JREE: Vol. 10, No. 1, (Winter 2023) 43-58

Journal of Renewable
Energy and Environment

Journal Homepage: www.jree.ir

Materials and Energy
Research Center
MERC

Review Article

A Brief Overview of Microgrid Performance Improvements Using Distributed FACTS Devices

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PAPER INFO

Paper history:
Received: 26 December 2021
Revised in revised form: 28 February 2022
Scientific Accepted: 24 March 2022
Published: 27 August 2022

Keywords:
Microgrid,
Distributed Flexible AC Transmission System,
Performance,
Connection Mode

ABSTRACT

Distributed flexible ac transmission system (D-FACTS) is a light-weight version of FACTS, which it is easily allocated and costs less than flexible ac transmission system (FACTS) devices. They have potential benefits to improve the system stability and improvement in power quality in microgrid (MG). The integration of distributed energy sources, loads, electrical energy storage devices, and electronic power devices, as well as the operation of microgrids in connected or island-connected modes has expanded their use. It is a small main grid that can generate electricity when disconnected from the main network. In addition, microgrids reduce the high investment costs required to upgrade the network. The application of DFACTS devices for improving the microgrid operation has been investigated by some researches. This paper provides a review of impact and role of various DFACTS devices in the function of microgrids, which has been reported in recent years in various pieces of the literature. DFACTS devices with their properties are described. Finally, a useful reference and framework for the study is provided for future expansion of DFACTS devices so as to improve the performance of the microgrid.

https://doi.org/10.30501/jree.2022.321435.1305

1. INTRODUCTION

Power systems are generally centralized, consisting of large power plants, and power is transmitted to consumption through long-distance transmission lines [1-10]. The demand for clean and free-of-contamination electric power is increasing day by day with the ongoing developments and advances [11-14]. A microgrid (MG) is a controllable local electrical network that can work independently or collaboratively with other small networks [15, 16]. It is a complex non-linear system with inter-coupling of thermodynamics, chemical energy, and electrodynamics [17-22].

Many types of renewable energy resources are utilized as power generators in MGs [23-27]. Thus, an MG is able to reduce the loss of transmission to improve the efficiency of grids and resolve energy crisis [28, 29]. It must, also, be capable to power flow control and supervise energy storage [30, 31]. The ability to export to or import energy from the main network is a must [32-35].

An MG system consists of different power quality issues [36-38]. Power quality problems can also be very costly for both utility and the customer [39]. Frequency changes, voltage fluctuations, voltage distortions, flicker, and voltage disturbances reduce the quality of energy supplied to consumers in an MG [40-43]. Figure 1 shows the classification of power quality problems and their impacts on grid-connected MG systems [44, 45].

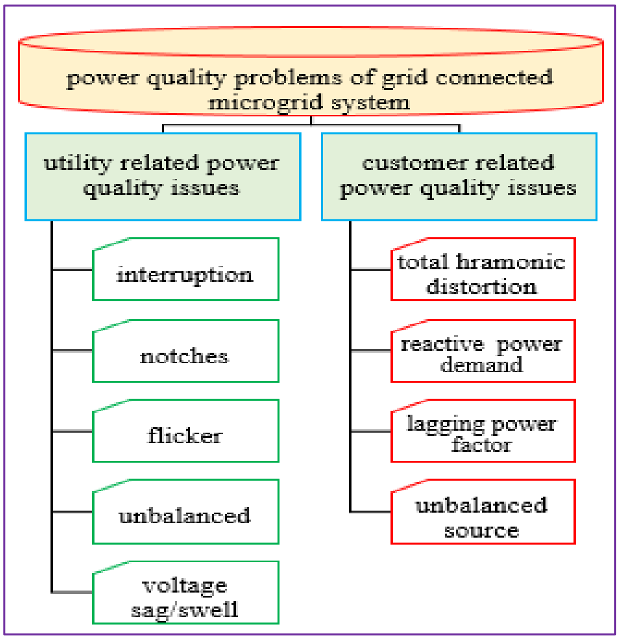

Figure 1. Power quality of MG system

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URL: https://www.jree.ir/article_155308.html

Please cite this article as: Shahgholian, Gh., "A brief overview of microgrid performance improvements using distributed FACTS devices", ***Journal of Renewable Energy and Environment (JREE)***, Vol. 10, No. 1, (2023), 43-58. (https://doi.org/10.30501/jree.2022.321435.1305).

1.1. Short summary of FACTS devices

FACTS devices are used in AC transmission networks to increase power transmission capability, stability, and control of networks [46, 47]. These devices are connected to the transmission system in terms of connection to four categories, according to Figure 2. The important advantages of FACTS controllers include the following: the ability to increase power transmission capability, restrict electricity to designated routes, improve transient and dynamic stability, reduce damping power system fluctuations, and adjust system voltage and flexible system operation with simple controls [48-60].

1.2. Importance of DFACTS devices

DFACTS device is used in distribution system, while FACTS device is used in transmission systems [61-67]. These devices are designed and installed to improve power quality anywhere in the power distribution system [68, 69]. DFACTS are used to improve the system stability and power quality improvement in MGs [70, 71].

Figure 3 shows a reduction in the MG power losses in the islanding mode due to the use of the DFACTS. The improvement in power factor values is shown in Figure 4. As can be seen, the power factor in heavy load has increased to 0.8 and at light load, the power factor has increased to unity [72].

1.3. Innovation and contributions

There are several papers results about DFACTS from various aspects of application in MG. This paper provides a comprehensive review of various DFACTS devices for performance improvement of MG that have been reported in the literature during recent years. The significance and the novelty of the work is as follows:

- Use of this paper review as an initial platform for research work on microgrids in industry.
- Review of DFACTS devices used by microgrids for enhancing power quality.
- Comprehensive review of DFACTS types.
- Review of the available types for application of different compensators.

1.4. Paper organization and structure

In Section 1, the whole subject of the study is mentioned. The structure and operation of an MG are investigated in Section 2. A classification of the most relevant MGs can be also found in this section. In Section 3, a brief overview of the application of DFACTS in power system is made, where the features and structure are stated. The effect of DFACTS on behavior of the MG is discussed in Section 4. Finally, the conclusion of the research is presented in Section 5.

2. CHARACTERISTICS OPERATING OF MICROGRID

MG is a controllable and independent power system, which is a localized group of distributed energy resources, loads, energy storage devices, inverters, and protection devices [73, 74]. Figure 5 depicts the typical structure of an MG. The MG connects to the network in a PCC whose aim is to maintain the same voltage as the main grid. It is characterized by a variety of parameters such as mode of operation, distribution system, source, scenario, and sizes, as shown in Figure 6 [75].

