SRE+RE* Δ/2

PC = 100.* SLD/SRE

where Δ = integration step size

```
SUBROUTINE TL        ENTRY POINT 000173

STORAGE USED  CODE(1) 000251; DATA(0) 000033; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL   000001
 0004   CSIMUL  000010
 0005   CTIME   000001
 0006   COST    000006

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   TBLU1
 0010   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

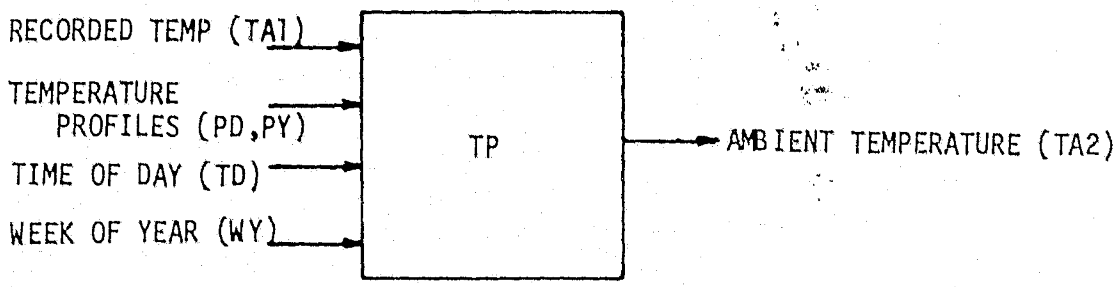
 0001     000034 100L     0006     000000 CC      0006 R 000004 CLD     0006     000001 CM      0006     000002 CO
 0006 R 000005 CRE      0006 R 000003 CV      0004     000000 DUM     0003 I 000000 IMPL    0000     000012 INJP$
 0000 I 000000 ITL      0000 I 000001 ITW     0007 R 000000 TBLU1   0005 R 000000 TIME    0004 R 000006 TINC
 0000 R 000003 TINCI    0000 R 000004 TLD     0004 R 000007 TMAX    0000 R 000002 TMAX1   0000 R 000005 TW


00100     CTL                                                                      000001
00101           SUBROUTINE TL(TLO,TWT,VDE,DVD,IVD,RE,PC,SLD,SRE,TA,LD,TD,VE,NC)    000001
00101     C                                                                        000001
00101     C   PURPOSE    COMPUTE ENERGY RESPONSE FROM A THERMAL LOAD REQUEST      000001
00101     C                                                                        000001
00101     C   METHOD     ENERGY DELIVERED IS EQUAL TO THE LOAD REQUESTED OR       000001
00101     C                                                                        000001
00101     C              THE MAXIMUM DISCHARGE RATE.                               000001
00101     C                                                                        000001
00101     C   WRITTEN BY F. O. MAHONY               VERSION 1, APRIL 1 1977        000001
00101     C                                                                        000001
00101     C   CALL SEQUENCE                                                        000001
00101     C         TABLES                                                         000001
00101     C              TLO - THERMAL LOAD AS FUNCTION OF AMBIENT TEMPERATURE     000001
00101     C              TWT - DAILY PROFILE WEIGHTING FUNCTION VS TIME OF DAY     000001
00101     C                                                                        000001
00101     C         OUTPUTS                                                        000001
00101     C              VDE - VALUE OF ENERGY DELIVERED (STATE), $                000001
00101     C              DVD - DERIVATIVE OF VDE                                   000001
00101     C              IVD - INDICATOR FOR VDE                                   000001
00101     C              RE  - LOAD REQUEST, KW                                    000001
00101     C              PC  - CUMULATIVE PERCENT OF LOAD DELIVERED                000001
00101     C              SLD - TOTAL ENERGY DELIVERED, KWH                         000001
00101     C              SRE - TOTAL ENERGY REQUESTED, KWH                         000001
```


TL

```
00101    C                                                                        000001
00101    C        INPUTS                                                          000001
00101    C            TA   - AMBIENT TEMPERATURE, DEG F                           000001
00101    C            LD   - POWER DELIVERED, KW                                  000001
00101    C            TD   - TIME OF DAY, HR                                      000001
00101    C            VE   - VALUE OF THERMAL ENERGY, $/KWH                       000001
00101    C            NC   - NORMALIZING CONSTANT FOR LOAD REQUEST                000001
00101    C                                                                        000001
00103          DIMENSION TLO(3),TWT(5)                                            000001
00104          COMMON/CIMPL/IMPL /CSIMUL/ DUM(6),TINC,TMAX/CTIME/TIME             000001
00105          COMMON/COST /CC,CM,CO,CV,CLD,CRE                                   000001
00106          REAL LD,NC                                                         000001
00106    C                                                                        000001
00107          ITL=TLO(2)                                                         000001
00110          ITW=TWT(2)                                                         000010
00111          IF(IMPL.GT.0)GO TO 100                                             000017
00111    C                                                                        000017
00111    C                                                                        000017
00113          TMAX1=TMAX*0.99999                                                 000022
00114          TINC1=TINC*.5                                                      000025
00114    C                                                                        000025
00115          PC =0.0                                                            000030
00116          SLD=0.0                                                            000031
00117          SRE=0.0                                                            000032
00117    C                                                                        000032
00117    C                                                                        000032
00117    C                      COMPUTE LOAD REQUEST                              000032
00117    C                                                                        000032
00120      100 TLD=TBLU1(TA,TLO(4),TLO(ITL+4),1,-ITL)                             000034
00121          TW=TBLU1(TD,TWT(4),TWT(ITW+4),1,-ITW)                              000053
00121    C                                                                        000053
00122          RE =TLD*TW*NC                                                      000073
00122    C                                                                        000073
00122    C                      VALUE OF ENERGY                                   000073
00122    C                                                                        000073
00123          IF(IVD.NE.0)DVD=LD*VE                                              000076
00123    C                                                                        000076
00125          IF(IMPL.LE.1)RETURN                                                000103
00125    C                                                                        000103
00125    C                      PERFORMANCE STATISTICS                            000103
00125    C                                                                        000103
00127          SLD=SLD+LD*TINC1                                                   000115
00130          SRE=SRE+RE*TINC1                                                   000120
00130    C                                                                        000120
00131          IF(SRE.GT.0.0)PC=100.0*SLD/SRE                                     000124
00131    C                                                                        000124
00133          IF(TIME.LT.TMAX1)RETURN                                            000133
00133    C                                                                        000133
00135          CV=CV+VDE                                                          000142
00136          CLD=CLD+SLD-LD*TINC1                                               000145
00137          CRE= CRE+ SRE-RE*TINC1                                             000151
00137    C                                                                        000151
00140          RETURN                                                             000157
00141          END                                                                000250
```

7.42 AMBIENT TEMPERATURE



This component is very similar to the wind component. Ambient temperature is output either from user supplied time histories on storage files or by generating a set of random numbers with user specified random variations. If user supplied profiles are available, then the temperatures are generated from the following equation:

$$TA2 = [PD(TD) + CN(t)] * PY(WY)/MØ$$

where PD and PY are the user supplied daily and weekly profiles, TD and WY are the time of the day and week of the year, CN is a colored noise term and MO is the average value of PY:

$$MØ = \frac{1}{J} \sum_{j=1}^{J} PY(j)$$

Tables	Description	Units
PD	Daily profile versus TD	^{o}F
PY	Yearly profile versus WY	arbitrary

Inputs

Parameter/Port		Description	Units
TA	1	Ambient temperature data file	^{o}F
TD		Time of day	hr
WY		Week of the year	-
CT		Correlation time of colored noise	hr
MN		Mean temperature of colored noise	^{o}F
STD		Standard deviation of colored noise	^{o}F

Outputs

Variable/Port		Description	Units
CN		Colored noise sample	^{o}F
TA	2	Ambient temperature	^{o}F
AV		Mean of daily temperature	^{o}F
MO		Mean of yearly profile	
TIM		Last time a random sample was generated	hr

Calculation Sequence

1) Initialization (first pass only)

Compute AV, MO, and initial CN

$$AV = MN + \frac{1}{N} \sum_{J=1}^{N} PD(J)$$

2) Check for data file input

If TA1 = .99999 go to 3)

TA2 = TA1

Return

3) Generate colored noise sample CN

If TIME = TIM RETURN

$$A = \begin{cases} EXP(-TINC/CT) & CT>0 \\ 0. & CT=0 \end{cases}$$

where TINC = integration step size

CN = CN * A + W

Where W is white noise with mean = MN*(1-A) and

standard deviation = STD* $\sqrt{1-A^2}$

TIM = TIME

4) Compute Temperature

TA2 = (PD(TD) +CN) *PY (WY)/MO

```
SUBROUTINE TP        ENTRY POINT 000265

STORAGE USED  CODE(1) 000350; DATA(0) 000044; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000001
 0004    CSIMUL  000007
 0005    CTIME   000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0006    RN
 0007    TBLU1
 0010    EXP
 0011    SQRT
 0012    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000121 10L       0001     000127 100L      0001     000057 117G      0001     000102 127G      0001     000247 150L
 0000 R 000005 A          0000 R 000000 AX         0000 R 000011 DTP        0004     000000 DUM        0000 I 000003 I
 0003 I 000000 IMPL       0000   000016 INJP$      0000 I 000004 L          0000 I 000001 ND         0000 I 000002 NY
 0007 R 000000 TBLU1      0005 R 000000 TIME       0004 R 000006 TINC       0000 R 000010 W          0000 R 000006 WMN
 0003 R 000007 WSD        0000 R 000012 YTP

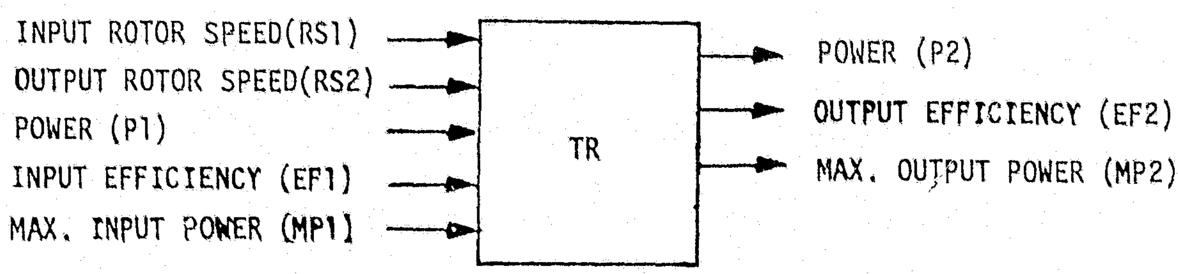

00100      CTP                                                                                    000007
00101          SUBROUTINE TP (PD,PY,TAO,AV,XM,TIMO,XN, TAI, TD,WY,CT,XMN,STD)                     000007
00101      C                                                                                      000007
00101      C   PURPOSE    GENERATE AMBIENT TEMPERATURE FROM DAILY, YEARLY AND RANDOM DATA         000007
00101      C                                                                                      000007
00101      C   METHOD     COLORED NOISE WITH SPECIFIED PARMS IS ADDED TO A MEAN DAILY             000007
00101      C              PROFILE AND MULTIPLIED BY A YEARLY PROFILE.                             000007
00101      C                                                                                      000007
00101      C   WRITTEN BY  A.W. WARREN                          VERSION 1, MARCH 7 1977           000007
00101      C                                                                                      000007
00101      C   CALL SEQUENCE                                                                      000007
00101      C         TABLES                                                                       000007
00101      C              PD   - MEAN DAILY PROFILE, DEG.F                                        000007
00101      C              PY   - MEAN YEARLY PROFILE, DEG.F                                       000007
00101      C         OUTPUTS                                                                      000007
00101      C              TAO  - AMBIENT TEMPERATURE OUTPUT, DEG.F                                000007
00101      C              AV   - MEAN DAILY TEMPERATURE, DEG.F                                    000007
00101      C              XM   - MEAN YEARLY TEMPERATURE,DEG.F                                    000007
00101      C              TIMO- LAST TIME COLORED NOISE WAS USED, HR                              000007
00101      C              XN   - COLORED NOISE SAMPLE, DEG.F                                      000007
                                                                                                  000007
```

```
00101        C          INPUTS                                                       000007
00101        C               TAI - TEMPERATURE INPUT FROM DATA FILE,DEG.F            000007
00101        C               TD  - TIME OF DAY, HR                                   000007
00101        C               WY  - WEEK OF YEAR (1-52)                               000007
00101        C               CT  - CORRELATION TIME FOR COLORED NOISE, HR            000007
00101        C               XMN - MEAN TEMPERATURE OF COLORED NOISE, DEG.F          000007
00101        C               STD - STANDARD DEVIATION OF COLORED NOISE, DEG.F        000007
00101        C                                                                       000007
00103              DIMENSION PD(1),PY(1)                                             000007
00104              COMMON/CIMPL/IMPL /CSIMUL/DUM(6),TINC /CTIME/TIME                 000007
00105              DATA AX /.99999/                                                  000007
00105        C                         INITIALIZATION                                000007
00105        C                                                                       000007
00107              ND=PD(2)                                                          000007
00110              NY=PY(2)                                                          000016
00111              IF(IMPL.GT.0) GO TO 10                                            000025
00113              TIMO=-1.                                                          000030
00114              CALL RN(XN,AX,STD,XMN)                                            000032
00114        C                                                                       000032
00115              AV = 0.                                                           000040
00116              DO 20 I=1,ND                                                      000057
00121              L = 3+ND+I                                                        000057
00122           20 AV = AV + PD(L)                                                   000062
00124              AV = AV/ND +XMN                                                   000071
00124        C                                                                       000071
00125              XM=0.                                                             000076
00126              DO 30 I=1,NY                                                      000102
00131              L=3+NY+I                                                          000102
00132           30 XM=XM+PY(L)                                                       000107
00134              XM=XM/NY                                                          000114
00134        C                         CHECK FOR DATA FILE INPUT                     000114
00134        C                                                                       000114
00135           10 IF(TAI.EQ. .99999) GO TO 100                                      000121
00137              TAO = TAI                                                         000123
00140              GO TO 150                                                         000125
00140        C                         GENERATE COLORED NOISE SAMPLE XN              000125
00140        C                                                                       000125
00141          100 IF(  TIMO.EQ.TIME) GO TO 150                                      000127
00143              A=0.                                                              000131
00144              IF(CT.GT.0.) A=EXP(-TINC/CT)                                      000132
00146              WMN = XMN*(1.-A)                                                  000152
00147              WSD = STD*SQRT(1.-A*A)                                            000156
00150              CALL RN(W,AX,WSD,WMN)                                             000167
00151              XN = A*XN+W                                                       000175
00151        C                         COMPUTE AMBIENT TEMPERATURE                   000175
00151        C                                                                       000175
00152              DTP = TBLU1(TD,PD(4),PD(4+ND),1,-%                                000201
00153              YTP = TBLU1(WY,PY(4),PY(4+NY),1,-N..                              000220
00154              TAO = (DTP + XN)*YTP/ XM                                          000237
00155              TIMO=TIME                                                         000244
00155        C                                                                       000244
00156          150 RETURN                                                            000247
00157              END                                                               000347
```

ORIGINAL PAGE IS
OF POOR QUALITY

TP

7.43 VARIABLE RATIO TRANSMISSION



This component models a transmission which couples a fixed speed rotor input (or output) to a variable speed rotor output (or input) component. Power losses are modeled as a table lookup depending on gear ratio and input power.

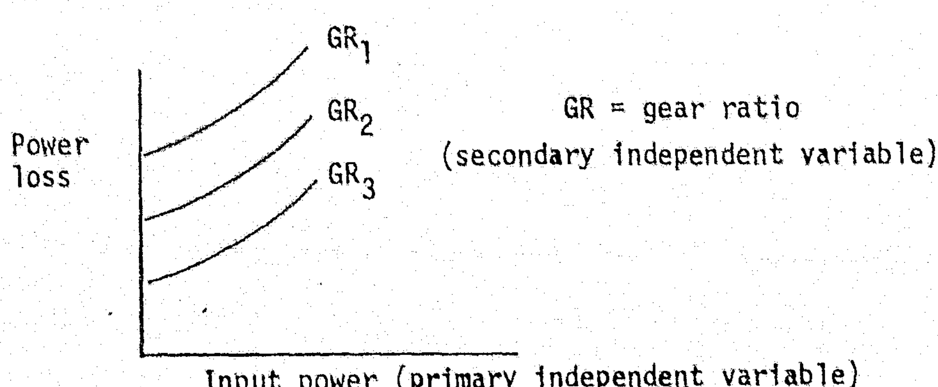


FIGURE 7.43 TRANSMISSION MODEL - LOOKUP TABLE

Tables		Description	Units
PLØ		Power loss versus input power and gear ratio (TABLE DIMENSION = 66)	kw

Inputs

Parameter/Port			
RS	1	Input rotor speed	rpm
RS	2	Output rotor speed	rpm
P	1	Input power	kw
EF	1	Input product efficiency	–
MP	1	Maximum input power	kw
CC		Capital cost/year	$
CM		Maintenance cost/year	$

Outputs

Variable/Port			
P	2	Output power	kw
TØ		Output torque	ft-lb
PL		Power loss	kw
EF	2	Output product efficiency	–
MP	2	Maximum power output	kw

Calculation Sequence

If P1 ≤ 0 or RS1 ≤ 0 set P2 = TØ = PL = 0 and go to 4)

1) Determine gear ratio and power terms

GR = RS2/RS1

PL = PLØ(P1,GR)

P2 = P1 - PL

2) Determine output torque

TØ = P2*737.6/(RS2*(2π/60))

3) Efficiency and maximum power

EF2 = EF1*(P2/P1)

If P2 ≤ 0, set EF2 = EF1 and write Diagnostic

MP2 = MP1 - PLØ(MP1,GR)

MP2 ≤ 0 ⇨ DIAGNOSTIC

4) Compute Costs

```
SUBROUTINE TR        ENTRY POINT 000307

STORAGE USED  CODE(1) 000374; DATA(0) 000075; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL   000002
 0004   CTIME   000001
 0005   CSIMUL  000010
 0006   COST    000002

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   TBLU2
 0010   NWDU$
 0011   NI02$
 0012   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001   000014 10L      0001   000245 400L     0000   000007 408F     0001   000165 409L     0000   000023 508F
 0000 R 000006 AMP2     0006 R 000000 CCI      0006 R 000001 CMI      0005   000000 DUM      0000 R 000005 GR
 0003 I 000001 ICNT     0003 I 000000 IMPL     0000   000047 INJP$    0000 I 000004 MN4      0000 I 000003 M4
 0000 I 000001 NNGR     0000 I 000002 NNP1     0007 R 000000 TBLU2    0004 R 000000 TIME     0005 R 000007 TMAX
 0000 R 000000 TMAX1
```

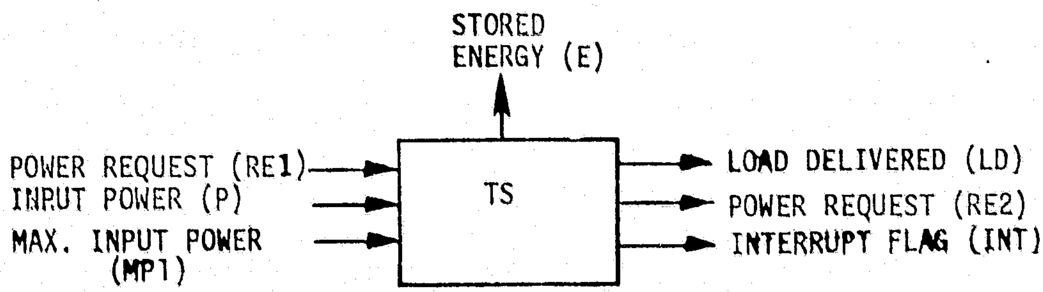
```
00100      CTR                                                                           000003
00101            SUBROUTINE TR(PLO,P2,TO,PL,EF2,MP2,RS1,RS2,P1,EF1,MP1,CC,CM)           000003
00101      C                                                                             000003
00101      C                PURPOSE    TRANSMISSION MODEL                                000003
00101      C                                                                             000003
00101      C                METHOD     OUTPUT POWER AND TORQUE COMPUTED FROM             000003
00101      C                           INPUT AND OUTPUT ROTOR SPEEDS. POWER              000003
00101      C                           LOSS MODELED BY TABLE LOOKUP DEPENDING            000003
00101      C                           ON GEAR RATIO AND INPUT POWER                     000003
00101      C                                                                             000003
00101      C                WRITTEN BY Y.K.CHAN          VERSION 1,JUNE 17,1977          000003
00101      C                                                                             000003
00101      C  CALL SEQUENCE                                                              000003
00101      C          TABLES                                                             000003
00101      C                PLO -POWER LOSS VERSUS INPUT POWER  AND GEAR RATIO ,KW       000003
00101      C          OUTPUTS                                                            000003
00101      C                P2  -OUTPUT POWER,KW                                         000003
00101      C                TO  -OUTPUT TORQUE,FT-LB                                     000003
00101      C                PL  -POWER LOSS,KW                                           000003
00101      C                EF2 -OUTPUT PRODUCT EFFICIENCY                               000003
00101      C                MP2 -MAXIMUM POWER OUTPUT,KW                                 000003
```

TR

```
00101      C          INPUTS                                                    000003
00101      C               RS1 -INPUT ROTOR SPEED,RPM                           000003
00101      C               RS2 -OUTPUT ROTOR SPEED,RPM                          000003
00101      C               P1  -INPUT POWER,KW                                  000003
00101      C               EF1 -INPUT PRODUCT EFFICIENCY                        000003
00101      C               MP1 -MAXIMUM INPUT POWER,KW                          000003
00101      C               CC  -CAPITOL COST/YEAR,$                             000003
00101      C               CM  -MAINTENANCE COST/YEAR,$                         000003
00101      C                                                                    000003
00103            COMMON/CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX           000003
00103           X      /COST/CCI,CMI                                            000003
00104            REAL MP2,MP1                                                   000003
00105            DIMENSION PLO(1)                                               000003
00105      C                                                                    000003
00106            IF(IMPL.GT.0)GO TO 10                                          000003
00110            TMAX1=TMAX*.99999                                              000006
00111            RS2=RS1                                                        000011
00112         10 CONTINUE                                                       000014
00113            NNGR=PLO(3)                                                    000014
00114            NNP1=PLO(2)                                                    000022
00115            M4=NNGR*4                                                      000031
00116            MN4=NNP1+M4                                                    000033
00116      C                                                                    000033
00116      C               COMPUTE GEAR RATIO AND POWER TERMS                   000033
00116      C                                                                    000033
00117            P2=0.                                                          000035
00120            TO=0.                                                          000036
00121            PL=0.                                                          000037
00122            EF2=EF1                                                        000040
00123            MP2=MP1                                                        000042
00124        100 IF((RS1.LE.0.).OR.(P1.LE.0.))GO TO 400                         000044
00126            P2=P1                                                          000060
00127        200 IF(RS2.LE.0)GO TO 400                                          000062
00131        300 GR=RS2/RS1                                                     000071
00132            PL=TBLU2(P1,GR,PLO(M4),PLO(4),PLO(MN4),1,1,-NNP1,-NNGR,NNP1,NNGR)  000074
00133            P2=P1-PL                                                       000124
00133      C                                                                    000124
00133      C               OUTPUT TORQUE                                        000124
00133      C                                                                    000124
00134            TO=P2*737.6*30./(RS2*3.14159)                                  000126
00134      C                                                                    000126
00134      C               EFFICIENCY AND MAXIMUM POWER                         000126
00134      C                                                                    000126
00135            EF2=EF1*P2/P1                                                  000134
00136            IF(EF2.GT.0.)GO TO 409                                         000140
00140            EF2=EF1                                                        000142
00141            IF(IMPL.EQ.2)WRITE(6,408)PL,P1                                 000144
00146        408 FORMAT(1H0,25H TRANSMISSION POWER LOSS ,F12.3,                 000156
00146           X  21H EXCEEDS INPUT POWER   ,F12.3)                            000156
00147            IF(IMPL.EQ.2)ICNT=ICNT+1                                       000156
00151        409 CONTINUE                                                       000165
00152            AMP2=TBLU2(MP1,GR,PLO(M4),PLO(4),PLO(MN4),1,1,-NNP1,-NNGR,     000165
00152           XNNP1,NNGR)                                                     000165
00153                                                                           000220
00153             MP2=MP1-AMP2                                                  000220
00154            IF(MP2.GT.0.)GO TO 400                                         000222
00156            IF(IMPL.EQ.2)WRITE(6,508)AMP2,MP1                              000224
```

```
00163      508 FORMAT(1H0,25H TRANSMISSION POWER LOSS ,F12.3,        000236
00163         X 29H EXCEEDS MAXIMUM INPUT POWER  ,F12.3)              000236
00164           IF(IMPL.EQ.2)ICNT=ICNT+1                              000236
00164       C                                                         000236
00166      400 IF(IMPL.LE.1)RETURN                                    000245
00170           IF(TIME.LT.TMAX1)RETURN                               000253
00172           CCI=CCI+CC                                            000262
00173           CHI=CHI+CH                                            000265
00173       C                                                         000265
00174           RETURN                                                000270
00175           END                                                   000373
```

7.44 THERMAL STORAGE CHAMBER



The thermal storage chamber is modeled by a "lumped" parameter approach. The entire storage media mass is characterized by a single temperature (no temperature gradient). The storage media is either a sensible heat or a phase change media. Energy is input via electrical resistance heaters and withdrawn by a heat exchanger. Energy is deposited in the media at a rate equal to the available electrical power up to a maximum charging power. The discharge heat exchanger fluid mass flow rate is adjusted to provide the desired heat load demand. The maximum mass flow rate condition determines the maximum thermal load. The maximum energy limit represents the point where the maximum media temperature is reached.

The model initially calculates the required storage media mass to provide the rated thermal energy storage (design point). Cost calculations are also made on the design point conditions. Initial checks on charge and discharge power and initial stored energy level are made. The storage temperature is determined based on the energy level.

Basic Equation

$$E = P - LD - NU*E$$

TS

Tables	Description	Units
HT	Media temperature versus enthalpy in KWH/LB[1]	^oF

Inputs

Parameter/Port		Description	Units
P		Input power	kw
RE	1	Demand thermal load	kw
NU		Stored energy loss coefficient (D = 0.02)	$(h)^{-1}$
TS		Rated storage time[2]	h
V0		Rated input voltage[2]	V
TM1		Maximum allowable storage temperature (D = 212)	^oF
T01		Minimum allowable storage temperature (D = 60)	^oF
DH		Design point enthalpy	kwh/lb
PD		Rated storage thermal power[2]	kw
PM		Maximum charge rate (D = 2*PD)	kw
MFM		Maximum working fluid mass flow rate (D = 9000)	lb/h
TDE		Temperature deadband for priority resequence (D = 4)	^oF
EF	1	Input product efficiency	–
MP	1	Maximum input charging rate (D = $1.\times10^{8}$)	kw
CP2		Working fluid heat capacity (D = 2.93×10^{-4})	kwh/lb-^oF
T02		Working fluid return temperature (D = 40)	^oF
TM2		Maximum allowable working fluid temperature (D = 212)	^oF
R		Effective heat exchanger thermal resistance (D = 3.08×10^{-4})	^oF/kw
CM		Storage device yearly maintenance cost (D = 0.6)	$/kw
CSA		Storage device capacity cost (D = 50)	$/kw
CSB		Storage device energy cost (D = 15.2)	$/kwh
LE		Unit life expectancy	years

D – Default values specified
1 – See Figure 7.44
2 – Design point conditions

Outputs

Variable/Port		Description	Units
E		Stored energy (state)	kwh
I		Input current	amps
MP	2	Maximum discharge rate allowable	kw
INT		Priority interrupt flag	–
T		Storage temperature	^oF
M		Required storage media mass	lb
CCØ		Storage device capital cost/year	$
RE	2	Maximum charging rate request	kw
MF		Working fluid mass flow rate	lb/h
LD		Power Delivered	kw

Statistics

TSU	Maximum storage temperature	^oF
TSL	Minimum storage temperature	^oF
ME	Maximum stored energy	kwh
MFU	Maximum working fluid mass flow rate	lb/h

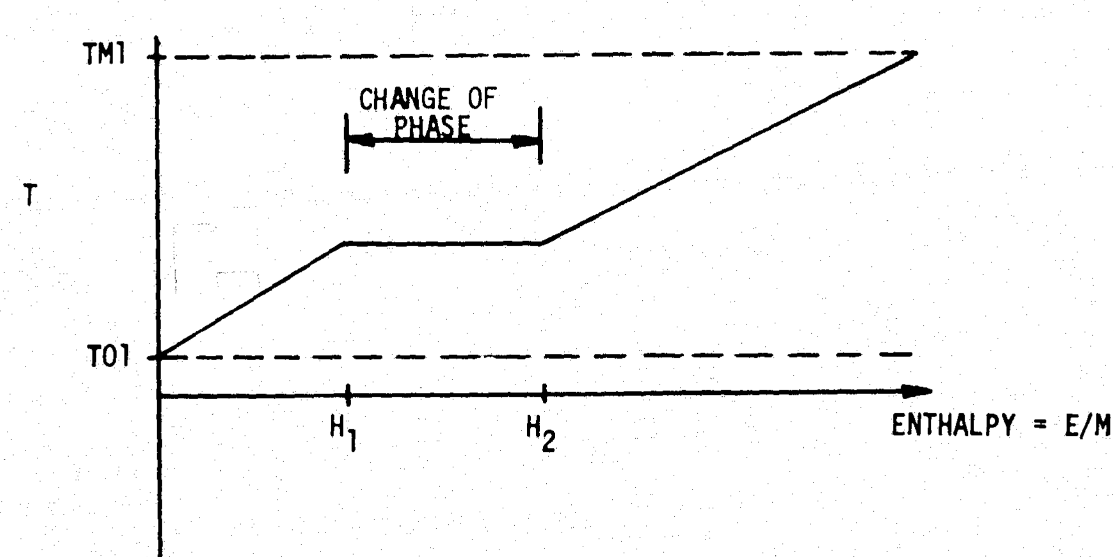


FIGURE 7.44: TEMPERATURE - ENTHALPY DIAGRAM

The calculation sequence and default values assume a thermal storage device sized to provide 10kw for 24 hours. A paraffin wax phase change storage medium is assumed. Water is assumed as the thermal transport fluid. Costs are assumed to be given by data for the phase change storage device given in Reference 1. The thermal resistance value, R, is assumed equal to that determined for the device of Reference 1. The value for the maximum charging rate, PM, reflects the acceptance of twice the design charge rate. The actual numbers which should be used will depend on specific design and performance requirements obtained from a desired application.

