Chapter

Architecture of a Microgrid and Optimal Energy Management System

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Abstract

With the growing population trends, the demand for electricity is accelerating rapidly. The policy planners and developers have great focus to utilize renewable energy resources (RERs) to encounter the scarcity of energy since they offer benefits to the environment and power systems. At present, the energy generation is evolving into a smart distribution system that assimilates several energy resources assuring to generate clean energy, to have reliable operational procedures, and to enhance the energy supervision and management arrangements. Therefore, the model of a distributed microgrid (DMG) with optimal energy management strategies based on multi-agent systems (MASs) technique has been focused in this chapter. Distributed energy resources (DER) have been considered for the generation of electrical power to fulfill the consumer's load demands. Thus, a fully controlled architecture of a grid along with concept of MAS and its development platforms, implementation, and operational procedures have been discussed in detail. In addition, agent's operations and their coordination within the MG arrangements have been focused by considering the supervision of the entire system autonomously. Moreover, optimal procedures of a microgrid (MG) energy supervision and power distribution system have also been presented considering the cost control and optimal operations of the entire MG at the distributed level.

Keywords: distributed microgrid, multi-agent system, distributed generation, energy management, optimization, agent-based solutions, renewable energy resources

1. Introduction

The microgrids (MGs) which have a low energy arrangement involves a fragment of power-driven delivery system specifically situated at the consumer's premises of the distribution network and comprises a variety of distributed energy resources (DER) such as solar photovoltaic (PV), wind energy turbines, fuel cells (FC), and other microlevel turbines, along with storage system including chargeable battery arrangements, capacitor banks, and flywheels with diverse features and dimensions at the culmination manipulators of electrical energy to accomplish their load requisition competently [1]. Certain controllable rudiments are usually installed in order to offer smooth and clean electrical energy in the optimal way.

In current period, the petition of electrical energy is rising rapidly; to satisfy such requests on regular basis, renewable energy resources (RERs) are pledged very productive. Operational accomplishment and governor of disseminated generating units with their incorporation with power storing approaches, manageable load arrangements like heaters for water boiling, and air-conditioning schemes are the vital acuity of the distributed microgrid (DMG). A variety of electricity clients serves at MG level in a form of domestic/residential customers, commercial/industrial manipulators, and also including some recreational parks. Thus, the architecture of the distributed hybrid MG is presented in **Figure 1.**

Nevertheless, the complication carried about by consuming two or more different RERs together develops the hybrid structure more problematic to inspect. These forms of energies are environmentally friendly and do not harm the atmosphere by excreting any harmful gases during the generation process. Thus, solar PV and wind energy system have developed and are broadly popular due to being segmental and environmentally friendly in nature [2–5]. Normally, solar PV and wind systems for power generation works isolated or grid-connected mode, but due to stochastic behavior of such resources, the efficiency of the generation reduces. Therefore, a model to quickly enhance turbine blade geometry, to boost power generation for the applications of the wind tunnel, is accessible in [6]. The momentous characteristics of the hybrid system are to associate two or more RERs to establish the suitable practice of their operational features and to acquire effectiveness higher than that might be gained from a single renewable source technology. Several linking facilities such as optical fibers, microwaves, 4G, and GPRS/GSM are now attractive incorporated parts of the power networks [7–10].

To integrate multi-agent system (MAS) into the power network applications, it significantly leads to make the system smoother, quicker, easier, feasible, and relatively more consistent. Likewise, in [11] architecture of distributed control is created using MAS for monitoring complex energy management of disseminated power production network. A noncooperative game theory accomplishes significant job in interlinking MAS to the organization. Arrangement was assessed by simulation, generation capabilities, cyclical load demands, variations in RERs, and certain grid instabilities; it was confirmed to deliver relatively high-performance

