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Review Article

The Impact of Integrating Multi-Microgrid System with FACTS Devices for Voltage Profile Enhancement and Real Power Loss Reduction in Power System: A Review

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ABSTRACT

Renewable energy is crucial for reducing emissions and meeting future energy demands. However, due to concerns regarding intermittent supply, integrating RE into a multi-microgrid system might pose various power system problems, for instance, unstable electrical power output. As a result, increased load reactive power demands result in voltage losses during peak load demand. Therefore, it can be minimized by utilizing Flexible Alternating Current Transmission System (FACTS) devices in electrical networks, which are designed to strengthen the stability and control of power transfer and act as a controller for the AC transmission specification, which also provides speed and flexibility for certain applications. By identifying the need to implement solutions that can sustain the electric power quality of a microgrid, this paper presents a review of various method approaches which could be used to evaluate the impact of integrating the multi-microgrid systems with FACTS devices for voltage profile improvement and real power loss reduction in power system. In this paper, a comprehensive study is carried out for optimum multi-microgrid placement, considering the minimization of power losses, enhancement of voltage stability, and improvement of the voltage profile. An attempt has been made to summarize the existing approaches and present a detailed discussion that can help the energy planners

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decide which objective and planning factors need more attention for optimum locations and capacity for multi-microgrid and FACTS devices.

Keywords: Flexible alternating current transmission system, multi-microgrid, power loss, renewable energy, voltage profile

INTRODUCTION

Decades ago, Malaysia had many natural resources used to generate electricity, despite being heavily dependent on imported coal and oil until impacts were seen on carbon emissions, thus leading to the greenhouse effect. In response to these environmental concerns, the government announced in 2015 to implement renewable sources to create a cleaner and more sustainable environment. Thus, Tenaga Nasional Berhad (TNB) is a well-known Malaysian utility company that runs smart grid projects involving large-scale distributed resources generations (DRGs) in Negeri Sembilan and Kedah (Zahurul et al., 2016). A smart grid (SG) system is an intelligent electrical network that operates inventively in coordinating and controlling all users' actions. This system ensures that power supply and demands are reliable, cost-effective, and stable.

With Malaysia's efforts in moving towards a smart grid system, the Energy Commission has initiated several programs in support of the National Green Technology Master Plan by introducing a 2000 MW Large Scale Solar Photovoltaic coupled with Net Energy Metering (NEM), which is capable of contributing a substantial amount of energy (Malaysia Energy Commission, 2018). Furthermore, in 2019, the government introduced the 10-year Generation Development Plans for Malaysia for the period 2020–2030, where the preferred RE is solar power (Peninsular Malaysia) and hydro (Sabah) to achieve 20% RE by 2025 and a 35% reduction in carbon emission intensity by 2030. Therefore, five companies have been awarded under the LSS scheme in balancing energy security and sustainability while encouraging and strengthening renewable energy in a 21st-century global challenge.

Over these last years, microgrids have gained growing significance and set a new economic model in electricity systems. The increased number of distributed generators is due to increasing load demand growth in the power system (Ackermann et al., 2001). Therefore, microgrid systems have already been introduced in other developed countries such as the USA, China, European Union, and Japan, where they can cope with an increase in electricity demands and saves non-renewable energy consumption, as well as help to prevent major blackouts, or during a power failure. However, the integration of renewable energy resources in microgrid systems can cause several power system problems due to intermittent supply issues. RE technologies in a microgrid, such as solar and wind energy, can cause unstable electrical power output, and the increased load reactive power demands result in voltage losses during peak load demand (Urquizo et al., 2018). These can be minimized by utilizing FACTS devices in electrical networks. FACTS devices are designed to strengthen the stability and control of power transfer and a controller in AC transmission that provides speed and flexibility for certain applications. However, a few barriers have been identified, including the formation of voltage unbalance, voltage sag and swell, power loss, and poor voltage regulation of the system due to the intermittent nature of the high penetration of renewable energy resources. By identifying the need to implement solutions that can sustain the electric power quality of microgrids, this paper presents a review of various improvement approaches that could enhance the stability and performance of multi-microgrid (MMG) systems with FACTS devices.

SMART GRID SYSTEM

A smart grid is a combination of digital and advanced technologies that allows bi-directional connection between utility and end-users in the same transmission lines and works to monitor, communicate and control the power generation in meeting the electric demands. They also can manage the needs of all generators, grid operators, energy market stakeholders, and end-users to maximize reliability, resilience, and stability while reducing costs and environmental implications. In addition, smart grids incorporate distributed and active resources into power networks and energy markets, such as generating, electric demands, storage, and electric vehicles. These general features of the smart grid system include renewable energy resources, plug-in electric vehicles, electric demand, and a control system, as shown in Figure 1.

