UNIT V

HYBRID ENERGY SYSTEMS

SYLLABUS: Need for Hybrid Systems- Range and type of Hybrid systems- Case studies of Wind-PV Maximum Power Point Tracking (MPPT).

5.1 HYBRID RENEWABLE ENERGY SYSTEMS

5.1.1 Introduction

The renewable energy technologies include power generation from renewable energy sources, such as wind, PV(photovoltaic), MH (micro hydro), biomass, ocean wave, geothermal and tides. In general, the key reason for the deployment of the above energy systems are their benefits, such as supply security, reduced carbon emission, and improved power quality, reliability and employment opportunity to the local people. Since the RE resources are intermittent in nature therefore, hybrid combinations of two or more power generation technologies, along with storage can improve system performance. Hybrid Renewable Energy System (HRES) combines two or more renewable energy resources with some conventional source (diesel or petrol generator) along with storage, in order to fulfill the demand of an area.

5.1.2. Methodology

It is essential to have a well-defined and standardized frame work/steps taken for hybrid system based power generation for rural electrification. These steps are as follows:

Demand Assessment:

Using accurate load forecasting of remote villages, the load demand can be fetched. During load survey, following factors may be considered:

- Demand for street lighting
- Number of houses, schools, health centers, commercial establishment and their energy requirement
- Number of small scale industries and their energy demand
- Miscellaneous demand

Resource Assessment:

Resource assessment can be done by calculating potential available in wind, MHP, solar, Biomass, Biogas, and other renewable energy resources using meteorological data available.

Demand is fulfilled by Hybrid renewable energy system.

This can be done by combining one or more renewable energy sources with conventional energy sources. Some Hybrid renewable system configurations are as follows:

- PV/Wind/diesel generator HRES
- PV/wind/fuel cell HRES
- Wind/battery HRES
- Biomass/wind/diesel generator HRES
- PV/Wind/Biomass/fuel cell HRES

5.1.3 Need for Hybrid Systems

As convention fossil fuel energy sources diminish and the world‘s environmental concern about acid deposition and global warming increases, renewable energy sources (solar, wind, tidal, biomass and geothermal etc) are attracting more attention as alternative energy sources. These are all pollution free and one can say eco friendly. These are available at free of cost in India, there is severe power shortage and associated power quality problems. The quality of the grid supply in some places is characterized by large voltage and frequency fluctuations, scheduled and un-scheduled power cuts and load restrictions. Load shedding in many cities in India due to power shortage and faults is a major problem for which there is no immediate remedy in the near future since the gap between the power demand and supply is increasing every year.

In India wind and solar energy sources are available all over the year at free of cost whereas tidal and wave are coastal area. Geothermal is available at specific location. To meet the demand and for the sake of continuity of power supply, storing of energy is necessary. The term hybrid power system is used to describe any power system combine two or more energy conversion devices, or two or more fuels for the same device, that when integrated, overcome limitations inherent in either. Usually one of the energy sources is a conventional one (which necessarily does not depend on renewable energy resource) powered by a diesel engine, while the other(s) would be renewable viz. solar photovoltaic, wind or hydro. The design and structure of a hybrid energy system obviously take into account the types of renewable energy sources available locally, and the consumption the system supports. For example, the hybrid energy system presented here is a small-scale system and the consumption of power takes place during nights.

The wind energy component will make a more significant contribution in the hybrid system than solar energy. Although the energy produced by wind during night can be used directly without storage. Battery is needed to store solar and wind energy produced during the day. In addition to the technical considerations, cost benefit is a factor that has to be incorporated into the process of optimizing a hybrid energy system. In general, the use of wind energy is cheaper than that of solar energy. In areas where there is a limited wind source, a wind system has to be over-dimensioned in order to produce the required power, and these results in higher plant costs. It has been demonstrated that hybrid energy systems (renewable coupled with conventional energy source) can significantly reduce the total life cycle cost of a standalone power supplies in many off-grid situations. Numerous hybrid systems have been installed across the world, and expanding renewable energy industry has now developed reliable and cost competitive systems using a variety of technologies.