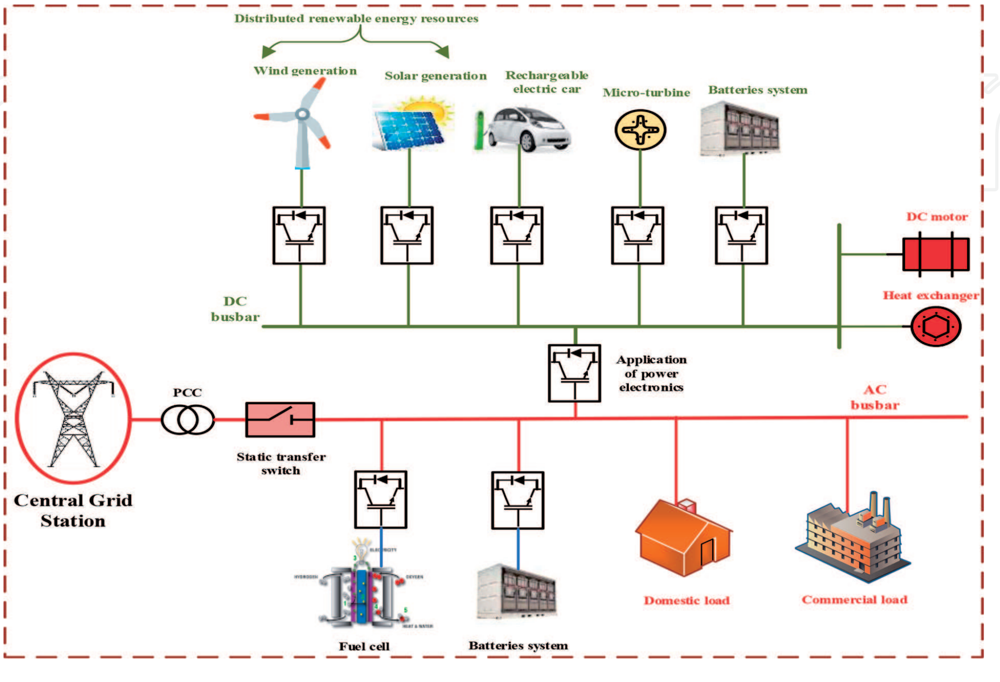

Figure 1.
Architecture of the hybrid MG at the distributed level.

supervision and additional robustness to that of conventional centralized energy managing arrangements. Similarly, based on MAS smart restoration edifice is practiced to a distribution network, simulated by an open spreading classification simulator. The uniqueness of the agent structure comprises fading the network losses while restoring the provision to the loads according to their priority deprived of disturbing the system impairments [12]. Construction built on original resident data, to complete the arrangement procedures steadily and effectively, and DG fundamentals inside the MG are delimited and constructed on energy management scheme using MASs [13, 14]. Consistently, virtual bidding is created for arrangement of scheduling progression and competency reserve, recognized on alteration impairment, drop, or upsurge on the energy request received from single or multiple manageable feeding rudiments operating in the scheme.

Numerous optimization practices, such as graphical construction technique, probabilistic method, and iterative practice, have been suggested by scientists and researchers, promising investment at the lowest price with the complete usage of solar arrangement, wind scheme, and storage system. A graphical construction practice for supposing the finest amalgamation of battery-operated and PV collection in a hybrid solar-wind arrangement has been presented in [15]. Such type of graphical approaches usually has only two constraints (wind turbine and PV, wind turbine and storage system, or PV and storage system) which were involved in the optimization procedure. In an article [16], authors offered a probabilistic method constructed on the convolution performance to integrate the unstable performance of the resources and load, therefore removing the essential for time-series statistics, to measure the long-term operation of a hybrid arrangement. In [17, 18], an iterative optimization method was used ensuring the loss of power supply probability prototype for a hybrid wind-solar organization. From this iterative technique, numerous conceivable combinations of wind-solar power generation measurements were attained. The assessment of wind resource with power generation competency along with solar stills with varied temperature storing materials was carried out to investigate the efficiency and performance improvements in [19, 20]. The entire annual cost for individual arrangement is then considered, and the mixture with the minimum price is designated to signify the optimum combination [21].

2. Concept of multi-agent systems

Agents are usually referring to an entity that have enough intelligence ability to operate in an environment autonomously and continuously to perform tasks efficiently and have the competency to interact with the neighbor agents where they share the desired information to take place in the system together to attain both their specific goals and the cooperative objective within the system. To be more specific, agents must have the following abilities to provide enough intelligence to the entire system in order to make the network more consistent [22]:

- To observe
- To supervise the system
- To communicate and cooperate
- To quick operate in case of any uncertainties
- To accomplish the tasks autonomously

2.1 Agent development platforms

To implement MAS, several open-source agent development platforms are available online that basically provide the software environment or setting where agents activate and run by the use of programming. These platforms help the agent developers to design a complex task agent system in a simplified way. Four stages are very important to be considered in the early development stage of the MASs [23]. First, the investigation stage deals with demonstrating the agent's performances and characteristics, which can be easily achieved to recognize the proper zone and issues arising in the network. Second, the designing phase is quite complicated and significant for categorizing composite difficulties and handling by using improved technique achieved in the first part. Third, the expansion period usually deals to achieve the targets of the intelligent agents in an efficient way to enhance the process of the organization. In the final phase, initiation of the created MAS, agent's interaction capabilities with different RERs, their progressive management aptitudes, and production and circulation of the data are involved.

2.2 Implementation and operation of agents

The agent's implementation stage typically requires a precise prototypical system design, which completely improves prior design models to acquire a specification that is competent enough to be operated by code generators or complier tools automatically. Several agents are needed to be considered in the modeling phase of the system having sufficient ability to activate in a particular position to serve exact information. Making such comprehensive model normally needs matching the theoretical/conceptual entities, assembled from investigation and architectural design deliverables to the real industrial items that are profitable to be used to form the system. By employing the MAS technology, a complete intelligent design can be achieved to follow a prescribed method of providing the information and carrying it to the individual assigned agent optimally. Thus, the NetLogo/Skeleton, Java Agent Development Framework (JADE), JANUS, ZEUS, and VOLTTRON are several foremost tools which are used for the implementation of MASs. Such tools allow the designers to interface their design with the system by applying the MAS technology [1].