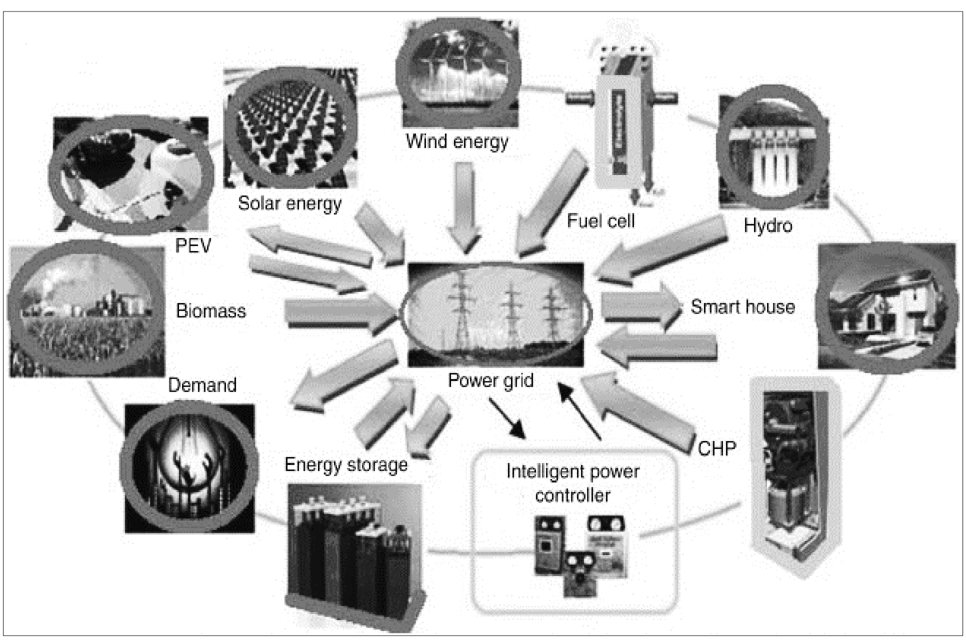

Figure 1. Smart grid system architecture (Funabashi, 2016)

MULTI-MICROGRID COMPONENT

In recent years, microgrid research has expanded dramatically due to the growing interest in microgrid deployment. Later, the idea of multi-microgrids (MMGs) was introduced, which connected several distributed generations (DGs) and loads that could enhance the system's performance and controllability (Haddadian & Noroozian, 2017). Multi-microgrid system comprises several adjacent microgrids with multiple types of distributed generations and loads, which have better performance and reliability in connected and islanded operations modes than a microgrid. The idea of the MMG was developed through the EU's "More Microgrid" program that was proposed in 2006 (Xu et al., 2018). It can be built at the medium-voltage (MV) level by connecting a few low-voltage (LV) microgrids and DG units directly to nearby MV-controlled loads (Vasiljevska et al., 2012). Multi-microgrid systems can be categorized into: alternating current (AC) multi-microgrids, direct current (DC) multi-microgrids, and AC-DC hybrid multi-microgrids. The AC multi-microgrids are conventional multi-microgrids consisting of distributed generations, energy storage systems, and loads connected to AC buses through converters without changing the original structure of the power grid, as shown in Figure 2 (Xu et al., 2018).

There are significant elements for microgrid operation, such as distributed generation, distributed storage, interconnection switches, and control systems. Distributed energy resources are small-scale energy resources that can be implemented at utility plants or house residences to provide local electricity supplies. Distributed generations include microturbines, fuel cells, wind, photovoltaic (PV), and reciprocating internal combustion engines with generators. Some DG needs power electronics to form one form to another by converting power. Distributed storage (DS) also connects the power and energy required in the microgrid. Several kinds of energy storage were used in the microgrid, including flywheels and batteries. A switch that connects the microgrid to the rest of the distribution system is interconnected. The microgrid control system is constructed to operate in grid-parallel and stand-alone modes. The MG control system focuses on the voltage and frequency when the grid is disconnected and provides the real-time power differences between generation and load, differentiating between the reactive power produced and the true power used by the load and protecting the inner of the microgrid (Kroposki et al., 2008). The main advantages of the microgrid are the reduced transmission losses by increasing stability and reliability and powering local loads to avoid any disturbance in the primary grid. Finally, it can enhance renewable energy resources integration such as solar, wind, and biomass.

Multi-Microgrid Controls

Figure 2 shows a multi-microgrid control architecture controlled by the remote terminal unit, with the central autonomous management controller (CAMC) placed at the MV level.

In this way, the system's complexity will be distributed among smaller individual control agents that act as a small distribution management system (DMS) capable of scheduling distributed generation and other control agents deployed under normal and critical events in the system. Apart from that, DMS is in charge of monitoring, controlling, and managing the distribution system. There are two management levels of central DMS where the central autonomous management controller will be installed, and which will accommodate a set of local capabilities assigned to the DMS at the HV/MV substation stage and liable to connect the DMS to lower agents. Furthermore, the microgrid central controller is assigned at the microgrid level for each MV/LV substation to administer the MG, which uses the MG communication infrastructure to control sources and responsive loads in each LV grid voltage monitoring (Lopes et al., 2013). The standard operating mode occurs when the multi-microgrid system is interconnected to the primary distribution grid. Meanwhile, the emergency operating mode is operated when the MMG is in an autonomous or islanded mode or following a power outage. When a black start procedure is triggered, the MMG system will be in restoration service.

