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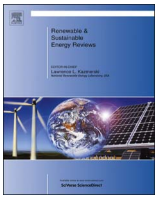

Enhancing smart grid with microgrids: Challenges and opportunities

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ABSTRACT

The modern electric power systems are going through a revolutionary change because of increasing demand of electric power worldwide, developing political pressure and public awareness of reducing carbon emission, incorporating large scale renewable power penetration, and blending information and communication technologies with power system operation. These issues initiated in establishing microgrid concept which has gone through major development and changes in last decade, and recently got a boost in its growth after being blessed by smart grid technologies. The objective of this paper is to presents a detailed technical overview of microgrid and smart grid in light of present development and future trend. First, it discusses microgrid architecture and functions. Then, smart features are added to the microgrid to demonstrate the recent architecture of smart grid. Finally, existing technical challenges, communication features, policies and regulation, etc. are discussed from where the future smart grid architecture can be visualized.

1. Introduction

Modern society has been facing an unsustainable energy due to increasing energy demand, diminishing of primary energy availability, traditional and aged electrical transmission and distribution networks. The global warming, limited significant amounts of investment, limited energy generation resources, growing energy dependency emerge that modernization of traditional grid architectures, innovative solutions and technologies are inevitable.

In the recent years, Distributed Generation (DG) of electricity has begun to take attention as a modern solution since it provides several advantages such as high efficiency and environmental protection, reduction of transmission and distribution losses, supporting the local power grid and improving system stability. DG plants often integrate with renewable energy technologies such as photovoltaic system, wind power, small hydro turbines, tidal, biogas, etc. Application of individual distributed generators can cause as many problems as it may solve. A better way to realize the emerging potential of distributed generation is to take a system approach which views generation and associated loads as a subsystem or a “microgrid” [1–3].

The microgrids can be defined as small, local distribution systems including a set of microsources such as microturbines, fuel cells, photovoltaic (PV) arrays and wind turbines, storage systems, such as flywheels, energy capacitors, and batteries and controllable and uncontrollable loads. It can be connected to utility grid (grid mode) or operated independently when isolated from utility grid (island mode) during faults or other external disturbances, thus increasing the quality of supply, customers can obtain a higher efficiency, cheaper and cleaner energy. This ability of microgrids is one of the key features. Additionally, microgrids may enhance local reliability, provide lower investment cost, reduce emissions, improve power quality and reduce the power losses of distribution network [4].

Despite many advantages of microgrids, there are major challenges to connecting microgrid system to distribution grid. These challenges can be classified as technical challenges associated with control and protection system, regulation challenges and customer participation challenges. While regulation challenges may be related to regulation policies, microgrid legality and engagement between microgrid firms and customers, technical challenges contain integration of renewable sources and problems associated with that, protection issues with the renewable integration as well as operation constraints.

The rest of the paper is organized as follows: Section 2 begins with detailed specification of microgrid, based on owner ship and its essentials. Section 3 specifies the architectural model of future smart grid. Section 4 presents an overview of function of smart grid components including interface components, control of generation units, control of storage units, data transmission and monitoring, power flow and energy management and vehicle to grid. Then, the

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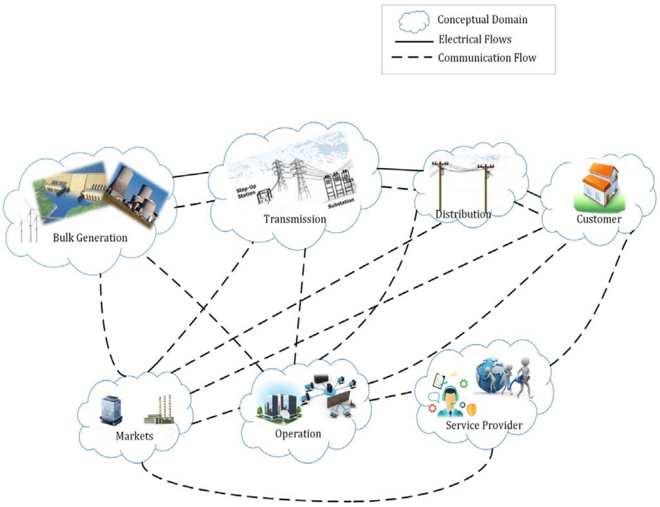

Fig. 1. Smart grid conceptual model.

technical, regulation, operation and customer challenges will be focused along with their solutions and opportunities in microgrid systems in Section 5. Finally, the paper ends with conclusions in Section 6.

2. Microgrid to smart grid

Smart grid [5,6] states to the progress of electricity grids. According to The European Regulators Group for Electricity and Gas (ERGEG), developed based on the definition from the European Technology Platform Smart Grids (ETPS): smart grid is an electricity network that can cost efficiently integrate the behavior and actions of all users connected to it – generators, consumers and those that do both – in order to ensure economically efficient, sustainable power system with low losses and high levels of quality and security of supply and safety [7]. The concept of smart grid model can briefly be explained under few domains shown in Fig. 1.

Smart grid is characterized by the following [8]:

- Self-healing
- Consumer friendly
- Resistant to physical and cyber attacks
- Optimizes asset utilization
- Eco-friendly
- The use of robust two-way communications, advanced sensors and distributed computing technology
- Improve the efficiency, reliability and safety of power delivery and use.

