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Microgrid

Nithiyananthan Kannan

Abstract

A microgrid has a group of electrical generation and various types of loads operated as single controllable power system. Microgrid is a best option for configuration of recent model power grids. Microgrids are capable of work in parallel with the existing grid as well as off grid as isolated mode. The microgrid enables the grid connection as either AC grid or DC grid and it provides connections of variable AC and DC sources with loads. Microgrid has modeled such a way that it avoids multiple reverse connections. Power electronic devices such as converters and inverters are ensures safe operation and control of the microgrid. The proper modeling and simulation results ensure the successful implementation of microgrid. The challenges involved in implementation and the modeling of AC/DC and hybrid grid in the tied mode have been discussed. The simulation modeling of the microgrid in MATLAB/SIMULINK platform is explained with neat circuit diagram. This chapter provides the readers complete and comprehensive overview about microgrids and their different modes of operations.

Keywords: microgrid, AC grid, DC grid, renewable energy, MATLAB/SIMULINK

1. Introduction

Energy requirements of the world are increasing day by day since there is a constant increase in the world population. The main source of energy consumed is from oil, gas, and coal. The rate at which fossil fuels are utilized is alarming because the stock of fossil fuels is depleting at a higher rate, and after few years, fossil fuels become out of stock. Due to high demand, the fossil fuel energy cost is very high, and it becomes difficult to extract. Usage of fossil fuels creates problem to the environment and life of the livid hoods in earth. The combustion of oil, gas, and coal produces a pollutant gas which destroys the environment and also contributing to air pollution such as emission of nitrogen, sulfuric, carbon, hydrocarbon, and metal oxides. Oil spills and acid rain are the classical example of this polluted environment. The increase in demand for energy forces to find alliterative fuels has to utilize for green energy production. The best alternative and more suitable for this type of requirement is renewable energy sources. Renewable energy generation source is environment friendly and is available in abundant in nature. This source will not deplete, since the power is extracted from solar, fuel cells, wind, hydro, geothermal, and biomass. From renewable energy sources, energy is derived from direct and indirect way. Now-a-days due to advancement in technology efficiency of renewable energy source, sources improved and cost per unit is reduced. Most of the nations started investing in renewable energy power plants for long-term growth based on their energy growth requirements as shown in **Figure 1**. Since last few years, global investment on renewable energy sources exceeds four trillion billions and in is expected much more in coming years [1–5].
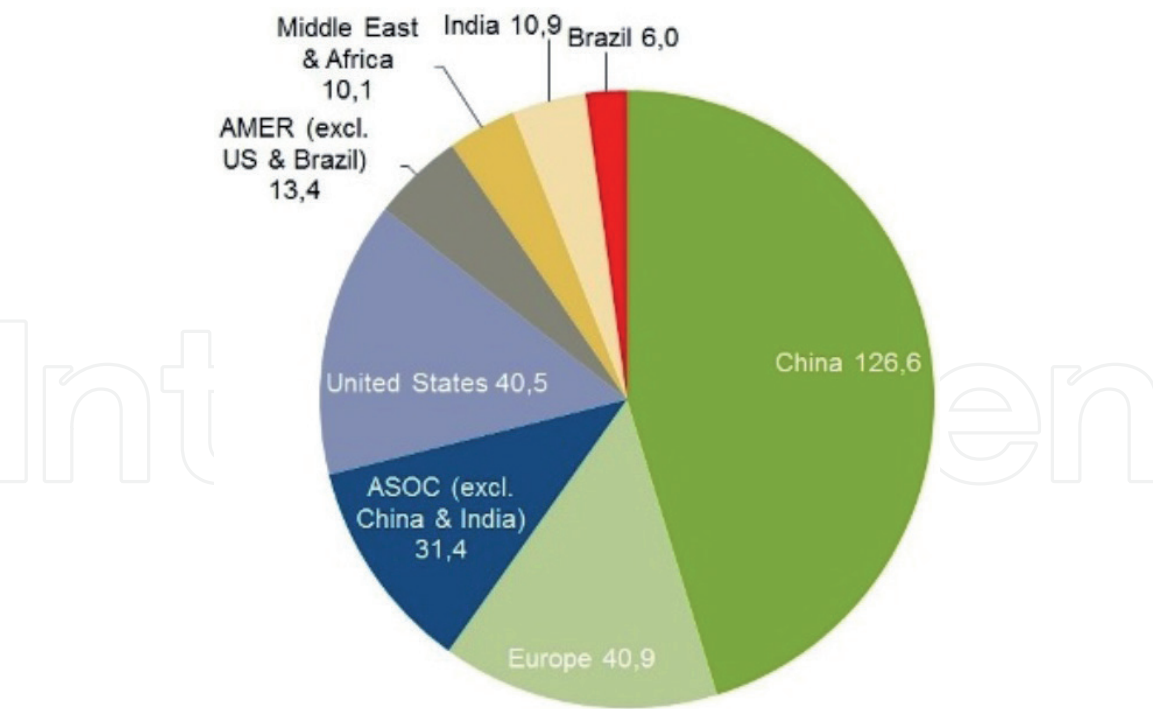
Figure 1.
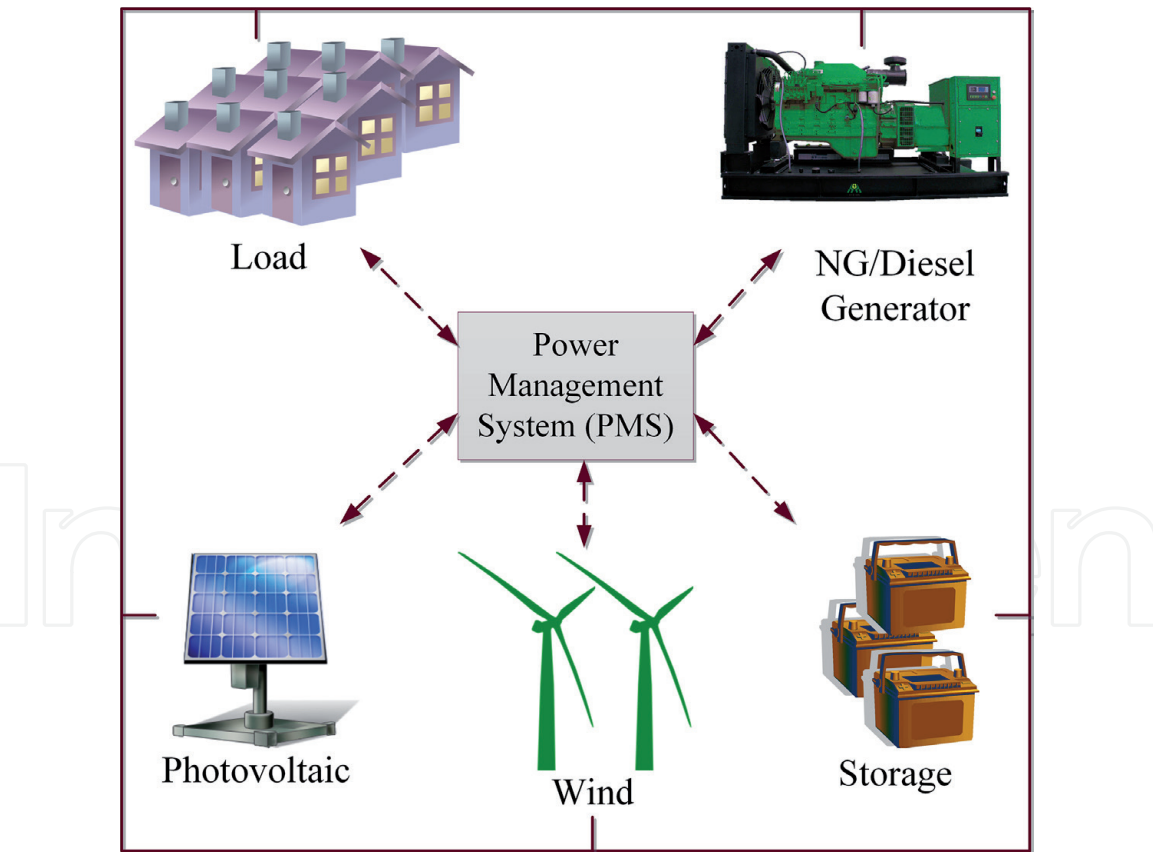*Global investment in renewable energy in billions.*