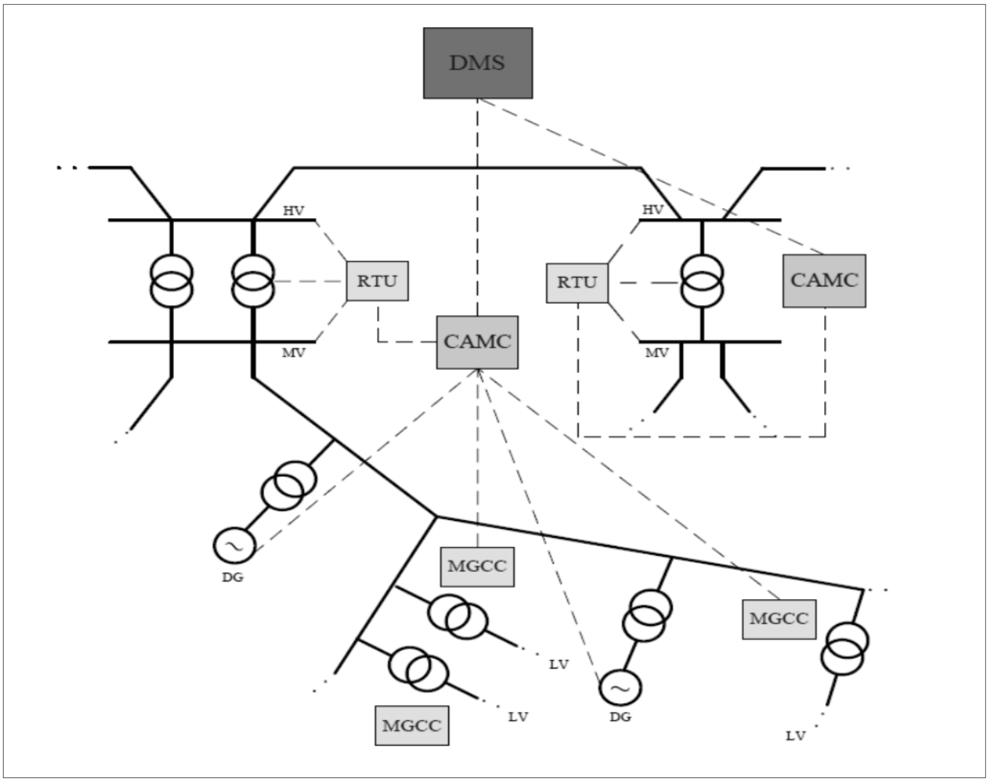

Figure 2. Multi-microgrid control architecture (Lopes et al., 2013)

FLEXIBLE AC TRANSMISSION SYSTEM DEVICES

FACTS technology is a power electronic controller containing some controllers. Researchers have proven the FACTS devices (Jordehi, 2015) to be a very efficient and viable way to deal with transmission systems. Meanwhile, a distribution flexible alternating current transmission system refers to a group of power electronic devices used in distribution networks and has the same benefits as FACTS technology. Hingorani introduced D-FACTS technology in 1985, strengthening and controlling the power system's stability. At the same time, the FACTS controller can improvise the characteristics of the power system and can also control the essential parameters in the transmission network, such as the transmission line power flow, voltage control, transient stability improvement, and oscillation damping (Urquizo et al., 2018). Research is done by Wang et al. (2012) also pointed out that advanced and flexible power electronics are one of the keys to providing a high-quality electricity supply to both customers and utilities, which are divided into three categories (series, shunt, and a combination of series and shunt) as shown in Table 1.

Table 1
Classification of the FACTS devices (Al Ahmad & Sirjani, 2019)

Configuration of FACTS devices	Flexible alternating current transmission system (FACTS devices)	
Shunt connection	SVC	Static var compensator
	TCR	Thyristor controlled reactor
	TSC	Thyristor switched capacitor
	TSR	Thyristor switched reactance
	STATCOM	Static synchronous compensator
Series connection	TCSC	Thyristor-controlled series compensator
	IPC	Interphase power controller
	TSSC	Thyristor switched series capacitor
	TCSR	Thyristor-controlled series reactor
	TCSC	Thyristor-controlled series capacitor
	TSSR	Thyristor switched series reactor
	TCVR	Thyristor-controlled voltage regulator
	SSSC	Static synchronous series compensator
Combination of series and shunt connections	TCPST	Thyristor-controlled phase shift transformer
	UPFC	Unified power flow controller
	IPFC	Interlink power flow controller
	GUPFC	Generalized unified power flow controller

Moreover, voltage stability in the electrical network may be affected by the loss of reactive power demand. Therefore, the characteristics of FACTS controllers can absorb or inject real power into the network and sustain voltage stability. Since the distribution system is usually exposed to power losses, it will produce other issues, such as excessive energy losses and transient and dynamic instabilities. Implementing FACTS devices leads to dynamic and transient stability improvement, increased power transfer capability in the transmission line, enhancement of voltage stability, voltage regulation, power factor correction, and power loss reduction (Chirantan et al., 2018).

