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An Overview of DC-Microgrid Architecture with Renewable Energy Resources

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Abstract - **In this paper DC-microgrid architecture with Renewable Energy Resources is described. Microgrid is a part of distribution network embedding multiple distributed generation systems (mostly non-conventional renewable energy sources like wind turbine, photovoltaic panels etc.) and storage systems with local loads, which can be disconnected from the upstream network under emergency conditions or as planned. Microgrid is defined as a cluster of distributed generation sources, distributed storage devices and distributed loads that operate so as to improve the reliability and quality of the local power supply and of the power system in a controlled manner. The present power system is established on AC that provide supply to the AC power machine, but the new on-going revolution in power electronics and many smart devices are coming in the list of domestic goods, which are powered by DC. To provide DC, AC supply should be rectified and regulated which produce losses. Instead of rectification a new independent DC microgrid architecture is designed to which the DC load can be connected. In this review paper, DC microgrid architecture can be independently powered by renewable energy resources which can directly generate DC power. This paper also presents challenges in integration of renewable energy sources and their solution of integrating renewable energy sources utilization.**

Keywords -***microgrid, DC microgrid, islanded mode , Distributed Generator (DG), power electronics devices, renewable energy resources.***

I. INTRODUCTION

Microgrid can be defined as the combination of distributed generation (DG), electrical energy storage and loads [1].The generators which are used in microgrid are wind turbine, PV array, fuel cells, and many other alternatives power sources. The main microgrid function is that to provide stable operation during faults and various network disturbances.

Microgrid is developed in places like shopping center, parks, college campus, industries, hospitals, buildings, etc. The application of individual distributed energy resources such as micro-generation can cause problem such as voltage rise, potential to exceed thermal limits of certain lines and transformers and have high capital cost [2]. Microgrid can be the best solution for these problems.

In microgrid system, the Distributed Energy Resources (DERs) should be equipped with proper power electronics interfaces and control to ensure the flexibility to operate as a single aggregated system which maintains the power quality and energy output [3]. From the customer's point of view, microgrid is more beneficial because, they can meet electrical requirement locally, supply uninterruptible power supply, it improves power quality (PQ), reduce feeder loss, and also provide voltage support. Microgrid also reduces environmental pollution and global warming for utilizing low-carbon technology [3].

A. Microgrid

Following important key features of microgrid;

1) It can operate in island mode and/or, grid connected mode.

2) It provides good Power Quality and reliability to customers.

3) Microgrid supplies energy according to the system energy needs.

4) Interconnection loads and different power generation sources and energy storage devices.

5) It presents itself as a single controllable entity [4].

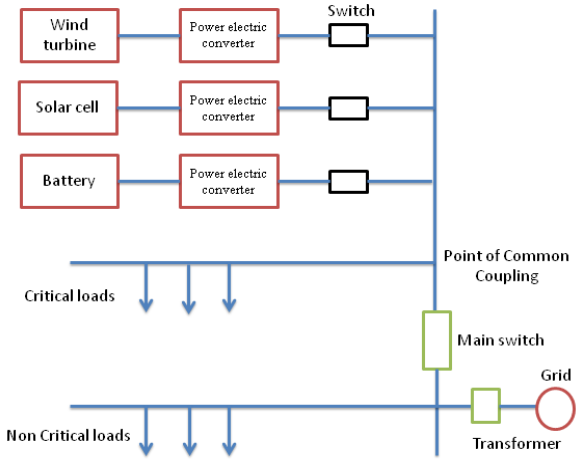

Figure 1 Microgrid diagram

The use of smart grid technologies and the integrated control of distributed power generation can be achieved in Figure -1.depicts a normally operated microgrid in a grid–connected mode through the substation transformer via Point of common coupling (PCC). PCC is the point in the electric circuit where a microgrid is connected to the main grid. The converter plays an important role by connecting Distributed Generators (DG) system in parallel with grid or other sources, and secondly to continue functioning in stand- alone mode, when critical loads don't get supply from other sources [5].

B. Advantages of microgrid are as follows:

1) Provide good solution to power supply in the case of an emergency and power shortages during power interruption in the main grid.

2) It can provide high quality uninterrupted power supply to the consumers.

3) It has the ability to automatically disconnect or reconnect to the main grid when there is a disturbance or when the microgrid standards do not match.

4) It enables high penetration of renewable resources and other distributed generations into the power system.