Figure 2.
Microgrid and its components.

With the increase in power demand and raise in the global warming plays a critical role in distributed renewable energy sources. Local generation sources such as wind, biomass, solar, microturbines, and fuel cells are the future renewable sources. Latest power grids have advantages like integration of green energy, scalability, and modularity supported by different renewable and non-renewable energy sources.

Microgrids are the latest evolving grid which effectively extract power and manage in the distributed energy sources. Microgrids are the future grids of the world. The components of microgrids are distributed energy sources such as PV cells, fuel cells, wind turbines, and mini hydro turbines. along with storage devices such as fly wheels, energy capacitors and batteries and diesel generators for peak load management as shown in **Figure 2**.

Microgrids are operated in two modes such as grid connected mode and islanded mode. Microgrids are low voltage grid which can be operated in autonomous state and non-autonomous state. The effective coordination of the components or sources involved in a microgrid will provide energy as minimum cost with high reliability in power supply. Microgrids are the classical example of smart grid applications. The data communications in all nodes of microgrids make the power management much more effective and accurate. Microgrids are low voltage, low power grids ranging from few kW to hundred kW. Based on the size of the load specifications and its applications, microgrids are called as mini grids, house grids, university grids, army grids, and nanogrids [6–13].

2. Technical challenges in microgrid

The challenges related with the control and operations of microgrids are very high. Microgrids are required to ensure the reliable operations even at fault conditions, power system stability during disturbances, and power quality in the island mode. The grid connected microgrid is needed to be maintained synchronism at any situations. Microgrids need to have advanced control strategies for microgrid inverters to maintain correct frequency and voltage to ensure stable operations for the power system connected with dynamically variable load. The growth of microgrids and its challenges has gained attention of researchers and various government and private organizations to play a vital role in finding out the solutions of effective implementation of microgrid. One of the major problems in microgrid is protection system in main grid and microgrid faults. When there is any fault in main grid protection, microgrid needs to be isolated immediately, and similarly if there is any fault in microgrid, the protection system should isolate the smallest part of the microgrid to clear the fault. The selectivity and sensitivity plays a vital role in low voltage microgrid power management. False tripping, unnecessary tripping, delayed tripping, and undetected faults are the major challenges in design of protection system in microgrids. The number of installation of distributed energy resources and availability of short-circuit current in the islanded mode of microgrid are the major issues while considering the protection of microgrids. Compared to main grid, the short-circuit current will drop down drastically and will give problem in the protection of microgrid. There is a need for designing a proper protection system for distributed energy resources with short-circuit calculations and placement of over current relays, reverse power relays, and directional over current relays. In real time, the operating conditions of microgrid are variable because of intermittent distributed sources and dynamic electrical load demand. This leads to change in network topology frequently to aim to minimize loss, economic load dispatch, and proper unit commitment with satisfying all the constraints. The directions and magnitudes of short circuit will vary because of these situations. The different sizing of equipment in various components of microgrid creates often a loss of relay coordination, and generic over current protection will become ineffective in protection of the microgrid from faults. The invention of new methodology in protection mechanism is very much needed to set different parameters for over current protection, parameters of relays, deal with low short circuit current, and interfacing of power electronic devices with the microsources [14].

3. Microgrid benefits

The evolution of microgrid is able to provide solution to problem of integrating huge amount of micro-energy sources without affecting the main power supply from the power utility provider. With the intelligent controllers, microgrid works effectively with the existing power system distribution services to match the variable load demand. Some of the times, microgrid can act as an auxiliary for the main grid to support the distribution and utilization. With the support of protection systems is able to disconnect from the disturbance if there is any fault in main grid, and microgrid is able to operate in a standalone mode which improves the reliability and quality of the power to the consumer. Microgrid is a decentralized grid with improved efficiency, located near to the load, and capable of extracting power from distributed renewable energy sources. Microgrid special features are highlighted in **Figure 3**.