As well as the many advantages, smart grid is faced with many barriers such as bidirectional communication systems, integration to grid with renewable energy resources, ineffective utilization of the DG, inadequate existing grid infrastructure and storage etc. One of the methods to attain effective utilization of the DG is to handle electricity generations, energy storages, and loads as a localized group [5,9].

Microgrid plays a key role in the smart grid concept. It is a piece of the larger grid, which involves nearly all of components of utility grid, but these components are smaller sizes. While smart grids take place at larger utility level such as large transmission and distribution lines, microgrids are smaller scale and can operate independently from the larger utility grid.

3. Architectural model of future smart grid

Microgrids can be classified into three main groups, depending on the way in which the AC and DC buses are connected. The proposed classification is as follows: AC-microgrid, DC-microgrid, hybrid AC/DC microgrid.

3.1. AC microgrids

AC microgrids have a common AC bus which is generally connected mixed loads (DC and AC loads), distributed generations, energy storage devices. AC microgrids are easily integrated to conventional AC grid because most of loads and grid itself are AC. Therefore it has more capacity, controllability and flexibility. But, as DC loads, DC sources and energy storage devices are connected to the AC bus via DC/AC inverter, it causes a significantly decrease in efficiency [10–12].

3.2. DC microgrids

In DC microgrid, common DC bus is used to connect to the grid through an AC/DC converter. The operation principle of DC microgrid is similar to AC microgrid. Compared with AC microgrid, DC microgrid is a good solution to reduce the power conversion losses because it only needs once power conversion to connect DC bus. Therefore, DC microgrid has higher system efficiency, lower cost and system size. Moreover, DC microgrid is better compatible to integration of distributed energy resources (DERs), and better stability due to absence of reactive power [10,13–15].

Different types of DC microgrids have been presented in the literature [11,16], i.e. the monopolar, the bipolar and the homopolar type.

3.3. Hybrid AC-DC microgrid

Hybrid AC/DC microgrid is a combination of AC and DC microgrids in same distribution grid, facilitating the direct integration of both ac- and dc- based DG, Energy Storage System (ESS) and loads as shown in Fig. 2. This architecture has advantages of both AC microgrid and DC microgrid, such as minimum number of interface elements, easier integration of DERs, reduced conversion stages, energy losses and total costs, and higher reliability. Moreover, when DG, loads and ESS are directly connected either to the ac or dc networks, there is no need for synchronization of generation and storage units [17–19].

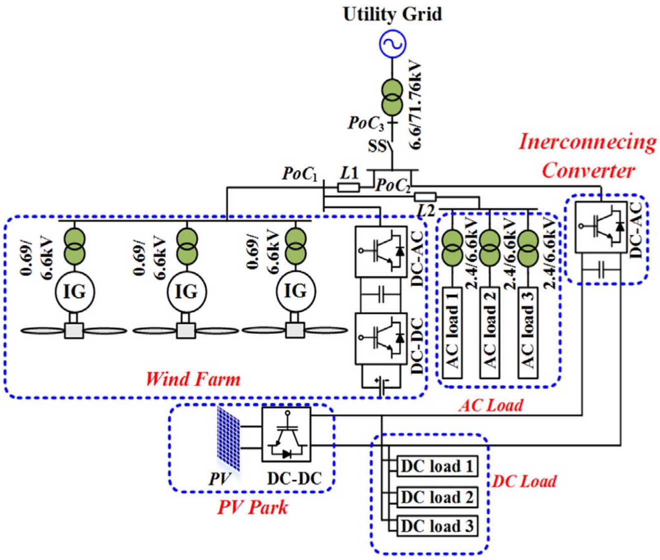

Fig. 2. A general structure for hybrid microgrid.

4. Functıons of smart grid components

4.1. Smart device interface components

The elements that form a microgrid are described as follows:

4.1.1. Distributed Generators (DG)

DG units are the base of microgrids and located at or near the point of use. Two types of generation technologies can be implemented into microgrid systems: renewable resources such as solar photovoltaics (PV), wind, small hydro power, ocean, etc.; non-renewable resources such as reciprocating engines, gas turbines, modern Combined Heat and Power (CHP) units etc. [14,20].

Most of the DG technologies require a power electronics interface in order to convert the energy into grid-compatible ac power. The power electronics interface contains the necessary circuitry to convert power from one form to another [21]. These converters may be a single-stage converter (DC-AC converter) or a double stage converter (DC-DC and DC-AC converter). The converter contains the necessary output filters (L, LC, LCL, and LCL with damping resistor), connected in series with the converters improves harmonic performance at lower switching frequencies [22].

Distributed generation for a microgrid must be properly selected according to the characteristics and cost of the different technologies [12,23].

4.1.2. Energy storage devices

Energy storage devices can be classified into three categories as electrochemical systems (batteries and flow batteries), kinetic energy storage systems (flywheel) and potential energy storage (pumped hydro and compresses air storage). In Refs. [24–27], detailed comparison of different energy storage devices can be found. Since pumped hydro storage and compressed air energy storage systems are large scale energy storage system, they are mostly used in high power range for standard power systems, hence are not suitable for small-scale renewable energy systems [28].