Calculation Sequence

1) Media mass, capital cost, maintenance cost (first pass)

$$M = \frac{PD*TS}{DH}$$

$$CC = (CSA+CSB*TS)*PD/LE$$

$$CM = CM*PD$$

2) Storage Temperature and Working Fluid Temperature

$$T = HT(E/M)$$

$$TF = \min\{TM2, \max[T02, T-RE1*R]\}$$

$$E2 = M*HT^{-1}(TM1)$$

1. "Advanced Thermal Energy Storage," BEC/EPRI RP 788-1, July 1976.

Calculation Sequence Cont.

3) Discharge Rate and Thermal Load

$$E1 = M*HT^{-1}(T01)$$

$$MP2 = MFM*CP2*(TF-T02)$$

$$LD=MIN(RE1,MP2,(E-E1)/TINC)$$

$$MF = LD/(CP2*(TF-T02))$$

4) Diagnostic Checks

$$MF \leq MFM$$

$$P \leq PM$$

$$T01 \leq T \leq TM1$$

5) Current calculations

$$I = \frac{P*1000}{V0}$$

6) Energy dynamics

$$\dot{E} = P-LD-NU*E$$

7) Maximum Charging Rates

$$RE2 = min(PM,MP1,(E2-E)/TINC)/EF1$$

where TINC = integration step size

Calculation Sequence Cont.

8) Priority resequencing

if T ≤ TØ1, INT = 1

if T ≥ TØ1+TDE and INT=1, INT=0

if T ≥ TM1, INT=-1

if T < TM1-TDE and INT=-1, INT=0

9) Compute Statistics and Costs

```
SUBROUTINE TS         ENTRY POINT 000612

STORAGE USED  CODE(1) 001071; DATA(0) 000131; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000002
 0004    CTIME   000001
 0005    CSIMUL  000010
 0006    COST    000002

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    TBLU1
 0010    NWDU$
 0011    NIO2$
 0012    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000144 100L      0000    000007 1010F     0000    000025 102GF     0000    000043 1030F     0001    000407 200L
 0000 R 000006 A          0006 R 000000 CCI       0006 R 000001 CMI       0005 R 000000 DUM       0000 R 000003 E1
 0003 I 000001 ICN        0003 I 000000 IMPL      0000    000107 INJP$     0000 I 000002 NH        0000 R 000005 PM1
 0007 R 000000 TBLU1      0000 R 000004 TF        0004 R 000000 TIME      0000 R 000001 TINC      0005 R 000007 TMAX
 0000 R 000000 TMAX1


00100       CTS                                                              000000
00101             SUBROUTINE TS(HT,E,DE,IE,I,MP2,INT,T,M,CCO,RE,MF,LD        000000
00101            1          ,TSU,TSL,ME,MFU,P,RE1,NU,TSO,VO,TM1,TO1,DH,PD,PM,  000000
00101            2        MFM,TDE,EF1,MP1,CP2,TO2,TM2,R,CM,CSA,CSB,LE)        000000
00101       C                                                                000000
00101       C   PURPOSE    COMPUTE ENERGY CONTAINED IN A THERMAL STORAGE MEDIA  000000
00101       C                                                                000000
00101       C   METHOD     A PHASE CHANGE OR SENSIBLE HEAT MEDIA IS MODELED AS  000000
00101       C                                                                000000
00101       C              A SINGLE TEMPERATURE MASS WITH NO GRADIENTS.         000000
00101       C                                                                000000
00101       C   WRITTEN BY F. O. MAHONY              VERSION 2, JULY 1977       000000
00101       C                                                                000000
00101       C   CALL SEQUENCE                                                000000
00101       C                                                                000000
00101       C         TABLES                                                 000000
00101       C            HT  - MEDIA TEMPERATURE VERSUS ENTHALPY IN KWH/LB, DEG F  000000
00101       C         OUTPUTS                                                000000
00101       C            E   - STORED ENERGY (STATE VARIABLE), KWH           000000
00101       C            DE  - POWER INTO STORAGE, KW                        000000
00101       C            IE  - STATUS INDICATOR                              000000
```

TS

```
00101   C          I    - INPUT ELECTRIC CURRENT, KW                         000000
00101   C          MP2  - MAXIMUM DISCHARGE RATE ALLOWABLE, KW               000000
00101   C          INT  - PRIORITY FLAG INTERRUPT                            000000
00101   C          T    - STORAGE TEMPERATURE, DEG F                         000000
00101   C          M    - REQUIRED STORAGE MEDIA MASS, LB                    000000
00101   C          CCO  - STORAGE DEVICE CAPITAL COST/YEAR, $                000000
00101   C          RE   - MAXIMUM CHARGING RATE REQUEST, KW                  000000
00101   C          MF   - WORKING FLUID MASS FLOW RATE, LB/HR                000000
00101   C          LD   - THERMAL LOAD DELIVERED, KW                         000000
00101   C          TSU  - MAXIMUM STORAGE TEMPERATURE, DEG F                 000000
00101   C          TSL  - MINIMUM STORAGE THEMPERATURE, DEG F                000000
00101   C          ME   - MAXIMUM STORED ENERGY, KWH                         000000
00101   C          MFU  - MAXIMUM WORKING FLUID MASS FLOW RATE, LB/HR        000000
00101   C      INPUTS                                                        000000
00101   C          P    - INPUT POWER, KW                                    000000
00101   C          REI  - THERMAL DISCHARGE REQUEST, KW                      000000
00101   C          NU   - STORAGE ENERGY LOSS COEFFICIENT, 1/HR              000000
00101   C          TSO  - RATED STORAGE TIME, HR                             000000
00101   C          VO   - RATED INPUT VOLTAGE, VOLTS                         000000
00101   C          TM1  - MAXIMUM ALLOWABLE STORAGE TEMPERATURE, DEG F       000000
00101   C          TO1  - MINIMUM ALLOWABLE STORAGE TEMPERATURE, DEG F       000000
00101   C          DH   - DESIGN POINT ENTHALPY, KWH/LB                      000000
00101   C          PD   - RATED STORAGE THERMAL POWER, KW                    000000
00101   C          PM   - MAXIMUM CHARGE RATE, KW                            000000
00101   C          MFM  - MAXIMUM WORKING FLUID MASS FLOW RATE, LB/HR        000000
00101   C          TDE  - TEMPERATURE DEADBAND FOR PRIORITY RESEQUENCE, DEC F  000000
00101   C          EF1  - INPUT PRODUCT EFFICIENCY                           000000
00101   C          MP1  - MAXIMUM INPUT CHARGING RATE, KW                    000000
00101   C          CP2  - WORKING FLUID HEAT CAPACITY, KWH/LB-F              000000
00101   C          TO2  - WORKING FLUID RETURN TEMPERATURE, DEG F            000000
00101   C          TM2  - MAXIMUM ALLOWABLE WORKING FLUID TEMPERATURE, DEG F 000000
00101   C          R    - EFFECTIVE HEAT EXCHANGER THERMAL RESISTANCE, F/KW  000000
00101   C          CM   - STORAGE DEVICE YEARLY MAINTENANCE COST, $/KW       000000
00101   C          CSA  - STORAGE DEVICE CAPACITY COST, $/KW                 000000
00101   C          CSB  - STORAGE DEVICE ENERGY COST, $/KWH                  000000
00101   C          LE   - UNIT/LIFE FILE EXPECTANCY, YEARS                   000000
00101   C                                                                    000000
00103         COMMON/CIMPL/IMPL,ICN/CTIME/TIME /CSIMUL/DUM(7),TMAX /COST/CCI,CMI  000000
00104         REAL NU,I,MP2,INT,MF,LD,ME,MFU,MFM,MP1,LE,M                    000000
00105         DIMENSION HT(1)                                                000000
00105   C                                                                    000000
00106         IF(IMPL.GT.0)GO TO 100                                         000000
00110         TMAX1=TMAX*.99999                                              000003
00111         TINC= DUM(7)                                                   000006
00111   C                                                                    000006
00111   C                                                                    000006
00112         IF(NU.EQ. .99999)NU=0.02                                       000010
00114         IF(TM1.EQ. .99999)TM1=212.0                                    000015
00116         IF(TO1.EQ. .99999)TO1=60.0                                     000022
00120         IF(PM. EQ. .99999) PM=2.0*PD                                   000027
00122         IF(MFM.EQ. .99999)MFM=9000.0                                   000035
00124         IF(TDE.EQ. .99999)TDE=4.0                                      000042
00126         IF(CP2.EQ. .99999)CP2=2.93E-4                                  000047
00130         IF(TO2.EQ. .99999)TO2=40.0                                     000054
00132         IF(TM2.EQ. .99999)TM2=212.0                                    000061
00134         IF(R  .EQ. .99999)R  =3.08E-4                                  000066
[illegible]   IF(CM .EQ. .99999)CM =0.6                                      000073
```

```
00140       IF(CSA.EQ. .99999)CSA=50.0                          000100
00142       IF(CSB.EQ. .99999)CSB=15.2                          000105
00144       IF(MP1.EQ. .99999) MP1= 1.0E8                       000112
00144 C                                                         000112
00146       INT=0.0                                             000117
00147       RE1=0.0                                             000120
00147 C                                                         000120
00150       TSU=0.0                                             000121
00151       ME =0.0                                             000122
00152       MFU=0.0                                             000123
00153       TSL=1.0E8                                           000124
00154       CM= CM*PD                                           000126
00154 C                                                         000126
00155       M =PD*TSO/DM                                        000131
00156       CCO=(CSA+CSB*TSO)*PD/LE                             000135
00156 C                                                         000135
00156 C                 COMPUTE STORAGE TEMPERATURE             000135
00156 C                                                         000135
00157   100 NH= HT(2)                                           000144
00160       T= TBLU1(E/M,HT(4),HT(4+NH),1,NH)                   000152
00161       E1= M*TBLU1(TM1,HT(4+NH),HT(4),1,NH)                000173
00161 C                                                         000173
00161 C                                                         000173
00161 C               WORKING FLUID TEMPERATURE                 000173
00161 C                                                         000173
00162       TF =AMIN1(TM2,AMAX1(TO2,T-RE1*R))                   000212
00162 C                                                         000212
00162 C               MAXIMUM DISCHARGE RATE AND THERMAL LOAD   000212
00162 C                                                         000212
00163       MP2=MFM*CP2*(TF-TO2)                                000226
00164       IF(INT.EQ.1.)MP2=0.                                 000234
00166       LD =AMIN1(RE1,MP2)                                  000240
00166 C                                                         000240
00166 C               WORKING FLUID MASS FLOW RATE              000240
00166 C                                                         000240
00167       IF(LD.GT.0.0) MF =LD/CP2/(TF-TO2)                   000246
00167 C                                                         000246
00171       IF(IMPL.LE.1)GO TO 200                              000255
00173       IF(IMPL.GT.2) GO TO 200                             000261
00175       PM1= PM/.9999                                       000265
00175 C                                                         000265
00176       IF(MF .GT.MFM)WRITE(6,1010)MF,MFM                   000270
00203       IF(P  .GT.PM1 )WRITE(6,1020)P ,PM                   000303
00210       IF(MF.GT.MFM .OR. P.GT.PM1)ICN=ICN+1                000316
00212       IF(T  .LT.TO1.OR.                                   000337
00212      1   T  .GT.TM1)WRITE(6,1030)T,TO1,TM1                000337
00220       IF(T.LT.TO1 .OR. T.GT.TM1) ICN=ICN+1                000365
00220 C                                                         000365
00220 C               CURRENT CALCULATION                       000365
00220 C                                                         000365
00222   200 I =P*1000.0/V0                                      000407
00222 C                                                         000407
00222 C               ENERGY STATE                              000407
00222 C                                                         000407
00222 C                                                         000407
00223       IF(IE.NE.0)DE=P-LD-NU*E                             000412
                                                                000412
```

TS

```
00223   C                    MAXIMUM CHARGING RATE REQUEST           000412
00223   C                                                            000412
00223   C                                                            000412
00225         A= AMAX1(E1-E,0.)/TINC                                 000422
00226         RE =AMIN1(PM,MP1,A)/EF1                                000432
00226   C                                                            000432
00226   C                                                            000432
00226   C                    PRIORITY RESEQUENCING                   000432
00226   C                                                            000432
00227         IF(T.LE.TO1)INT=1.0                                    000445
00227   C                                                            000445
00231         IF(T.GE.(TO1+TDE).AND.                                 000453
00231        1  INT.EQ.1.)INT=0.0                                    000453
00231   C                                                            000453
00233         IF(T.GE.TM1)INT=-1.0                                   000472
00233   C                                                            000472
00235         IF(T.LT.(TM1-TDE).AND.                                 000500
00235        1   INT.EQ.-1.)INT=0.0                                  000500
00235   C                                                            000500
00237         IF(IMPL.LE.1)RETURN                                    000517
00237   C                                                            000517
00241         TSU=AMAX1(TSU,T)                                       000526
00242         TSL=AMIN1(TSL,T )                                      000534
00243         ME =AMAX1(ME ,E )                                      000542
00244         MFU=AMAX1(MFU,MF)                                      000550
00245         IF(TIME.LT.TMAX1)RETURN                                000556
00245   C                                                            000556
00245   C                    COST                                    000556
00245   C                                                            000556
00247         CMI=CMI+CM                                             000565
00250         CCI=CCI+CCO                                            000570
00251         CM = CM/PD                                             000573
00251   C                                                            000573
00252         RETURN                                                 000576
00253    1010 FORMAT(1HO,26HTS WORKING FLUID FLOW RATE,F12.3         001070
00253        1         ,32H   GREATER THAN MAXIMUM ALLOWED,F12.3)    001070
00254    1020 FORMAT(1HO,14HTS INPUT POWER,F12.3                     001070
00254        1         ,44H   GREATER THAN MAXIMUM ALLOWED CHARGE RATE,F12.3)  001070
00255    1030 FORMAT(1HO, 23HTS STORAGE TEMPERATURE  ,F12.3          001070
00255        1   ,20H      OUTSIDE MINIMUM ,F12.3                    001070
00255        2         ,15H     AND MAXIMUM,F12.3)                   001070
00255   C                                                            001070
00256         END                                                    001070
```

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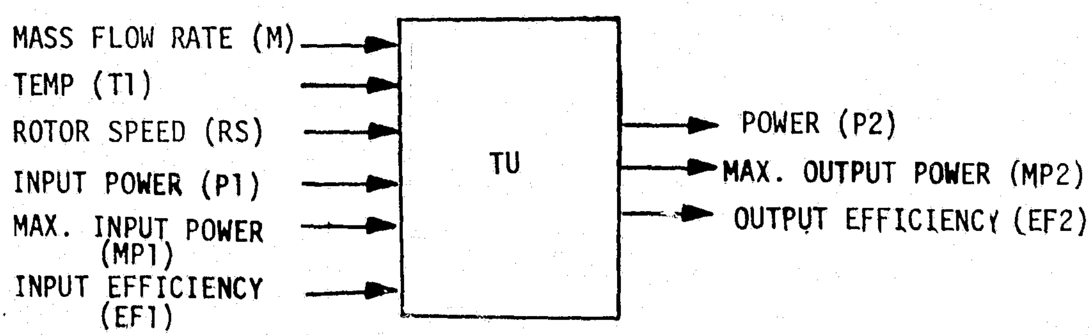
TS

7.45 TURBINE (PNEUMATIC)



The turbine model is based on a high pressure ratio, constant angular velocity design. The turbine is assumed to be designed to a set of of operating conditions defined in terms of user specified parameters. The polytropic efficiency is only weakly related to angular velocity. Initial calculations are made with the design polytropic efficiency, and refinements are then computed after off-design parameters are calculated.

Basic Equation

The equation for output power P2 is

P2 = M*CP*(T1-TA)

Inputs

Parameter/Port		Description	Units
M		Inlet mass flow rate	lb/h
CP		Air heat capacity (D = 7.2×10^{-5})	kwh/lb/°F
T	1	Input air temperature	°F
TA		Ambient air temperature	°F
MD		Design mass flow rate (D = 4800)	lb/h
TID		Design inlet air temperature (D = 600)	°F
PID		Design inlet pressure (D = 117.6)	psi
P2D		Design exit pressure (ambient) (D = 14.7)	psi
T2D		Design exit temperature (ambient) (D = 70)	°F
PS		Storage vessel pressure	psi
RS		Angular velocity	rpm
EF	1	Input product efficiency	–
MP	1	Maximum input power	kw
P	1	Input power	kw
CK		Capacity cost coefficient[1] (D = 0.015)	
FØ		Turbine mass flow exponent for capital cost (D = 0.75)	–
G		Turbine temperature exponent for capital cost (D = 0.5)	–
NPD		Design Polytropic Efficiency (D = 0.88)	

Outputs

Variable/Port			
P	2	Output power	kw
CCØ		Turbine cost/year	$
PR		Back pressure	psi
TO		Torque	ft-lb

D – Default values supplied

1 CK = Capital cost (known unit)/[(design point mass flow rate)^{FO}* (design point temperature + 460)^{G} * LN (inlet/outlet pressure ratio)*LE], where LE = life expectancy in years.

Outputs Cont.

Variable/Port		Description	Units
EF	2	Output product efficiency	-
MP	2	Maximum discharge power	kw

Statistics

MØP	Maximum power observed	kw

The calculation sequence and the default values are based on the assumption of a high pressure ratio, constant angular velocity turbine, rated at 150 kw and a pressure ratio of 8. The equations used relate first order effects among the various physical quantities and were derived from first principles originally in support of the research work of Reference 1. Cost scaling was also developed in that reference based on cost estimates from turbomachinery manufacturers.

1. "Closed Cycle High Temperature Control Receiver Concept for Solar Electric Power," BEC/EPRI RP377-1, June 1976.

Calculation Sequence

1) Costs

```
CC = CK*(MD)**F0*(TID+460)**G*LN(PID/P2D)
```

2) Back Pressure PR determined by

$$PR = (M/MD)*PID* \sqrt{(T1+460)/(TID+460)}$$

If PR > PS write DIAGNOSTIC

3) Efficiency

```
RAT = (PID/P2D)**(2/7)
EFF = (RAT-1.)/(RAT**(1/NPD)-1)
```

4) Power Out

```
P2 = M*CP*(T1-TA)*EFF
```

5) Torque

If RS = 0, set TO = 0 and go to 6)

$$T0 = P2*(737.6)/(RS*2\pi/60)$$

6) Efficiency and maximum power

```
EF2 = EF1*EFF
MP2 = min(MP1*EFF,MD*CP*(T1-TA))
```

7) Compute Statistics and Costs

```
SUBROUTINE TU          ENTRY POINT 000335

STORAGE USED  CODE(1) 000471; DATA(0) 000065; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000002
 0004    CTIME   000001
 0005    CSTMUL  000010
 0006    COST    000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    XPRR
 0010    ALOG
 0011    SQRT
 0012    NWDU$
 0013    NI02$
 0014    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000137 100L      0001     000304 1000L     0000     000004 1010F     0001     000204 200L      0001     000233 300L
 0006  R  000000 CCI       0005     000000 DUM       0000  R  000003 EFF       0003  I  000001 ICNT      0003  I  000000 IMPL
 0000     000047 INJP$     0000  R  000000 PI        0000  R  000002 RAT       0004  R  000000 TIME      0005  R  000007 TMAX
 0000  R  000001 TMAX1


00100      CTU                                                                      000000
00101            SUBROUTINE TU(P2,CC,PR,TO,EF2,MP2,MOP,M,CP,T1,TA,MD,TID,PID,P2D,   000000
00101           1            T2D,PS,RS,EF1,MP1,P1,CK,F,G,NPD)                       000000
00101      C                                                                        000000
00101      C     PURPOSE      TURBINE PERFORMANCE MODEL                             000000
00101      C                                                                        000000
00101      C     METHOD       COMPUTE TURBINE POWER OUTPUT FROM INPUT DESIGN        000000
00101      C                                                                        000000
00101      C                  CONDITIONS AS A FUNCTION OF INLET TEMPERATURE         000000
00101      C                                                                        000000
00101      C                  AND MASS FLOW RATE                                    000000
00101      C                                                                        000000
00101      C     WRITTEN BY F.O. MAHONY                  VERSION 1, MARCH 22 1977   000000
00101      C                                                                        000000
00101      C     CALL SEQUENCE                                                      000000
00101      C           OUTPUTS                                                      000000
00101      C                  P2  - OUTPUT POWER, KW                                000000
00101      C                  CC  - TURBINE COST PER YEAR, $                        000000
00101      C                  PR  - BACK PRESSURE, PSI                              000000
00101      C                  TO  - TORQUE, FT-LB                                   000000
```

TU

```
00101     C              EF2 - OUTPUT PRODUCT EFFICIENCY                                000000
00101     C              MP2 - MAXIMUM DISCHARGE POWER, KW                              000000
00101     C              MOP - MAXIMUM POWER OBSERVED,KW                                000000
00101     C         INPUTS                                                              000000
00101     C              M   - INLET MASS FLOW RATE, LB/HR                              000000
00101     C              CP  - AIR HEAT CAPACITY, KWH/LB/DEG F                          000000
00101     C              T1  - INPUT AIR TEMPERATURE, DEG F                             000000
00101     C              TA  - AMBIENT AIR TEMPERATURE, DEG F                           000000
00101     C              MD  - DESIGN MASS FLOW RATE, LB/HR                             000000
00101     C              TID - DESIGN INLET AIR TEMPERATURE, DEG F                      000000
00101     C              PID - DESIGN INLET PRESSURE, PSI                               000000
00101     C              P2D - DESIGN EXIT PRESSURE (AMBIENT), PSI                      000000
00101     C              T2D - DESIGN EXIT TEMPERATURE (AMBIENT), PSI                   000000
00101     C              PS  - STORAGE VESSEL PRESSURE, PSI                             000000
00101     C              RS  - ANGULAR VELOCITY, RPM                                    000000
00101     C              EF1 - INPUT PRODUCT EFFICIENCY                                 000000
00101     C              MP1 - MAXIMUM INPUT POWER, KW                                  000000
00101     C              P1  - INPUT POWER, KW                                          000000
00101     C              CK  - CAPACITY COST COEFFICIENT                                000000
00101     C              F   - TURBINE MASS FLOW EXPONENT FOR CAPITAL COST              000000
00101     C              G   - TURBINE TEMPERATURE EXPONENT FOR CAPITAL COST            000000
00101     C              NPD - DESIGN POLYTROPIC EFFICIENCY                             000000
00101     C                                                                             000000
00103           COMMON /CIMPL/IMPL,ICNT/CTIME/ TIME /CSIMUL/DUM(7),THAX /COST/CCI       000000
00104           REAL MP2,MOP, M,MD, MP1,NPD                                             000000
00105           DATA PI /3.14159/                                                       000000
00105     C                                                                             000000
00107           IF(IMPL.GT.0) GO TO 100                                                 000000
00111           IF(CP .EQ. .99999) CP = 72.0E-6                                         000002
00113           IF(TA .EQ. .99999) TA = 70.0                                            000007
00115           IF(MD .EQ. .99999) MD = 4800.                                           000014
00117           IF(TID.EQ. .99999) TID=600.0                                            000021
00121           IF(PID.EQ. .99999) PID=117.6                                            000026
00123           IF(P2D.EQ. .99999) P2D=14.7                                             000033
00125           IF(T2D.EQ. .99999) T2D=70.0                                             000040
00127           IF(CK .EQ. .99999) CK =0.015                                            000045
00131           IF(F  .EQ. .99999) F  =0.75                                             000052
00133           IF(G  .EQ. .99999) G  =0.5                                              000057
00135           IF(NPD .EQ. .99999)NPD= .88                                             000064
00137           MOP = 0.                                                                000071
00140           RS= AMAX1(0.0,AMIN1(RS, 4000.))                                         000072
00141           TMAX1=.99999*TMAX                                                       000104
00142           CC = CK*MD**F*(TID+460.)**6*ALOG(PID/P2D)                               000107
00142     C                    DETERMINE BACK PRESSURE                                  000107
00142     C                                                                             000107
00143       100 RAT= (PID/P2D)**.2857                                                   000137
00144           EFF= (RAT-1.0)/(RAT**(1./NPD) - 1.0)                                    000146
00145           PR = M/MD*PID*SQRT((T1 + 460.0)/(TID+460.))                             000162
00145     C                                                                             000162
00146           IF(PR.GT.PS) GO TO 1000                                                 000200
00146     C                                                                             000200
00146     C                    POWER OUTPUT                                             000200
00146     C                                                                             000200
00146     C                                                                             000200
00150       200 P2= M*CP*(T1-TA)*EFF                                                    000204
00151           TO = 0.                                                                 000212
00152           IF(RS.EQ.0. .OR. P1.EQ. 0.) GO TO 300                                   000213
```

```
00152    C                      TORQUE                                                     000213
00154         TO = P2*737.6/(RS*2.0*PI/60.0)                                               000223
00154    C                                                                                 000223
00154    C                      EFFICIENCY AND MAXIMUM POWER                               000223
00154    C                                                                                 000223
00155     300 EF2 = EF1*EFF                                                                000233
00156         MP2 = AMIN1(MP1*EFF ,MD*CP*(T1-TA))                                          000235
00157         IF(IMPL.LE. 1) RETURN                                                        000251
00161         MOP = AMAX1(MOP,P2)                                                          000260
00162         IF(TIME.LT.TMAX1) RETURN                                                     000266
00164         CCI = CCI + CC                                                               000275
00164    C                                                                                 000275
00165         RETURN                                                                       000300
00165    C                                                                                 000300
00166    1000 IF(IMPL.EQ.2)WRITE(6,1010) PR,PS                                             000304
00173    1010 FORMAT (1H0,21HTURBINE BACK PRESSURE,F12.3,                                  000315
00173       1           39H   GREATER THAN STORAGE VESSEL PRESSURE ,F12.3)                 000315
00174         IF(IMPL.EQ.2)ICNT=ICNT+1                                                     000315
00174    C                                                                                 000315
00176         GO TO 200                                                                    000323
00176    C                                                                                 000323
00177         END                                                                          000470
```

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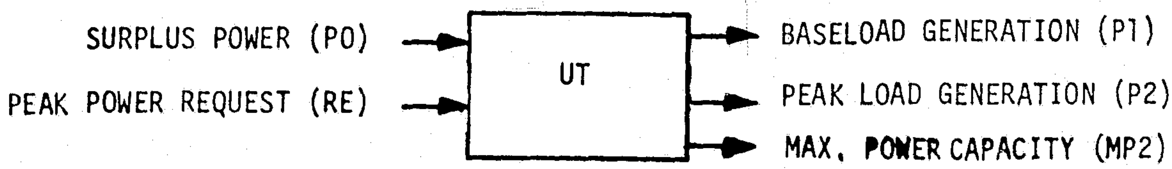
7.46 UTILITY



The utility model has two power outputs corresponding to baseload and peak generation, with corresponding generation cost inputs. A surplus power input is also provided with cost credit depending on whether baseload or peak power is reduced. Total energy cost, total output power and total peak load requests are monitored.