Consumers able to get advantages from microgrid because it is developed and utilized for the local needs in terms of temperature and energy consumption, able to provide uninterruptible power, highly reliable, reduced losses, and improved voltage profile. Apart from the power generation and distribution microgrid involves in storage, control of load profile and extracting energy from heat. The success behind microgrid is capability of the grid to have smooth mode change from island to grid and vice versa.
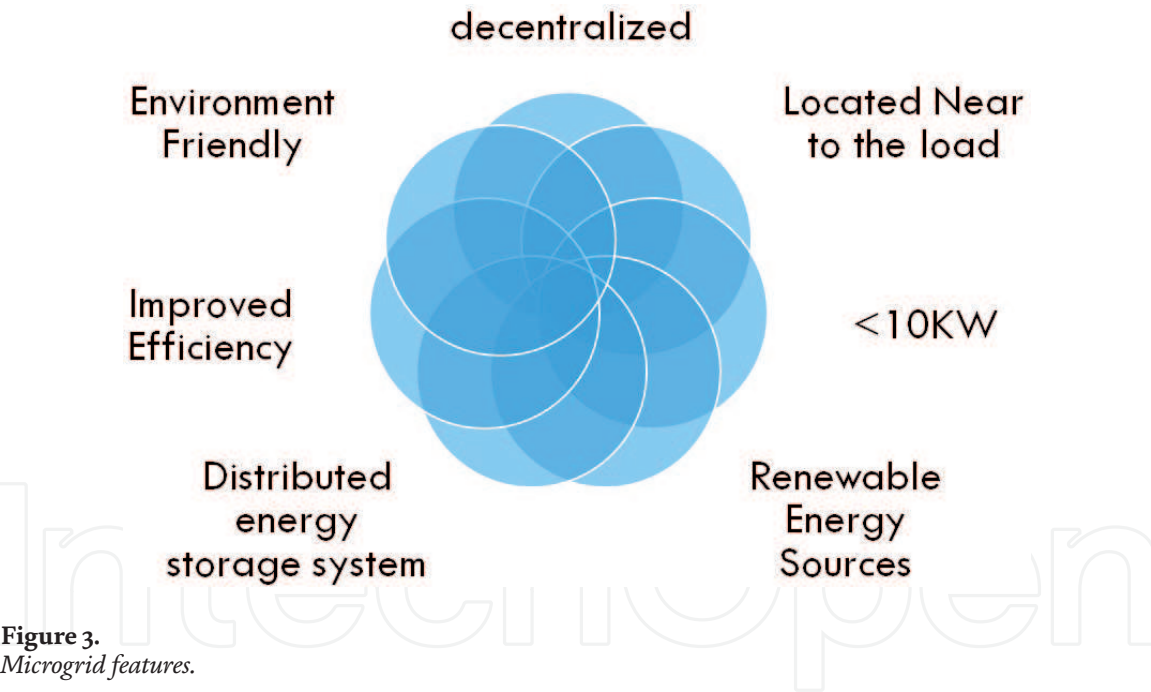

Figure 3.
Microgrid features.

4. Renewable energy sources

Back bone of the microgrid power supply is renewable energy sources. Most commonly used renewable energy sources are fuel cells, microturbines, solar, and wind. Fuel cells can produce power through electrochemical actions among oxygen and hydrogen. This reaction is highly effective and gives bi product as water and temperature. Due do this environment friendly bi products, this technology becomes popular compared to conventional diesel engines which are more expensive and pollute environment by releasing flue gases. Even though fuel cells are discovered in eighteenth century, it has been in use in late nineteenth century. Because of usage in commercial and domestic applications, fuels cells power technology become popular. Fuel cells have more advantages such as power quality, very

Figure 4.
Bloom box servers.

Figure 5.
Wind turbines.

high efficient, environment friendly, and modularity. Recent times in microgrid applications, fuel cells are very effective in replacing IC engine usage which makes microgrid environment free. Further fuel cell technology usage will reduce greenhouse gases and improved efficiency of the microgrid. Advancement in fuel cell technology leads to bloom box energy servers which convert fuel into electricity through electrochemical approach. Bloom box servers are available as building box as clusters ratings from hundred kilowatts to megawatts. Bloom box is highly efficient in power production, modular, and scalable (**Figure 4**).

Wind energy is most promising sources of renewable energy source, which has more potential in future. Wind energy power plants are sustainable energy producers. Wind turbines play a vital role in supplying power along with fuel cells and solar cells to microgrids. Wind turbines are bundled into components such as rotor, generator, turbine blades, and driver or a coupling device as shown in **Figure 5**. As high speed rotates the blades, the air exerts aero dynamic forces will make the blades to turn the wind rotor. In turn rotor rotates the generator through gear box. Wind generators are mostly induction generators or permanent magnet generators which supplies power to the microgrid.

Solar power plant generation systems are conversion of sunlight into electric power either directly using PV cells or indirectly using concentrated solar power plants.

Figure 6.
Solar power plants.

Photovoltaic generation is systems, which convert the sunlight directly to electricity as shown in **Figure 6**. PV cell technology is very well established and used extensively in microgrid. The DC output of the connected PV cells is given as input to the inverter and AC power supply given to the load through inverter. The most common renewable energy source in the world is solar energy.

All microgrids are more effective in extracting local energy source is only from solar. The main advantages of these solar power plants are very less time required to design and install the power plant. These plants are highly modular, and it is good alternative for peak load demand. Since solar structures are static and no moving parts which gives no noise power plant status to solar power plants. Solar power plants are portable and mobile because of light weight. Since there is no moving part, PV generation systems are having longer life time which makes one of the attracting renewable energy sources connected with microgrid.