The operation of agents is also very significant in the system environment that allows the entire system to operate accurately and efficiently. Thus, the operation of agents comprises the following three phases:

1. Perception and awareness: the operation of assembling information in the location either by monitoring existing working state of the arrangement or by foreseeing responsibilities to be complete in upcoming.

2. Decision-making and alternation: by intellectual reasoning they act and vary the setting freely. It might be possible that making the decision and the system alteration movements fixed either offline or online.

3. Action and execution: the agent's action changes the setting either physical or nonphysical, and the execution of the agents can be done either by hardware or software actions.

2.3 Role of MASs in MG dependability

The MASs play an important role in the MG dependability especially in the applications of agents at the energy management of the MG at the distributed side. In order to make the power system faster and more secure, the employment of agents has the ability to achieve the goal of protection by a competent way compared to other traditional technologies. In addition, MASs have the aptitude of self-learning, flexibility, cooperation, and autonomy, which demonstrate the efficiency of their practice in MGs reconfigurations and diagnosis. Similarly, by focusing on the self-healing MG systems using MAS, the efficiency and safety of the entire system boost up, because its development is directly associated with the system to increase the system reliability. Many researchers have focused on the submission of the self-healing of MG using MASs. For instance, the self-healing of a MG in an emergency situation using the MAS architecture has been proposed in [24]. Moreover, the employment of MASs in multiple MGs that associate altogether and working in cooperation to control the flow of reactive power, to keep the stability works (voltage and frequency), to perform the synchronization jobs, and to consider the economic aspects of the system.

2.4 Key features and shortcomings of MASs

MAS technology has a variety of advantages upon employing agents in a power system, especially at the distributed level of the MG. Agents have been considered one of the most intelligent approach practices with RERs at the distributed level when compared to other traditional systems; the benefits can be seen in the form of smooth operations of the system, improving the stability jobs and also enhancing the entire system reliability.

2.4.1 Key features of MASs

MAS has offered numerous benefits to the organizations with different aspects; some of the key advantages are considered and have been listed below:

- *Robust and flexible*: MASs provide the platform to the formation of flexible, robust, and extensible network. To transform the system, the agents should be modeled considering the demands of the users, and thus it leads to offer a flexible system to accomplish the tasks according to the user's demands.

- *Distributed in nature*: the MASs best fits into the distributed generation system where the agents can perform tasks independently by the use of their local installed programs and best fits into the arrangement that rely on local data and selection creation.

- *Supervision*: the agents have strong supervision ability; they observe the discrepancies in their network or in their neighbor agent network and supervise the entire system according to the nature of their goals.

- *Stability and efficiency*: MASs have the ability to quickly respond to the faults and adjust them in a possibly minimum time to prevent the arrangements from the blackout or even to maintain the efficiency of the entire system.

- *Data reduction and cost control*: the agents are usually responsible to operate distinctly in their location. Therefore, the data processing of the agents limits to their local network which leads to minimize the processing of the data along with their costs. In addition, by processing the limited data, the communication burdens among the two agents also decreases, and thus the system leads to reliable operations.

2.4.2 Shortcomings of MASs

MASs have some shortcomings which have also been discussed below in order to improve the agent's performances in the future [25]:

- *Agent's emergent behavior*: the goal of the intelligent agents is usually pre-programmed to operate according to the instruction inserted by the developer, which might lead to unpredictable results because the effect of run-time operations cannot be predetermined. The result might be beneficial for the market operations but may be problematic for the system service restoration.

- *Practical consideration and implementation*: usually, most of the MASs designs are conceptual based and practiced on software or simulation based that it might be challenging to install such designs in real-time MG. Therefore, such designs should be widely tested on real-time actual MG hardware to validate and implement for the transparent use of the agents.

- *System scalability*: recently, more computational power is accessible that allow scholars to design larger MG with various agents coordinating activities on a single podium. However, the capability of MAS to measure such system with rise in problems for an agent across multiple platforms or for an agent of multiple types is not well understood.

- *Security and safety*: MAS technology is smarter enough to control the space of the MG. Therefore, the change of large physical setup of the system toward smarter technology increases the risks of safety and security from malicious external or disruptive elements.