Inputs

Parameter/Port		Description	Units
BS		Baseload generation (default = 0.)	kw
CB		Cost of baseload generation/kwh	$
MP	1	Maximum power capacity (default = 1×10^8)	kw
P	0	Surplus power returned to utility	kw
RE		Peak generation request	kw
CP		Cost of peak load generation/kwh	$
CC		Capital cost/year	$
CM		Maintenance cost/year	$

Outputs

Variable/Port			
P	1	Baseload generation (= BS)	kw
MP	2	Maximum power capacity (= MP1)	kw
P	2	Peak load generation	kw
CØ		Cost of energy used (state)	$

Statistics

SR	Sum of requested peak generation	kwh
SPØ	Sum of output energy	kwh
SP	Sum of surplus energy	kwh
VSP	Value of surplus energy	$

Calculation Sequence

1) Power outputs

If BS > MP1, write diagnostic

P1 = BS, MP2 = MP1

P2 = MIN (MP1-BS,RE)

2) Energy cost dynamics

$\dot{C}\emptyset = BS*CB + (P2-P\emptyset)*CX$

$$CX = \begin{cases} CP & \text{if } P2-P\emptyset > 0 \\ 0 & \text{if } P2-P\emptyset < 0 \end{cases}$$

3) Statistics

SR = SR + RE * TINC

$$DEL = \begin{cases} 0 & \text{if } P2 > P\emptyset \\ (P\emptyset-P2)*TINC & \text{if } P\emptyset > P2 \end{cases}$$

SPØ = SPØ + (P1+P2-PØ)*TINC + DEL

SP = SP + DEL

VSP = VSP + DEL * CB

Where TINC = integration step size/2

4) Compute Costs

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```
SUBROUTINE UT        ENTRY POINT 000217

STORAGE USED  CODE(1) 000341; DATA(0) 000045; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL  000002
 0004   CTIME  000001
 0005   CSIMUL 000010
 0006   COST   000011

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   NWDU$
 0010   NIO2$
 0011   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000053 100L      0001     000146 200L     0000     000004 208F     0006 R 000000 CCI     0006 R 000001 CMI
 0006     000002 COP       0000 R 000002 CX         0005 R 000000 DUM       0003 I 000001 ICNT    0003 I 000000 IMPL
 0000     000023 INJP$     0006 R 000010 SPD        0006 R 000004 TDE       0000 R 000003 TERM    0004 R 000000 TIME
 0000 R 000001 TINC1       0006     000005 TLD      0005 R 000007 TMAX      0000 R 000000 TMAX1   0006 R 000007 UTD
 0006 R 000006 UTV         0006 R 000003 VDE


00100      CUT                                                                      000000
00101            SUBROUTINE UT(P1,MP2,P2,CO,COD,ICO,SR,SPO,SP,VSP                   000000
00101           1                  ,BS,CB,MP1,PO,RE,CP,CC,CM)                       000000
00101      C                                                                        000000
00101      C                PURPOSE   MODEL OF UTILITY CAPABLE OF PRODUCING         000000
00101      C                          BASELOAD AND PEAKLOAD POWER, AND OF           000000
00101      C                          ABSORBING SURPLUS POWER                       000000
00101      C                                                                        000000
00101      C                METHOD    COMPUTE PEAKLOAD GENERATION AND ENERGY COST   000000
00101      C                                                                        000000
00101      C                WRITTEN BY Y.K.CHAN      VERSION 1,JUNE 8,1977          000000
00101      C                                                                        000000
00101      C   CALL SEQUENCE                                                        000000
00101      C        OUTPUT                                                          000000
00101      C                P1  -BASELOAD GENERATION,KW                             000000
00101      C                MP2 -MAXIMUM POWER CAPACITY,KW                          000000
00101      C                P2  -PEAKLOAD GENERATION,KW                             000000
00101      C                CO  -COST OF ENERGY USED (STATE), $                     000000
00101      C                COD -ENERGY COST RATE, $/HR                             000000
00101      C                ICO -INTEGRATOR CONTROL FOR CO                          000000
00101      C        STATISTICS                                                      000000
00101      C                SR  -SUM OF REQUESTED PEAK GENERATION,KW                000000
```

UT

```
00101   C                SPO -SUM OF OUTPUT ENERGY, KWH                              000000
00101   C                SP  -SUM OF SURPLUS ENERGY, KWH                             000000
00101   C                VSP -VALUE OF SURPLUS ENERGY, $                             000000
00101   C          INPUTS                                                            000000
00101   C                BS  -BASELOAD GENERATION (DEFAULT=0.),KW                    000000
00101   C                CB  -COST OF BASELOAD GENERATION/KWH, $                     000000
00101   C                MP1 -MAXIMUM POWER CAPACITY,KW                              000000
00101   C                PO  -SURPLUS POWER RETURNED TO UTILITY,KW                   000000
00101   C                RE  -PEAK GENERATION REQUEST, KW                            000000
00101   C                CP  -COST OF PEAKLOAD GENERATION/KWH, $                     000000
00101   C                CC  -CAPITAL COST/YEAR, $                                   000000
00101   C                CM  -MAINTENANCE COST/YEAR, $                               000000
00101   C                                                                            000000
00103         COMMON /CIMPL/IMPL,ICNT/CTIME/TIME/CSIMUL/DUM(7),TMAX                  000000
00103        X  /COST/CCI,CMI,COP,VDE,TDE,TLD,UTV,UTD,SPO                            000000
00104         REAL MP2,MP1                                                           000000
00104   C                                                                            000000
00105         IF(IMPL.GT.0)GO TO 100                                                 000000
00107         IF(BS.EQ..99999)BS=0.                                                  000002
00111         IF(MP1.EQ..99999)MP1=1.E8                                              000006
00113         TMAX1=TMAX*.99999                                                      000013
00114         SR=0.                                                                  000016
00115         SP=0.                                                                  000017
00116         SPO=0.                                                                 000020
00117         VSP=0.                                                                 000021
00120         RE=0.                                                                  000022
00121         PO=0.                                                                  000023
00121   C                                                                            000023
00121   C                COMPUTE POWER OUTPUTS                                       000023
00121   C                                                                            000023
00122         TINC1=DUM(7)*.5                                                        000024
00123         IF(BS.LE.MP1)GO TO 100                                                 000027
00125         WRITE(6,208)BS,MP1                                                     000033
00131     208 FORMAT(1H0,10H BASELOAD ,F12.3,32H EXCEEDS MAXIMUM POWER CAPACITY,     000042
00131        1 F12.3)                                                                000042
00132         IF(IMPL.EQ.2)ICNT=ICNT+1                                               000042
00134         BS=MP1                                                                 000050
00134   C                                                                            000050
00135     100 P1=BS                                                                  000053
00136         MP2=MP1                                                                000054
00137         P2=AMIN1(MP1-BS,RE)                                                    000056
00137   C                                                                            000056
00137   C                COMPUTE ENERGY COST                                         000056
00137   C                                                                            000056
00140         CX=0.                                                                  000064
00141         IF(P2.GT.PO)CX=CP                                                      000065
00143         IF(ICO.NE.0)COD=BS*CB+(P2-PO)*CX                                       000073
00145         IF(IMPL.LE.1)RETURN                                                    000104
00145   C                                                                            000104
00145   C                STATISTICS                                                  000104
00145   C                                                                            000104
00147         SR=SR+RE*TINC1                                                         000113
00150         SPO=SPO+ (P1+P2-PO)*TINC1                                              000117
00151         IF(P2.GT.PO) GO TO 200                                                 000125
00153         TERM=(PO-P2)*TINC1                                                     000131
00154         SPO= SPO+TERM                                                          000135
00155         SP= SP+ TERM                                                           000137
```

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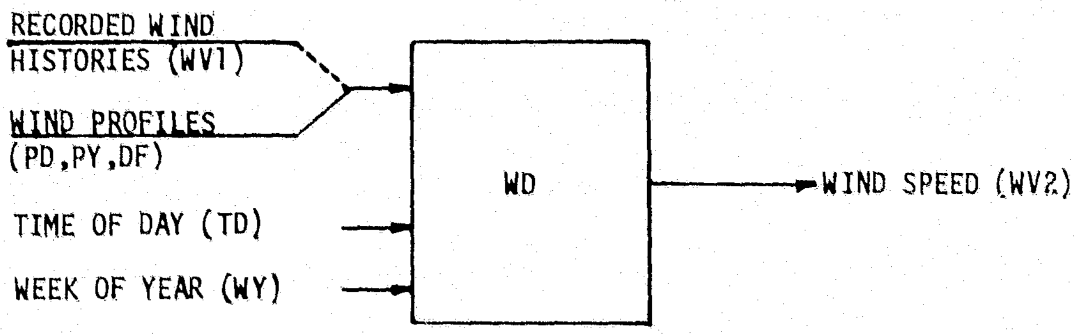
00156        VSP= VSP+ CB*TERM                    000141
00157                                             000146
00157   C                                         000146
00157     200 IF(TIME.LT.TMAX1)RETURN             000146
00161        CCI=CCI+CC                           000154
00162        CMI=CMI+CM                           000157
00163        VDE=VDE-CO+VSP                       000162
00164        TDE=TDE-SPO+SP                       000166
00165        UTV=UTV+CO                           000172
00166        UTD=UTD+SPO                          000175
00167        SPD= SPD+SP                          000200
00170        RETURN                               000203
00171        END                                  000340
```


UT

7.47 WIND



This model computes wind speed either from user supplied time histories (data tape) or by generating a set of random numbers with user supplied daily and yearly average profiles and user specified random variation. If user supplied profiles are available then the wind speeds are generated from the following equation:

Basic Equation

$$WV = [PD(TD) + N(T)]*PY(WY)/M$$

where PD is the user supplied daily mean profile
TD is the time of the day
PY is the user supplied yearly profile
WY is the week of the year
N is white noise with user specified probability distribution

$$M = \frac{1}{J} \sum_{I=1}^{J} PY(I)$$

WD

Tables	Description	Units
PD	Daily profile versus TD (default = 0)	miles/hr
PY	Yearly profile versus WY	arbitrary
DF	Densit function for white noise terms (tabular with speed WV)	arbitrary

Inputs

Parameter/Port		Description	Units
WV	1	Wind speed data file input	miles/hr
TD		Time of day	hr
WY		Week of the year	-

Outputs

Variable/Port		Description	Units
WV	2	Wind speed	miles/hr
M		Mean of yearly profile	
TIM		Last time a random sample was generated	hr

Statistics

MV	Maximum speed	miles/hr
AV	Average speed (expected daily wind)	miles/hr

Calculation Sequence

1) Compute distribution function and mean M (first pass only)

$$F(WV) = \frac{(\sum DF(V_i) : V_i \leq WV)}{\sum DF(V_i)}$$

2) Check for data file input

If WV1 = .99999 go to 3)

WV2 = WV1

Go to 5)

3) Generate white noise input N

If TIME = TIM go to 5)

U = random noise sample, uniformly distributed [0,1]

Interpolate to find $N = F^{-1}(U)$

TIM = TIME

4) Compute wind speed

WV2 = [PD(TD) + N] * PY(WY)/M

5) Compute Statistics

```
SUBROUTINE WD        ENTRY POINT 000412

STORAGE USED  CODE(1) 000473; DATA(0) 000063; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    CIMPL   000001
 0004    CTIME   000001

EXTERNAL REFERENCES (BLOCK, NAME)

 0005    UNIF
 0006    TBLU1
 0007    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001    000245 10L      0001    000253 100L     0001    000074 122G     0001    000133 137G     0001    000353 150L
 0001    000202 155G     0001    000225 165G     0001    000146 40L      0000 R 000010 A         0000 R 000005 AMN
 0000 R 000014 DWV       0000 I 000006 I         0003 I 000000 IMPL      0000   000024 INJP$     0000 I 000000 IX
 0000 I 000007 L         0000 I 000002 ND        0000 I 000001 NP        0000 I 000012 NP1       0000 I 000003 NY
 0000 R 000004 SUM       0006 R 000000 TBLU1     0004 R 000000 TIME      0000 R 000011 U         0000 R 000013 WN
 0000 R 000015 YWV


00100   CWD                                                                              000016
00101         SUBROUTINE WD (PD,PY,WF,WVO,AMV,AV,XM,TIMO ,WVI,TO,WY)                     000016
00101   C                                                                                000016
00101   C   PURPOSE    GENERATE WIND SPEED FROM DAILY, YEARLY, AND RANDOM PROFILE DATA   000016
00101   C                                                                                000016
00101   C   METHOD     RANDOM NOISE WITH SPECIFIED DIST. IS ADDED TO MEAN DAILY PROFILE  000016
00101   C              AND MULTIPLIED BY A YEARLY PROFILE. INITIALLY THE DENSITY TABLE   000016
00101   C              WF IS CONVERTED TO A DIST. FUNCTION.                              000016
00101   C                                                                                000016
00101   C   WRITTEN BY A.W. WARREN                          VERSION 1, MARCH 4 1977      000016
00101   C                                                                                000016
00101   C   CALL SEQUENCE                                                                000016
00101   C         TABLES                                                                 000016
00101   C              PD  - MEAN DAILY WIND PROFILE, MPH                                000016
00101   C              PY  - MEAN YEARLY WIND PROFILE                                    000016
00101   C              WF  - WIND FREQUENCY FUNCTION (NON-GUST, RANDOM COMPONENT), HR     000016
00101   C                                                                                000016
00101   C         OUTPUTS                                                                000016
00101   C              WVO - WIND VELOCITY OUTPUT, MPH                                   000016
00101   C              AMV - MAX. OBSERVED WIND SPEED, MPH                               000016
00101   C              AV  - MEAN DAILY WIND SPEED, MPH                                  000016
00101   C              XM  - MEAN YEARLY WIND, -                                         000016
                       TIMO- LAST TIME A RANDOM SAMPLE WAS USED, HR                      000016
```

WD

```
00101   C                                                          000016
00101   C       INPUTS                                             000016
00101   C            WVI - WIND VELOCITY INPUT FROM DATA FILE, MPH  000016
00101   C            TD  - TIME OF DAY, HR                          000016
00101   C            WY  - WEEK OF YEAR (1-52)                      000016
00101   C                                                          000016
00101   C                                                          000016
00103         DIMENSION PD(1),PY(1),WF(1)                          000016
00104         COMMON/CIMPL/IMPL /CTIME/TIME                        000016
00105         DATA IX/1/                                           000016
00105   C                     INITIALIZATION                       000016
00105   C                     COMPUTE MEAN DAILY WIND SPEED AND DIST. FCN  000016
00105   C                                                          000016
00107         NP=WF(2)                                             000016
00110         ND=PD(2)                                             000025
00111         NY=PY(2)                                             000034
00112         IF(IMPL.GT.0) GO TO 10                               000043
00114         SUM=0.0                                              000046
00115         AMN=0.0                                              000047
00116         TIMO=-1.                                             000050
00117         IF(WF(4+2*NP).EQ. 1.) GO TO 40                       000052
00121         DO 20 I=1,NP                                         000074
00124         WF(I+2) = WF(I+3)                                    000074
00125         L = 3+NP+I                                           000076
00126         A=WF(L)                                              000101
00127         WF(L)=SUM                                            000105
00130         SUM=SUM+ A                                           000107
00131      20 AMN = AMN + A*WF(2+I)                                000111
00133         AMN = AMN/SUM                                        000116
00134         WF(3+NP)= WF(NP+2)*2. - WF(NP+1)                     000120
00135         WF(L+1)= 1.                                          000124
00135   C                                                          000124
00136         DO 30 I=1,NP                                         000133
00141         L=3+NP+I                                             000133
00142      30 WF(L) = WF(L)/SUM                                    000140
00144      40 CONTINUE                                             000146
00144   C                     DEFAULT TABLE FOR PD                 000146
00144   C                                                          000146
00145         IF(PD(2).EQ. 1.99999) PD(4)=0.                       000146
00147         IF(PD(2).EQ. 1.99999) PD(5)=0.                       000151
00151         IF(PD(2).EQ. 1.99999) PD(2)=1.                       000171
00151   C                                                          000171
00153         AV = 0.                                              000176
00154         DO 25 I=1,ND                                         000202
00157         L = 3+ND+I                                           000202
00160      25 AV = AV+PD(L)                                        000205
00162         AV = AV/ND + AMN                                     000214
00162   C                                                          000214
00163         XM=0.                                                000221
00164         DO 15 I=1,NY                                         000225
00167         L=3+NY+I                                             000225
00170      15 XM=XM+PY(L)                                          000232
00172         XM=XM/NY                                             000237
00173         AMV =0.                                              000243
00173   C                     CHECK FOR DATA FILE INPUT            000243
00173   C                                                          000243
00174      10 IF( WVI.EQ. .99999) GO TO 100                        000245
```

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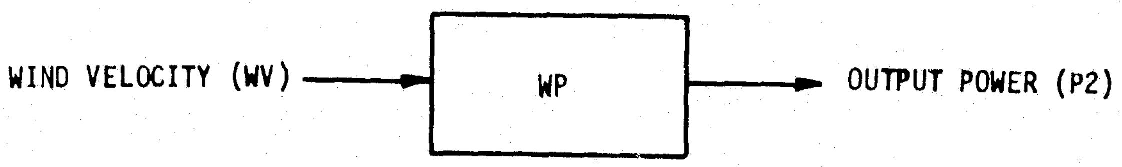
WD

```
00176            WVO = WVI                                                000247
00177            GO TO 150                                                000251
00177      C                       GENERATE WHITE NOISE WITH DIST. WF     000251
00177      C                                                              000251
00200        100 IF(  TIME.EQ.TIMO) GO TO 150                             000253
00202            CALL UNIF(U,IX)                                          000255
00203            NP1=NP+1                                                 000261
00204            WN  = TBLU1(U,WF(4+NP),WF(3),1,-NP1)                     000264
00204      C                                                              000264
00204      C                       GENERATE WIND SPEED USING DAILY AND YEARLY PROFILES   000264
00205            DWV  = TBLU1(TD,PD(4),PD(4+ND),1,-ND)                    000303
00206            YWV  = TBLU1(WY,PY(4),PY(4+NY),1,-NY)                    000323
00207            WVO  = (DWV + WN)* YWV / XM                              000343
00210            TIMO=TIME                                                000350
00210      C                                                              000350
00210      C                       MAX. OBSERVED WIND SPEED               000350
00211        150 IF(IMPL.LE.1) RETURN                                     000353
00213            AMV  = AMAX1(AMV,WVO)                                    000361
00214            RETURN                                                   000367
00215            END                                                      000472
```

7.48 TURBINE/GENERATOR



This component uses a power curve relationship with wind velocity to model the wind turbine and generator. It may be used in place of the more detailed wind turbine-transmission-generator components where a simplified analysis is desirable, or where a nonstandard wind generator model is desired. The model may be used for either A.C. or D.C. power generation.

Basic Equations

$$P2 = I = 0 \qquad \left(\begin{array}{l} WV < WV0 \\ WV > WV1 \end{array} \right.$$

$$P2 = V*I/1000 \qquad WV0 \leq WV \leq WV1$$

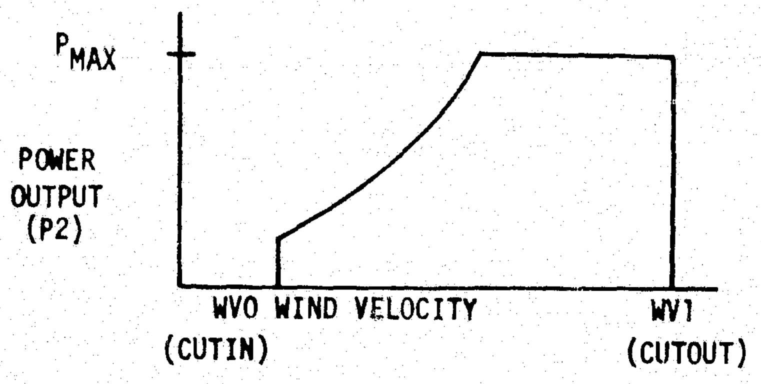


FIGURE 7.48: OUTPUT POWER VERSUS WIND VELOCITY

Tables	Description	Units
PW	Wind generation power versus wind velocity [1]	kw

Inputs

Parameter/Port		
V	Bus voltage (Rated)	volts
WV0	Power cutin velocity	mph
WV1	Power cutout velocity	mph
WV	Wind velocity	mph
CC	Capital cost/year	$
CM	Maintenance cost/year	$
EC	Control Energy Rate	$/hr

Outputs

Variable/Port		
I	Bus current	amps
P 2	Real power output	kw

Statistics

MI	Maximum current	amps
MPØ	Maximum power	kw
SP	Total output energy	kwh
CØ	Total operating costs	$

[1] Output power including mechanical and electrical efficiencies

Calculation Sequence

1) Initialize statistics

2) Compute P2 and I

$$P2 = \begin{cases} PW(WV) & WV0 \le WV \le WV1 \\ 0 & \text{otherwise} \end{cases}$$

$$I = P2*1000/V$$

3) Compute Statistics and Costs

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```
SUBROUTINE WP          ENTRY POINT 000153

STORAGE USED  CODE(1) 000232; DATA(0) 000024; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003   CIMPL   000001
 0004   COST    000003
 0005   CTIME   000001
 0006   CSIMUL  000010

EXTERNAL REFERENCES (BLOCK, NAME)

 0007   TBLU1
 0010   NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

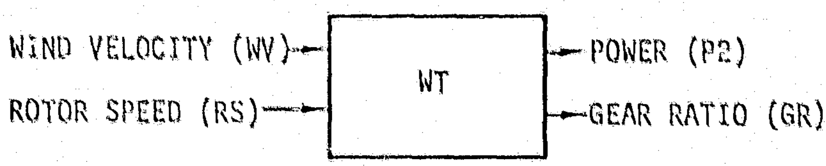
 0001     000046 10L       0001     000064 20L       0004 R 000000 CC         0004 R 000001 CM         0004 R 000002 COP
 0006     000000 DUM       0003 I 000000 IMPL       0000     000006 INJP$     0000 I 000000 N          0007 R 000000 TBLU1
 0005 R 000000 TIME       0006 R 000006 TINC       0006 R 000007 TMAX       0000 R 000001 TMAX1


00100      CWP                                                                               000000
00101            SUBROUTINE WP ( PW,BI,PO,AMI,AMP,SP,CO,VO,WV0,WV1,WV,CCI,CMI,EC)            000000
00101      C                                                                                 000000
00101      C   PURPOSE    MODEL THE WIND TURBINE AND GENERATOR USING A POWER CURVE           000000
00101      C                                                                                 000000
00101      C   WRITTEN BY A.W. WARREN                          VERSION 1, MARCH 3 1977       000000
00101      C                                                                                 000000
00101      C   CALL SEQUENCE                                                                 000000
00101      C          TABLES                                                                 000000
00101      C               PW   - WIND GENERATION POWER IN KW VERSUS WIND VELOCITY IN MPH     000000
00101      C                                                                                 000000
00101      C          OUTPUTS                                                                000000
00101      C               BI   - OUTPUT BUS CURRENT, AMPS                                   000000
00101      C               PO   - POWER OUTPUT, KW                                           000000
00101      C               AMI  - MAX. OBSERVED CURRENT, AMPS                                000000
00101      C               AMP  - MAX. OBSERVED POWER, KW                                    000000
00101      C               SP   - TOTAL OUTPUT ENERGY,KWH                                    000000
00101      C               CO   - OPERATING COST, $                                          000000
00101      C                                                                                 000000
00101      C          INPUTS                                                                 000000
00101      C               VO   - RATED BUS VOLTAGE, VOLTS                                   000000
00101      C               WV0  - POWER CUTIN VELOCITY, MPH                                  000000
00101      C               WV1  - POWER CUTOUT VELOCITY, MPH                                 000000
00101      C               WV   - WIND VELOCITY, MPH                                         000000
00101      C               CCI  - CAPITOL COST / YEAR, $                                     000000
```

WP

```
00101      C          CMI  - MAINTENANCE COST / YEAR, $                    000000
00101      C          EC   - CONTROL ENERGY RATE, $/HR                     000000
00101      C                                                               000000
00103          DIMENSION PW(1)                                             000000
00104          COMMON / CIMPL / IMPL                                       000000
00105          COMMON/COST/ CC,CM,COP /CTIME/ TIME /CSIMUL/ DUM(6),TINC,TMAX  000000
00105      C                                                               000000
00105      C                    POWER OUTPUT CALCULATIONS                  000000
00105      C                                                               000000
00106          PO = C.                                                     000000
00107          IF(WV.LT.WVO .OR. WV.GT.WV1) GO TO 10                       000001
00111          N = PW(2)                                                   000017
00112          PO = TBLU1(WV,PW(4),PW(4+N),1,-N)                           000026
00113       10 BI = PO*1000/VO                                             000046
00113      C                   STATISTICS                                  000046
00113      C                                                               000046
00114          IF(IMPL.GT.0) GO TO 20                                      000051
00116          CO= 0.                                                      000054
00117          AMI = 0.                                                    000055
00120          AMP = 0.                                                    000056
00121          SP = 0.                                                     000057
00122          TMAXI=TMAX*.99999                                           000060
00123       20 IF(IMPL.LE.1) RETURN                                        000064
00125          AMI = AMAX1(AMI,BI)                                         000072
00126          AMP = AMAX1(AMP,PO)                                         000100
00127          SP = SP + PO*.5*TINC                                        000106
00130          CO= CO + EC*.5*TINC                                         000113
00130      C                   COST SUMMATION                              000113
00131          IF( TIME.LT.TMAXI) RETURN                                   000120
00133          CC = CC + CCI                                               000127
00134          CM = CM + CMI                                               000132
00135          COP= COP + CO                                               000135
00136          RETURN                                                      000140
00137          END                                                         000231
```

7.49 WIND TURBINE



This component models the wind turbine in terms of physical properties such as blade radius, power coefficient, and design tip speed ratio.[1] The step-up gear ratio is computed based on design rotor speed.

<u>Basic Equations</u>

Output power is given by

$$P2 = CP*1/2*AD*A*(WV*C)^3*k$$

where:

CP = effective power coefficient (tabular with WV)

$A = \pi*(BR)^2$

$C = 1.4667$ (mph to ft/sec. conversion)

$k = 1.3558 \times 10^{-3}$ (ft-lb to kw-sec. conversion)

---

[1] NASA CR 134937 "Design Study of Wind Turbines - 50kw to 3000 kw - For Electric Utility Applications", Kaman Aerospace Corporation, February 1976.

Inputs

Parameter/Port	Description	Units
WV	Wind speed	mph
VØ	Mean wind speed (yearly)	mph
VR	Rated wind speed (default = 1.35 x VO)	mph
RS	Rotor speed	rpm
RSG	Generator shaft speed (design)(default = 1800)	rpm
BR	Blade radius	ft
EC	Cost to operate controls	$/h
AD	Air density (default = 0.0023)	slugs/ft^3
LAM[1]	Design tip speed ratio (default = 9.4)	–
CPM[2]	Maximum power coefficient at VO (default = 0.4)	–
CP	Effective power coefficient (default table versus VO/WV)	–
CC	Capital cost/year	$
CM	Maintenance cost/year	$

Outputs

Variable/Port		Description	Units
P	2	Output mechanical power	kw
TØ		Mechanical torque	ft-lb
CØ		Total operating cost	$
GR		Step-up gear ratio	–
RAP		Rated output power	kw

Statistics

MT	Maximum torque	ft-lb
MPØ	Maximum power	kw
SP	Total energy delivered	kwh

---

1 LAM may be computed using the design equation:

LAM = SQRT(8/(3* solidity constant * design lift coefficient))

2 If default CP table not used then set CPM = CP(rated wind speed)

Calculation Sequence

1) First pass - Compute Gear Ratio and Rated Power

RS = (LAM*V0*C/BR)*(60/2π)

GR = RSG/RS

RAP = .5*CP1*AD*A*(VR*C)^3

where

CP1 = CPM*F(V0/VR) if CP default used; CPM otherwise

2) Compute power coefficient CP

If WV = 0 set P2=T0=0 and go to 4)

If CP default used, then

CP = CPM*F(V0/WV)

where F is shown in Figure 7.49

3) Power and torque

A = π*BR^2

P = .5*CP*AD*A*(WV*C)^3 (C = 1.4667)

TO = P/(RS*2π/60)

P2 = P*k (k = 1.3558×10^{-3})

4) Compute Statistics and Costs

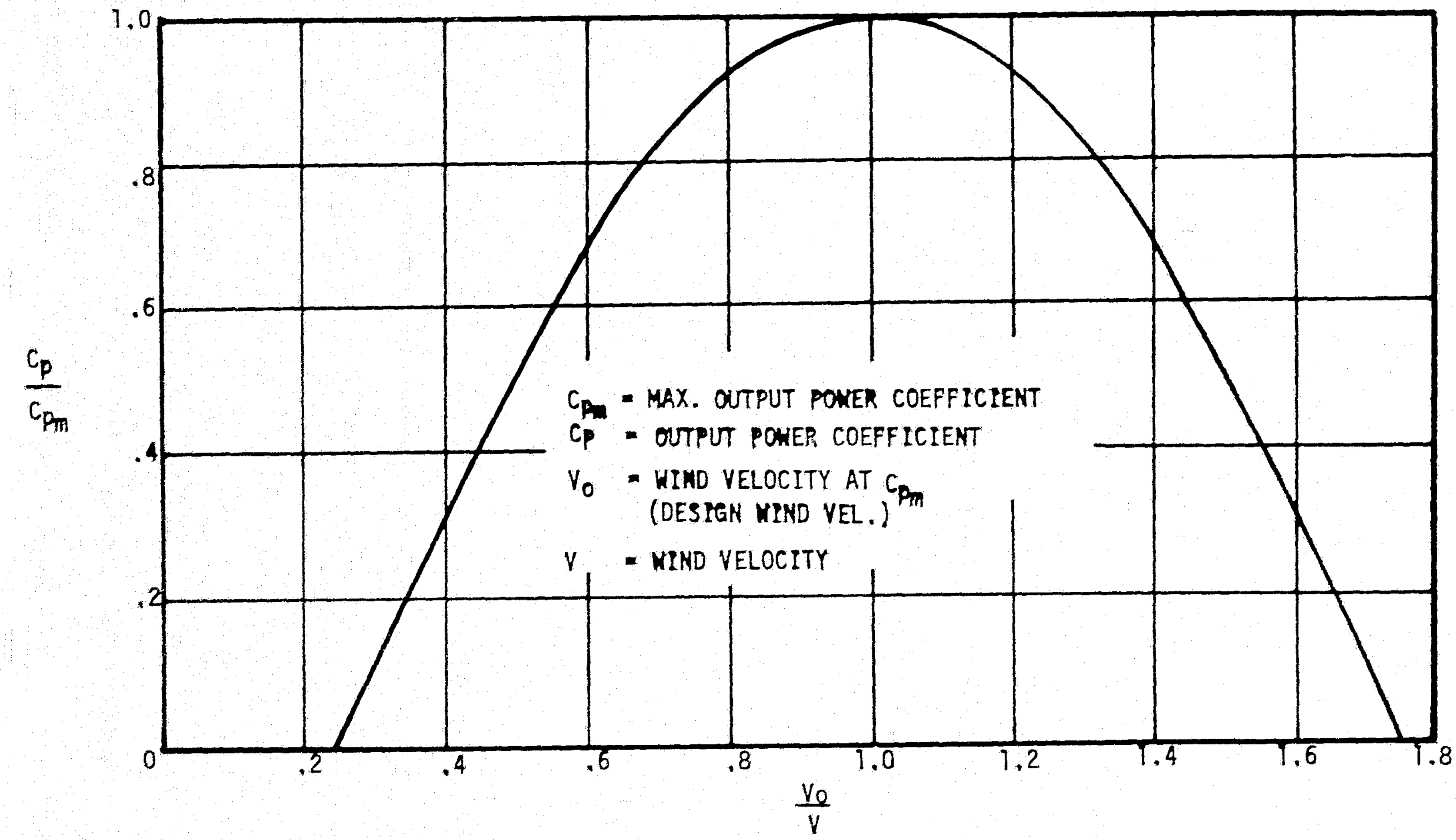


FIGURE 7.49 GENERALIZED MACHINE POWER OUTPUT PERFORMANCE