Microturbines and microhydro turbines are gas and hydro electric generators ranging in size from 25 to 500 KW connected with microgrid. These microturbines are very much useful in dealing with peak load demands for the microgrids. Biomass is also another renewable source contributing energy supply to microgrids located in remote villages or urban waste sources. The source materials are scrap lumper, forest debris, certain crops or manure, etc. Geo thermal power plants are recent renewable energy sources generating power from geo thermal energy. Geo thermal energy is a thermal energy stored in the earth is utilized. In future, microgrids are expected to add mini geo thermal power plants in its pool of distributed energy resources. In future, the other renewable energy power supply from tides of the sea and hot hydrogen fusion will be a part of microgrid energy sources.

5. AC/DC and hydro microgrid

Microgrids are the most prominent grids to extract various types of distributed renewable energy sources with the distribution grid. The distribution utility side grids are AC grids, since today electrical loads are connected with power electronic devices, and since most of the renewable energy sources are DC power supply, now the DC microgrids concepts are gaining more attraction. The most common

grids are AC microgrids which uses standard protection technique's to manage disturbances. But the distributed generation sources for microgrid comprising of solar cell arrays and fuel cells are DC power which needs to convert to AC power through power electronic device. This DC power source in the microgrid is connected to the power supply through inverter to the utility grid. The AC power on the utility side is converted back to DC for some of the latest electrical loads such as UPS batteries, DC lighting loads, DC motor drives, and hybrid electric vehicles. Due to multiple conversions, AC microgrid becomes inefficient due to more power losses due to multiple conversions. Apart from that maintain synchronism, stability issues and reactive power requirements are the challenges faced by AC microgrids. Due to this reason, DC microgrids are emerging as alternate grids. But the diesel generator, small microturbines connected synchronous generator, and wind energy generators are required to connect with AC/DC converter to distribution side grid. Due to multiple conversions, DC microgrid also becomes inefficient due to more power losses due to multiple conversions. The reason for this problem is now-a-days electrical load becomes mix of both AC and DC power. It leads AC/DC grids to less efficient operation. The best solution to avoid this multiple conversion energy losses is hybrid AC/DC microgrid. The hybrid AC/DC microgrid is formed with an objective to minimize the conversion losses to make the microgrid more efficient as shown in **Figure 7**. But the implementation of hybrid of AC/DC grid required several technical challenges.

Hybrid microgrid comprises both AC and DC sources as shown in **Figure 7**. The respective AC and DC sources are connected to the corresponding AC and DC networks. The AC bus and DC bus are linked together with three phase converters and the transformers. The AC bus of hybrid grid is tied with distribution grid with transformer and circuit breaker. The successful operations of hybrid microgrid are based on power conditioning converters. The converters are classified based on their input and output power supply. The converters used in hybrid microgrids are rectifier, inverter, buck/boost converter, and transformers. Among these converters, inverters and boost converters need more attention than conventional converters in the microgrid. Because the boost converter is very much required to interface low voltage PV arrays into the microgrid and then converted into AC power through inverter to feed the loads. **Figure 8** shows how the converters are theoretically
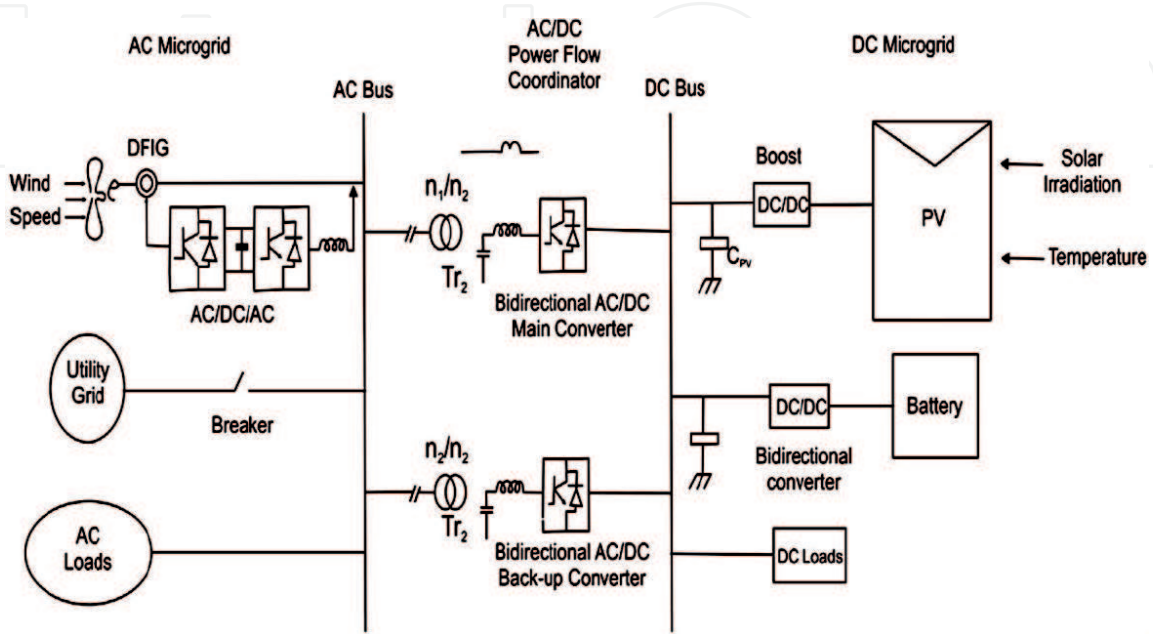
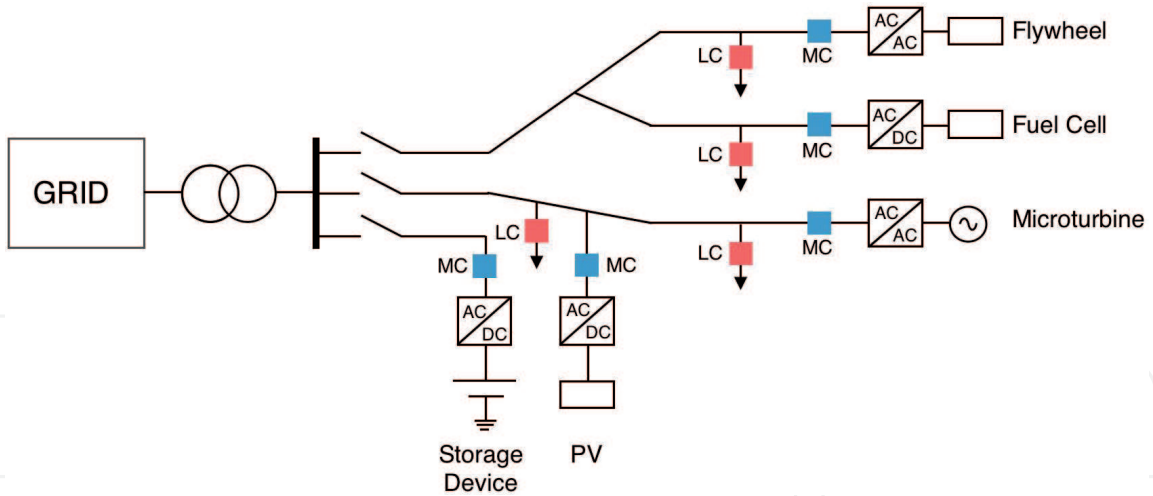