IMPACT OF INTEGRATING MULTI-MICROGRID SYSTEM IN CURRENT DISTRIBUTION AND TRANSMISSION SYSTEM

Renewable energy (RE) is critical in reducing emissions and meeting future energy demands. Hence, configuration from the existing electricity networks with the integration of renewable resources has formed an intelligent grid system where the DGs play a significant part in the smart grid system. Since the traditional approach to energy management systems has steadily evolved, some of the networks' DGs have increased. Therefore, high penetration of RE sources in the network will increase the active load, such as storage and loads. Incorporating active power sources in DGs leads to a complex power network. Furthermore, as the generation of renewable sources is weather-dependent, it will indirectly impact power fluctuation, causing voltage instability, frequency deviation, and voltage flicker inside the network.

Furthermore, this problem has been overcome by utilizing energy storage devices, which can cost money to install and maintain. As the power fluctuation of MMG rises, the energy storage capacity of devices will increase. MMGs are usually placed near the demand side to avoid traveling long distances will be costly and inefficient transmission power due to transmission loss. Thus, integrating the MMGs into the transmission and distribution system will enhance the power system efficiency. In addition, MMG produces jobs in the local community while creating clean power generation. Similarly, MMG supplies power to remote and inaccessible areas to help remote populations build their economies. On the other hand, the impact of integrating MMGs is gaining greater attention in the smart home, where the house can send electricity to the grid if it generates greater than the demands. As a result, the homeowner can benefit from the profit generated by selling excess power to a utility provider like TNB. Furthermore, MMG has a shorter installation time and faster reaction than a centralized power plant, which takes longer to set up and provide electricity for additional demand. In extreme weather circumstances like natural disasters, human error, or terrorism, integrating MMG increases energy security over centralized power plants.

Subsequently, the centralized power plants will probably collapse, resulting in a massive power cut affecting residential areas and commercial industries. As a result, all developed nations have improved their supply reliability and power management, with grid systems operated by independent utilities that allow for effortless power, frequency, and voltage maintenance. Furthermore, it also includes utilizing power storage and control systems to reduce obstruction. Besides, the smart grid may accommodate a high RE capacity, decreasing global dependence on fossil fuels and minimizing greenhouse gas emissions. In the meantime, engineers have faced challenges integrating MMGs into an existing power system. Therefore, MMGs are an essential element of a smart grid, an initiative to move toward an intelligent grid system. Albeit issues and challenges, such as an intermittent supply due to high penetration of RE, can be reduced by determining the best location and capacity of FACTS controller proposed in previous literature. Therefore, introducing FACTS devices into a power system might help solve problems such as increasing power transfer capability in the transmission line, enhancing voltage stability, and reducing power losses caused by integrating a multi-microgrid system.

TECHNIQUES FOR OPTIMAL FACTS DEVICE'S LOCATION AND SIZING IN OPTIMIZING MULTI-MICROGRID PERFORMANCE

Researchers are working on various ways to improve performance in multi-microgrids. Optimization problems in electrical systems are popular for power researchers, especially with microgrid integration. Various optimization methods have been proposed in previous studies to highlight the success rate of the proposed approach in recent years. However, the most optimized methods require extremely high computing resources for large problems relevant to power systems. All existing methods used in the previous study to determine the optimal location and sizing of FACTS devices can be categorized into four groups*:* (1) analytical approaches, (2) conventional approaches, (3) meta-heuristic approaches, and (4) hybrid approaches (Ismail et al., 2020).

Analytical approaches or sensitive-based approaches utilize mathematical formulation. Conventional approaches are also known as traditional methods that generally start with randomly determining an initial solution and achieving the optimal solution in every solution such as Newton-Raphson (NR), linear programming, nonlinear programming, sequential quadratic programming, dynamic programming, and many more (Ismail et al., 2020). Numerous metaheuristic optimization algorithms have been developed and used in power systems. These techniques are categorized based on the source of inspiration, including evolutionary phenomena, collective animal behavior (swarm techniques), physical rules, or human-related concepts. Furthermore, hybrid-based approaches are combined with existing techniques such as analytical-metaheuristic approaches, traditional-metaheuristic approaches, and metaheuristic-metaheuristic approaches to create hybrid-based approaches. This approach is also known as the two-stage approach, which helps reduce the proposed methods' search space and shows the simpler structure of algorithms that requires less computation time to solve the optimization problems (Ismail et al., 2020). Table 2 lists the summary of the previous research. Based on Table 2 was assessed through the type of optimization, aims, methods, and indices used for DG and FACTS device integration, benchmark test systems, and case studies.

Yenealem et al. (2019) presented the MG integration, including FACTS devices, using the Newton Raphson (N-R) method to obtain the candidate bus for the MG, STATCOM, and UPFC integration to increase the voltage profile and reduce power losses. However, the MG integrations with STATCOM and UPFC were tested on the IEEE 30 bus system. Furthermore, this study case was compared based on the MG and FACTS device integrations. Based on the findings, the MG system was placed on the weakest bus, Bus 30, and it was observed that voltage fluctuation and high-power losses were further improved. It is observed that in MG integration, the real power loss is further increased. Hence, UPFC was introduced to reduce the real power loss. In Rao and Rao (2017), the author used a two-stage algorithm where in the first stage of the algorithm, the loss sensitivity analysis was adopted to determine the optimum placement for the STATCOM. Next, in the second stage, the parameter setup of STATCOM, the voltage magnitude, and the phase angle have been considered using the N-R power flow technique to reduce power loss and improve the voltage profile. The study was done in IEEE 14 bus test system, and the results were obtained by comparing the power losses before and after STATCOM was integrated.