```
SUBROUTINE WT          ENTRY POINT 000274

STORAGE USED  CODE(1) 000413; DATA(0) 000070; BLANK COMMON(2) 000000

 COMMON BLOCKS

 0003    C1MPL   000001
 0004    CTIME   000001
 0005    CSIMUL  000010
 0006    COST    000003

EXTERNAL REFERENCES (BLOCK, NAME)

 0007    TBLU1
 0010    NERR3$

STORAGE ASSIGNMENT  (BLOCK, TYPE, RELATIVE LOCATION, NAME)

 0001     000122 100L      0001     000211 200L      0000 R 000034 A          0006 R 000000 CCI        0006 R 000001 CMI
 0006 R 000002 COI         0000 R 000033 CP1        0000 R 000026 C1         0000 R 000027 C2         0005     000000 DUM
 0000 R 000000 F           0003 I 000000 IMPL       0000     000051 INJP$     0000 R 000035 P          0000 R 000030 PI
 0007 R 000000 TBLU1       0004 R 000000 TIME       0005 R 000006 TINC       0000 R 000032 TINC2      0005 R 000007 THAX
 0000 R 000031 THAX1


00100        CWT1                                                                              000000
00101              SUBROUTINE WT (P2,TO,CO,GR,RAP,MT,MPO,SP,WV,VO,VR,RS, RSG,BR,EC,            000000
00101             1              AD,LAM,CPM, CP,CC,CM)                                         000000
00101        C                                                                                 000000
00101        C    PURPOSE    MODEL WIND TURBINE POWER OUTPUT                                   000000
00101        C                                                                                 000000
00101        C    METHOD     COMPUTE POWER COEFFICIENT AND ROTOR SPEED FROM PHYSICAL           000000
00101        C               DESIGN PARAMETERS.  RATED POWER COEFF. IS 3/4 OF CPM.             000000
00101        C                                                                                 000000
00101        C    WRITTEN BY A. W. WARREN                          VERSION 2, APRIL 6 1977     000000
00101        C                                                                                 000000
00101        C    CALL SEQUENCE                                                                000000
00101        C           OUTPUTS                                                               000000
00101        C               P2   - OUTPUT MECHANICAL POWER, KW                                000000
00101        C               TO   - OUTPUT MECHANICAL TORQUE, FT-LB                            000000
00101        C               CO   - OPERATING COST SUM, $                                      000000
00101        C               GR   - TURBINE/GENERATOR  GEAR RATIO                              000000
00101        C               RAP  - RATED OUTPUT POWER, KW                                     000000
00101        C               MT   - MAXIMUM TORQUE STATISTIC, FT-LB                            000000
00101        C               MPO  - MAXIMUM POWER STATISTIC, KW                                000000
00101        C               SP   - TOTAL OUTPUT ENERGY DELIVERED, KWH                         000000
00101        C                                                                                 000000
00101        C           INPUTS                                                                000000
```


WT

```
00101      C               WV  - WIND SPEED  MPH                                  000000
00101      C               VO  - MEAN WIND SPEED (YEARLY), MPH                    000000
00101      C               VR  - RATED WIND SPEED, MPH                            000000
00101      C               RS  - ROTOR SPEED, RPM                                 000000
00101      C               RSG - GENERATOR SHAFT SPEED, RPM                       000000
00101      C               BR  - BLADE RADIUS, FT                                 000000
00101      C               EC  - CONTROL ENERGY RATE, $/HR                        000000
00101      C               AD  - AIR DENSITY, SLUGS/FT**3                         000000
00101      C               LAM - DESIGN TIP SPEED RATIO                           000000
00101      C               CPM - MAXIMUM POWER COEFFICIENT AT VO                  000000
00101      C               CP  - EFFECTIVE POWER COEFFICIENT AT WV                000000
00101      C               CC  - CAPITAL COST PER YEAR                            000000
00101      C               CM  - MAINTENANCE COST PER YEAR                        000000
00101      C                                                                      000000
00103            COMMON /CIMPL/IMPL /CTIME/ TIME /CSIMUL/ DUM(6),TINC,TMAX        000000
00104            COMMON /COST/ CCI,CMI,COI                                        000000
00105            REAL MT,MPO,LAM                                                  000000
00106            DIMENSION F(22)                                                  000000
00107            DATA F/.24,.4,.6,.68,.8,1.,1.2,1.31,1.4,1.6,1.74,0.,.31,.68,.8,  000000
00107          1      .92,1.,.92,.8,.68,.3,0. /,C1,C2,PI/1.4667,.0013558,3.14159  000000
00107      C                                                                      000000
00107      C                        INITIALIZATION                                000000
00107      C                                                                      000000
00114            IF(IMPL.GT.0) GO TO 100                                          000000
00116            TMAX1 = TMAX* .99999                                             000002
00117            TINC2 = .5* TINC                                                 000005
00117      C                                                                      000005
00120            IF( VR .EQ. .99999) VR = 1.35* VO                                000010
00122            IF(RSG .EQ. .99999) RSG= 1800.                                   000016
00124            IF( AD .EQ. .99999) AD = .0023                                   000026
00126            IF(LAM .EQ. .99999) LAM= 9.4                                     000033
00130            IF(CPM .EQ. .99999) CPM= 0.4                                     000040
00130      C                                                                      000040
00132            RS = C1*LAM*VO/BR*(30./PI)                                       000045
00133            GR = RSG /RS                                                     000055
00134            CP1= CPM                                                         000060
00135            IF(CP.EQ. .99999) CP1= CPM*TBLU1(VO/VR,F(1),F(12),1,-11)         000062
00137            RAP= .5*CP1*AD*PI*BR*BR*(VR*C1)**3*C2                            000101
00140            CO = 0.0                                                         000115
00141            SP = 0.0                                                         000116
00142            MPO= 0.0                                                         000117
00143            MT = 0.0                                                         000120
00143      C                                                                      000120
00143      C                        POWER COEFFICIENT CALCULATION                 000120
00143      C                                                                      000120
00144        100 P2 = 0.0                                                         000122
00145            TO = 0.0                                                         000122
00146            IF( WV.EQ. 0.) GO TO 200                                         000123
00150            CP1 = CP                                                         000125
00151            IF( CP1.EQ. .99999) CP1 = CPM*TBLU1(VO/WV,F(1),F(12),1,-11)      000127
00153            IF(CP1.EQ. 0.) GO TO 200                                         000151
00153      C                                                                      000151
00153      C                        OUTPUT POWER AND TORQUE                       000151
00153      C                                                                      000151
00155            A = PI*BR**2                                                     000153
00156            P = .5*CP1*AD*A*(WV*C1)**3                                       000157
00157            IF(WV.GT.VR)P= RAP/C2                                            000170
```

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WT

```
00161                TO=P/(RS*PI/30.)                        C00177
00162                P2 = P*C2                               C00205
00162          C                                             C00205
00162          C                  STATISTICS AND COSTS       C00205
00162          C                                             C00205
00163            200 IF(IMPL.LE.1) RETURN                    C00211
00163          C                                             C00211
00165                CO = CO + EC*TINC2                      C00217
00166                MT = AMAX1( MT,TO)                      C00223
00167                MPO= AMAX1(MPO,P2)                      C00231
00170                SP = SP + P2*TINC2                      C00237
00170          C                                             C00237
00171                IF(TIME.LT.TMAX1)RETURN                 C00243
00173                CCI = CCI + CC                          C00252
00174                CMI = CMI + CM                          C00255
00175                COI = COI + CO                          C00260
00175          C                                             C00260
00176                RETURN                                  C00263
00177                END                                     C00412
```

8.0 EXAMPLES

This section gives five simple example simulations using the SIMWEST program. These examples exercise all physical components of the SIMWEST library and many of the model features such as Fortran code insertion and the file read capability. Each example contains the input data for model generation and analysis, selected printer output generated by the programs and a discussion of the results obtained. It is recommended that a user work through and understand the model connections for these examples before attempting to build more complex models such as that of Figure 1-7.

8.1 WIND TURBINE AND FILE READ MODEL

Figure 8.1-1 shows a simplified schematic of the wind turbine and file read model. In this example a wind turbine is used to feed power directly to a load. Wind and load time histories are read from a mass storage file and then used to drive the simulation. A histogram for power output is also included. Figure 8.1-2 shows the input data to build the model and print out some of the load file data. The order of the component definitions is such that information passes down the list, i.e. no component is defined before components in the INPUTS list. This assures that the component subroutines in the Fortran model will be called in the right order. The first Fortran statement is inserted in the model prior to the Fortran which sets up the iteration loop, while the second set of Fortran statements is within the loop and writes out the load file data from array TEMP the first pass through the model. Figure 8.1-3 shows the model schematic generated. In addition to showing the component connections, the names of the input connections are printed out. Notice that information passes not only from WT to GR but also vice-versa. The input RSIGR to WT is a feedback variable and so is the input RS GE to GR. It is the presence of the feedback variables which require several iterations to attain steady state.

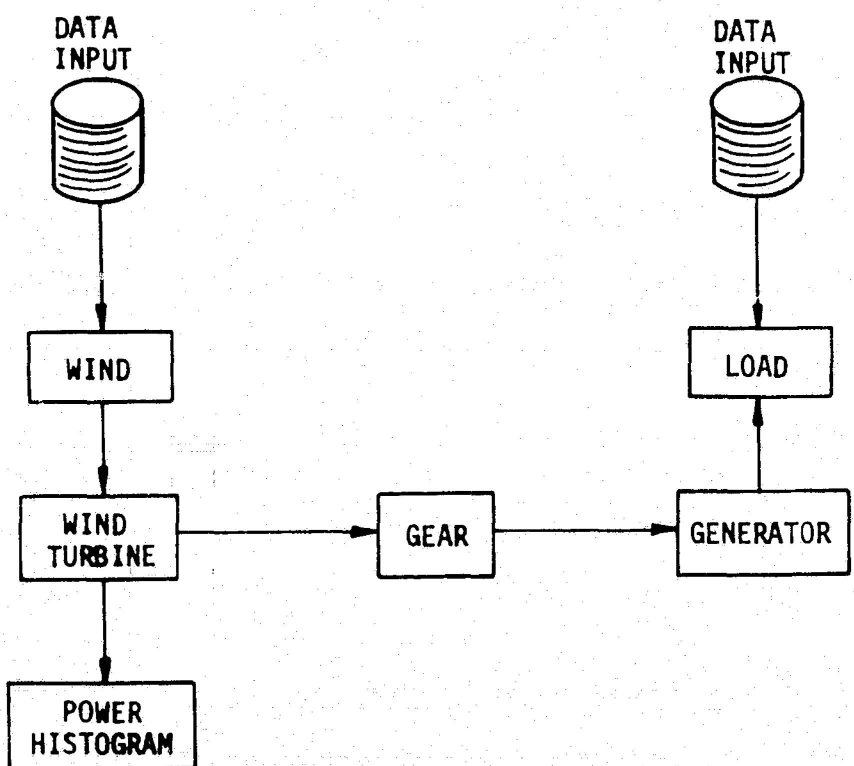

FIGURE 8.1-1: WIND TURBINE AND FILE READ EXAMPLE

```
MODEL DESCRIPTION      TAPE READ TEST
      FORTRAN STATEMENTS
      COMMON /DATARD/ TEMP(448)
LOCATION=15       TI
LOCATION=3        TAW       INPUTS=TI
LOCATION=11       WD        INPUTS=TI,TAW(VAR=WV)
LOCATION=31       WT        INPUTS=WD
LOCATION=35       GR        INPUTS=WT
LOCATION=51       HG        INPUTS=WT(P =FIN)
LOCATION=39       GE        INPUTS=GR
LOCATION= 7       TAL       INPUTS=TI
LOCATION=19       LO        INPUTS=GE,TI,TAL(VAR=LO)
      FORTRAN STATEMENTS
      IF(IMPL.GT.0) GO TO 2
      WRITE (6,100) (TEMP(I),I=1,448)
  100 FORMAT(1H ,12F10.3)
    2 CONTINUE
END OF MODEL
LIST STANDARD COMPONENTS
PRINT
```

FIGURE 8.1-2 INPUT DATA FOR FILE READ MODEL

The input data for several simulations using this model is shown in Figure 8.1-4. The component parameter values are first specified, those inputs not specified taking default values. A number of tables are then specified. The WD and LO tables are not really needed here. The wind and load file data was originally generated from an earlier run using these tables. Following the tables are the printer plot input commands, and the simulation values and print commands for a one week run. The parameter values for a second simulation which reads to the end of the file are then given. The last simulation attempts to read past the end of file.

Some of the output for the first simulation are shown in Figures 8.1-5 to 8.1-8. Figure 8.1-5 shows the output resulting from the FORTRAN STATEMENTS code. This data is formatted to output the time of the initial load value (0.0), the data increment step (0.25), and 446 load values at successive time increments. Figure 8.1-6 shows the power output histogram from the wind turbine. Almost 40% of the time the turbine reaches rated power (800 kw). Figure 8.1-7 shows a crossplot of wind turbine output versus wind velocity. The cutin velocity is about 12 mph and rated power is attained at about 28

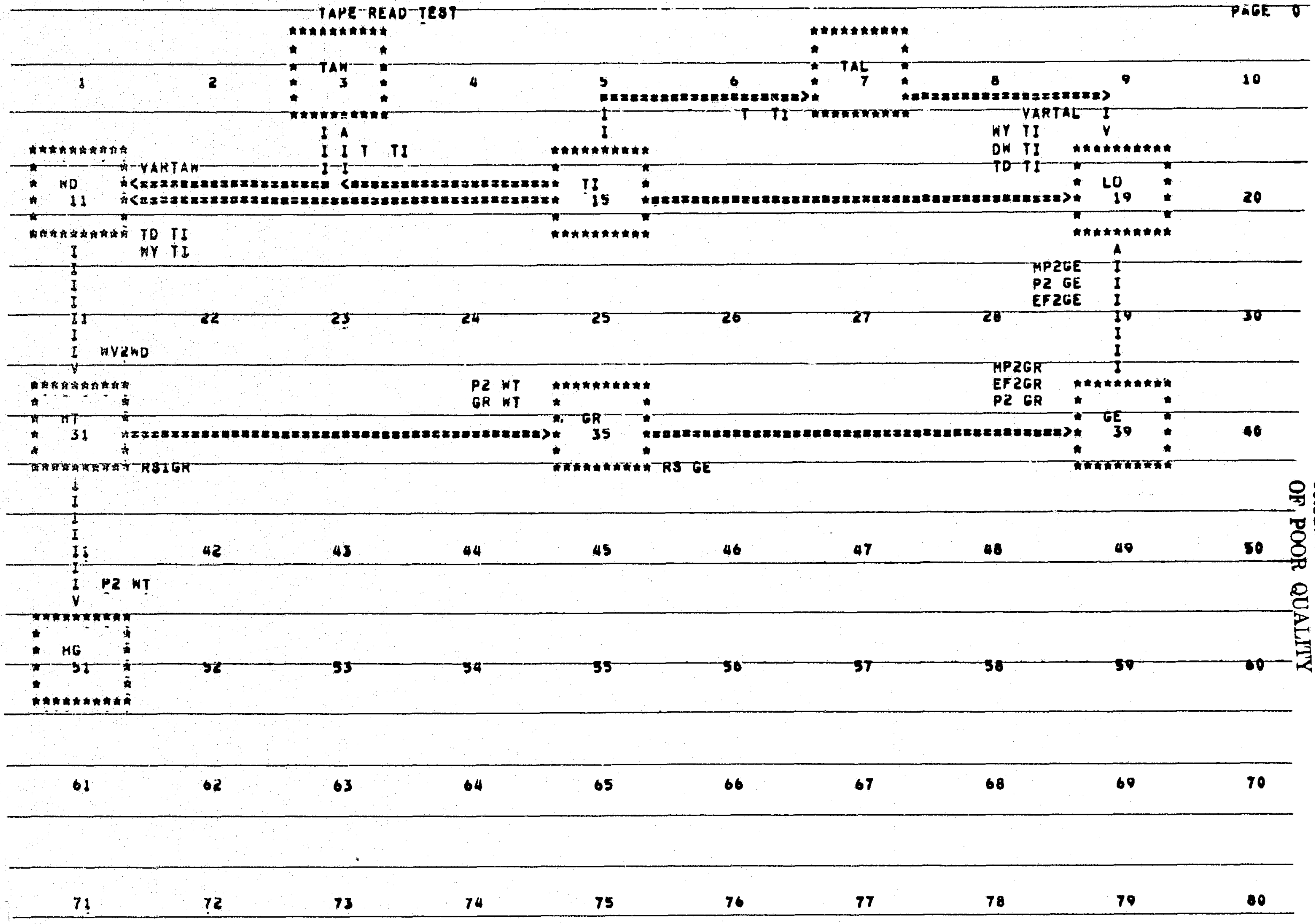

FIGURE 9.1-3. WIND TURBINE AND FILE READ MODEL SCHEMATIC

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```
 ITLE= TAPE READ TEST
PARAMETER VALUES
CYCLES=2.01,T0 TI=0,FUPHG=1000,FLOHG=50,NSTTAW=0,ITFTAW=1
 D WT=21,BR WT=80,EC WT=1,CPMWT=.41,CC WT=16000,CM WT=2000
RASGE=.01, CC GR=1000,CM GR=200,NSTTAL=0,ITFTAL=2
FFPGE=750,RSYGE=1800,DA GE=0.2,SR GE=.005,VO GE=400,CC GE=1000,CM GE=200
N  LD=.00574,CT LO=4,MN LO=0,STDLO=6,VE LO=.023
TABLE,PY WD=13
 .,4.33,8.67,13.,17.33,21.67,26.,30.33,34.67,39.,43.33,47.67,52.
65,67,68,65,61,56,51,49,49,52,56,61,65
TABLE,PD WD=7
0,4,8,12,16,20,24
0,0,0,6,6,6,0
TABLE,DF WD=16
0,3,6,9,12,15,18,21,24,27,30,33,36,39,42,45
5,44,160,380,480,512,440,376,307,270,148,76,40,22,9,3
TABLE, PLOGR =7
0,100,200,300,400,500,600
 ,4,9,18,32,50,72
TABLE,PD LO=17
0,1.5,3,4.5,6,7.5,9,10.5,12
13.5,15,16.5,18,19.5,21,22.5,24
45 , 60,372,330,450,660,810,798,804
690,702,699,702,750,708,570,450
TABLE,PW LO=7
1,2,3,4,5,6,7
1,1,.9,.9,.9,.6,.5
TABLE,PY LO=6
0,10,20,30,40,52
 6,194,180,174,194,226
PRINTER PLOTS,DISPLAY1
  WD,VS,TIME
P  KT,VS,  WD
P  GR,VS,P2 WT
LC2LO,VS,TIME
PC LO,VS,TIME
DISPLAY2,P2 GE,VS,TIME
TINC=.25,TMAX=168.,PRATE=24,PRINT CONTROL=3,INT MODE=3,OUTRATE=2
 IMULATE
 PARAMETER VALUES,T0 TI=4200,NSTTAW=38,NSTTAL=39,TMAX=220
SIMULATE
 PARAMETER VALUES,NSTTAL=40,
```

FIGURE 8.1-4 INPUT DATA FOR ANALYSIS PROGRAM mph. The load-time profile for the simulation is shown in Figure 8.1-8. Daily peaks and troughs are clearly indicated. The lower levels of the last two days reflect week-end load modeling.

/*/*/*/ SIMULATION ANALYSIS /*/*/*/ /

PRINT RATE= 24 DISPLAY RATE= 2 MODE= 3 TINC= .25000 TMAX= 168.00

TAPE READ TEST

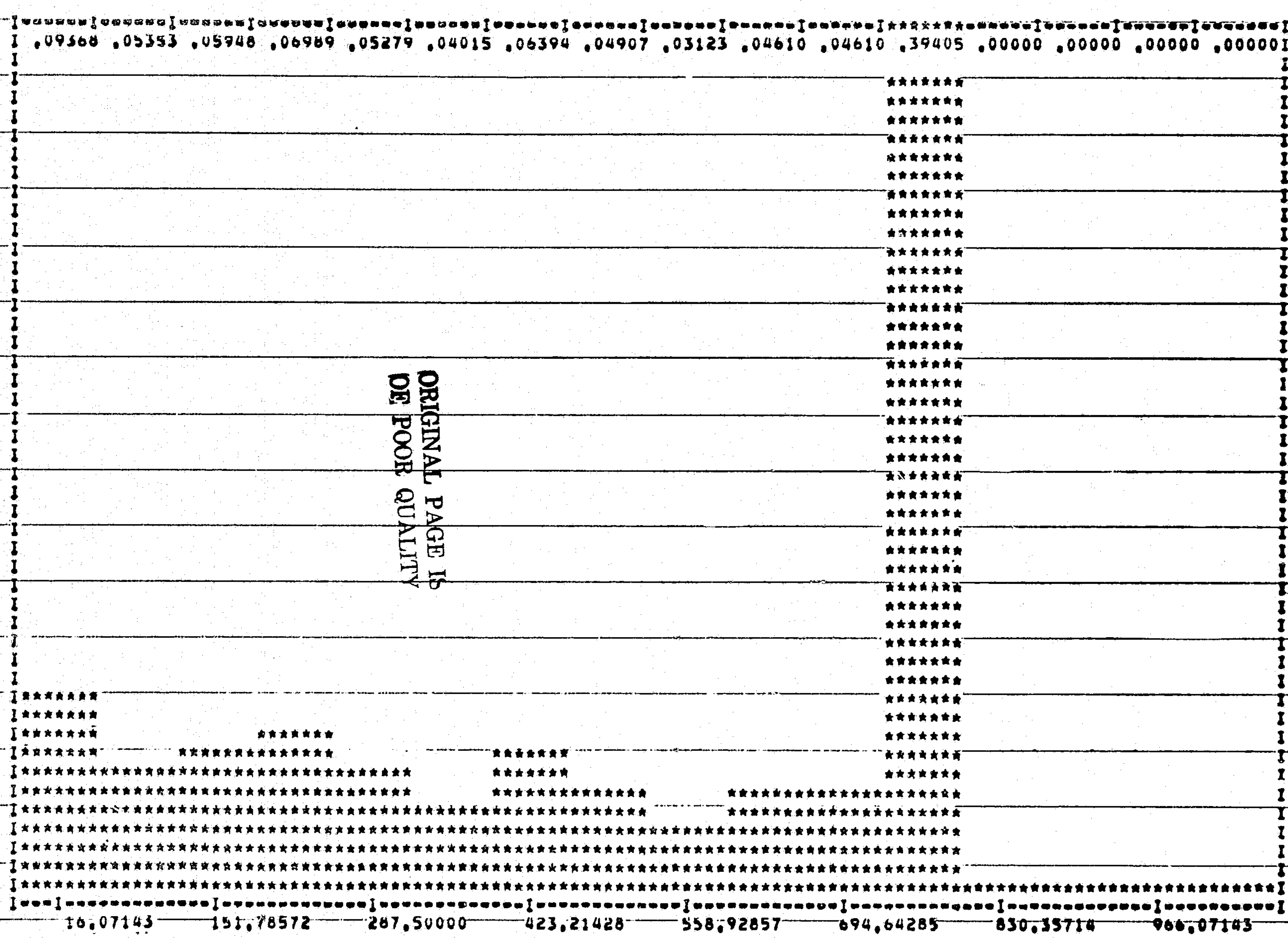
CASE NO. 1

IDENTIFICATION HEADER FOR UNIT 11
WD GENERATED WIND DATA

IDENTIFICATION HEADER FOR UNIT 12
LD GENERATED LOAD DATA

,000	,250	572,020	576,458	541,275	542,305	504,160	490,027	458,856	465,241	471,429	461,310
472,202	469,504	484,207	478,548	457,784	462,708	428,157	417,025	435,024	424,541	477,498	477,597
524,078	529,235	580,327	574,953	655,125	684,704	751,090	774,545	849,244	842,653	919,063	906,349
976,191	971,344	1035,062	1030,417	1019,400	1025,785	1025,351	1015,678	1029,436	1016,803	1021,731	1030,062
1036,085	1020,695	1024,203	1026,614	982,779	972,742	929,110	935,981	880,547	874,323	888,260	897,320
894,755	914,397	906,599	905,685	896,960	897,141	895,857	899,829	899,173	897,042	908,923	887,126
902,818	898,822	898,457	898,273	910,522	928,584	951,416	932,214	966,968	961,958	927,407	940,644
906,296	909,801	914,014	904,625	848,249	849,443	783,334	799,167	737,316	728,981	668,681	668,212
622,550	633,111	566,890	571,579	529,372	544,840	509,411	501,604	464,107	453,340	459,528	467,007
460,501	477,917	482,686	483,800	462,589	457,579	444,235	439,874	419,515	429,792	483,195	466,143
526,520	528,161	572,035	570,269	660,377	652,042	770,330	756,319	843,668	857,838	896,782	901,220
957,964	976,595	1026,770	1039,277	1021,489	1024,710	1030,602	1024,092	1031,524	1028,826	1013,459	1024,933
1010,194	1036,326	1032,617	1025,094	991,659	974,384	937,970	924,526	874,771	866,031	886,739	888,582
910,631	899,333	897,415	907,327	909,429	902,392	897,479	895,145	901,262	885,588	900,631	888,768
897,689	893,247	886,110	907,132	909,001	926,617	950,342	937,912	958,230	960,458	963,353	935,515
929,145	918,661	895,342	903,105	849,891	844,314	785,423	780,048	725,415	734,232	684,312	683,844
620,583	621,210	527,518	515,674	487,255	479,243	454,255	434,638	413,080	415,578	421,951	409,596
425,091	425,911	429,801	427,555	417,808	404,359	389,100	388,022	376,195	378,948	417,267	427,101
469,653	461,386	516,310	539,500	592,569	600,906	670,397	672,822	764,028	771,088	805,735	828,013
872,988	858,882	932,067	940,076	917,971	932,658	923,327	932,503	929,850	921,327	920,069	942,602
917,149	934,573	925,140	924,464	878,517	881,672	830,214	842,894	801,363	796,343	790,602	795,509
808,635	804,783	818,895	811,978	807,374	814,032	812,055	807,109	803,271	810,696	812,447	801,771
806,953	818,793	799,780	808,956	826,075	820,398	835,254	839,504	854,944	865,672	850,213	837,347
822,271	837,615	832,466	814,272	757,037	770,703	702,264	691,332	654,351	653,748	608,418	607,997
566,499	567,063	522,901	523,648	498,076	490,064	449,639	451,553	411,712	436,143	423,429	408,227
420,876	436,731	431,681	429,435	413,593	408,683	405,614	402,090	378,074	386,922	421,993	438,323
474,379	466,112	508,445	528,789	594,047	596,289	680,816	677,548	750,470	775,412	807,615	820,550
868,372	872,950	942,887	935,459	925,544	915,451	925,206	921,792	913,044	913,864	912,204	922,549
915,379	911,673	926,217	919,446	883,644	883,150	834,940	841,525	791,053	794,974	805,072	799,833
801,172	794,474	811,432	814,259	824,690	812,262	807,840	811,835	801,501	806,079	804,181	800,402
814,525	820,271	800,856	819,777	827,553	837,715	861,511	838,135	850,327	864,102	858,187	844,919
838,785	823,656	812,413	809,656	756,070	757,145	709,836	711,495	659,479	661,320	609,896	615,971
571,225	562,447	518,686	512,937	481,270	488,695	448,270	450,184	410,343	406,747	403,375	418,646
416,260	429,268	417,722	425,220	421,165	413,810	392,056	388,131	376,304	385,152	429,967	427,612
472,609	473,684	513,171	521,326	592,678	592,074	679,849	682,274	761,291	758,607	818,435	812,685
863,755	874,428	935,424	940,586	939,612	929,921	920,590	930,167	914,924	918,590	923,426	908,991
923,353	916,399	928,498	927,420	878,626	885,029	827,477	834,062	804,720	796,452	809,396	801,713
796,556	789,857	809,662	803,548								