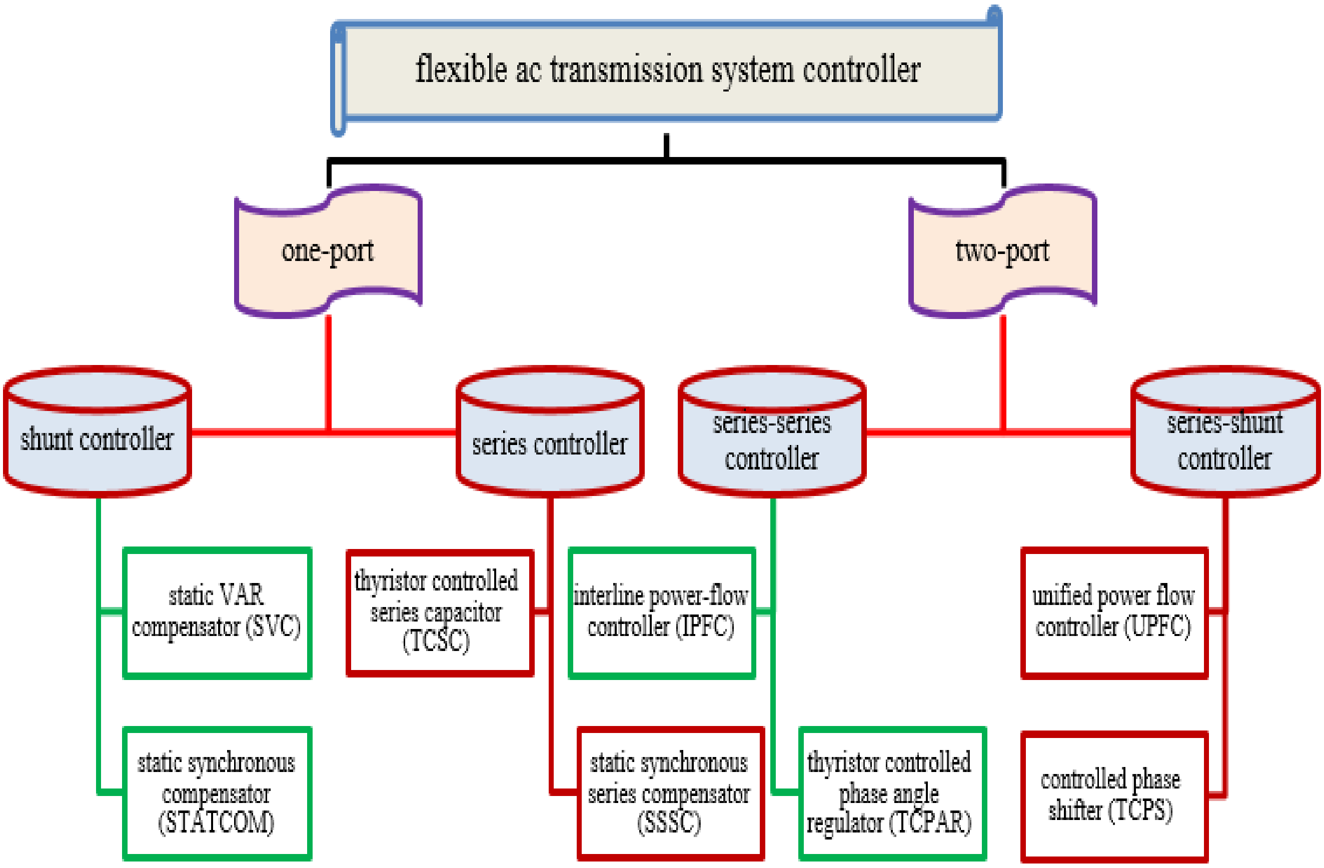

Figure 2. Classification of facade devices based on the type of connection

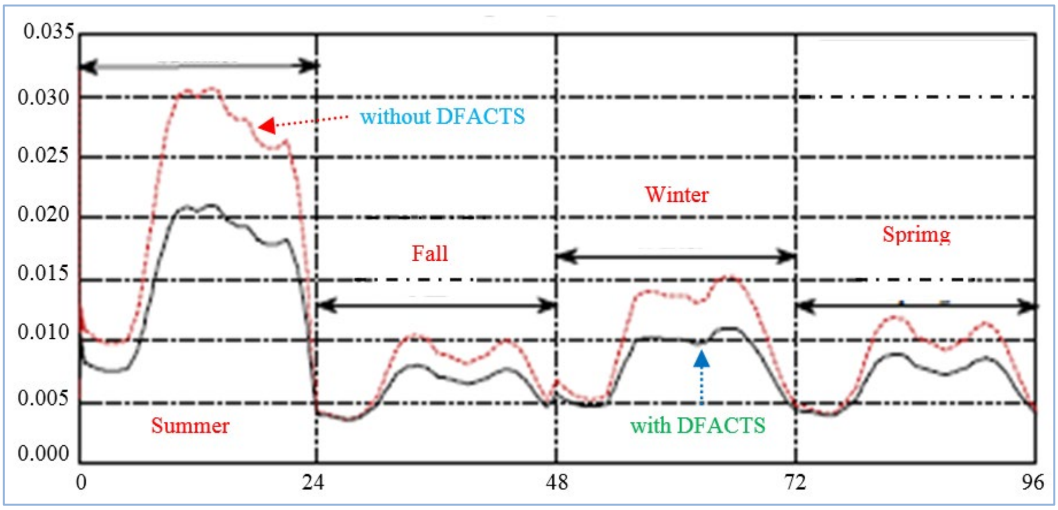

Figure 3. MG power loss profile

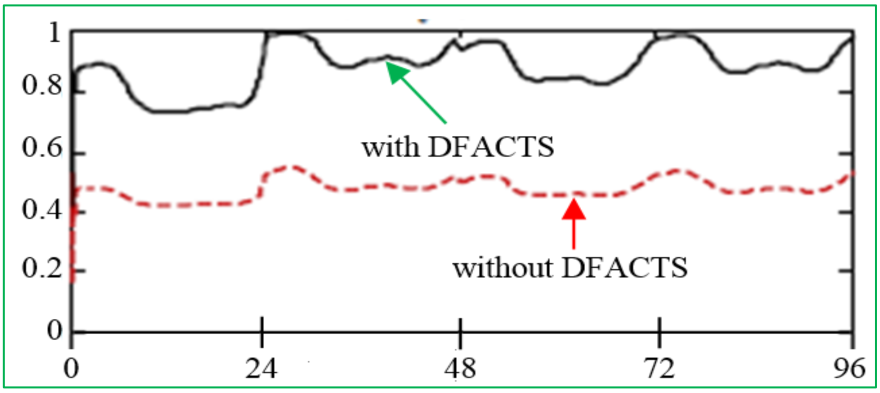

Figure 4. Power factor profile at the utility grid bus

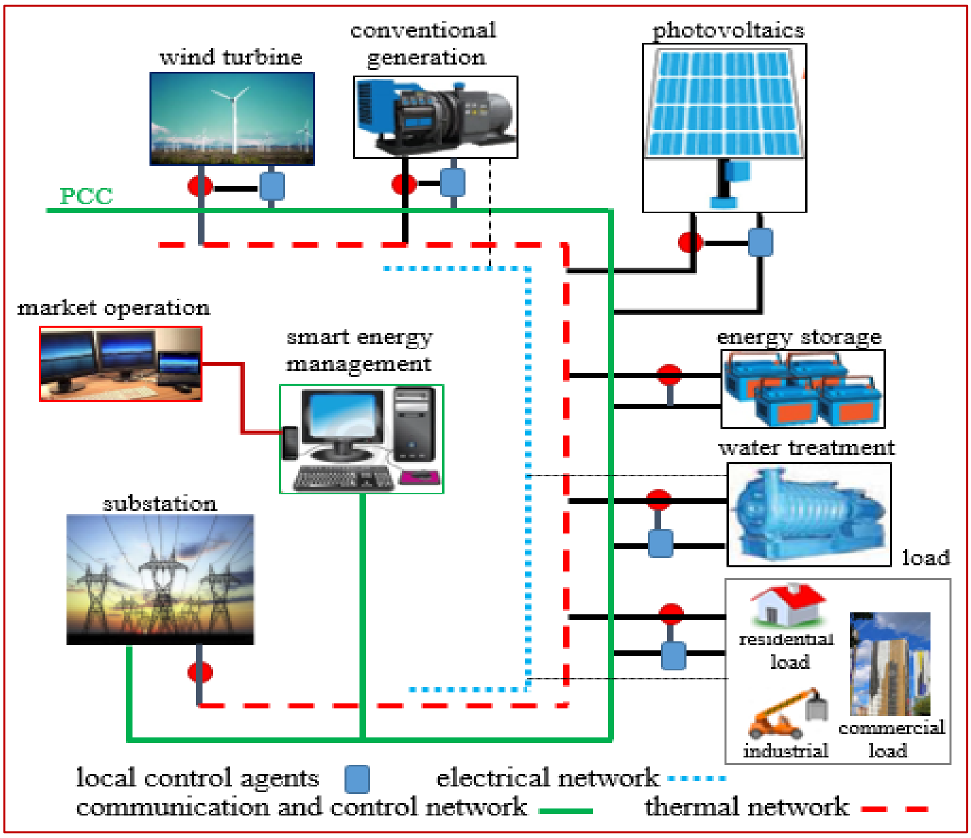

Figure 5. Microgrid architecture

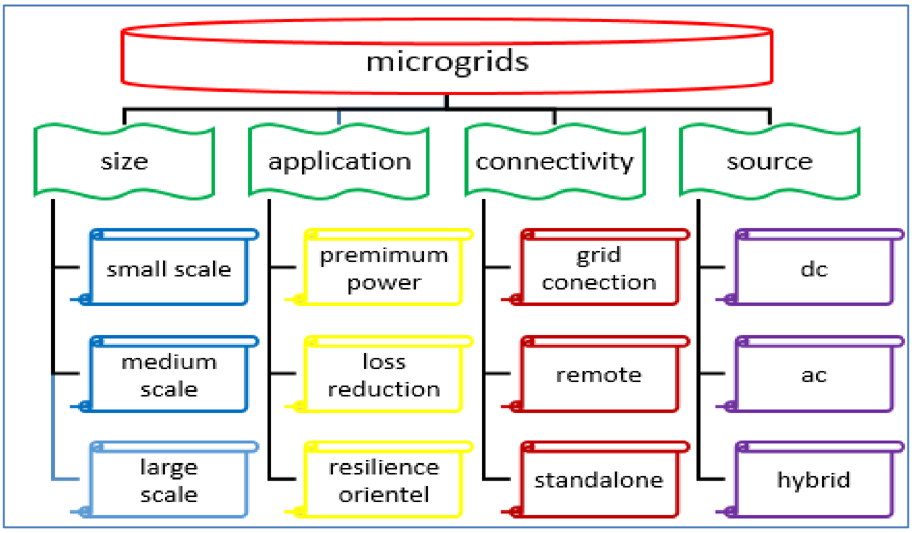

Figure 6. Microgrid types

This classification has been performed based on the studies found in the literature. MGs are classified based on location to remote MGs and urban MGs. MGs are divided into different types and classes in terms of their controlling topology [76]. With regard to power, the MG is classified as an ac power system [77], a dc power system [78, 79], or a hybrid system [80, 81] which reveal their advantages and disadvantages upon its application.

The operating modes for MGs are recognized and defined as follows: grid-connected mode, transition to island mode, island mode, and reconnection mode [82, 83]. Therefore, in the event of reduced power quality or network faults, microgrid increases the reliability of energy sources [84]. In the grid-connected mode, the power flow of MGs is bidirectional. While in the islanded mode, the power supply of MGs must meet the demand of load [85, 86]. Depending on their topology, MG control can be divided into three classes: simple (or virtual prime mover), master control (or physical prime mover), and peer-to-peer control (or distributed control).

3. OVERVIEW OF DFACTS DEVICES

The devices for improving the quality of power and reliability of supply can be divided into three categories: (a) passive mitigation devices such as transformers and rotating machine; (b) DC system; and (c) power-based electronics. DFACTS devices such as Unified Power Quality Compensator (UPQC) [87, 88], Distributed Power Flow Controller (DPFC) [89], Dynamic Voltage Restorer (DVR) [90-91], DSSC [92, 93], and DSTATCOM [94-96] have many potential benefits in a power system. They are applied to low-voltage distribution systems.

3.1. Introduction of DFACTS devices

DFACTS devices are divided into four categories based on the type of connection: series, shunt, series-shunt, and series-series. This section briefly explains the DFATCS types.