According to the study presented (Sirjani, 2018), the optimal location and sizing of PV-STATCOM were determined using adaptive particle swarm optimization and power loss index to minimize cost and voltage profile improvement and reduced power loss by considering the real power loss, voltage deviation investment cost, where the constraints for solving the optimization problem are power flow balance, size limit, and bus voltage limits. The case study was tested in the Northern Cyprus electrical transmission system, and the results were obtained by comparing it with three algorithms: lightning search algorithm (LSA), bee colony optimization (BCO), and adaptive particle swarm optimization (APSO). The results show that APSO offers a further reduction in real power loss with the fastest computational time compared to other algorithms. Next, the mixed-integer nonlinear programming (MINLP) was used to find the best placement and sizing of the PV and microturbine with STATCOM, as presented in Luo et al. (2018), in order to reduce annual cost, enhance voltage profile, and reduce power loss considering the power flow equation, voltage limit, branch current limit, DG size constraints, and PV power factor. It was tested in the IEEE 33-bus system and was analyzed using DG and FACTS integration. The results prove that integrated PV solar farms with STATCOM can reduce voltage recovery time and voltage sag depth during an emergency. Also, PV-STATCOM has a high economic value, an improved voltage profile, and reduced power losses. The idea of improving multi-MGs' performance by incorporating IPFC was proposed as a

Table 2

Taxonomy of studies on optimal placement and sizing of DG and FACTS devices

Reference	Optimization Type	Objectives	Method/ Techniques	Index	Type of DG	Type of FACTS	IEEE test system	Case study
Yenealem et al. (2019	Location	Voltage Profile, Power Losses	Analytical approach	PLF	PV, Wind	UPFC, STATCOM	30-bus	DG and FACTS integration
Gerbex et al. (2001)	Location	System Loadability, Power Losses, Voltage Profile	GA	PLF	PV	TCSC, TCPST, TCVR, SVC	118-bus	Comparative studies using FACTS integration.
Rao and Rao (2017)	Location	Power Losses, Voltage Profile, Power Flow	Analytical Approach	LSF	PV	STATCOM	14-bus	FACTS integration
Sirjani (2018)	Location, Sizing	Power Losses, Voltage Profile, Cost Minimization	APSO	PLI	PV	STATCOM	30-bus 57-bus	DG and FACTS integration
Luo et al. (2018)	Location, Sizing	Total Annual Cost, Voltage Profile, Power Losses	Mixed integer nonlinear programming (MINLP)	WVSAI	PV Micro-Turbine	STATCOM	33-bus	Comparative studies using DG integration.
Kargarian et al. (2012)	Location, Sizing	Power Losses, Voltage Profile, MMG Operating Cost	MOPF	SI	PV	IPFC	33-bus 69-bus	FACTS integration
Yenealem et al. (2020)	Location	Power Losses, Voltage Profile, Power Flow	Fuzzy Logic	CPF	PV, WT	STATCOM	33-bus 69-bus	FACTS integration
Selim et al. (2019)	Location, Sizing	Total Losses, oltage Profile	Hybrid analytical-metaheuristic (sine-cosine algorithm)	VSI	PV, WT BESS	DSTATCOM	12-bus 69-bus	Comparative studies using other analytical and metaheuristic methods.
Iqbal et al. (2018)	Location	Power Losses	Analytical Approach	PLF, LSF, VD	PV, WT Biomass	DSTATCOM	33-bus	Comparative studies using DG and DSTATCOM integration.
Relic et al. (2020)	Location	Real Power Losses, Voltage Profile, and ROI	Conventional approach	NR	PV, WT Micro-hydroelectric	SVC	20 kV rural DN	Comparative studies using SVC integration.