FIGURE 8.1-5 TAPE READ FORMATTED LOAD DATA



HISTOGRAM FOR 1345 SAMPLES MEAN= 500.77955 STANDARD DEV.= 290.39880

TIME = 168.0 STATES
1 VDELO = 1696.7

FIGURE 8.1-6 WIND TURBINE POWER HISTOGRAM

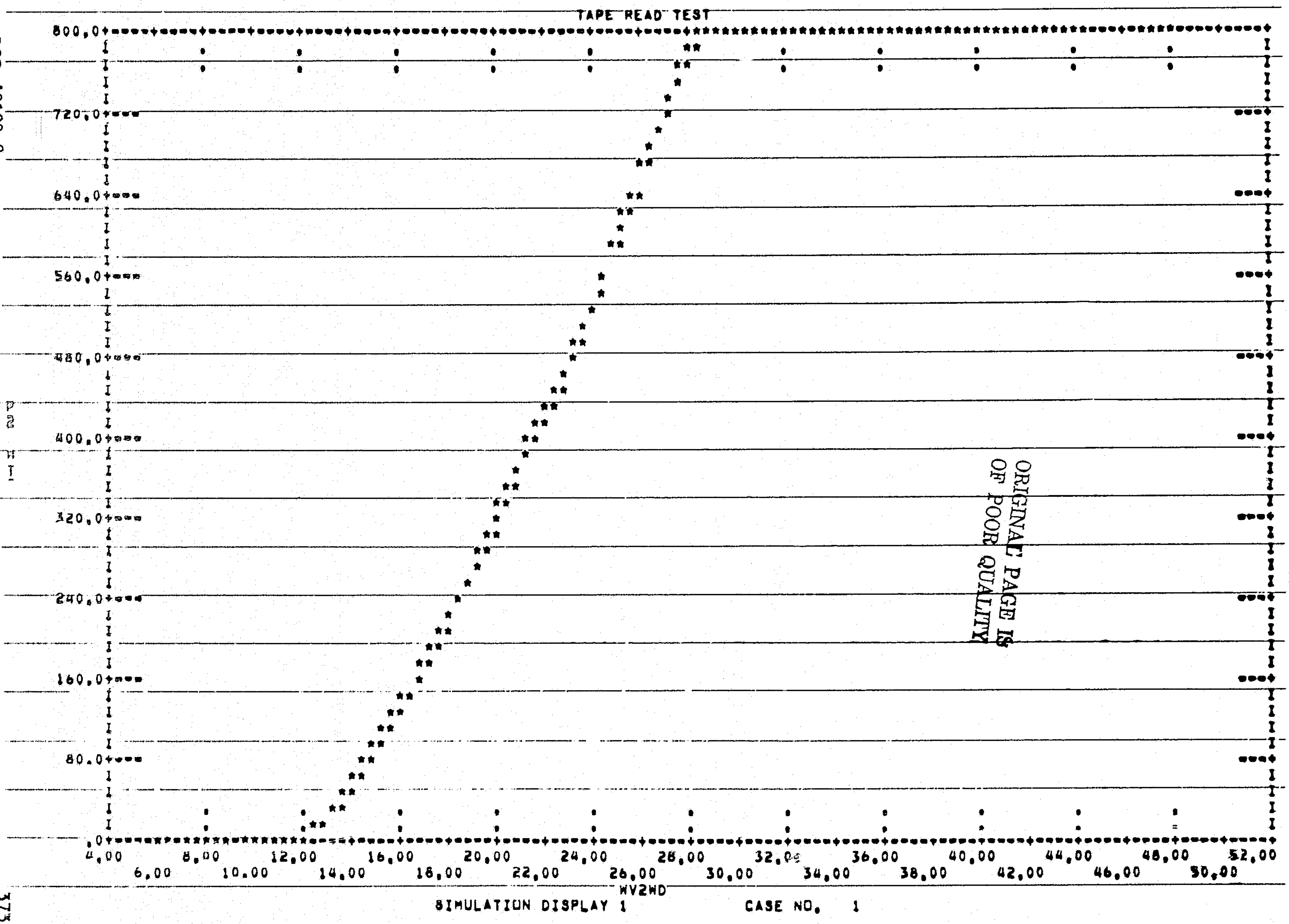


FIGURE 8.1-7 WIND POWER OUTPUT VERSUS WIND VELOCITY

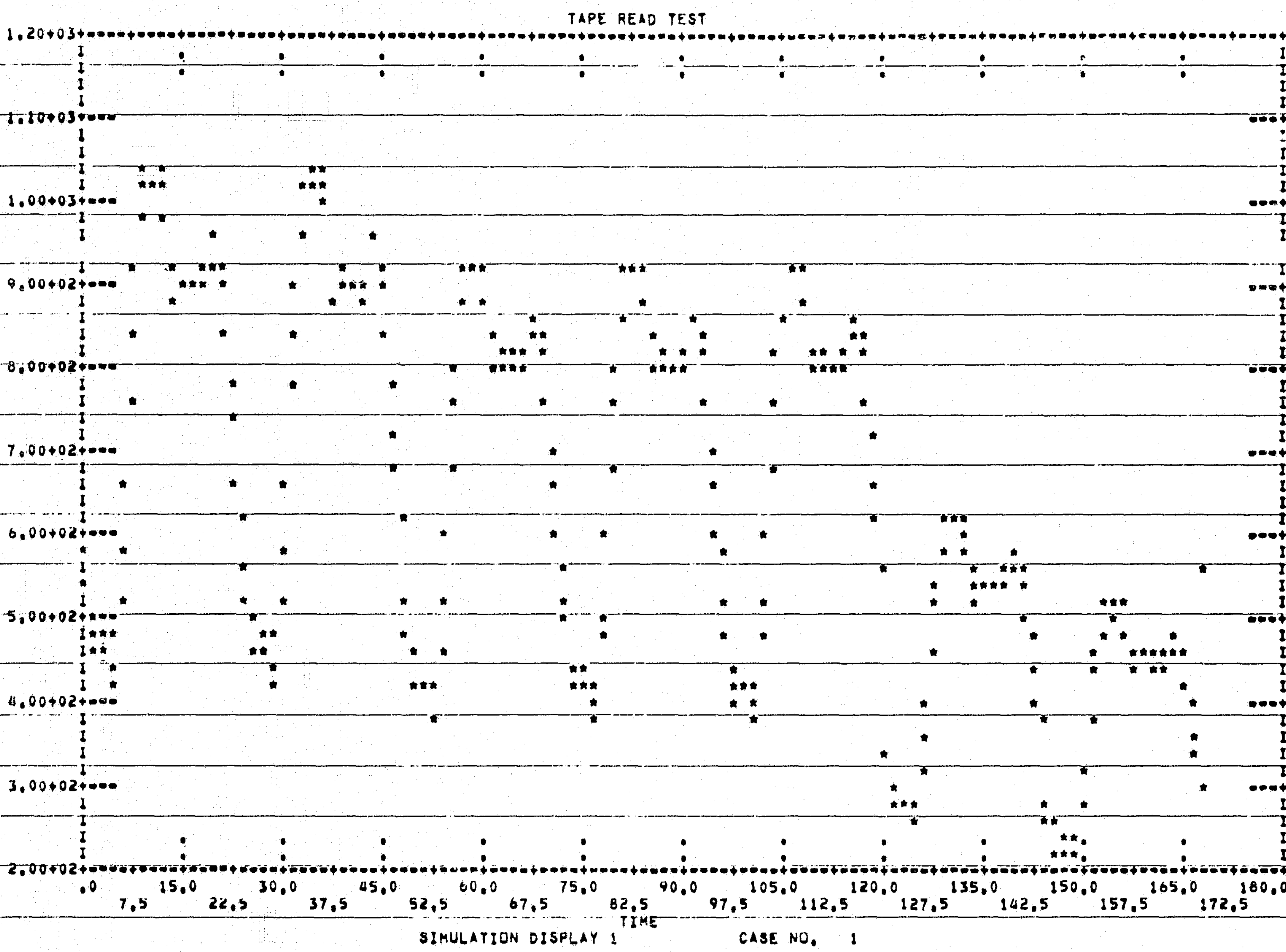


FIGURE 8.1-8 WEEKLY LOAD PROFILE

8.2 BATTERY STORAGE MODEL

A simplified schematic of the battery storage model is shown in Figure 8.2-1. In this model, wind power supplemented by a utility generation source is supplied to a power divider, which delivers power to the load as a first priority, and battery storage as second priority. Similarly, if the load cannot be met from the wind or storage, then the utility is requested to supply peaking power to meet the load. This model exercises the logic components including the priority interrupt.

Figure 8.2-2 shows the model generation input data for the model. The components are generally defined in the order of power flow shown in Figure 8.2-1. Ordering the component definition in this way is recommended to avoid convergence problems in the iteration loop. Thus, it would be somewhat better for consistency to define UT after WP rather than after LO in the model. All three types of model connections are illustrated in this example. For example, WP has the general input connection WD, MAB has the specific input connection WP (P,2 = FIN), and PD has the port to port connection PA (1,1). The port connections are especially useful for connecting up the multiport logic components PA and PD. The connection PA (1,1), for example, connects an input request of PD to PA and a power and maximum power input of PA to PD. It may be observed that the utility is connected up to the surplus port of PD. Thus the baseload power sent to MAB in effect is reduced whenever the load and battery cannot absorb all the power generated. The last component defined is the cost monitor CM, which receives cost input data from other components through a common block rather than by model connections. Figure 8.2-3 shows the model schematic generated by the program. Most of the connection inputs are shown but occasionally a model connection will be overprinted. For example, the input RE1PA to PD is not shown in 8.2-3. In cases like this it is necessary to check the Fortran model (EQMO) in order to verify the model connections.

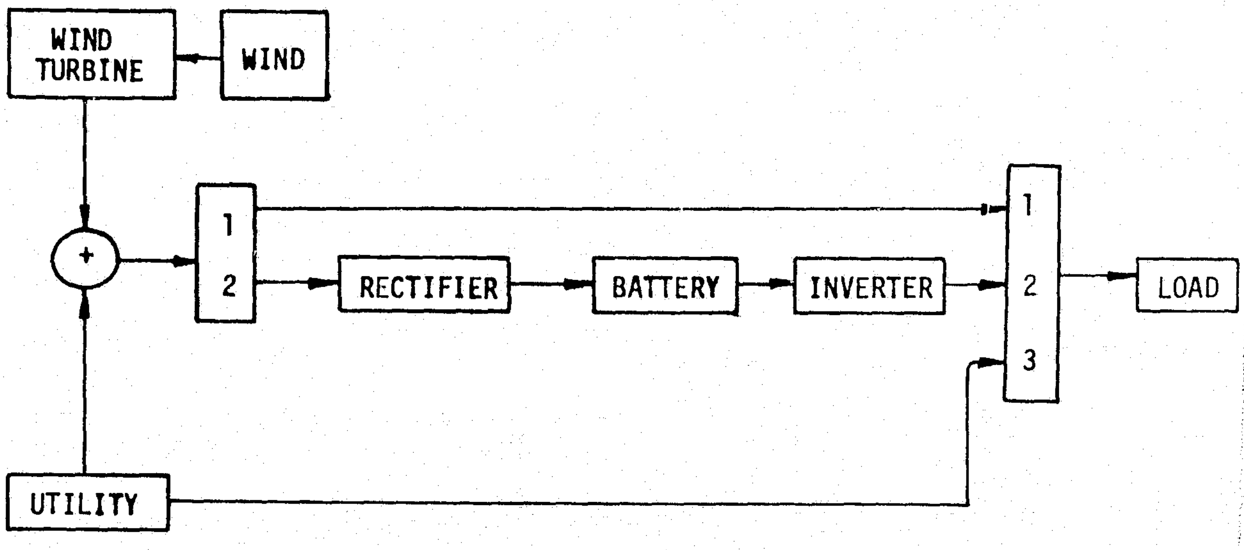


FIGURE 8.2-1: BATTERY STORAGE EXAMPLE

```
MODEL DESCRIPTION          BATTERY TEST CASE
LOCATION=74       TI
LOCATION=61       WD       INPUTS=TI
LOCATION=21       WP       INPUTS=WD
LOCATION=42       MAB      INPUTS=WP(P,2=FIN),UT(P,1=C2)
LOCATION=33       PD       INPUTS=MAB(FO=P),MAB(FO=MP),PA(1,1),PIB(2,2),
                           BA(RE=RE,2)
LOCATION=15       RE       INPUTS=PD (2,1)
LOCATION=17       BA       INPUTS=RE,PA(RE,2=RE)
LOCATION=45       PIB      INPUTS=BA
LOCATION=19       IV       INPUTS=BA
LOCATION=69       PA       INPUTS=IV(2,2),LO(1,0)PIB(4,2),UT(2,3)
LOCATION=76       LO       INPUTS=TI
LOCATION=62       UT       INPUTS=PD(SP=P,0)
LOCATION=1        CM
END OF MODEL
LIST STANDARD COMPONENTS
PRINT
```

FIGURE 8.2-2 BATTERY MODEL INPUT DATA

The input data for two simulations is shown in Figure 8.2-4. In the first simulation the battery is nearly full at time = 0 and the load is chosen larger on the average than the wind and utility power supplied. In the second simulation the reverse is true, i.e. the load is less than that supplied by the wind system, and the battery storage is fairly low. Figures 8.2-5 to 8.2-8 show results from the first simulation. The cost monitor output is shown in Figure 8.2-5. The energy cost of the wind system is low because the wind profile delivers high energy winds during most of the simulation. The average wind velocity in Figure 8.2-6 is about 22 mph. Figure 8.2-7 shows the wind power output supplied directly to the load. The median power output is seen to exceed 450 kw and occasionally output reaches 800 kw or rated power. Figure 8.2-8 shows the usage of battery energy to meet the load during the week, and the increase in storage capacity during the weekends. Since the battery subsystem was limited to 180 kw maximum discharge, the utility was frequently called to meet peak load. Thus about 10% of the load was satisfied by the utility.

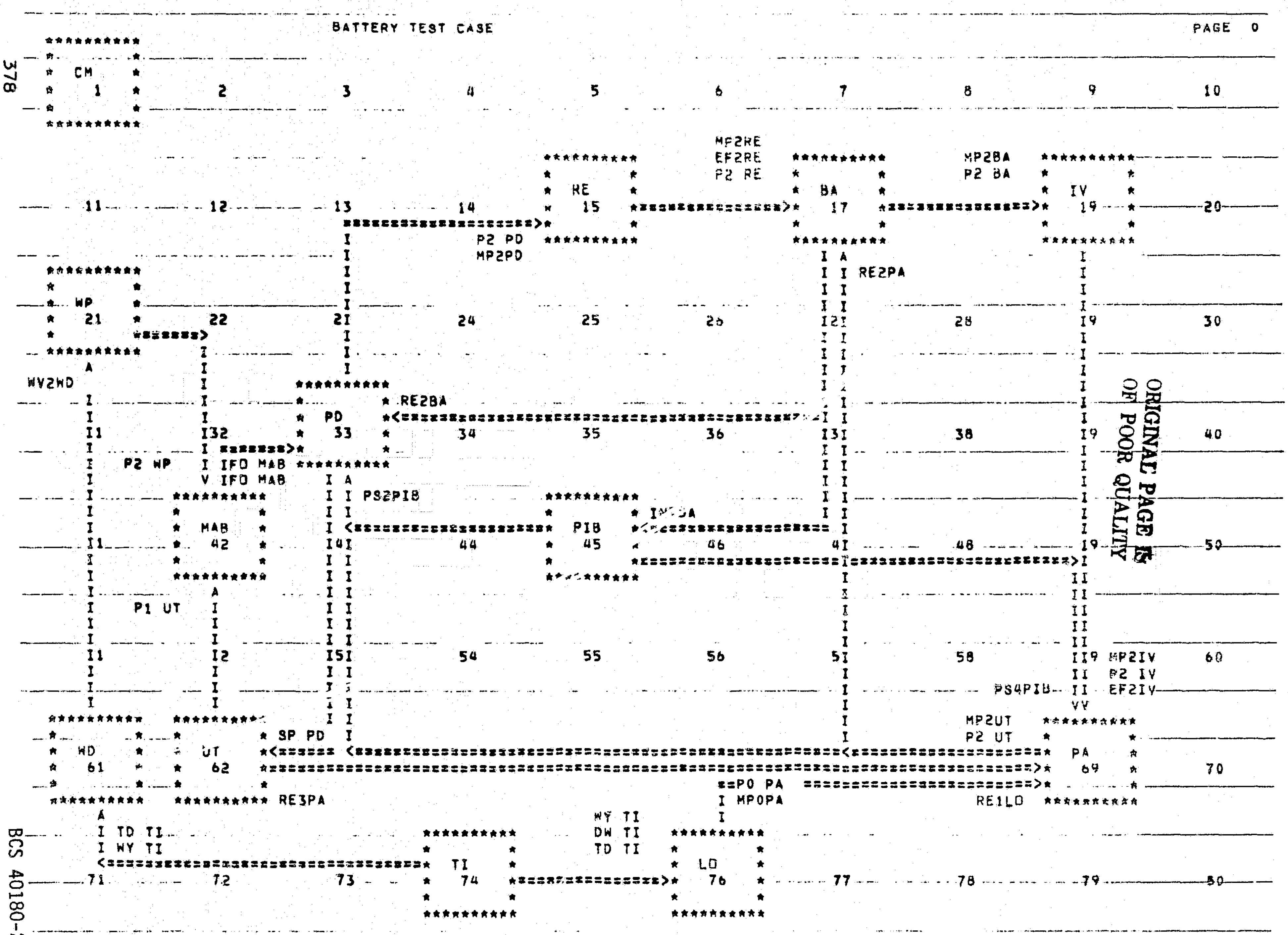


FIGURE 8.2-3 BATTERY MODEL SCHEMATIC

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OF POOR QUALITY

```
TITLE= BATTERY MODEL TEST
PARAMETER VALUES
CR CM=15.,LE CM=30.
BS UT=20.,CB UT=.016,CP UT=.03,CC UT=1000.,CM UT=1000.
C1 MAB=1.
CYCLES=4.01,TO TI=0,V  WP=400,WV0WP=8,WV1WP=60,DLINES=100.
CC WP=16000,CM WP=1200,PS1PTB=2.
EC WP=.2
NC LD=.005,CT LD=4,MN LD=0,STDLD=6,VE LD=.023
RAPBA=200.,E1 BA=2000.,EDEBA=100.
VO BA=100
DT BA=10.,CC BA=2000.,CM BA=100.
RAPRE=200.,CC RE=200.,RAPIV=200.,CC IV=0.
TABLE,PW WP=10
8,10,12,14,16,18,20,21.53,25,30
25.6,50.1,86.5,137.4,205.1,292.,400.6,500,782.8,800
TABLE,PY WD=13
0.,4.33,8.67,13.,17.33,21.67,26.,30.33,34.67,39.,43.33,47.67,52.
65,67,68,65,61,56,51,49,49,52,56,61,65
TABLE,PD WD=7
0,4,8,12,16,20,24
10,12,14,16,14,12,10
TABLE,DF WD=16
0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
5,44,160,380,480,512,440,376,307,270,148,76,40,22,9,3
TABLE,PD LD=17
0,1.5,3,4.5,6,7.5,9,10.5,12
13.5,15,16.5,18,19.5,21,22.5,24
450,360,372,330,450,660,810,798,804
690,708,699,702,750,708,570,450
TABLE,PW LD=7
1,2,3,4,5,6,7
1,1,.9,.9,.9,.6,.5
TABLE,PY LD=6
0,10,20,30,40,52
226,194,180,174,194,226
INITIAL CONDITIONS, PE BA =1990.
PRINTER PLOTS,DISPLAY1
WV2WD,VS,TIME
P1 PD,VS,TIME
P2 PD,VS,TIME
PE BA,VS,TIME
DISPLAY2
P2 IV,VS,TIME
RE2BA,VS,TIME
RE1LD,VS,TIME
TINC=.25,TMAX=336.,PRATE=8,PRINT CONTROL=3,INT MODE=3,OUTRATE=8
SIMULATE
PARAMETER VALUES,BS UT=0.,NC LD=.003
E1 BA=1000.,EDEBA=200.
CC IV=1000.
INITIAL CONDITIONS,PE BA=250.
SIMULATE
```

FIGURE 8.2-4 INPUT DATA FOR BATTERY SIMULATION

WIND ENERGY STORAGE COST SUMMARY

30 YEAR LIFE CYCLE

- YEARLY SYSTEM COSTS

CAPITAL COST (INCLUDING FIXED CHARGES)	86400. $
FIXED O + M COST	2300. $
OPERATING + FUEL COST	1753. $
TOTAL	90453. $

- ENERGY DELIVERED

ENERGY DELIVERED	4682165. KWH

```
****************************************************
*                                                  *
*       ENERGY COST PER KWH         19.3 MILLS     *
*                                                  *
****************************************************
```

VALUE OF ENERGY DELIVERED (VALUE OF FUEL SAVED)	105440 $
ENERGY VALUE PER KWH	22.5 MILLS
COST PER VALUE DELIVERED	.86

- LOAD FACTOR

PERCENT OF LOAD SUPPLIED BY TOTAL WID SYSTEM	90.4
PERCENT OF LOAD SUPPLIED BY UTILITY	9.6
PERCENT OF WIND ENERGY SURPLUSED	4.0
COST TO MEET LOAD (WIND + UTILITY)	19.8 MILLS