3. Agent-based architecture of the MG

3.1 The MG architecture

To boost the outcomes of the integrated distributed generating units (DGUs) and to overcome the difficulties associated to the supervision and management of a grid components, DGUs, storage system, load demands, control arrangements and other equipment-from MG utility viewpoint because of their multi-dimensional behavior, the concept of MG has invented. MGs are considered the low-voltage scheme situated at the distribution side that includes DGUs to generate electrical power from the RERs (solar PV, biomass, FC, wind energy, thermal energy turbines, diesel engines, etc.), storage system to store electrical energy during excess generation of power (ultra-capacitor banks, battery system, and flywheels), and including certain supervisory arrangements to protect the entire system during failure in the MG arrangements to deliver smooth energy to the power consumers optimally. All such elements in the MG environment ensure the stable frequency and voltage profiles and reliable flow of power within a particular distribution region. Therefore, the hybrid MG architecture at the distribution side is depicted in **Figure 1**, and the relative features of the MG compared with centralized and decentralized system are given in **Table 1.**

3.2 Unit sizing and proper technology

The unit sizing in MG organization is very important because the use of proper technology and unit sizing leads to make the system more reliable and efficient. It is understood that the unit sizing issues are complex tasks since they require high costs and steadiness but later always lead to control the load demands efficiently. In the MGs which are grid-connected, the sizing of the components is less difficult as they require the area where the unit has installed and the time period to transfer the power to the load, while the self-sustainable MGs unit sizing is complex as they involve many components and guarantee to transfer quality power to the consumers within the allocated boundaries.

S. no.	Characteristic	Details	Comparison	
			Centralized system	Decentralized system
1.	Multiple distributed generating units	• Photovoltaic • Wind • Fuel cell • Biomass • Thermal, etc.	√	√
2.	Multiple storage arrangements	• Batteries • Capacitor banks • Flywheels, etc.	√	√
3.	Construction	Can be constructed at the centralized and distribution or remote area	Complex	Easy
4.	Supervision or monitoring	• Voltage • Power • Frequency	√	√
5.	Protection and control of power flow	• Controls the power supply during both grid-connected and islanded operations • Use information to control the power flow of DG units	Use the central controller instructions	Use the local controller instructions
6.	Processing the data	Processing of data and tasks execution in the arrangements	Time-consuming	Quick processing
7.	Connecting MG with distribution network	Separation switch known as point of common coupling (PCC)	√	√
8.	Subset of multiple voltage levels	• Medium voltage • Low voltage	No	Yes
9.	Two operating modes	• Grid-connected mode • Islanded mode	√	√
10.	Costs	MGs can be easily constructed with low/high capital costs	High	Low
11.	Supply multiple voltages	Supply both types of voltages • AC • DC	√	√
12.	Fault detection and recovery	The capabilities of controlling arrangements to detect and recover the faults	Difficult	Easy

Table 1.
Characteristics of MG and their comparison.

Assortment of technology and system sizing can sometimes be as concise and precise as accomplishing certain local necessities such as utilizing the accessible technology for power production within power rating of the device, or it can be as multifaceted as sustaining numerous constrictions and attaining several goals at the same time to govern the system effectively. Generally, based on accessible statistical data about power extraction from RERs, consumer load demand, consistency of the anticipated scheme, fiscal limits (amount of interest), cost factors, geographical facets, and supplementary case-specific information, power production technologies and their sizes can be enhanced to satisfy exact purposes, for example, minimizing functioning and developmental charges, ecological impact, and remuneration stages on asset and/or increasing the overall consistency of the system. Therefore, various optimization techniques are available that solve the unit sizing issues employed at the MG level and realize the progress in the development of the MG system, for instance, computational approaches, such as artificial intelligence and classical techniques. The classical approach uses dynamic programming, linear and nonlinear programming, and optimal power flow, while artificial intelligence, which are stimulated by natural behavior that includes harmony search, ant colony, simulated annealing, interior point method, evolutionary algorithm, and heuristic methods such as genetic algorithms and particle swarm optimization, can be used for the sizing of the units to enhance their capabilities to make the arrangements more consistent, to control the costs, and to improve the operational schedules.

3.3 Distributed power generating systems

In present time, as petition of energy is growing quickly to accomplish the requirements on regular basis, RERs are considered enormously effective. Actual accomplishment and governor of circulated power production sources and its incorporation with energy storage arrangements such as capacitor banks, flywheel, electrical batteries system, and certain governable loads like water boilers/heaters and air-conditioner system are the main perception of MG at distributed level [26]. The main DGUs at commercial and domestic regions are given in **Table 2.**

S. no.	DGS	Operational region		Comment
		Domestic	Commercial	
1.	Solar	Yes	Yes	—
2.	WTs	Yes	No	Variable speed
		No	Yes	Fixed speed
3.	FC	Yes	Yes	—
4.	CHPS	No	Yes	—
5.	Hydropower	No	Yes	Microlevel turbines only
6.	Biomass	No	Yes	—
7.	AGSG*	Yes	Yes	Normally diesel/gas/gasoline fueled
8.	WMCG**	No	Yes	Need extra environment protection

**Alternative grid-supporting generators are expensive but in practice to fulfill the load demands.*
***Waste material combustion generators are expensive because they need extra environmental protection system.*

Table 2.
Most commonly used distributed generating systems at domestic and commercial zones.