Energy storage devices in microgrid applications may improve power imbalance, power quality, reliability and stability between loads and distributed generated resources output. More suitable energy storage devices can be determined according to characteristic of loads and distributed energy resources. Some key energy storage technologies available for MG applications are summarized as follows:

- Batteries are one of the most used energy storage devices. They are classified as lead acid, nickel cadmium (Ni-Cd), nickel metal hydride (NiMh) and lithium-ion (Li-on) batteries. Lead acid batteries are suitable for storing energy for long periods of time, and it has relatively poor performance and limited cycle life (1200–1800 cycles). When Ni-Cd batteries are in comparison with lead acid batteries, Ni-Cd batteries have longer cycle life, higher energy densities and low maintenance. But, its main hindrance is a high initial capital cost. NiMh batteries have more energy density than Ni-Cd batteries, approximately 25–30% more, and additionally with equivalent cycle life as that of lead acid battery. The highest energy density is in Li-on batteries compared to lead acid, Ni-Cd and NiMh batteries, but the investment cost and limited life cycle are the main drawbacks of Li-on batteries [28–30]. In Ref. [31], battery storage system integrated into solar PV systems has been proposed to mitigate the negative impacts of PV integration. Analyses performed by Simulink and Homer have been done to assess different battery storage systems from a techno-economic point of view in Ref. [28].
- Flywheel energy storage devices have long life cycle, high energy and power density. Despite that, the drawback of flywheel energy storage is inclined to have high friction losses. They can be used to mitigate the fluctuations in power generated by wind and solar systems [26]. Flywheel storage systems coupled with diesel generator are used in Refs. [32,33] to provide UPS service to the critical loads.
- Supercapacitors are also known as ultracapacitor or electric double layer capacitor, which are based on characteristic of capacitor and electrochemical batteries without chemical process. The main difference between capacitor and super capacitor is the use of porous membrane which provides ion transfer between two electrodes, thus electrical energy can be stored directly and the response time is very small [29]. Moreover, its capacitance and energy density values can be from hundreds to thousands time larger than that of the capacitors. When it is compared with lead acid batteries, supercapacitor has lower energy density but has higher power density, long cycle life, and energy efficiency of about 75–80%. But the most important disadvantage of this technology is their high cost which is about five times bigger than that of lead acid batteries [30]. [34] and [35] have presented that supercapacitors are good choice to mitigate the inherent natural fluctuations for intermittent renewable sources, wind and wave respectively.
- SMES systems have very long life cycle from ten to thousands of cycle, very high efficiency up to 95%, very fast response time and high implementation cost. Possible applications are power factor improvement, frequency regulation, transient stability, power quality improvement [36,37]. In Ref. [38], SMES integrated with wind power is used to control the frequency and voltage of the microgrid in island mode. When the microgrid operates in the grid-connected mode, the SMES system is used to provide the constant power flow at PCC to overcome the fluctuations in power arising from the wind power.
- One of the commercially available flow batteries is Vanadium Redox Battery (VRB) which has many advantages over many traditional BESS such as long life cycle, low maintenance, independent power and energy capacity, quick charge and discharge response, and high efficiency. However, the initial operating and maintenance costs are still relatively high in comparison to BESS [29]. The current literature in the VRB based microgrids is limited, since this technology is recently commercialized [39–41].

To demonstrate the importance of ESS on smart grid, a case study is made based on the model shown in Fig. 3. A 6.0 GW power system in Hokkaido Island of Japan consists of Hydro, Thermal, and Nuclear generators is scaled down to 100 MW. Then a renewable energy park consists of wind and/or photovoltaic system is connected to the power system considering a maximum renewable power penetration of 10% of original power system capacity. The original model shown in Ref. [42] is modified in this study to show the effect of high penetration of renewable energy to the modern smart grid and a path forward to overcome grid code barriers using storage technology.

The wind turbines are equipped with advanced pitch controllers [43] which can smooth the power going to the line when generated power is greater than the reference power produced from a low pass filter, i.e., advanced pitch controller works even at wind speed lower than rated speed. The conventional pitch controller only works once the wind speed is above the rated speed. Fig. 4 shows the different wind speed for different wind generations of 2 wind farms shown in Fig. 3. Figs. 5 and 6 show frequency fluctuations levels for different wind power penetration levels at high and low load conditions when only conventional pitch controller is used. It is seen that when the wind power penetration level is maximum, the frequency fluctuation goes high. However, when the advanced pitch controller is used, the frequency fluctuation is within acceptable range for high load condition as shown in Fig. 7. Fig. 8 shows that the advance pitch controller is not effectively control the frequency at low load condition. However, when an ESS is used in the smart grid (Fig. 3), the frequency can be maintained at rated value as shown in Fig. 9. In this study, an Energy Capacitor System is used as ESS. Therefore, ESS will play a vital role in future smart grid operation, though cost and lifecycles of ESSs' are still the prime challenges.