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FIGURE 8.2-5 COST MONITOR OUTPUT FOR BATTERY MODEL

BCS 40180-2

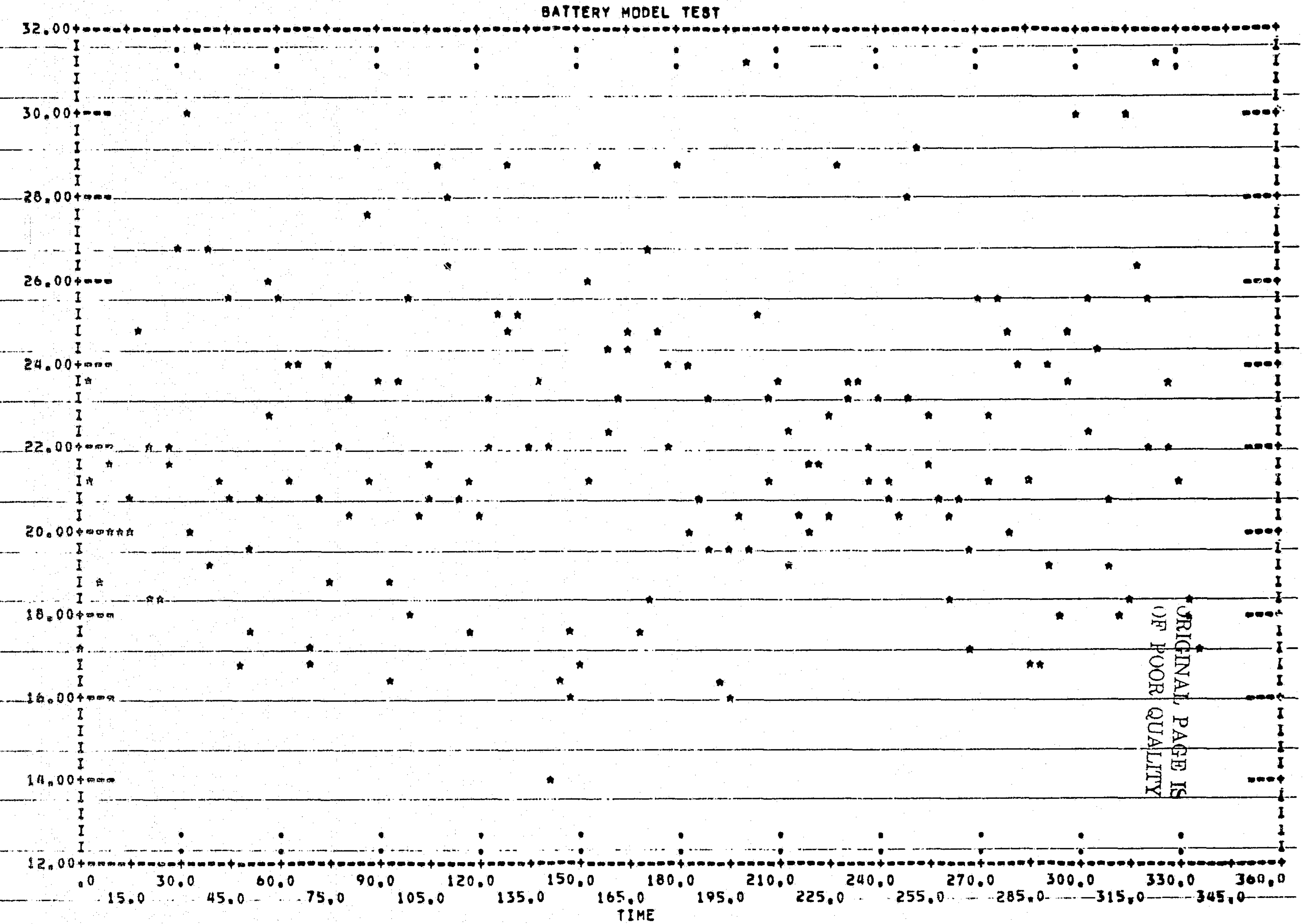

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FIGURE 8.2-6 WIND PROFILE FOR BATTERY SIMULATION

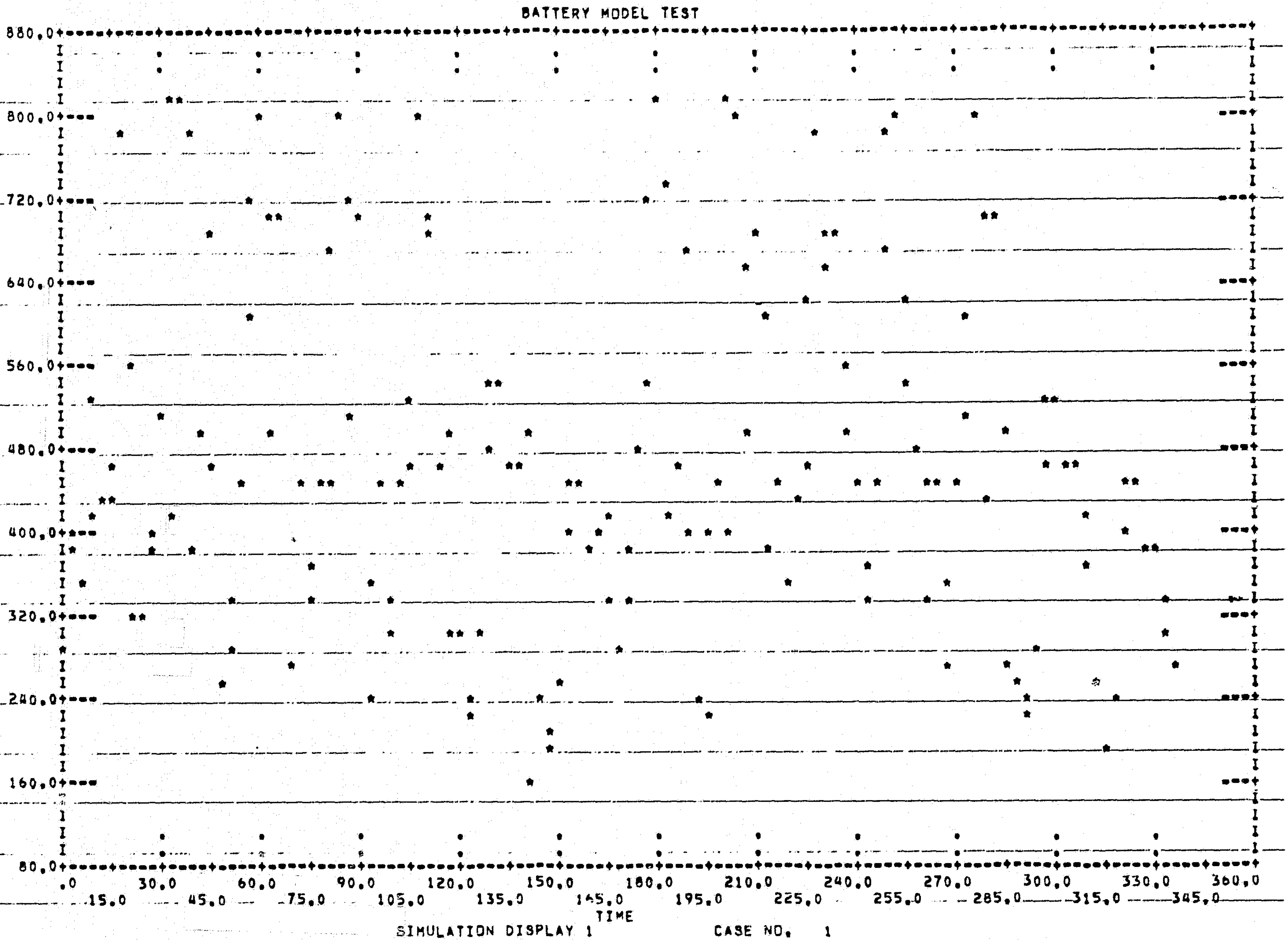

FIGURE 8.2-7 WIND POWER SUPPLIED TO LOAD

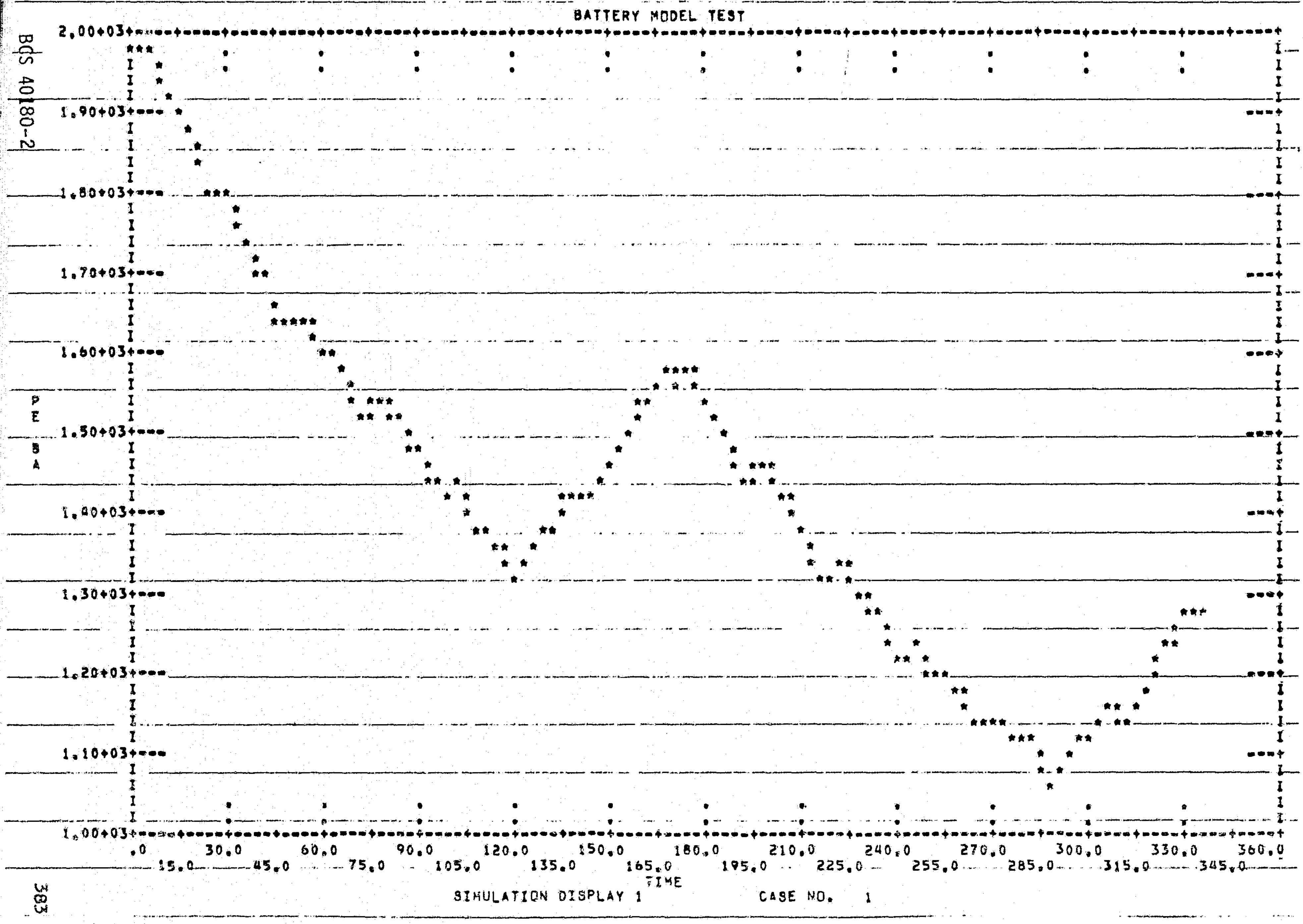

FIGURE 8.2-8 BATTERY POTENTIAL ENERGY STORAGE

8.3 FLYWHEEL STORAGE MODEL

Figure 8.3-1 shows a simplified schematic of the flywheel storage model. This model is very similar to that of 8.2 except that flywheel storage replaces battery storage, and a power line loss is included in the model. The input data for this model is shown in Figure 8.3-2. Observe that the components are defined in the order of information flow shown in 8.3-1. The admittance component AD is used to model transmission line power losses. The model schematic is shown in Figure 8.3-3.

```
MODEL DESCRIPTION           FLYWHEEL TEST CASE
LOCATION=74       TI
LOCATION=61       WD        INPUTS=TI
LOCATION=21       WP        INPUTS=WD
LOCATION=42       MAB       INPUTS=WP(P,2=FIN),UT(P,1=C2)
LOCATION=33       PD        INPUTS=MAB(FO=P,0),MAB(FO-MP),PA(1,1),PIB(2,2)
                                      FL(RE=RE,2)
LOCATION=13       MO        INPUTS=PD(2,1)
LOCATION=4        TRI       INPUTS=MO(2,1),FL(RS=RS,2)
LOCATION=6        FL        INPUTS=TRI,PA(2,1)
LOCATION=8        TRO       INPUTS=FL,GE(RS=RS,2)
LOCATION=19       GE        INPUTS=TRO
LOCATION=45       PIB       INPUTS=FL
LOCATION=69       PA        INPUTS=GE(2,2),LO(RE,1=RE,0),PIB(4,2)
                                  UT(2,3)
LOCATION=78       AD        INPUTS=PA
LOCATION=76       LO        INPUTS=TI,AD
LOCATION=62       UT        INPUTS=PD (SP=P,0)
LOCATION=1        CM
END OF MODEL
LIST STANDARD COMPONENTS
PRINT
```

FIGURE 8.3-2 FLYWHEEL MODEL INPUT DATA

The simulation input data shown in Figure 8.3-4 uses the same wind and load data as Example 8.2. However, the storage component is rated at 400 kw with one hour storage, simulating a system used for temporary storage and discharge during peak power generation and load demand periods. It may be noted that the transmission power loss table is input for both TRI and TRO. Figures 8.3-5 to 8.3-7 show results from the simulation. Charging power to the

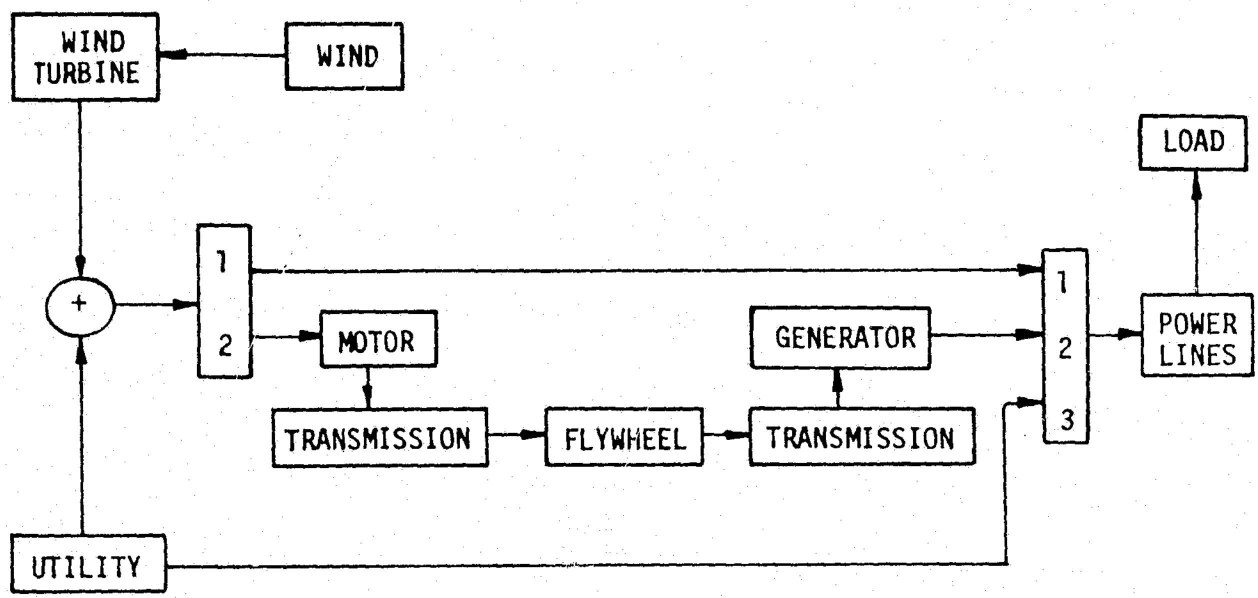

FIGURE 8.3-1: FLYWHEEL STORAGE EXAMPLE

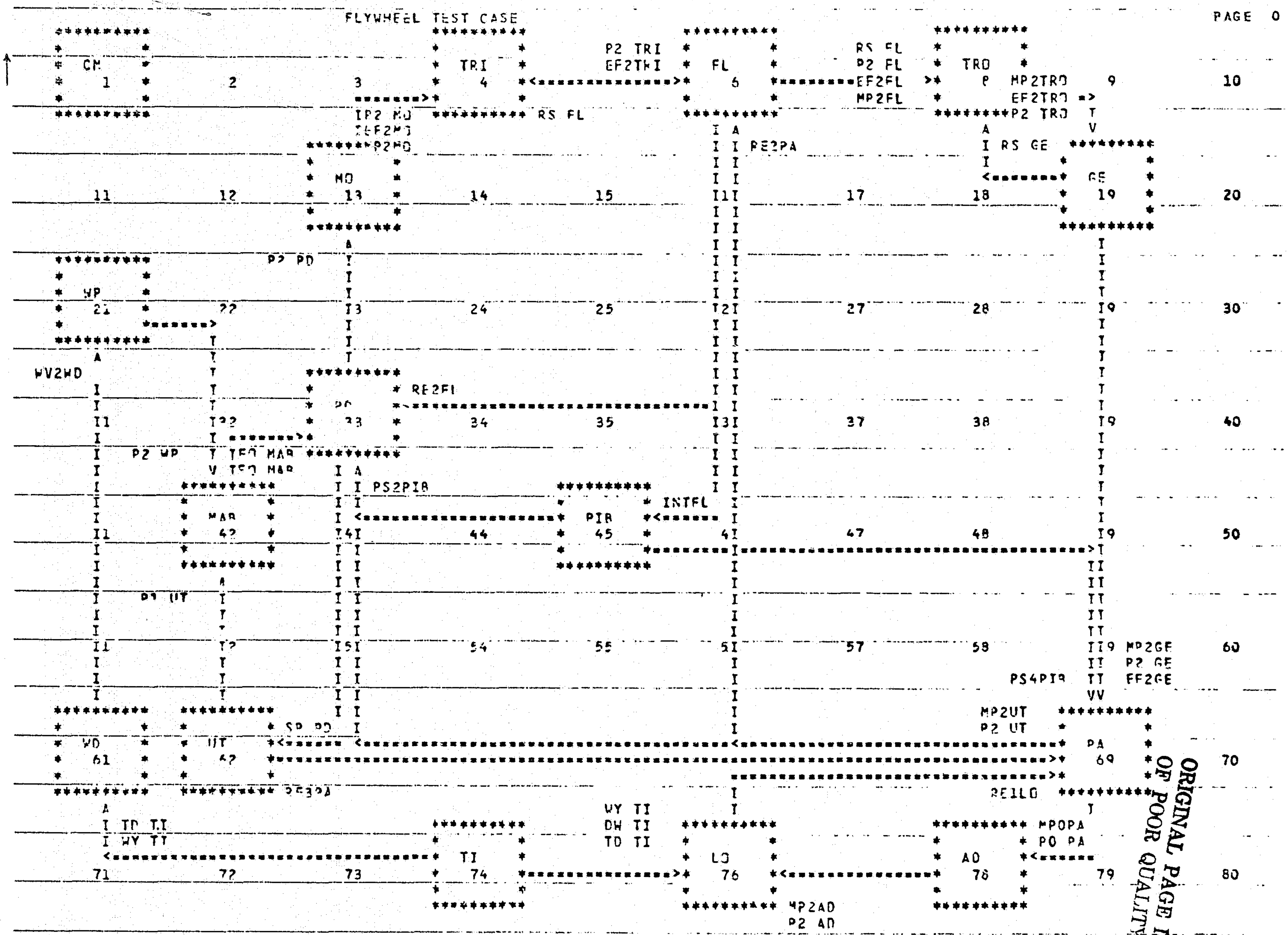

FIGURE 8.3-3 FLYWHEEL MODEL SCHEMATIC

flywheel in excess of that needed for the load is shown in Figure 8.3-5. Even with average load demand exceeding wind generation, the flywheel is charged at rated power fairly often. The kinetic energy stored by the flywheel over a two week period is shown in Figure 8.3-6. During the week energy is frequently withdrawn and storage is generally not much above the deadband (80 kwh), whereas during the weekend the reverse is true. Output from the cost monitor is shown in Figure 8.3-7. The capital costs are probably low since nominal values were used for component costs. The utility supplied nearly 20% of the load in this case, since flywheel storage capacity is quite low.

```
TITLE= FLYWHEEL MODEL TEST
PARAMETER_VALUES
VO AD=100,G1 AD=8.,G2 AD=8.,GH AD=-8.,BM AD=200
SR GE=.008,C2 FL=3.E-8
PR FL=.02,HM FL=3372,RF FL=3.5,SR FL=.4,WT FL=24000,KF FL=1.3E-5
ZE FL=.1,RAPFL=400,EO FL=40,E1 FL=400,EDEFL=20,CM FL=800,CC FL=300
RS MO=1750,RAPMO=1000,MP1MO=1.E8,CC MO=500,CM MO=0.
RS1TRI=1750,CC TRI=500,CM TRI=0,CC TRO=500,CM TRO=0.
RAPGE=1000,CC GE=1000,CM GE=100.
CR CM=15.,LE CM=30.
BS UT=20.,CB UT=.016,CP UT=.03,CC UT=1000.,CM UT=1000.
C1 MAB=1.
CYCLES=4.01,TO TI=0,V  WP=400,WVOWP=8,WV1WP=60,DLINES=100.
CC WP=16000,CM WP=1200,PS1PIB=2.
EC WP=.2
NC LO=.005,CT LO=4,MN LO=0,STDLO=6,VE LO=.023
TABLE,PLOTRI=5,4
0.5,1,1.5,1.72
0,400,900,1100,1300
0,16,18,18.5,20
0,10,11,11.5,12
0,10,10,10.5,11
0,6,6.5,7,10
TABLE,PLOTRO=5,4
.5,1,1.5,1.72
0,400,900,1100,1300
0,16,18,18.5,20
0,10,11,11.5,12
0,10,10,10.5,11
0,6,6.5,7,10
TABLE,CLOFL=3,3
-1000,  0,  1000
2000,4000,7000
2.8,    7.4,    15
 .9,     2.5,    5
2.6,     7.2,   15
TABLE,CL1FL=3
2000,4000,7000
 .8,     2.4,    4
TABLE,PW WP=10
8,10,12,14,16,18,20,21.53,25,30
25.5,50.1,86.5,137.4,205.1,292.,400.6,500,782.8,800
TABLE,PY WD=13
0.,4.33,8.67,13.,17.33,21.67,26.,30.33,34.67,39.,43.33,47.67,52.
65,67,68,65,61,56,51,49,49,52,56,61,65
TABLE,PD WD=7
0,4,8,12,16,20,24
10,12,14,16,14,12,10
TABLE,DF WD=16
0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
5,44,160,380,480,512,440,376,307,270,148,76,40,22,9,3
TABLE,PD LO=17
0,1.5,3,4.5,6,7.5,9,10.5,12
13.5,15,16.5,18,19.5,21,22.5,24
450,360,372,330,450,660,810,798,804
690,708,699,702,750,708,570,450
TABLE,PW LO=7
1,2,3,4,5,6,7
1,1,.9,.9,.9,.6,.5
TABLE,PY LO=6
0,10,20,30,40,52
226,194,180,174,194,226
INITIAL CONDITIONS, KE FL=300.
PRINTER PLOTS,DISPLAY1
WV2WD,VS,TIME
P1 PD,VS,TIME
P2 PD,VS,TIME
KE FL,VS,TIME
DISPLAY2
P2 GE,VS,TIME
RE2FL,VS,TIME
RE1LO,VS,TIME
TINC=.25,TMAX=336.,PRATE=8,PRINT CONTROL=3,INT MODE=3,OUTRATE=8
SIMULATE
```


FIGURE 8.3-4 FLYWHEEL SIMULATION DATA

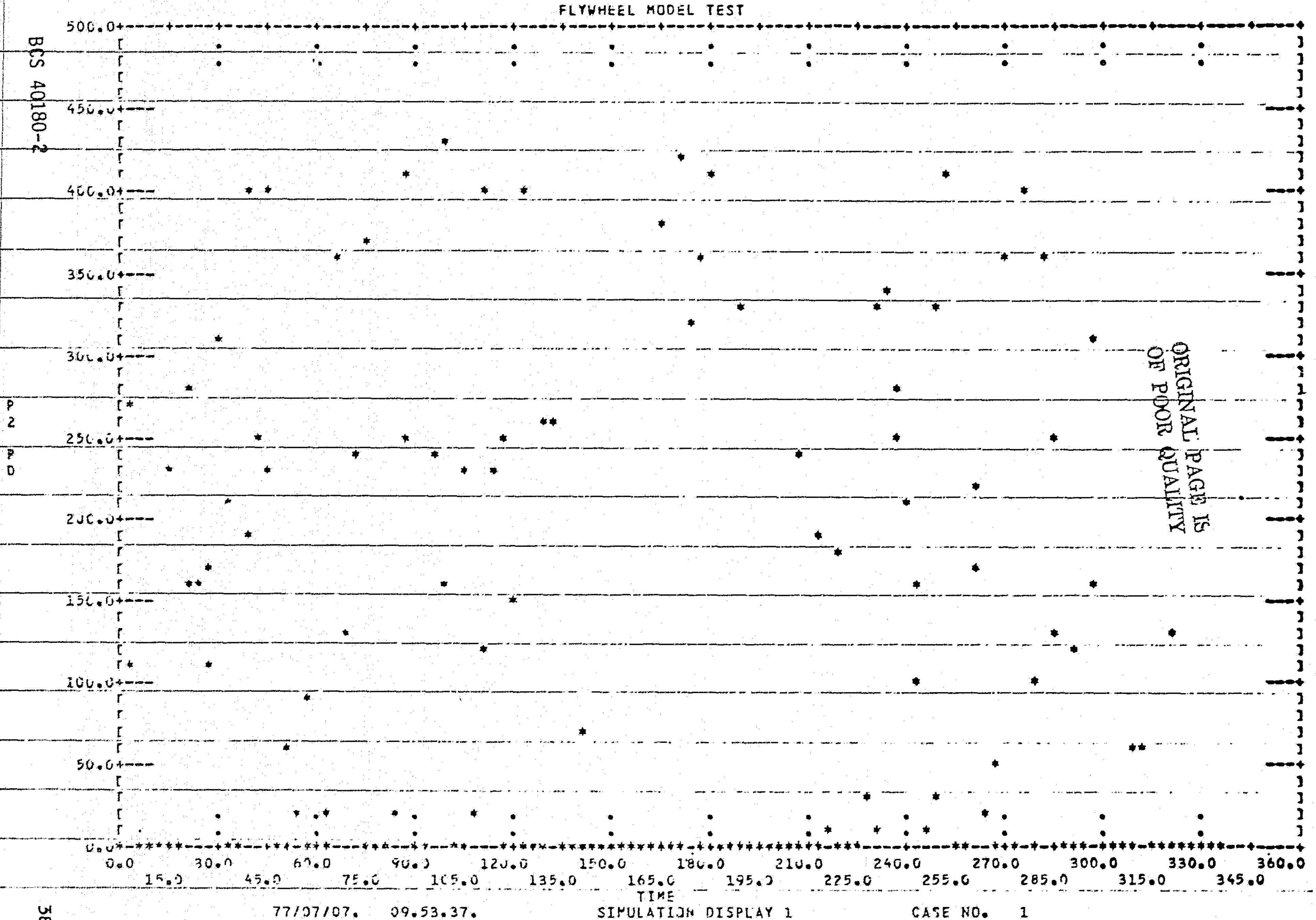

FIGURE 8.3-5 WIND POWER SUPPLIED TO FLYWHEEL STORAGE

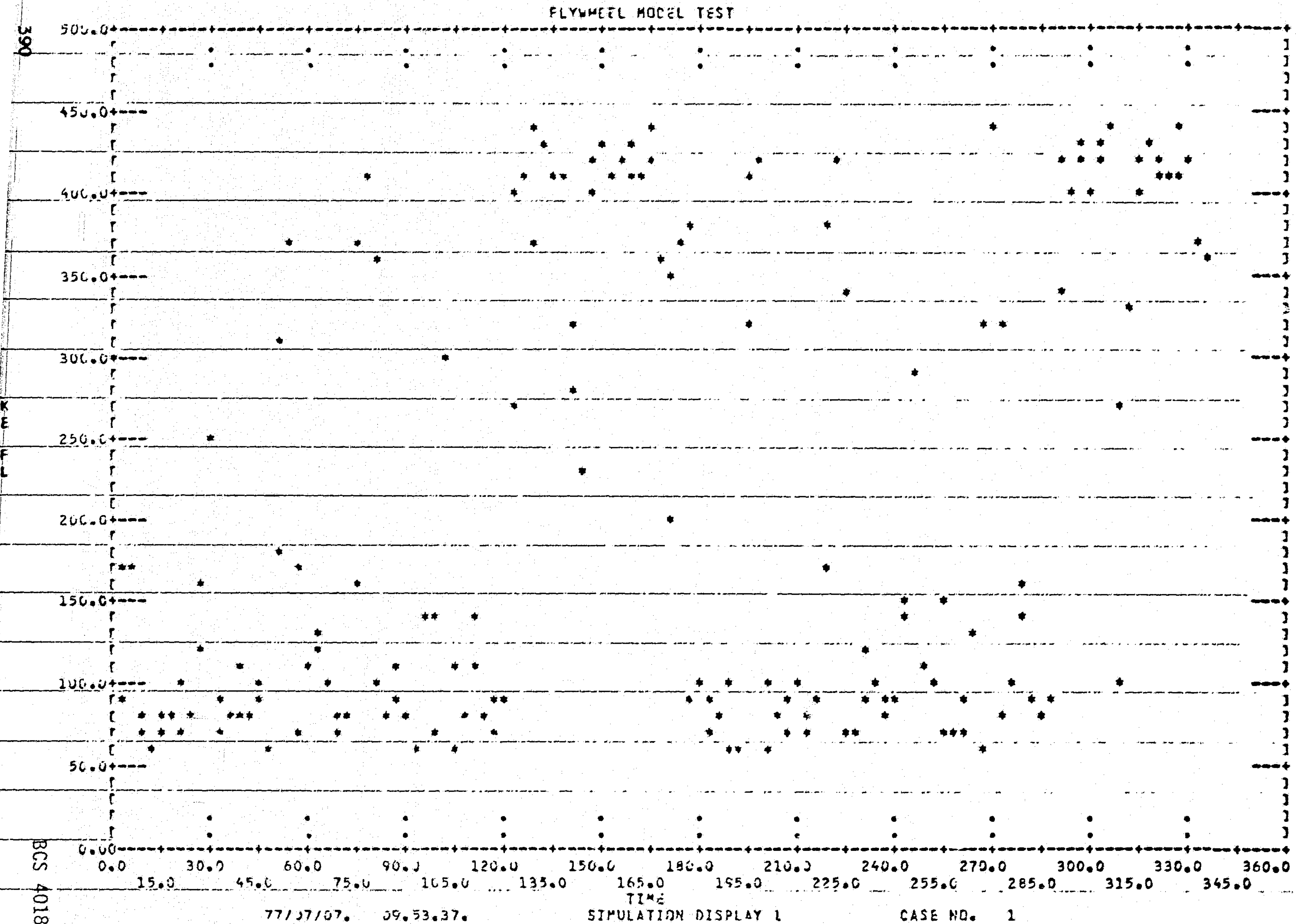

FIGURE 8.3-6 FLYWHEEL KINETIC ENERGY STORAGE

WIND ENERGY STORAGE COST SUMMARY

30 YEAR LIFE CYCLE

YEARLY SYSTEM COSTS

CAPITAL COST (INCLUDING FIXED CHARGES)	89104. $
FIXED O + M COST	3100. $
OPERATING + FUEL COST	1753. $
TOTAL	93957 $

ENERGY DELIVERED

ENERGY DELIVERED	4440974. KWH
ENERGY COST PER KWH	21.2 MILLS
VALUE OF ENERGY DELIVERED (VALUE OF FUEL SAVED)	95217 $
ENERGY VALUE PER KWH	21.4 MILLS
COST PER VALUE DELIVERED	.99

LOAD FACTOR

PERCENT OF LOAD SUPPLIED BY TOTAL WIND SYSTEM	81.3
PERCENT OF LOAD SUPPLIED BY UTILITY	18.7
PERCENT OF WIND ENERGY SURPLUSED	8.3
COST TO MEET LOAD (WIND + UTILITY)	22.3 MILLS

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FIGURE 8.3-7 FLYWHEEL MODEL COST MONITOR OUTPUT

8.4 HYDRO AND THERMAL STORAGE MODEL

Figure 8.4-1 shows the basic model schematic for a model with both thermal and electrical loads. Wind power is supplied first to meet the electrical load, with excess power going into hydro and thermal storage. The thermal load is driven by an ambient temperature component and electrical load energy value is supplied by a time dependent look-up table. Figure 8.4-2 shows the model input data. The components are ordered according to the flow of information in 8.4-1. Observe that the maximum power input of the power divider is connected up to the wind power output P. The model schematic is shown in Figure 8.4-3.

```
LIST STANDARD COMPONENTS
MODEL DESCRIPTION        HYDRO AND THERMAL TEST CASE
LOCATION=77      TI
LOCATION=51      WD       INPUTS=TI
LOCATION=21      WP       INPUTS=WD
LOCATION=33      PD       INPUTS=WP,WP(P=MP),PA(1,1),PIH(2,2),HS(RE=RE,2)
                          INPUTS=TS(2,3),PIT(2,3)
LOCATION=13      MO       INPUTS=PD(2,1)
LOCATION=15      PU       INPUTS=MO
LOCATION=17      HS       INPUTS=PU,PA(RE,2=RE)
LOCATION=45      PIH      INPUTS=HS
LOCATION=19      HT       INPUTS=HS
LOCATION=40      GE       INPUTS=HT
LOCATION=59      PA       INPUTS=GE(2,2),LO(1,0),PIH(4,2)
LOCATION=78      FU       INPUTS=TI(TD=FIN)
LOCATION-80      LO       INPUTS=TI,FU(FO=VE)
LOCATION=63      TS       INPUTS=TL
LOCATION=52      PIT      INPUTS=TS
LOCATION=67      TP       INPUTS=TI
LOCATION=65      TL       INPUTS=TI,TP
LOCATION= 1      CM
END OF MODEL
PRINT
```

FIGURE 8.4-2 HYDRO AND THERMAL MODEL INPUT DATA

The input data for a two week simulation with this model is shown in Figure 8.4-4. CYCLES is equal to 6 in this model for sufficient iterations to attain steady state in the hydro storage subsystem. The hydro system has