3.3.1 RERs and their impact on the environment

Different technologies are usually installed at the MG level that operate proficiently to generate power where the consumers need environmentally friendly generating system with reasonable prices. Hence, RERs have been considered the best way to generate power since they deliver electrical power to the energy consumers locally without producing any harmful gases. The RERs are usually installed at the distributed level to overcome the load demands locally by less comparable costs and transmission losses including the environmental impact on producing the electrical energy. Therefore, different RERs that include solar PV, wind turbines, biomass, FC, etc. are usually installed in the MG system to generate and distribute electricity locally. These generation resources assure the reliable operational procedures and produce clean energy without causing any harm to the environment in the form of generating harmful gases. In addition, due to unpredictable nature of the wind and solar, it is necessary to consider the fluctuation in the system due to different levels of energy generation at different intervals. Thus, employing the RERs having storage arrangement at the distributed level will lead to produce clean energy, to control the instabilities, and to deliver clean energy with less operational, generation, and distribution costs.

3.3.2 Storage system

The storage of energy in the MG arrangement is very important and offers a wide range of benefits to the power generation companies. The electrical power during off-peak period can be stored in batteries, flywheels, and in super capacitor banks that can be used during peak hours or even blackout of the grid. Therefore, the grid operations, costs, and dependability of the entire system can be guaranteed upon installing the storage system. In addition, by incorporating storage system in RERs power generation system at the distributed level, it helps to minimize the instabilities and enhances the stability jobs during load deviations. Thus, a series of batteries are usually installed with biomass, solar PV, wind turbines, and microturbine power production system to store electrical energy. Similarly, FCs and hydropower plants contain supercapacitor bank and flywheel technologies to store electrical power during off-peak hours, respectively.

Storage of electrical energy has been extensively evaluated for MG arrangements; a wide collection of submissions persevere for energy storing arrangements. In [27], the authors discussed improvement of power quality, dynamic distribution organizations, supporting operations of MG in islanded process, and plug-in electric vehicles technologies. Storing of electrical energy has significant benefits, including refining dynamic constancy, transient steadiness, provision of voltage, and deviations in frequency [28, 29]. Moreover, such arrangements can also be functional for diminishing the entire charges and impact on the environment. An extensive range of applications exists for storage system, and the existing RERs power production at MG are now intelligent enough to operate efficiently by receiving benefits from MAS technology. In [30], batteryless schemes are being experienced and have been identified as what has been termed as green substitutes. In Ref. [31], the power delivery difficulties along with storage arrangements deal with interaction with numerous diverse MG components, including energy storage schemes, RERs power generation capabilities, and predicting agents.

3.4 Implementation of MAS in the DMG

MAS technology offers the smart intelligence approach that make the MG system more competent to operate efficiently with less instabilities at the distributed level than centralized approach. The initial designing and implementation of the agent has already been discussed in detail in Section 2, including different tools that the agents can be implemented. The agent works independently and locally, that is why they perform their tasks autonomously with less communicational data processing which makes the system more reliable and competent. In the MG arrangements, different agents are usually inserted in each power generating unit, protection arrangement, and even at the consumer's load side to evaluate the current process of the system and create the feasible protection and operational arrangements upon causing any instability in the assigned location autonomously. Hence, the main steps of the implementation and task accomplishment of the agents at the MG level are discussed below and are also deliberated in the flow-chart in **Figure 2**:

1. The system operation starts with no initial fault.

2. The activation of the agents takes place in order to supervise the grid efficiently.

3. Upon fault condition, the system checks the current status of the agents.

4. The neighbor agents check for the cooperation, and the agents start cooperation among themselves.

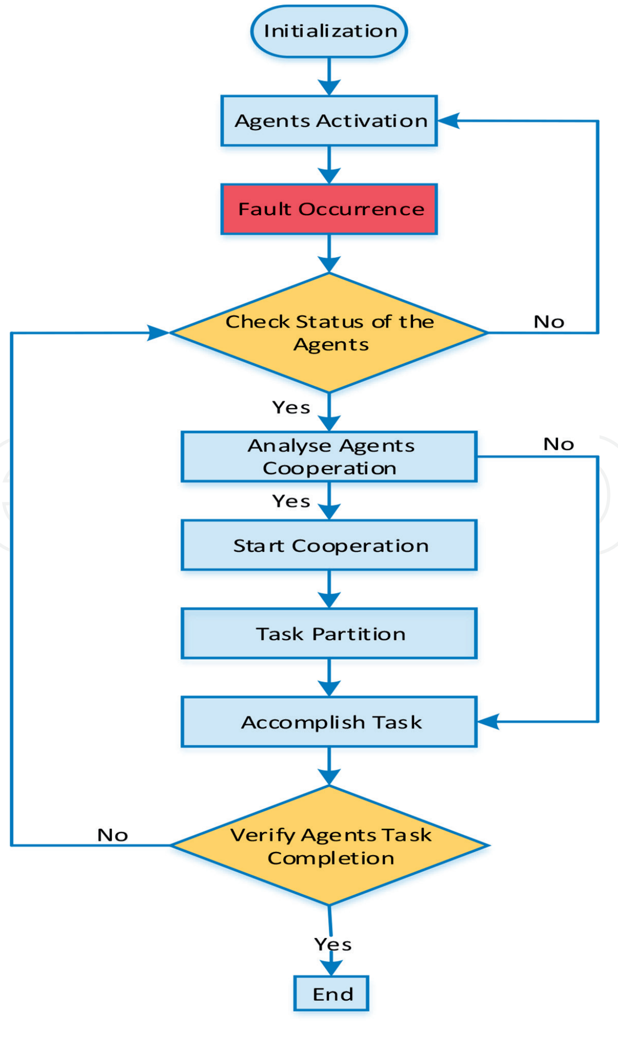

Figure 2.
Implementation and task accomplishment of the agents at the DMG.

5. The agents divide the task and perform their operation to overcome the specific fault within the system.

6. The assigned agent accomplishes the task in the specific fault location with the cooperation of the neighbor agents.

7. The control agent verifies the specific task completion and activates the agent or terminates the current situation according to the agent's performance.

3.5 Control strategies and operations

The matching of active and reactive power plays a significant role in the enhancement of the power system reliability. As an evidence, the authors in [32, 33] proved that imbalanced active and reactive powers lead to voltage deviation and frequency instability from their rated values, respectively. Therefore, management of active power, and controlling the frequency are observed the identical governor petition, and thus voltage controlling, and coordination of reactive power can be led to a reliable system operation. In islanded mode, MG missing support from the central grid, and it is quite difficult for MG arrangements to stay in a steady state. Thus, recent research resolves such difficulties by applying MAS technique in MG at distributed level. The agents offer an effective and appropriate governor functionality in current advances of the MGs. The technology comprises several supervisions and controlling operative procedures, which make the MG arrangements more intelligent and reliable; such roles cover the matching difficulties of active/reactive powers, enhance the system stability, and uphold the voltage and frequency balancing roles in grid operation mode.

3.5.1 Centralized MG control system

In the centralized MG control arrangement, the main central controller takes the responsibility to process all the instructions and perform the jobs within the grid. Several local controllers are also in operation in such approach, but due to being centralized in nature, all local controllers send instructions to the main central controller, and thus the decision-making and supervision of the entire system are only carried out by the central controller. This system has the advantage of accomplishing complete optimization calculated on all current information in the multi-objective energy management system. However, due to increasing energy demands, the structure of the system becomes more complex and expensive to build. In addition, the processing of data is also complicated, and in case of any short circuit or mishappening, the entire system leads to blackout. Thus, the reliability of the grid is also challenging.

3.5.2 Decentralized MG control system

The decentralized control arrangement is also known as distributed control system. Several local controllers are usually installed in every DER and with protection arrangement to supervise the system independently. The local controllers measure the signals and perform tasks locally within their assigned location that make the system more intelligent and reliable. Such controllers process less data and also have the competency to communicate with their neighbor controllers to perform tasks according to the nature of the system autonomously. Similarly, as every sub-level controller is responsible for their assigned location to handle, thus the processing of data reduces that leads to make the system structure simpler and control the costs as well. However, the complexity of communication in the MG arrangement is still an issue; therefore the intelligent algorithms discussed earlier in Section 3.2 should be considered along with their hybrid groupings to handle such issues efficiently.

3.6 Protection arrangements

The hybrid system that delivers both direct current (DC) and alternating current (AC) powers to the load needs certain controllable arrangements to supervise the whole system. Thus, application of power electronics has widely been in practice to achieve the anticipated outcomes. Lopes et al. [34] explored dual control method for triggering an inverter in the system. Although inverter model is ensuing consulting to subsequent governor method, the PQ inverter controller is in practice in which inverter establish specified active/reactive power set points. Voltage source inverter (VSI) control technique is applied in which inverter is monitoring "provender" consignment based on pre-defined values for system frequency and voltage. Depending on active/reactive powers of the arrangements, load demand outputs of VSI are illustrated. MG-allied VSI is anticipated in [35]; power delivery supervisor is considered for creating system frequency and magnitude of significant output voltage allowing by droop features and by identical action of traditional synchronous generator; voltage controller is implemented to generate position filter-inductance current path; also, current controller is applied to generate vector command voltage to be created by pulse width modulation technique. Linking inductor outlines with inverter output impedance, consequently active/reactive power connection is minimized precisely.

In [36], Gandomi et al. proposed a multilevel system voltage utilizing a single DC source which minimizes the number of power switches, not signifying the minor voltage matching problem. Such type of inverter has also a competency to improve voltage at the input without any additional boost electronic circuitry. In [37], authors offered segmental cascaded multilevel H-bridge PV inverter considering maximum power point tracking at distributed grid-connected applications. Such topology advantages to increase flexibility and efficiency of the PV schemes. In addition, to uphold the system constancy, linear and nonlinear switching loops can easily control the operational capabilities and has the competency to manage capacitance/inductance current of the filter at the output to accomplish dynamic and fast responses within the scheme [38].