5) It improves overall efficiency, stability and reliability of power system.

6) It helps to reduce the CO_2 emission by optimal operation of distributed generation and conventional power generation [6].

C. Operating modes in Microgrid

Microgrid is operated in two modes grid connected mode, islanded mode.

1) Grid connected mode: Microgrid is connected to the utility grid via a switch at the point of common coupling (PCC). At this stage, the DGs of the microgrid share its local loads with the grid supply. So, any common load inside the microgrid is entirely supplied by the grid power system. Therefore in this mode the grid determines the voltage amplitude and frequency of the entire microgrid [7]. This mode encourages the possibility of a bidirectional flow , where excess generation by the Distributed Generation system is returned to the utlility grid system.

2) Islanded mode: In this mode microgrid behaves as an autonomous power sytem, which supplies both local and common with the help of proper control actions [7]. In the absence of the utility grid, renewable energy sources provides frequency and the voltage of the microgrid.

II. MICROGRID IN ISLANDED MODE

A. Reasons for Islanded Operation

The concept of islanding is not new in conventional grid system.With the integration of renewable energy sources like PV, wind turbine etcto the conventional grid, the grid becomes more vulnerable to islanding phenomenon, as the renewable sources keeps on energizing the distribution line, irrespective of its connection to utility grid. Situation like increase the risk of the maintenance workers and make its very difficult for post fault reconnection. This necessitates the use of separate power entity that can accommodate the renewable sources and storage units, and can disconnect itself from the utility grid on occurrence of a fault [7]. This eliminates the risk of having an energized system within a tripped network.

Conventional centralized grid system incurs a considerable amount of transmission loss in supplying loads long distance apart. Sometimes, even it's not possible to install transmission lines across unfavourable terrains to supply loads to remote locations. This has encouraged the use of an autonomous, self–sustaining grid system [7, 8]. Moreover, the potential of the renewable energy sources to harness energy from natural resources like solar, wind and water has increased the scope of operating a separate grid system in remote places, where power generation by conventional method would have been impossible. Some examples of islands (geographically) are mountain resorts and villages, shipboard power system.

Modern microgrid with some advanced controllers has solution to all of the above problems. It can provide a complete isolation from the grid and still maintain the required power supply for its loads. It is equipped with the mechanism of prompt detection of any grid disturbance [8]. Such event opens up a switch that connects the microgrid to the main grid.

A solution to a permanently isolated grid system, a microgrid provides a compact power system, with the advanced controls that can supply critical loads irrespective of its location and type of energy sources.

The main reasons for islanded operation of microgrid can be pointed as follows:

1) At instances of grid blackout, islanding of a microgrid is more important to feed the local loads until the grid is available.

2) During the grid disturbances, in the form of transient variation of phase of voltage and load voltage harmonics, and grid fault, disconnection of the microgrid from the main grid is necessary in order to prevent any impact of the disturbances on its loads [9].

3) During the grid fault, in order to prevent the presence of any undesired active power network or system, an isolation of the active microgrid is done , by opening a switch, which connects the microgrid with the utility grid

4) Permanently isolated microgrid is designed to operate in autonomous or islanded mode for supplying its load and handle any disturbances or generation outage without any help from the main grid [9].

5) Microgrid can intentionally enter an islanded state to protect the main grid from faults and disturbance or generation outage without any help from the main grid system.

III. DC MICROGRID

Microgrid can be generalized basically in two types AC microgrid and DC microgrid. Compared to AC microgrid DC microgrid have many advantages, it needs less power converters, high system efficiency and easier interface of renewable energy sources to DC system, there is no requirement of frequency, phase synchronization, or reactive power control. In the other hands, the consumer electronics, such as LED lightning, computer, pager, phone and so on can be more conveniently powered by DC power, so DC microgrid will be the main power supply system for the future sustainable home and buildings [11]. In order to ensure the stability of DC microgrid, the power flow within the DC microgrid must be balanced all the times to maintain a constant DC bus voltage.

