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Chapter 4

Microgrid Integration

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http://dx.doi.org/10.5772/intechopen.78634

Abstract

Hybrid energy systems are becoming attractive to supply electricity to rural areas in all aspects like reliability, sustainability, and environmental concerns, and advances in renewable energy technology; especially for communities living far in areas where grid extension is difficult so generation of renewable energy resources like solar and wind energy to provide reliable power supply with improved system efficiency and significant cost reduction is best way. Besides this, the demand for renewable energy source in large urban cities is increasing, and their integration to the existing conventional grid has become more fascinating challenges. So the future requires stable and reliable integration of renewable distributed generators to the grid, and the local loads are close to distributed generators. Most existing power plants have centralized control system and remote power generation site while most renewable power generations are distributed and connected to lower or medium voltage networks near the customer. When the power demand increases, power failure and energy shortage also increase so the renewable energy can be used to provide constant and sustainable power. The chapter will provide a complete overview of microgrid system with its complete operation and control.

Keywords: distributed generation (DG), microgrid, grid integration and control, renewable energy

1. Introduction

The conventional power network comprises large generating stations with extra high voltage links, which connect transmission substations with distribution system for delivering power to end users. Therefore, the basic concept in traditional power system is the central controlling with unidirectional energy flow for transmitting power to load centers.

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Renewable sources of energy are becoming the most important sources for supplying electrical energy straight to the customer without traditional distribution system, especially for communities living far in areas where grid extension is difficult so generation of green sources such as photovoltaic (PV) and wind power for providing reliable energy with improved system efficiency and significant cost reduction is best way. Therefore, renewable energy sources are the most sustainable remedies for producing energy and heat. The main advantages of renewable energy sources are the instant availability, less dependence on fossils fuels, low cost variation, and no transportation cost with higher economic efficiency [1].

Microgrid is among the new technology that has attracted a great attention; recently, the dependency on the centralized power system is changing; and replaced by smaller and more distributed generation (DG) located closer to load to meet their requirements effectively and heat. That is, everyone is a producer and consumer of energy at the same time; by doing so, they became energy independent from the overcharging utility companies. Microgrids are not a replacement for traditional utility infrastructure. From the utility viewpoint, the transmission and distribution cost is lowered; reduction in line losses, network congestion, and load shedding; improvement in power quality and reliability; and reduction in infrastructure investment needs.

Microgrid consists of group of multiple distributed sources with interconnected demands. It is operated either in stand-alone mode or grid connected mode [2, 3]. Microgrid can be defined as a system or a subsystem, which incorporates single, or multiple sources, controlled demands, energy storage systems, security and supervision system. These elements and subsystems make microgrid operational in utility integrated or isolated mode. Here, the main function of the utility grid is to maintain system frequency and bus voltage by supplying deficient power instantly [4]. Microgrid consists of bidirectional connections that means it can transmit and receive power from utility grid. Wherever any fault occurred on utility grid, microgrid switched to stand-alone mode [5]. Even though, emerging power electronic (PE) technologies and digital control systems make possible to build advanced microgrids capable to operate independently from the grid and integrating multiple distributed energy resources. There are a lot of challenges in integration, control, and operation of microgrid to whole distribution system. Microgrid is not designed to handle the large power being fed by the utility distribution feeders. Further, the characteristic of large microgrid components possesses big challenges. The issues related to the integration of microgrid raise the challenges to operation and control of main utility grid. Therefore, this chapter deals with the various microgrid integration issues faced by the main utility in the practical power system.

2. Microgrid power system

Microgrid system is a configuration of single or multiple renewable energy sources with even nonconventional sources as main energy generation source, so that the capacity shortage of power from one source will substitute by other available sources to provide sustainable power. Additionally, it incorporates energy storage and power electronics circuitry [6]. Some of the components produce direct current (DC) power and other alternating current (AC) power directly with no use of converter.

2.1. Microgrid power systems configurations

Microgrid is configured based on the following technical topologies to couple the available renewable sources and to meet the required load. Here, voltage and the load demand are the determinant factors. According to [6, 7], any power system configurations are grouped in the following forms.

2.1.1. AC/DC-coupled microgrid systems

Different configurations are described in [8, 9] for the microgrid, which contains wind turbine, PV system, a diesel generator, and a battery storage system. Generally, for microgrid technological configurations, three established classes are there and are discussed below.

2.1.1.1. Microgrid systems: AC coupled

In this configuration, various renewable sources and the energy storage system are linked at the AC bus with the demands. For this type of configuration, two subcategories are available.

2.1.1.1.1. Centralized AC-coupled microgrid

All the elements are linked to the AC bus. AC power producing elements are connected to AC line in direct manner or with the help of AC/AC converter, for getting even component coupling topology. For controlling the energy flow to the battery and from the battery to the load, the master inverter required. Furthermore, DC electricity can be provided from battery if needed. **Figure 1** depicts centralized AC-coupled hybrid system configuration.