3.7 Cost control and safe operations of the MG

The MG at the distributed level needs proper equipment, protection arrangements, and storage system to generate and store electrical energy optimally [39]. Thus, such arrangements usually cover a huge initial investment cost. The implementation costs of such scheme are high but have positive impact on the environment and consumers. The main points that show that the costs of the MG could be minimized with optimal operational procedures are given below:

- The RERs are usually in practice to generate electrical energy and distribute it locally that leads to produce clean energy without the creation of any harmful gases that pose a hazard to all living organisms.

- Generate and distribute the power locally to eliminate the high transmission losses.

- In case of emergency, the whole scheme is prevented from the blackout, and only the specific grid is affected.

- Due to limited components installed at that MG level, the maintenance becomes easy.

- Easy to connect with the central grid to share electrical power upon surplus generation.

Considering the above points, it is noteworthy that installing the MGs integrated with RERs at the distributed level is very productive, and the outcomes become more economical. Moreover, employing the MAS technique in the MG organization makes the grid more intelligent and provides enough supervision competency that lead to optimal operations.

4. Advanced energy management system for the DMG

A very promising and reliable approach to handle problems and operate the system efficiently at the distributed level is MAS approach. A MAS operation consists of three stages, perception, decision-making, and action. Perception can be performed by collecting information in the location either by monitoring the existing operational data or by forecasting duties to be performed in upcoming. In decision making, by cognitive intelligence conducts and altering the environment freely (might be either online/offline), while in actions, arrangements of the agents affect the system either by software or hardware actions, which work together and will lead to achieving a comprehensive global objective. MAS has been widely used for integration of power systems, power system reconfiguration, restoration, and management of electrical power in MGs [40, 41].

4.1 Structure of the proposed supervision system

The proper supervision arrangements in the MG organization are very important. Due to unpredictable nature of the RERs, it is very difficult to supervise and predict the actual amount of power that will be generated in a specific interval of time; therefore, the use of MASs in the MG energy management plays a vital role that leads to supervise and optimally operate the entire system. In order to get the appropriate amount of energy from the RERs and to fulfill the consumer's energy demands, the MASs technique has been presented and inserted in the MG organization that spreads throughout the system and supervises the system properly as shown in **Figure 3.** Different agents have been installed in power generating units, storage, protection system, and load demand side. Each of these agents supervises their assigned location tasks in the MG system and manages the electrical energy efficiently. Moreover, the supervision of the MG system is also important in order to smoothly operate the system, to control the costs, and to prevent the system from any mismatches or failure to enhance the system reliability.

4.2 Agent's communication arrangements

The agent's communication technique and exchanging of data are significant to identify and perform the task according to the current status of the MG. Khan et al. in [42] presented the three levels of agent's communication technique in the MG organization which are shown in **Figure 4.** The agent's communication has been carried out in order to make the system more intelligent and to supervise and operate the MG at the distributed level optimally. The proposed three levels of agent's communication system are discussed below:

1. The RERs have been considered for the generation of electrical power that associated with the generation agent to supervise the generation capabilities from the RERs and transfer the energy according to the production.

2. The storage system and energy loads are considered for the consumption of the electrical energy and associated with the storage and load agents that supervise the electrical energy to store directly from the RERs or to transfer to the consumers considering the generation capabilities and consumer's energy demands.

3. Different control and supervision agents have been created that are linked in the MG arrangements and responsible for balancing of electrical energy, monitoring, and supervision. Such agents have the aptitude to accomplish responsibilities in possibly minimum time to direct the strategies efficiently and to improve the dependability of the grid.