3.1.1. Unified power quality conditioner

UPQC is a major custom power device. It is a multifunction power conditioner [97, 98]. The UPQC power circuit consists of a common dc-link capacitor and two filters including a shunt active power filter and a series active power filter. One of the methods to compensate for various disturbances in the power system such as voltage disturbances in the power supply, correcting voltage fluctuations, and preventing the harmonic flow of load is the use of UPQC [99]. Schematic structure of the UPQC is shown in Figure 7. Several applications of UPQC in the power systems are listed in Table 1.

Table 1. Various applications of UPQC in the power system

Ref.	Subject	Suggested method	Contributions (Cause of use in power system)
[100]	Improvement of power quality	Adaptive frequency passiveness control	The application of UPQC to improve power quality in the manufacturing industry indicates that the adaptive frequency passiveness control method is used.
[101]	Effect mitigating of supply voltage sags	Power injection method	A UPQC-Q control structure is provided so as to achieve the minimum active power injection. Also, this method takes into consideration the limitations of the phase difference during voltage sag events.
[102]	Power quality enhancement	Adaptive JAYA algorithm	An online tuning method is adopted for PI control gains in PV-UPQC shunt and serial converter controllers. The JAYA adaptive algorithm has two independent objective functions.

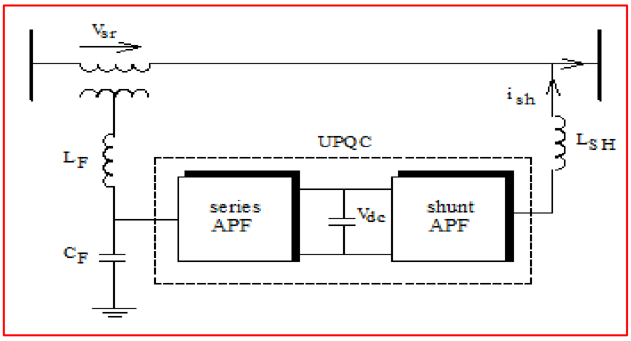

Figure 7. UPQC system configuration

3.1.2. Dynamic voltage restorer

The two main parts of DVR are the power circuit and control circuit. It is a series compensation device composed of an energy storage system with a dc link, a filter circuit, an inverter, and a series voltage injection transformer [103, 104]. A schematic diagram of the DVR is shown in Figure 8.

The coupling transformer is connected in series to the grid to correct the voltage disturbances during faulty grid conditions [105]. Several DVR applications in power systems are listed in Table 2.

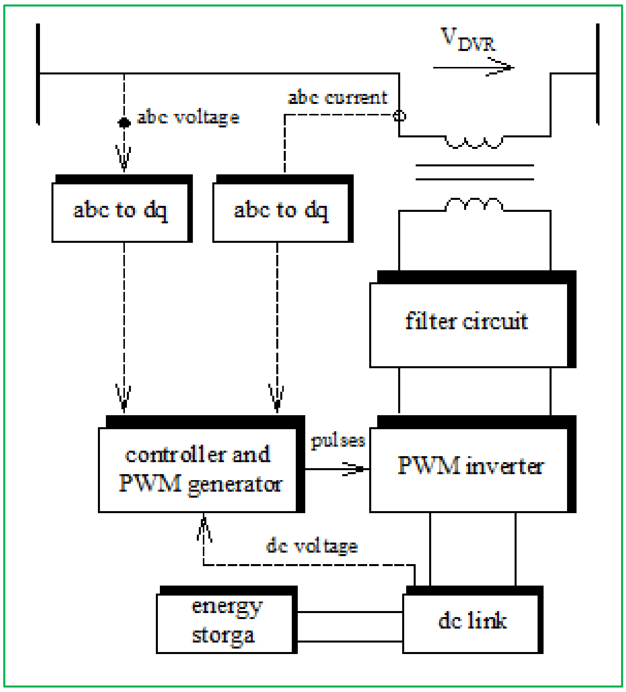

Figure 8. Schematic structure of the DVR compensator

Table 2. Various applications of DVR in the power system

Ref.	Subject	Suggested method	Contributions (Cause of use in power system)
[106]	Voltage droop compensation and automatic power recovery	Adaptive control	An improved control structure is proposed for sensitive loads to improve voltage quality using DVR during the voltage compensation stage and maximum active power absorption during the energy self-recovery stage.
[107]	Enhanced voltage sag compensation	Compensation of phase jump with minimum active power injection	An increased compensation method is proposed that reduces the load voltage phase jump while improving the overall bending compensation time.
[108]	Balanced voltage sag compensation	Discrete-time domain control	The proposed control strategy is implemented with two nested regulators in the synchronous reference frame.
[109]	Fault ride improve	Hybrid genetic algorithm optimized	Custom DVR enhances the regulation of network voltage in unusual conditions.

3.1.3. Distributed static series compensator

DSSC is a low power device that can act as a variable impedance [110]. It is connected in series providing active power flow control through transmission line [111]. DSSC structure is similar to Static Synchronous Series Compensator (SSSC) differentiating in power rating, but has the same capability as the SSSC. The distributed concept of the DSSC provides much lower cost and higher reliability than the SSSC [112, 113]. DSSC basic structure is shown in Figure 9. Several applications of DSSC in power systems are listed in Table 3.

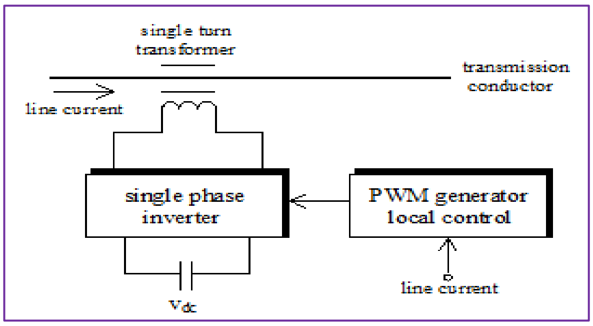

Figure 9. Schematic structure of the DSSC

Table 3. Various applications of DSSC in the power system

Ref.	Subject	Suggested method	Contributions (Cause of use in power system)
[114]	Loadability and reliability in power system	Flow model of DC load	The load flow model is used to find the optimal location for the DSSC and linear integer linear programming is used to solve the optimization problem.
[115]	Active power flow control	Line reactance changing	To achieve the desired flow controlled performance, the distribution of DSSC modules is used to operate by effectively changing the interface reaction.
[116]	Control of power flow in grid	Change the impedance of the line	DFACTS is proposed as an alternative approach to realize cost-effective energy flow control.