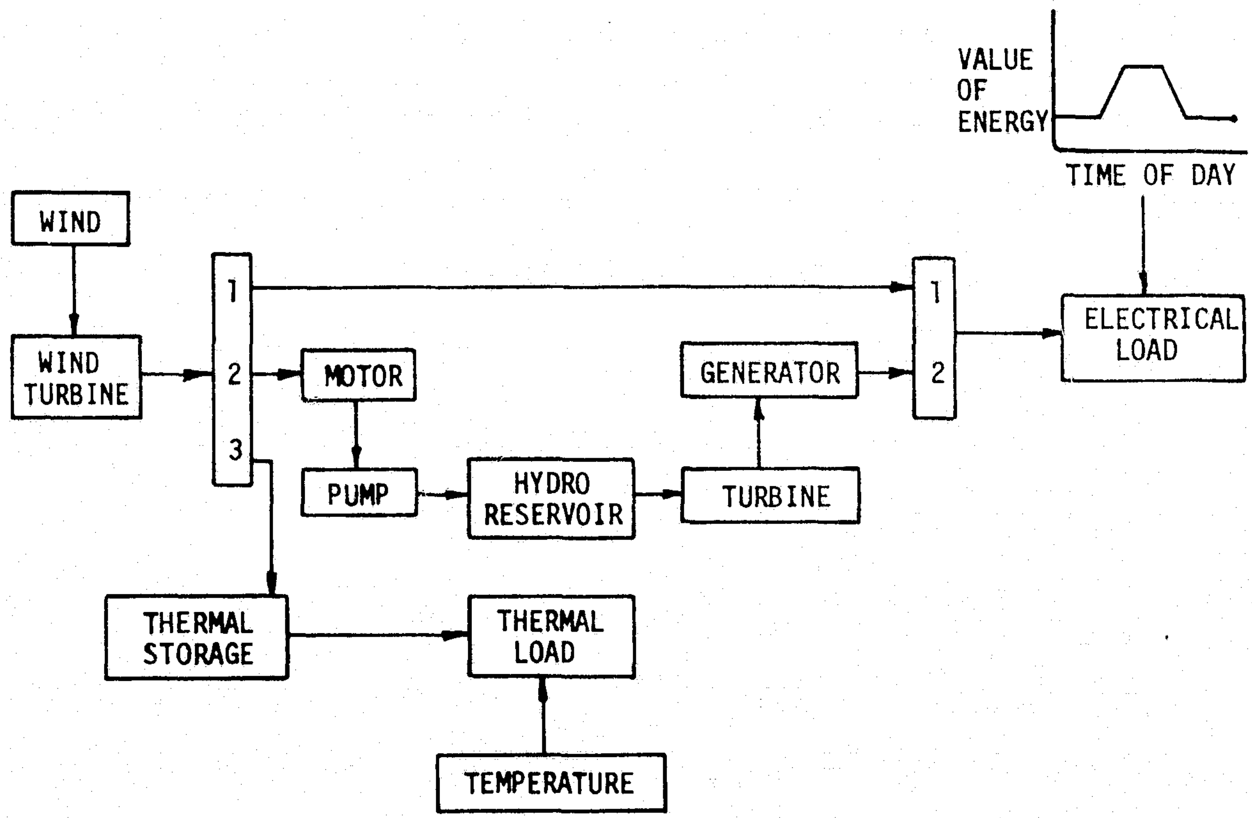

FIGURE 8.4-1: HYDRO AND THERMAL STORAGE EXAMPLE

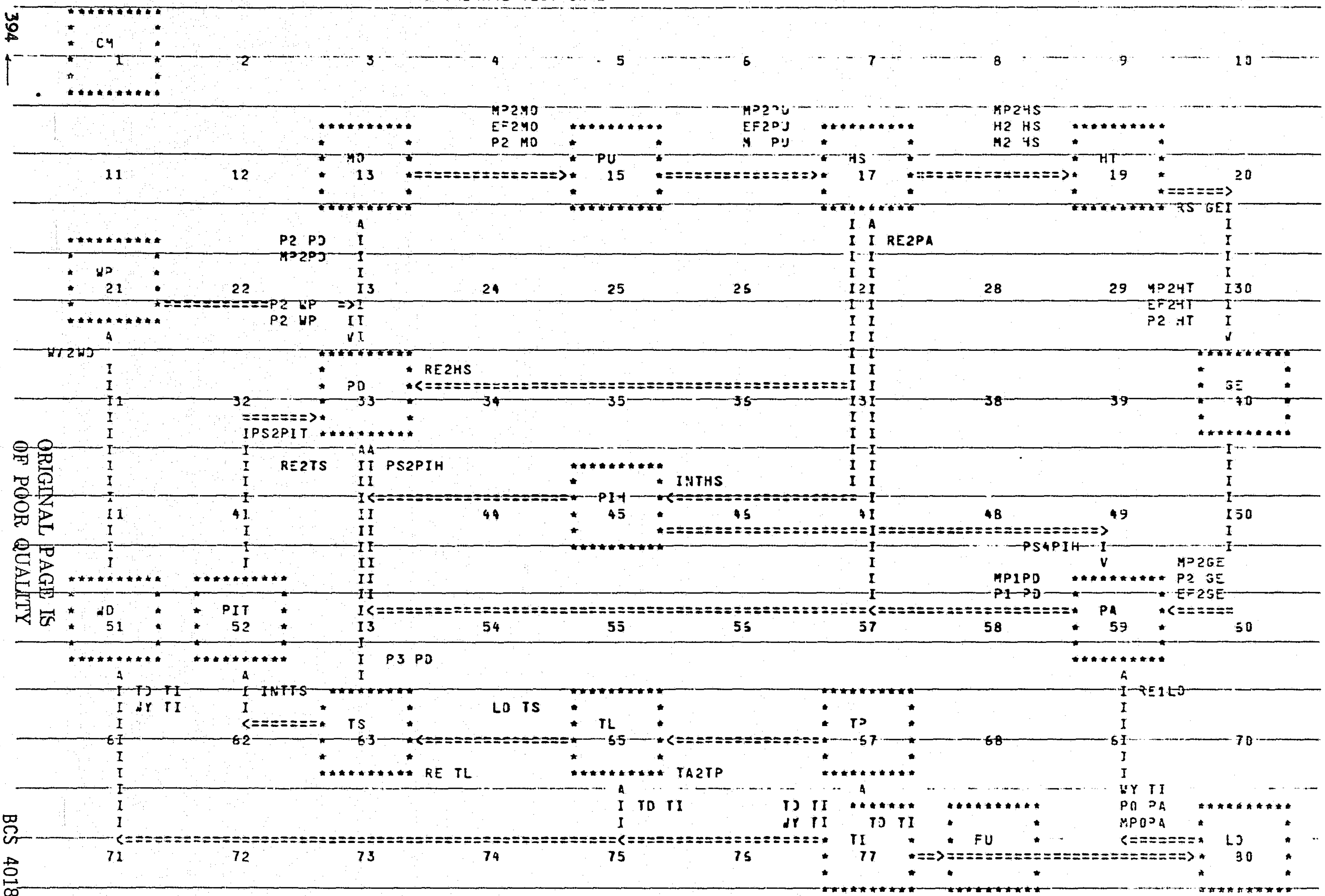

FIGURE 8.4-3 HYDRO AND THERMAL MODEL SCHEMATIC

```
PARAMETER VALUES
CYCLES=6.01,TO TI=0,V WP=400,WVOWP=8,WV1WP=60,DLINES=100.
CC WP=15000,CM WP=1200,PS1PIH=2.,EC WP=.2,CR CM=15,LE CM=30
H1 PU=200,AS HS=3600,MDRHS=80,MO HS=80000,CM HS=1000
H1 HS=200,MDEMS=400000,LE MS=30,F2 PD=.5,F3 PD=.5
RAPGE=200,RSYSE=3600,SR GE=.0333,CC GE=1000,CM GE=120
VC LO=.004,CT LO=4,MN LO=0,STDLO=5,AN FU=-1.
PSLPIT=2.,FS TS=10,VO TS=110,PD TS=100,LE TS=30,MFMTS=10000.
OH TS=.01465,TDETS=2,RS MO=1750,RAPMO=200,CC MO=500,CM MO=100
VE TL=.023,VC TL=40.,CT TP=12,MN TP=0,STDTP=5.
TABLE,PW WP=10
8,10,12,14,16,18,20,21.53,25,30
25.6,50.1,85.5,137.4,205.1,292.,400.6,500,782.8,800
TABLE,PY WD=13
0.,4.33,8.67,13.,17.33,21.67,26.,30.33,34.67,39.,43.33,47.67,52.
55,67,68,65,51,55,51,49,49,52,55,61,65
TABLE,PD WD=7
0,4,8,12,16,20,24
10,12,14,16,14,12,10
TABLE,DF WD=16
0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
5,44,160,380,480,512,440,376,307,270,148,76,40,22,9,3
TABLE,HT TS=4
.008879,.025431,.047371,.064072
90,147,147,204
TABLE,PD LD=17
0,1.5,3,4.5,6,7.5,9,10.5,12
13.5,15,16.5,18,19.5,21,22.5,24
450,360,372,330,450,660,810,798,804
590,708,699,702,750,708,570,450
TABLE,PW LD=7
1,2,3,4,5,6,7
1,1,.9,.9,.9,.6,.5
TABLE,PY LD=6
0,10,20,30,40,52
225,184,180,174,184,226
TABLE, FTAFJ = 6
0,5,10,18,22,24
.019,.019,.028,.028,.019,.019
TABLE,TLDTL=4
0,32,60,100
4.,2.,1.5,1.
TABLE,TWTTL=4
0,5,18,24
.4,1.,1.,.4
TABLE,PD TP=9
0,3,6,9,12,15,18,21,24
45,45,48,55,62,64,56,48,46
TABLE,PY TP=5
0,13,26,39,52
40,50,75,65,40
INITIAL CONDITIONS, MA HS=1600000,E  TS=600
PRINTER PLOTS,DISPLAY1
WVPWD,VS,TIME
P1 PD,VS,TIME
M  PU,VS,TIME
DISPLAY2
E  HS,VS,TIME


M2 HS,VS,TIME
REDHS,VS,TIME
DISPLAY3
PC LO,VS,TIME
P3 PD,VS,TIME
E  TS,VS,TIME
RELLO,VS,TIME
DISPLAY4
LD TS,VS,TIME
PC TL,VS,TIME
TA2TP,VS,TIME
FD FU,VS,TO TI
TINC=.50,TMAX=336.,PRATE=6,PRINT CONTROL=3,INT MODE=3,OUTRATE=4
TITLE = HYDRO AND THERMAL TEST
SIMULATE
```

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FIGURE 8.4-4 HYDRO AND THERMAL SIMULATION DATA much larger capacity and supplies a bigger load than the thermal system in this run. Figures 8.4-5 to 8.4-9 show results of the simulation. Hydro energy storage is shown in 8.4-5. During the week most of the wind energy goes directly to the load except at night. The reservoir builds up to capacity during the week-ends. The cumulative percent load delivered by wind and hydro storage is shown in 8.4-6, and averages about 91%. Similarly, thermal energy stored and percent thermal load delivered are shown in 8.4-7 and 8.4-8. The ambient temperature profile for a similar, one week simulation is shown in 8.4.9.

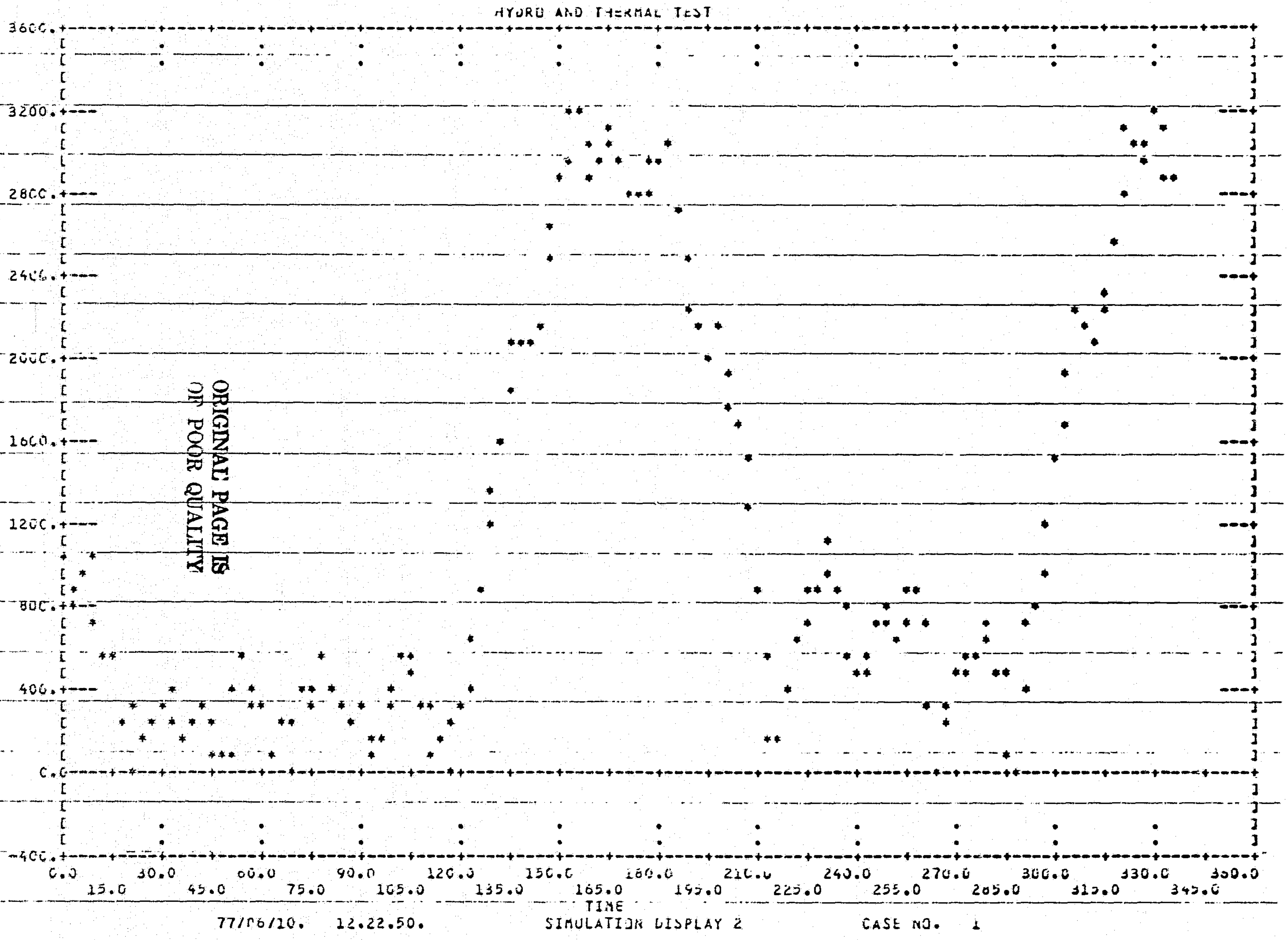

FIGURE 8.4-5 HYDRO RESERVOIR ENERGY STORAGE

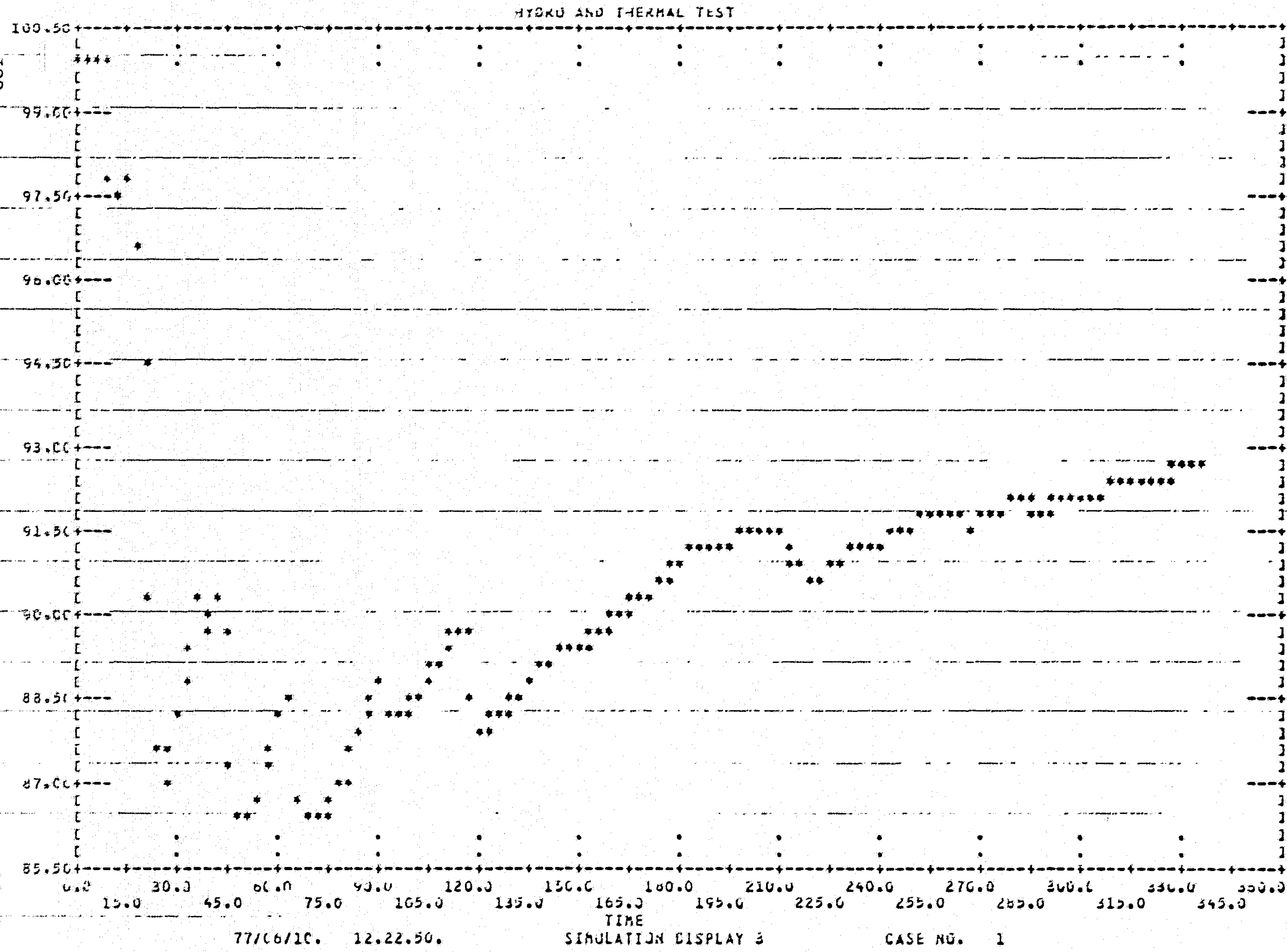

FIGURE 8.4-6 PERCENT CUMULATIVE LOAD DELIVERED

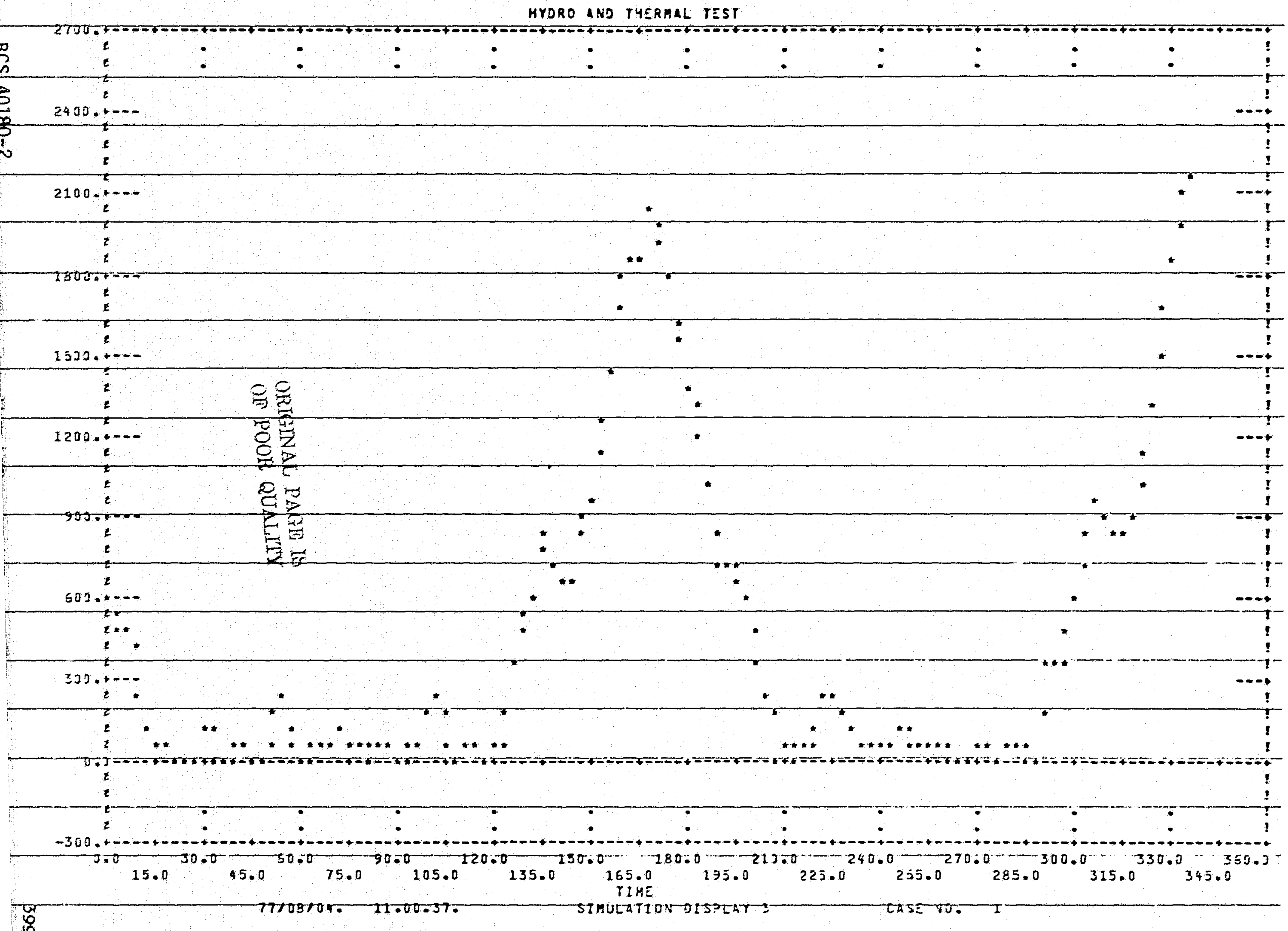

FIGURE 8.4-7 THERMAL ENERGY STORAGE

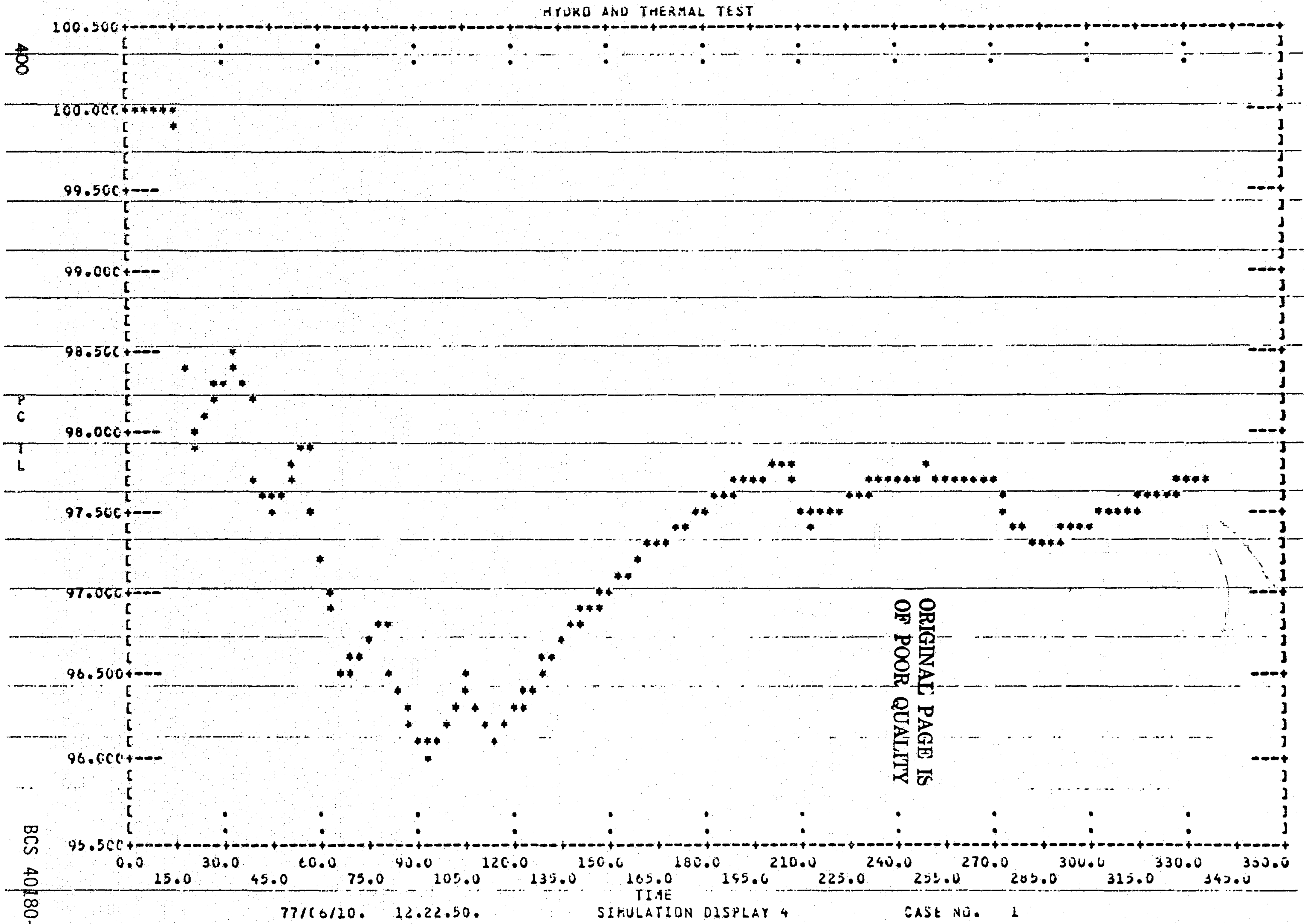

FIGURE 8.4-8 PERCENT CUMULATIVE THERMAL LOAD DELIVERED

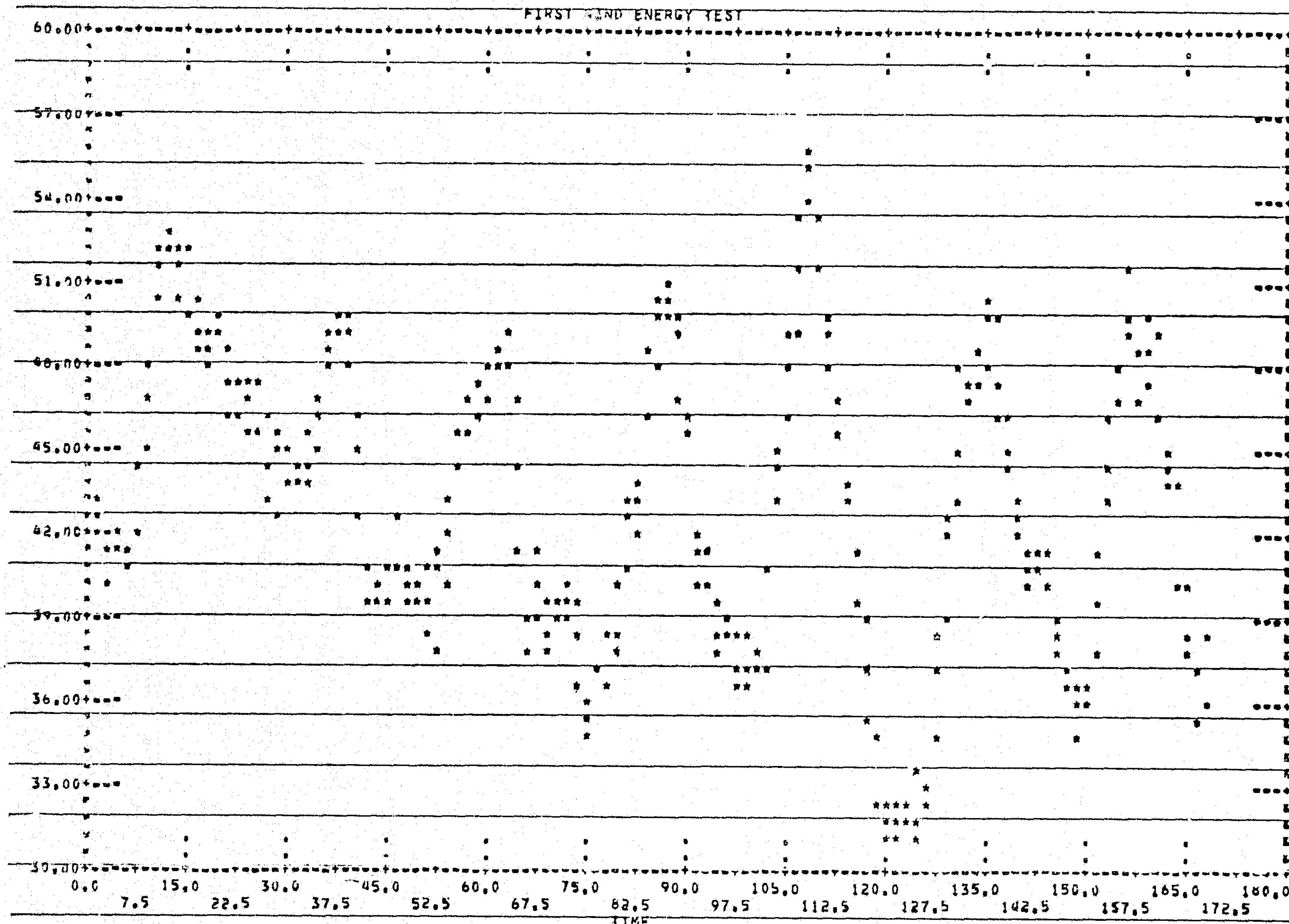

FIGURE 8.4-9 AMBIENT TEMPERATURE SIMULATION OVER ONE WEEK

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8.5 PNEUMATIC STORAGE MODEL

Figure 8.5-1 shows the simplified schematic for the pneumatic storage model. For simplicity the motor and generator have been omitted from the pneumatic storage subsystem. A burner is used if needed to heat the exiting air to the turbine. The heat exchanger has a phase change medium. Figure 8.5-2 shows the input data for this model.

```
MODEL DESCRIPTION        PNEUMATIC STORAGE TEST CASE
LOCATION= 1      TI
LOCATION=21      WD       INPUTS=TI
LOCATION=51      WP       INPUTS=WD
LOCATION= 5      TP       INPUTS=TI
LOCATION=43      PD       INPUTS=WP,WP(P=MP),PA(1,1),PI(2,2),CS(RE=RE,2)
LOCATION=64      UT       INPUTS=PD(SP=P)
LOCATION=15      CO       INPUTS=PD(2,1),TP
LOCATION=17      HX       INPUTS=CO,TP,CS
LOCATION=47      CS       INPUTS=HX,PA(RE,2=RE)
LOCATION=36      PI       INPUTS=CS
LOCATION=49      HY       INPUTS=CS,HX
LOCATION=59      BN       INPUTS=HY
LOCATION=80      TU       INPUTS=BN,TP,CS(PR=PS)
LOCATION=76      PA       INPUTS=TU(2,2),LO(1,0),PI(4,2),UT(2,3)
LOCATION=72      LO       INPUTS=TI
LOCATION=71      CM
END OF MODEL
LIST STANDARD COMPONENTS
PRINT
```