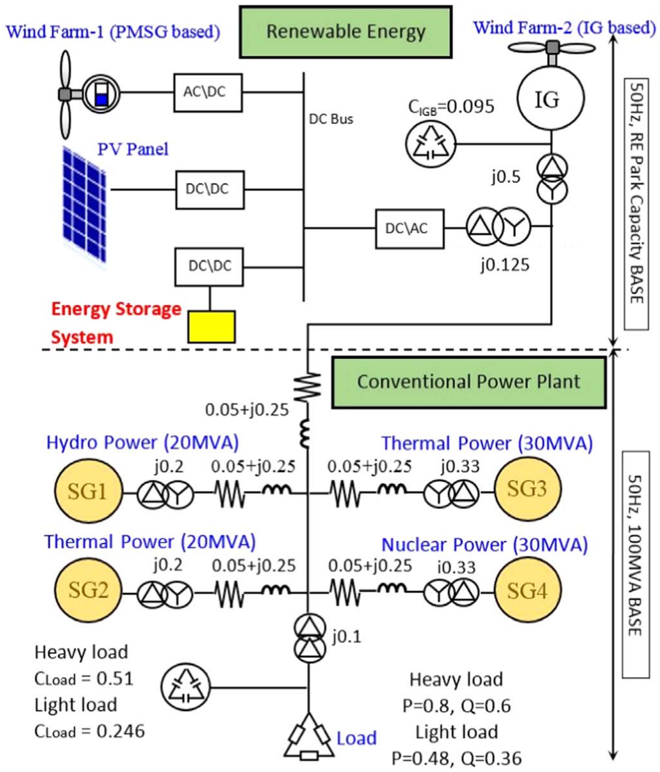

Fig. 3. Smart grid with energy storage system.

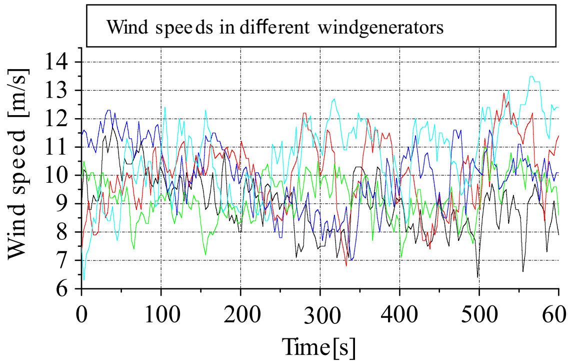

Fig. 4. Wind speed in Hokkaido Island, Japan.

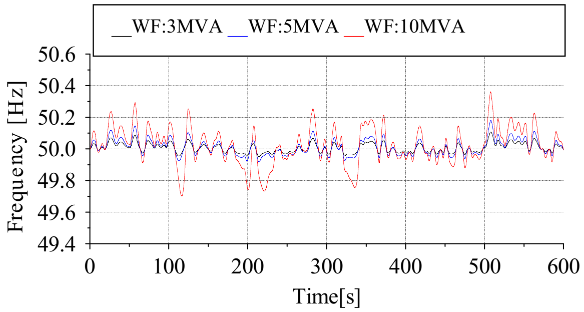

Fig. 5. Frequency fluctuation at heavy load (conventional pitch controller).

4.1.3. Loads

Microgrids can supply electrical energy to different types of loads such as residential, commercial, and industrial. These loads can be categorized into two sections: critical load and noncritical loads. In general, commercial and industrial users are defined as critical loads, which require high degree of power quality and reliability, while most of residential loads are considered as non-critical loads, which require a lower service quality [12]. The load classification provides advantages listed below while to get the desired operation, stability and control [23,44]:

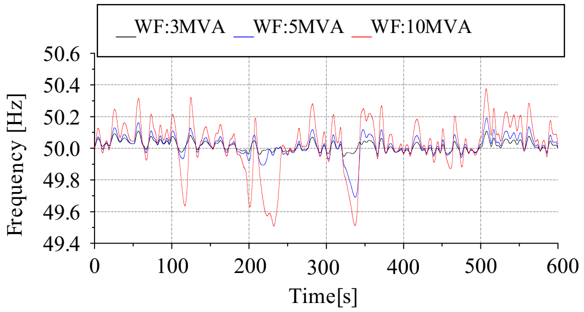

Fig. 6. Frequency fluctuation at low load (conventional pitch controller).

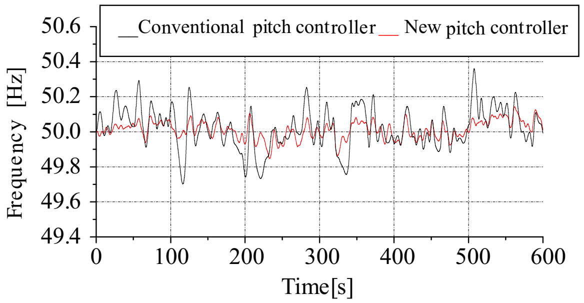

Fig. 7. Frequency fluctuation at heavy load (conventional and new pitch controllers).