3.1.4. Distributed power flow controller

DPFC can be installed directly on the conductor. Using the control center located in the control post, the DPFC installed on the lines can be controlled. A DPFC controlled for operation is reactive voltage injection mode and series reactor mode. DPFC is derived from UPFC, which includes adjustment of line impedance, transmission angle, and bus voltage [117]. The converter inside the DPFC is independent and the required DC voltage is supplied by its own DC capacitor.

Figure 10 shows the schematic diagram of the DPFC. The DPFC consists of one shunt converter and several series converters [118]. Several applications of DPFC in power systems are listed in Table 4.

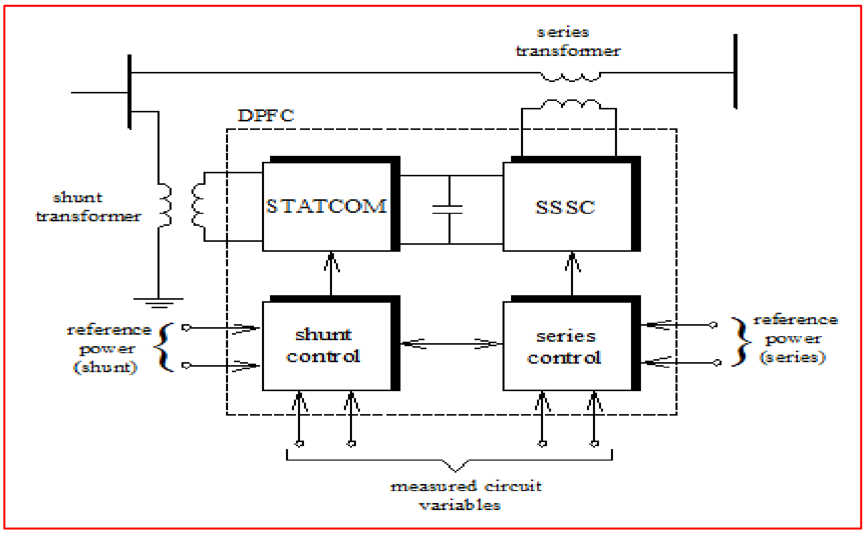

Figure 10. Schematic structure of the DPFC

Table 4. Various applications of DPFC in the power system

Ref.	Subject	Suggested method	Contributions (Cause of use in power system)
[119]	Improve power system stability	Optimization problem using PSO	An oscillation damping controller is designed for DPFC to damp LFOs, in which the optimal design problem is considered as an optimization problem.
[120]	Energy balance	Multi-objective coordinated control	A multi-objective coordinated control equation is proposed in which the equation minimizes the variance between the actual value of the control target and its given value to ensure that the DC capacitor voltage, both in the series and shunt side, is stable at target value.
[121]	Increase system loading capability	Linear programming of complex integers	An optimal DPFC configuration method is proposed to increase system load according to economic performance, in which DPFC investment and system loading behavior are analyzed and optimal solutions are used.

3.1.5. Distribution static synchronous compensator

DSTATCOM is a voltage source converter and is used as a shunt connection. This compensator is used to compensate for the bus voltage in distribution networks and it improves power factor and reactive power control [122, 123].

It works through exchanging the reactive power between the DSTATCOM and the power system [124]. DSTATCOM basic structure is shown in Figure 11. Several applications of DSTATCOM in power systems are listed in Table 5.

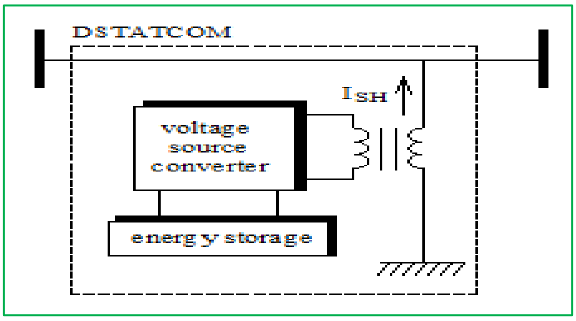

Figure 11. Schematic structure of the DSTATCOM

3.1.6. Solid-state circuit breaker

SSCB is a semiconductor-based protection device with no moving parts to cut off the fault current [129, 130]. Solid state circuit breakers are divided into two groups: hybrid circuit breaker and all SSCBs [131, 132]. The SSCBs solve the problem of slow reactive devices [133]. It is suitable for voltage systems at both high and low levels. A typical of the solid-state DC circuit breaker is shown in Figure 12 [134, 135]. Several applications of SSCB in power systems are listed in Table 6.

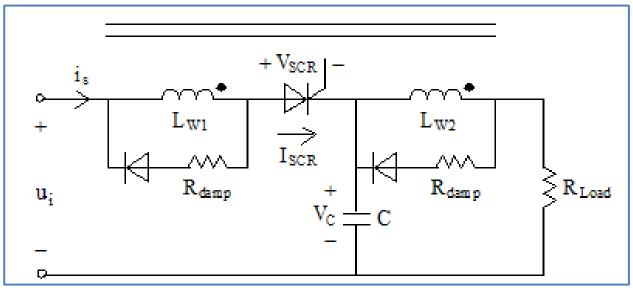

Figure 12. Schematic structure of the SSCB

Table 5. Various applications of DSTATCOM in the power system

Ref.	Subject	Suggested method	Contributions (Cause of use in power system)
[125]	Loss reduction and voltage profile	Direct load flow	A DG is placed optimally for reduction of losses in the network and under voltage at several buses is solved by the optimal placement of DSTATCOM.
[126]	Improve dynamic response and power quality	PSO-tuned PI controller	The PI controller set to PSO works better than the traditional PI controller set to the Ziegler-Nichols technique.
[127]	Power quality enhancement	Composite observer based control technique	This method is used to reduce reactive power, balance the load, and reduce harmonic distortion.
[128]	DSTATCOM nonlinear controller	Hybrid optimization	The basis of nonlinear control is partial feedback linearization, which is used to better regulate the DC capacitor voltage in DSTATCOM.

Table 6. Various applications of SSCB in the power system

Ref.	Subject	Suggested method	Contributions (Cause of use in power system)
[136]	Protection against short circuit	Switches design	Implemention of a simplified prototype of SSCB as a fault current limiter with DG is studied.
[137]	DC fault protection for modular multi-level	Advanced planning stage	The concept of protection for SSC and DC high voltage systems based on the overhead transmission is proposed and analysed.
[138]	Systematic evaluation of solid-state devices	Hybrid circuit breakers	Due to the simplicity of the control circuit and the switching resistance due to dv/dt, voltage controlled devices are selected.