Figure 7.
Hybrid microgrid.

Figure 8.
Implementation of converters in a typical microgrid.

implemented; in this Figure, LC stands for load controller and MC for microsource controller. Arrow indicates the electrical load.

5.1 Inverter

Inverter is a power electronic device, which converts DC to AC. The design of the inverter fixes the values of the input voltage, output voltage, frequency, and power output. An inverter is classified into single phase and three phase inverter. The single phase full bridge inverter consists of four switches, and it creates an AC output voltage by switching on and off as shown in **Figure 9**.

Three single three-phase inverters form the three phase inverter. Three-phase inverter has six switches each switch operated at 60 degree point of the fundamental output waveform. Based on the switching frequency and switching pattern, the output voltage, frequency, and power output have been controlled. **Figure 10** shows the general standard equivalent circuit of a three-phase inverter interfaced with solar panels output to microgrid.

5.2 Boost converter

A boost converter is used as DC to DC power converter to increase the voltage and in turn it will step down the current. In microgrid, one of the major sources is solar energy with DC power supply. The PV panel output voltage is not suitable to feed the loads straightaway. The boost converter is used to step-up the voltage to a required level. **Figure 11** shows the equivalent circuit of boost converter in two modes. One mode switch is closed and other mode switch is open.

Based on the operation of switches, the boost converter operations are divided into two modes. When the switch is closed, the energy is stored in inductor as magnetic energy. Since the diode is switched off, the capacitance is blocked from the power supply. When the switch is open, the inductance is then series with the source which enhances the voltage as boost voltage. The boost voltage is depending on the value of inductor and capacitor.

5.3 Operating modes of the microgrid

Microgrids are operated in two modes, one is grid connected and another one is islanded mode. The first one is the classical scheme, which is the most
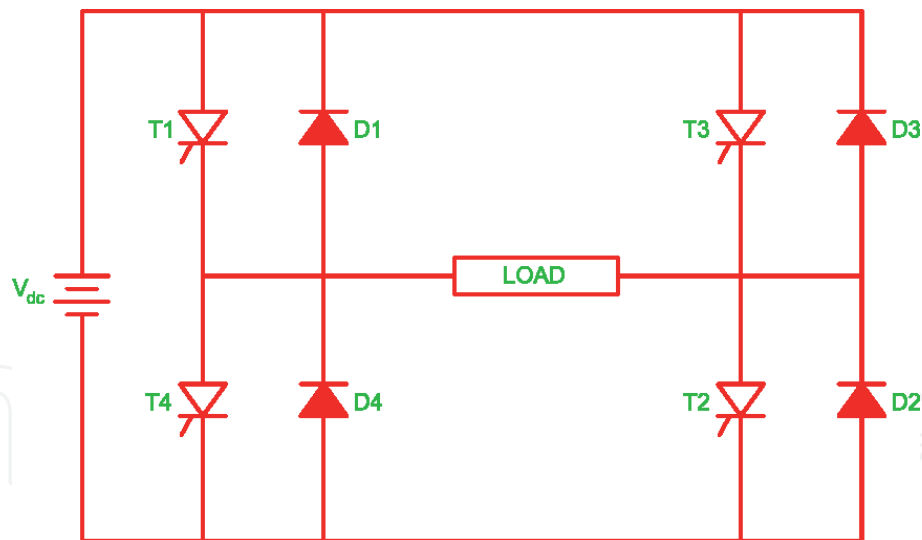
Figure 9.
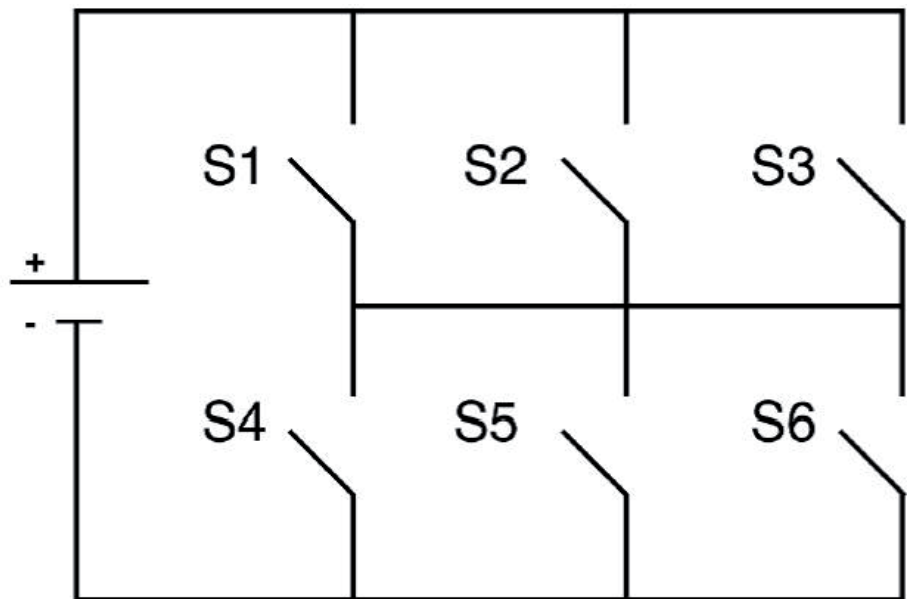*Equivalent circuit of a single-phase full bridge inverter.*