Table 2 *(Continue)*

Reference	Optimization Type	Objectives	Method/ Techniques	Index	Type of DG	Type of FACTS	IEEE test system	Case study
Sannigrahi et al. (2019)	Location	Total Losses, Voltage Profile	Analytical approach	VSI, VPII	PV, WT	DSTATCOM	33-bus 69-bus	DG and FACTS integration
Magham et al. (2012)	Location	Transmission Losses, Voltage Profile	GA	PLF	PV	SVC	2500 kVA DN	Comparative using different times of a day
Ghatak et al. (2018)	Location	Voltage Profile, Benefit Cost Ratio, and Emission Cost Benefit	Particle swarm optimization (PSO)	VSI, VPEI	PV	DSTATCOM	33-bus 69-bus	Comparative studies using the evolutionary method.
Devi and Geethanjali (2014)	Location, Sizing	Power Losses, Voltage Profile	Particle swarm optimization (PSO)	LSF	PV	DSTATCOM	12-bus 34-bus 69-bus	DG and FACTS integration
El-Arini and Ahmed (2012)	Location	System Stability, Power Losses, Voltage Profile	NGSA-II	PLF	PV	SVC, TCSC, UPFC	14-bus	Comparative studies using FACTS integration.
Ćalasan et al. (2020)	Location	Power Losses, Power Flow	Metaheuristic (CONOPT)	OPF	WT	SVC	9-bus 30-bus	DG and FACTS integration, comparative studies using metaheuristic method.
de Koster et al. (2020)	Location, Sizing	MG Performance, Voltage Profile,	Tabu Search	L-index	BESS	Multi-type FACTS	8-bus	FACTS integration
Taher and Afsari (2012)	Location, Sizing	Power Losses, Voltage and Current Profile, Investment Cost	DE	PL	DFIG	UPQC	33-bus 69-bus	Comparative studies using evolutionary method.
Muthubalaji et al. (2018)	Location	Power Losses, Total Cost, Voltage Profile.	MACO- BFOA	SAIDI, SAIFI	PV BESS	DSTATCOM	30-bus 69-bus	Comparative studies with others MOA.
Anbarasan and Kumar (2019)	Location	Real Power Losses, Voltage Profile	Analytical approach	PLF, FVSI	DFIG	STATCOM	9-bus	Comparative with power flow result, DG and STATCOM integration

Table 2 *(Continue)*

Reference	Optimization Typ	Objectives	Method/ Techniques	Index	Type of DG	Type of FACTS	IEEE test system	Case study
Kanwar et al. (2015)	Location	Power loss, voltage profile	Improved cat swarm optimization (ICSO)	-	DG	DSTATCOM with DG	69-bus	Load growth, an optimal solution for DSTATCOM and DG allocation
Weqar et al. (2018)	Location	Active power losses, voltage profiles	Hybrid analytical approaches	VSI LSF	PV	DSTATCOM with DG	33-bus	Optimum location of DG and DSTATCOM. Comparative before and after the installation of the DG and DSTATCOM
Arouna et al. (2019)	Location	Total Losses, installation costs, and voltage deviation	NGSA-II	-	PV	SVC with DG	138 node Calavi HTA	Identify the optimum location and cost installation for PV and SVC
Zellagui et al. (2021)	Location	Active power loss, voltage deviation, techno-economic, and environmental benefits	Hybrid Firefly algorithms-PSO	-	PV	DSTATCOM With DG	33-bus 69-bus	Comparative studies with other hybrid approaches with and without installation of DG and DSTATCOM.
Isha and Jagatheeswari (2021)	Location	Voltage profile, voltage stability, power losses	Hybrid Fuzzy-lightning search algorithm (FLSA)	-	PV	DSTATCOM with DG	30-bus	Optimum location of PV and DSTATCOM. Comparative before and after the installation of the PV and DSTATCOM

multi-objective optimal power flow (MOPF) algorithm that can reduce overall losses and enhance voltage profiles simultaneously (Kargarian et al., 2012). In this study, two different cases have been done: in the first case, only multi-MGs were integrated, and in the second case, both multi-MGs and IPFC were introduced. In each case, there were four strategies, where the first strategy was to reduce operating costs only; the second strategy was to decrease total power loss; the third strategy was to minimize the voltage profile deviation; and the last strategy was to identify the operating point of the system by using proposed multi-objective optimization. The results show that the proposed MOPF with IPFC provides a high-quality MMG system operating point, reduces overall losses, and simultaneously enhances voltage profiles.

Yenealem et al. (2020) proposed using a hybrid approach to solve the optimal location and capacity of PV and wind turbine-based MG integration with STATCOM using fuzzy logic. It was tested in an IEEE 33-bus system connected to the main distribution network. The optimal placement of the MG system and STATCOM was determined using the N-R method as the candidate bus and placed at the weakest bus, bus 30. Meanwhile, the capacity of the MG system and STATCOM has been solved by using fuzzy logic. These case studies compared studies without MG and FACTS integration, with MG, and with both MG and STATCOM integrations. From the findings, it is observed that when both MG and STATCOM are integrated into the benchmark test system, the overall system performance is further enhanced, where the real power is reduced, and the voltage profile is increased compared to the two cases. Selim et al. (2019) conducted a study to obtain the optimal location and sizing of the MG with DSTATCOM using a hybrid approach and tested it on 12-bus and 69-bus radial distribution networks. This study also covered minimizing the total power loss, increasing the voltage profile, and using the voltage stability index (VSI) to determine the candidate location for MG systems and DSTATCOM. The proposed sine-cosine algorithm (SCA) was used to obtain the optimal sizing of the MG systems and DSTATCOM. The results of VSI in IEEE 12-bus obtained clearly show that the optimal location of DG at bud 9 and the appropriate DG sizing, the real power loss, was further reduced. After adding DSTATCOM and incorporating DG into the system, the total active power loss was further reduced.