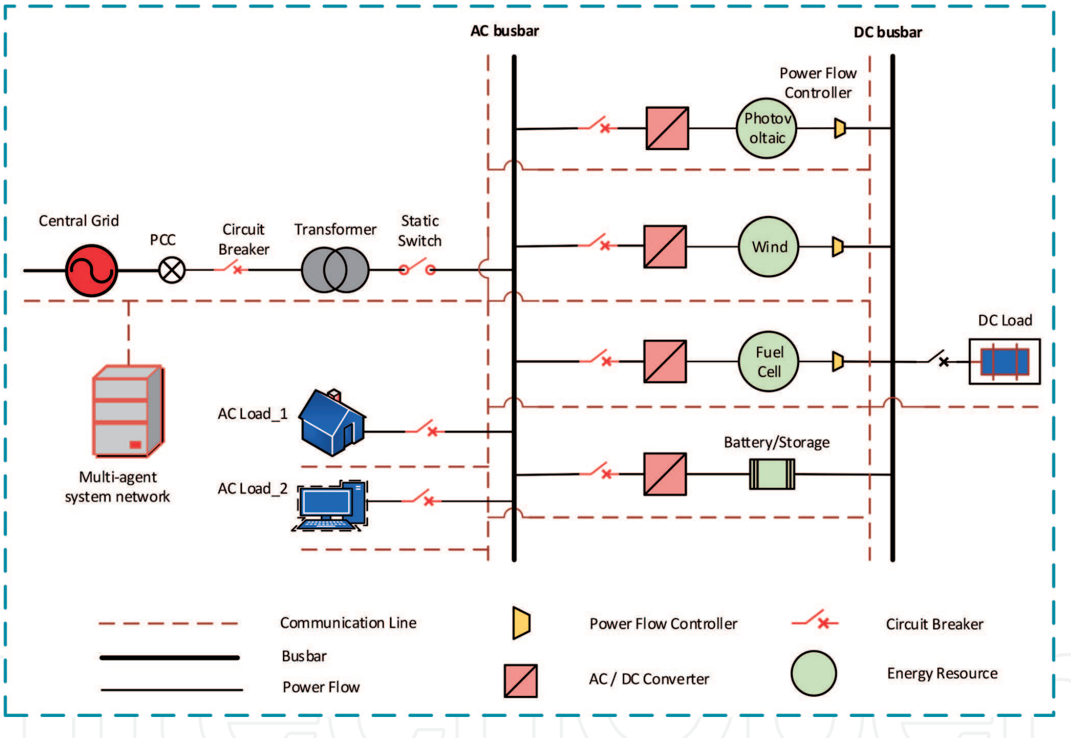

Figure 3.
Structure of the proposed supervision system at the DMG level.

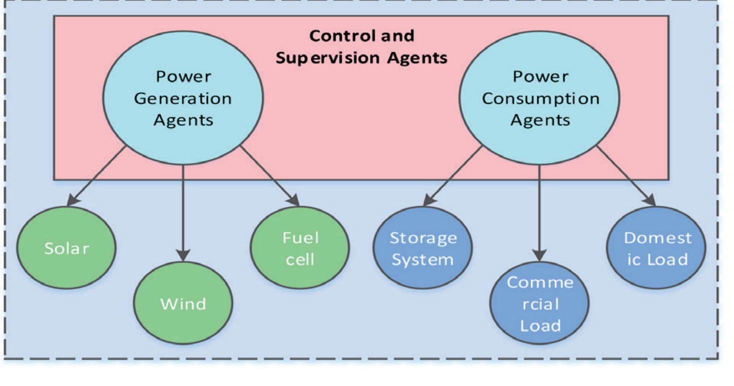

Figure 4.
Three levels of agent's communication technique [42].

4.3 Objectives of the smart energy system

The purpose of the smart energy management is to make the system more reliable and economical that is beneficial for both the electrical power generating companies and the consumers. Therefore, the main objectives of the smart energy management using MASs are given below:

1. Accomplish the best regulation and switching mechanism to extract the possible highest amount of power from the RERs considering the load petition.

2. Provide an environment where agents are inserted in different units to operate autonomously and perform tasks accordingly.

3. The podium where different agents communicate with their neighbor agents to make the synchronization job and operate the system optimally.

4. To create best monitoring strategies that applies in the MG network to enhance the trade-off between the technical and recital custodies.

5. To attain the finest operations considering the optimization of the units since the disparities occur in power generation from the RERs and consumers energy needs.

6. Transport reliable and clean energy to the consumers with less harmonics that leads to consumer satisfaction without creating any harm to the environment.

5. Conclusions

MGs are low-energy networks that are capable to increase the dependability and economy and offer clean generation of electrical energy and its supply to sustain the consumer's satisfaction. The incorporation of RESs in the MG system has developed to generate electrical power and distribute and supervise the arrangement optimally. Hence, many researchers have been involved in the designing procedures, controlling strategies, finest management of energy, and optimal operations of the MGs to deliver reliable, quality, and sustainable energy to their customers with low energy costs. Therefore, a DMG with optimal energy management strategies based on MAS technique has been focused in this chapter. A fully controlled architecture of a MG has been offered that associated with a combination of several RERs, which lead to generate clean energy without producing any harm to the environment. The concept of MAS has been employed in the MG network that supervises the entire arrangements in an efficient way. Similarly, MASs development platforms, its implementation, and operational procedures, along with some key features/drawbacks, have also been discussed in detail. In addition, agents have the ability to supervise their assigned duty competently; thus, operations and coordination of agents in the MG network have been provided by considering the supervision of the entire system autonomously. Lastly, optimal procedures of the MG energy supervision and power distribution system along with objectives of the smart energy managements system have been conferred considering the cost control and optimal operations of the entire MG at the distributed level.

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Conflict of interest

The authors declare no conflict of interest.

Dedication

I dedicate this chapter to my inspiring parents, brothers, and sisters, for being the role models, pillows, catapults, and cheerleading squad that I have needed throughout the completion of this research work!

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