Figure 10.
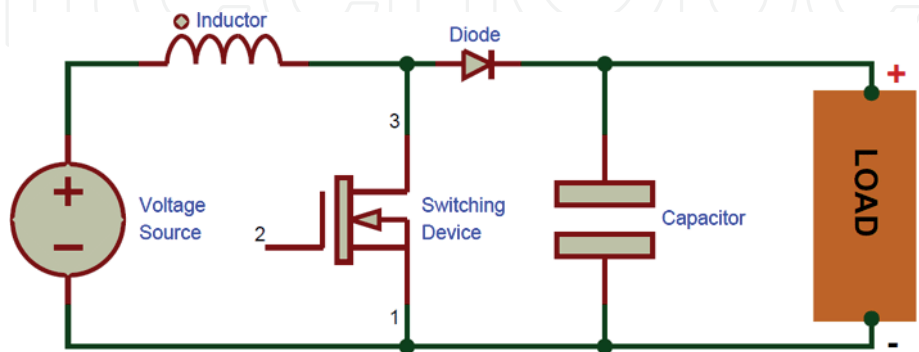*Equivalent circuit of a three-phase inverter.*

Figure 11.
Equivalent circuit of a boost converter.

common mode in use. Microgrids are designed to operate in both modes.
Microgrids are designed such a way to get maximum power from renewable
energy sources with wind, solar, and microturbines and able to fill its remaining

required power from the grid. This mode of operation ensures maximum possible power to extract from local sources ensures the cost of energy cheapest. In the second mode, when the network gets isolated to faults, emergency conditions or natural calamities, the microgrid designed to operate in isolated mode. In the isolated mode, the entire power is supplied from locally available power sources of the microgrid.

6. Microgrid modeling and simulations

The MATLAB/SIMULINK-based modeling is used for designing a microgrid. Based on the individual microgrid specifications, model has been formed and implemented in MATLAB/SIMULINK environment. A hybrid microgrid sample system has been implemented in the MATLAB/SIMULINK environment as shown in **Figure 12**. In this model, microgrid is carried out for the grid connected mode. Along with this microgrid model, the performance of the wind generator and solar panel output is also analyzed. While considering the performance analysis of the simulation model, the solar irradiation, temperature of the panels, wind speed, and wind direction also possible to consider getting the results accurately.

The simulated results are analyzed in the runtime environment of MATLAB. Normally for the performance analysis, the load flow of the microgrid has been carried out at one-day simulation results. By running the simulation model in the MATLAB/SIMULINK environment at different day environment and performance of the microgrid has been analyzed. The stage wise output characteristics such as PV panel output, battery, and converter gate signals of the simulation has been represented as **Figures 13–16**, respectively. The output characteristics of AC load voltage and current are represented by **Figures 17 and 18**, and also the **Figures 19 and 20** indicate the converter side AC voltage and current. The simulations need to perform many times repeatedly under various simulated situations, and the final pool proof design needs to be finalized. All the figures output indicates the performance under one similar situation which is useful for the readers to understand the operations of microgrid.
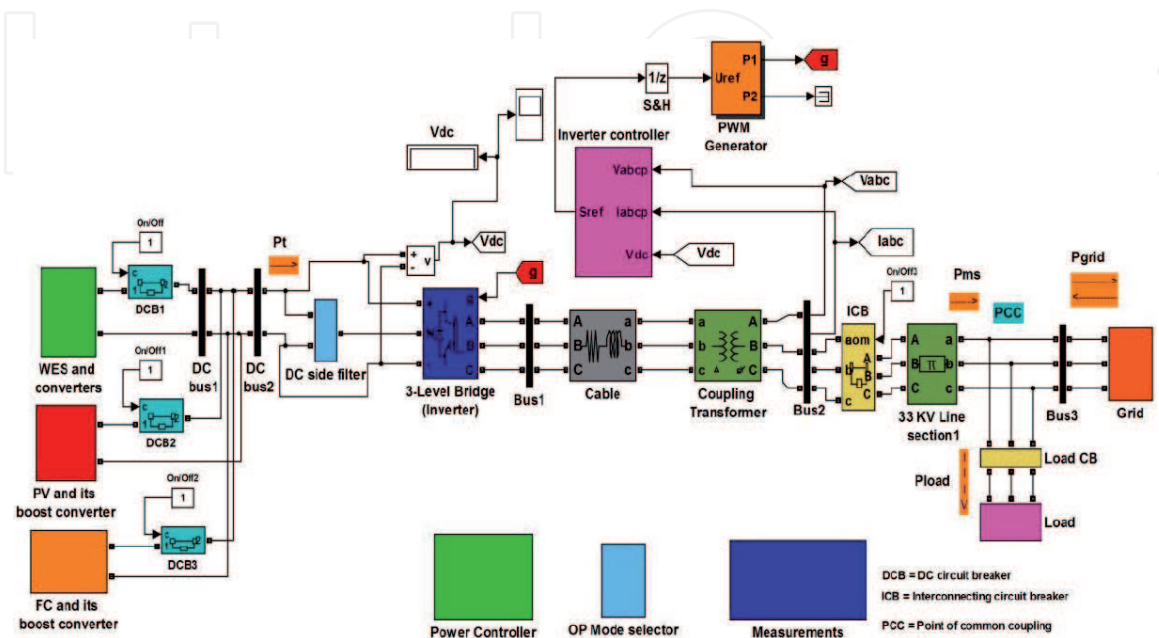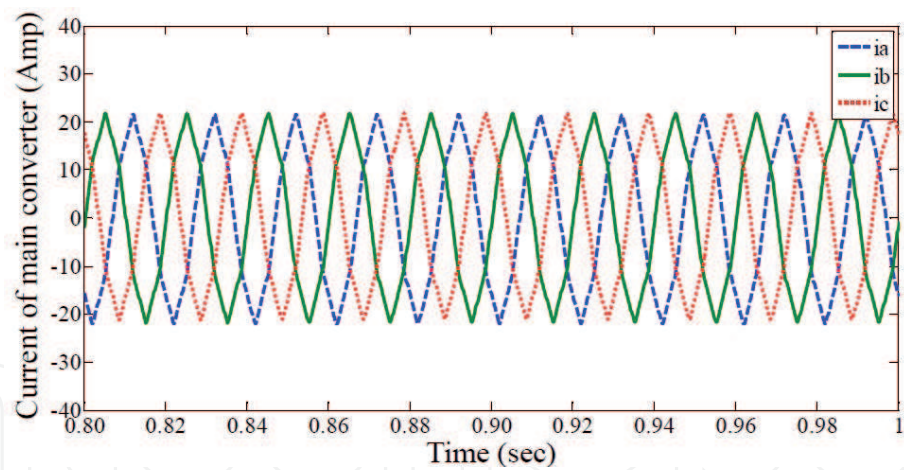