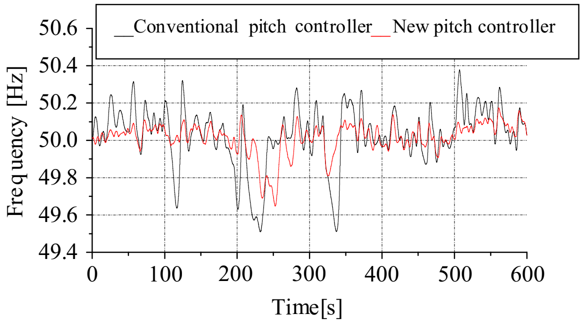

Fig. 8. Frequency fluctuation at low load (conventional and new pitch controllers).

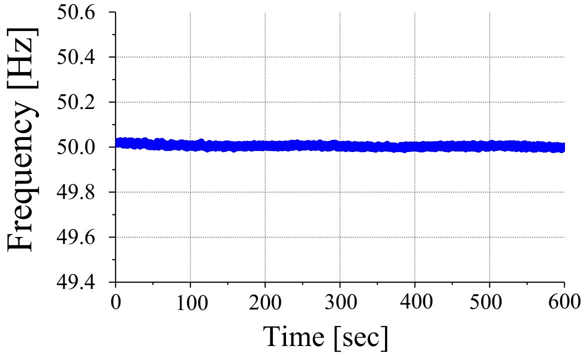

Fig. 9. Frequency fluctuation at low load (using ESS).

i. the load/source operation strategy required to meet the net active/reactive power in grid-tied mode, and stabilization of the voltage and frequency in island mode,
ii. improvement power quality and reliability of critical and sensitive loads,
iii. reduction of peak load to enhance the DER ratings,

iv. maintaining desired operation and control.

4.2. Advanced forecasting

4.2.1. Demand (load) forecasting

Demand (Load) forecasting [45,46] plays a crucial role in smart grid. The aim of demand forecasting is to accurately predict future energy requirements of system for specific period of time. That prediction helps unit commitment strategies to match demands and generations. Since demands depend on weather conditions and activities of customers, predictions may be for the next 24/48 h in hourly for operation process, and may be for 20–50 years for planning purposes [47]. Many of methods for demand forecasting are introduced in literature. These methods can be classified as two sections: i) statistical based methods, ii) artificial intelligence (AI) based methods. Statistical based methods include Auto Regressive (AR) [48], Moving Average (MA) [49], Auto Regressive Moving Average (ARMA) [45], and Auto Regressive Integrated Moving Average (ARIMA) [50]. Some of the artificial intelligence based forecasting models are Artificial Neural Network(ANN) [51], Grey-Back Propagation (GBP) Neural Network [52], improved variable learning rate back propagation (IVL-BP) [53], support vector machines (SVMs) [54], Least Squares-Support Vector Machine (LS-SVM) Algorithm [55], particle swarm optimization (PSO) [56], and fuzzy logic (FL) [57].

4.2.2. Electricity price forecasting

Electricity price forecasting may be important in real time electricity markets. Extreme difference between the agreed cost and the cost of the power to be sold can lead to huge financial losses or even bankrupt [58]. In the literature [59,60], authors investigated relationship between electricity price and demand.

4.2.3. Wind and PV production forecasting

The output power of renewable energy sources such as wind energy, solar energy depends on several variables like weather, location, etc. Accurate forecasts of wind and PV output power can alleviate negative impacts on the required spinning reserves for reliable operation of the grid. They reduce the total cost of integration of renewable energy into the grid [61]. The methods used to forecast wind and PV [62] production are partly similar to demand forecasting methods [61]. For instance, in the literature, the methods of SVM [63,64], vector auto regression theory [64], Bayesian Method with Monte Carlo [65] are used for PV.

4.3. Control of generation units

Smart grid technologies can include large amount of different DERs such as solar, wind or fuel cells that are connected to grid either directly or by power electronic interface. The voltage source inverter (VSI) is connected to grid as interface to contribute to proper adjustment of the grid voltage and frequency [66]. In the literature, while some authors classify VSI based DG interface as two groups, it is categorized in three groups by the other researchers. In this review study, these controllers are investigated under two topics as former classification: grid-forming and grid-following. A grid forming controller is responsible for voltage control between DG units and loads. A grid-following controller is generally used in current-control mode in order to maximize obtained power from DGs. This control strategy is the most widely used for DGs units, and the most common used grid-following techniques are synchronous reference frame (dq), stationary reference frame (αβ). [22,67,68]. M. Mehrasa [69] et al. proposed passivity-based control technique to improve system stability of DGs. In the [70], unbalance mitigation is investigated by using symmetrical component transformation for different types of grid-following controllers.

Besides the voltage and current control, DGs must also regulate active and reactive powers. The most used methods in smart grid are Q/f and P/V droop controller. When Q/f droop controller is used for reactive power compensation, active power controller uses P/V droop control [71–74].

4.4. Control of storage units

Energy storage devices are essential component of microgrids, which effectively balance power between renewable energy resources and loads. Specific charge/discharge control strategies are needed to achieve this objective. In the literature, different control strategies are available. Authors in Ref. [75] explained how to improve the wind output power rate using fuzzy control for energy storage system in wind farm. There are also hysteresis current control, neural network, PI and PID control, sliding mode control, H-infinity control, Monte Carlo simulation method among other strategies [30,76–78].