3.2. Summary of the review study of DFACTS

Some of the available review studies on application of the DFACTS in power system are mentioned in Table 7.

Table 7. A review run on studies on different aspects of DFACTS

Ref.	Specifications (Summary of the review studies)
[139]	The impact of installing DFACTS devices by studying the linear sensitivities of power system quantities has been investigated.
[140]	Various conventional and adaptive algorithms used to control DFACTS devices for improvement of power quality in utility grids with renewable energy penetration are reviewed and discussed.
[141]	A survey on the optimal allocation of DSTATCOM in distribution networks is presented. Reducing power loss, reducing voltage deviation, improving reliability standards, and increasing voltage stability are some of the goals of using DFACTS.
[142]	For DVR with flywheel energy storage, input–output linearization ac voltage controller theory and performance are presented.
[143]	Various challenges related to SSCB design from the perspective of general applications and comparison of several SSB technologies based on key criteria are discussed.

4. LITERATURE REVIEW

Several researchers have studied the effect of DFACTS devices on the improvement the performance of MGs [144, 145]. In this section, upon reviewing the research, the application of each device in improving the performance of the MG is examined.

4.1. Improved MG performance

In this section, various indicators assocaited with MG performance improvement by DFACTS devices are mentioned.

4.1.1. Grid voltage disturbances

Grid voltage disturbances are the most common power quality problems in industrial distribution systems. The voltage disturbances of the network include voltage sags, swells, flicker, and harmonics.

At the moment of voltage droop, the rms value of the line voltage decreases, which lasts for a period of one half cycle of voltage up to 500 ms.

The objective of [146] is to investigate reactive power compensation in MG for voltage sag/swell mitigation using UPQC such that the MG is developed with two DGs units, a PV-cell and a wind generator, to give the output voltage equal to a typical 3-phase 4-wire distribution system.

To manage power quality in an MG, a DVR compensation strategy based on three basic strategies was presented in [147] and its method protects against sensitive voltage droops against main voltage droop with phase jump.

A DC microgrid-integrated DVR system to mitigate the grid voltage sag and swell was presented in [148]; compared to the conventional DVR designated by pure energy storage, the DC microgrid extends the DVR performance.

The utilization of the custom power device specifically DVR in mitigating the problem of voltage sags and swells occurring in MG was proposed in [149], in which the MG was modeled and simulated under different loading conditions causing power quality problems. Moreover, for the performance of DVR in overcoming the problems, reactive power compensation was analyzed.

The voltage profiles of the IEEE 69-buses without DSTATCOM and the multiple DSTATCOM effect under various load conditions are shown in Figures 13 and 14 [150].

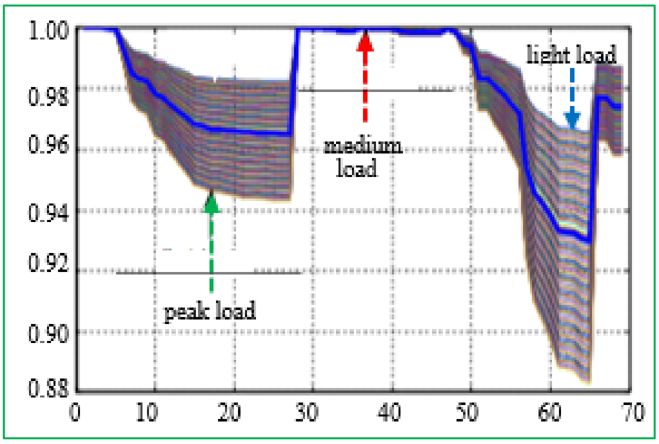

Figure 13. Voltage profile in system without DSTATCOM for different load variations

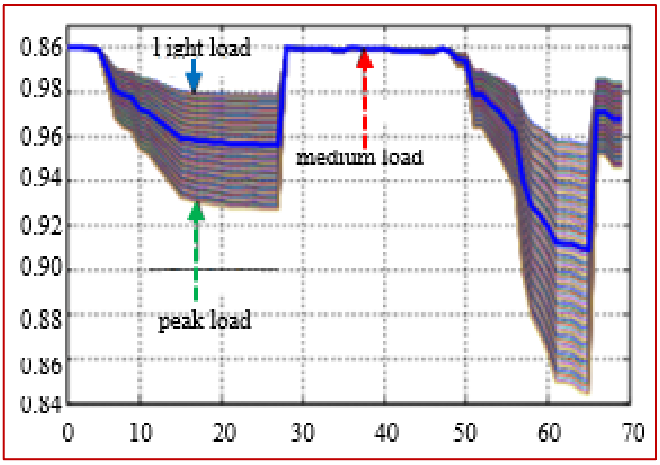

Figure 14. Voltage profile in system equipped with DSTATCOM for different load variations

The x-axis and the y-axis show voltage in perunit and bus number, respectively. As can be seen, the specifications of the distribution system have been improved using DSTATCOM. Figure 15 shows the reactive current variations through the distribution transformers of MG system with three DGs due to a fault at one of the busbars. Accordingly, the operation of DFACTS in MG1 and MG2 reduced the reactive current flowing out of MG3, which does not have a DFACTS connected mode.

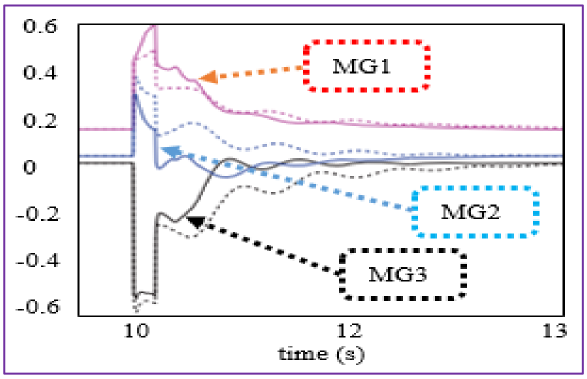

Figure 15. Reactive current variations with and without DSTATCOM

4.1.2. Improvement of Low-Voltage Ride-Through Capability

In a high-penetration MG under some minor or temporary faults, improved LVRT capability can help strengthen force support and reduce system instability [151]. The LVRT characteristics of MGs in different operating conditions were investigated in [152], in which the DSTATCOM at different locations of the MG was used to compensate for voltage droop to provide additional reactive power.