Figure 12.
MATLAB/SIMULINK model for microgrid.

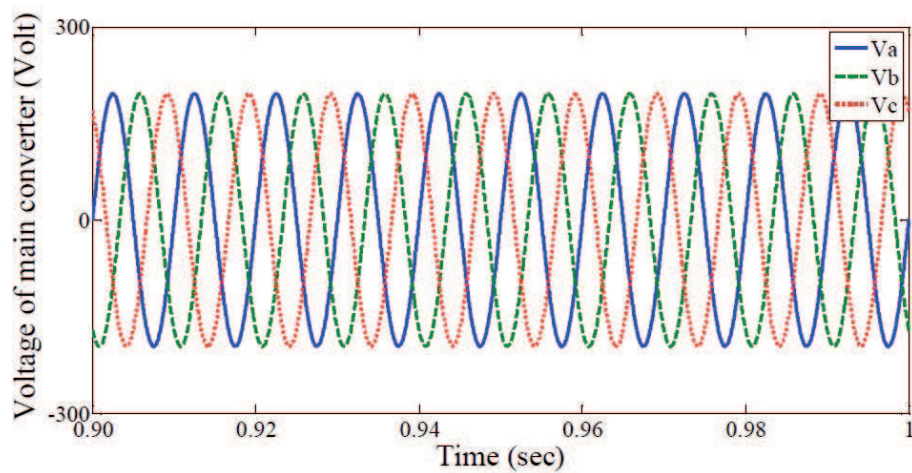**Figure 13.**
Output voltage of PV array.

Figure 14.
Output current of PV array.

Figure 15.
Generated PWM signals for the boost converter.

In this hybrid microgrid during one day simulation, it is needed to phasor power gui instead of discrete power gui in MATLAB environment. The individual components are specified with their values in the blocks. The battery block in the MATLAB/SIMULINK model is of 300 Ah capacity and PV panels arrays are modeled by a current source and load current is specified based on the input power. The power management and voltage profile are done for the hybrid microgrid controlled
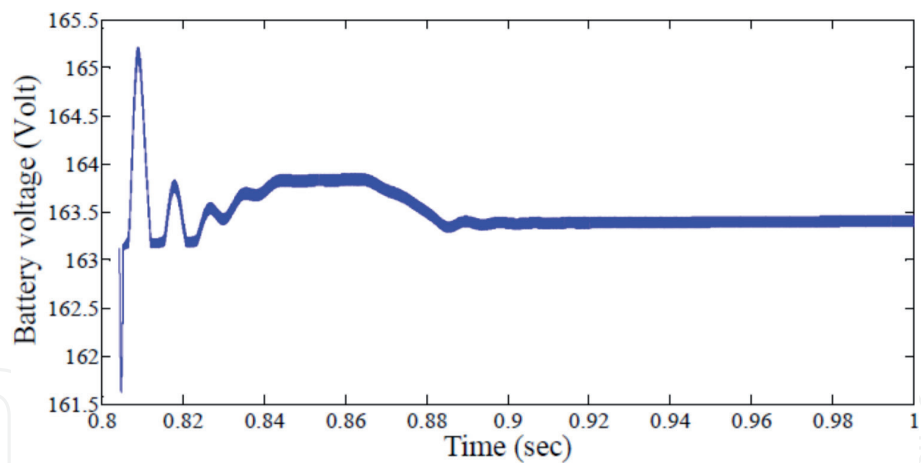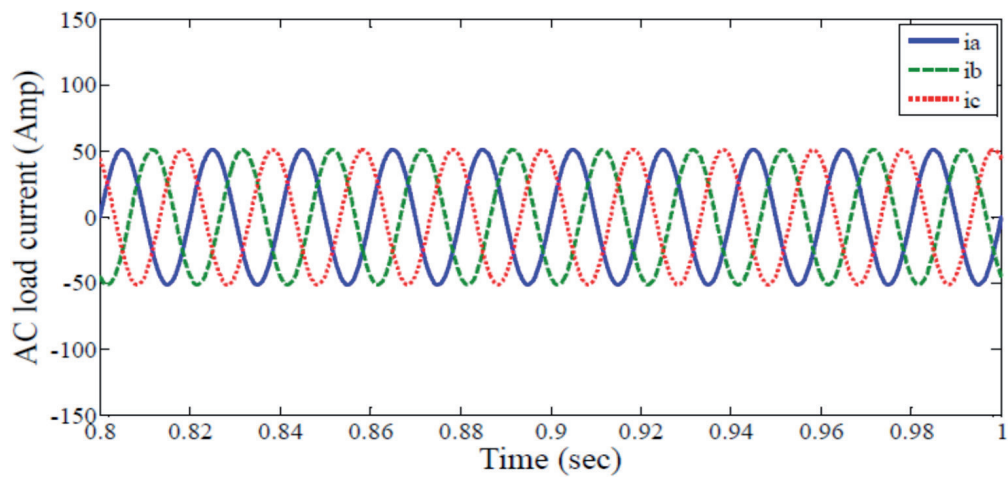
Figure 16.
Voltage of battery.