4.5. Data transmission and monitoring

4.5.1. Smart Metering Infrastructure (SMI)

Smart metering and infrastructure (SMI) [79,80], which is also called advanced metering infrastructure (AMI), provides bidirectional communication for smart grids. The SMI consists of integration of smart meters, communication system, hardware and software that enables the measurement, gathering, storage, analysis, and usage of energy between smart meter and utility or between smart meter and customer [81].

i. *Smart meter:* Smart meter is the advanced new generation of meters, which measures real-time consumption of energy, records and storages this measurement at predefined time intervals. It also has the ability to transfer bidirectional communications of data. Thus, data transfer realizes not only from smart meter to meter data management system (MDMS) but also from MDMS to smart meter [82,83]. In the [84], authors investigated the relationship between electricity consumers and smart meters and formed a report at the end of 2012 for Romania, which demonstrated that smart meter is user-friendly and profitable for customers, and is important to devote close attention to the customer in terms of acceptability and affordability of the smart meters.

ii. *Wide area network (WAN):* Wide area network (WAN) provides communication between smart grid and utility grid, which collects data from multiple NANs and sends it to control center [85]. It connects the highly distributed smaller area networks that serve the power systems at different locations. It consists of two types networks: backhaul and core network. A variety of technologies such as WiMAX, 4G, and PLC could be used in WAN networks. The WAN can cover over thousands of square miles area, so data transfer rates may be up to 10–100 Mbps [86].

iii. *Home (local) area network (HAN/LAN):* Home (local) area network (HAN or LAN) implement to in-home smart devices and appliances such as plug-in electric vehicles (PEVs), programmable communicating thermostats, in-home displays (IHD) and distributed energy generation facilities [82,83]. Typically, HANs need to cover areas of up to 200 m^2 and support from 10 to 100 kilobits per second (kbps) [85]. One important component of HAN is IHD that allows measuring how much power is consumed and displaying real-time energy price to the customers. IHD also allows the consumer to customize their power usage profile in order to minimize their electricity bill.

iv. *Neighborhood area networks (NANs):* Neighborhood Area Network (NAN) is one important component of communication network infrastructure that connected to smart meter in customer domain and some field gateways in distribution domain [87]. The NANs are used for data collection from smart meter to exchange energy data and control information between other components. This network can be designed based on wired and wireless communication technologies such as WiMAX, 3G and 4G. With these technologies, it covers long distances up to 1–10 square miles and the data rate is around 10–1000 Kbps [86].

v. *Meter data management system (MDMS):* A meter data management system (MDMS) is a system or an application which imports, verifies, edits and processes on the AMI data before making it available for billing an analysis [88].

4.5.2. *Communication systems*

Communication technologies are key feature of smart grids to implement in real world. Communication technologies to be chosen have to be cost efficient, and should provide good transmittable range, better security features, bandwidth, power quality and with least possible number of repetitions [82]. They can be classified into two categories: wired technologies and wireless technologies.

i. *Wired technologies*: Wired technologies may include three systems: Power line communication (PLC), Optical communication and Digital Subscriber Lines (DSL). PLC system is a popular method for communication [89], which consists of introduction of the modulated carrier over the power line cable in order to provide bidirectional communications [80]. The power line cable is used in both energy transmission and data communication. In a typical PLC network, smart meters are connected to the data concentrator through power lines. And data is transferred to the data center via cellular network technologies [81]. PLC systems use existing communication infrastructure. Thus, the cost of installation is lower than other communication system [90]. It can be classified two categories: Narrowband PLC and Broadband PLC. Fiber optic communication technology has been widely connected to substations to provide communication between substations and control centers. It has many advantages such as data transmission over long distances with very high data rate, lower losses and less expensive than traditional communication system. DSL is a high-speed communication technology using the wire of telephone lines. Because of using existing communication infrastructure, this technology reduces installation costs. The most important advantages of DSL are low-cost, high data rate and widespread availability [79,81].

ii. *Wireless technology:* Wireless Sensor Network (WSN) [91,92] is a crucial part in a smart grid that provides highly reliable and self-healing power grid, strong flexibility since a complex infrastructure construction is not needed [93]. WSN can improve efficiency and stability of network. In the smart grid, WSN collects and processes the specific and useful data in target area, and monitors control devices allowing bidirectional information exchange, monitoring, control and maintenance in real time [94–96]. Wifi which is the family of IEEE 802.11 standards is generally used for home and local area networking due to simple and flexible access structures based on CASMA/CA principle, operation in unlicensed 2.4 GHz and 5 GHz frequency bands, and availability low-cost radio interfaces [79]. The most popular among IEEE 802.11 standards are IEEE 802.11b and IEEE 802.11g, IEEE 802.11g supports data rates maximum 54 Mbps while IEEE 802.11b supports data rate up to 11 Mbps for indoor environment and 1 Mbps for outdoor environment. The latest release is the IEEE 802.11n that supports the highest data rates up to 150 Mbps [86,97]. In the smart grid, Wifi is the key connection for all smart devices to accessing the Internet and manage their energy usage. Especially, Wi-Fi is a superior technology for the HAN of the Smart Grid [98]. WiMAX (Worldwide Interoperability for Microwave Access) also known as the IEEE 802.16 standard is a wireless broadband technology. It supports thousands of simultaneous users over large distance (up to 48 km) with high data rates up to 70 Mbps. WiMAX technology provides reliable, high data rate and automatic network connectivity along with low overall installation costs and large coverage area for the Smart Grid Applications [97,99,100]. GSM/ GPRS technologies are a good option for communicating between smart meters and the utility, which transfers data and control signals over long distances [81]. Global System for Mobile (GSM) is considered among the most secure communication networks. General Packet Radio Service (GPRS) employs wireless packet based on GSM network. If the infrastructure exists, extra cost for building the communications infrastructure will not be needed. In Smart Grid applications mostly it is used for remote monitoring purposes [97]. Satellite Technologies are used in rural or geographically remote locations where other communication technologies are not available. This technology has high cost. But recent developments in satellite systems may open up new opportunities for the use of satellite communications in smart grids [79]. ZigBee is relatively low in power usage, data rate, complexity and cost wireless communication technology based on the IEEE 802.15.4 standard. It is used for home automation, security systems, remote control, smart meter, healthcare, computer peripheral applications and so on [101,102].