Various methods can be used to increase the LVRT capability of fixed-speed induction generator-based wind turbines, some of which were presented in [153], where DVR series connection and STATCOM shunt connection in simulation results had very efficient approaches to increasing LVRT capability.

DVR was used in between the source voltage and critical or sensitive load in the MG system to improve the LVRT capability in [154], where in case of using DVR, it usually requires the series transformer, energy storage system, and converter.

In order to increase the power quality and modify the ability of LVRT in a three-phase medium voltage network, the use of DVR was proposed in [155], where the network is connected to a hybrid distributed generation system and there are WTG, PV plants and sensitive load at the same PCC. A comparison between SFCL and DVR for LVRT improvement of an MG was presented in [156]; according to the demonstrated results, in power stabilization, SFCL exhibited better control effects. Figure 16 shows the frequency characteristics of the MG under the fault. As is seen, two devices can both mitigate the fault current from the microgrid to the PCC. Figure 17 shows the load power variation curves of the microgrid before and after the fault.

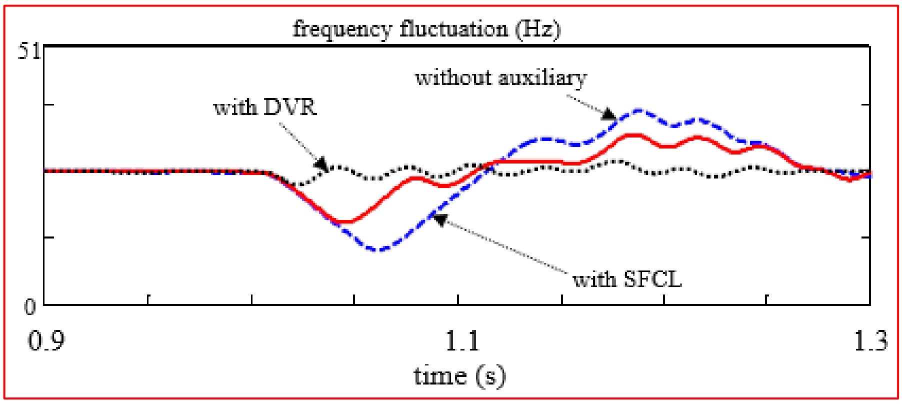

Figure 16. Frequency fluctuation in microgrids under the short-circuit fault

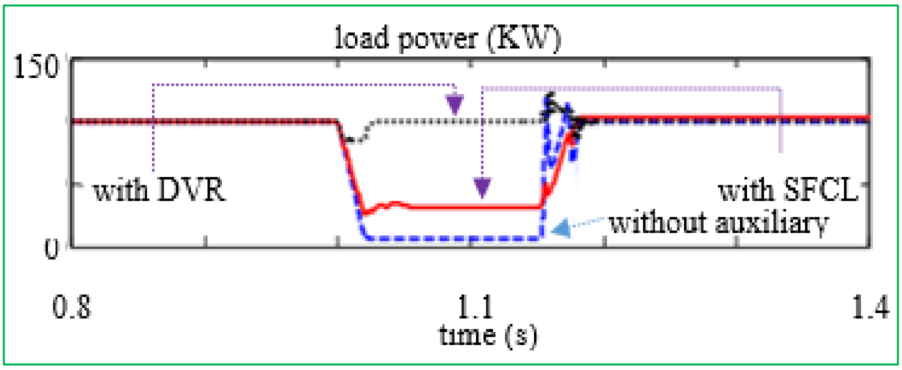

Figure 17. Load power in microgrids under the short-circuit fault

4.1.3. Power quality profile enhancement

When the microgrid is connected to the main grid, the impact of power quality issues is concerning and that can be a major issue for research. The major power quality problems are low power factor, high harmonic in distribution system, voltage flicker, active power and reactive power, increased reactive power required, and system voltage fluctuations [157].

In order to compensate for the power quality problems created in the system connected to the microgrid, the use of UPQC device was investigated in [158], where an ANFIS was used to increase the UPQC compensation capacity based on the voltage estimate of link DC and its voltage regulation.

For non-conventional sources based MGs, adaptive management of the voltage and reactive power required for them was presented in [159], where UPFC was used to investigate the hybrid MG and analysis of the test system and the tuned parameters of the PI controller of UPFC were with fuzzy.

An online method to adjust tracking of DSTATCOM set point in MGs by monitoring the PCC voltage and distributed resources currents was presented in [160], where online control of DSTATCOM was obtained through reinforcement learning algorithm. Based on the most modern power conditioning equipment such as UPQC in the microgrid energy system, the use of fuzzy logic method was proposed in [161] where the MG working in conjunction with this method was employed to track disruption in smart grids and improve system quality with high flexibility.

In order to improve the power quality and reduce fluctuations when changing the microgrid connection modes, UPQC was used in [162], where UPQC integration and control was done using the control method in distribution generation-based MG systems.

The performance of stand-alone hybrid renewable energy system was enhanced in [163] using an optimal PI controller of DVR. There are three energy sources in this hybrid system including wind turbines, fuel cells, and solar PV cells. In all the three sources, the voltage, current, and power waveforms were enhanced. Also, WTG dynamics improvement and continuous performance of three sources in fault conditions were achieved. This indicates an increase in system performance. Figures 18 and 19 show the current and rms voltage of the fuel cell, respectively, and illustrate the effect of DVR when a three-phase fault with a fault clearing time of 0.05 seconds is applied to the system. Fault clearing time ranges between 0.5 and 0.55 seconds.

4.1.4. Reliability enhancement

There are two types of objective functions used to solve the optimization problem: reliability indicators and system cost. Reliability enhancement is one of the benefits of MG system because it can work in grid-connected and islanding modes [164].