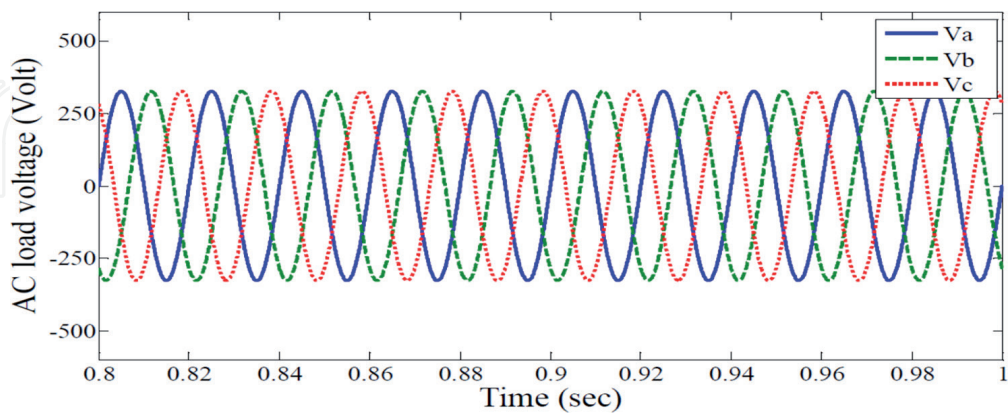**Figure 17.**
Microgrid AC bus load current.

Figure 18.
Microgrid AC bus load voltage.

by PI controller. Once the performance analysis of the simulation model is satisfied, the microgrid can be implemented in real time. Many microgrids are implemented across the world and for example the real time implemented the microgrid as shown in **Figure 21** [15].
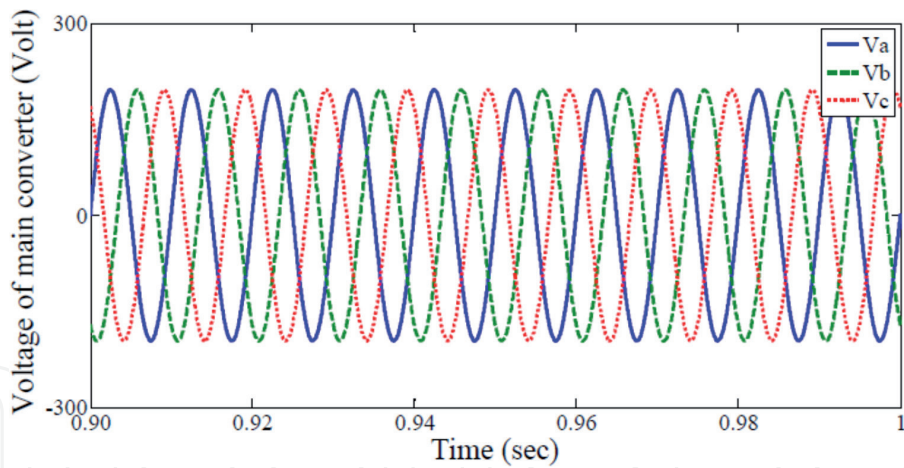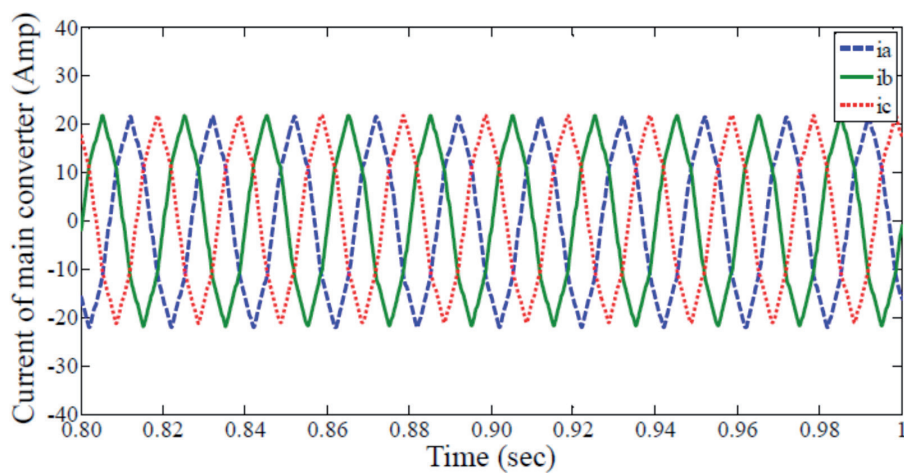
Figure 19.
AC side voltage of the main converter.

Figure 20.
AC side current of the main converter.

Figure 21.
Microgrid in real time [15].

7. Conclusion

The implementation of microgrids reduces the energy cost and increases reliability. Microgrids are excellent in extracting energy from renewable energy. Microgrid is a controlled system which offers both power and heat. The heat

collected by solar thermal collectors is used to heat the air as well as water, which reduces the burden of microgrid energy supply which is becoming popular in residential and commercial loads. Distributed power source is becoming more attractive because the green energy, pollution free, modular, and availability are in plenty, and it can supply power to the existing transmission and distribution systems without any alterations. Microgrids are excellent system for extracting power from distributed generation. In otherwise, microgrids are operating as a locally controllable cell of power system network. Microgrid operations are done by grid connected and islanded mode. In grid connected mode each individual, the microsources able to act as current source with maximum power transfer capability to the grid. Any fault or emergency situation microgrid will operate under islanded mode automatically which ensures the reliability of the power supply. The implemented simulation model for the hydro microgrid is explained in a MATLAB/SIMULINK environment. Although the hybrid grid model replaces the AC and DC grid, there is a technical challenge for the implementation of the hybrid grid model based on the AC dominated utility electrical setup. The peer-to-peer and plug-and-play model are used in the microgrids, which ensures that any component loss will also make the microgrid operational and it can continue the power supply. The data communications and control mechanism implementations make the hybrid microgrid as smart grid. The microgrid is acting as application of smart grid which is the future grid of the world.

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