4.6. *Power flow and energy management*

An energy management system (EMS) [103] is a control tool which controls the power flows among main grid, DERs and loads in order to provide stable, reliable and sustainable operation of microgrid, and other operational goals such as minimizing costs, fuel consumption [104,105]. It is also responsible for system resynchronization during transition between grid and island mode. Two main approaches can be identified for EMS: decentralized and centralized control, with various hierarchical controls [106–108].

4.6.1. *Centralized controller*

The centralized controller gathers all the measured data of all DERs in microgrid, and then adjusts the control variable for each control equipment and sends them to central system [109]. This control is especially very suitable for small scale MGs. However, this type of control has low reliability and redundancy. Other drawbacks of this control are that may cause several communication problems, and requires shutdown the whole system in case of system maintenance.

From an economic point of view, centralized hierarchical control provides efficient solution. The hierarchical control architecture depends on the type of microgrid or the existing infrastructure. In this case, a centralized hierarchical control scheme may consist of three layers controller: a) Local controllers, b) Microgrid central controller (MGCC) [110], c) Distribution management system (DMS). The local controllers use local measurements to control voltages and frequency of MG system without communication systems, because communication system is often avoided due to reliability reasons. A MGCC is available for each microgrid to interface with DMS. The MGCC performs power management of microgrid by determining DERs active power, load demand and storage requirements. The MGCC has a two-way communication with LC, which enables to meet the utility requirements [111]. At DMS level, overall grid demands and stability requirements are met [112].

4.6.2. *Decentralized controller*

The decentralized EMS enables to independently control of DER units and loads. This type EMS is more suitable if users of microgrid have different aims or a different operational environment. In this management system, all local controllers are connected with communication bus. This bus is used to exchange data among each household or DG [105]. Local controllers are no longer subject to a MGCC to determine the optimal power output in such a distributed system. Hence, this kind of structure significantly reduces the computational need and releases the stress on the communication network of the entire microgrid system [104].

The multi-agent system (MAS) approach can be the best example of decentralized energy management system [113]. This approach is aimed to make large and complex systems to small and autonomy subsystems, and is used artificial intelligence based methods such as neural network, fuzzy systems to determine each DG's operation point while improving the stability of microgrid [105].

The decentralized based MAS has several advantages compared with centralized EMS. Since the MAS enables to autonomously operate DGs and uses the essential data from local controller, it reduces computation time. But the centralised control requires a significant flow of data to a central point [114,115]. Another advantage is plug-and-play capability. If a new DER is connected to the microgrid, a programmable agent in its control is provided without modifying the rest of the control. However, in centralised controls the MGCC has to be programmed when a new DER is connected [115].

4.7. Vehicle to grid (V2G)

Recently, vehicle to grid (V2G) technologies are more attractive to researchers in smart grid, which can improve efficiency, reliability, stability, and flexibility of the utility grid. Under this concept, electric vehicles can either be charged or discharge by providing power to grid; in other words either the utility grid can absorb power from V2G or the grid can send power back to the electric vehicle during charging. By providing power to grid, this technology provides many benefits such as voltage and frequency regulation, spinning reserve, electrical demand side management, active/reactive power compensation, load balancing, and harmonic filtering. Furthermore, the electric vehicles would be used to store power produced by renewable energy resources [116–119]. V2G is also used both unidirectional and bidirectional applications [120]. K.M. Tan et al. [121] classify the V2G technology to two categories: unidirectional V2G and bidirectional V2G. This paper also presents advantages and disadvantages, and optimization algorithms of V2G in smart grid. In the [122], authors examined requirements, economic costs, benefits and limitations of V2G technology.

5. Challenges and opportunıtıes

5.1. Technical challenges

5.1.1. Operation

Large mismatches which lead to a severe frequency and voltage control problems occur between generation and loads, because microgrid systems have ability to transition from grid-connected mode to islanded mode [44,123]. If the connection and disconnection operations contain a large number of generation units at once, the "plug and play" capability can be a serious problem [124].

5.1.2. Components and compatibility

Because a microgrid may have many components such as diesel generator, microturbine, fuel cell, CHP, energy storage devices, inverters, communication system, control software and so on, these components have different characteristic in their generation capacity, startup/shutdown time, operation cost/efficiency, energy storage charging/discharging rate, control and communication limits [44,125].

