HYBRID MICRO-GRID

A Project report submitted in partial fulfillment
of the requirements for the degree of B. Tech in Electrical Engineering

by

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CERTIFICATE

TO WHOM IT MAY CONCERN

This is to certify that the project work entitled **HYBRID MICRO-GRID** is the bona fide work carried out by **Atria Ghosh (11701617066)**, **Soumyajit Dutta (11701617034)** and **Samyadeep Das (11701618004)** students of B.Tech in the Dept. of Electrical Engineering, RCC Institute of Information Technology (RCCIIT), Canal South Road, Beliaghata, Kolkata-700015, affiliated to Maulana Abul Kalam Azad University of Technology (MAKAUT), West Bengal, India, during the academic year 2020-2021, in partial fulfillment of the requirements for the degree of Bachelor of Technology in Electrical Engineering and that this project has not submitted previously for the award of any other degree, diploma and fellowship.

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Respected Sir,

In accordance with the requirements of the degree of Bachelor of Technology in the Department of Electrical Engineering, RCC Institute of Information Technology, we present the following thesis entitled “**HYBRID MICRO-GRID**”. This work was performed under the valuable guidance of **Mr. Nijam Uddin Molla**, Assistant Professor in the Dept. of Electrical Engineering. We declare that the thesis submitted is our own, expected as acknowledge in the test and reference and has not been previously submitted for a degree in any other Institution.

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ABSTRACT

HYBRID MICRO-GRID

The opportunities for use of renewable energy sources to drive power systems at various levels has increased due to increase in fuel prices, climate change and local environmental constraints. In order to use these sources efficiently, integration of various renewable sources is a necessity. To integrate the renewable sources a concept of microgrid is required. A type of renewable energy sources, distributed energy resources (DER) has started dominating in recent years but many challenges are faced due the integration of renewable energy resources in operation of microgrid. With use of wind biomass or solar, it is easy to produce energy on small scale but not sufficient to supply to the grid. Therefore, in order to tackle the problem of global warming, alternative methods are required so as to efficiently utilize the renewable energy. However, it is tough to monitor the energy consumption at any day as these renewable resources depends on weather and thus provides irregularity in power supply. Due to all the reasons mentioned above, there are discrepancies and system overloading in distributed generators (DG).

In the course of time, DC microgrids are making its way into the power industry as the technology to harness DC power efficiently has improved. To use this DC power generated efficiently into AC system, integration of AC and DC system is carried out to form Hybrid AC/DC microgrid.

Thus, hybrid AC/DC microgrid offer the best solution to existing problems in power industry and thereby minimize the energy losses to a large extent. Along with these several problems are faced when these systems are practically implemented and those issues needs to be addressed. This paper provides an overview on Hybrid AC/DC microgrid addresses the topics optimal sizing, reliability and mainly highlights the issues in this system and the methods to overcome them by help of simulations.

The project proposes a hybrid system which combines AC and DC system interconnected with inverters so as to form a hybrid micro grid. On AC side, Photovoltaic (PV), Wind and Diesel generator are connected into the main grid. On DC side, two battery banks are used as a distributed generator. The impact of different wind speeds and sun irradiation have been investigated for this hybrid microgrid in both islanded and grid-connected modes of operation. A 0.4 kV hybrid microgrid is developed and simulated using Proteus Professional Software and Electrical Transient and Analysis Program (ETAP) Software. Steady state energy management performance as well as transient stability analysis have been analyzed for different case studies. The impact of wind turbine control has been determined to verify the voltage and dynamic stability of the microgrid.

1. INTRODUCTION

Energy in general means capacity or ability to produce work. Energy is essential part of our life and it’s impossible to survive without it. As time passed by and with technological advancement humans were able to use this energy in various forms. Considering the utilization of energy in daily life it was possible to categorized it as renewable and nonrenewable sources. This thesis sheds light upon combined use of renewable sources i.e., solar & wind energy, hoping to discover and determine the extent to which energy generated using this technology is capable of satisfying the demand of energy. Using the combination of PV and wind renewable system has the advantage of using it in regions having higher wind speeds and less sunny days and the other way round.

The statistical data in recent years show that 33% of world population is non-electrified and most of such region lies in developing countries. The way in which such region can be electrified is either by extending the existing grid or by development of new isolated power systems using alternative energy sources [1].

The energy crisis and environmental problems are at peak in several countries due to power systems running on diesel or coal. Additionally, in remote areas the power distribution network suffers from huge line losses in transmission systems as a result of low voltage or centralized power flow. As these problems are getting complicated over time and also financial and economic losses to the utilities technologist are finding ways to use alternative energy sources efficiently. Thus, microgrid concept claims to provide clean, reliable, efficient and flexible source of energy by use of renewable sources therefore gaining popularity in industry. [4]

Supplying power to small electrical loads at remote locations or isolated grids Hybrid PV/Wind power generation systems have become a prevalent option as it offers highly reliable solution for continuous power supply. Most previous studies of these systems concentrated on local feasibility analysis. But the practical application of these systems needs to consider parameters such as stability, control and reliability. Therefore, in this project characteristics of hybrid PV/Wind power systems is investigated by applying simulation modeling.

1.1 Literature Review:

As technology improves over time, it’s possible to gather more information on how renewable energy can be used efficiently [2]. Depending on the distribution sources and connected loads microgrids are classified as AC or DC microgrids based on type of power transmitted [1]. AC microgrids have advantage as it utilizes the existing technology along with its protection circuits and required standards but the reactive component of the system should be stabilized and synchronized. DC microgrid is typically easy to control and can be benefited as it eliminates the AC-DC conversions using power electronic devices [6]. However, DC microgrid requires proper operating range for the DC voltage and the protection devices to work efficiently [10]. It is important to develop an appropriate control system and simulate for micro grids as the system is not enough understood even though its components are reasonably justified. A hybrid microgrid needs to be simulated in ETAP or Simulink to check the coordination and power flow [9] [11]. The microgrid behavior is unpredictable when large number of sources are coupled to it [5].

1.2 Definition of Microgrid:

“In Microgrid it is assumed that a cluster of loads and micro-sources is working as a unity controllable system which supplies power as well as heat to its local area.” - This idea yields a new prototype for operating distributing generations [1].

From the above definition a microgrid includes following features:

1. A microgrid consist of an integration of micro resources, battery storage units and strategically controlled loads as a part of local grid.
2. It has the capability to operate in grid-connected and islanding operating modes.
3. It demonstrates the ability of coordinated control and energy management functions.

Micro-sources having low cost and voltage, high reliability is laid out at customer site. These micro-sources are power electronic devices and controllers that ensure continuity of supply to the customer and reciprocate with the utilities. Microgrid (MG) have some defined characteristics as follows:

- Decentralized
- Remotely dispatched
- Less than 50-100 MW
- Connected with distribution system

Microgrids are possibly implemented in two ways; it can be similar to small electrical generator to provide backup power or a complex system integrated with the Grid consisting of generation, storage and power management systems. These systems consist of a bunch of technologies on the supply side as well as on demand side and located at or near the location of loads. Thus, MG technology has **wide application for local controlling electricity usage.**

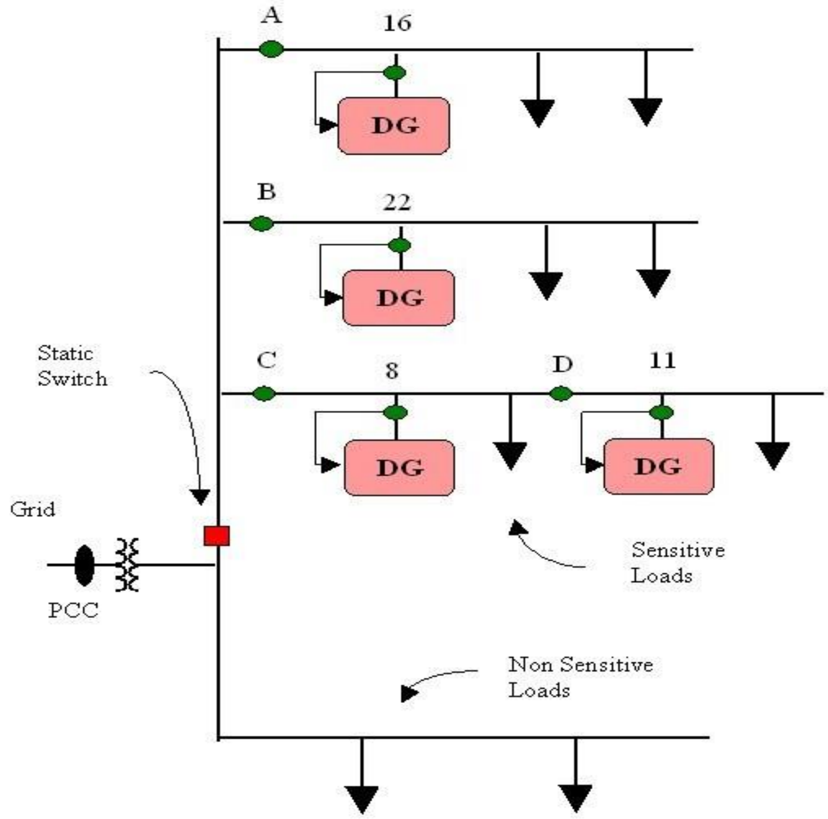


Figure 1.1 Micro-grid Architecture Diagram

1.3 Types of Microgrid:

In general, microgrid are classified into three types [6]:

1.3.1 Residential Microgrid:

These type of microgrid is utilized in communities, residential houses and campus. The only problem associated with this type is that it can cause impulse to the grid voltage and frequency when switching from grid connected to islanding mode. Therefore, stability and reliability of the system is a matter of concern in residential microgrid.

1.3.2 Remote Microgrid:

As the name suggest it can be applied in rural areas or islands where it is difficult for utilities to maintain the adequate energy supply. This type of microgrid prevents transmission and distribution line losses and CO2 emissions of the utilities. Only problem with this type is that the system should be self-sustainable enough.

1.3.3 Mobile Microgrid:

This type is applied in military-based camps or naval systems. Thus, flexibility of the system the main reason for using this MG as it can be easily moved from place to place as and when needed.

1.4 Reasons for using Microgrid:

The conventional arrangement of modern power systems has numerous advantages. Efficient operation of large generating stations is possible because of interconnection with high voltage transmission network which are capable of efficiently transferring bulk power with limited losses and to large distances. The distribution network is designed such that they can supply power in unidirectional flow and only to specific customer load types. [11] However, recently, the utilization of microgrid technology is increasing and lot of research work is carried out in this direction to constantly improve this technology and the reasons encouraging them are:

- Necessity to Reduce gaseous emissions
- Increasing effect of climate change
- Constant increase in power requirement
- Need to develop Energy efficient systems
- Government Deregulation or competition policy
- Diverse availability of energy sources

Investigation on the feasibility and benefits of MG is carried out by several research groups around the world as problems like dealing with unbalanced loads and harmonics associated with it needs to be rectified. However, this report does not concentrate on addressing such problems, rather it focuses on modelling the MG’s to investigate the transient and steady state response.

As electric distribution technology improves over period of time, noticeable changes are seen that will alter the energy requirements. The required modifications are carried on demand side where high availability and efficiency is needed as well as in the supply side where the distribution network and other critical technologies merge to maintain continuity of supply.

Distributed energy resources (DER's) and deregulation methods have brought considerable changes in modern power system operations and control. DER's makes use of renewable sources (RES) such as solar, wind or hydroelectric technologies and also allows participation of micro sources. Thus has an advantage over conventional distribution systems. Moreover, it helps in reducing the transmission and distribution line losses as these systems are modelled near to the load. Also, this helps as uninterrupted power can be delivered to the load and MG's can be operated in islanding mode in case of severe system collapse. [8] The storage device in microgrid ensures the balance between energy generation and consumption when rapid changes occur at load side.

Using combination of gas turbines, fuel cells photovoltaic systems, wind turbines etc. microgrid supply electricity to the customers. The storage device in microgrid usually includes batteries and flywheels and this combination is similar to rotating reserve of large generators in conventional grid. It ensures balance between generation and consumption during rapid changes in load or generation side.

Technical studies need to be carried out in two major fields when distributed generators are installed. Firstly, without making large modifications in existing system the influence of distributed generators has to be deal with. Secondly, new concepts for utilization of microgrid has to be generated.

1.5 Microgrid structure and components:

A Microgrid components are Distributed Energy Resources like PV, Small turbines, fuel energy cells, internal combustion engines, micro turbines, flywheels and batteries. DERs are mainly of two types: Firstly, directed-coupled systems to conventional rotating machines like a fixed seed wind turbine driving an induction generator. Secondly, inverter-based grid-coupled system like PV, Fuel cells or flywheels. Thus, in order to enhance the reliability of system and make it work efficiently and cost effective, the energy storage devices are periodically charged or discharged in controlled manner to cover the power deficit. Moreover, energy storage devices have fast response and thus they prevent instability in system due to transients. The figure below provides a brief idea of classification of Distributed Generations.

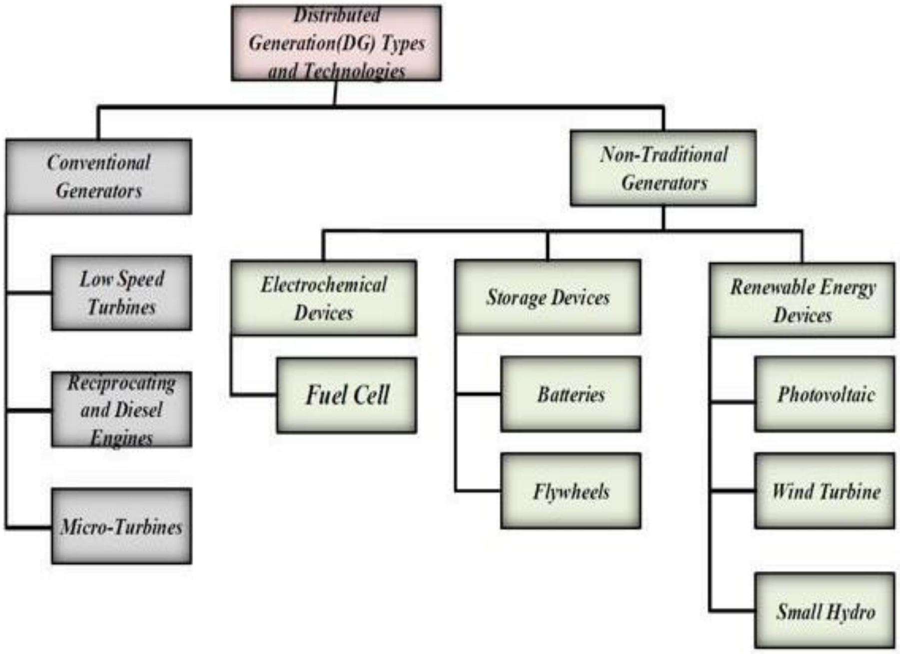


Figure 1.2 Classification of DG and technology used

1.6 Microgrid operation

Microgrid operation is divided into two parts: Islanding mode and Grid connected mode. In the island mode, the system should be efficient enough to generate as well as support sudden increase in demand to supply the load. On the other hand, in grid connected mode, it can exchange power from the main grid at times when system is inefficient of self-generation and fulfilling its load. [9] Also, in such cases when the microgrid is generating excess power it can supply it to the main grid. Furthermore, this system has an advantage, in situation when large disturbances occur in main grid, microgrid can be disconnected from the distribution network to avoid any damage to the system. Thus, it operates in islanding mode for such cases. Therefore, the economical, technical and environmental aspects of microgrids are factors that needs to be studied in detail.

The microgrid operation mode can be defined as [8]:

- **Grid-connected Mode:** Here, the micro grids are connected to the upstream distribution network and thus depending on the power sharing strategy it is capable of receiving total or partial power from the main grid furthermore, when total production exceeds consumption, the excess power generated is sold back to the main grid.

- **Island Mode:** Islanding mode is the autonomous mode of operation and is used when the upstream distribution network has a failure or need to perform planned maintenance action. In such cases MG's can run smoothly in islanding mode.

It is also necessary to understand that the microgrid operation is dependent on various entities such as network operators, DG owners, energy suppliers and regulatory bodies. Thus, for optimal operation of microgrids, factors related to economics, technical or environmental aspects are considered [2] [7].

1.7 Background:

Hybrid AC-DC technology consists of mostly the renewable sources. These sources are available in abundant and can be utilized to maximum extent possible. These technologies previously consisted of only Batteries, wind turbines and diesel to supply the load, but was not sufficient to manage the load as the system was not stable in different conditions. Thus, to overcome this problem, controller is used along with addition of PV module. Output of the PV arrays depends on the irradiation of the sun and it varies depending on the location. It’s necessary to carry out the transient analysis in such conditions where number of Distributed Energy Resources (DER’s) are present. Transient analysis will help in verifying the stability of this system during the occurrence of fault on different locations. This can be done by using Proteus Professional and ETAP simulation.

1.8 Implementation of microgrid:

A typical fossil fuel based industrial microgrid was built in Indiana at Whitling refinery having installation capacity of 64 MW. but till 2015, up to 3.1 GW of new capacity is installed worldwide. It can be seen from the figure below that United States is the currently leading with exactly 626 MW of operating capacity which is expected to increase to 2352 MW by 2018 [10].

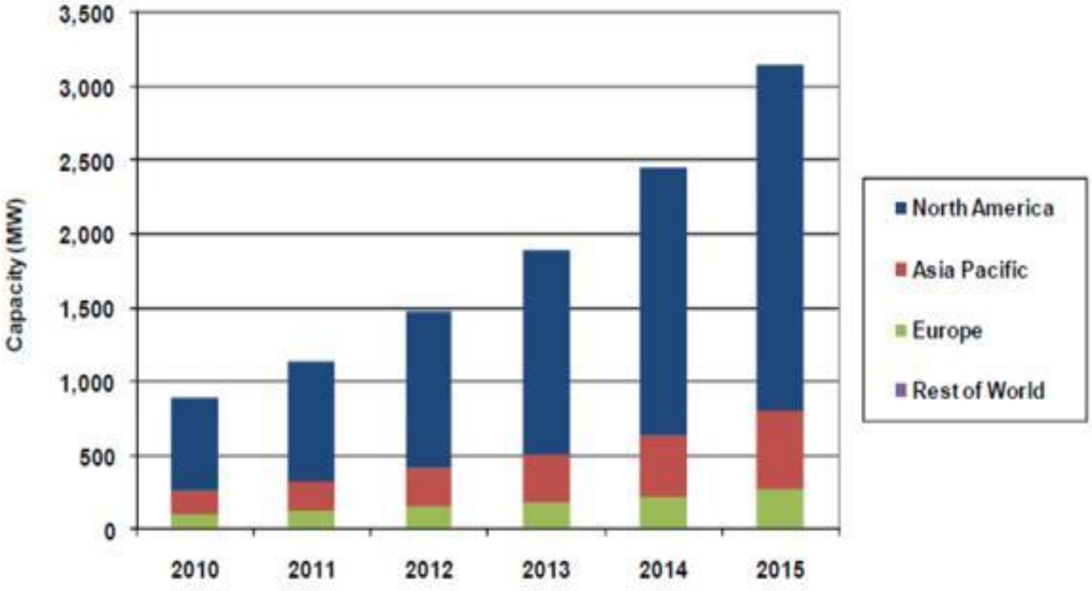


Figure 1.3 Microgrid capacity in the world [10]

As weather conditions vary at different locations and also the solar index depends on the season it is necessary to control the output to achieve maximum efficiency. Thus, in order to produce maximum power from the PV modules, maximum power point tracking methods can be utilized.

2. REAL MICROGRID OVERVIEW

Here are few examples of microgrid implementation in recent years:

2.1 The Consortium for Electric Reliability Technology Solution (CERT)

Microgrid:

It consists of three combined heat and power sources (CHP), operated by natural gas and is parallel connected with energy storage systems assembled with bi-directional DC/AC converter. In this system each unit has individual control which is controlled by P-F and V-Q droop line and PI control loop strategies. Thus, this scheme is called as Peer to Peer or distributed control as there is absence of central controlling unit. The microgrid model is as show below:

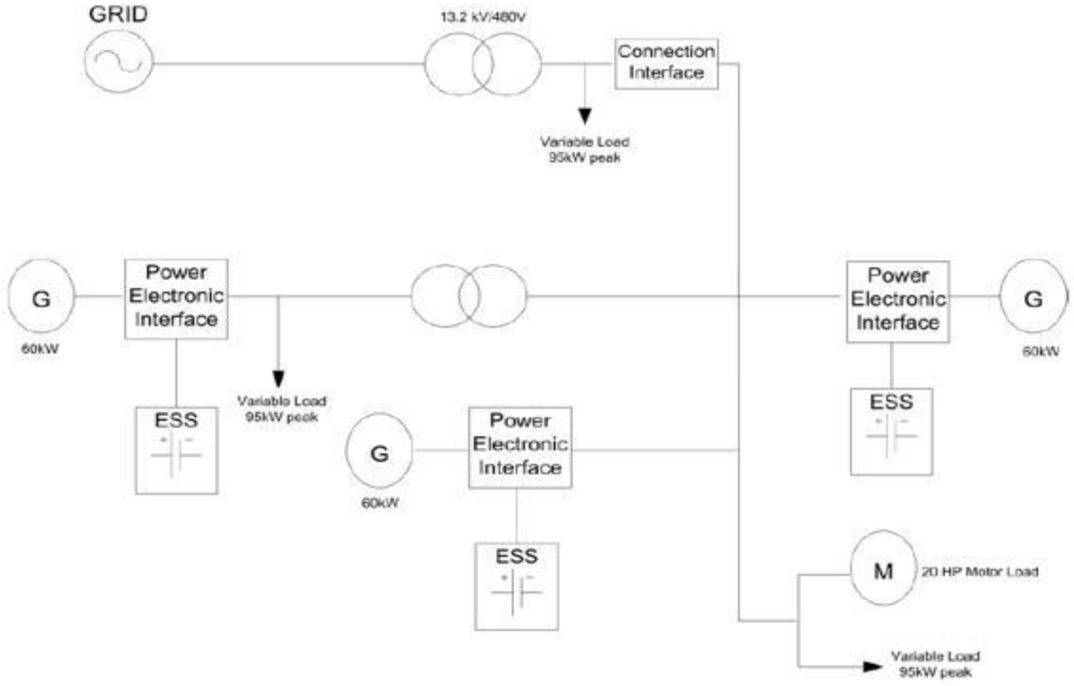


Figure 2.1 CERTS AEP type of design [3]

2.2 Mad River Microgrid in Northern power systems:

This is a central controlled microgrid controlling MV loads. It uses telecommunication signals of a simple controller or virtual “prime mover” to control the system and there is no master unit such as ESS.

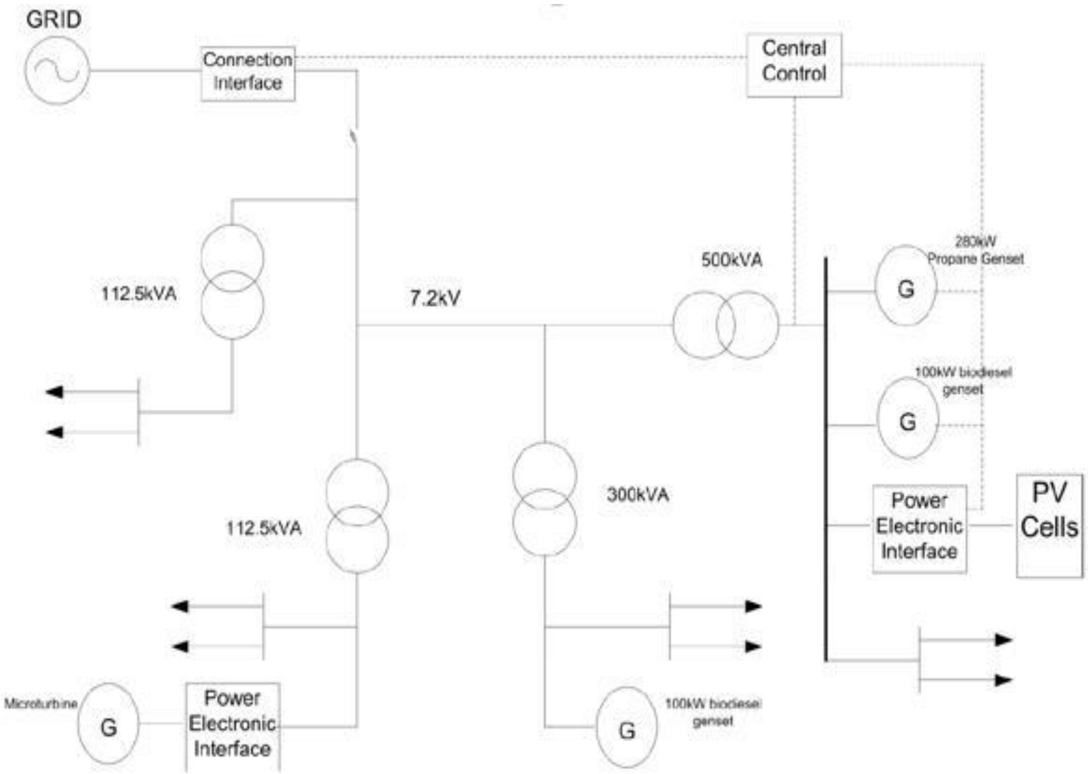


Figure 2.2 MAD River design of Microgrid [3]

2.3 The Shimizu Microgrid:

Located in Tokyo, Japan, developed by Shimizu Corporation it has 4 gas engine models, a PV array and three ESS particularly a lead-acid battery, NiaMH battery and ultra-capacitors. It implies a central unit but without a master unit i.e., virtual prime mover. The microgrid is shown below:

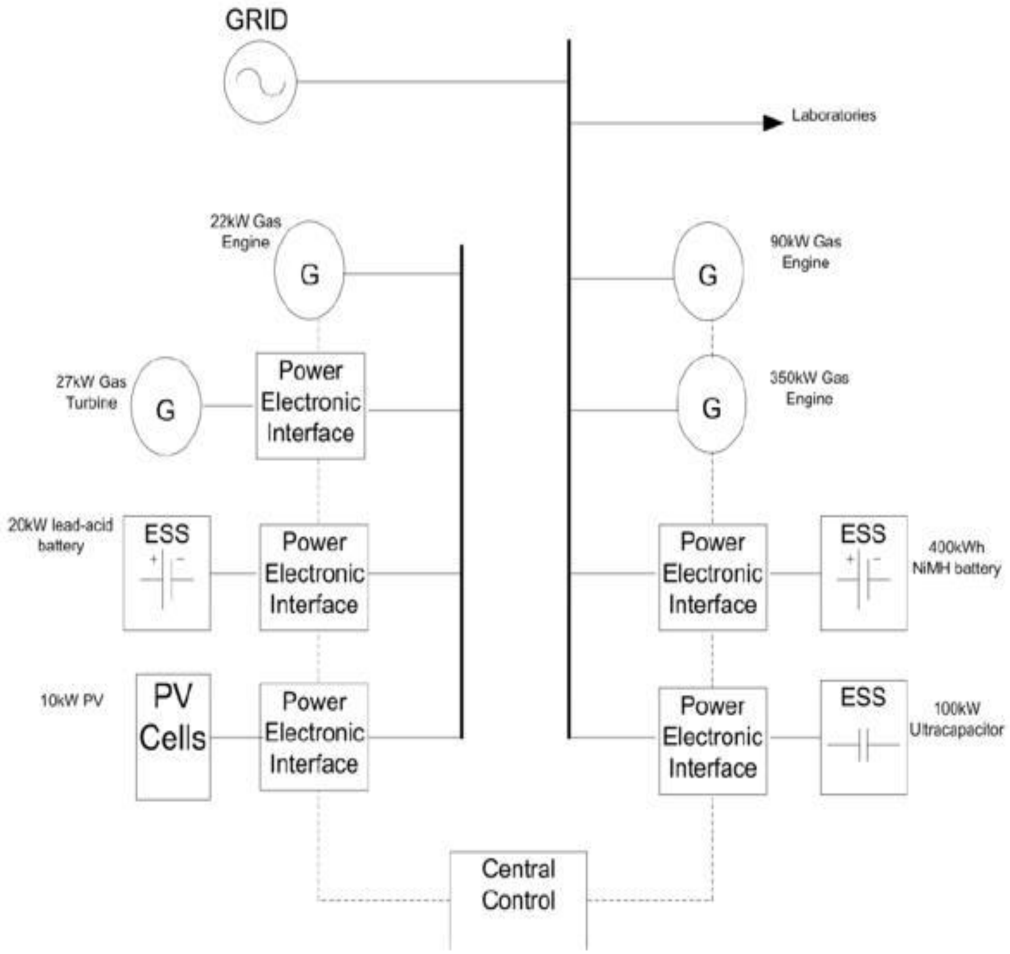


Figure 2.3 Shimizu Extended design of Microgrid [3]

2.4 Hachinohe System Microgrid:

This microgrid is a private distribution line consisting of a 6 kV feeder and electricity is primarily generated using several PV systems, Gas system and small wind turbines. It generates power from three 170 kW gas engines and 50 kW PV system located on a sewage plant. Hachinohe MG makes use of Central Control System without master unit, and communicates using telecommunication signals. Thus, it is similar to Virtual prime mover control strategy. The model of Hachinohe MG is as shown below:

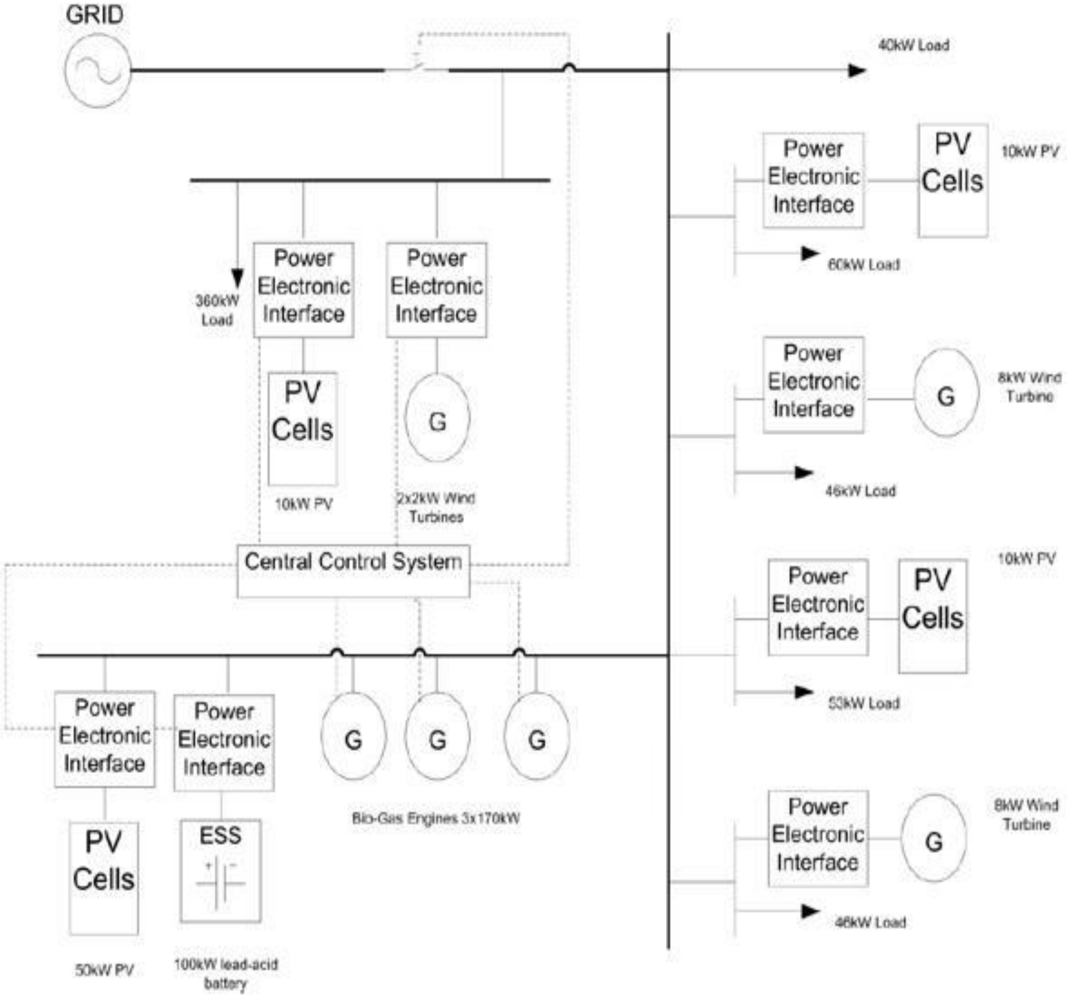


Figure 2.4 Hachinohe System design of Microgrid [3]

2.5 Smart Energy Campus - KEPCO, South Korea:

- MG Site Construction –
  - MG Cells: PV (675kW), ESS(1MWh), RTUs, Controllable Loads.
  - Site acceptance test (SAT) completed.

- Web-based EMS –

– Compact platform, user-friendly interface.

– Schedule based Applications: PV and Load forecasting, ESS scheduling.

– Alarm/Event driven Application: Emergency autonomous control.