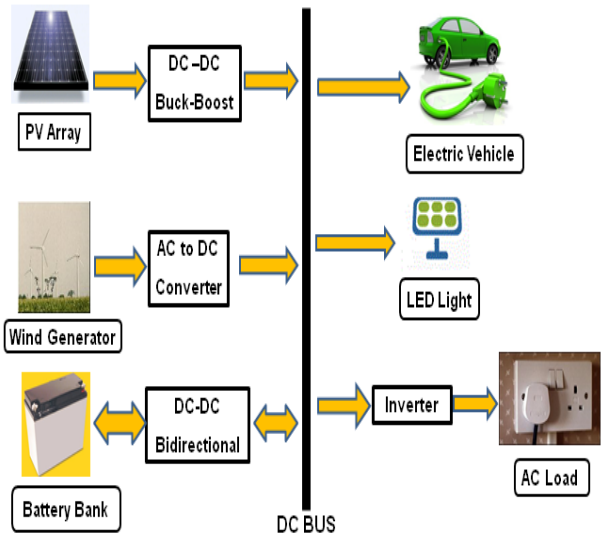

Figure 2 DC Microgrid architecture

A. DC microgrid Architecture

The DC microgrid architecture is presented in [11] Fig. 2. that shows the proposed DC microgrid structure. PV arrays are connected to DC bus through a DC/DC boost converter. A wind turbine generator with permanent magnet synchronous generator (PMSG) is connected to DC bus through an AC/DC converter. A battery as energy storage is connected to a DC bus through a Bi-directional DC/DC converter. Variable DC load are connected to a DC bus. A nominal voltage of DC bus is chosen as 400V. However, in the proposed DC microgrid architecture all power is fed from electronics power converters that are controllable and can provide active current limiting, thus reducing the need for electromechanical protection devices.

The main benefit of DC microgrid is battery which stores the energy in battery and when required it is supplied to the DC grid. This battery energy stored is used when the distribution energy does not fed power in the grid. For critical equipment's it avoid supply interruptions in office buildings, hospitals, industries etc. Nowadays it is used as an Uninterruptible Power Supply (UPS) and also by back to back conversion [11, 12]. A direct connection with DC microgrid saves power converter conversions and increasing system efficiency.

B. DC microgrid system has following advantages over AC microgrid.

1) Synchronisation of power generators is not needed.

2) Unlike AC microgrids, loads connected to the DC bus are not affevted by voltage sag and three-phase voltage unbalance and voltage harmonics.

3) The power generators nd energy storage sources with the DC microgrid are operated cooperatively to control the DC bus voltage and to improve the power quality of the grid[13].

4) Energy storage devices re used in the DC microgrid to compensate power fluctuations caused by the energy sources such as the wind turbine.

5) The DC microgrid can supply power to the loads connected with the DC bus when the AC utlity line experiances abnormal or fault conditions.

6) Aside from reducing carbon dioxide emission and financial costs, DC microgrid may provide the best solution for increasing the penetration of renewable energy sources in a distribution network, improving the system efficiency and also making plug and play grids conceivable.operated as only DC voltage is required to be controlled [14].

7) Connected to DC microgrid can be easily operated as only DC voltage is required to be controlled, because in AC microgrid the phase synchronization is needed [11].

8) Distribution Genrations in DC system are not easily trip against these disturbances. In means DC microgrid alredy has fault ride through capability of its own [14].

C. Drawback of DC microgrid

1) The main disadvantages is that when the whole microgrid system fails to supply AC power if the DC–AC inverter is out of service, when the load is AC load, because it requires inverter from DC to AC conversion [12].

2) It needs to construct private DC distribution lines for DC microgrid.

3) DC power distribution lines have short length in kilometers.

4) The protection in DC system is some more difficult than AC because there is no Zero cross point of voltage in DC system [12,13].

5) The loads adapted to power supply are required for high system efficiency[14].

D. Applications of DC microgrid

1) Commercial/ Industrial: It generally demand for high capacity, it is mean to serve as industrial plants and sensitive loads.Mostly in commercial the data centers uses the DC microgrid.

2) Institutional/campus: Some common ownership, this microgrid offers the oppurtunity for testing a prototype system in active time scenario, and so thereby encouraging further development.

3) Remote off-grid system: This type of sources like PV and wind energy, and are popularlyknown to sustem load demands in remote places. Howeve, it can only maint low demand loads for small capacity [11].

4) Military microgrid: As the operation of an autonomous microgrid is independent of any conventional fuel supply.Microgrid with its renewable energy sources can sustain the shipload in case of fuel deficiency. In Military microgrid they use the DC microgrid for electric charging vehicles.