5.1.3. Integration of renewable generation

The variability, unpredictability, and weather dependence of renewable energy resources are several of the major challenges for integration of renewable generation to main grid. Therefore, the power output of these resources can vary abruptly and frequently and imposes challenges on maintaining microgrid stability [8,126,127]. Furthermore, one of the problems experienced is that the increasing renewable shares may cause congestion in distribution networks [128]. Other problems may include the intermittency of renewable energy generation and the lack of dispatch ability.

5.1.4. Protection

Microgrid protection is the most important challenges since it is not easy to design an appropriate protection system that must respond to both main grid and microgrid faults. That is because fault current magnitudes in the system depend on the microgrid operation mode, and may vary significantly between grid-connected and autonomous operation [129]. Traditional power systems have been designed and constructed with unidirectional fault current flow for radial distribution systems. But the integration of DGs into main grid with microgrids changes the flow of fault currents from unidirectional to bidirectional. Microgrid is interfaced to main power system by a fast static switch to protect a microgrid in both the modes of operation against all types of faults [123]. Several papers in the literature review existing microgrid protection schemes [130–132].

5.2. Regulation challenges

Regulation is a crucial topic to facilitate microgrid application, which provides guidance and allows DER penetration, integration, and main network connection. But regulations for microgrid implementation are limited and prevent the properly use of microgrids. Moreover, interconnection rules between microgrid and main grid are designed in order to standardize the process and manage the impacts of DG integration without disturbing the functionality and safety of the main grid [44]. These rules must immediately disconnect with grid connection in case of any faults, blackouts, etc. However, the most complained challenge to interconnect microgrids with main grid is the high connectivity costs because of high connection fee policies [133].

5.3. Smart consumer

The smart consumers are members of end users in the future smart grid and take an active role in the problem of balancing demand with supply [134]. They are mostly interested in decreasing the electricity bill, at least maintaining present levels of comfort, availability and ease of use when they are against the volatile production capacity over volume and time [134,135]. With the consumers providing an active participation in the management of the demand, utilizing the intelligent information and communication technology devices (ICT) has become widespread in domestic environments [136]. It is easy to envision that in the near future smart homes will be equipped with energy management systems in order to optimize the electricity consumption, to minimize costs and meet supply constraints, while at the same time keeping the desired level of comfort for the users [137].

5.4. Opportunities in microgrid

Some of the possible solutions used in literature for microgrid challenges are summarized below:

- Stability and reliability problems occurred due to integration of renewable energy resources will solve with the FACTs devices like static synchronous compensator (STATCOM), static VAR compensator (SVC), static series synchronous compensator (SSSC) and unified power flow controller (UPFC). Additionally, the harmonics resulting from power circuits will be mitigated by filters integrated these devices [127]. The stability classifications and analysis methods for microgrid have been investigated in Ref. [138]. Also researchers compiled available methodologies to improve the microgrid stability.
- The study [139] present a protection scheme in microgrid for both of modes of operation based on microprocessor-based overcurrent relays and directional elements. Among other protection solution methods: adaptive protection system [140], symmetrical component theory [141], differential protection [142].

- Fast static switch, fault current limiter and energy storage devices can be used as external protection devices [143]. Fast static switch provides high-speed isolation for loads when transition from grid-connected to islanded mode.
- Some authors investigate novel algorithms to minimize system costs [144–147]. The [148] mixed integer programming optimization method is used to minimize total system costs including investment and operation costs of candidate generation units, transmission lines and microgrids. The paper [149] proposed decentralized voltage control algorithm, which is designed with two control layer. When low control layer regulates the power output and terminal voltage, high level controller minimizes power losses of microgrid with cost function concept.
- The study [150] proposed a new islanding detection method (IDM) with intelligent hybrid automatic transfer switch (HATS). The HATS provides detects operation modes of microgrid and is able to manage grid status.

6. Conclusıon

Power system is facing with challenges to provide efficient, reliable energy to customer. One of the big challenges is increasing energy demand while primary energy supplies are being limited. That necessitates that more generation should be provided by distributed energy sources. That brings new problems such as uncertain power generation and intermittency. That problem also requires storage units to provide better power quality. A better way to solve problems of energy demand, uncertain and non-sustainable power from renewable sources is to take a small subsystem approach to match demand and supply balance. This was the key motivation for microgrid development and expansion.

The inherent characteristics of microgrids are providing flexibility to connect/disconnect from grid when needed. That feature of microgrid provides better reliability, lower investment cost, reduce emissions, improve power quality, and reduce the power losses of distribution network. This review provides technical development status of existing microgrid with it's various functions and features. The microgrid architecture is categorized into three categories based on future smart grid vision, i.e., AC, DC, and hybrid microgrids.

Elements that used in microgrid, control of generation, forecasting techniques, data transmission and monitoring techniques are reviewed as smart grid functions. It is possible to implement microgrid with the usage of these functions, but these still cannot solve all issues.

Finally, somel other important issues to implement microgrid are discussed: technical, regulation, and customer barriers, and opportunities to solve these barriers are presented.

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