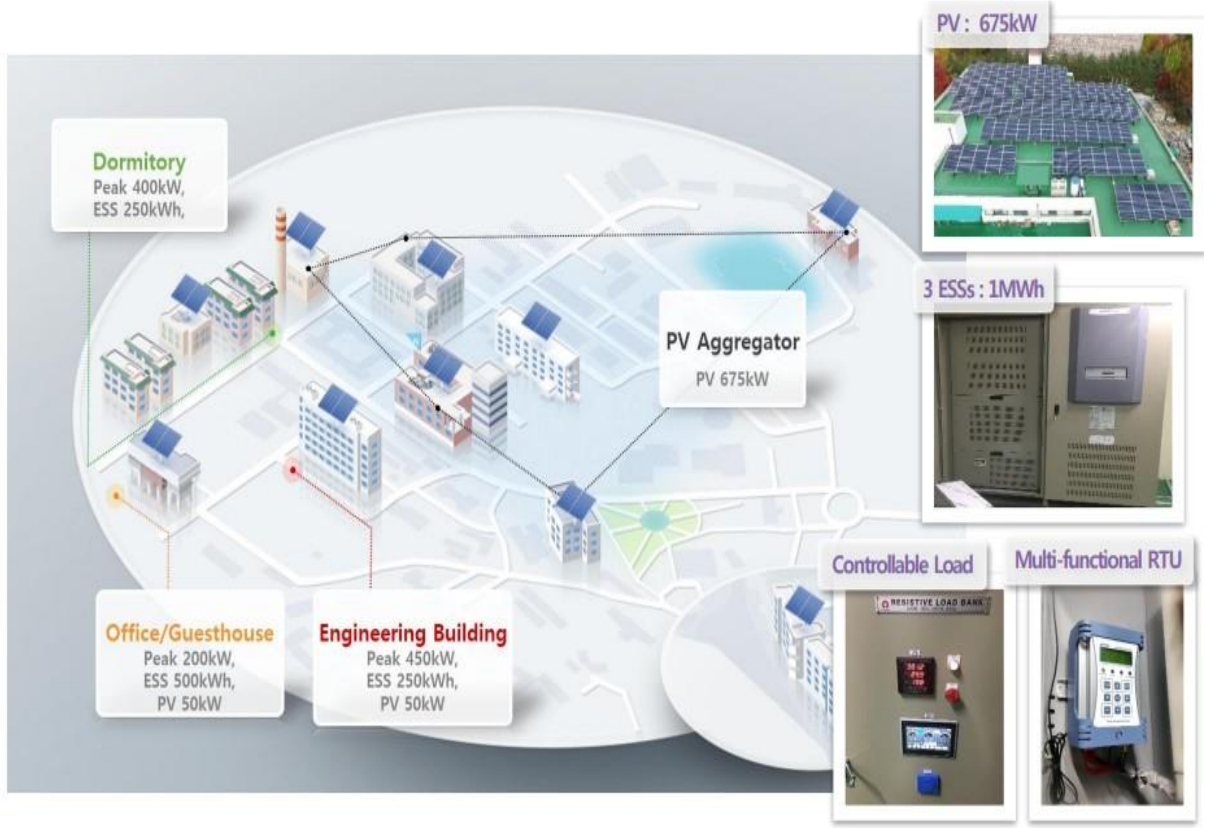


Figure 2.5 KEPCO Microgrid proposed model

2.6 Sendai DC Microgrid:

Other than these MG, DC microgrid are implemented as an experimental project. One such MG is in Sendai, Japan. This system is currently under construction and will include a 50 kW of PV microgeneration, a molten carbon fuel cell, two gas engine systems. In order to supply a full uninterrupted power, supply it makes use of a DC/AC converter. Figure below shows the Sendai DC microgrid:

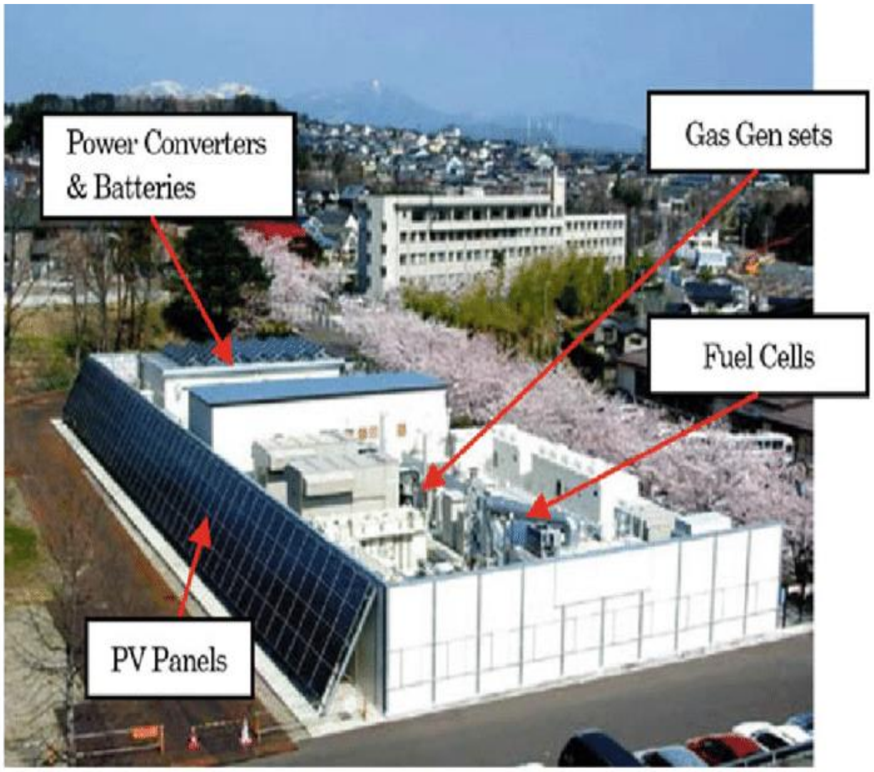


Figure 2.6 Sendai DC Microgrid proposed model [3]

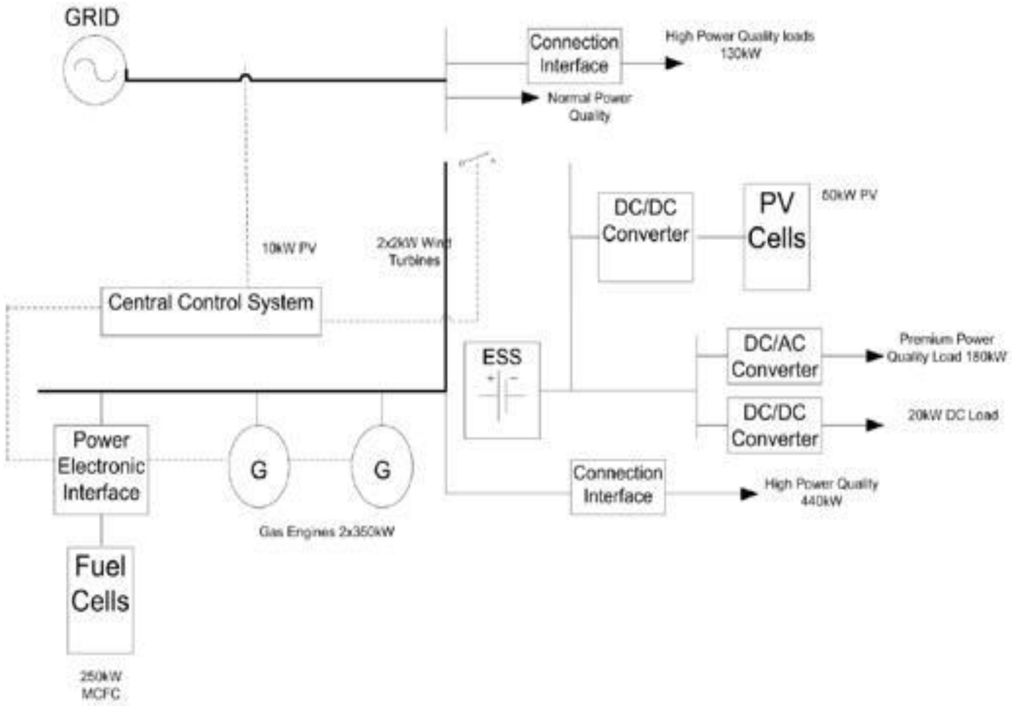


Figure 2.7 Sendai Project: layout of multiple power project [3]

3. DISTRIBUTION GENERATION SOURCES

3.1 Photovoltaic System:

Large amount of electricity is harnessed from PV modules connected in an array configuration. PV systems are very dependable as it produces constant DC voltage. The PV configuration consist of power electronics devices to interface with the grid, the inverter circuit changes the DC to required AC voltage (50 Hz).

But the power generation varies with changes in weather conditions and thus it is necessary to control the output to achieve maximum efficiency possible. Therefore, maximum power point tracking (MPPT) technique is used to extract maximum power produced by various PV module under various weather conditions [2].

3.1.1 Solar Radiation:

PV cells have the ability to absorb solar energy. It can convert this absorbed energy into usable electrical power as they are made of semiconductor devices. The PV module structure is constructed using P-N junction diodes. These diodes have the capability to convert incident light reaching its surface into electrical energy. As the energy generated in PV cells is directly proportional to incident radiation. The working of PV cell is shown in figure below:

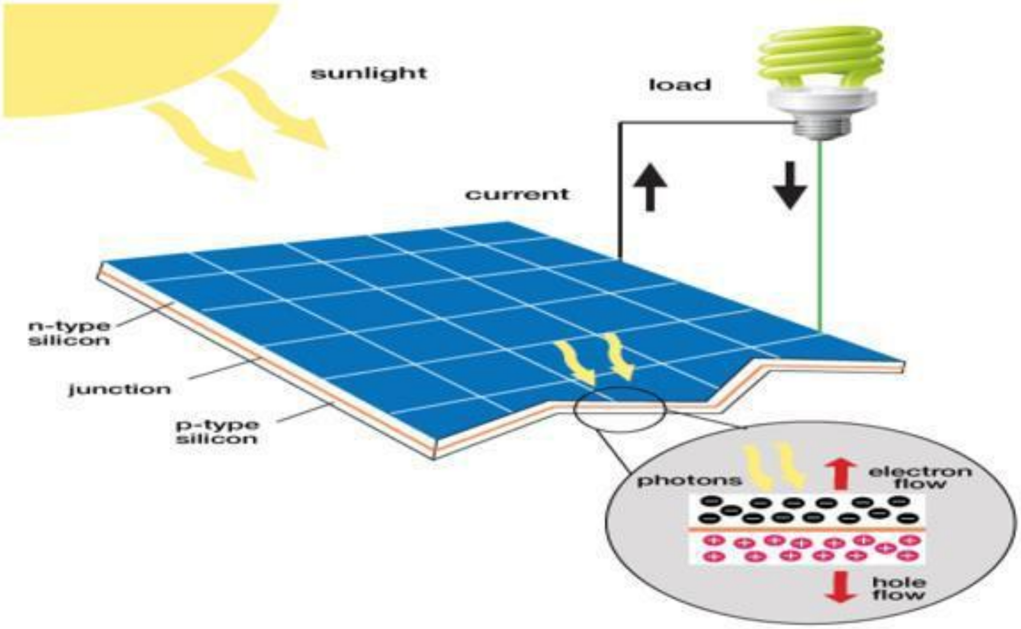


Figure 3.1 Working of Photovoltaic

3.1.2 Working of PV:

As seen from the figure below two silicon layers; a positive P layer of boron doped and negative N layer are present. When sunlight falls on the PV module coated with tempered glass, the energy is absorbed. After certain period of time the energy absorbed exceeds the band gap energy level and triggers movement of electrons to valence band via conduction band. This creates electron-hole pairs and free movement of electrons in conduction band. This movement of electrons is the reason for flow of electric current and thus the electricity generated in the process is used to supply the load. [9]

It can be seen that; PV cells are placed within a black sheet and the front panel. The number of cells in a module depends on the manufacturer and requirement as per specification of the location. The isometric view of PV module is as shown below:

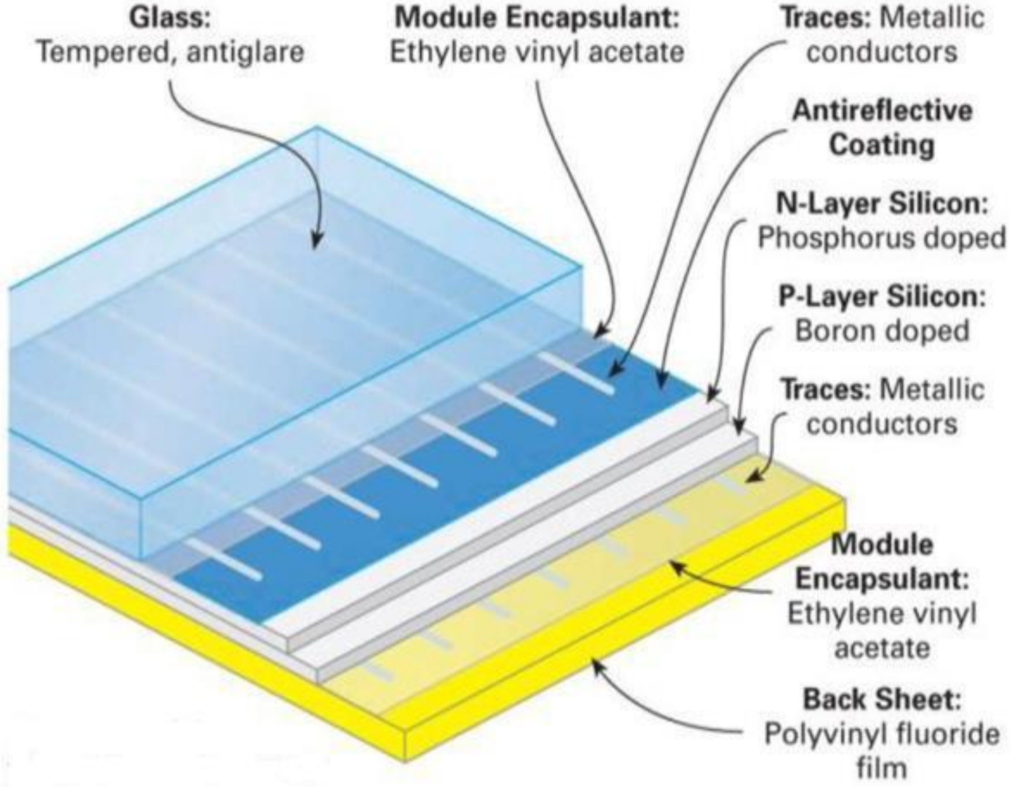


Figure 3.2 Module of PV

As seen the PV module consist of number of PV cells, enclosed within back sheet and front panel. The number of PV modules depends on the manufacturer but mostly a module consists of either 36 or 72 PV cells.

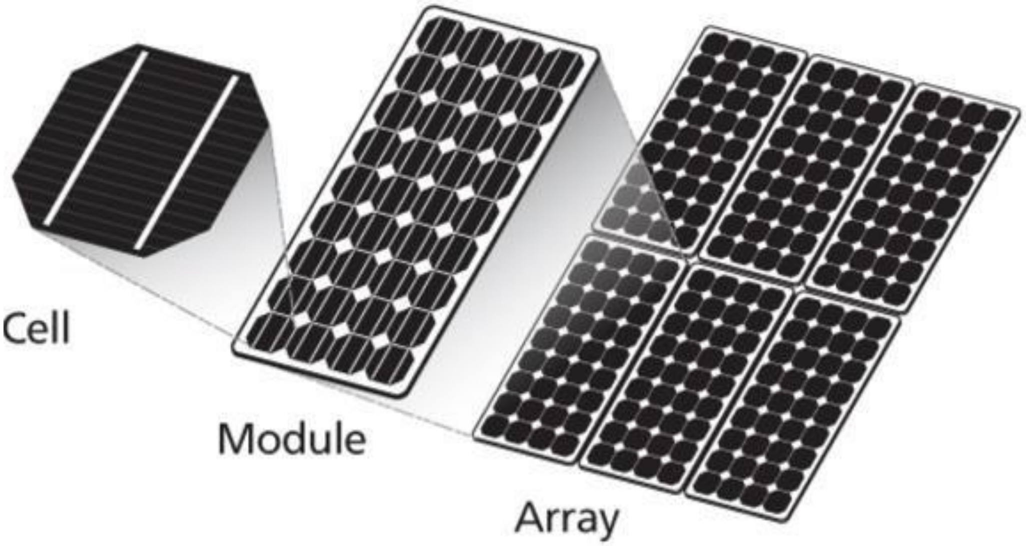


Figure 3.3 Solar cell

The advancement from cell to array is as shown in figure above. The array configuration is done as a single cell cannot produce enough energy to generate electricity. Practically, there are various losses occurring in this type of configurations and in order to get maximum efficiency MPPT is applied to each string. Applying this control technique, it is possible to extract maximum amount of power generated from the PV modules.

Methods applied in order to develop MPPT algorithm are [5]:

“Perturbation and observation algorithm”

“Progressive conductance”

“Parasitic capacitance”

“Maximum power tracking utilizing voltage”

“Maximum power tracking utilizing Current”

3.1.3 Advantages:

As PV system makes use of sunlight, it's practically free, available in abundant and easily accessible.

- These panels are extremely reliable and needs low maintenance.
- PV system are versatile as they can be operated off grid as well as in grid connected mode or even hybrid mode.
- These systems are cheaper for remote application and the cost of application is less as transmission cost of contemporary system can be avoided.
- This system is economical as it reduces infrastructure cost and can easily meet the peak demands.
- As they are constructed in modular designs, additional generating capacity can be easily added to this system
- It has a long working efficiency almost 30 years of uninterrupted service, without any noise or pollution.

3.1.4 Disadvantages:

- The initial cost of construction and assembly is high as compared to many other large scale electricity systems.
- The sunlight reaching the earth is more than enough to suffice the energy requirement of the globe, its density is relatively low.

- The output of the PV system is dependent on the availability of radiation from sun. Also, the cloud cover and short days will impact the efficiency of solar panels.

- As this energy is stored in batteries, it further increases the maintenance cost.

- PV cells are only 13-18% efficient and thus has low efficiency and is the reason for high cost.

3.2 Wind System:

Wind energy system makes use of the kinetic energy of winds that flow across the globe due to effect of earth’s motion. These systems generate electricity by converting the available kinetic energy into mechanical energy. [5]

In order to generate electricity, generator or induction motors are used along with power electronic devices. But these generators are affected by the flow of wind as wind speed varies and results in discrepancy in generated output.

The generating capacity of wind energy system ranges from 10W to 2.5MW depending on wind speed at particular location. The components and basic functioning of wind energy system is shown in graphical representation below [3]:

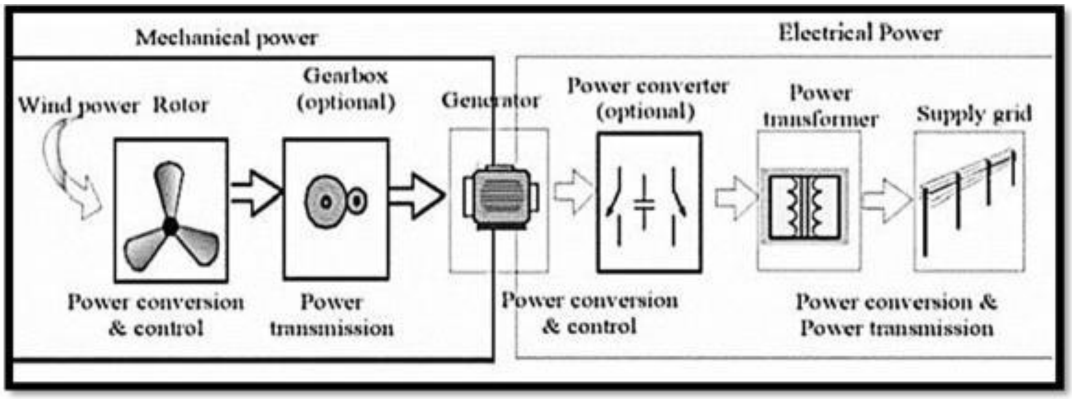


Figure 3.4 Wind system and its components

3.3 Micro Turbine:

These are small combustion turbines operated using gas cycle turbines. They are included in microgrid and range from 25 to 300 kW which is driven by high-speed generator of 120,000 rpm. To convert the high frequency of output, this system requires AC-DC-AC converter.

3.4 Energy Storage System:

Energy storage System (EMS) is used to help the distribution systems at peak load as the consumption of electricity is high by the customers. Thus, energy storage units are used in order to supply the required balanced power between the load and generation units. Thereby providing energy to the grid and other micro units having insufficient energy to manage the load. This problem arises as the demand increases in certain area and that excess requirement is difficult to meet by the distributed resources present in that area. In order to meet these additional requirements, the Energy Storage System can be used to boost the system requirement in given period of time and avoid power outage.

Energy storage system stores the excess power generated during off-peak time and during peak demand, when there is heavy utilization of power, the stored energy in EMS is used to feed the demand. Various technology is implemented to store this energy in battery system but most commonly flywheels and electrochemical capacitor. Few other technologies used in this sector are compressed air energy storage (CAES) and superconducting magnetic energy storage system (SMES).

The reasons for using the energy storage systems are presented below [2]:

3.4.1 Peak demand period tends to increase the generation cost

Also, as the electricity consumption at peak demand is high the output power from generator needs to be increased. This means more fuel is burned and releases more harmful gases like carbon monoxide in the environment. During off-peak period, the generation cannot be stopped completely and burns more fuel than needed as demand is less. Thus, to overcome all these issues, energy storage systems are required. These systems can be charged during off-peak period and can be utilized to fulfill the load demand during peak demands. One more advantage of EMS system is that the excess production from PV systems and Wind turbine generators can be stored and utilized later which further reduces the cost of generation.

3.4.2 Increase in renewable energy penetration

Energy storage systems when used with distributed generators helps in improving the system reliability. It also stores the excess power from wind generators and PV systems and thus helps in increasing the renewable energy penetration into the grid.

3.4.3 Line-congestion reduction

Energy storage systems reduces the transmission and distribution line losses during peak demands by supplying excess power to the load from local storage stations. Thus, it contributes to existing distribution infrastructure.

3.4.4 Stores energy for electric vehicles

With the recent trend, large numbers electric vehicles are being launched in the market. Energy storage devices with local charging stations can be set up in order to provide charging of electric vehicles. This helps in minimizing the impact on the grid due to EV charging. [4]

Thus, due to the above mention reasons the microgrid concept including energy storage devices are economical and efficient solution for development of smart grids.

For the below mentioned regions, the estimated increase in electrical storage capacities from the year 2011 to 2050 is described in graphs below. A significant increase can be seen in electricity storage capacities in all regions.

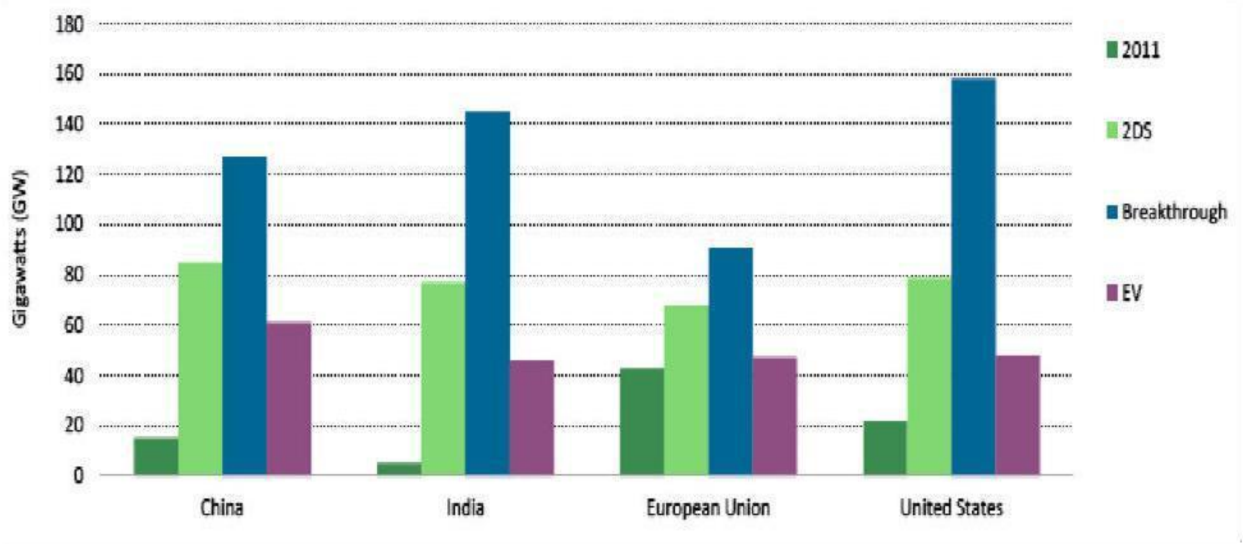


Figure 3.5: Daily electricity storage capacity by region in 2011 and estimated increase in 2050 (Source: http://www.iea.org)

The figure 3.6 below provides a detailed analysis of evaluation of battery prices from year 2009 to 2013. It can be seen that with advancement in technology, the battery prices have dropped from $2000 to $700 till year 2013.

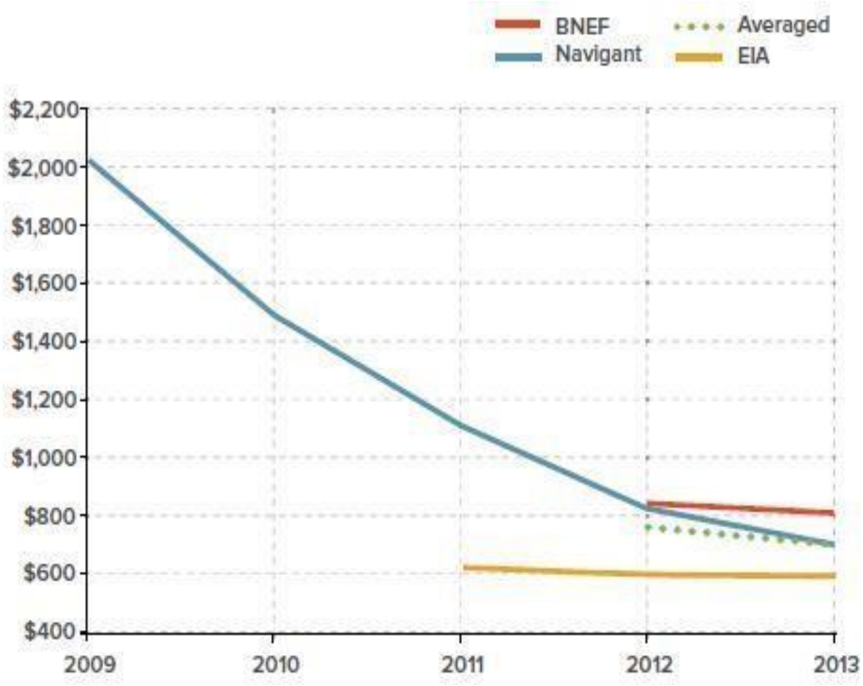


Figure 3.6: The Battery price from 2009 to 2013 (Source: www.rmi.org)

The figure 3.7 below provides an estimated values of battery prices in near future. As seen the estimated cost drops to around $150 till the year 2030 and predicts a near stabilized value till 2050.

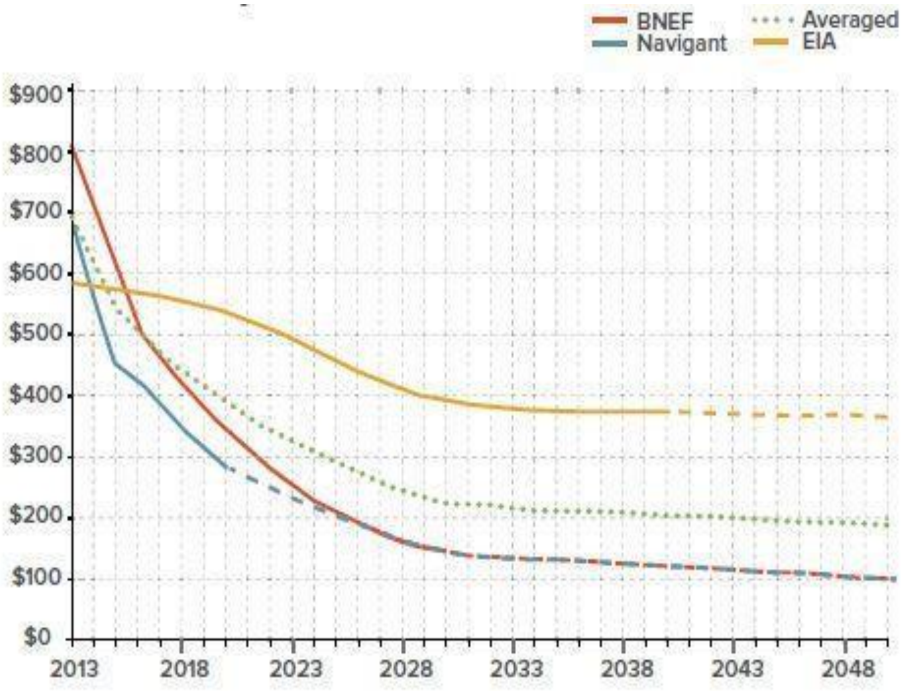


Figure 3.7: The Battery price provision from 2013 to 2050
(Source: www.rmi.org)

3.5 Fuel Cell:

Fuel cell makes use of chemical reaction to generate electricity. It is possible to generate electricity with minimum pollution by making use of Fuel cell as it makes use of hydrogen and oxygen to ultimately generate electricity and a harmless byproduct, water.

Fuel cells provide efficient and clean energy using this energy conversion and thus regarded as renewable energy resources. In general, chemical reaction takes place inside the fuel cell and it makes use of two electrodes, an anode and cathode respectively and an electrolyte between them for the reaction to take place. Hydrogen is the basic fuel for the reaction to take place but it also makes use of oxygen and a catalyst to speed up the reaction.

As fuel cells are static in nature because of their quiet operation without noise or vibration and its simple modular construction makes them highly efficient. Thus, fuel cell provides a cleaner, much efficient and flexible source of energy. A fuel cell consists of following components: Anode, cathode and an electrolyte between them. The figure below shows the process of fuel cell operation:

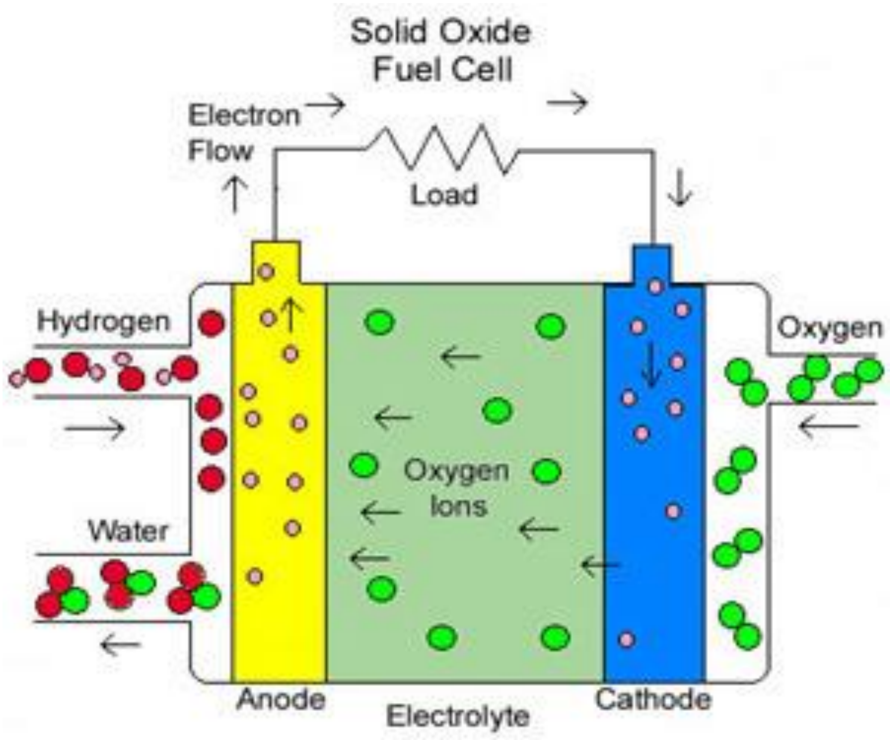


Figure 3.8 Fuel cell operation

The chemical reaction on which this occurs is as follows:

$H_2 = 2H^+ + 2e^-$

The hydrogen ions travel through the acidic electrolyte and the electrons travel to the cathode end to complete the circuit. At cathode end, the electrons and hydrogen ions react with oxygen which is supplied to the tank through external pipeline to form water.

$O_2 + 2H^+ + 2e^- = H_2O$

The total reaction of fuel cell is shown below which gives out water, electric work and heat as output:

H2O + O2 = H2O + Wele + Qheat

The by-products; heat and water are continuously removed so as to continuously maintain the isothermal operation for generation of electricity. Therefore, water and heat need to be managed efficiently for effective operation of fuel cells.