IV. RENEWABLE ENERGY RESOURCES

A. Wind Turbine(WT)

Wind turbine converts wind energy into electrical energy by using wind energy conversion system. Wind turbine captures kinetic energy of wind and transfer the energy to the Permanent magnet synchronous generator direct driven. The generator shaft is driven by wind turbines to produce electric power. The generator shaft is driven by wind turbines to produce electric power. The capacity of generates power

depends upon speed of wind, therefore wind farms are installed in the region where maximum wind flows.

The major components of a wind energy conversion system include a wind turbine, generator, gearbox, and energy storage along with power converters. Wind turbines can be classified into the vertical axis type and the horizontal axis type. Most modern wind turbine uses a horizontal axis configuration with two or three blades, operating either down wind or up wind [14]. A wind turbine can be designed for a constant speed or variable speed operation. Variable speed wind turbines can produce 8% to 15% more energy output as compared to that with constant speed. They use power electronics converters to provide a fixed frequency and fixed voltage.

Direct driven configuration, where a generator is coupled to the rotor of a wind turbine directly, offers cost for certain turbines. Several manufacturers uses direct drive configuration in the recent turbine designs. Presently and in the near future, generators for wind turbines will be synchronous generators,

Permanent magnet synchronous generators, and induction generators, including the squirrel cage type and wound rotor type [15, 16]. For small to medium power wind turbines, permanent magnet generators and squirrel cage induction generators are often used because of their reliability and cost advantages. Induction generators, permanent magnet synchronous generators and wound field synchronous generators are currently used in various high power wind turbines.

The wind power advantages are as follows:

1) Wind turbines take up less space than the average power station.

2) Wind turbines are a great resource to generate energy in remote locations

3) When combined with solar generation, this energy source provides steady and reliable supply of electricity [15].

Following are some limitations of wind power system.

1) The strength of the wind is not constant and it varies according to wind speed. This means that wind turbines do not produce the same amount of electricity all the time. Some times when they produce no electricity at all [15].

2) Wind turbine construction can be very expensive and costly.

3) Wind turbines are noisy.

B. Photovoltaic system (PV)

In the Photovoltaic (PV) cells can convert sunlight directly into electricity using the photovoltaic effect. The cost of PV has declined considerably since the first solar cell was manufactured. A photovoltaic generator consists of a number of modules, formed by the interconnection of photovoltaic cells, connected together in series and parallel to provide the required voltage and current.

The output power of PV systems ranges from a few watts for portable applications such as calculators, to megawatt power stations [14]. Photovoltaic arrays integrated in the roofs and buildings are becoming an increasingly common method of power generation within the urban environment. PV is a DC generator source, therefore a DC–AC inverter is required to convert the DC power into AC power at the specified frequency and voltage level and then interfaced with the AC utility grid and loads.-

For stand-alone or grid connection, PV system can be combined with energy buffer to store the energy in order to be used when the sun is not shining. While PV cells can be effectively used as a source in microgrids, it they suffer currently from high installation costs and low energy efficiency [15, 17].

PV system offers following advantages:

Solar energy is clean and renewable energy sources.

1) Though the installation cost is high, at present, the production cost is almost Zero.

2) Solar energy causes no pollution.

3) Environmental friedly (does not emit any green house gasses).

4) Longer life span.

5) Direct conversion of sunlight into electricity.

6) Most suitable option of electrical energy in remote places. [18].

The PV generation is now preferred worldwide as distributed energy resources (DER).

Following are some limitations of the PV system:

1) Very high installation cost.

2) Careful selection of location.

3) Weather dependence(less effective in rainy season and cloudy ambiance).

4) Solar power stations do not match the power output of similar sized (area wise) conventional power stations.

5) Solar power is used to charge battries so that solar powered devises can be used at night.The batteries are large, heavy and expensive also requires storage space and costly maintenance. The life span of the batteries is very much less than that of PV system [17].

C. Energy Converters

Power semiconductor based converters have the key elements in the areas of distribution and management of electrical energy.In developed as well as developing countries, the use of power electronics system is growing with rapid rate. The main task of power electonic converters is to control and convert electrical power from one form to another [19]. Power electronics circuits which converts voltage and current in one form into another form. In these converters, at least one power semiconductor devices is used as a static switch.The main form of conversion and converters are as follows:

- AC to DC (rectifier)
- DC to AC(inverter)
- DC to DC (chopper)

AC to DC converter:

In DC microgrid, the wind turbine, PV system and energy storage battery is integrated in renewable energy resources as shown in figure2. Wind generates AC power and in DC microgrid the requirement is DC power. So, there is requirement of rectifier that converts AC to DC. In PV system .DC to DC boost converter is needed for the step up converter.