In addition, the studies by Iqbal et al. (2018) and Sannigrahi et al. (2019) have suggested the same approach, which is the analytical method to find the placement of multiple distributed generations, including DSTATCOM integration to reduce system losses and improve voltage profile. The proposed method by Sannigrahi et al. (2019) for determining the optimal location of DG with DSTATCOM used VSI to determine the weakest bus locations. It was tested on the IEEE 33-bus and IEEE 69-bus distribution networks. The results showed that the optimum placements for DSTATCOM and DG in the 33-bus system are bus 30 and 31, respectively, whereas the optimal placement for both devices in the 69-bus system is bus 61. The integration of DG, as compared to DSTATCOM, yields better results in terms of voltage profile improvement and line loss reduction. Besides, Magham et al. (2012) introduced the genetic algorithm (GA) to find the suitable location for PV and SVC to reduce transmission losses and improve voltage profile. It was tested on a 2500 kVA distribution network. The results showed that the effectiveness of the proposed algorithm had been proven after being applied to the distribution system as the voltage profile improved. In this paper, the improved particle swarm optimization algorithm (IPSO) was presented to determine the optimal location of DG and DSTATCOM, and security limits were considered (Ghatak et al., 2018). The study was tested in the IEEE 33-bus and IEEE 69-bus systems and has been compared with differential evolution (DE), real-coded genetic algorithms, and PSO. The proposed technique results show that the proposed approach achieved the best performance, including computational efficiency and solution quality.

Since the PSO algorithm is easy to implement and highly relevant for practical application, considering nonlinear constraints and different objectives, Devi and Geethanjali (2014) proposed PSO to estimate the capacity for the DG and DSTATCOM. Meanwhile, the optimum allocation of DG and DSTATCOM was determined using the loss sensitivity factor (LSF). The study was simulated in the 12, 34, and 69 bus radial distribution systems, where the objectives were to reduce the total power loss and improve the voltage profile. Taher and Afsari (2012) proposed a DE algorithm to determine the optimal location and sizing of the Doubly Feed Inductor Generator (DFIG) and UPFC to reduce power losses and improve voltage and current profiles. The efficiency of the proposed algorithm was compared to other evolutionary algorithms like GA and immune algorithms (IA) in terms of minimizing the continuous space functions. The results show that integrating the UPQC reduces power loss by 18.2% and 21.42% in 33-bus and 69-bus distribution systems, respectively. Kanwar et al. (2015) introduced improved cat swarm optimization (ICSO) to reduce power loss and increase voltage profiles. The proposed method was implemented on a 69-bus test distribution network. After optimally placing the DSTATCOM and DG, the results show that a net annual energy loss was decreased by about 94% from the base case and the voltage profile increased to 96%. Finally, the proposed method has also been compared by CSO and PSO and based on the findings, ICSO has a better solution than CSO and PSO in terms of computational time and fast convergence.

Weqar et al. (2018) used analytical approaches to find the optimal location for DG and DSTATCOM to minimize the power losses and enhance the voltage profile. This study uses a voltage stability index and loss sensitivity factor to find the weakest and critical lines, resulting in the optimal allocation for DG and DSTATCOM. This technique was tested on the 33-bus radial distribution system. The results show that the optimum placement of

DG is obtained on buses 9, 13, and 28, while the candidate location for DSTATCOM is on bus 30. The results were analyzed, and there has been an improvement in the voltage profile and reduced total real power loss. In Arouna et al. (2019), SVC and PV placement were done using NGSA-II. The multi-objectives had been set to reduce the installation cost of SVC and PV and minimize the power loss. The proposed method has been tested on a real network of 138 nodes. The results show that the optimally placed FACTS and DG contribute to efficiently improving the distribution network's performance while minimizing the installation cost.

Isha and Jagatheeswari (2021) have proposed a hybrid fuzzy-lightning search algorithm to identify the optimum placement of PV with DSTATCOM to minimize power loss and improve voltage profiles. This proposed method was tested on the IEEE 30-bus system. The results show that the power losses were decreased, and voltage profiles improved after the PV with DSTATCOM installation. A few studies validate the proposed optimization approaches' efficiency in terms of computation time and rate of convergence. Based on previous studies, PSO is the most popular optimization method because of its simplicity, small computational load, and fast convergence. Moreover, PSO is very efficient in solving complex problems. However, PSO has a lack of premature convergence upon solving complex problems. The second most popular optimization that has been used is the genetic algorithm (GA). The GA optimization technique is one of the first metaheuristic techniques to solve optimal MMG and FACTS locations. However, it has drawbacks, such as divergence and local minimum problems. In conclusion, most previous researchers have used the common heuristic algorithm such as PSO and GA optimization techniques in the power system to identify the optimal sizing and location.

KEY FINDINGS AND RECOMMENDATIONS

Table 2 summarizes 36 recent research articles from 2012 to 2021 that were reviewed based on the type of optimization involved, the objectives set in the study, the method or techniques adopted, the index involved, the type of FACTS utilized, the adopted benchmark test system and lastly, case studies involved. From the 36 articles reviewed, the most preferred optimization techniques for solving optimal location and sizing are metaheuristic-based approaches (Figure 3). Besides, most previous works have used the common heuristic algorithm such as PSO and GA optimization techniques in the power system to identify the optimal sizing and location.