Comparison of Fuel cell and Battery with IC engine:

The fuel cell and heat engines make use of hydrogen-based fluid as fuel and air as oxidants. But the fuel cell electrochemically converts the fuel and oxidants whereas IC engine uses combustion process for the same. As combustion is a multistep process it firstly, produces thermal energy from chemical energy of the fuel and then is converted to mechanical energy and eventually generators are used to convert it into electrical energy.

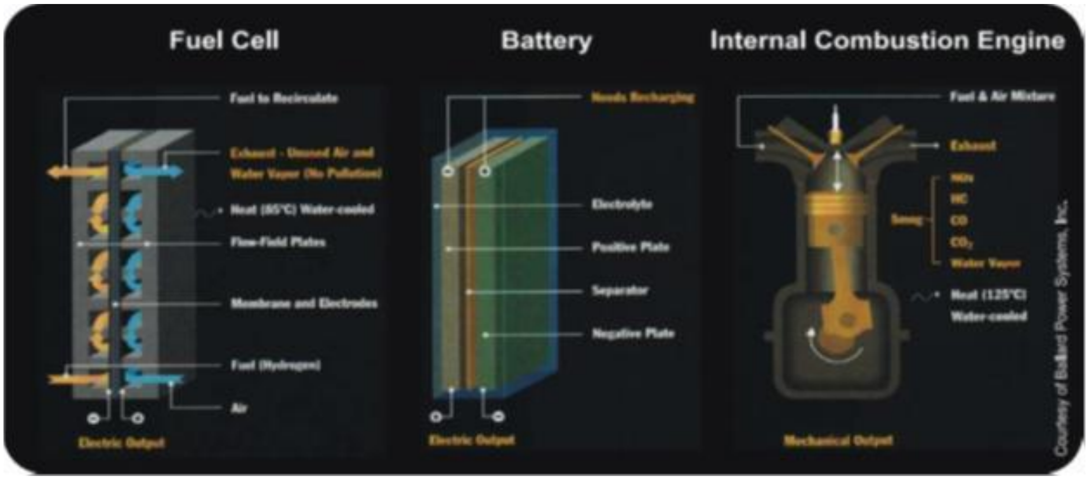
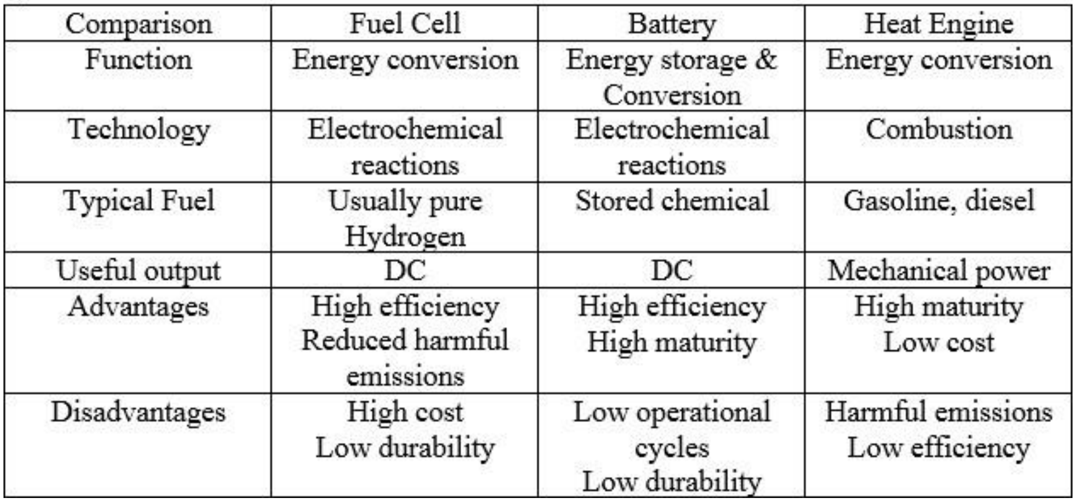


Figure 3.9 Comparison of Fuel cell, Battery and IC engine

Fuel cell and batteries work on same working principle and consist of electrochemical cells i.e., electrolyte between two electrodes. In order to generate electrical energy, both systems use oxidation reduction methods to convert the stored chemical energy. But the type of material and its composition significantly differs for both of them. In a battery metal rods are immersed in acidic solutions. The fuel cell consists of 2 electrodes and an electrolyte for conduction and transportation of electrons. In a battery, the energy stored in electrodes is utilized by electrochemical reactions at certain potential difference. Thus, a battery has limited life time and can be used till complete depletion of electrode material doesn’t take place.

Table below shows some basic comparison parameters for each of them:



Comparison	Fuel Cell	Battery	Heat Engine
Function	Energy conversion	Energy storage & Conversion	Energy conversion
Technology	Electrochemical reactions	Electrochemical reactions	Combustion
Typical Fuel	Usually pure Hydrogen	Stored chemical	Gasoline, diesel
Useful output	DC	DC	Mechanical power
Advantages	High efficiency Reduced harmful emissions	High efficiency High maturity	High maturity Low cost
Disadvantages	High cost Low durability	Low operational cycles Low durability	Harmful emissions Low efficiency

Table 3.1 Comparison between Fuel cell, Battery and Heat engine

4. CLASSIFICATION OF MICROGRID BASED ON POWER TYPE

4.1 Overview:

Microgrids are classified as AC systems, DC systems or Hybrid systems based on the power drawn from it. Any of these typical microgrid is identical to a small power system consisting interconnected components like DG units, loads and storage devices. Although controlling large number of DG’s is challenging considering the safety and efficiency of the system, modern technology plays a crucial role in overcoming these problems using power electronic devices which interfere with DG’s to create an architecture called as microgrid. As discussed earlier the components of microgrid are connected to power distribution network using point of common coupling and thereby it appears as a single unit to the entity. The classification based on power type is shown below:

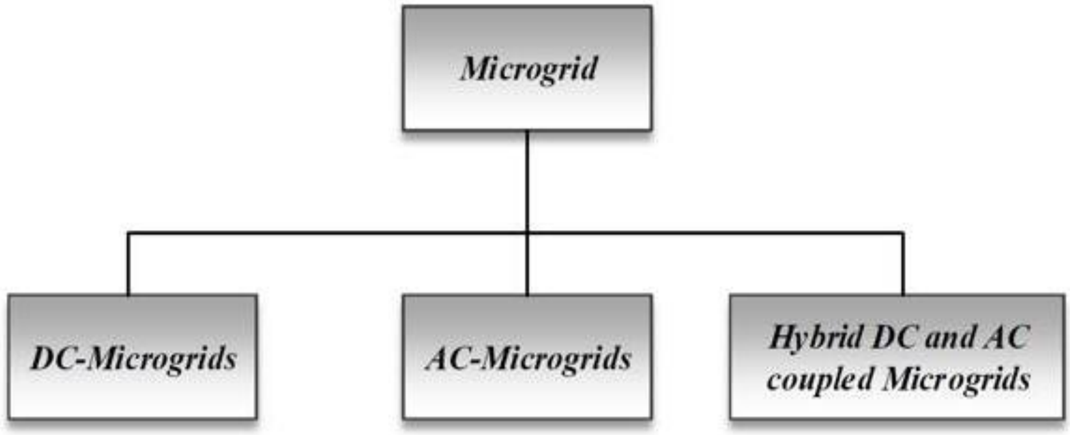


Figure 4.1 Classification based power type: AC or DC microgrid [5]

4.2 DC Microgrid:

Recently DC microgrid has a rising popularity in coming years and provides most attractive options over AC microgrid structure. DC microgrid inherits two modes of operation: grid-connected mode and autonomous mode and has several advantages of AC microgrid.

DG system in MG's mostly consist of PV units, fuel cells Wind turbines or any other renewable energy resource. It utilizes the dc output voltage from its storage devices andthus its utilization can be easily carried out by help of voltage regulator. There is no need of additional synchronization system for to match the voltage magnitude, phase or frequency as needed for AC systems. Thus because of better compatibility, higher efficiency and better stability & reliability DC microgrid is an emerging option in microgrid technology.

A typical example of DC microgrid is as shown below:

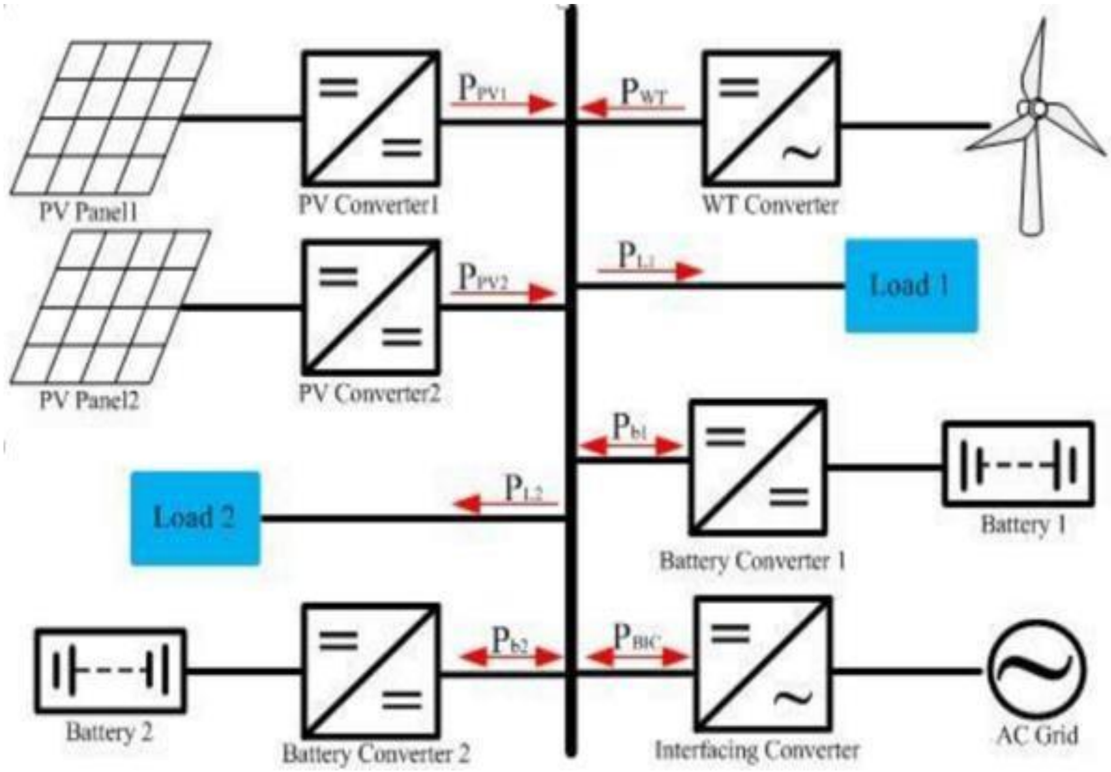


Figure 4.2 Structure of basic DC Microgrid [6]

As seen, the PV panels are connected to the DC bus via DC/DC converters and the wind turbine is connected using an AC/DC rectifier. Also, two battery units acting as power storage element are used to store excess power by help of DC/DC converters, this allows charging and discharging as and when required. As seen by making use of interfacing converters the load can be supplied to the AC grid.

4.3 AC Microgrid:

Although DC microgrid were widely preferred initially because of its easy utilization, AC microgrids has won over DC systems for several reasons. AC system can easily alter the voltage levels thereby providing flexibility to the generation, transmission and consumption side. Also, the cost of AC equipment is relatively cheaper than DC equipment. As AC distribution network is predominantly preferred worldwide, integration of AC microgrid in distribution network adds excellent benefit to the conventional power system. AC microgrid can be utilized and extended to rural as well as in cities and thereby generate reliable power in case of occurrence of any disturbances. Thus, it can also be easily operable in off grid mode.

A basic example of microgrid is as shown below:

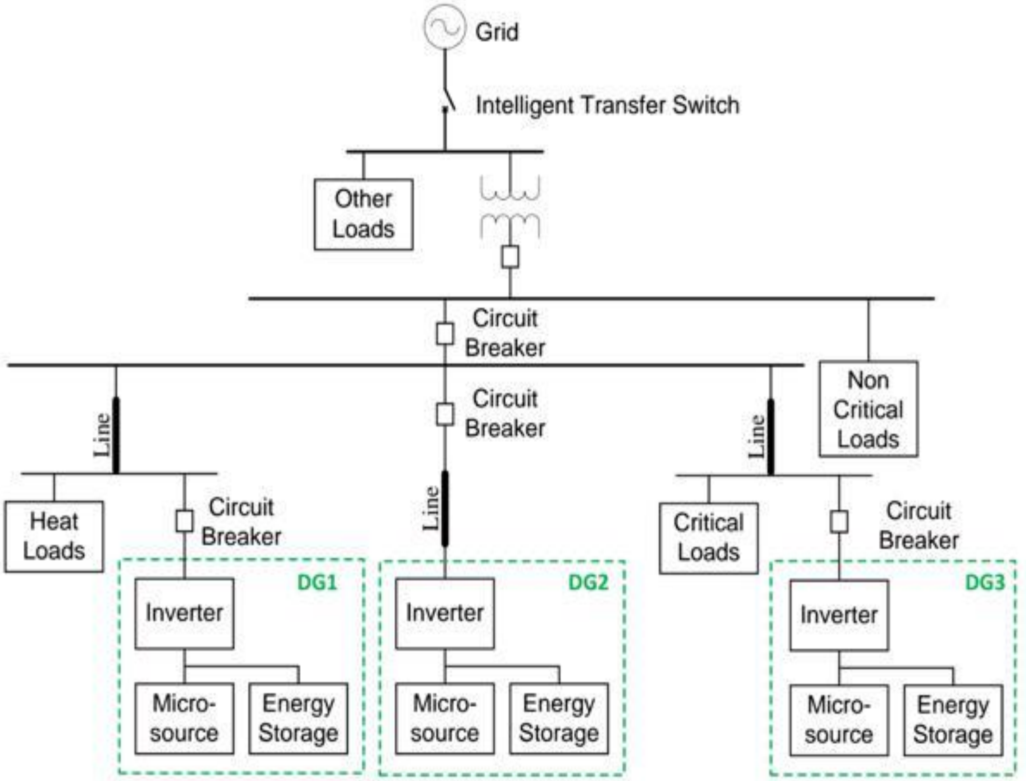


Figure 4.3 Structure of basic AC Microgrid [6]

From the typical example shown above it can be seen that the microgrid is connected to the mains using an intelligent transfer switch, which allows the MG to operate in grid connected as well as off grid mode. As seen in the figure each DG consist of inverter system, a micro-source typically photovoltaic, wind turbines and fuel cells etc and energy storage systems. This type of microgrid structure makes less losses, and flexibility in power supply.

4.4 Hybrid AC/DC Microgrid:

Due to predominant existence of AC systems and lack of efficient technological advancement in DC systems paved the way for combining AC & DC microgrid technology to form Hybrid AC/DC microgrid. Also taking into consideration the present situation and resources available to solve existing problems, a hybrid system offers an efficient way in this technology. Thus, the reasons for using hybrid concept for microgrid is as follows:

4.4.1 Load tendency from AC to DC:

The power supply system is designed to supply residential, commercial & industrial loads. Initially the ac and dc loads and generators were designed such that the they can adapt to both AD or DC system as whole but very complicated and inefficient system had to be installed eventually suffering heavy losses. Later on, AC systems became standard and dominant source for energy supply in all sectors, since then everything was designed keeping AC system and its shortcoming in mind. Also, the DC loads were still being used by connecting them with AC/DC converter neglecting the efficiency of such converters.

The development of power electronic devices and its control techniques has led to change in load tendency from AC to DC because now it’s possible to achieve higher efficiency, flexibility and reliability in implementing the DC systems. The change is also taking place as most of the modern electrical equipment and power systems make use of DC system for their operation, e.g., computers, printers, home theaters, refrigerators, air conditioners, washing machines, commercial buildings. On the other - hand, many devices make use of AC/DC converters for their operation to adjust the speed and save energy. Also, the modern technology is inclined towards creating energy efficient devices which mostly makes use of DC components and systems. Therefore, DC loads can be now efficiently utilized and integrated with exiting AC systems.

4.4.2 Recent trend of renewable energy resources:

With the growing research in RES technology such as PV systems, Wind turbines, Energy storage system, fuel cells and tremendous demand for energy is the reason for looking at alternative options to supply energy efficiently to the increasing population. Hence, there is increase in utilization of DC systems in existing AC power systems and upgradation leading to hybrid technology coming into existence.

4.4.3 Power conversion in AC and DC systems:

The power conversion in AC and DC can be analyzed as follows:

When PV system, Fuel cells are integrated into AC systems there is a need for DC/AC converter so as to supply the power into AC system. Other than that DC power can also be directly utilized for DC operating systems.

When AC power is generated, it need not be converted in order to be supplied to the AC load. This minimizes the conversion cost and makes the system easy to use. When DC loads are connected to such system rectifiers are used such as DC-AC-DC-AC along with DC/AC inverters.

In DC systems, no DC conversion is required for DC loads and the power consumed by the system is DC. If DC sources are consumed by AC system, then conversion from DC-AC or AC/DC is required as per specification of the system.

System	Source	DC load	AC load	ACwC load
AC	DC	DC-AC-DC	DC-AC	DC-AC-DC-AC
	AC	AC-DC	—	AC-DC-AC
DC	DC	—	DC-AC	DC-AC
	AC	AC-DC	AC-DC-AC	AC-DC-AC

Table 4.1 Power conversion techniques

4.4.4 Mode of operation of Hybrid microgrid:

The operating modes of hybrid microgrid is based on the type of topology used and flow of power in the system.

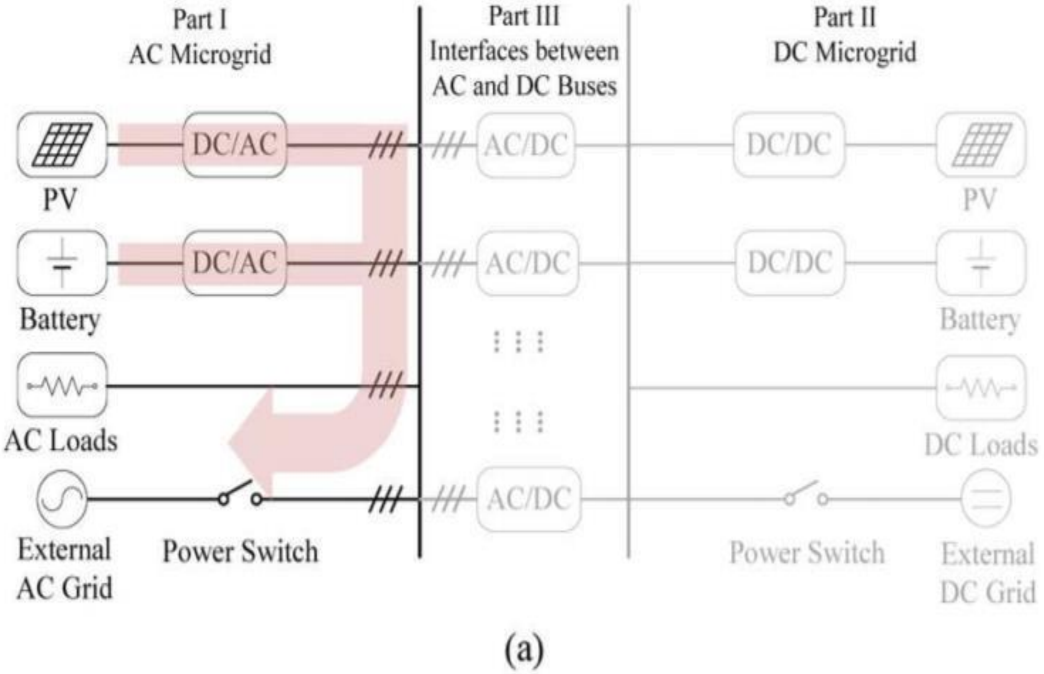


Figure 4.4 Operation of AC Microgrid [4]

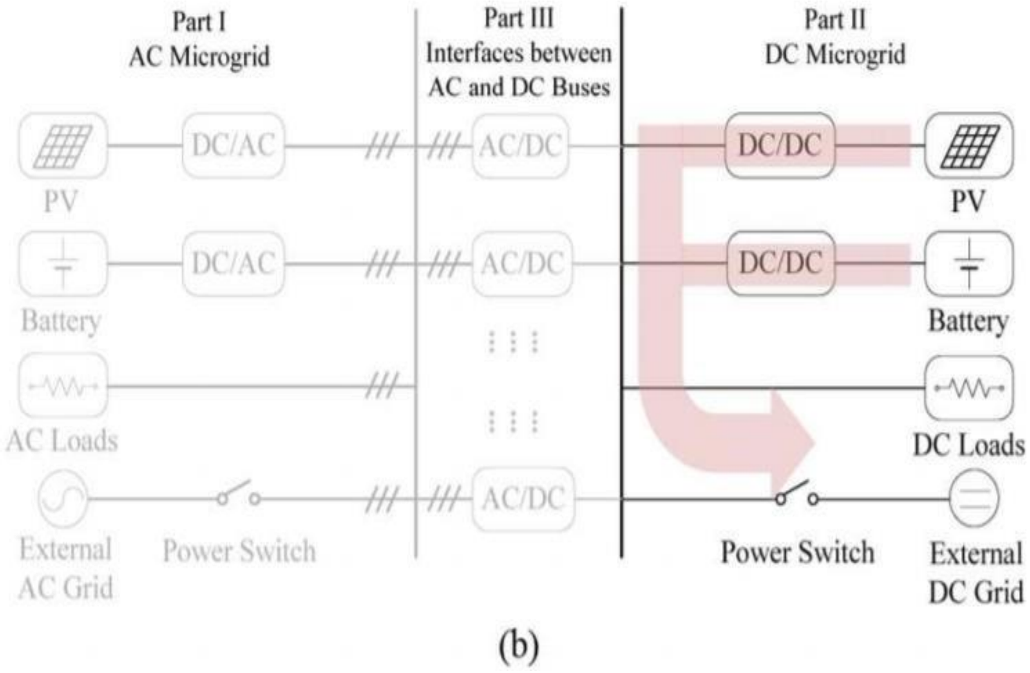


Figure 4.5 Operation of DC Microgrid [4]

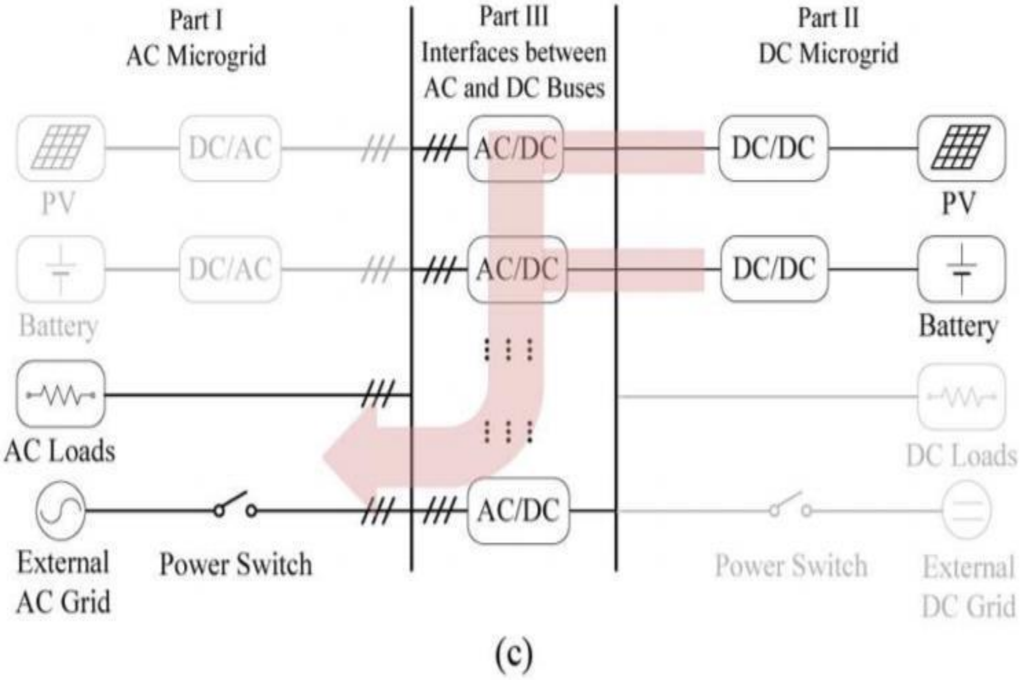


Figure 4.6 Operation of Hybrid Microgrid: DC to AC flow [4]

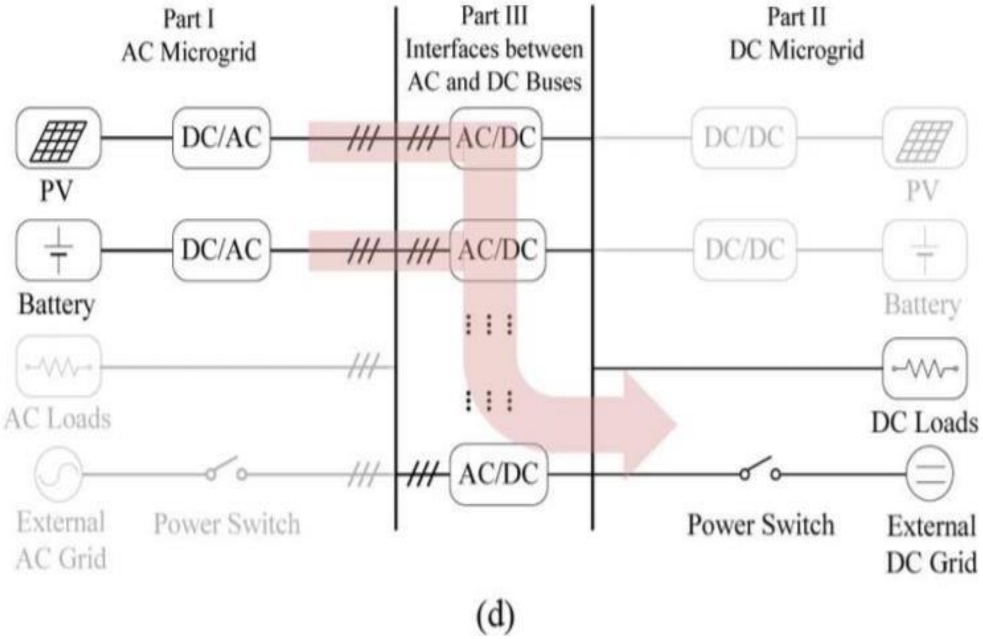


Figure 4.7 Operation of Hybrid Microgrid: AC to DC flow [4]

As seen in figure (a) and (b) the system is working as pure AC and pure DC microgrid respectively. In figure (c) & (d) shows interfacing between AC and DC systems.
In figure (a) only the AC sources are working and supplying power to AC load. There is no connection with the DC microgrid and its interconnecting bus bars. Also, when needed it can share power to the external AC grid. In Figure (b) only the DC sources are working to supply power to DC load. It has no connection with AC microgrid and its interconnecting bus bars. Similarly, it shares power to the external DC grid. In Figure (c) depict that the DC sources are in connection with the interfacing bus bars to supply AC load and also share power to the grid. This concept shows a type of hybrid technology. Figure (d) is for the AC source is connected to the interconnecting bus bars to supply DC load using AC/DC converter. Also, it shares power to the dc grid as and when required.

5. OPTIMIZATION STRATEGIES OF HYBRID MICROGRID

5.1 Optimal sizing of a microgrid

A microgrid is a small-scale power system with distributed energy resources (DER), which can be of two types namely renewable and non-renewable. Renewable resources are photovoltaic systems (PV), Turbines and biomass generators whereas non-renewable resources are IC engines, micro-turbine and fuel cells. The recent increase of fuel prices and the development of renewable energy technologies, better opportunities for using renewable sources for microgrid operation are being implemented. However, PV and wind energy are unreliable sources due to the fact thatthey depend on the weather. Therefore, it is difficult to produce as per demand in the case of renewable resources. This makes the sizing process complicated in technical and economic aspects. Concerns with optimization involve not only sizing of the components but also the operation strategies of the microgrid. Therefore, for optimal sizing of a microgrid, it is necessary to optimize all the components and energy fluxescontrol. [12]

The optimal sizing of a microgrid takes into account the added value of direct profits and also other important functions of power availability, reliability, environmental foot print, power quality and renewable integration for connected and disconnected grid modes.

Current important research issues are optimal sizing, control and energy management strategies. In the literature survey, several methods for optimal sizing have been proposed. Some of the many methods are artificial intelligence (AI), Genetic Algorithm (GA) and Particle Swarm optimization (PSO). Other methods utilize the iterative method to find the optimal size of a microgrid that satisfies the optimal operation strategy. Recently, software are being developed that used Load following method or Cyclic-Charging method for microgrid energy management. The Rule-based method, optimalglobal methods like Linear

Programming (LP), Mix-Integer-Linear-Programming (MILP) and Dynamic Programming (DP) as well as the artificial intelligent (AI) methods are also used to find the optimal energy management for a microgrid.

The figure below shows the operation strategy available for microgrid:

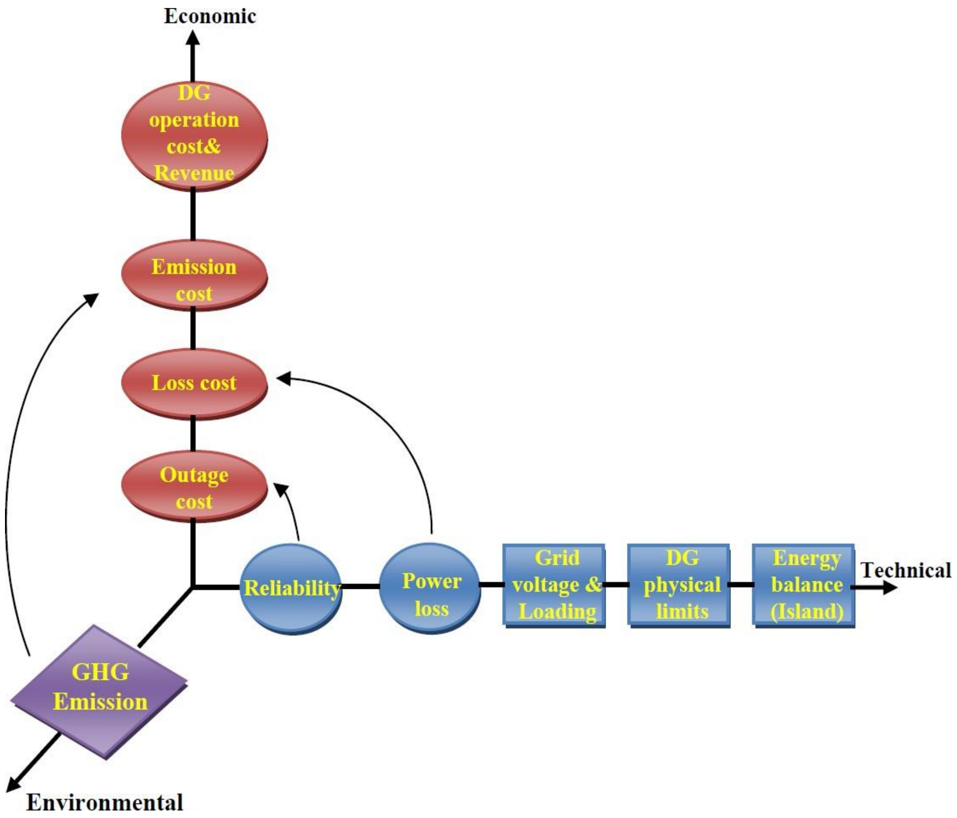


Figure 5.1: Microgrid operation strategy [14]

There are four operational options as follows:

- Economic operation mode option

- Technical operation mode option

- Environmental operation mode option

- Combined objective operation mode option.

A brief overview of the above - mentioned options is as follows [11]:

1) The economic option

The economic option minimizes the total cost of the DER operation and revenue. This option assumes lost cost and emission obligations. The constraintsare expressed as the physical constraints of the DER and energy balance. The economic mode of microgrid operation is shown in Figure 5.2.

2) The technical option

The technical mode of microgrid operation is presented in Figure 5.2. In this option, power loss is the main objective function. The constraints of this methodare voltage variation, device loading, DER physical limits and energy balance.

3) The environmental option

The environmental mode of MG operation is shown in Figure 5.2. The DER units with lower specific emission level are used here. The objective of this option is focused on the emission cost. This option does not consider the financial or technical aspects of the microgrid.

4) The combined option

The combined option, as the name suggests, completes multiple objectives to satisfy all of the economic, technical and environmental requirements. The objective function of the combined option considers the economic needs along with the technical and environmental aspects. Constraints from the voltage variation and loading, DER physical limits and the balance energy are used to derive this combined option.