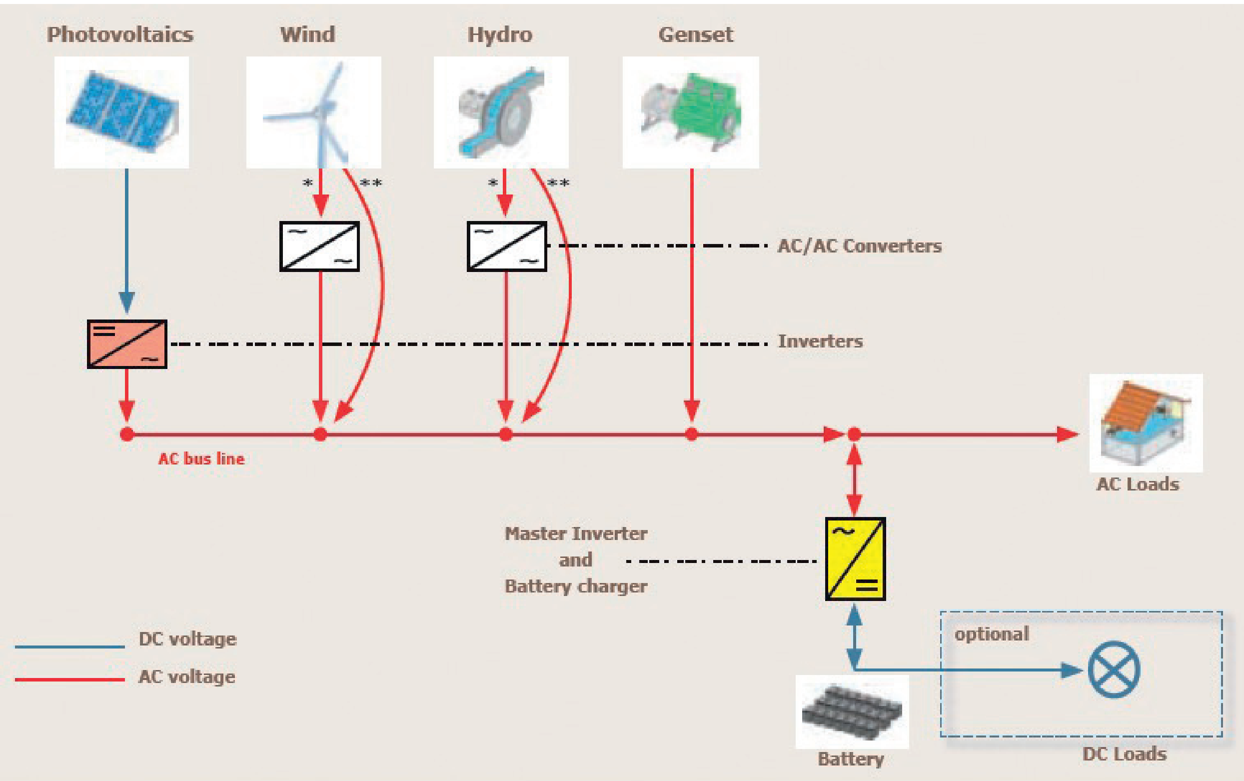

Figure 1. AC-coupled centralized microgrids [10].

2.1.1.1.2. Decentralized AC-coupled microgrid

In this type of architecture, all the technologies are not connected to any of the bus, rather they individually connect to the load directly as shown in **Figure 2**. The energy sources may not be situated in one location or close to one another and they can connect to the load from anywhere the renewable resources are available. The merit of such configuration is that the power-generating components can install from the location where renewable resource is available. But it has a disadvantage due to the difficulty of power control of the system. Thus, comparing the two configurations, the centralized system is better due to its controllability than the distributed system [6].

2.1.1.2. Microgrid system: DC coupled

In the direct current (DC) combination, all the energy sources are linked to the DC bus prior to connect the AC bus as illustrated in **Figure 3**. All AC power sources are converted to DC and then linked to the AC demand by using converter. The merit of DC-coupled topology is that the demand is met with no cutoffs. Despite the advantage of this, it has disadvantages of low conversion efficiency and no power control of diesel generator. Wind turbine and diesel generator produce AC voltage and need AC/DC converter to supply appropriate load to the

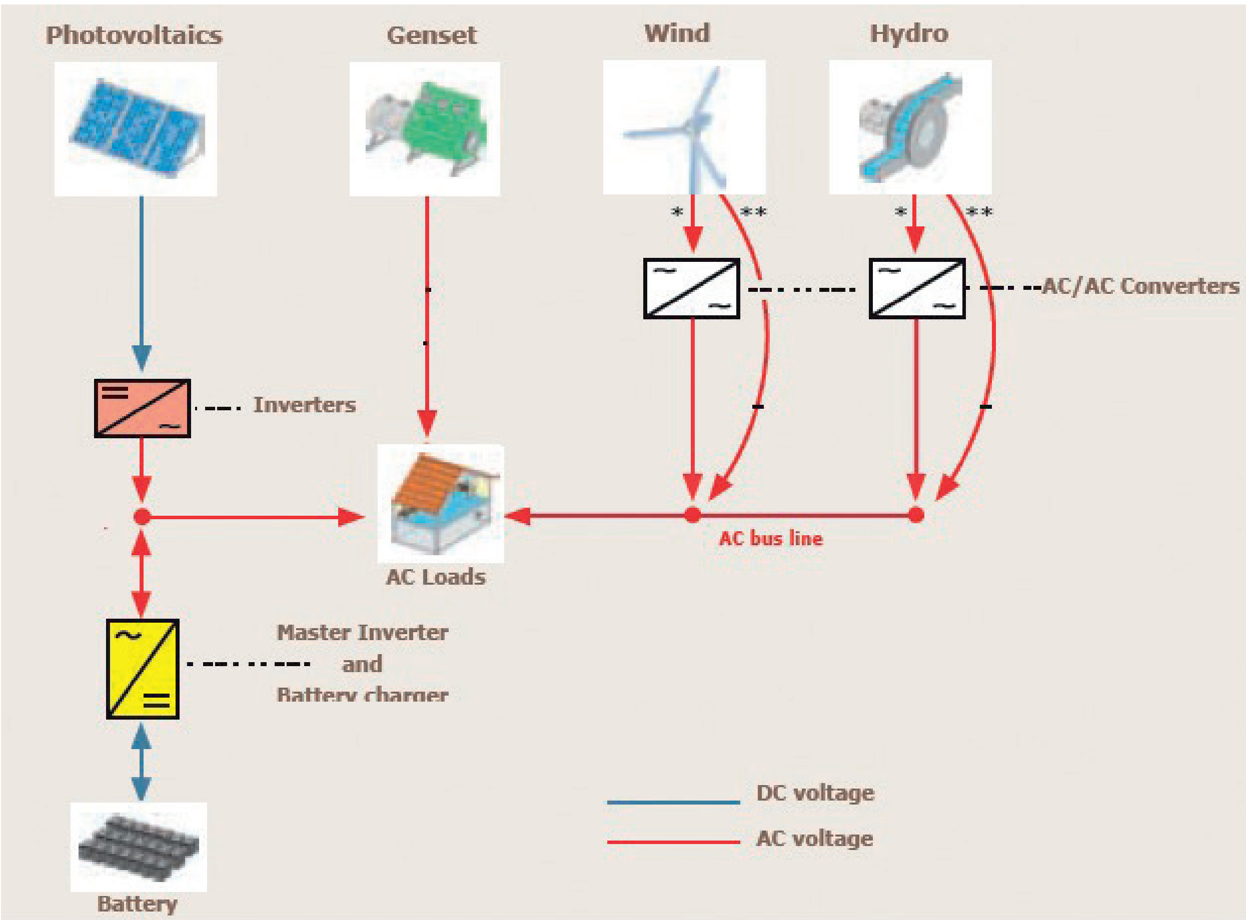

Figure 2. Decentralized AC-coupled microgrids [10].