Figure 3 Rectifier

DC to AC converter:

An inverter is a DC to AC converter, used to convert a DC input voltage into a symmetrical AC output voltage of desired magnitude and frequency. The wave shape of output AC voltage of inverter should be sinusoidal. Here, in DC microgrid when the load is AC then the conversion gets more, and so losses will be more, cost will also be increased, so that is the drawback in DC microgrid [19]. When the DC microgrid is grid connected mode means if is connected to the main grid or utility grid back to back conversion is needed. Therefore, at the time of inversion in back to back converter inverter is needed [19].

Figure 4 Inverter

Inverters are widely used in various industrial and household appliances such as,

- AC drives
- Induction heating
- Standby power supply

DC to DC converter:

Fixed voltage DC supply can be converted into variable voltage DC supply by using DC to DC chopper. In DC microgrid DC to DC chopper is used in wind turbine to maintain the voltage constant of the DC bus. Here, buck converter is used because the rectifier output voltage is greater than the DC bus voltage. DC bus voltage is 400V.

Figure 5 DC-DC Chopper

In DC microgrid battery is directly connected to the DC bus by the using the conversion of DC-DC converter and it's more efficient for the single conversion. In PV system boost converter is needed to step up the voltage of solar to DC bus voltage.

D. Integration of Renewable Energy Resources

1) Wind Turbine

The below Fig. 6 shows the overall architecture of the proposed Micro grid with wind sources [1]. The main sources, of wind converted into interfaced with a DC bus and feed power to the load, therefore dc-dc converter are used. The Bus can balance the voltage between the energy storage system and the DC load. Power Electronics Converter is used to interface the load and the Renewable Source. A common DC Bus is shared between the loads and to store the energy.

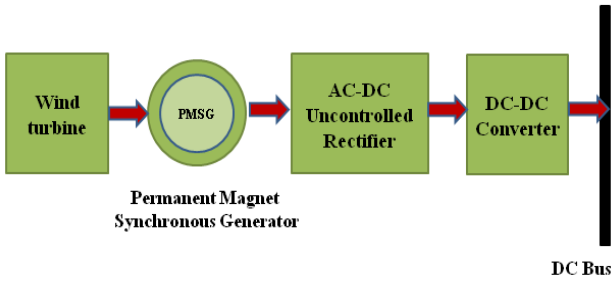

Figure 6 Wind turbine block diagram

The above figure explanation about DC–DC buck converter is used to maintain the voltage constant in this proposed paper. Input voltage is more in compared to output voltage so buck converter is used. By comparing the triangle to reference signal the pulse is generated [14]. When reference is more than the triangle, then after the gate pulse is given to the IGBT switch and the gate pulse is given to the buck converter accordingly and so the voltage is maintain constant.

2) PV system

In proposed PV system, as shown in figure 7 PV output is measured by MPPT controller and according to that DC-DC converter gives the variable output voltage and stores the energy in capacitor [17]. To make the DC voltage constant the closed loop control is needed in the DC-DC buck-boost converter to measure the output voltage.

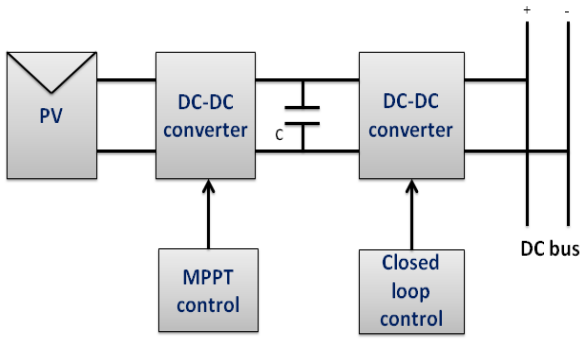

Figure 7 PV Block diagram

V. CHALLENGES IN INTEGRATION OF RENEWABLE ENERGY SOURCES

A. Challenges in integration of Renewable Energy Resources

The fact that solar and wind power are intermittent and non-dispatchable is widely recognized. The challenges in integration of Renewable energy sources [20] are as follows:

1) **High variabiltiy of wind power :** Not only wind speeds changes rapidly, but because the mechanical power contain-ed in the wind is proportional to wind speed cubed, a small changes in wind speed causes a large change in power output from a wind rotor.