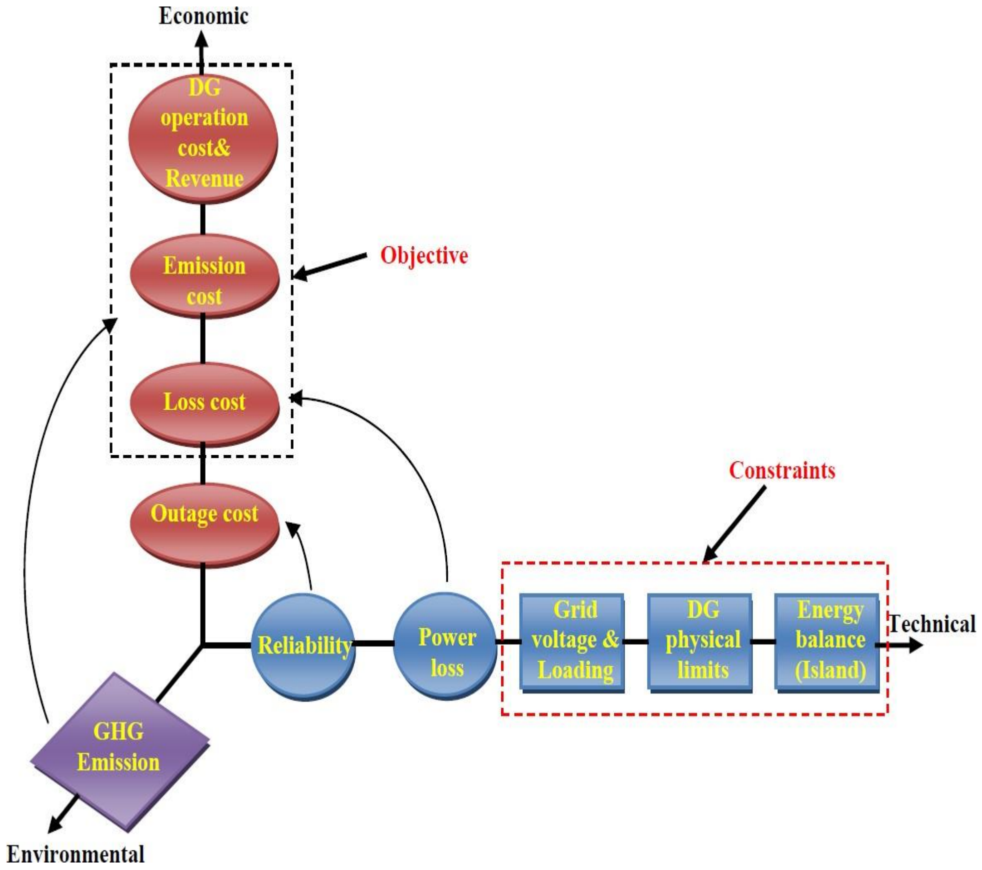


Figure 5.2: The combined objective mode of microgrid operation [14]

The combined mode of microgrid operation is shown in Figure 5.2 Both the economic and environmental have been combined to obtain the final result.

6. HYBRID MICROGRID SIMULATION IN PROTEUS & ETAP

6.1 Steady State Load Flow Analysis:

To provide convenience in comparing results researching various cases of network operation with different combination of renewable and conventional sources the circuit figure is designed in Proteus Profession 8.9 and ETAP.

Here an AC bus is connected to DC bus to form a hybrid connection as required for the simulation network. Wind turbine and PV systems are located at the AC side which are renewable sources of energy. For the backup of these systems a Diesel engine is used and also to minimize the power outage. This system is connected to the existing grid to provide the excess power demand to the new loads.

At the DC side batteries are used as source to power the demand and inverter and converter circuits is placed to interlink the DC bus with AC and improve the output from battery circuits respectively.

Also, PV system is connected to the AC side of the circuit which is capable of linking PV with the converter and DC load connected with it.

The circuit has two system buses AC bus 3 and DC bus 1. Both buses are on 400 V and connected with interlink (inverter). AC bus is loaded by 80 kVA lump load and 80 kVA static load. DC bus is loaded with 50 kW load. AC buses are supplied from wind unit 80 kW, Diesel generator rated 70 kW and Photovoltaic unit of 300 V, 30 kW. DC bus is connected with two batteries having 495 Ah and 285 Ah. The grid has the rating of 35 kV, 15 MVA. The transformer has a rating of 400 MVA, 35/0.4 kV.

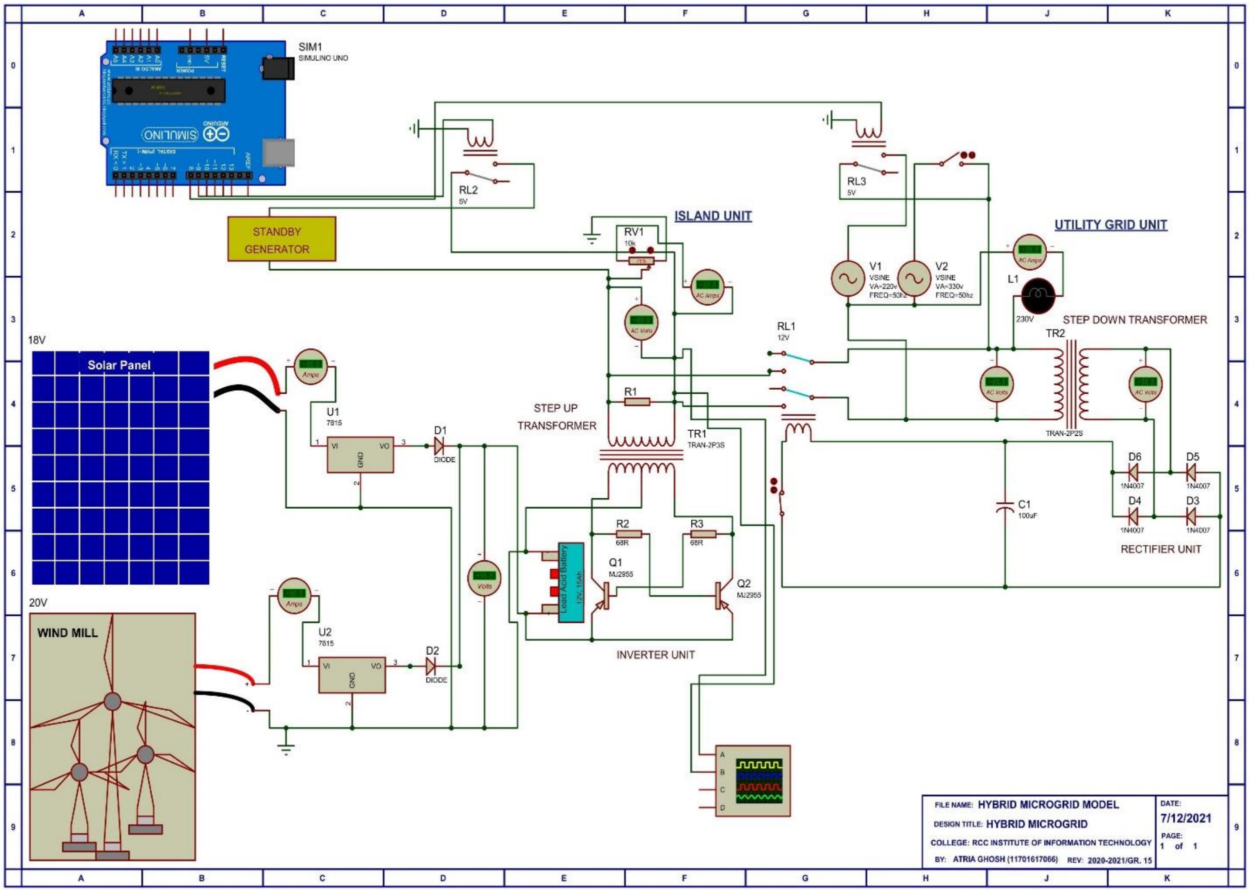


Figure 6.1 Simulation model of Hybrid Microgrid in Proteus

LOAD VALUE (in Ω)	VOLTMETER READING (V)	AMMETER READING (A)	ENERGY RESOURCE USED
5000	216	0.04	Non-Conventional
10000	222	0.025	Non-Conventional
15000	230	0.018	Conventional
20000	235	0.012	Conventional

Table 6.1 Resistive Loads applied to the circuit

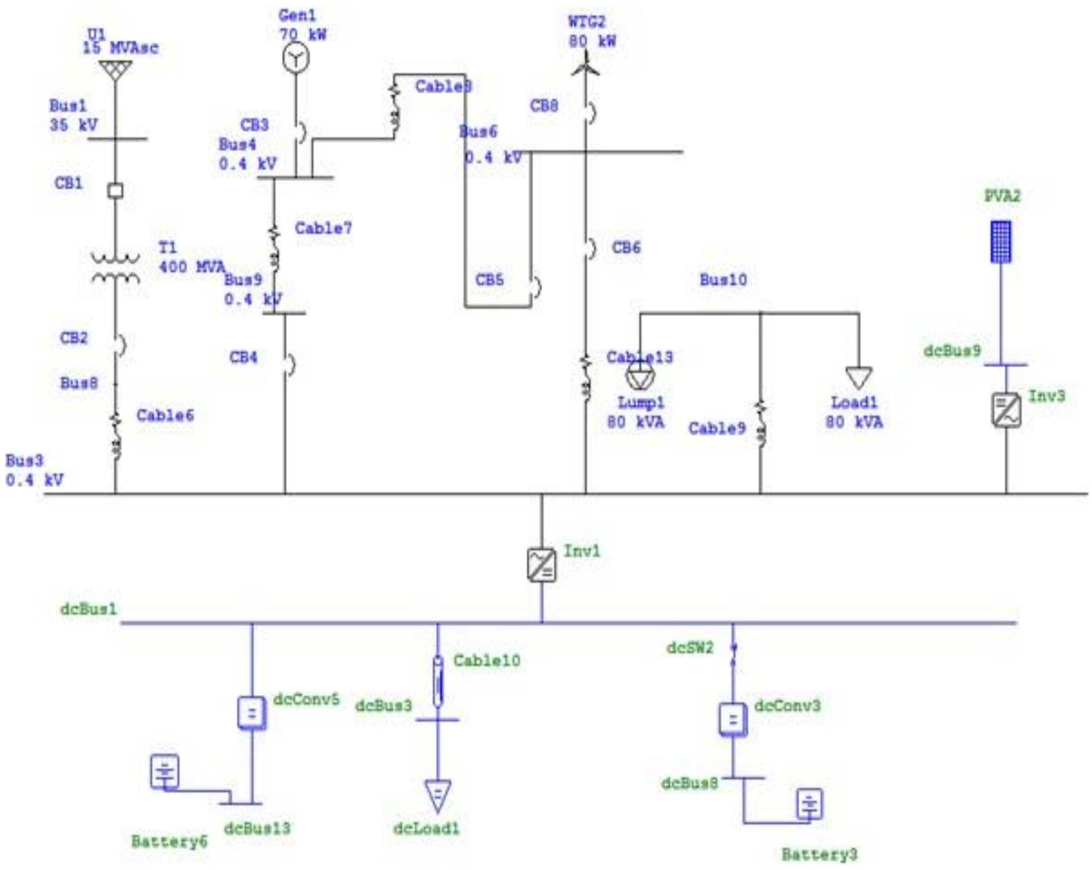


Figure 6.2 Simulation model of Hybrid Microgrid in ETAP

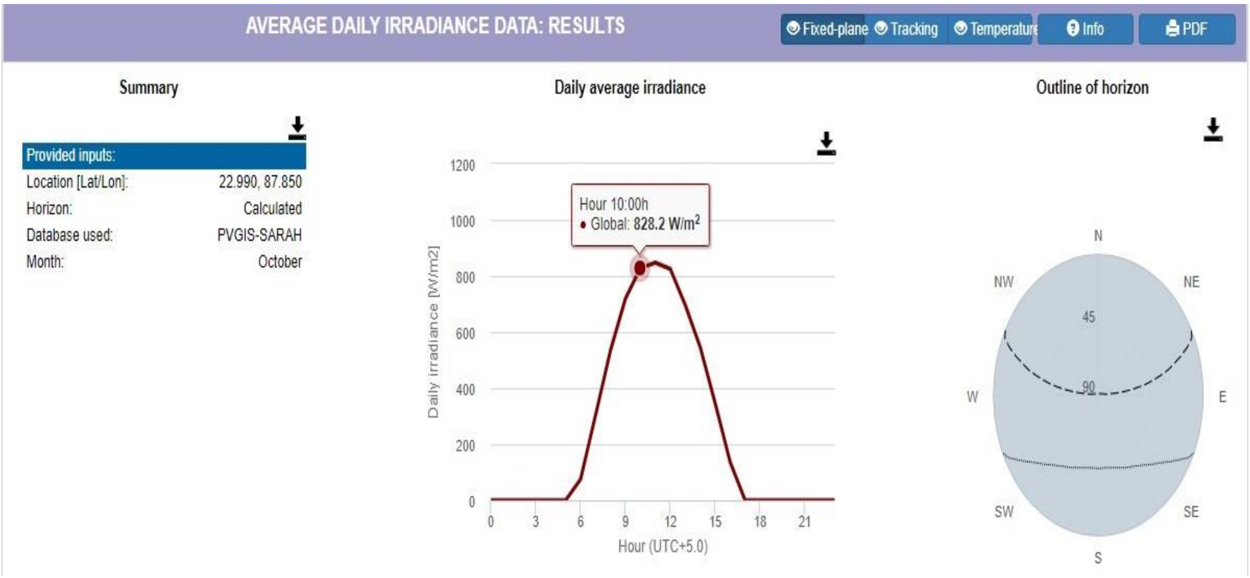
Steady state evaluation in the studied network is made for two cases:

1) Microgrid is operating in parallel with Grid.
2) Microgrid is in islanded mode.

6.1.1 Grid Connected Mode

i) Wind speed = 0 m/s; Irradiation = 828 W/m^2

In this case the diesel generator is switched off (no fuel) and wind turbine does not produce any power (wind speed is 0). For PV I, latitude 22.99° and longitude 87.85° of W.B., India is taken so in ETAP according to time zone irradiation is calculated and found to be 828 W/m^2.



Provided inputs:	
Location [Lat/Lon]:	22.990, 87.850
Horizon:	Calculated
Database used:	PVGIS-SARAH
Month:	October

Figure 6.3 Irradiance calculation for West Bengal

For this case steady state power flow result for AC and DC are as follows:

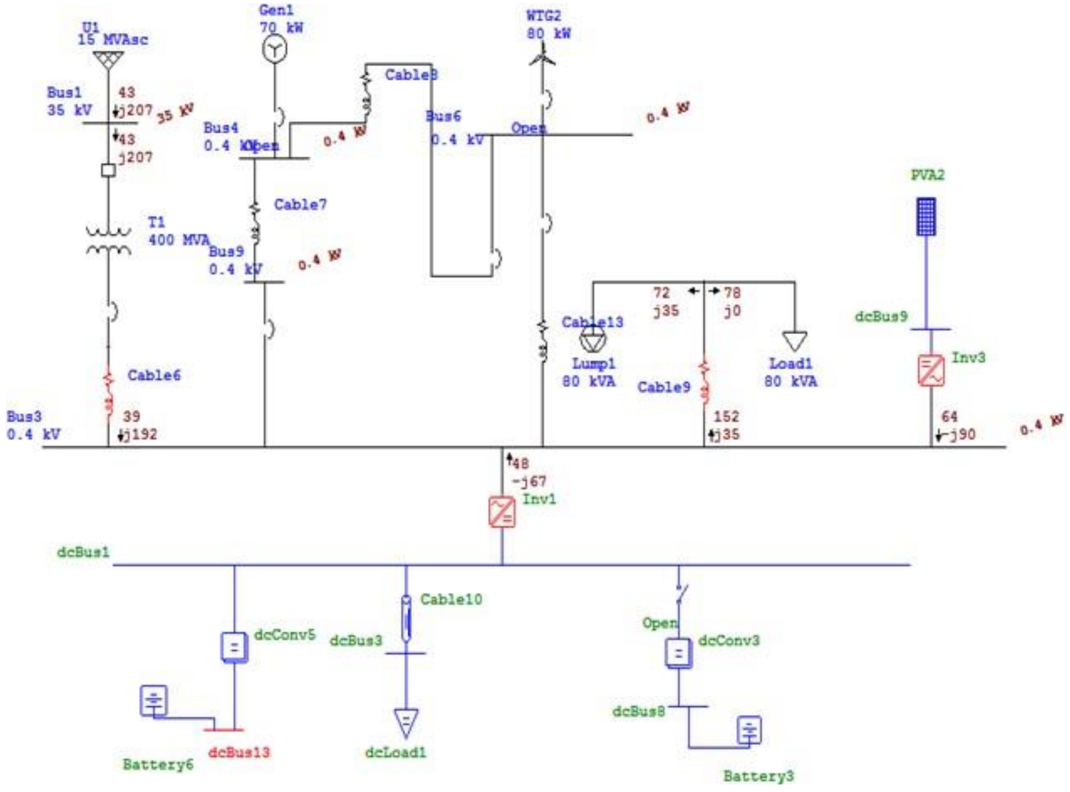


Figure 6.4 Load flow on AC side (without wind and diesel generators)

In this case the AC load supplied by PV, Grid and DC bus. Grid and PV provided 38 kW and 64 kW power respectively. The remaining 48 kW power for AC load is provided by DC bus through the inverter. Power obtained from the wind turbine and diesel generator is 0.

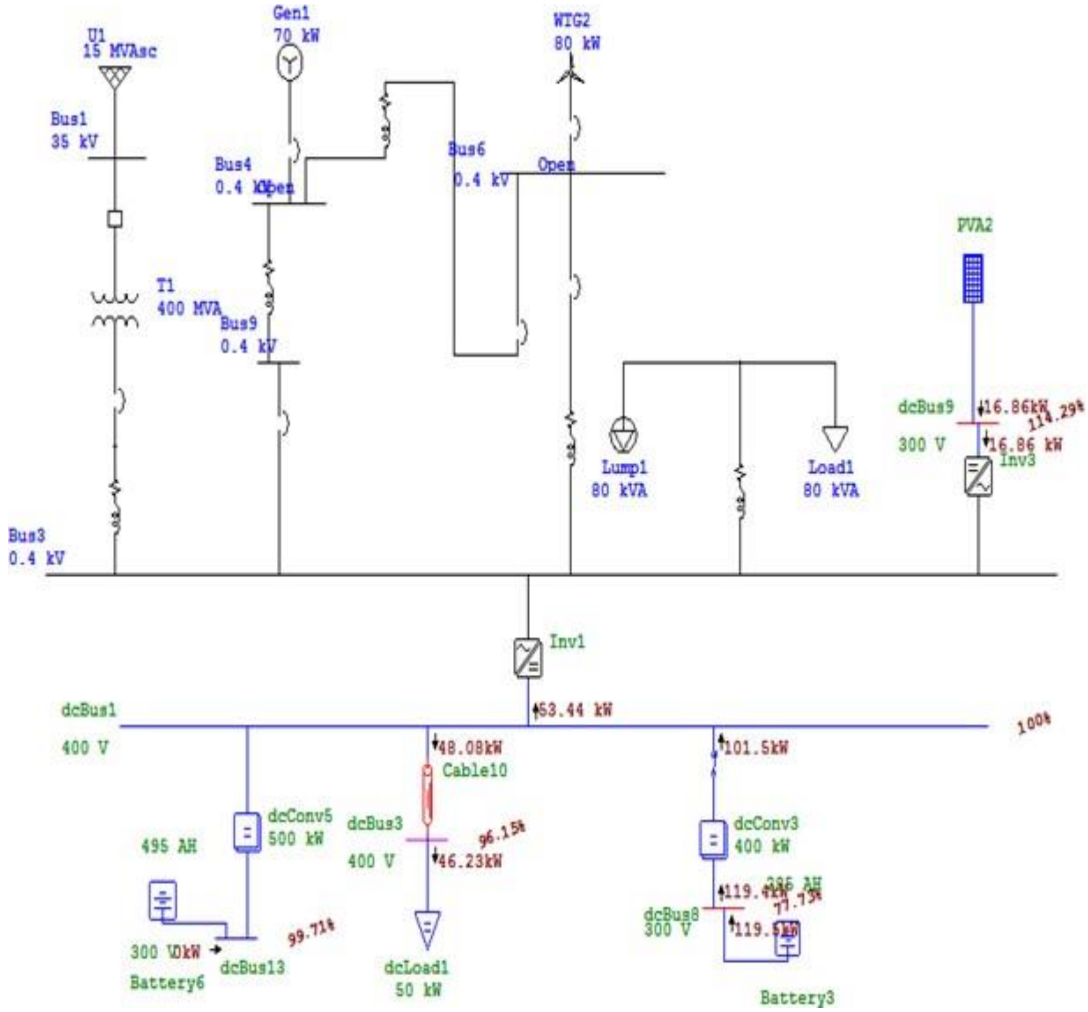


Figure 6.5 Load flow on DC side (without wind and diesel generators)

In DC analysis, power is supplied by Battery-3. It delivered 101.5 kW power to dc bus, and from it DC load took 48.08 kW and the rest is used by AC load through inverter. PV is supplied 16.86 kW of DC power and is converted into AC through the inverter.

AC Zone	DC Zone	Grid	Power exchange from DC to AC
PV = 64 kW	Battery = 119.4 kW	38 kW	48 kW
Wind = 0 kW			
Diesel = 0 kW			

Table 6.2 Power flow for case i

ii) Wind speed = 3 m/s; Irradiation = 828 W/m^2

In this case, diesel generator is still switched off (no fuel) and wind turbine has an average wind speed of 3 m/s. PV is on same irradiation of 828 W/m^2. AC and DC load flow analysis for this case is given below:

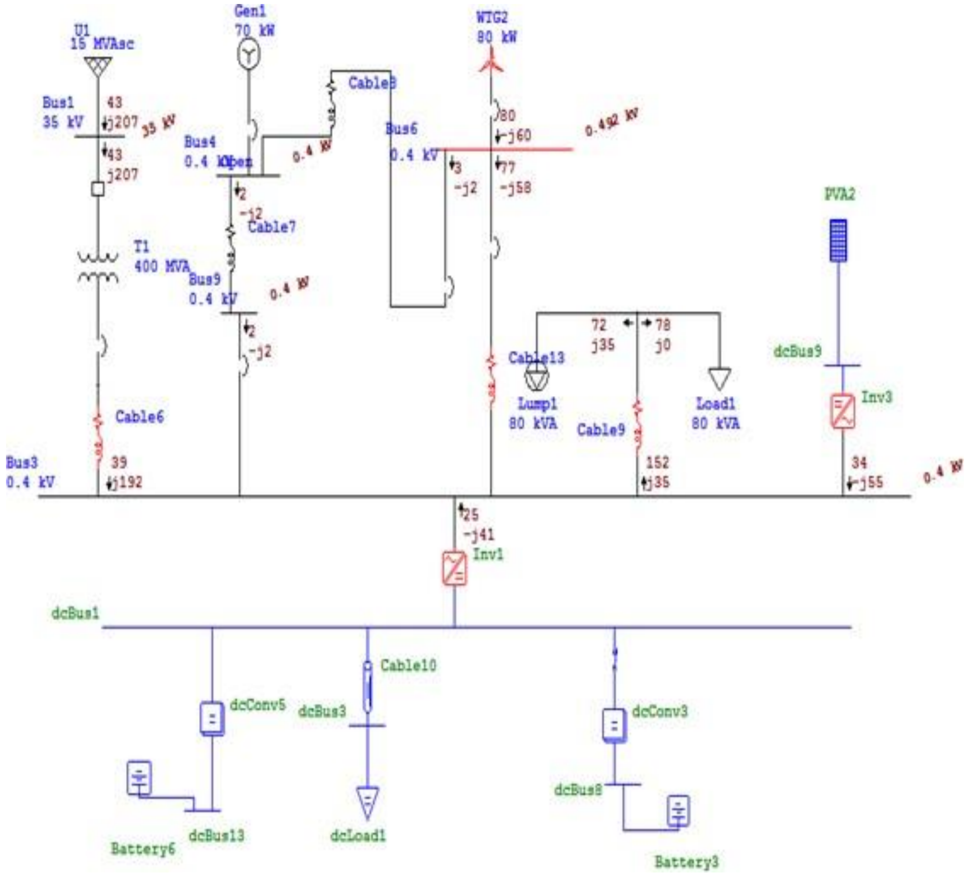


Figure 6.6 Load flow on AC side (with WTG & without diesel generators)

In this case the AC load is supplied by PV, Grid, WTG and DC bus. Grid, PV and WTG provided 38 kW, 34 kW and 77 kW power respectively. The remaining 24 kW power for AC load is provided by DC bus through the inverter. Power from the Diesel generator is 0.

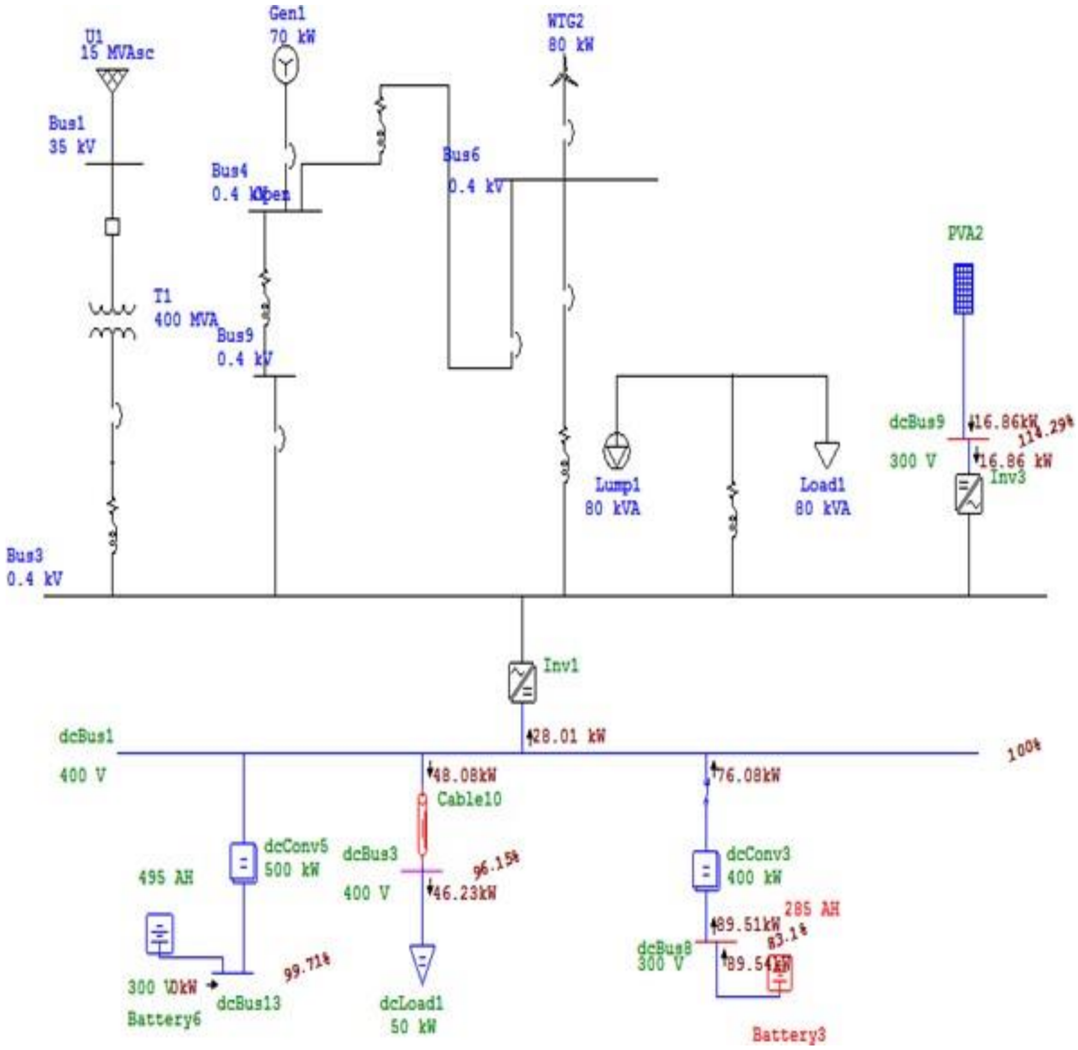


Figure 6.7 Load flow on DC side (with WTG and without diesel generators)

In DC analysis, power is supplied by Battery-3. It delivered 76.08 kW power to DC bus, and from it DC load took 48.08 kW and rest is used by AC load through inverter. PV is supplied 16.86 kW of DC power and is converted into AC through the inverter.

AC Zone	DC Zone	Grid	Power exchange from DC to AC
PV = 34 kW	Battery = 89.51kW	38 kW	24 kW
Wind = 77 kW			
Diesel =0 kW			

Table 6.3 Power flow for case ii

iii) Wind speed = 3 m/s; Irradiation = 828 W/m^2. Diesel Generator Connected. In this case, the diesel generator is on 70 kW and wind turbine has on average wind speed of 3 m/s. PV is on same irradiation of 828 W/m^2. AC and DC load flow analysis for this case is below:

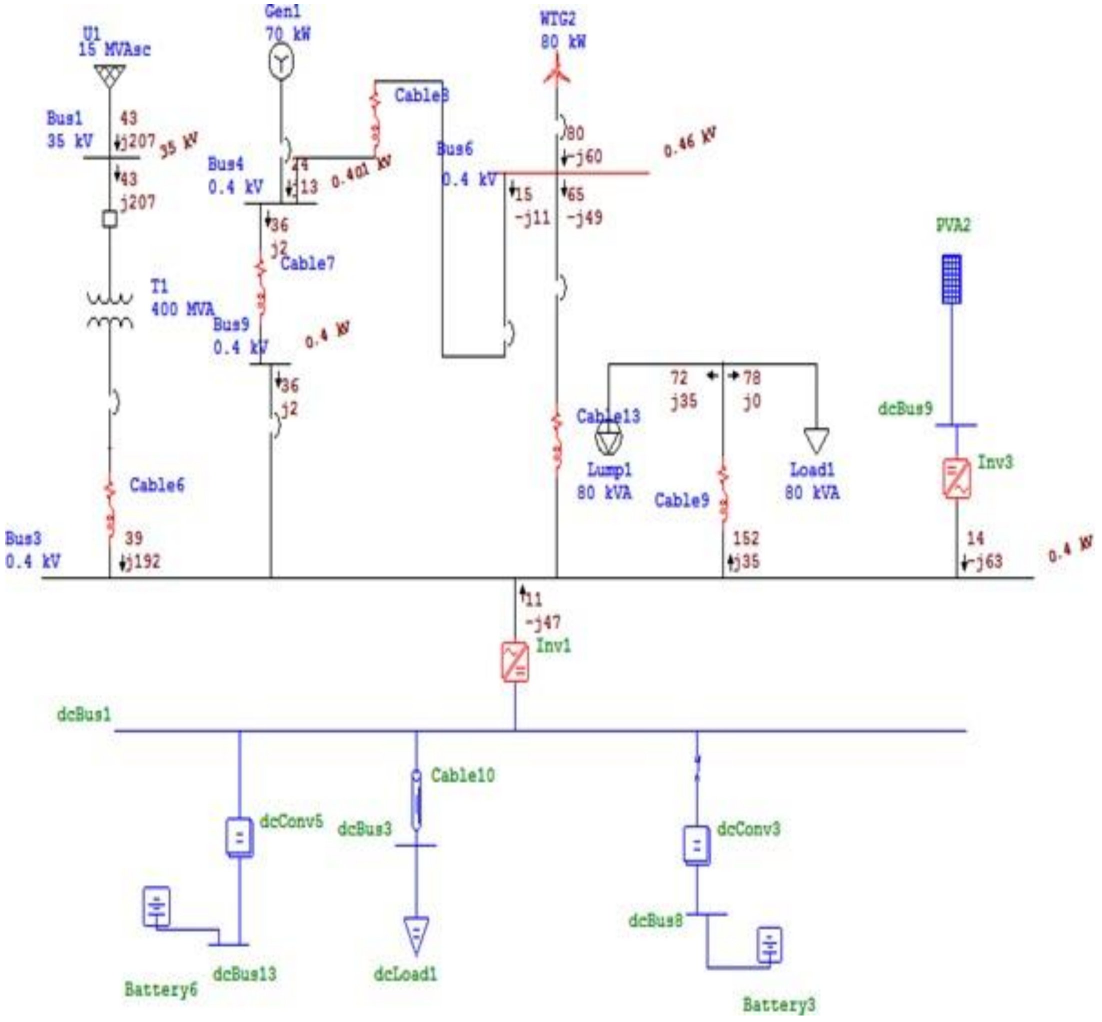


Figure 6.8 Load flow on AC side (with all generators connected)

In this case the AC load supplied by PV, Grid, WTG, Diesel generator and DC bus. Grid, PV, Diesel generator and WTG provided 38 kW, 14 kW ,36 kW and 65 kW power respectively. The remaining 11.6 kW power for AC load is provided by DC bus through inverter.