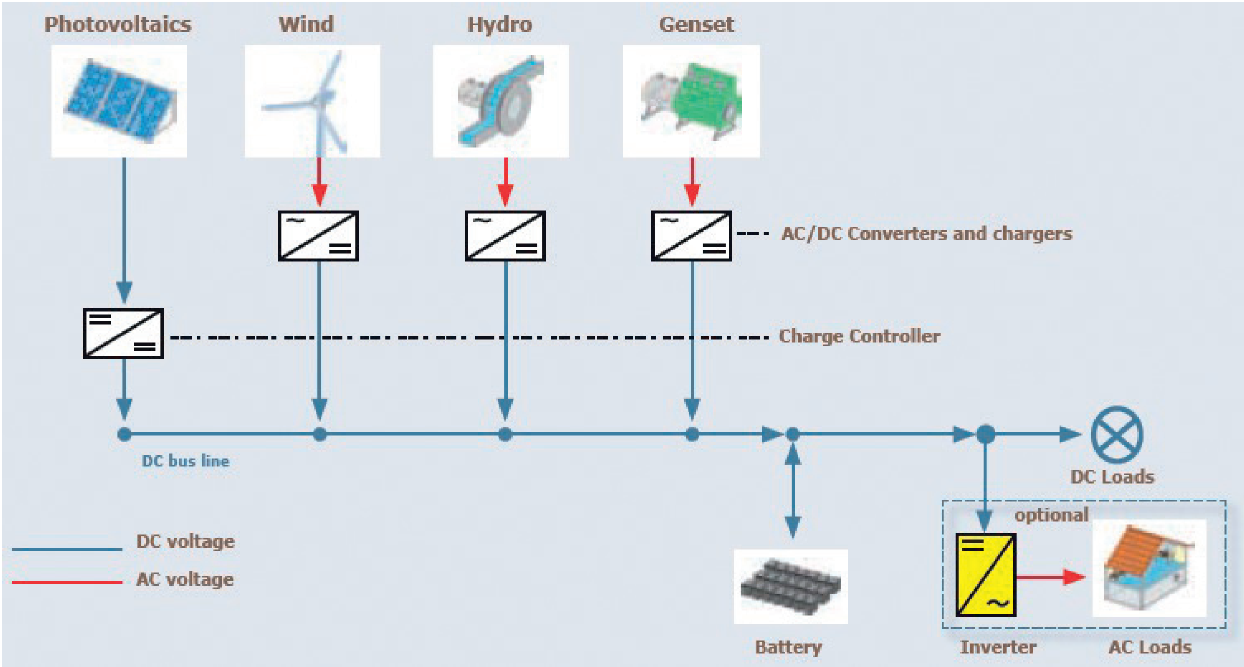

Figure 3. DC-coupled microgrids [10].

DC bus. Charge controller is also employed to protect the deep discharge and over charge of the battery. If required, AC load can be supplied using inverter.

2.1.1.3. Microgrid system: mixed coupled

There is a possibility to join AC- and DC-coupled microgrid systems. This type is called mixed-coupled microgrid system [8, 9]. In this kind of topology, some renewable are linked with battery storage at DC bus, while others are linked with DC at AC bus. **Figure 4** presents such configuration.

2.1.2. Series/parallel microgrid power system

Microgrid systems are also categorized on the basis of type of supply provided to the demands from renewables and diesel generators [6, 11]. Series and parallel hybrid microgrid are the two configurations and their detail discussions are given as follows.

2.1.2.1. Series microgrid power system

In this configuration, all the generated DC power supplied to the battery. Therefore, the energy produced by the PV, wind, and diesel generator is utilized for charging battery storage. Hence, charge controller is equipped with each component, other than diesel generator. Diesel generator is equipped with a rectifier. Afterward, inverter converts the DC power into standard AC power and feed to the AC demands. Overcharging of the battery storage by PV/wind is prevented by charge controllers. Similarly, deep discharging of the battery bank is also prevented by the charge controller. This topology is also called centralized DC bus