FIGURE 8.5-2 PNEUMATIC STORAGE MODEL INPUT DATA

The input data for a two week simulation is shown in 8.5-3. In order to keep the air entering the storage cavern from overheating, a fairly large leakage coefficient (NU = 0.01) is assumed. Hence the storage cavern loses about 2/3 of its heat energy every four days. The load constant NC LO can be adjusted to balance wind energy to the load so that weekly air mass flow in and out of the cavern is balanced. The initial values for the CS and HX states were chosen on the basis of an earlier one week simulation. Figures 8.5-4 to 8.5-8 show results of this simulation. Figure 8.5-4 shows the average temperature of the heat exchanger storage medium for the 'cool' cell. The initial

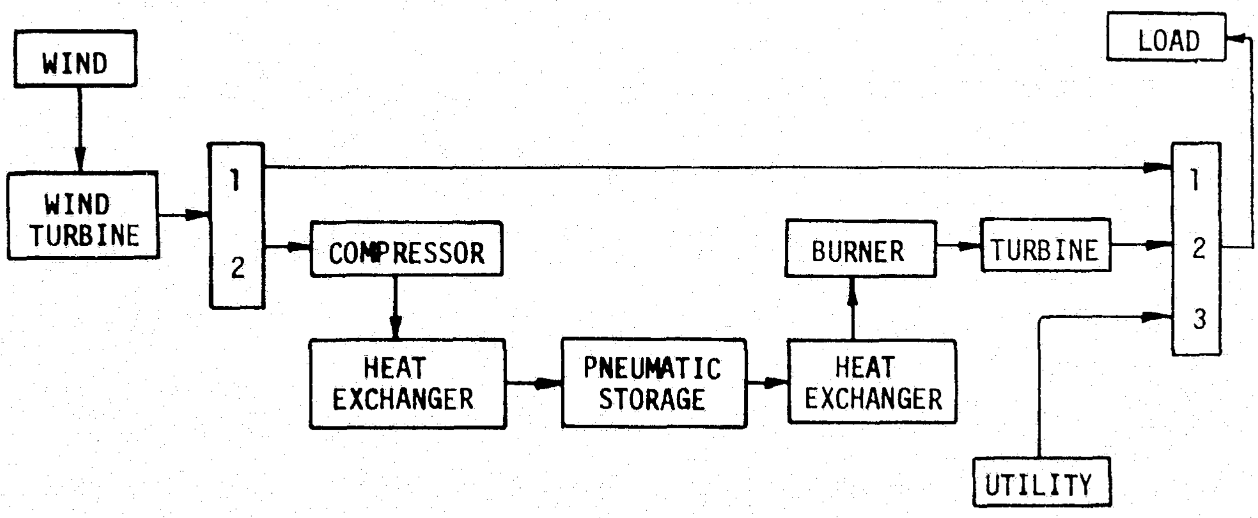

FIGURE 8.5-1: PNEUMATIC STORAGE EXAMPLE

```
TITLE= PNEUMATIC STORAGE TEST CASE2
PARAMETER VALUES
CYCLES=4.01,TO TI=0,CT TP=12,MN TP=0,STDTP=5,DLINES=100
V  WP=400,WVOWP=8,WV1WP=60,CC WP=16000,CM WP=1200,PS1PI=2.,EC WP=.2
LE CS=30,MDECS=10000,TEMCS=350,NU CS=.010,TM CS=125,BE HX=.001
MD CO=1500,T3 BN=600,LE BN=30,MDMBN=3000
ST HX=24,LE HX=30,PD HX=150,TMTHX=250,TEMHX=350,L  HX=8
MD CS=1500,TIDTU=600,RS TU=3600,CR CM=15,LE CM=30,CM CS=400
NC LO=.0043,CT LO=4,MN LO=0,STDLO=6,VE LO=.023
CB UT=.019,MP1UT=1.E8,CP UT=.023,CC UT=0,CM UT=0
TABLE,PW WP=10
8.10.12.14.16.18.20.21.23.26.30.
25.6,50.1,86.5,137.4,205.1,292.,400.6,500.,880.,880.
TABLE,PY WD=13
0.,4.33,8.67,13.,17.33,21.67,26.,30.33,34.67,39.,43.33,47.67,52.
65,67,68,65,61,56,51,49,49,52,56,61,65
TABLE,PD WD=7
0,4,8,12,16,20,24
10,12,14,16,14,12,10
TABLE,DF WD=16
0,1,2,3,4,5,6,7,8,9,10,11,12,13,14,15
5,44,160,380,480,512,440,376,307,270,148,76,40,22,9,3
TABLE,PD TP=9
0,3,6,9,12,15,18,21,24
46,45,48,55,62,62,56,48,46
TABLE,PY TP=5
0,13,26,39,52
40,50,75,65,40
TABLE,PD LD=17
0,1.5,3,4.5,6,7.5,9,10.5,12
13.5,15,16.5,18,19.5,21,22.5,24
450,360,372,330,450,660,810,798,804
690,708,699,702,750,708,570,450
TABLE,PW LD=7
1,2,3,4,5,6,7
1,1,.9,.9,.9,.6,.6
TABLE,PY LD=6
0,10,20,30,40,52
226,194,180,174,194,226
INITIAL CONDITIONS,E  CS=1250,MS CS=5.E5,EC1HX=1300,EC2HX=800
PRINTER PLOTS,DISPLAY1
M  CO,VS,TIME
T2 CO,VS,TIME
T2 HX,VS,TIME
TS1HX,VS,TIME
P2 UT,VS,TIME
DISPLAY2
E  CS,VS,TIME
MS CS,VS,TIME
T2 CS,VS,TIME
M2 HY,VS,TIME
T  HY,VS,TIME
DISPLAY3,P2 TU,VS,TIME,TS2HX,VS,TIME
TINC=.5,TMAX=336.,PRATE=6 ,PRINT CONTROL=3,INT MODE=3,OUTRATE=4
SIMULATE
```

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FIGURE 8.5-3 PNEUMATIC STORAGE SIMULATION DATA

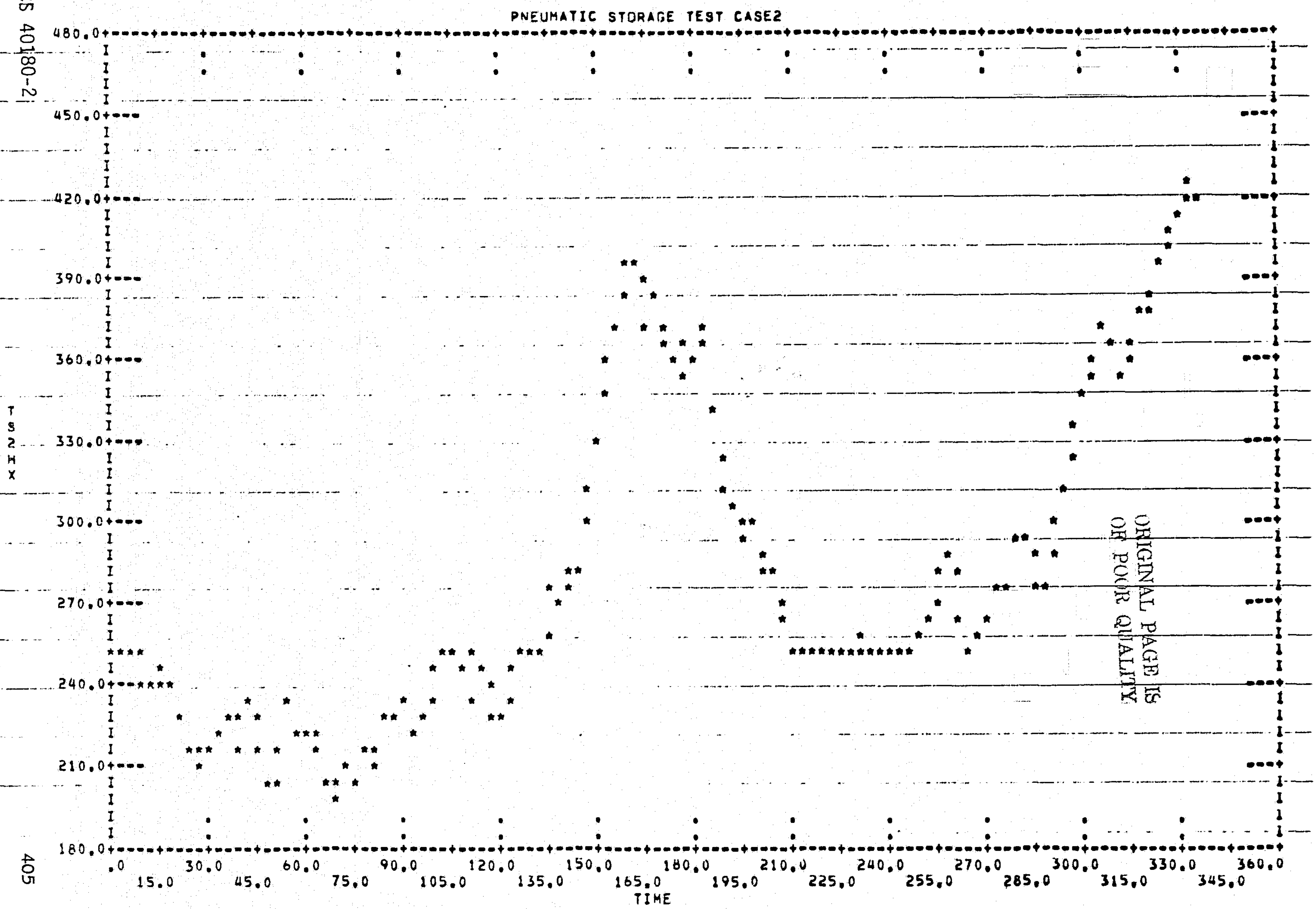

FIGURE 8.5-4 AVERAGE TEMPERATURE IN HEAT EXCHANGER CELL 2

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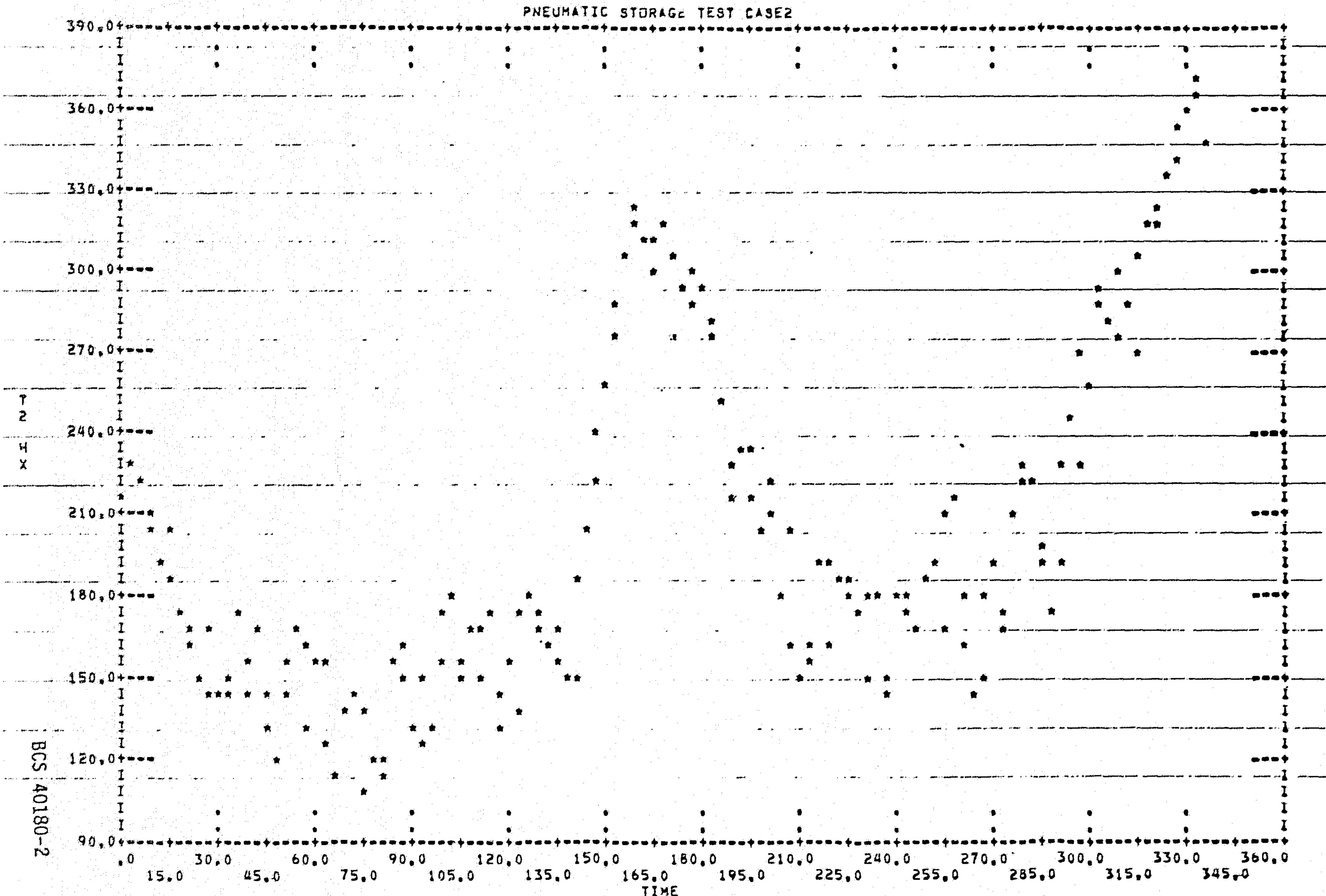

FIGURE 8.5-5 HEAT EXCHANGER OUTLET TEMPERATURE (CHARGING)

BCS 40180-2

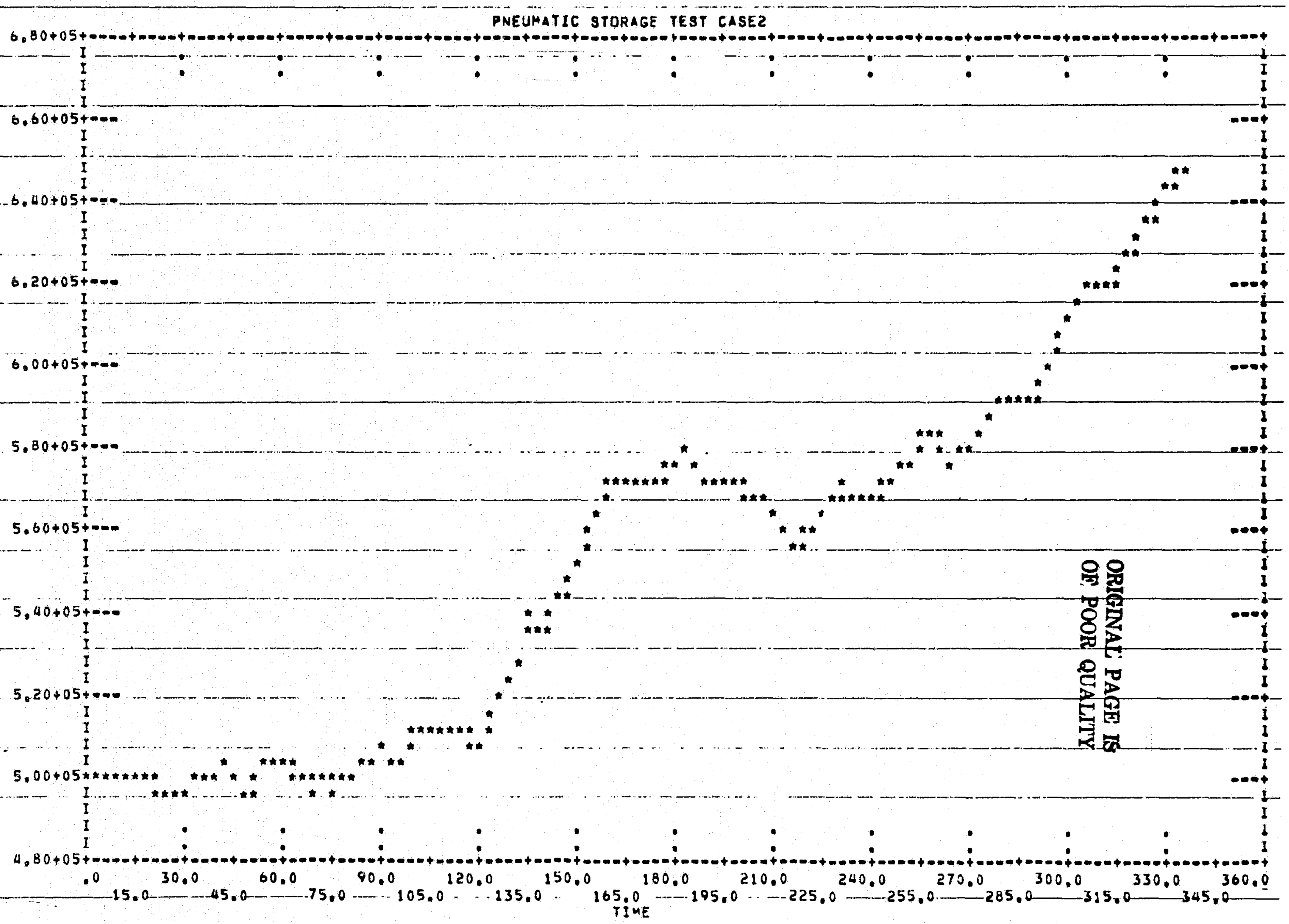

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FIGURE 8.5-6 AIR MASS IN PNEUMATIC STORAGE

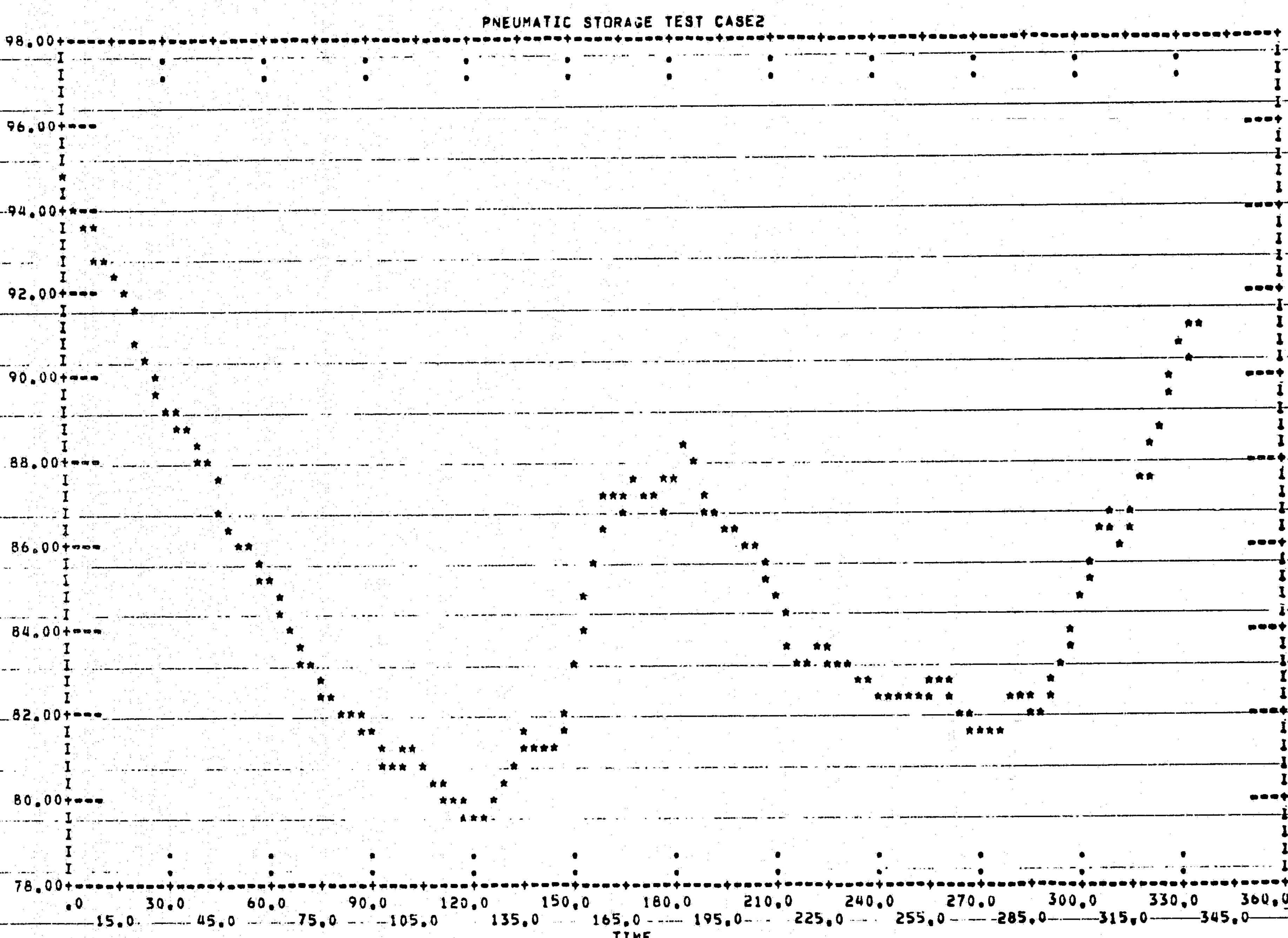

FIGURE 8.5-7 AIR MASS TEMPERATURE IN PNEUMATIC STORAGE VESSEL

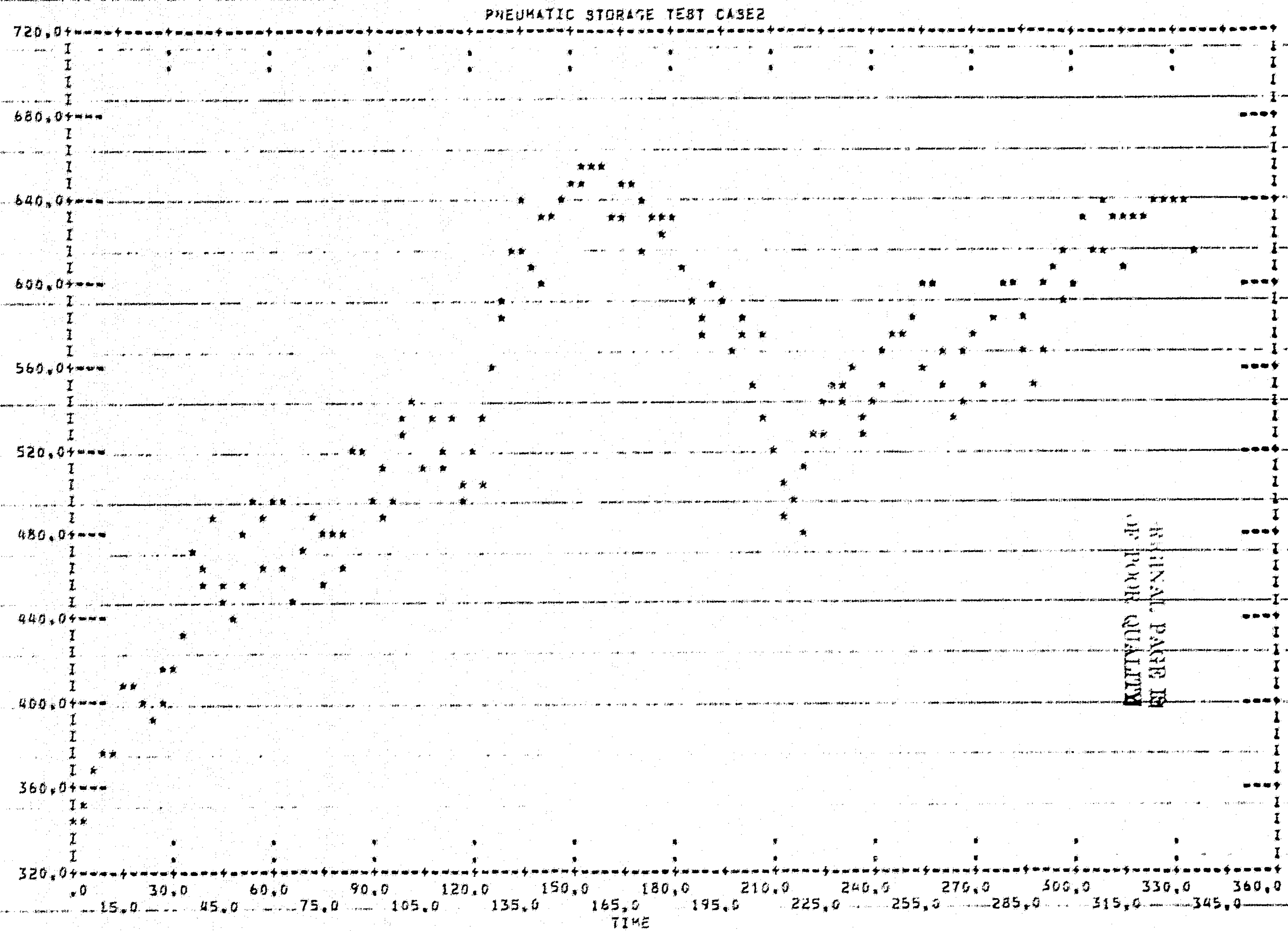

FIGURE 8.5-8 HEAT EXCHANGER OUTLET TEMPERATURE (DISCHARGING)

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temperature at the beginning of the week is a little too cool since the temperature rises to about 400° during the weekends. Phase change in this medium is indicated by the constant temperature intervals at 250°. Figure 8.5-5 shows the air temperature exiting from the heat exchanger into the cavern. During the week this temperature is generally held below 200° but may exceed 350° during the weekend. Figure 8.5-6 shows the air mass stored in the cavern. In this simulation wind power generated exceeded that of the load and thus there is a gradual buildup of air mass in the cavern. The temperature of the stored air mass is shown in Figure 8.5-7. There is about a 10° fluctuation in temperature each week in this case. The last figure, 8.5-8 shows the air temperature exiting from the heat exchanger to the burner. Neglecting the influence of the initial conditions, the average temperature is about 550° and thus a burner is probably not required for this system.

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