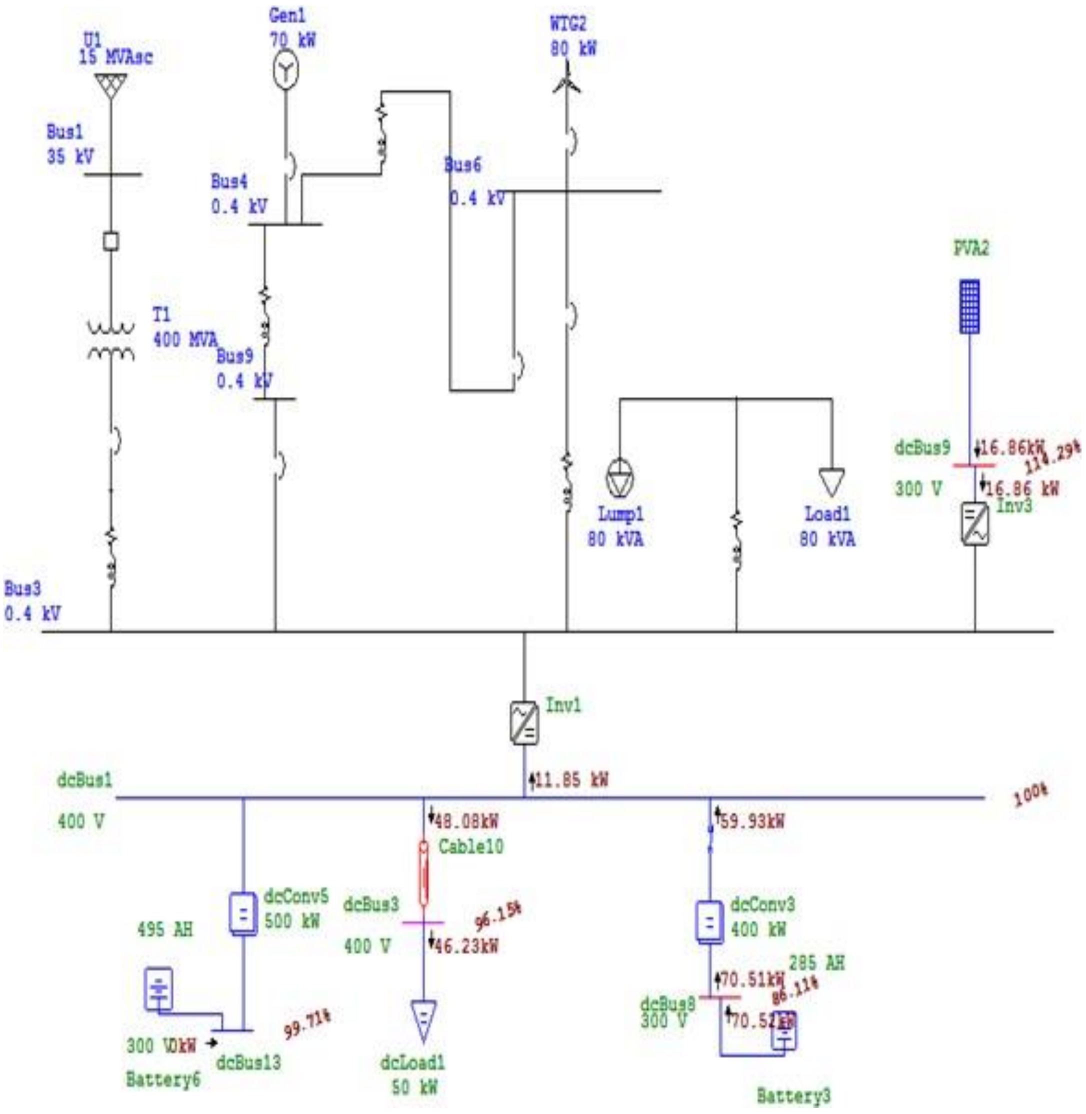


Figure 6.9 Load flow on DC side (with all generators connected)

In DC analysis, power is supplied by Battery-3. It delivered 59.93 kW power to DC bus. From which DC load took 48.08 kW and rest 12.15 kW is used by AC load through inverter. PV is supplied 16.86 kW of DC power and is converted into AC through the inverter.

AC Zone	DC Zone	Grid	Power exchange from DC to AC
PV = 14 kW	Battery = 70.51 kW	38 kW	12 kW
Wind = 65 kW			
Diesel =36 kW			

Table 6.4 Power flow for case iii

iv) Wind speed = 10 m/s; Irradiation = 828 W/m^2. Diesel Generator Connected. In this case, the diesel generator is on 70 kW and wind turbine has on average wind speed of 10 m/s. PV is on same irradiation of 828 W/m^2. AC and DCload flow analysis for this case is below:

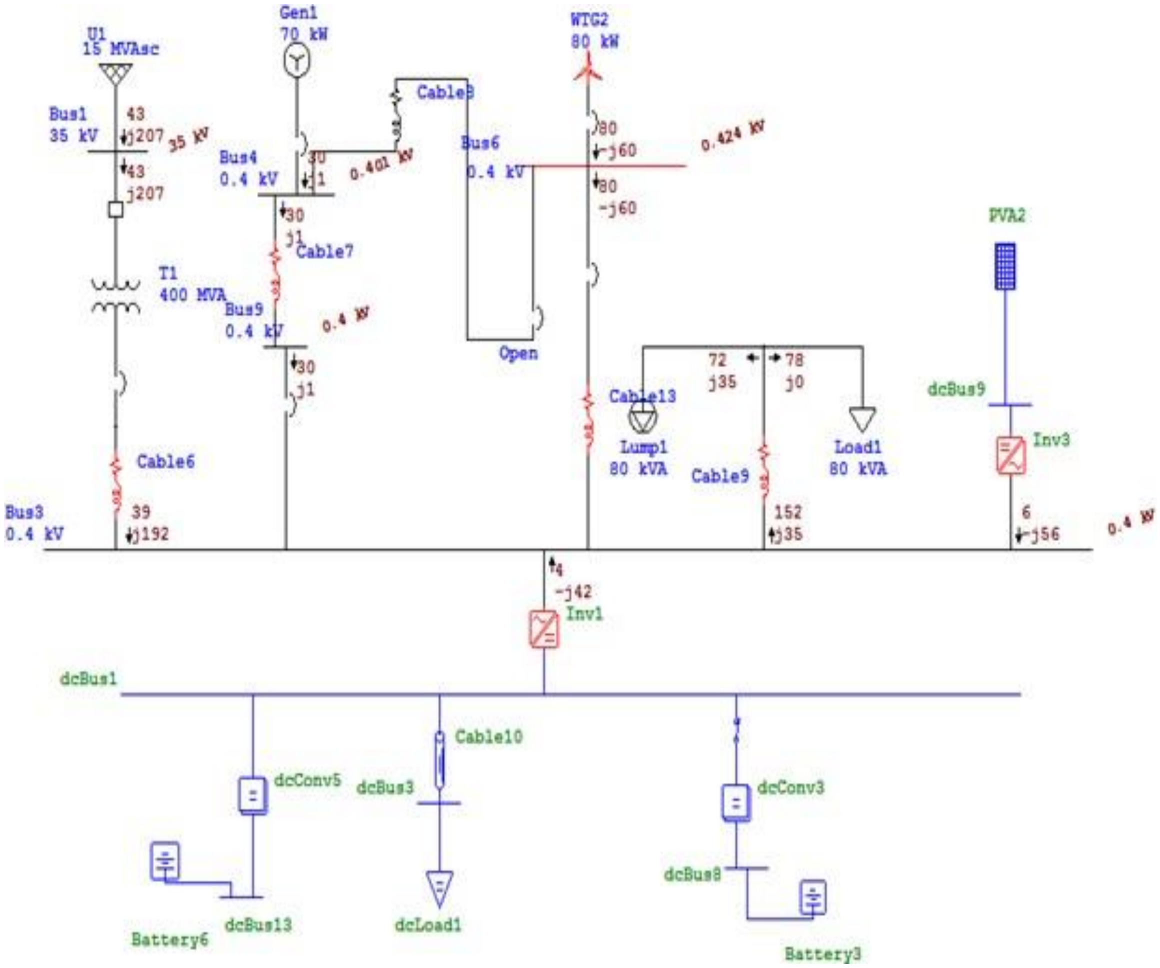


Figure 6.10 Load flow on AC side (average wind speed = 10 m/s)

In this case the AC load supplied by PV, Grid, WTG, Diesel generator and DC bus. Grid, PV, Diesel generator and WTG provided 38 kW, 6 kW, 30 kW and 80 kW power respectively. The remaining 4 kW power for AC load is provided by DC bus through inverter.

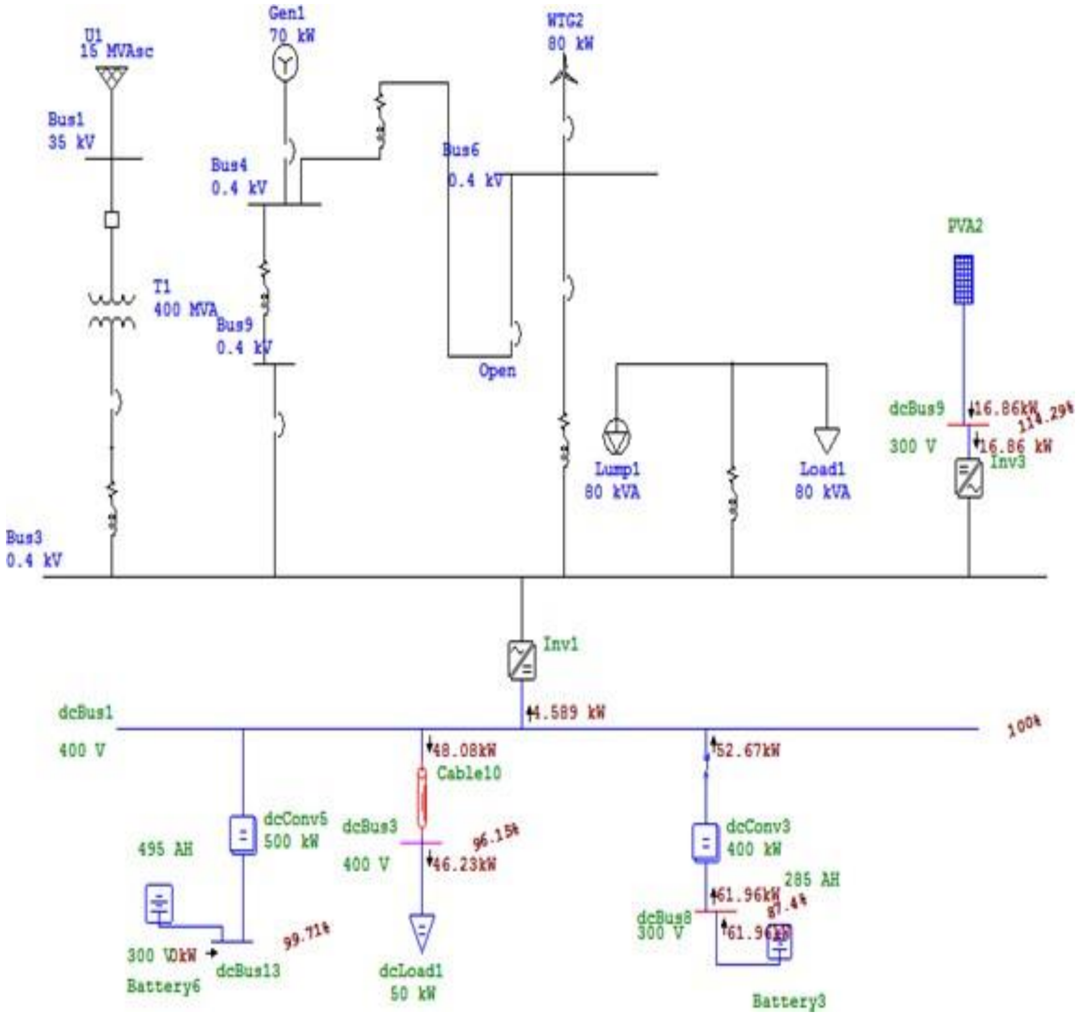


Figure 6.11 Load flow on DC side (average wind speed = 10 m/s)

In DC analysis, power is supplied by Battery-3. It delivered 52.67 kW power to DC bus. From which DC load took 48.08 kW and rest 4.589 kW is used by AC load through the inverter. PV is supplied 16.86 kW of DC power and is converted into AC through the inverter.

AC Zone	DC Zone	Grid	Power exchange from DC to AC
PV = 6 kW	Battery = 61.96 kW	38 kW	4 kW
Wind = 80 kW			
Diesel = 30 kW			

Table 6.5 Power flow for case iv

v) Wind speed = 10 m/s; Irradiation = 699 W/m^2, Diesel Generator Connected. In this case, diesel generator is on 70 kW and wind turbine has on average wind speed of 10 m/s. PV has irradiation of 699 W/m^2 (used Latitude 22.1°and Longitude 88.4°).

AC and DC load flow analysis for this case is given below:

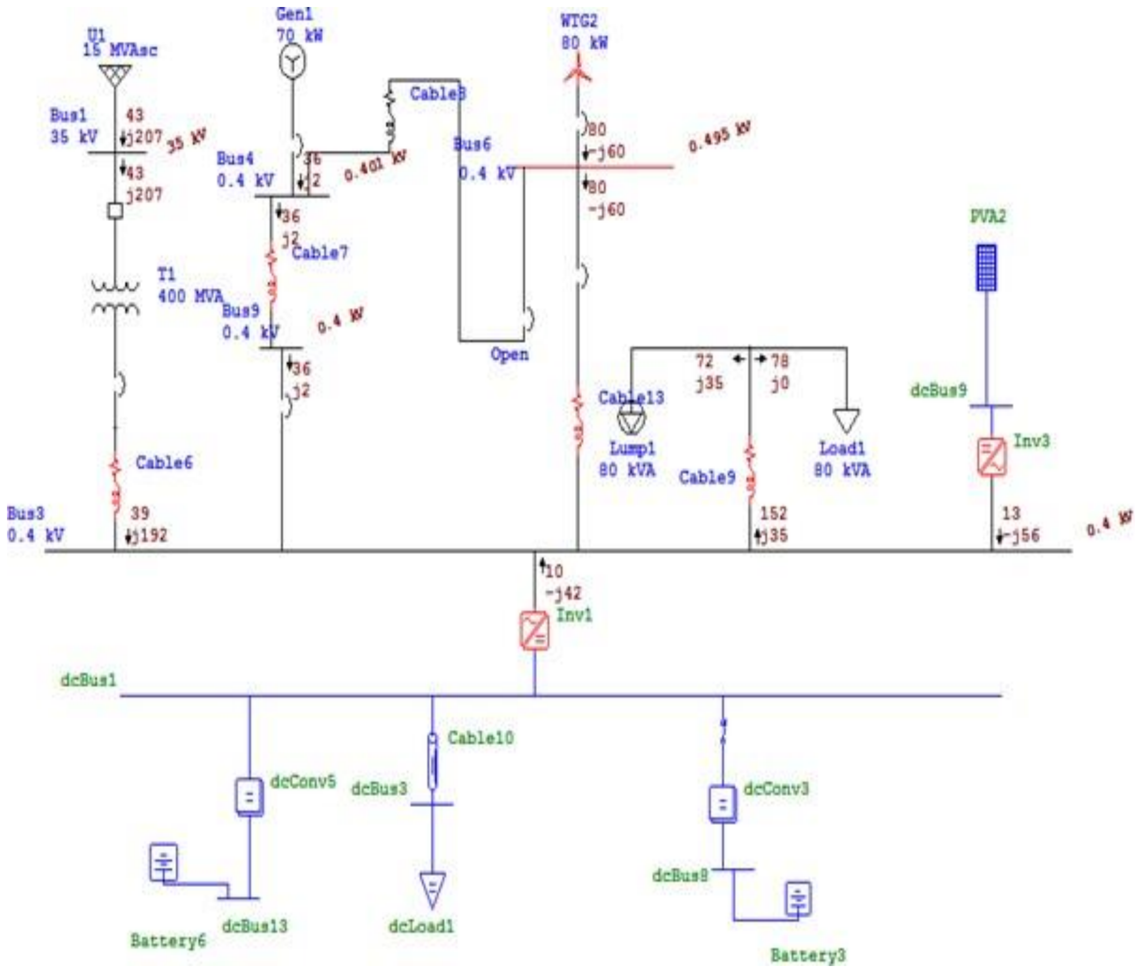


Figure 6.12 Load flow on AC side (699 irradiance with all generators connected)

In this case AC load supplied by PV, Grid, WTG, Diesel generator and DC bus. Grid, PV, Diesel generator and WTG provided 38 kW, 13 kW, 36 kW and 80 kW power respectively. The remaining 11 kW power for AC load is provided by DC bus through inverter.

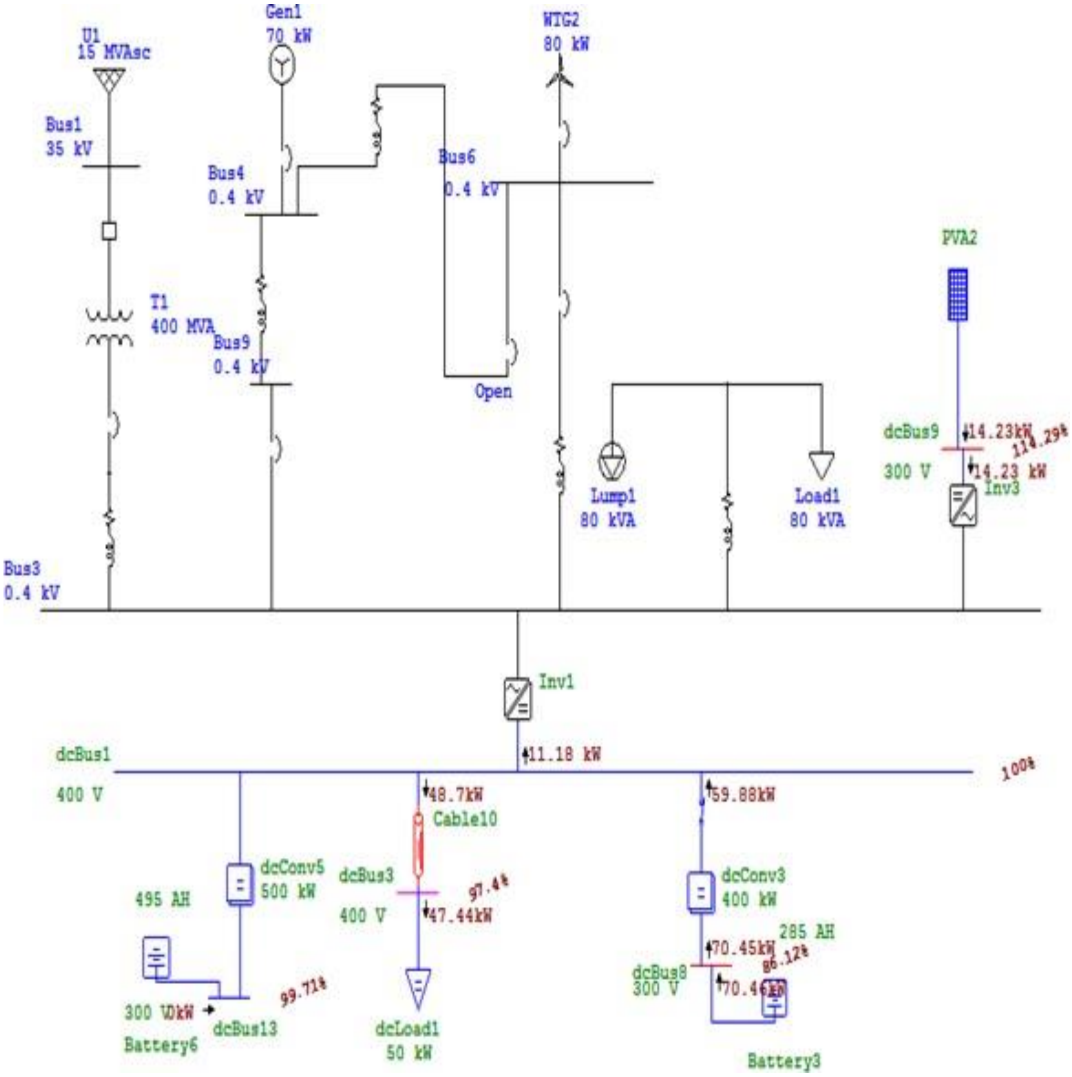


Figure 6.13 Load flow on DC side (699 irradiance with all generators connected)

In DC analysis, power is supplied by Battery-3. It delivered 59.88 kW power to DC bus. From which DC load took 48.7 kW and rest 11.18 kW is used by AC load through the inverter. PV is supplied 14.23 kW of DC power and is converted into AC through the inverter.

AC Zone	DC Zone	Grid	Power exchange from DC to AC
PV = 13 kW	Battery = 70.45 kW	38 kW	11 kW
Wind = 80 kW			
Diesel = 36 kW			

Table 6.6 Power flow for case v

vi) Wind speed = 12 m/s; Irradiation = 699 W/m^2, Diesel Generator Connected. In this case, diesel generator is on 70 kW and wind turbine has on average wind speed of 12 m/s. PV is on same irradiation of 699 W/m^2. AC and DC load flow analysis for this case is given below:

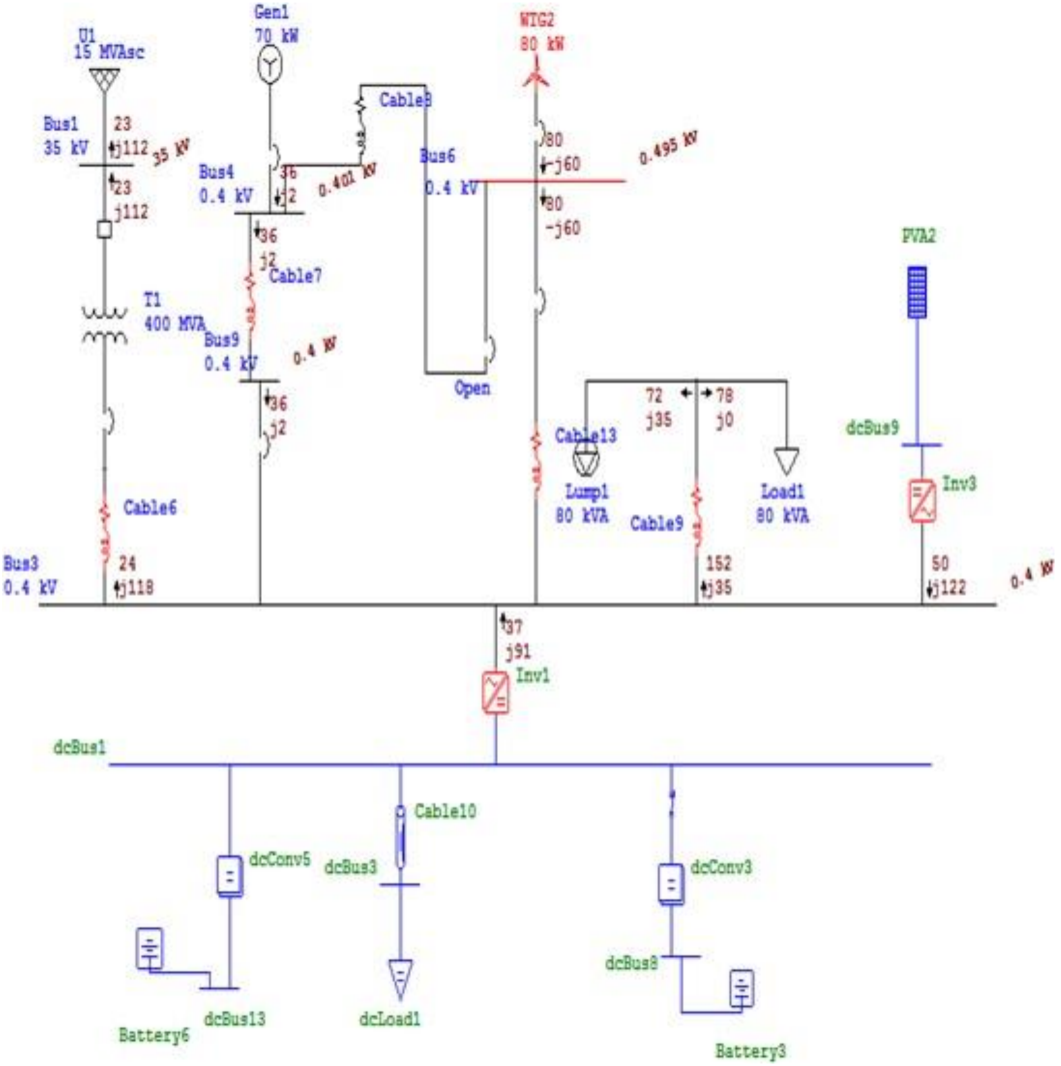


Figure 6.14 Load flow on AC side (wind speed 12 m/s and 699 irradiance)

In this case AC load supplied by PV, WTG, Diesel generator and DC bus. PV, Diesel generator and WTG provided 55 kW, 36 kW and 80 kW power respectively. The 40 kW power for AC load is provided by DC bus through the inverter. The additional 23 kW power fed back to grid.

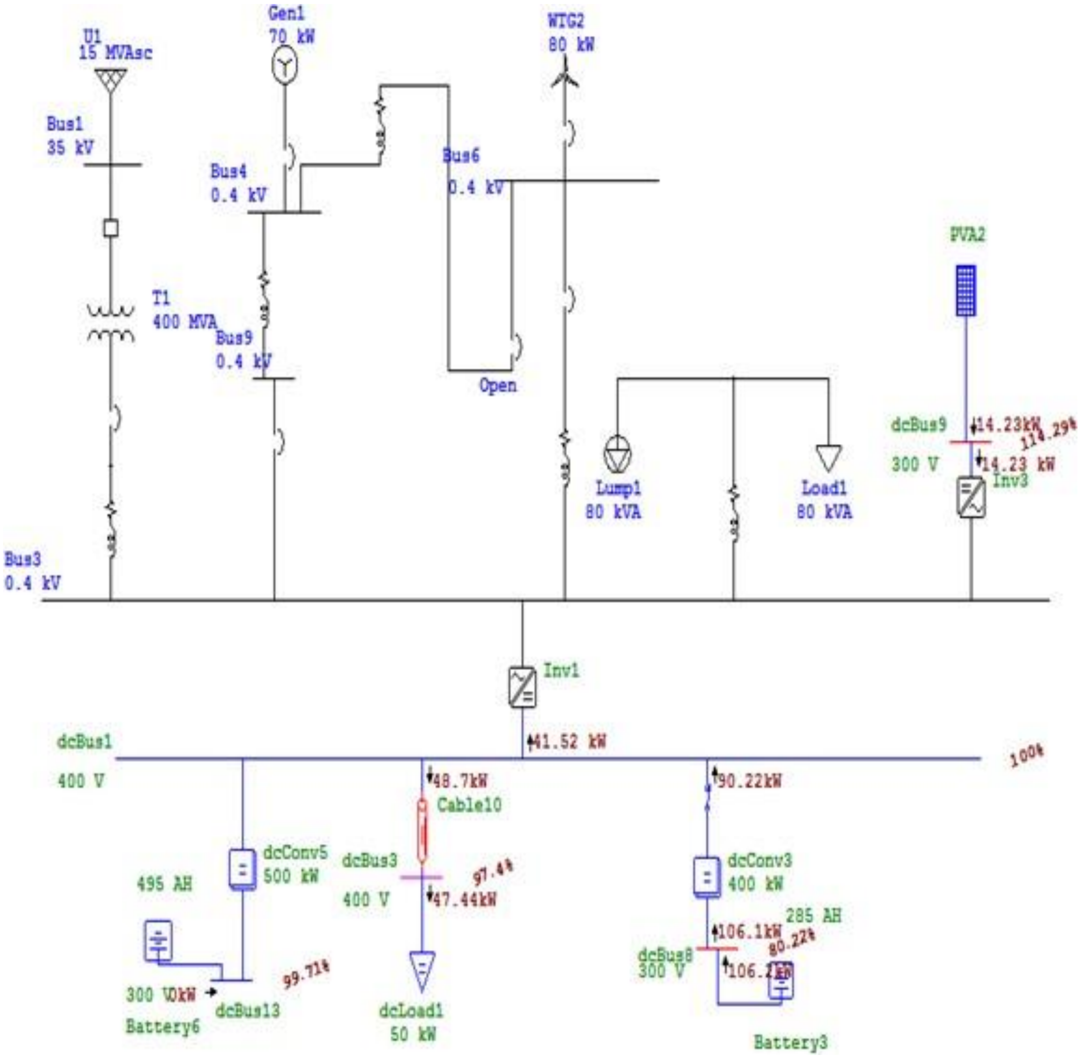


Figure 6.15 Load flow on DC side (wind speed 12 m/s and 699 irradiance)

In DC analysis, power is supplied by Battery-3. It delivered 90.22 kW power to DC bus. From which DC load took 48.7 kW and rest 41.52 kW is used by AC load through the inverter. PV is supplied 14.23 kW of DC power and is converted into AC through the inverter.

AC Zone	DC Zone	Grid	Power exchange from DC to AC
PV = 55 kW	Battery = 106.1 kW	-23 kW	40 kW
Wind = 80 kW			
Diesel = 36 kW			

Table 6.7 Power flow for case vi

Result table for all cases:

Cases	AC Zone			DC Zone	Power exchange from DC to AC (kW)	Grid (kW)
	PV (kW)	Wind (kW)	Diesel (kW)	Battery (kW)		
Case i	64	0	0	119.4	48	38
Case ii	34	77	0	89.51	24	38
Case iii	14	65	36	70.51	12	38
Case iv	6	80	30	61.96	4	38
Case v	13	80	36	70.45	11	38
Case vi	55	80	36	106.1	40	-23
	AC Load = 153 kW			DC Load = 47.07 kW		

Table 6.8 Power flow comparison with grid connected mode

Finally, after simulating all the different conditions for PV, Wind and Diesel generator the comparison power flow table is shown above. From this table it can be analyzed that, continuous supply of power is been provided to the load as desired and the analysis carried out meets the expectations.

6.1.2 Islanded Mode:

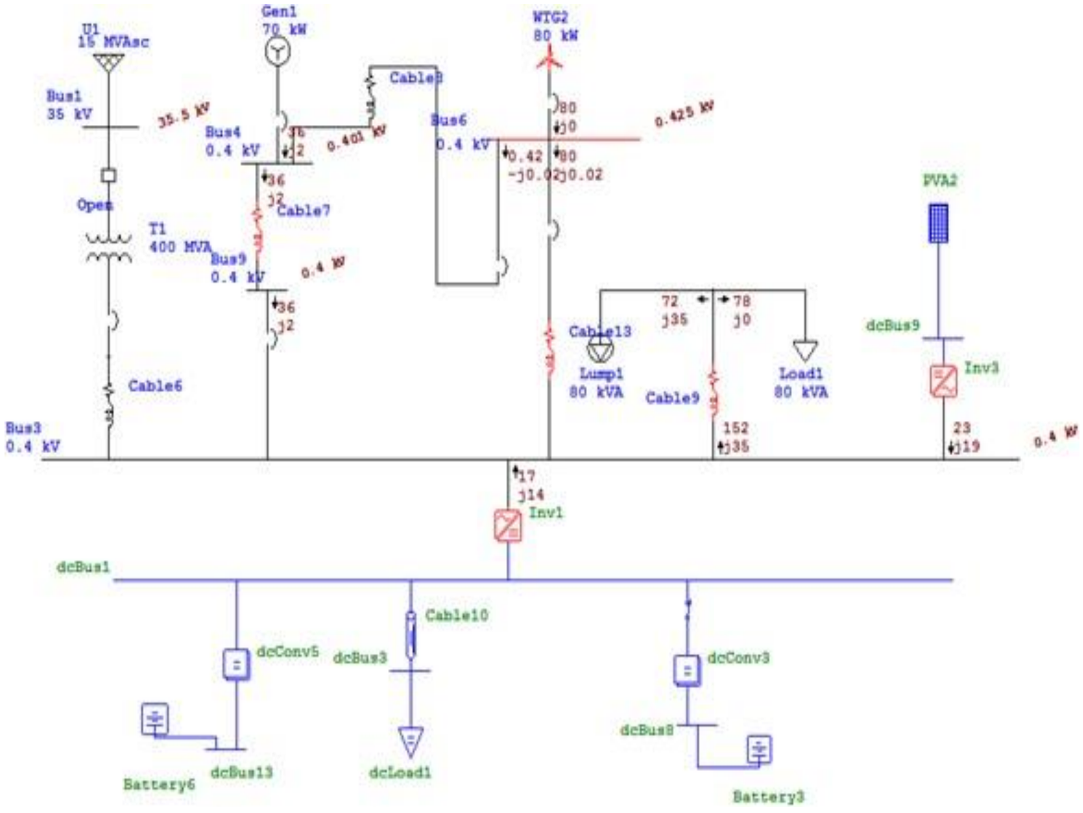


Figure 6.16 Load flow on AC side

In this case AC load supplied by PV, WTG, Diesel generator and DC bus. PV, Diesel and WTG provided 23 kW, 36 kW and 80 kW power respectively. The 17 kW power for AC load is provided by DC bus through the inverter.