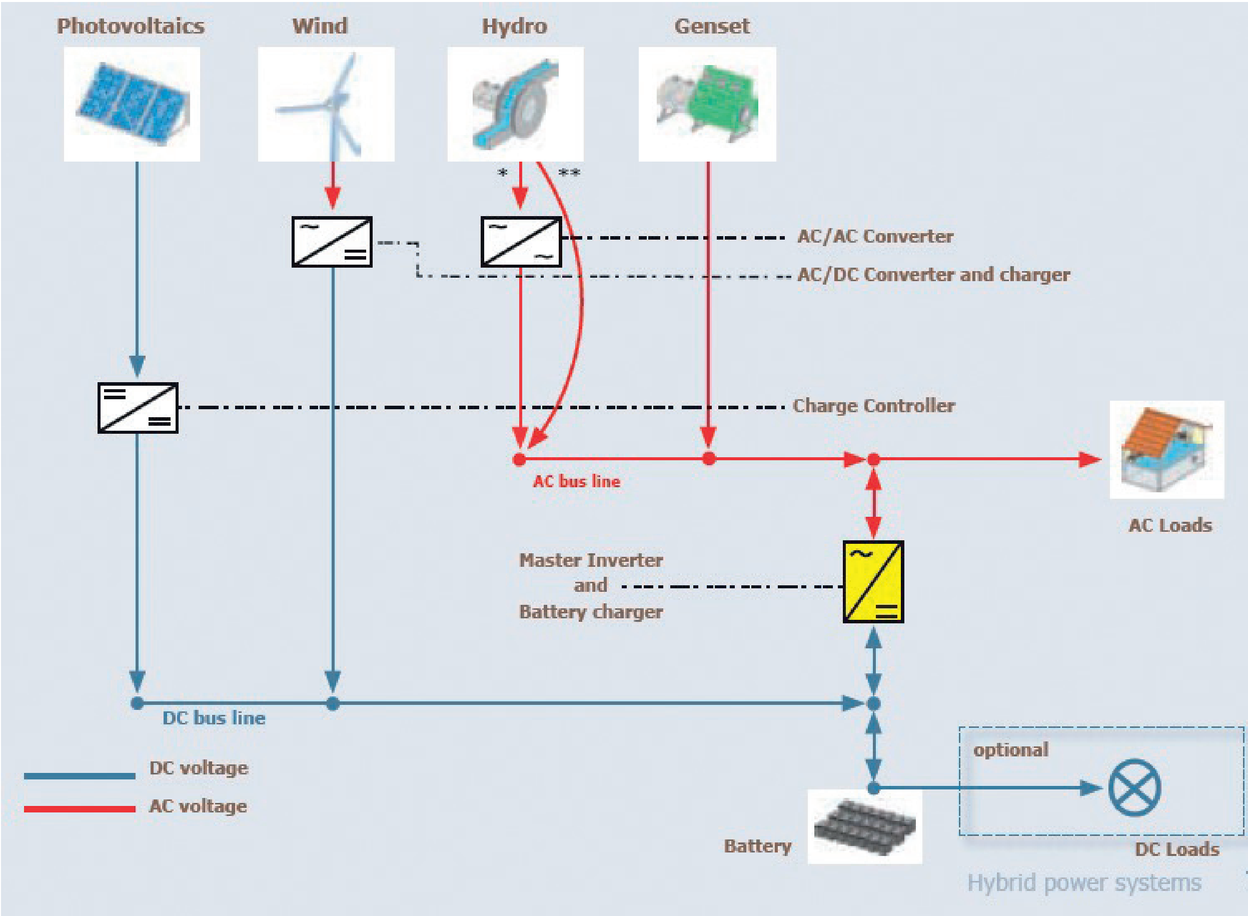

Figure 4. Mixed microgrids [10].

configuration, because all the sources are linked to DC bus and load is fed through a single point. **Figure 3** presents series microgrid power system.

2.1.2.2. Parallel microgrid power system

In this type of configuration, a part of supply demand is directly fed by the renewable sources and diesel generator directly. This configuration further classified into two subconfigurations: DC coupled and AC coupled, which are already discussed in this chapter in previous section.

3. Microgrid structure

It is a distribution network which is supplied through low and medium voltage distribution lines. Various self-sufficient and independent distributed energy sources, i.e., PV, wind, fuel cell, microhydro, etc., and storage devices such as battery storage, flywheel storage, etc., along with demands, are incorporated and grouped inside microgrid structure. **Figure 5** presents a typical overview of microgrid structure. Different distributed energy sources are integrated in microgrids by its corresponding bus bars equipped with power electronics converter. Point of common coupling (PCC) is the point where microgrid is connected to the upstream network.

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There are two modes in which microgrid operates. The first one is the grid connected mode and another one is the stand-alone mode or islanded mode. In grid interfaced mode of operation, PCC is closed and microgrid is linked with utility grid. Whenever there is any disturbance in utility grid or microgrid, PCC is opened and a microgrid is disconnected to the main grid, then the microgrid is operated in stand-alone mode [11].

There are two types of microgrids available. They are AC microgrid and DC microgrid, which are depending on distributed sources and demands connected. DC grid has the advantage of easier control. Further, it does not require DC-AC or AC-DC converters; therefore, it provides lower cost and better efficiency. On the other hand, AC grid has the advantage of full utilization of available AC grid technologies but it requires synchronization and stability from the reactive power point of view [12]. **Figure 6** presents the massive DGs in the power system.

DGs provide sufficient generation to supply all, or mostly loads connected, which is linked to the microgrid. While many renewable energy systems (RES) are large scale and are connected directly to the transmission system, there are small-scale and interconnected distributed energy resources located near consumption points within low-voltage electric distribution to achieve efficient and economical requisites. DG should be provided at strategic points in the microgrid system. These strategic points may be load centers. So that, these sources provide voltage and capacity support, reduce line losses, and improve stability [14].

The renewable energy production is further classified into dispatchable and nondispatchable production. Dispatchable production is able to change their power production upon demand and by the request of grid operators. They are microhydro and megahydropower, ocean/marine current power and wave power, geothermal and ocean thermal energy conversion, biofuel biomass, etc. [15]. Nondispatchable renewable energy-based generators are wind