2) **Frequency changes in wind generator:** Frequency behaviours of the system changes with wind penetration due to lower inertia of distributed wind generator.

3) **Fault occurs due to High penetration of wind:** Stress on breaker, transmission line, bus bar at the time of fault occurs, due to high penetration of wind energy resources, due to low fault ride through capability of wind generator [20] .

4) **Time lag between solar generation peak and late afternoon demand peak:** The availability of solar power generally has an excellent coincidence with summer peaking demand. Howevever, while the hightest load days are reliable sunny, the peak air-conditioning loads occur later in the afternoon due to the thermal inertia of buildings, typically lagging peak insolation by several hours.

5) **Rapid solar output variation due to passing loads:** Passing cloud events tend to be randomized over larger areas, but can cause very rapid output variations locally. This effect is therefore more important for larger, contiguous photovoltaic arrays(that can be affected by the cloud all at once) than for the sum of many smaller, distributed PV arrays. Passing clouds are also less important for solar thermal generation than for PV because the ramp rate is mitigated by thermal inertia [20].

6) **Power quality is reduced:** Wind energy penetration reduces overall efficiency and power quality.Problem occurs in power Quality such as voltage sag/voltage swell, over voltage/undervoltage, voltage transient, voltage harmonices, Flicker, current harmonics, Interruption, etc. occurs in wind and solar energy.

7) **Limited forecasting abilities:** Rapid changes of power output is especially problematic when it comes without warning.

Intermittence can be addressed by firming resources, including

- Reverse generating capacity
- Dispatchable generation with high ramp rates
- Generation with regulation capability
- Dispatchable electric storage
- Electric demand response

That can be used in various combinations to offset the variability of renewable generation output [19, 20].

B. Various solution of Renewable Energy Sources Utilization

The increasing number of renewable energy sources and distributed generators requires new strategies for the operation and management of the electricity grid in order to maintain or to improve the power-supply reliability and quality. The renewable energy sources such as solar, wind etc. has accelerated the transition towards greener energy source, and some of the solutions for the renewable energy utilization [20] are:

1) The power balance using renewable energy sources (RES) can be carried out by integrating renewable energy sources with energy storage unit. The benefits of battery energy storage system are classified based on end users as: Transmission level users, System level users, ISO Market users.

2) The power electronics play an important role in distributed generation and in integration of renewable energy sources into the electrical grid. Power electonics has undergone a fast evolution, due to some factors like development of semiconductor switches that are capable of switching quickly and can handle high power [20]. The performance of power electonics systems, in terms of efficiency and power density, has been continuously improved in research such as circuit topologies, control schemes, semiconductors, digital signal processors, and system integration.

3) Intermittence of power generation from the RES can be controlled by generating the power from distributing RES to larger geographical area in small units in one area.

4) When power is generated by renewable enrgy sources like solar PV is generated during day time so we can use this power for irrigation purpose.

5) In large solar PV plant output power is fluctuating during the whole day and this power is fed to the grid. Solar PV plant owner have to install the different types of storage system which gives gives additional cost to the plant owner. Once the storage system is fully charged then this storage elements give profit to system owner [20]. Therefore solar based water pumping system may be installed instead of storage system.

VI. CONLUSIONS

A microgrid is a part of distributed network embedding multiple distributed generation systems (mostly non-conventional renewable energy sources like photovoltaic panels, wind turbines etc.) and storage system with local loads, which can be disconnected from the upstream network under emergency conditions or if planned. The microgrid concept naturally to cope with the penetration of renewable energy sources, which can be realistic if the end user, is able to generate, store, control and manage the part of the energy that it will consume. The power connection in the microgrid can be done through AC link and DC link, that can be operated in either grid connected mode or islanded mode.

This paper presents operation mode and DC microgrid architecture is described. DC microgrid is in development because there is development in renewable energy resources and the battery storage. In this paper DC microgrid is in islanded mode, and so power is generated from the renewable energy resources. DC microgrid has many advantages over AC microgrid. It can eliminate DC/AC conversion stage and has advantages in stand of efficiency, cost and system size. Thus, the system can apply high quality power to loads in these types of conditions. Some of the challenges are described in integrating renewable energy sources such as wind, PV etc. To overcome the problem in renewable energy resources power electronics play an important role in distributed generators.

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