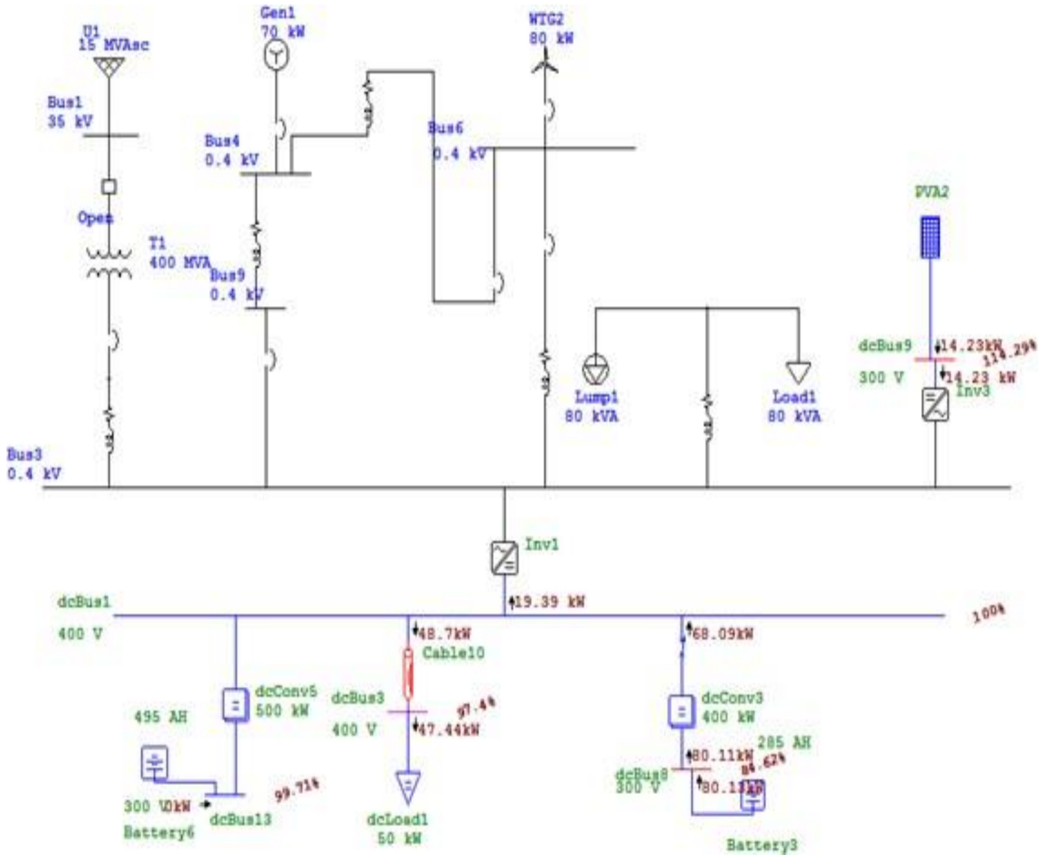


Figure 6.17 Load flow on DC side

AC Zone	DC Zone	Grid	Power exchange from DC to AC
PV = 23 kW	Battery = 68.09 kW	0	19.39 kW
Wind = 80 kW			
Diesel = 36 kW			

Table 6.9 Power flow for islanded mode

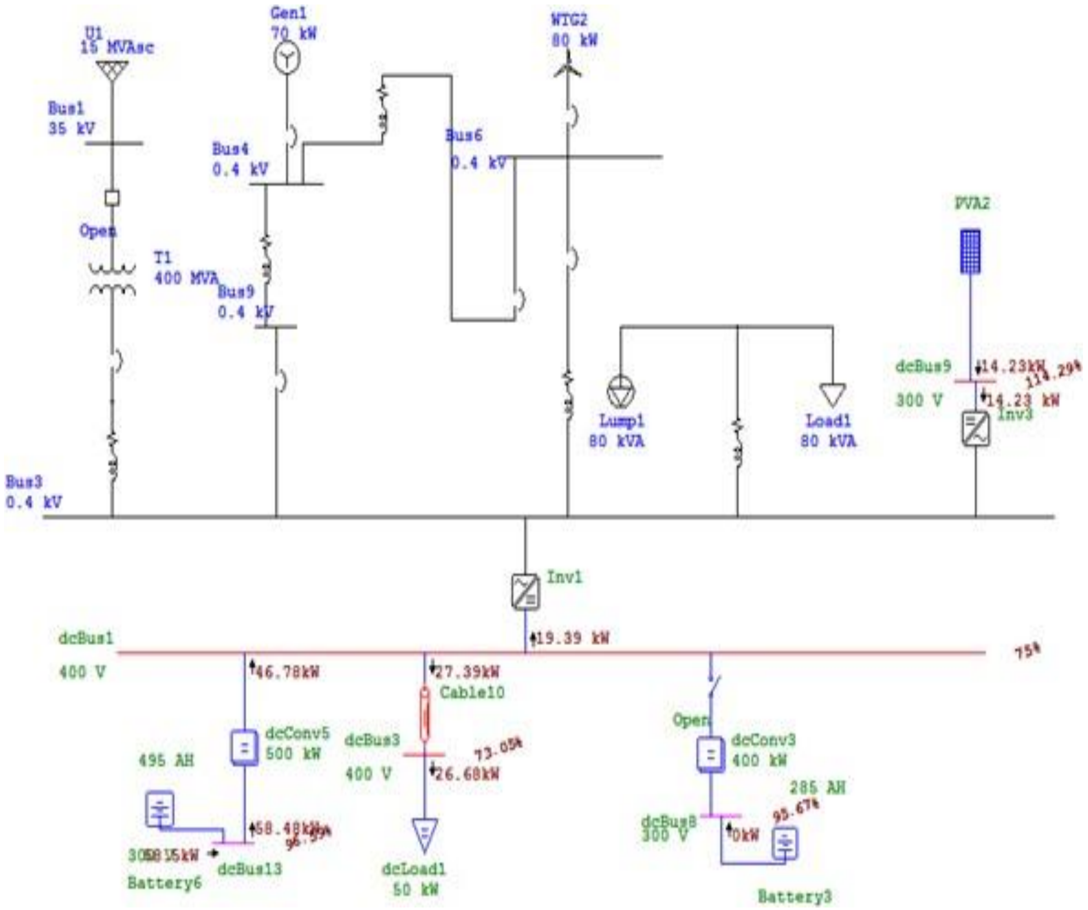
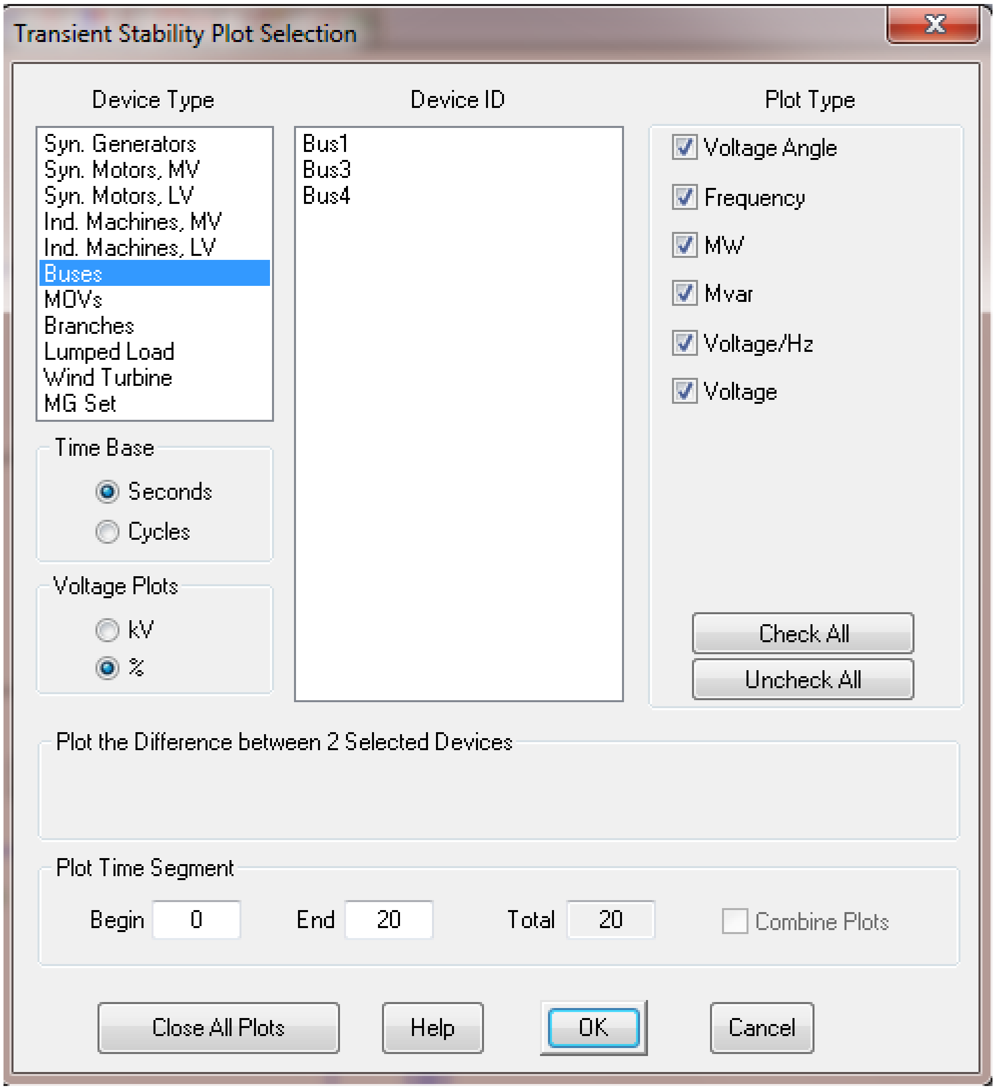


Figure 6.18 Load flow on DC side (Without Battery -3)

In DC analysis, if power is supplied by Battery-6 then it delivered 46.78 kW power to DC bus. From which DC load took 27.39 kW and rest 19.39 kW is used by AC load through the inverter. PV is supplied 14.23 kW of DC power and is converted into AC through the inverter.

6.2 Transient Stability Analysis:

Transient analysis is done to identify the disturbances and contingencies in system. Using action editor, it is possible to study the effect of faults on the system and its components. Along with this it is possible to carryout simulation of numerous operations like load shedding, generation re-dispatch and critical clearing time as shown in the table below:



Transient Stability Plot Selection

Device Type
Syn. Generators
Syn. Motors, MV
Syn. Motors, LV
Ind. Machines, MV
Ind. Machines, LV
Buses
MOVs
Branches
Lumped Load
Wind Turbine
MG Set

Device ID
Bus1
Bus3
Bus4

Plot Type
☑ Voltage Angle
☑ Frequency
☑ MW
☑ Mvar
☑ Voltage/Hz
☑ Voltage

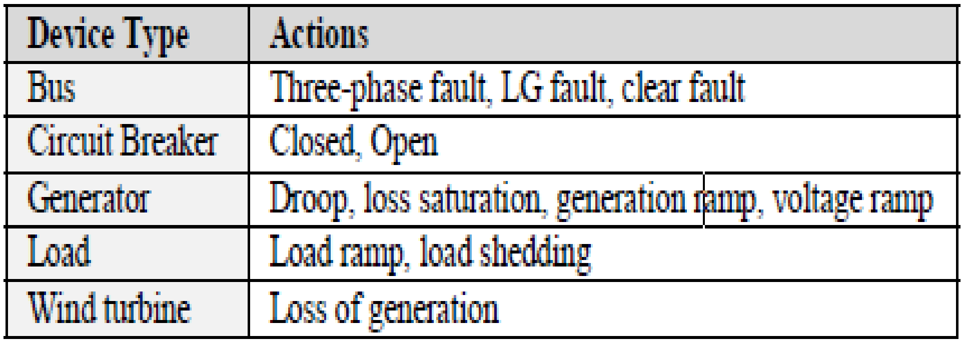
Time Base
● Seconds
○ Cycles

Voltage Plots
○ kV
● %

Plot the Difference between 2 Selected Devices

Plot Time Segment
Begin 0
End 20
Total 20
☐ Combine Plots

Figure 6.19 Selection of transient stability analysis parameters



Device Type	Actions
Bus	Three-phase fault, LG fault, clear fault
Circuit Breaker	Closed, Open
Generator	Droop, loss saturation, generation ramp, voltage ramp
Load	Load ramp, load shedding
Wind turbine	Loss of generation

Table 6.10 Different action on parameter

For example, a three-phase fault is simulated to occur at Bus 1 at t = 5s, the circuit breaker (CB1) is open at t = 5s and the micro-grid is switched into island mode. Then fault is cleared at 10s and CB1 is closed at 11s, so the micro-grid is on grid connected mode. The graphs shown below for bus voltage in percentage and power supplied to the load are used to see the variation in these parameters at the time of fault and during its clearance.

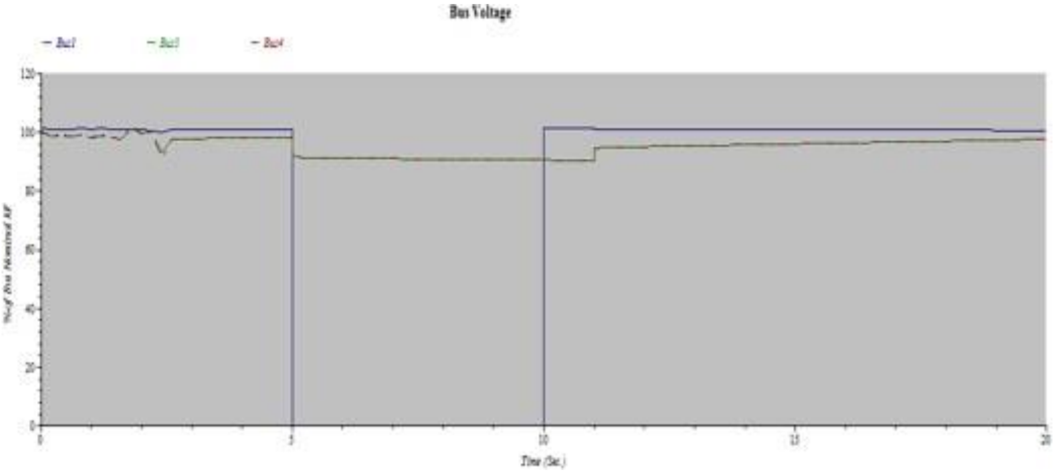


Figure 6.20 Bus voltage (in %) vs. time

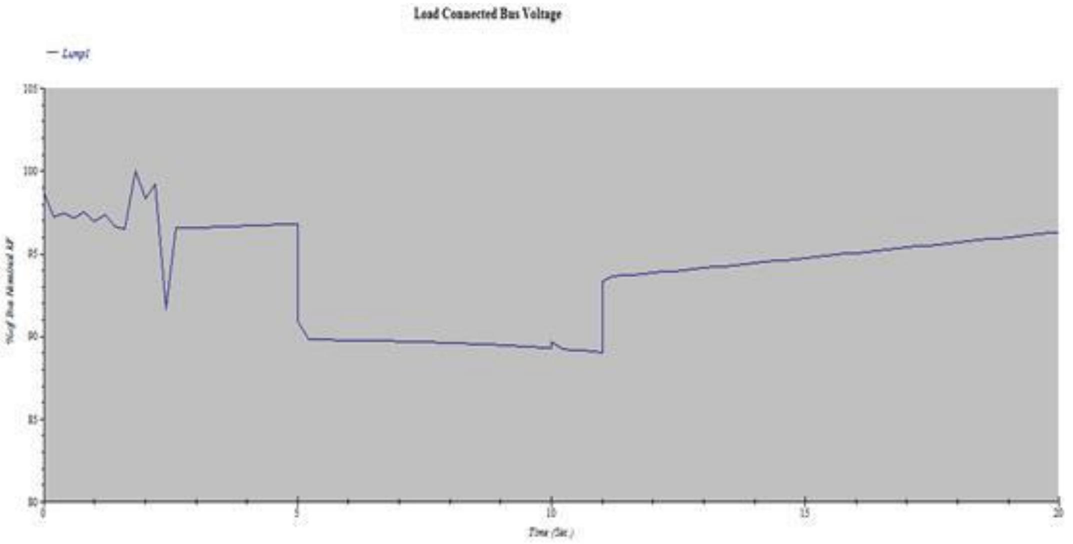


Figure 6.21 Load power (in MW) vs. time

Here to fulfill the stability criteria testing of the system is carried out at the time of fault:

For this purpose, fault is introduced on various buses at 5 sec. After the fault the Circuit breakers are simulated to open at 0.1 sec of the respective bus. Therefore, at 5.1 the circuit breaker of the respective bus is open so the faulty connection is detached from the system ensuring continuity of supply.

The clearance time is set at 0.5 sec after the occurrence of fault and the CB is closed at 5.6 sec to connected the previously disconnected part to the system.

Here as shown in the graphs below, the change in voltage angle is seen with respect totime due to fault on different buses:

Fault at Bus 1

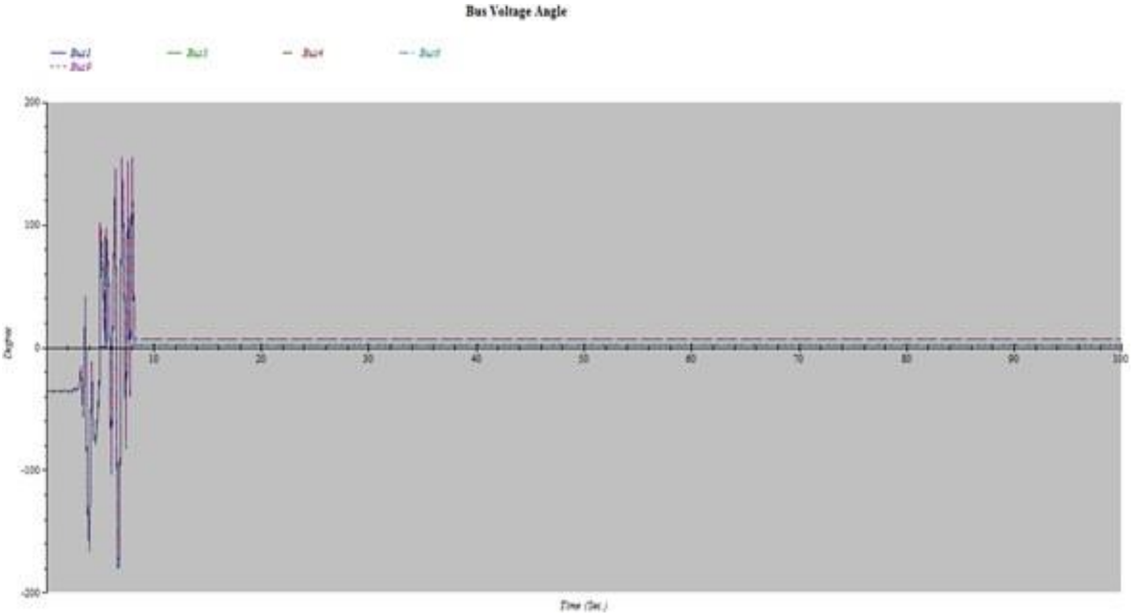


Figure 6.22 Variation in different bus voltage angle when fault at bus 1

Fault at Bus 3

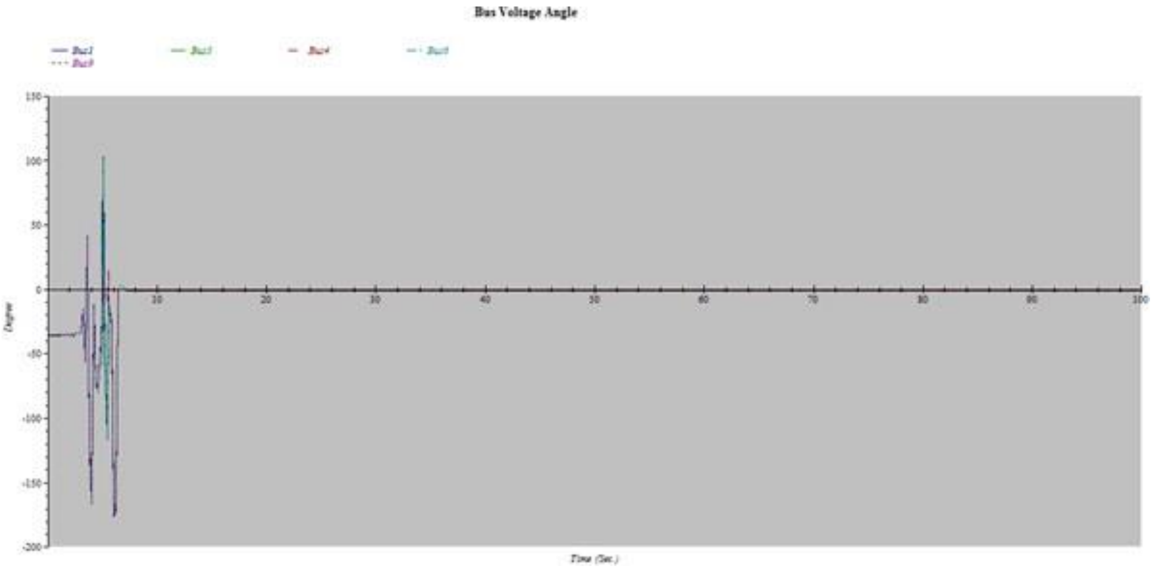


Figure 6.23 Variation in different bus voltage angle when fault at bus 3

Fault at Bus 6

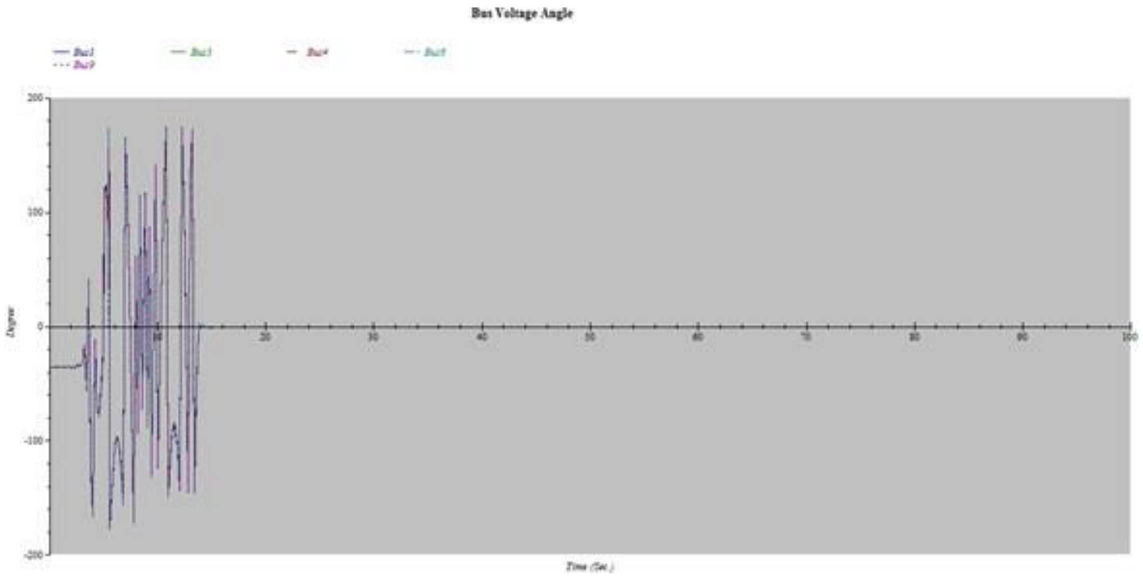


Figure 6.24 Variation in different bus voltage angle when fault at bus 6

From these graphs shown above, at the time of fault the transients can be seen in the system and after the clearance of fault, the system is stable as there is no fluctuation on the voltage angle of the buses.

7. CONCLUSION

This micro-grid learning is a useful resource to the power industry. This simulation in Proteus and ETAP provides flexibility to students while carrying out tedious simulation and performing them with efficient tools, so that it can be easy for us to understand the system and interplay with the constructed model.

The hybrid system can reduce the dependency on fossil fuels to great extent and supply individual power to AC or DC systems as required. The hybrid optimized system are capable of providing the energy efficiently between their respective buses.

The simulation performed in this project takes into account the transient and steady state operation of the system and the impact of addition or removal of any AC or DC system from the grid.

From the simulations performed it is possible to conclude that a hybrid model can efficiently fulfill the load demand. Using this system, it is possible to sufficiently supply energy to rural areas at least operating cost. The transient analysis proves that stability of system is an important parameter that needs to be considered and monitored while designing and modelling any system. The graphs obtained during our transient analysis shows that system remains stable in the given simulated time which is desired to maintain continuity of supply. Thus, the project satisfactorily provides the results which shows that analysis of hybrid model has earned some useful results and it can be practically implemented by taking into consideration all the discussed parameters.

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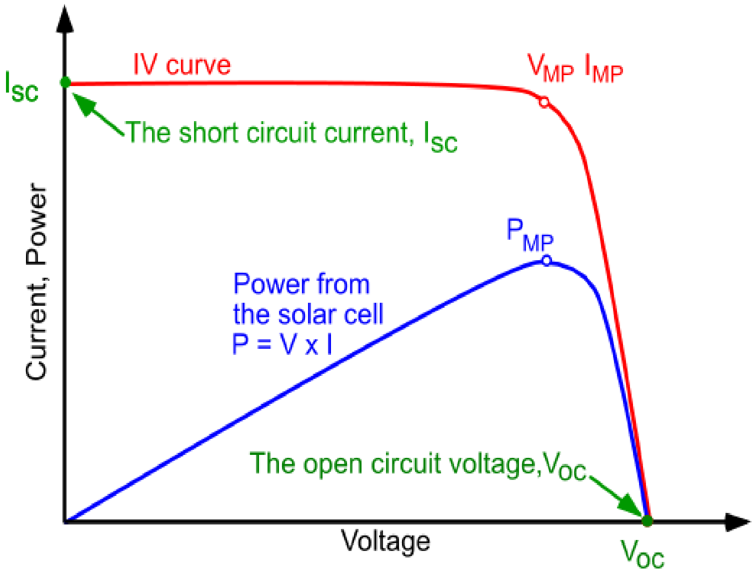
DESCRIPTION AND SPECIFICATIONS OF COMPONENTS

PHOTO VOLTAIC SYSTEM

Photovoltaic modules use light energy (photons) from the Sun to generate electricity through the photovoltaic effect. Most modules use wafer-based crystalline silicon cells or thin-film cells. The structural (load carrying) member of a module can be either the top layer or the back layer. Cells must be protected from mechanical damage and moisture. Most modules are rigid, but semi-flexible ones based on thin-film cells are also available.

The cells are usually connected electrically in series, one to another to the desired voltage, and then in parallel to increase current. The power (watts) of the module is the mathematical product of the voltage (volts) and the current (amps) of the module.

P-V and I-V Characteristics of PV Panel:



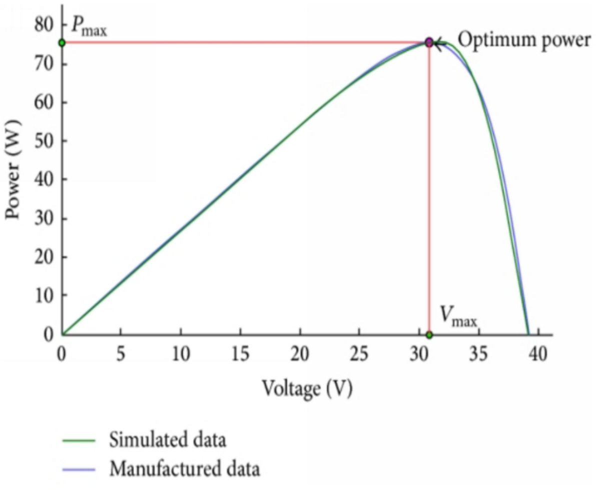


Figure: P-V Characteristics

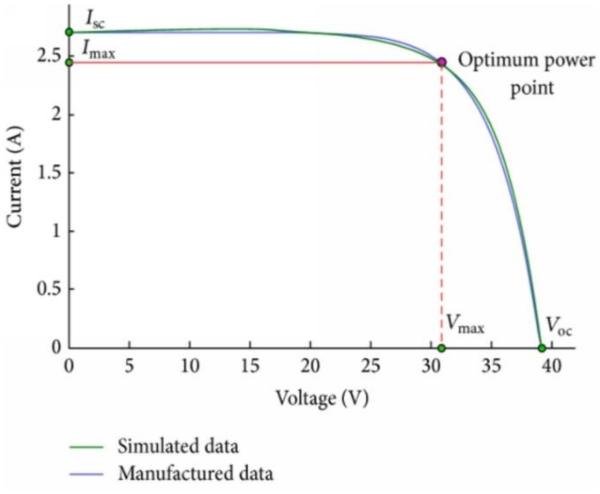


Figure: I-V Characteristics

Solar Panel 40W / 12V Specifications:

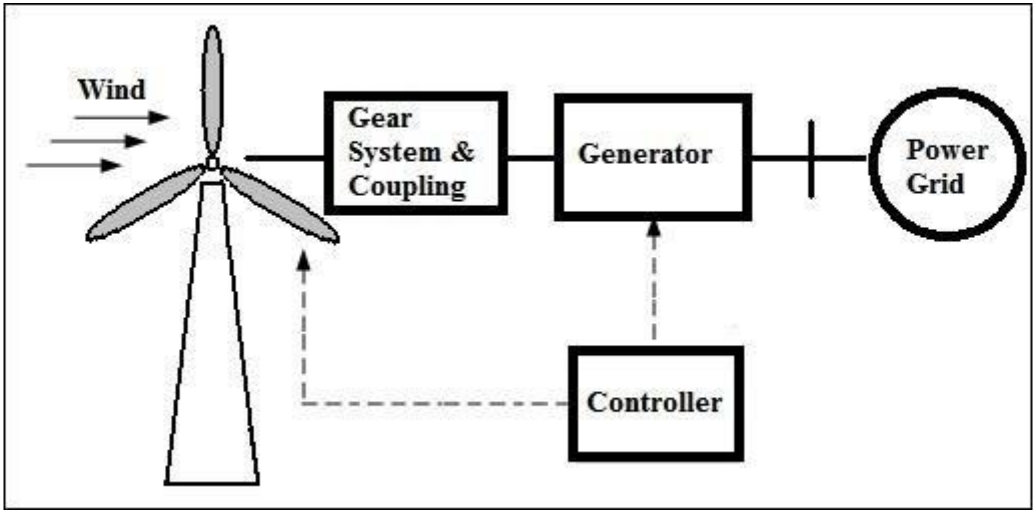
- Poly crystalline Cells type Panel.
- Capacity - 40 W, 12V.
- Voltage: Voltage at Max Power (Vmax) - 18V, Open Circuit Voltage (Voc) - 22V.
- Current: Current at Max Power (Imax) - 2.23A, Short Circuit Current (Isc) - 2.42A.
- 25 years performance warranty.
- Compliance to IEC standards.
- Best in Class conversion efficiency.
- Anti-reflective coating and back surface (BSF) for more light absorption.
- Advanced EVA (Ethyl Vinyl Acetate) encapsulation to give better protection to modules.

- High strength light-weight aluminium frame design for high torsion resistance against wind and snow loads.
- PID resistance Technology (Potential-Induced Degradation) for safety against substantial power loss due to stray currents triggered by certain climate conditions.
- Excellent Low light performance in low visibility in clouds, evening, and morning.

WIND TURBINES:

The other renewable source of energy is the Wind Turbines (Wind System). The wind system makes use of the gushing wind flowing across the globe due to the effect of earth’s motion. It converts the kinetic energy of winds into mechanical energy which is used to generate electricity.

But this mechanical rotation of blades is affected by the flow of wind, the electrical power is generated by a generator or induction motor using power electronic devices so as to connect to the microgrid.



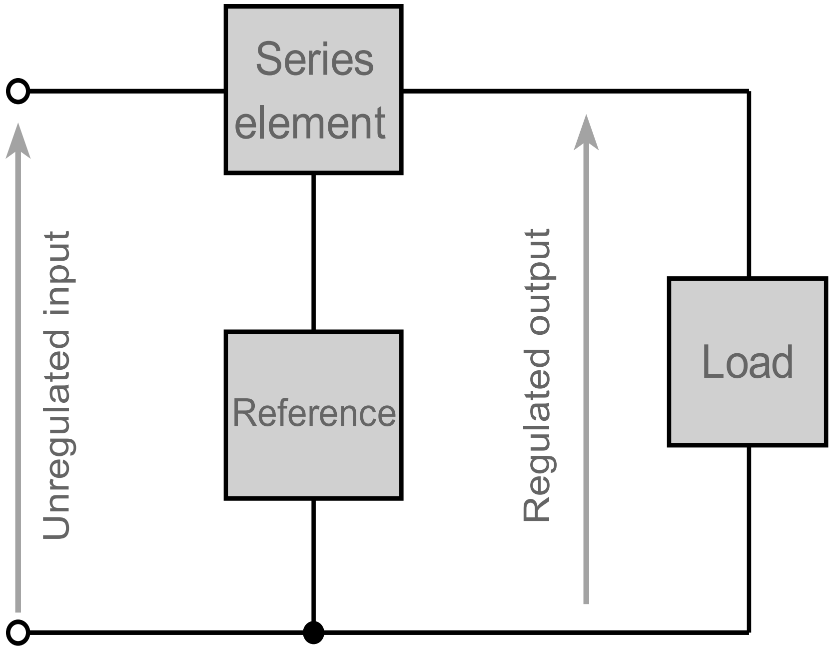
Technical Specifications:

Axis:	Horizontal
Rotor Diameter:	72″
Number of Blades:	12
Blade & Tower Material:	Galvanized Steel
Total Height:	20′, 16′ and 12′, Add 3 feet for total height
Transmission:	Direct Drive
Stroke:	0.5 in
Capacity:	1.5 -5 cu. ft. min., approx. 30 P.S.I.
Over speed Protection:	Automatic (speed limiting)
Base Diameter:	86″ base on 23′ windmill

SERIES VOLTAGE REGULATOR

With the evolution of smart grids, the need for reliable supply of electricity is an important issue. Among the different power quality issues concerning the consumers at distribution level, voltage swells and sags are critical power quality issues in distribution system. With the increase in complexity of electronics equipment in commercial appliances, customer have become more and more vulnerable to voltage disturbances. For compensating these voltage disturbances, the series voltage regulator is used.