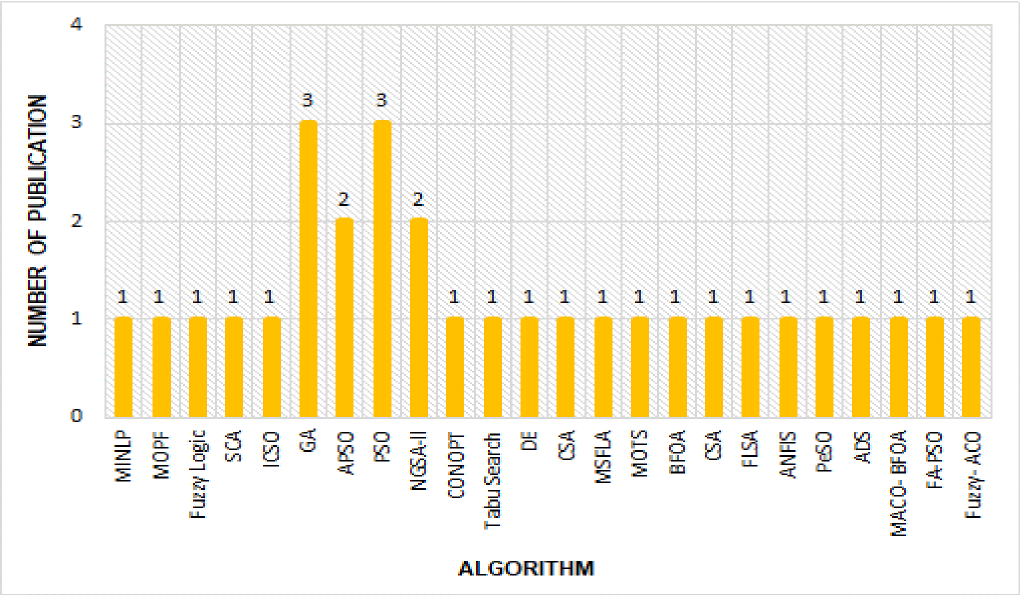

Figure 3. The applied algorithms for solving optimal location and sizing of MMG and FACTS devices

From the reviewed work, a few recommendations for future works in finding the optimal location and sizing of MMG incorporating FACTS devices are proposed below:

Most of the literature reviews were done using metaheuristic approaches that have been used to determine the allocation and sizing of MG and FACTS devices (Figure 3). Hence, there is a limited research technique that uses hybrid approaches. However, no comparative studies have been conducted between the existing hybrid approaches to examine their effectiveness and efficiency, which could be considered for future research.

In addition, most studies were conducted to identify the optimal placement of DG and FACTS devices instead of finding the optimum location and capacity for both DG and FACTS devices to reduce power loss and improve the voltage profile, as shown in Figure 5. Still, finding the proper placement and capacity for MMG and FACTS devices is quite low. Therefore, it must be considered in the future so that the results can be more practical to implement in the existing power system.

Much of the literature usually focuses on the implications of integrating single and multiple DGs to provide high efficacy and achieve better power system reliability, as in Figure 4. However, the consideration of integrating MMG with FACTS technology is still relatively low, and it could be a recommendation for the future to reduce real power losses and improve the voltage profile. Besides that, the potential impact of the high penetration of MMG systems that consist of a variety of renewable energies should also be considered to achieve better performance in the power systems.

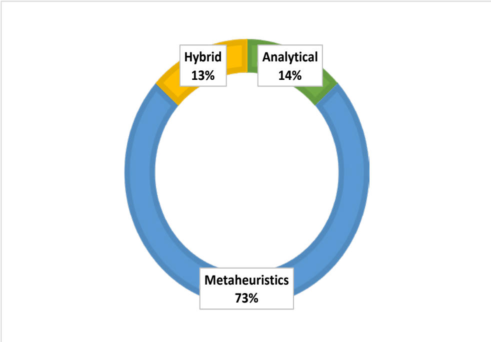

Figure 4. The percentage of the applied techniques for solving optimal location and sizing of MMG and FACTS devices

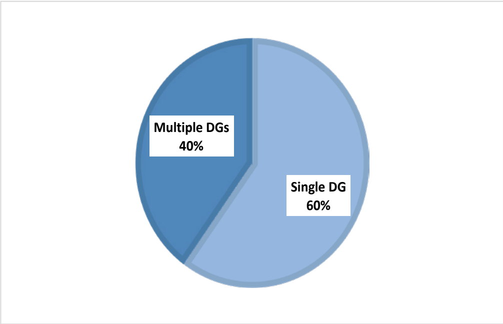

Figure 5. The percentage of the applied number unit of DGs in the power system

CONCLUSION

In conclusion, the best evaluation and optimization techniques in determining the appropriate size and placement of the MMG system and the FACTS controller will improve the MMG system. An attempt has been made to summarize the existing approaches and present a detailed discussion that can help the energy planners decide which objective and planning factors need more attention for optimum locations and capacity for multi-microgrid and FACTS devices. Therefore, a comprehensive study is carried out for optimum multi-microgrid placement considering the minimization of power losses, enhancement of voltage stability, and improvement of the voltage profile.

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