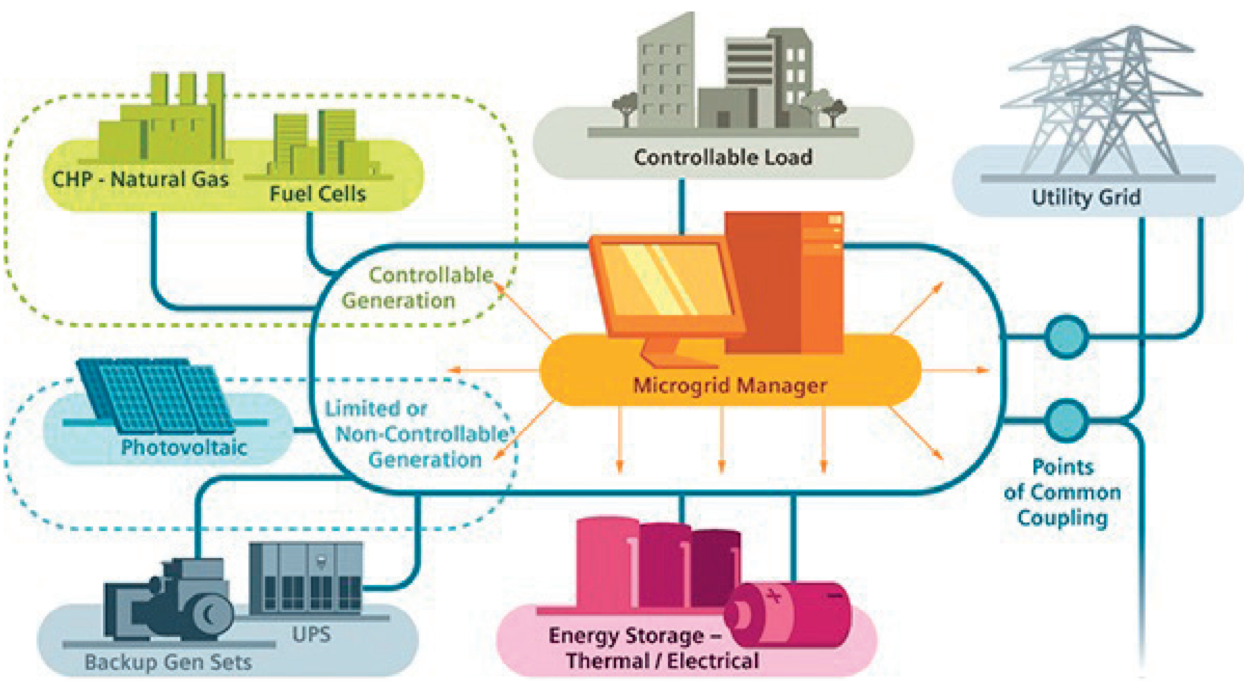

Figure 5. Microgrid power system [10].

Figure 6. Massive DGs in the electrical network [13].

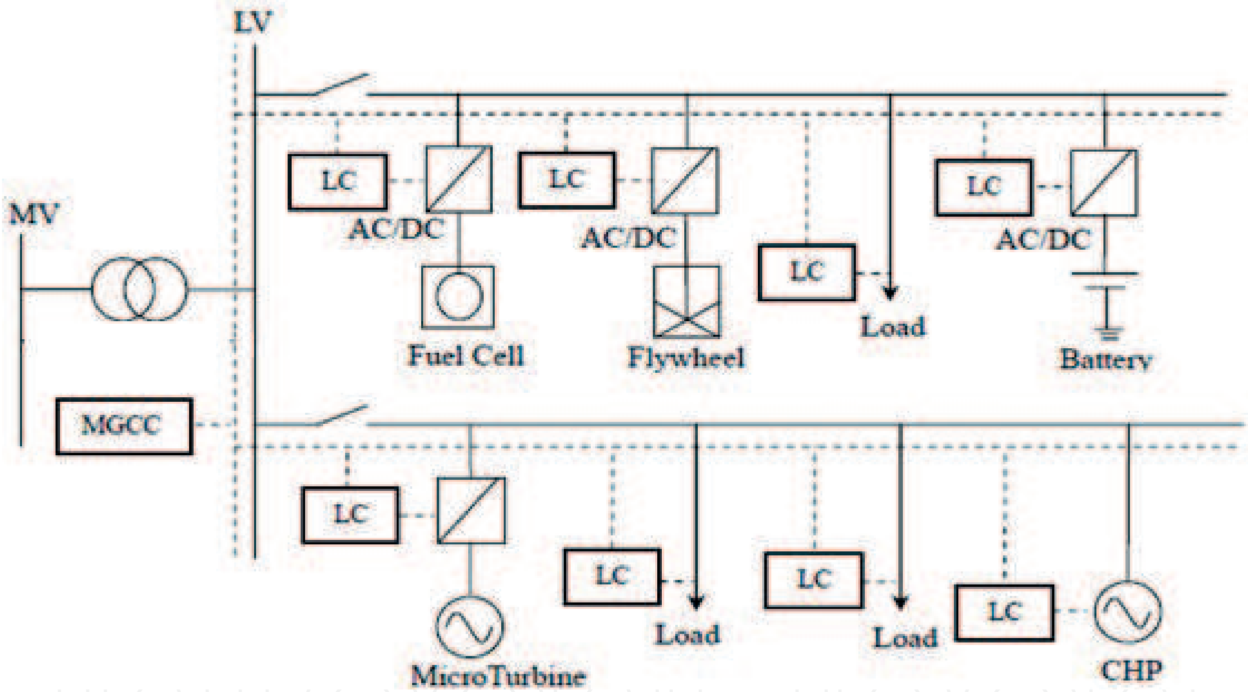

Figure 7. Basic microgrid architecture with an MGCC [17].

energy and photo voltaic, because wind turbine output depends on the wind speed and solar power available by the radiant light and heat of the sun [16].

3.1. Basic microgrid architectures

The assumed simple structure of microgrid network will be radial with several distribution feeders from different substations and a collection of loads and energy sources as illustrated in **Figure 7**. The radial power line arrangement is connected to the main utility grid at the point of common coupling (PCC) through a separation device, usually a static switch; having circuit breaker and a power flow controller for each feeder line [17]. The limited capacity

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of distribution generators has resulted in the development of several microgrids, which are interconnected to each other and operate with or without the main grid.

The overall architecture of a microgrid consists of an LV network on the consumer load side (both critical and noncritical loads), both noncontrollable and controllable power generators, energy storage units, and a hierarchical energy management. Controlling and monitoring each DG and loads and also managing energy system require communication infrastructure to support the control scheme so that the microgrid central control (MGCC), the center for the hierarchical control system, followed sequential low control level, like local controllers (LCs) of loads and DGs which exchange information with the MGCC for managing the whole MG operation by providing set-points to LCs. The common relevant data in exchange include mainly information about MG switch orders that are sent by the MGCC to LC and the sensed voltage/current information to MGCC from each local capture; power and frequency reference setting for each source and the state charge and discharge of the energy storage, and the protection device conditions the system in the case of fault happening to isolate the abnormal zone of the system.