The series voltage regulator or series pass voltage regulator uses a variable element placed in series with the load. By changing the resistance of the series element, the voltage dropped across it can be varied to ensure that the voltage across the load remains constant.



LM7815 Description:

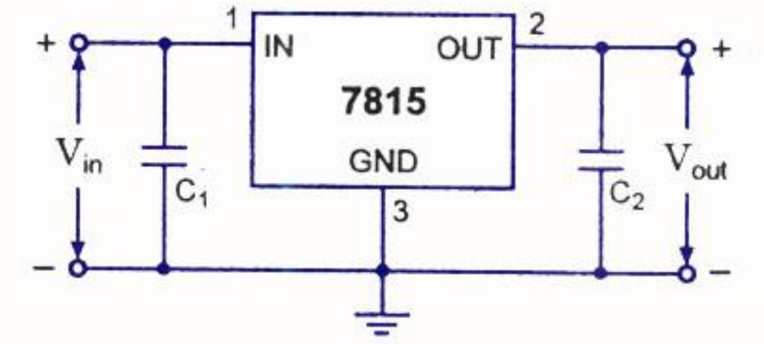
The IC we have used here is LM7815.
LM7815 is an anther fixed output voltage regulator IC from the series LM78xx. LM78xx is a series of fixed voltage regulator IC. The series contains different fixed output voltage regulator ICs like LM7805, LM7809, LM7812, LM7824 etc.

LM7815 IC Features / Technical Specifications:

- TO-220 Package.
- The Output current is 1A to 1.5A.
- Built-in short circuit shutdown function.
- Built-in over heat shutdown function.
- Low cost.
- Reliable and long life to use commercially.
- Stable and fixed output of 15V DC.
- Maximum input voltage is up to 35V DC.
- The standby current only 8mA.

Applications:

- Voltage Step Down Circuits
- Voltage Converter Circuits
- Power Supply Circuits
- Motor Drivers
- Battery Chargers Circuits
- Solar Power Supplies
- Microcontroller Related Applications



Connection of 7815 Voltage Regulator

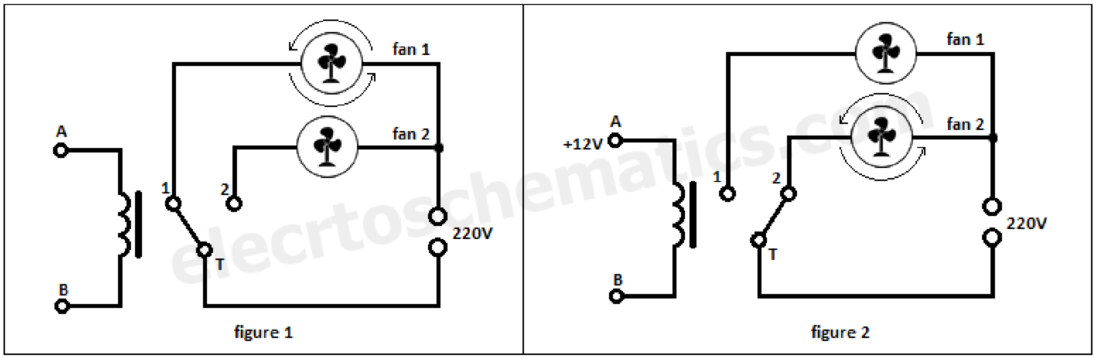
SPDT and DPDT RELAY

The SPDT Relay(30A) is a high quality Single Pole Double Throw Relay (SPDT). The Relay consists of a coil, 1 common terminal, 1 normally closed terminal, and one normally open terminal. When the coil of the relay is at rest (not energized), the common terminal and the normally closed terminal have continuity. When the coil is energized, the common terminal and the normally open terminal have continuity. This relay's coil is rated up to 5V and the contact is rated up to 30A (at 250VAC, 30VDC). You can use it to control high current devices.

Technical Specifications:

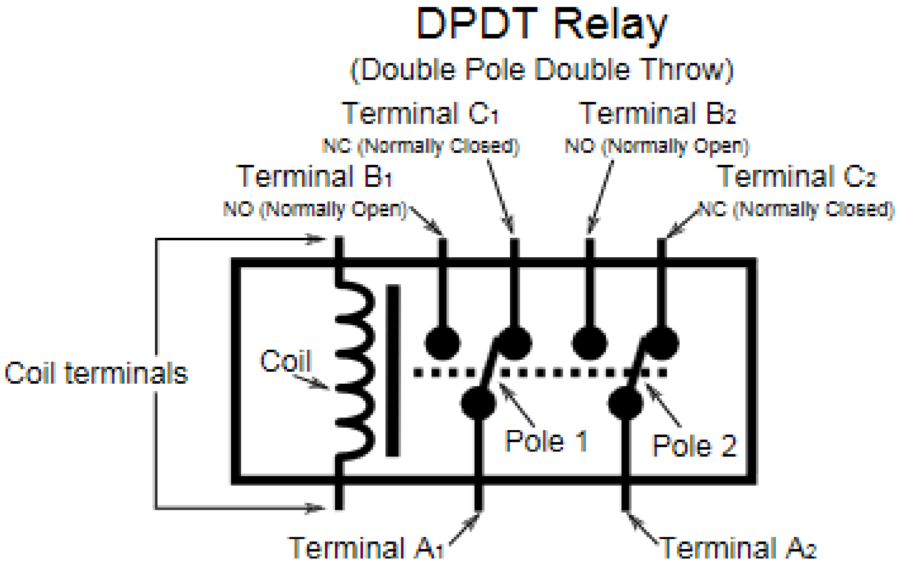
Item	**Min**	**Typical**	**Max**	**Unit**
working Voltage	4.75	5.0	5.25	VDC
Pull-In Voltage (Max)	-	3.75	-	VDC
Operation Time (Max)	-	15	-	ms
Release Time (Max)	-	10	-	ms
Operating Ambient Temperature	-25	-	70	°C

SPDT Relay



DPDT stands for double-pole double-throw relay which is an electromagnetic device used to separate two circuits electrically and connect them magnetically. They are often used to interface an electronic circuit, which works at a low voltage to an electrical circuit which works at a high voltage.

A DPDT relay can also be used to change the polarity at the terminals of a device connected at output. In case no input signal is given, the motor would rotate in one direction and when an input signal is provided, the connector changes their positions, resulting in the anticlockwise rotation of motor.



In smaller microgrids, relays are commonly utilized for control, metering, and protection functions. In larger microgrids, the functionality of the microgrid controls is predominantly performed in one or more centralized controllers.

ARDUINO UNO

The Arduino Uno is used here to switch between the utility grid and island grid at desired time periods. It is practically used as a timer.

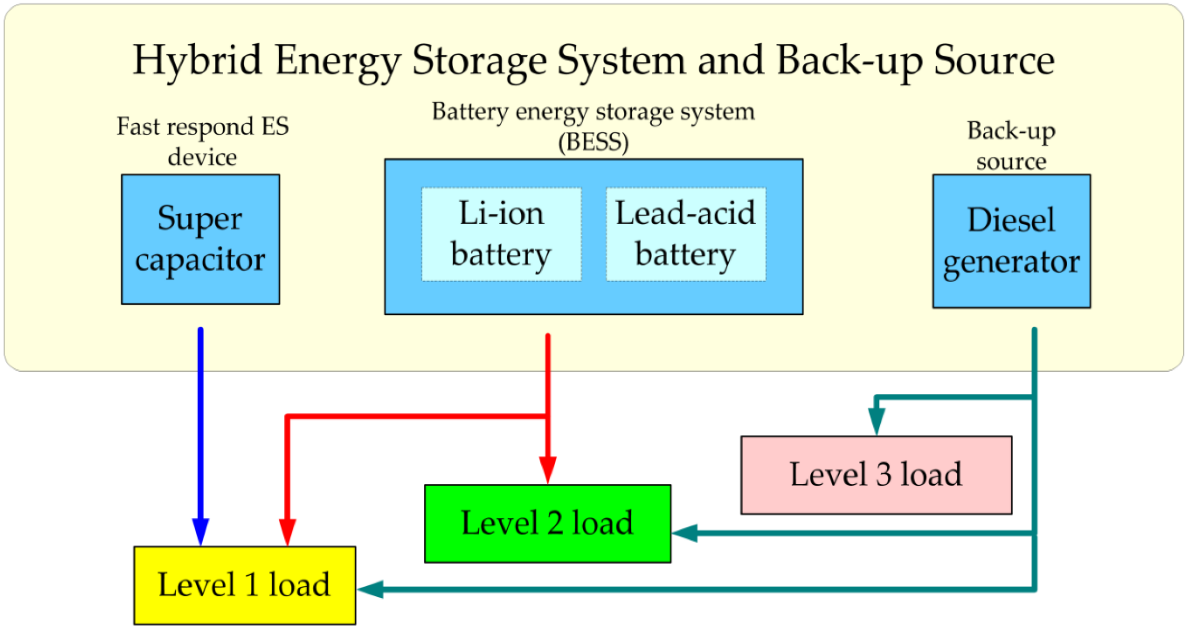
Arduino is a Microcontroller board based on the Atmega328 which gives faster response with inter-active control. An Arduino board consists of an Atmel 8-bit, 16-bit and 32-bit AVR microcontroller with complementary components that facilitate programming and incorporation into other circuits. Arduino board include a 5-volt linear regulator and a 16 MHz crystal oscillator (or ceramic resonator in some variants). It is an embedded system in which it collaborates the hardware circuit by monitoring and controlling.

Technical Specifications:

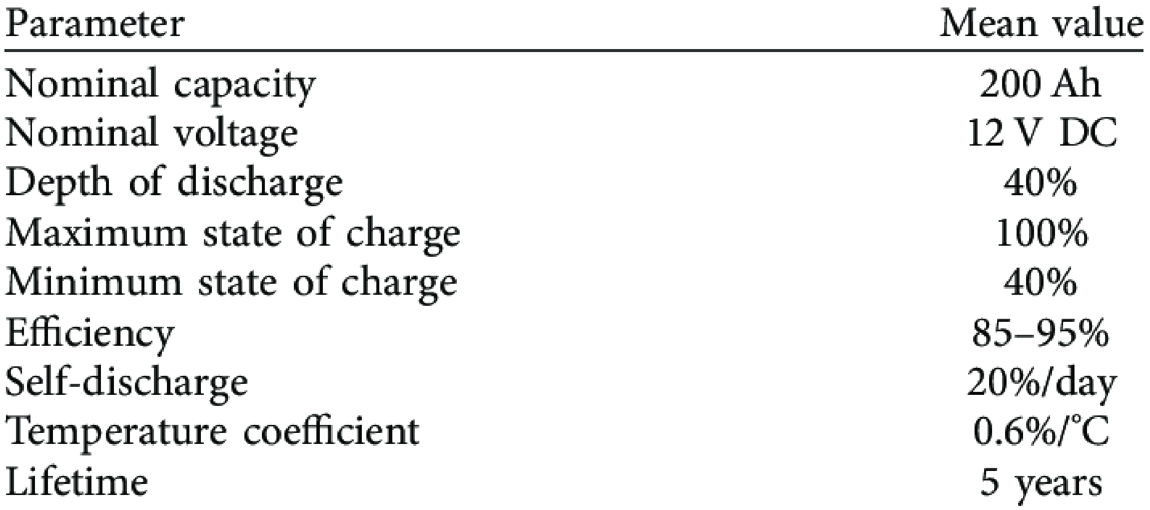
- Microcontroller: Microchip ATmega328P
- Operating Voltage: 5 Volts
- Input Voltage: 7 to 20 Volts
- Digital I/O Pins: 14 (of which 6 can provide PWM output)
- UART: 1
- I2C: 1
- SPPI: 1
- Analog Input Pins: 6
- DC Current per I/O Pin: 20 mA
- DC Current for 3.3V Pin: 50 mA
- Flash Memory: 32 KB of which 0.5 KB used by bootloader
- SRAM: 2 KB
- EEPROM: 1 KB
- Clock Speed: 16 MHz
- Length: 68.6 mm
- Width: 53.4 mm
- Weight: 25 g

BATTERY

A Microgrid consists renewable energy generators (REGs) along with energy storage in order to fulfil the load demand, even when the REGs are not available. The battery storage can meet the load demand reliably due to its fast response. The available technologies for the battery energy storage are lead-acid (LA) and lithium-ion (LI). The specific energy density of LI is higher than the LA battery and it has fast charge and discharge rate as compared to LA. Grid-connected microgrid consists the solar photovoltaic (SPV) as the primary power generator. The excess energy produced by SPV is stored in the batteries. If there is excess PV electricity after charging batteries to maximum state of charge then excess electricity can be fed to the mains-grid. If both PV and battery powers are not sufficient to fulfill the demand then the deficit power can be taken from the grid. It is found that for a typical load the power fed to grid is more with LI based system as compared to the LA based system. The power imported from the grid is lesser with LI battery storage in comparison with LA storage. The results provide the feasibility and economic benefits of LI battery over the LA battery.



Specifications:



Parameter	Mean value
Nominal capacity	200 Ah
Nominal voltage	12 V DC
Depth of discharge	40%
Maximum state of charge	100%
Minimum state of charge	40%
Efficiency	85–95%
Self-discharge	20%/day
Temperature coefficient	0.6%/°C
Lifetime	5 years

Lead Acid Battery Advantages

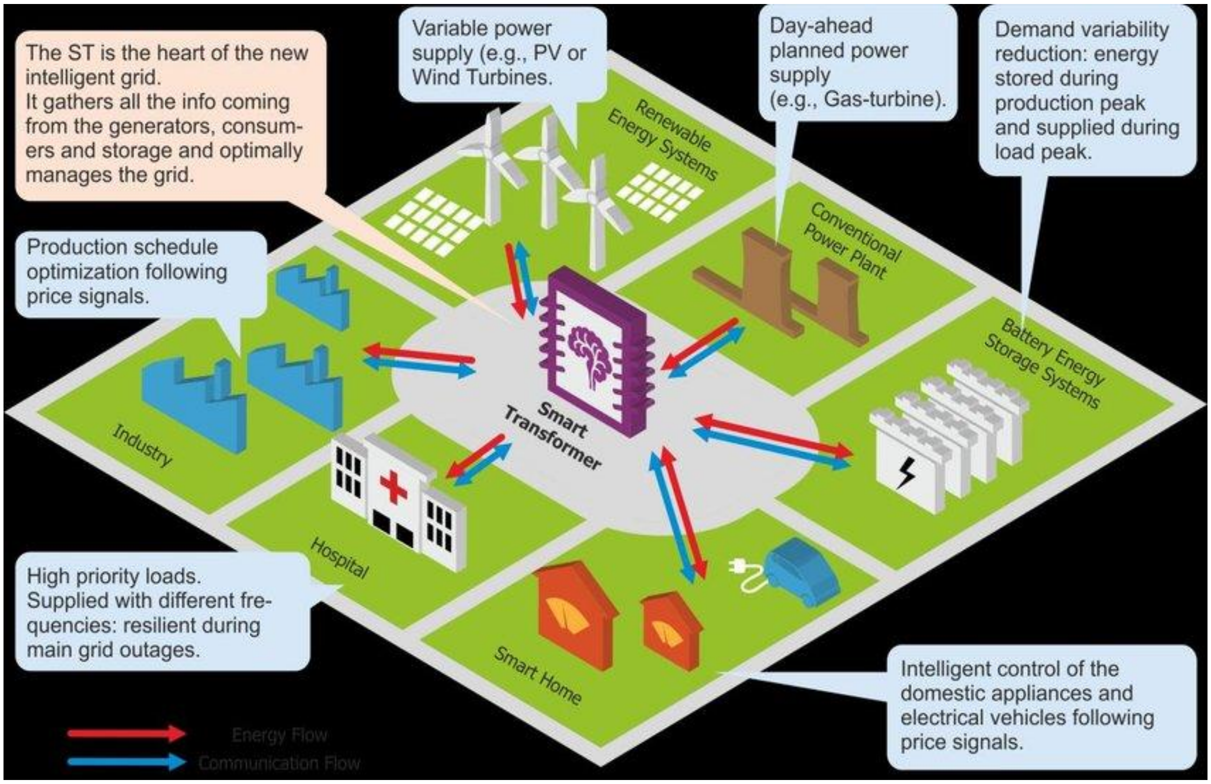
- Mature technology.
- Relatively cheap to manufacture and buy (they provide the lowest cost per unit capacity for rechargeable cells).
- Large current capability.
- Can be made for a variety of applications.
- Tolerant to abuse.
- Tolerant of overcharging.
- Wide range of sizes and specifications available.
- Many producers worldwide.

TRANSFORMER

Transformers serve to manipulate the level of voltage flowing through any point in a power grid in a way that balances efficiency of transmission with basic safety.

A smart transformer enables to control the power exchange between a microgrid and the utility network by controlling the voltage at the microgrid side within certain limits. The distributed generation units in the microgrid are equipped with a voltage-based droop control strategy.

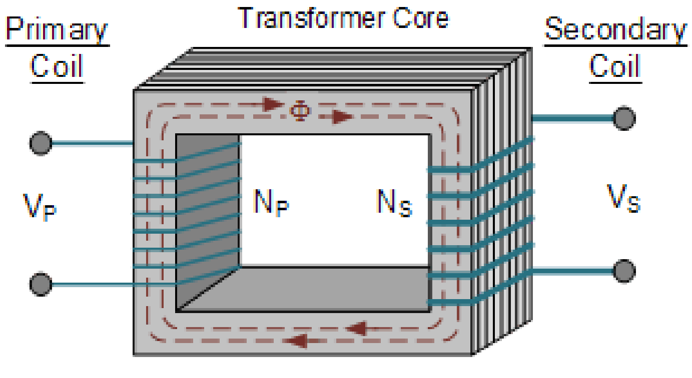
Grid transformers are used in similar situations to autotransformers but are used where the neutral point of both HV and LV system are required to be kept separately. They are physically larger than a correspondingly rated autotransformer as the windings are fully rated.



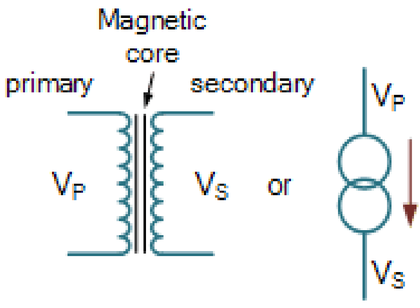
Power Transformer Specifications:

Power transformers can be designed as either a single phase or a 3-phase configuration. There are numerous important specifications to identify when searching for power transformers. The specifications of power transformer include a maximum power rating, maximum secondary current rating, maximum voltage rating and o/p type. Power transformer specifications mainly include

- Phase is 3Ø
- Frequency if 60Hz,50Hz
- Primary Voltage is 22.9 kV
- Secondary Voltage is 6.6/3.3 kV
- Tap Voltage 23.9-R22.9-21.9-20.9-19.9kV
- Vector Dd0, Dyn11, etc.



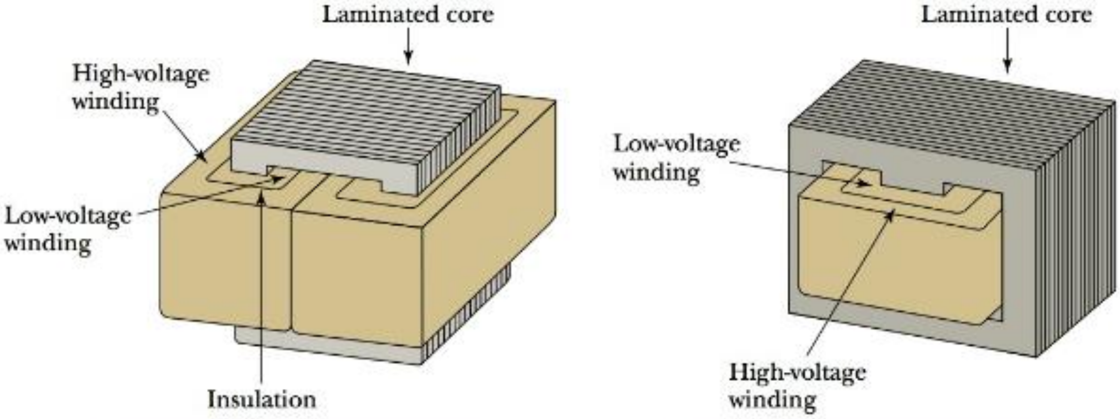
Transformer Construction



Transformer Symbols

Power Transformer Characteristics:

1. They are heavy (because of their iron core) and can be very large, like the transformers on telephone poles. However, power transformers in electronic devices are much smaller and vary considerably in size.
2. They have a laminated iron core to reduce eddy-current losses.



Coil arrangement for a core-type transformer

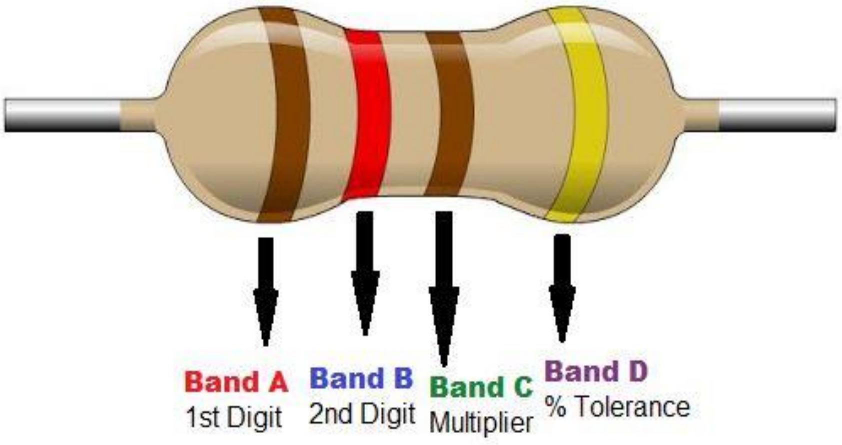
Coil arrangement for a shell-type transformer

Figure: Power transformers

3. The flux path is as short as possible to reduce leakage flux and minimize magnetizing energy needed.
4. They use one of two core shapes-core type (primary and secondary windings on separate legs of the core) and shell type (both primary and secondary windings on the center leg).
5. They have one or more primary and secondary windings.
6. They may have one tapped winding, such as the autotransformer. The autotransformer is a special single-winding transformer.

RESISTOR

A **resistor** is a passive two-terminal electrical component that implements electrical resistance as a circuit element. In electronic circuits, resistors are used to reduce current flow, adjust signal levels, to divide voltages, bias active elements, and terminate transmission lines, among other uses. High-power resistors that can dissipate many watts of electrical power as heat, may be used as part of motor controls, in power distribution systems, or as test loads for generators. Fixed resistors have resistances that only change slightly with temperature, time or operating voltage. Variable resistors can be used to adjust circuit elements (such as a volume control or a lamp dimmer), or as sensing devices for heat, light, humidity, force, or chemical activity.

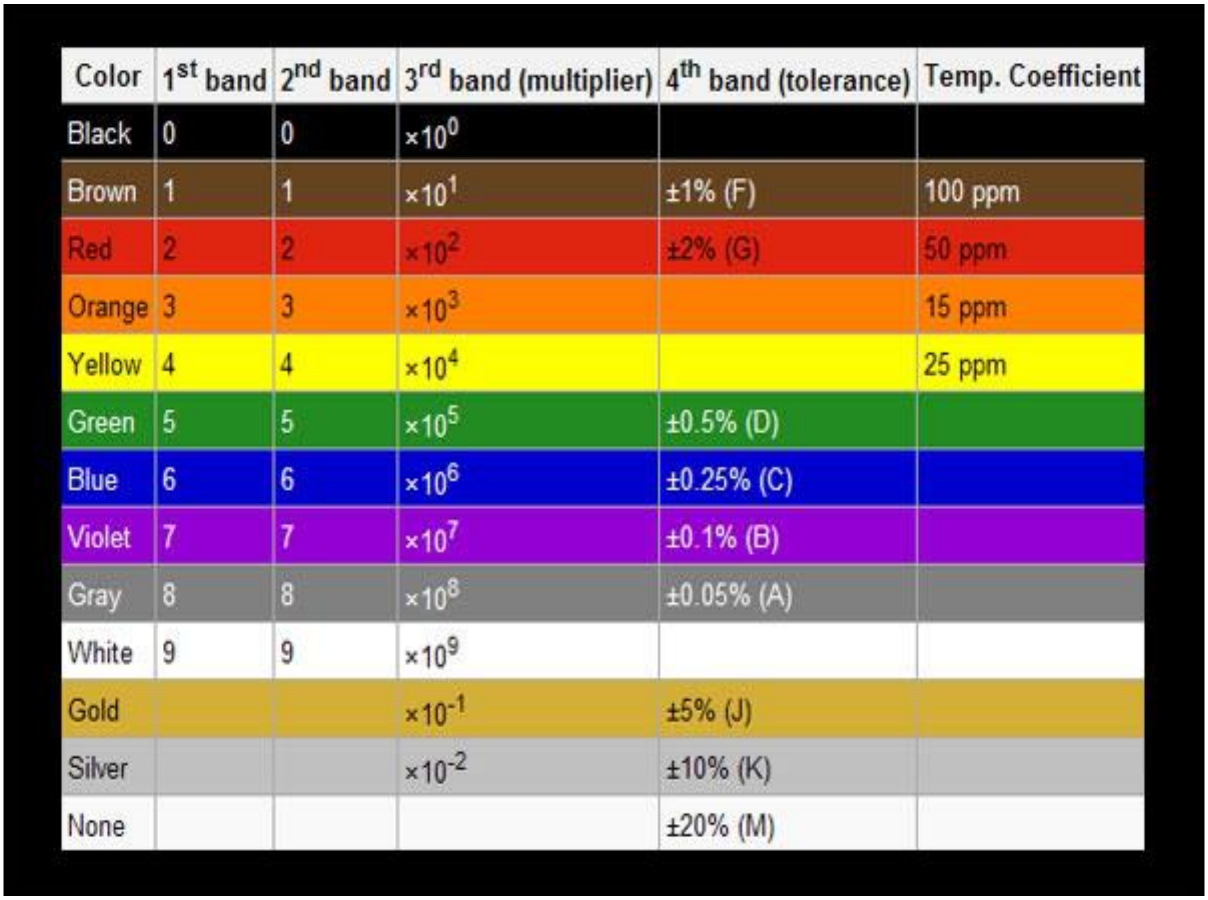


Applications of Resistor:

There are some important applications of resistors are as given below:

1. Resistors are used in high frequency instrument.
2. Resistor is used in power control circuit.
3. It is used in DC power supplies.
4. Resistors are used in filter circuit networks.

5. It is used in amplifiers, oscillators, telecommunication and digital multimeter.
6. It is used in wave generators.
7. Resistors are used in transmitters, modulators and demodulators.
8. It is used in medical instrument.
9. It is used in instrumentation applications.
10. Resistor is used in voltage regulators.
11. It is used in feedback amplifiers.

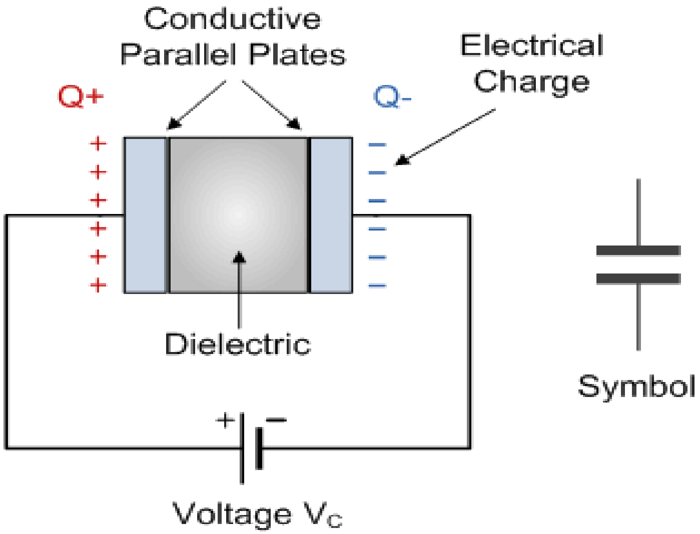


Color	1st band	2nd band	3rd band (multiplier)	4th band (tolerance)	Temp. Coefficient
Black	0	0	$\times 10^{0}$		
Brown	1	1	$\times 10^{1}$	±1% (F)	100 ppm
Red	2	2	$\times 10^{2}$	±2% (G)	50 ppm
Orange	3	3	$\times 10^{3}$		15 ppm
Yellow	4	4	$\times 10^{4}$		25 ppm
Green	5	5	$\times 10^{5}$	±0.5% (D)	
Blue	6	6	$\times 10^{6}$	±0.25% (C)	
Violet	7	7	$\times 10^{7}$	±0.1% (B)	
Gray	8	8	$\times 10^{8}$	±0.05% (A)	
White	9	9	$\times 10^{9}$		
Gold			$\times 10^{-1}$	±5% (J)	
Silver			$\times 10^{-2}$	±10% (K)	
None				±20% (M)	

CAPACITORS

The capacitor is a component which has the ability or "capacity" to store energy in the form of an electrical charge producing a potential difference (*Static Voltage*) across its plates, much like a small rechargeable battery.

There are many different kinds of capacitors available from very small capacitor beads used in resonance circuits to large power factor correction capacitors, but they all do the same thing, they store charge.



Key capacitor specifications:

Some of the key capacitor specifications and characteristics which need to be considered when selecting and buying capacitors include:

- **Capacitance value**
- **Tolerance**
- **Working voltage**
- **Dielectric**
- **Working temperature**
- **Temperature coefficient**
- **Leakage resistance / current**
- **ESR (Equivalent Series Resistance)**
- **Self-inductance**
- **Self-resonant frequency**
- **Ripple current**

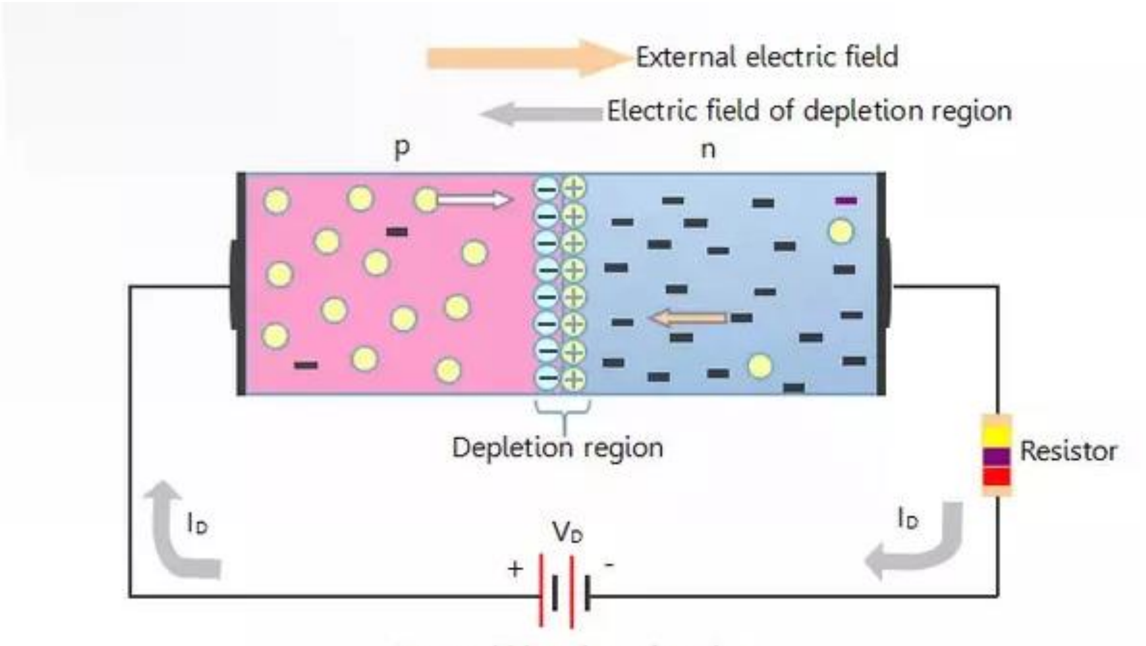
Nominal Capacitance	0.001 uF to 10 uF
Working Voltage (at 85°C)	200V to 1600V
Typical Tolerance	10%
Temperature Range	-55°C to 125°C
Temperature Coefficient (PPM/°C)	+/-800
Insulation Resistance (Meg Ohms)	5×10^3
Polarization	Non-Polarized
Dielectric Absorption	2.5%
Dissipation Factor (Operating Losses)	1%
Disadvantage	Size, Hygroscopic and susceptible to moisture
Advantage	Low Cost, Stable, High Voltage Rating
Applications	Motor Capacitors
Cost	Low

FORWARD BIASED DIODE

In a standard diode, forward biasing occurs when the voltage across a diode permits the natural flow of current, whereas reverse biasing denotes a voltage across the diode in the opposite direction.