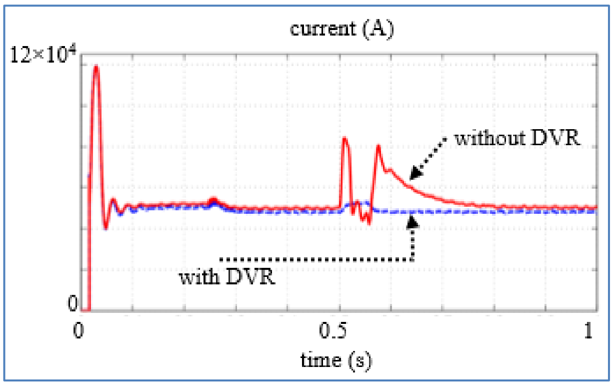

Figure 18. Influence of DVR on fuel cell output current at the three-phase fault

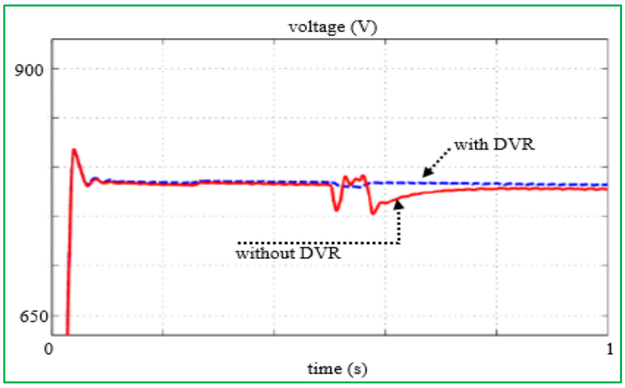

Figure 19. Influence of DVR on fuel cell output voltage at the three-phase fault

To improve the reliability and limit the fault current, a compensator was proposed as an interface between the main grid and the MG in [165]. To inject voltage when in the fault in the main network resurfaces in two different places, i.e., the main network and MG, the DVR is used to ensure normal operation.

A bidirectional dc SSCB to realize the bidirectional flow of energy was proposed in [166], which guaranteed higher dc MG operating efficiency.

4.1.5. Optimal scheduling

The goal of optimal scheduling is to optimize specific objective functions by planning the deployment of DGs, responsive loads, and power exchanges between the MG and the main network [167, 168].

Optimal scheduling of MG was presented in [169], where uncertain parameters for modeling based on a stochastic method include solar radiation, wind speed, and loads, and to transfer more power to the upstream grid, the compensator (DVR) is placed in line between the main grid and the microgrid.

To help the PV penetrate higher, a multi-objective method for programming microgrids was studied in [170]. In order to control the volt/var process, the existing control devices such as under-load tap changer and DSTATCOM were coordinated.

4.1.6. Dynamic stability

A number of approaches to enhancing microgrid stability exist: using different control methods, supplying the required reactive power, cutting off the load, and reducing its amount and distributed energy storage systems [171, 172]. Due to the weak inertia of the equivalent system, autonomous MG control and management is more difficult and requires public network support [173, 174].

An MG test system with DFACTS is considered to study the dynamic stability in [175] under various fault and load change conditions, in which the proposed method was given for control based on browser optimization and fuzzy logic.

The effect of an STATCOM on the frequency of islanded MGs based on frequency control using fuzzy cooperative control was investigated in [176], in which to achieve fast frequency control, instantaneous power balance between generation and consumption could be supplied through energy storage systems such as battery with a proper frequency control method.

An impact method to stabilize reactive power changes in islanded MGs was applied using advanced FACTS device and the UPFC connected to the MG was proposed in [177], leading to voltage instability control.

An SDTATCOM was presented in [178] to reduce the changes in the positive and negative sequence components of the main voltage and fundamental frequency. In this respect, the installation location of DSTATCOM in a low-voltage MG was discussed.

4.1.7. Short-circuit protection

Due to the development of commercially viable equipment with fast performance and the need for coordination and reliability, proper short-circuit protection in MGs is important.

A short-circuit protection methodology based on SSCBs that provides FCL in low-voltage dc MGs was evaluated in [179], where SSCB solutions based on IGCT were possible for low-voltage microgrids according to the simulation results in a simple dc MG system, but it is necessary to connect several devices in parallel to open fast-rising fault currents.

An improved topology of the SSCB in dc MG was proposed in [180]. To determine the position of the fault, it is able to inject the signal into the faulty line.

4.2. Review study of DFACTS in microgrid

Some of the available review studies on the application of the DFACTS for improving the performance in MGs are mentioned in Table 8.

Table 8. A review of studies on DFACTS in microgrids

Ref.	Research topic	Specifications (Summary of the review studies)
[181]	Protection dc microgrid	The benefits and shortfalls of the wide bandgap SSCBs and its application with PV generators were investigated.
[182]	Power quality improvement	The techniques commonly used for power quality enhancement of MGs were presented. Methodologies such as PSO, filters, controllers, compensators, and DFACTS devices were analyzed.
[183]	Improve stability and power quality	A number of DFACTS devices were reviewed in terms of function. DFACTS devices can contribute to building independent and high-quality microgrids along with stability and quality improvement.
[184]	Reactive power compensation methods	Challenges and issues related to power quality in the microgrid were investigated. Compensation methods were expressed using various control techniques, algorithms, and devices.

5. CONCLUSIONS

Microgrids have many advantages over conventional power grid networks. An MG reduces power losses in the distribution system and improves network power capacity and reliability. Also, it provides local support for voltage and frequency regulation. In this paper, several researches that are related to MG and DFACTS were studied and reviewed. To use the DFACTS devices, they were mounted on transmission towers or connected to conductors. They have been widely used in distribution systems to improve the system performance. They offer many potential benefits for MG operations. Further, this paper also throws light on the major role of DFACTS in microgrid performance, some of its limitations, and future prospects.

6. ACKNOWLEDGEMENT

The author would like to thank the respected journal executive, journal editor, and referees for making suggestions to improve the quality of the paper. This research has been conducted at the Smart Microgrid Research Center, Najafabad Branch, Islamic Azad University, Najafabad, Iran.

NOMENCLATURE

ANFIS	Adaptive Neuro Fuzzy Inference System
DFACTS	Distributed Flexible AC Transmission System
DG	Distributed Generator
DPFC	Distributed Power Flow Controller
DSSC	Distributed Static Series Compensator
DSTATCOM	Distribution Static Synchronous Compensator
DVR	Dynamic Voltage Restorer
FACTS	Flexible AC Transmission System
FCL	Fault-Current Limiting

HVDC	High-Voltage DC
IGCT	Integrated Gate-Commutated Thyristor
IGCT	Integrated Gate-Commutated Thyristor
LFO	Low Frequency Oscillation
LVRT	Low-Voltage Ride-Through
MG	Microgrid
PCC	Point of Common Coupling
PI controller	Proportional-Integral Controller
PSO	Particle Swarm Optimization
PV	Photovoltaic
SFCL	Superconducting Fault Current Limiter
SSCB	Solid-State Circuit Breaker
SSSC	Static Synchronous Series Compensator
UPQC	Unified Power Quality Compensator
WBG	Wide Bandgap
WTG	Wind Turbine Generator

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