3.2. Integration of microgrid to the main grid

Most of the small-scale DG sources in the load side are integrated at medium or low voltage network as low penetration fashion where they are connected as passive systems and they are not involving grid voltage controlling, frequency controlling, and stability activities. Still in the case of high penetration, the interfaces can be modified to work as active generators so that DER can participate in the frequency, voltage, and system stability control activities of the grid. Power electronic is used to interfaces between the grid and the renewable power source of microgrid so that there are not any negative influences in reliability, stability, and power quality of the supply after the interconnection DERs to the grid. Numerous components and constraints are involved in the integration of DER to the utility grid [18]. The integration of varying intermittent renewable sources like solar and wind energy conversion systems to the grid can provide a technical relief in the form of reduced losses, reduced network flows, and voltage drops. However, there are also several undesirable impacts due to high penetration of these variable DERs which include voltage swell, voltage fluctuations, reverse power flow, changes in power factor, injection of unwanted harmonics, frequency regulation issues, fault currents, and grounding issues and unintentional islanding [18]. Advanced protection system should be included in the DG units to disconnect the units in case of fault or unfavorable grid conditions.

Grid integration of distributed renewable sources are classified depending on the resource availability, load demand, and existing electrical power system, into three categories namely low penetration with existing grid, high penetration with existing grid, and high penetration with future smart-microgrid configuration.

3.2.1. Low penetration with existing grid

In low penetrated networks, the distributed generator units are not involving in frequency control activities and voltage control activities of the PCC point. Grid operator is responsible for managing the overall system stability, and DG operators can send the maximum available power to main grid and local loads without major consideration of grid constraints.

The DG operators have to deliver the power based by grid synchronization via PLL systems with correct phase sequence. Whenever grid frequency exceeds the allowable limit, the inverters are required to disconnect from the grid. And it operates in power factor (PF) correction mode, where PF keeps closer to unity. Most of PV units and wind generators can inject the maximum available active power into the grid; most existing voltage source converter (VSC) is operating in power factor correction mode (zero reactive power).

The network operators face real problem to when DG sources are connected to low-voltage lines since microgrids have dispersed generation units; sizes of the DGs are very small and low inertia characteristic, especially frequency deviations. The amount of DG units connecting to particular distribution network is limited by the voltage control margins of that distribution network; to overcome these challenges, static synchronous compensator (STATCOM), voltage source converter (VSC), automatic tap control transformers, and special control mechanism are used by operators to control the network voltage.

3.2.2. High penetration with existing grid

When growing the renewable energy source, penetration causes complication in the system constraints due to the intermittency of RES; that the percentage of the renewable power injected into the existing grid is relatively high as compared to the power assigned to the conventional power plant. Therefore, in such type of situation, intermittent power sources cannot work as passive generators, but they have to actively participate in grid frequency and voltage control activities. In addition to grid synchronization with phase sequence matching and protection system, controls and inverters should be more intelligent.

The grid operator cannot transfer the energy to or from main grid in the case of islanded power systems with a significant penetration of RES power, so the isolated system has to deal with intermittency issue. Since the amount of power delivered considerably effects the grid stability, phase-balanced operations and proper VSC inverter connection strategies have to be implemented in the system. Voltage control loop can be included in VSC inverters to provide the required reactive power to the grid, in this way VSC will intelligently response to the grid conditions. On the other hand, inverters have to operate within defined power factor range, not unit power factor so that VSC will have the capability to control the grid voltage at the PCC point.

3.2.3. High penetration with smart grid concepts

The combination of different renewable energy generation resources (such as microhydropower, photovoltaic arrays, geothermal, wind-turbine generators) in a microgrid can be integrating to the grid and increase the penetration of renewable energies to change the whole system into a smart grid with advanced technologies. Upcoming smart grid networks will provide a real-time, multidirectional flow of energy and information. Smart intelligent equipment with modern digital controls are used in entire electricity grid from central control office to end customer levels [18].

However, maintaining the stability and reliability of the network becomes a problem when the contribution from DGs is maximizing, then solution may be using smart grid concepts such as microgrids, large-scale energy storage with advanced energy management systems, smart homes with demand response management, etc. This will help in better communication and coordination between all the participants in the electricity business such as power plant operators, network operators, end consumers, and government.

3.3. Microgrid control

Generally, the control system must place at different level of the system and a consistent communication between several control units is required since there is a continuous change of power production in the DGs and the load demand in fluctuation with time. MG central controller (MGCC) installed at the medium-/low-voltage substation, which has a supervisory task of centrally control and managing the MG, integrates with the main grid. The MGCC includes several key functions, such as economically managing functions and control functionalities, is the head of the hierarchical control systems, and communicates between network operators.

The MG is intended to operate in the following two different operating conditions: the normal interconnected mode with a distribution network and the emergency mode in islanding operation via a central switch, which must also implement the synchronization between both power systems.

The typical single-line structure of a microgrid control system is described in **Figure 8**. It is clear that a direct connection of the microgrid LV line to DGRs (PV, wind generator, microturbine) and to the electrical grid network is not possible so power electronic interfaces (DC/AC or AC/DC/AC) are required due to the characteristics of the energy produced. Inverter control and circuit protection is thus an important concern in MG operation.