This forward-bias voltage drop exhibited by the diode is due to the action of the depletion region formed by the P-N junction under the influence of an applied voltage. If no voltage applied is across a semiconductor diode, a thin depletion region exists around the region of the P-N junction, preventing current flow.

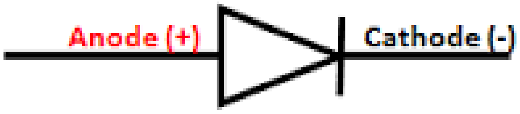
Conversely, if a forward-biasing voltage is applied across the P-N junction, the depletion region collapses becoming thinner. The diode becomes less resistive to current through it. In order for a sustained current to go through the diode; though, the depletion region must be fully collapsed by the applied voltage. This takes a certain minimum voltage to accomplish, called the *forward voltage*.

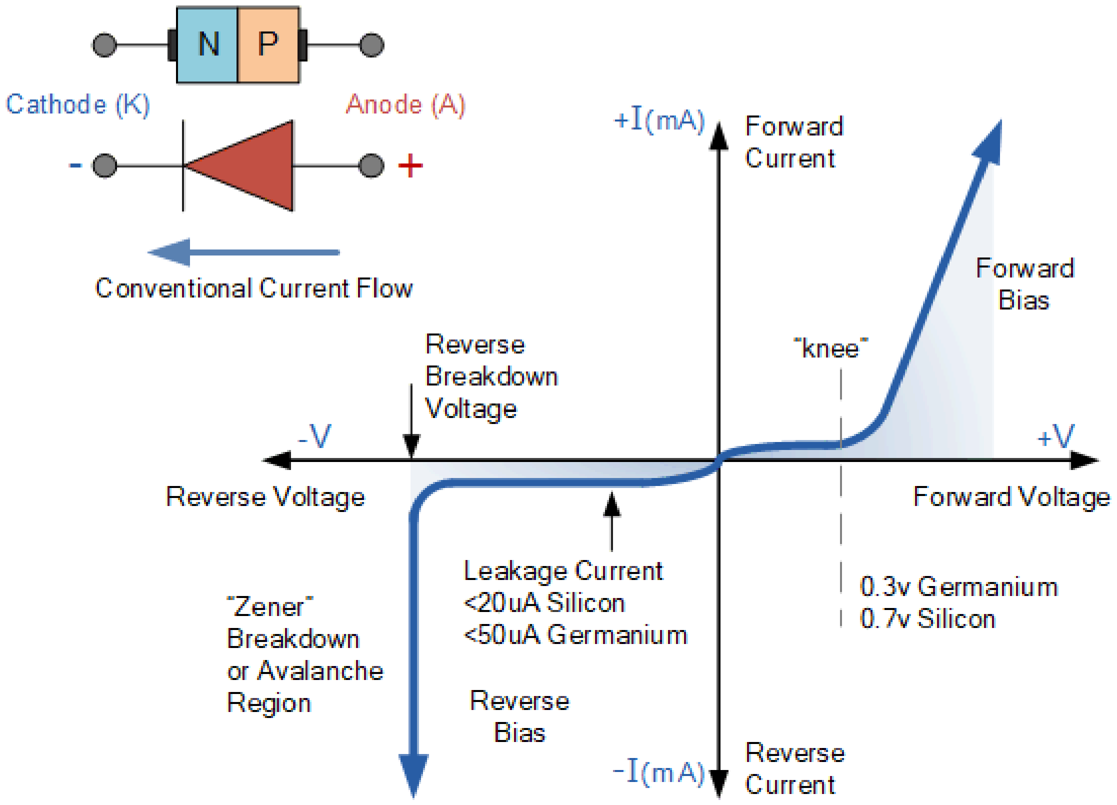


Forward biased p-n junction

1N4007 Characteristics:

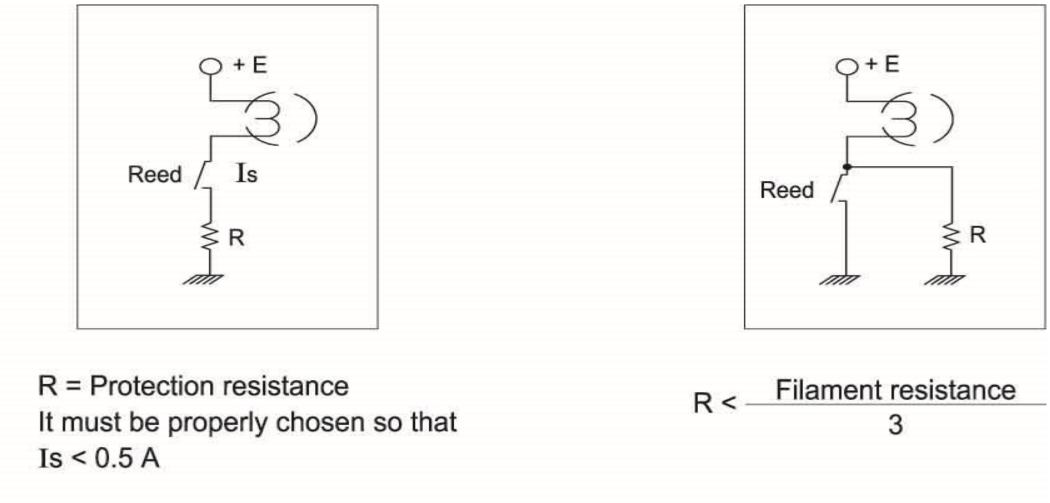
- Maximum Recurrent Peak Reverse Voltage 1000V.
- Maximum RMS Voltage 700V.
- Maximum DC Blocking Voltage 1000V.
- Average Forward Current: 1.0A.
- Peak Forward Surge Current: 30A.
- Maximum Instantaneous Forward Voltage: 1.0V.
- Maximum DC Reverse Current at Rated DC Blocking Voltage: 5.0µA @ 25°C.





LAMP LOAD

A lamp load/load lamp is simply a common light bulb in series with a device being tested. It can be used to vary the power of the load.



Electrical loads can be classified according to their nature as Resistive, Capacitive, Inductive and combinations of these.

Resistive Load

- Two common examples of resistive loads are incandescent lamps and electric heaters.
- Resistive loads consume electrical power in such a manner that the current wave remains in phase with the voltage wave. That means, power factor for a resistive load is unity.

Capacitive Load

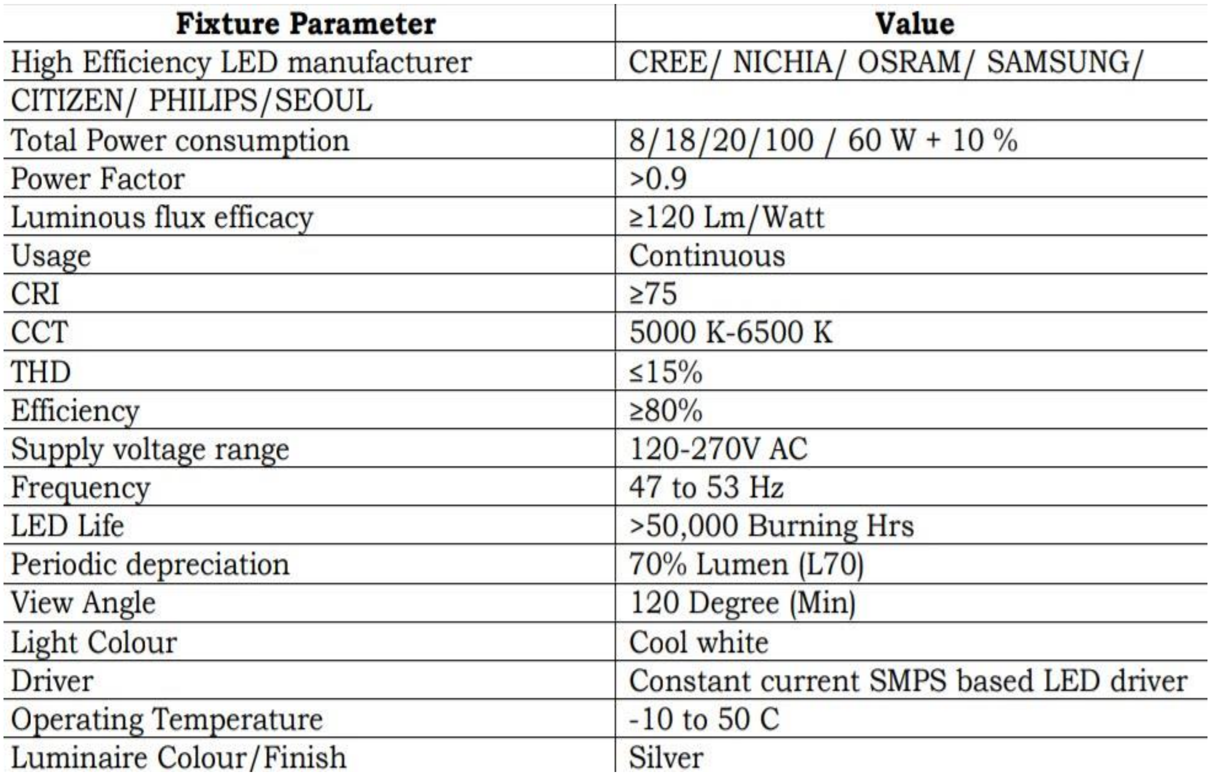
- A capacitive load causes the current wave to lead the voltage wave. Thus, power factor of a capacitive load is leading.
- Examples of capacitive loads are: capacitor banks, buried cables, capacitors used in various circuits such as motor starters etc.

Inductive Load

- An inductive load causes the current wave to lag the voltage wave. Thus, power factor of an inductive load is lagging.
- Examples of inductive load include transformers, motors, coils etc.

Combination Loads

- Most of the loads are not purely resistive or purely capacitive or purely inductive. Many practical loads make use of various combinations of resistors, capacitors and inductors. Power factor of such loads is less than unity and either lagging or leading.
- Examples: Single phase motors often use capacitors to aid the motor during starting and running, tuning circuits or filter circuits etc.



Fixture Parameter	Value
High Efficiency LED manufacturer	CREE/ NICHIA/ OSRAM/ SAMSUNG/
CITIZEN/ PHILIPS/SEOUL	
Total Power consumption	8/18/20/100 / 60 W + 10 %
Power Factor	>0.9
Luminous flux efficacy	≥120 Lm/Watt
Usage	Continuous
CRI	≥75
CCT	5000 K-6500 K
THD	≤15%
Efficiency	≥80%
Supply voltage range	120-270V AC
Frequency	47 to 53 Hz
LED Life	>50,000 Burning Hrs
Periodic depreciation	70% Lumen (L70)
View Angle	120 Degree (Min)
Light Colour	Cool white
Driver	Constant current SMPS based LED driver
Operating Temperature	-10 to 50 C
Luminaire Colour/Finish	Silver

SWITCH

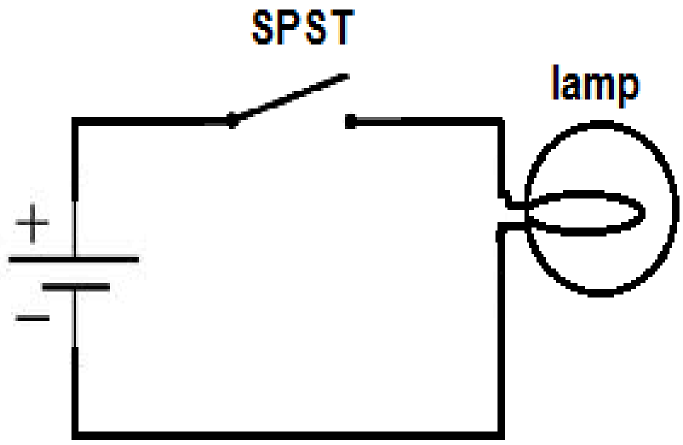
A Single Pole Single Throw (SPST) switch is a switch that only has a single input and can connect only to one output. This means it only has one input terminal and only one output terminal.

A Single Pole Single Throw switch serves in circuits as on-off switches. When the switch is closed, the circuit is on. When the switch is open, the circuit is off.

SPST switches are, thus, very simple in nature.

When the SPST is closed, the circuit is closed and light from the lamp switches on. When the SPST is then opened, the light from the lamp goes out and the circuit is off.

This shows the basic nature and function of a SPST.



Features and Electrical Specifications:

- Power switches.
- Snap-in type.
- **SDDJE** series comes in SPST (Single Pole Single Throw) and DPST (Double Throw Single Pole) configuration.
- **SDDJE11200** is SPST ON-OFF Rocker Switch with IO marking.
- Operating temperature range –10 °C to +55 °C
- Contact resistance 100mΩ max.
- Insulation resistance 500MΩ min. 500V DC.
- Voltage proof 2,000V AC for 1minute.
- Operating life 10,000 cycles.
- Actuator strength - Operating direction 25N.
- Actuator strength - Perpendicular direction 25N.

STATIC SWITCH

A **Static Switch** is a two-way, three phase 4 ways **automatic switch**. Powered by two independent synchronous or asynchronous AC power supply sources. The **switching** device are SCR. Under no operation conditions is simultaneous current **switching** between the two sources possible (Break Before Make).

Applications:

The static switches mainly find applications in relays, circuit breakers, UPS, flashers, and fuses. Along with these, they are also used in time delay circuits, transducers, and voltage detection circuits, etc.

Advantages of static switches

Static switches are now replacing mechanical and electromechanical switches both because of several advantages are listed below:

- A static switch has no moving parts; therefore, maintenance cost is very low.
- A static switch has a long operational life.
- A static switch has no bouncing at the time of when is turning on.
- On time of a static switch is of the order microseconds, it has therefore very high switching speed.

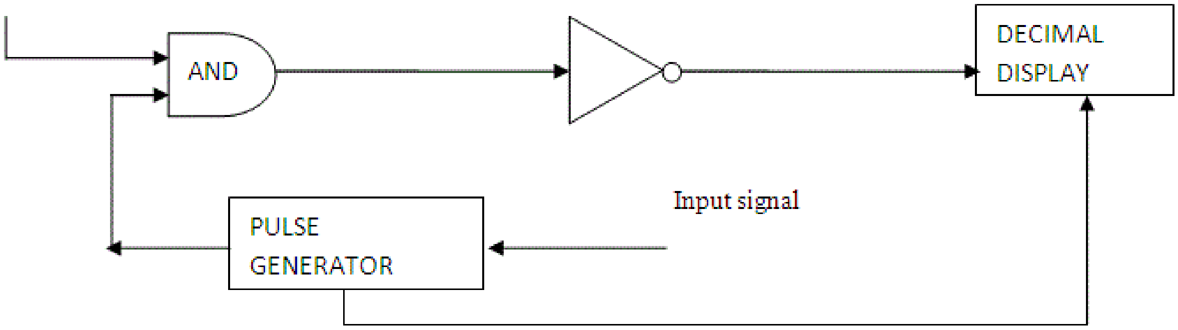
- Inbuilt AC overvoltage protection.
- High-performance AC line quality monitoring.

DIGITAL VOLTMETER

Digital Voltmeter abbreviated as DVM is an instrument used to measure the electrical potential difference between two points in a circuit. The voltage could be an alternating current (AC) or direct current (DC). It measures the input voltage after converting the analog voltage to digital voltage and displays it in number format using a convertor. The usage of digital voltmeter has increased the speed and accuracy with which the readings are noted. A typical DVM is shown below:

The working principle of a Digital Voltmeter can be categorized into five functional sections. They are:

- Pulse Generator
- Voltage Control and Gating
- Counting Clock Pulses
- Analog to Digital Conversion
- Latching and Display Section



The general specification of digital voltmeter is given below:

- **Input range:** The digital voltmeter has automatic range selection facility. The input range is from ± 1 V to ± 1000 V.
- **Accuracy:** The accuracy is about ± 1 percent for a 3-digit digital voltmeter and ± 0.0002 percent for a 6-digit digital voltmeter.
- **Speed:** A digital voltmeter can digitize the signal with a speed of about 1 millisecond.
- **Resolution:** The resolution is one part in 10^6.
- **Stability:** 0.002 of the reading for 24 hours.
- **Input resistance** : The input resistance is typically 10 MΩ.
- **Input capacitance** : The input capacitance is typically 40 pF.
- **Output signal:** The digital outputs are in the form of four-line binary code.

Types of Digital Voltmeter:

Digital Voltmeter is broadly classified into four types. They are:

- Ramp Type Digital Voltmeter
- Integrating Digital Voltmeter
- Continuous Balance Digital Voltmeter
- Successive approximation Digital Voltmeter

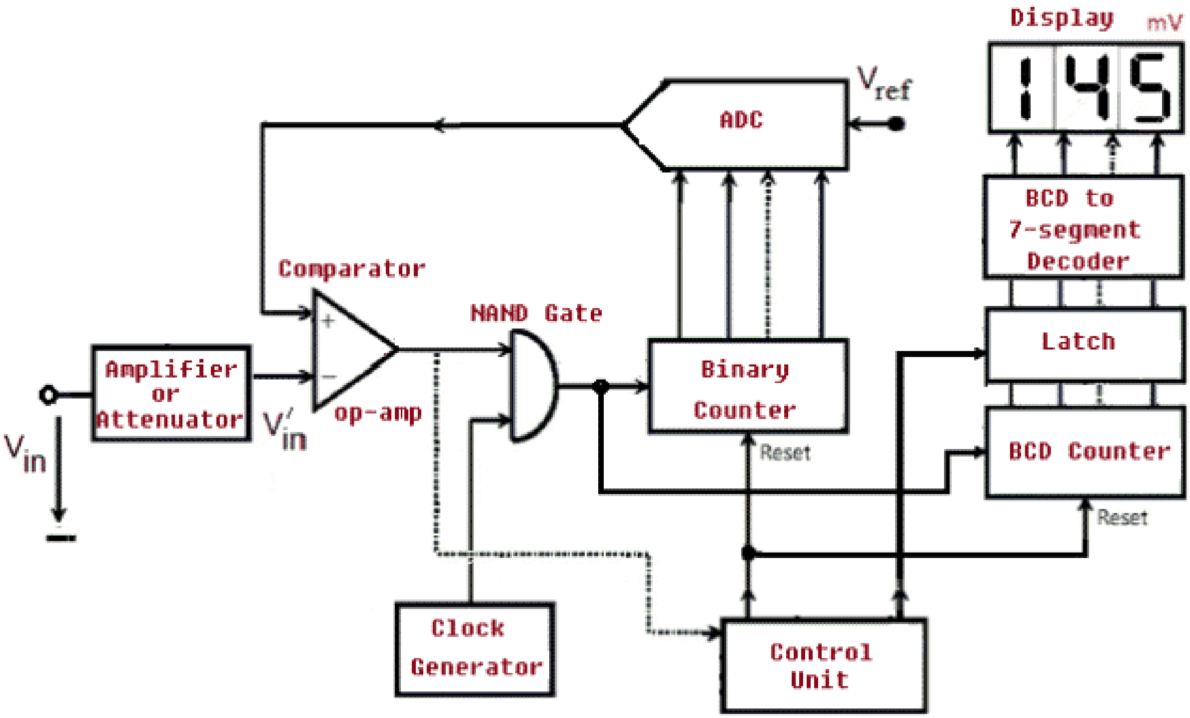
Applications of Digital Voltmeter:

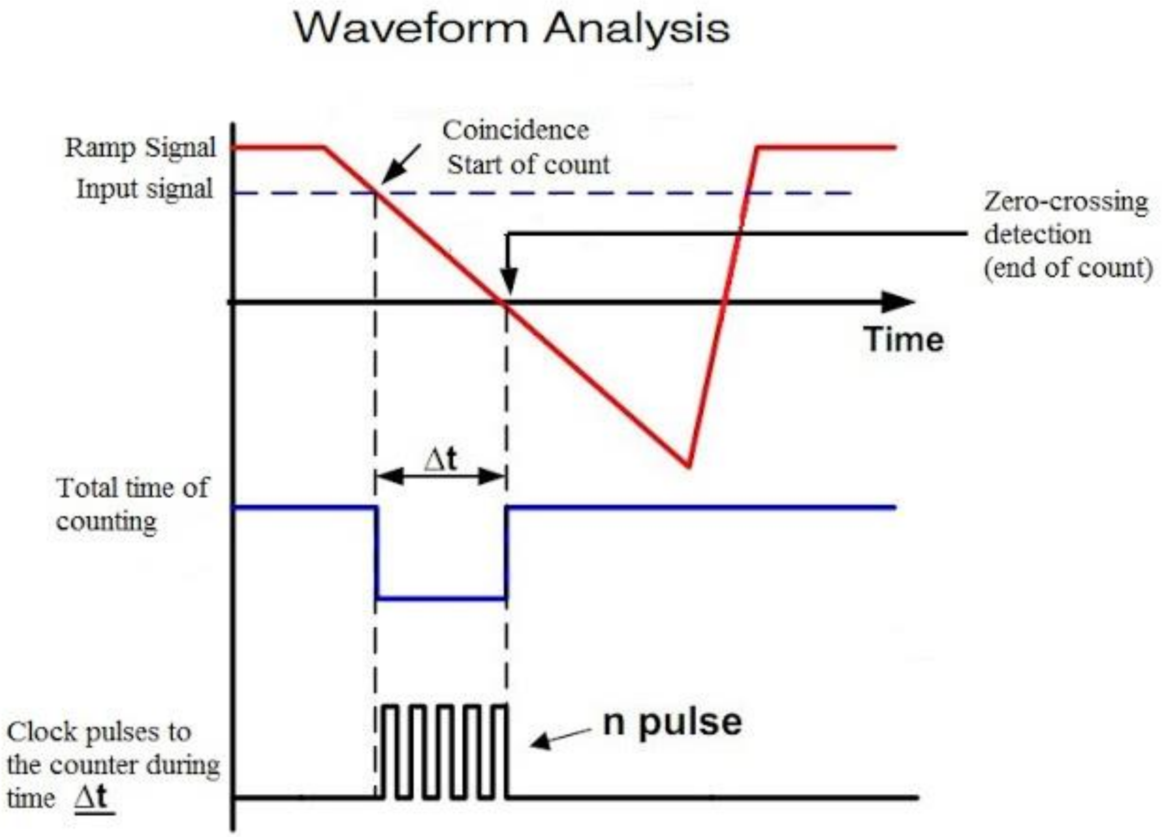
- Digital Voltmeter is used to know the actual voltage of different components.
- DVM is widely used to check if there is power in the circuit, such as mains outlet.
- Knowing the voltage across a circuit, current can be calculated.

Advantages of Digital Voltmeter:

- Digital display of the output eliminates human reading errors.
- Readings are accurate and fast compared to analog meters.
- Digital Voltmeter is more stable and reliable.
- Smaller in size and cost-effective.
- DVM can measure both AC and DC voltages.

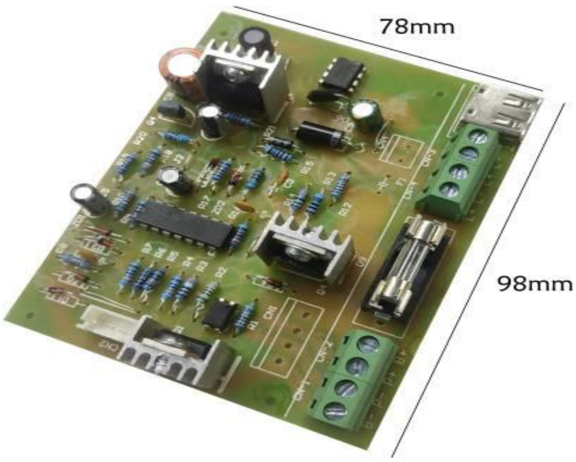
- Latest DVM are built with micro controllers which stores the readings for further processing.
- DVM is void of Parallax errors.
- DVMs have automatic range selection.
- DVMs have high input impedance.





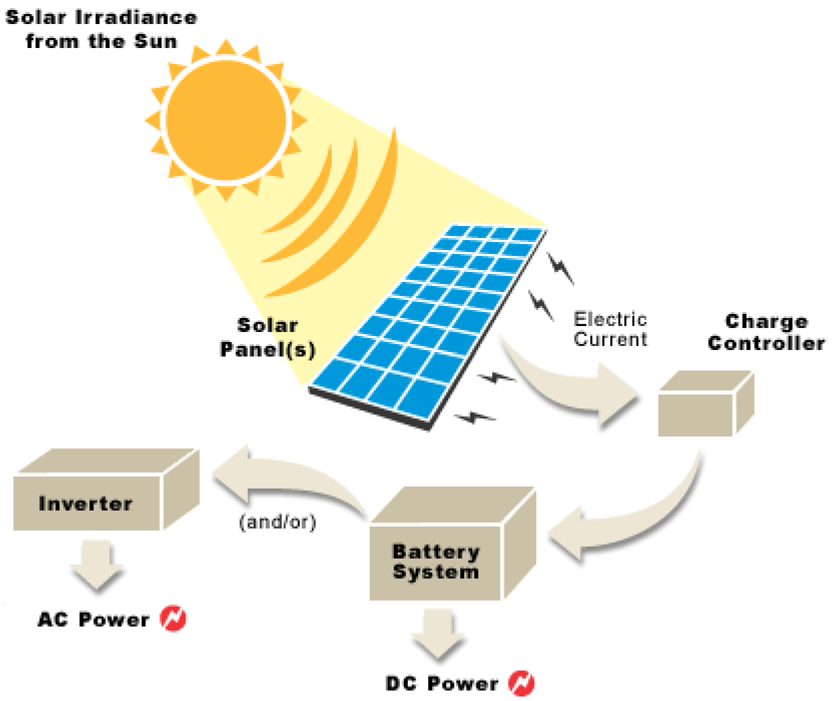
MICRO CHARGE CONTROLLER

A **charge controller**, **charge regulator** or battery **regulator** limits the rate at which electric current is added to or drawn from electric batteries. ... It may also prevent completely draining ("deep discharging") a battery, or perform controlled discharges, depending on the battery technology, to protect battery life.



Most charge controllers are a variation of one these four basic types:

- Shunt Regulator.
- Series Regulator.
- PWM Regulator.
- MPPT Charge Controller.

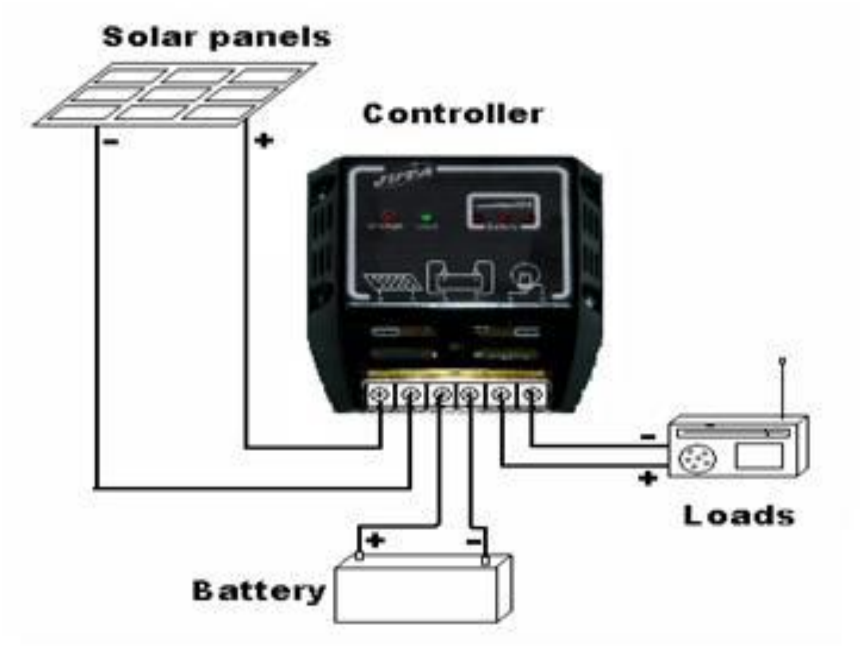


The function of the Solar Charge Controller:

The most essential charge controller basically controls the device voltage and opens the circuit, halting the charging, when the battery voltage ascents to a certain level. More charge controllers utilized a mechanical relay to open or shut the circuit, halting or beginning power heading off to the electric storage devices.

Generally, solar power systems utilize 12V of batteries. Solar panels can convey much more voltage than is obliged to charge the battery. The charge voltage could be kept at the best level while the time needed to completely charge the electric storage devices is lessened. This permits the solar systems to work optimally constantly. By running higher voltage in the wires from the solar panels to the charge controller, power dissipation in the wires is diminished fundamentally.

The solar charge controllers can also control the reverse power flow. The charge controllers can distinguish when no power is originating from the solar panels and open the circuit separating the solar panels from the battery devices and halting the reverse current flow.



Product Specifications:

Housing material	ABS/MS
Load disconnect battery voltage	11 +- 0.2 volts or as required
Load reconnect battery voltage	12.5 +- 0.2 volts or as required
Constant Charging Voltage	14.5 +- 0.2 volts or as required
Idle current consumption	Less than 5ma
Rated Voltage	12 V
Current	10 A
Application	Solar System Controller

Features:

Solar charge controllers can have many different features to enhance usability. Some of these features include:

Integral Display -- The controller will have a built-in display that will inform operator of various parameters such input/output voltage and or current, and battery voltage and charge condition.

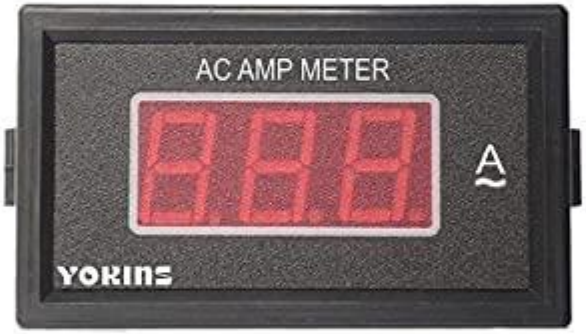
Datalogging -- The controller has built in datalogger to record important parameters for review and storage at a later point.

Reverse Current Protection -- The controller prevents current from flowing from the battery back to the controller when panel voltage is lower than battery voltage. This is important during the night-time, when no sun is hitting the panel.

DIGITAL AMMETER

Digital ammeters are instruments that measure current flow in amperes and display current levels on a digital display. These devices provide information about current draw and current continuity in order to help users troubleshoot erratic loads and trends. They have both positive and negative leads and feature extremely low internal resistance.

Digital ammeters are connected in series with a circuit (and never parallel) so that current flow passes through the meter. High current flow may indicate a short circuit, unintentional ground, or defective component. Low current flow may indicate high resistance or poor current flow within the circuit.



Working Principle of Ammeter:

The working principle of an ammeter depends on the current flowing along with its resistance. Very little impedance is used inside the ammeter as it must drop the least amount of voltage attached to it. The ammeter is connected to the series of circuits as the current in the series circuit is the same.

The main function of this tool is to measure the flow of current with the help of a set of coils. Inside this coil, there is very little resistance and inductive reaction.

Classification/Types of Ammeters:

These are classified into different types based on their applications which include the following.

- Moving Coil
- Electrodynamic
- Moving-iron
- Hotwire
- Digital
- Integrating

Specifications:	
Meter	Current
Function	0 to 150A
Input Voltage	80-249V
Display Character Size	0.5625in (14.29 mm)
Maximum Power Consumption	1 Watt
Minimum Power Consumption	0.60 Watt
Sleep Mode	Manual
Weight	0.78Lb (0.35 Kg)
Weight	0.72lb (0.33 kg)

Features:

Many digital ammeters provide special measurement types or advanced options or features.

- **Adjustable sampling rate** - The sampling rate is manually adjustable.
- **Alarm LED** - Alarm light-emitting diodes (LEDs) light when the RMS value or peak value is greater than the range. Typically, alarm LEDs light only when the range has been greatly exceeded.
- **Application software** - The device has embedded application software.
- **Auto-Ranging** - Auto-ranging devices are self-adjusting to offer the best measurement scenario.
- **Battery powered** - Devices are battery-powered.
- **Data acquisition** - Devices with data acquisition capabilities have a computer interface and software for uploading data.

- **Data storage / logging** - Data storage or data logging devices have internal memory for storing data.
- **External shunts** - External shunts can be used to extend the current input range. For example, an input that exceeds 5 A can be measured by providing a shunt.
- **Filters** - Devices have embedded filters.
- **Integrating functions** - Integrating functions allow the active power and current to be integrated (W-h and A-h).
- **Mirrored scale** - Mirrored scales make it easier to read the instrument to a given accuracy by enabling the operator to avoid parallax errors.
- **Overload protection** - Devices with overload protection have fuses or other devices to protect the meter.
- **Programmable** - Programmable devices can be programmed with trigger values to perform measurements.
- **Range switch** - Range switches can be used to select an appropriate range of units to be measured.
- **Removable data storage** - Devices with removable data storage have removable memory, drives, etc.
- **Scaling function** - Devices with a scaling function allow the pre-setting of the potential transformer and current transformer ratio, and the power scaling factor.
- **Temperature compensated** - Temperature-compensated devices are designed to counteract known errors caused by temperature changes.
- **Triggering** - Devices with triggering have an interface for external triggering.