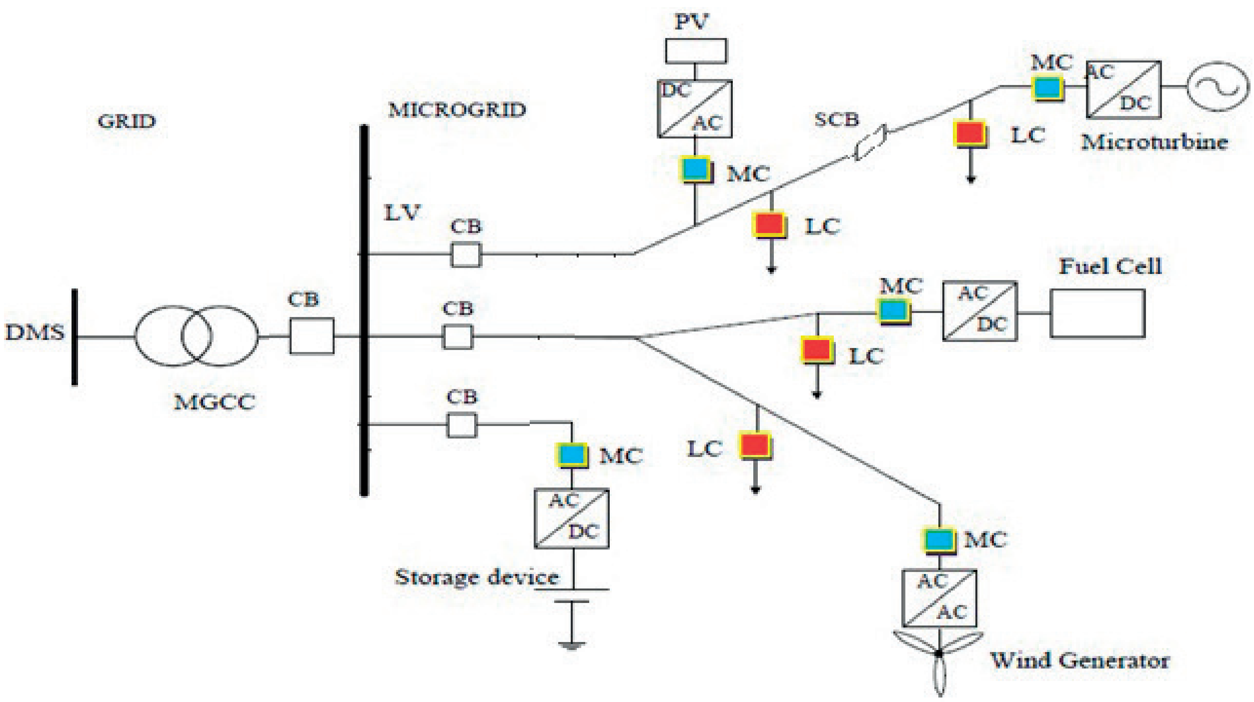

Figure 8. The microgrid control architecture [19].

In the microgrid control system, there are main parts including: microsource controllers (MCs) on the consumer production side and load controllers (LCs) on the consumer demand side; microgrid system central controller (MGCC) on the middle of the main grid; and microgrid structures and distribution management system (DMS) in the grid network side.

The different DG sources and energy storage devices are connected to the low feeder lines through the micro source controllers (MCs). MC has a function of controlling the power flow and bus voltage profile of the microsources according to the load changes or any other disturbances. These feeders are also supplied with several sectionalizing circuit breakers (SCBs) which help in isolating a part of the microgrid as needed in case trouble. Power electronics interfaces and inverters (AC/DC, AC/AC, DC/AC) are important mean for controlling and monitoring the loads using load controllers (LCs).

The overall operation and management in both the modes (isolated and grid-tied) is controlled and coordinated with the help of microsource controllers (MCs) at the local level and microgrid system central controller (MGCC) at the global level; there is a point of common coupling (PCC) through the circuit breakers (CBs) between the microgrid and the medium voltage-level utility grid. The MGCC is responsible for the overall control of microgrid operation and protection; like maintaining specified bus voltages and frequency of the entire microgrid; energy optimization for the microgrid. On the utility side, there is a distribution management systems (DMS) having several feeders including several microgrids; function for distribution area management and control.

So there are two parts in control tasks: first one is microgrid-side controller (MC and LC) to take the maximum power from the input source, and the protection of input-side converter must be considered. Second part is that grid-side controller (MGCC & DMS) which is having the following main tasks: (a) input active power control derived for network; (b) control of the reactive power transferred between network and microgrid; (c) DC link voltage control; (d) synchronization of network; and (e) assurance of power quality injected to the network [20].

3.4. Microgrid protection systems

The protection systems of a microgrid are very challenging since there is bidirectional flow of power in the system; in case of bulk power system, power flow is unidirectional. But with DG sources, the grid power flow become bidirectional; from both utility substation to microgrid energy storage and load or from local DG sources to the main grid or other microgrid, so there is a consistent reverse flow of current from maximum energy production to high energy consumption.

As a result, the old protection coordination schemes for the safety and stability in grid operations are no longer functional due to the different ways of the current flow for different operations; so innovative protection order is necessary for protecting the grid based on data collecting and information sharing to ensure proper operation in a microgrid.

The conventional overcurrent elecromechanical relay cannot sense the fault in the system since the fault current is limited and change direction depending upon the location of the fault. Sophisticated automatic protection system operation is essential for safe grid operation [20, 21]. Protection strategies can be based on communication, time grading, and other smart technologies like using microprocessors.

Differential relays offer perfect for transmission lines. They have many features over distance relays. These relays have better sensitivity.

A fast digital communication network is used to command the circuit breakers and protection relays from central control unit (MGCC). The digital current differential relays and wide area protection (WAP) are reliable and selective for the protection of microgrids when used with optical Ethernet-based communication, and wireless communications are also possible [21, 22].

The integration of distributed energy resources (DERs) into microgrid and/or into existing distribution systems faces a considerable challenge to existing power system protection. When the disturbance occurs in the utility grid system as well as in the microgrid protection system, microgrid must respond based on the location of the fault. First, when the disturbance happens in the utility grid, the protection has to trip the circuit to disconnect the microgrid from the main grid as quickly as possible by a fast semiconductor switch called static switch (SS). The other case is when the fault occurs within the microgrid, the protection system isolates the smallest possible zone of the distribution line to eliminate the fault [20].

If any events in the main grid appear, an islanded operating mode can be implemented because the electrical system is organized in the form of an MG with an MGCC. The MG islanding process may result from an intentional disconnection from the MV grid (due to maintenance needs) or from a forced disconnection (due to a fault in the MV network such as voltage dips). The disconnection is performed by a static bypass switch opening itself as a controllable load or source.

Protection system is one of the major challenges for microgrid which must react to both main grid and microgrid faults. The protection system should cut off the microgrid from the main grid as rapidly as necessary to protect the microgrid loads for the first case, and for the second case, the protection system should isolate the smallest part of the microgrid when clears the fault [23, 24].

4. Conclusion

The integration of microgrids with RES in the current utility grids is the first step toward the transition from the conventional power system to smart grid system. The main barrier to expand this technology is lack of readiness to change our dependence on the coal and oil-driven economy and life style, but the technology has been advancing, the Internet of things makes our societies to decide on different life choice. Most of the existing power system overall cost is also becoming expensive in the near future; RES technological improvement; advancement in energy storage systems can help the new microgrid system based on DG to become economically viable to consumer. More penetration of RESs is expected in microgrid systems as they are almost pollution-free and thus environment friendly.

Microgrid is well known in North America and Europe and used in those developed countries; however, there will be positive progress in less developing country to build their electricity and power infrastructure in a futuristic microgrid and smart grid model, one know that there is big financial obstacle and skill gap in those country but if there is the willingness from the government to transform their development plan into small-scale microgrid in power and heat demand.

In this chapter, the overall structural components of hybrid power system and the major challenges in the integration of microgrids like control and protection microgrids are presented. A significant research and development is required to transform and implement a microgrid system.

Acknowledgements

The authors are obliged to the authorities of Institute of Technology (IoT), Hawassa University for providing the enabling environment and support to carry out this work.

Conflict of interest

The authors declare no conflict of interest.

Notes/thanks/other declarations

The chapter is a collaborative effort of the authors. The authors have contributed collectively to the theoretical analysis, literature review, and manuscript preparation.

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References

[1] Khan B, Singh P. Selecting a meta-heuristic technique for smart micro-grid optimization problem: A comprehensive analysis. IEEE Access. 2017;**5**:13951-13977

http://dx.doi.org/10.5772/intechopen.78634

[2] Rezaei MM, Soltani J. A robust control strategy for a grid-connected multi-bus microgrid under unbalanced load conditions. Electrical Power and Energy Systems. 2015;**71**:68-76

[3] Khamis A, Shareef MH, Ayob A. Modeling and simulation of a microgrid testbed using photovoltaic and battery based power generation. Journal of Asian Scientific Research. 2011;**2**:658-666

[4] Fitgerald AE, Kingsley JC, Umans SD. Electric Machinery. New York: McGraw-Hill; 1990

[5] Momoh J. Smart Grid: Fundamentals of Design and Analysis, Institute of Electrical and Electronics Engineers. 1st ed. New Jersey, United States: John Wiley & Sons, Inc; 2012

[6] Jariso M, Khan B, Tesfaye D, Singh J. Modelling and designing of stand-alone photovoltaic system (case study: Addis Boder Health Center south west Ethiopia). In: IEEE International conference on Electronics, communication, and aerospace Technology, ICECA 2017; Coimbatore, India; 20-21 April. 2017. pp. 168-173

[7] Phrakonkham S, Le Chenadec J-Y, Diallo D, Remy G, Marchand C. Reviews on microgrid configuration and dedicated hybrid system optimization software tools: Application to Laos. Engineering Journal. 2010;**14**(3):15-34

[8] Yeshalem MT, Khan B. Design of an off-grid hybrid PV/wind power system for remote mobile base station: A case study. AIMS Energy. 2017;**5**(1):96-112

[9] Omari O, Ortjohann E, Mohd A, Morton D. An online control strategy for DC coupled hybrid power systems. IEEE Power Engineering Society General Meeting. 2007:1-8. ISSN: 1932-5517

[10] SIEMENS USA. Smart Grid Solution. Available from: https://w3.usa.siemens.com/smartgrid/us/en/microgrid/pages/microgrids.aspx [Accessed: April 5, 2018]

[11] Singh P, Khan B. Smart microgrid energy management using a novel artificial shark optimization. Complexity. 2017;**2017**:Article ID 2158926: 22 p

[12] Setiawan AA, Zhao Y, Susanto-Lee R, CVN. Design economic analysis and environmental considerations of mini-grid hybrid power system with reverse osmosis desalination plant for remote areas. Renewable Energy. 2009;**34**(2):374-383

[13] Edward JN, Ramadan A, El-Shatshat. Multi-Microgrid Control Systems (MMCS). IEEE Power and Energy Society General Meeting. 2010;**25**:1-6

[14] Saleh MS, Althaibani A, Esa Y, Mhandi Y, Mohamed AA. Impact of clustering micro grids on their stability and resilience during blackouts. In: 2015 International Conference on Smart Grid and Clean Energy Technologies (ICSGCE); 2015. pp. 195-200

[15] El-Khattam W, Salama MMA. Distributed generation technologies, definitions and benefits. Electric Power Systems Research. 2004;**71**:119-128

[16] Khan B, Singh P. Optimal power flow techniques under characterization of conventional and renewable energy sources: A comprehensive analysis. Journal of Engineering. 2017;**2017**:16. Article ID: 9539506

[17] Kifle Y, Khan B, Singh J. Designing and modeling grid connected photovoltaic system: (case study: EEU building at Hawassa city). International Journal of Convergence Computing. 2018;**3**(1):20-34

[18] Huang JY, Jiang CW, Xu R. A review on distributed energy resources and microgrid. Renewable and Sustainable Energy Reviews. 2008;**12**(9):2472-2483

[19] Passey R, Spooner T, MacGill I, Watt M, Syngellakis K. The potential impacts of grid-connected distributed generation and how to address them: A review of technical and non-technical factors. Energy Policy. 2011;**39**:6280-6290

[20] Mohamed Y, El-Saadany EF. Adaptive decentralized droop controller to preserve power sharing stability of paralleled inverters in distributed generation microgrids. IEEE Transactions on Power Electronics. 2008;**23**:2806-2816

[21] Mumtaz F, Bayram IS. Planning, operation, and protection of microgrids: An overview. In: 3rd International Conference on Energy and Environment Research, ICEER 2016, 7-11 September 2016; Barcelona, Spain: Elsevier Energy procedia; 2017. pp. 94-100

[22] Eissa MM. New protection principle for smart grid with renewable energy sources integration using WiMAX centralized scheduling technology. Electrical Power and Energy Systems, Elsevier. 2018;**97**:372-384

[23] Guerrero JM, Vasquez JC, Matas J, Castilla M, de Vicuna LG. Control strategy for flexible microgrid based on parallel line-interactive UPS systems. Industrial Electronics, IEEE Transactions. 2009;**56**(3):726-736

[24] Odavic M, Sumner M, Zanchetta P, Clare JC. A theoretical analysis of the harmonic content of PWM waveforms for multiple-frequency modulators. IEEE Transactions on Power Electronics. 2010;**25**(1):131-141

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