5.1.4 Benefits of Hybrid Systems

Improved reliability a robust power supply and downtime minimization during power outages could be achieved by virtue of varying the power sources, which is vital indeed due to its ability to provide backup power. System failure or disruption of diesel supply to the community are factors leading to utilizing an alternate generating system encompassing renewable energy / diesel hybrid system as to encourage continuous and reliability power supply. Photovoltaic and wind energy system attributive to fewer moving parts, requiring less maintenance than diesel, thus reduces downtime during repairs or routine maintenance. In fact, renewable energy sources being original and free, is more securing than diesel thus, beneficial to facilities.

The ability of renewable energy working in tandem with diesel, contributes to high quality and dynamic electricity services for 24 hours / day even as in a conventional system, the hours / day. The cost of photovoltaic or wind power generation lies in the form of upfront capital expenditures whereby the operation and maintenance expenses are low. Therefore, the generating cost via photovoltaic or wind is marginally more than a conventional system with respect to the additional generating capacity, nevertheless promises customer satisfaction of a continuous electricity supply. Reduced emissions and noise pollution Diesel generation emits air / water pollution agents as well as loud noise, proving the essentiality of renewable energy or diesel retrofits application in power generation which adopts an environmental-friendly technology. In fact, renewable energy system is also substantially quieter than diesel generators. Continuous power by incorporating diesel generator with renewable energy system, diesel generator is able to boost up the electricity supply during sudden increase in energy demand or when the batteries capacity decreases and thus, facilities face no supply interruption.

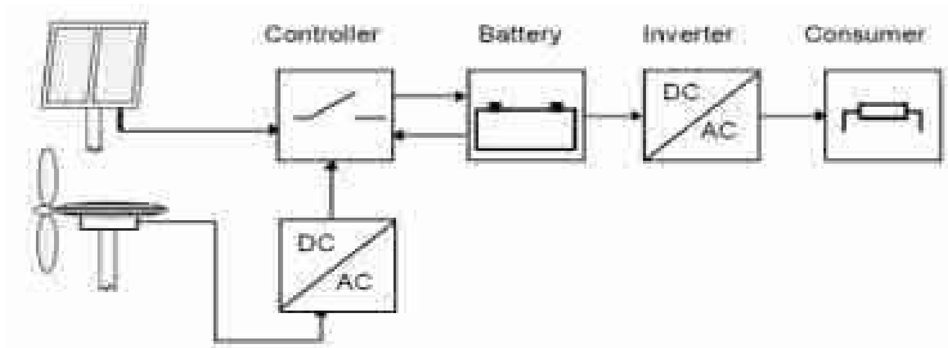
Reduced cost Renewable energy or diesel hybrid system act as the most cost-effective way of generating electricity with regards to savings on fuel consumption and lower maintenance cost. For a conventional diesel system at remote area, the fuel and transportation cost is typically very high, as well as the service and spare parts cost which grossly excessive to rural community. Efficient use of energy Hybrid system promotes efficient use of power since renewable energy system could be configured to cope with base load whilst the peak load could be met via diesel generator

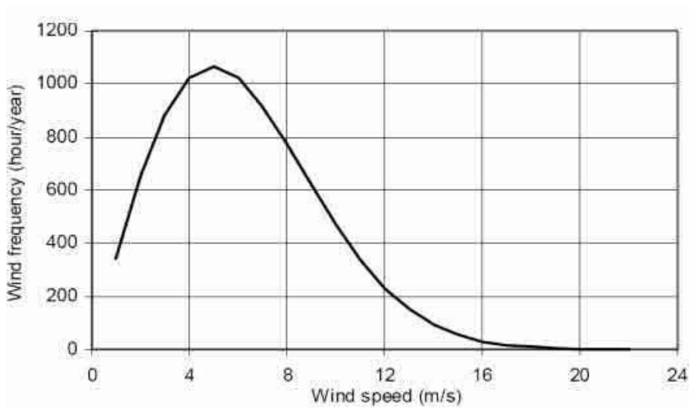
5.2 RANGE AND TYPE OF HYBRID SYSTEMS

5.2.1 Hybrid System Characteristics

Although hybrid energy systems are open, they can have the characteristics of a closed system if a subsystem with the function of ―monitoring‖ is introduced as a feedback between output (consumer) and input (controller). As inputs of particular hybrid system cannot be changed. However, the load may be changed. With a backup system as another energy source the system can be designed as a partial closed-loop feedback system. There are various possibly to make combination of different energy sources. Selection of energy source for hybrid system is mainly depends upon availability at the place where it going to stabilized. In general in India solar energy is available almost all the places and infrastructure for power generation is rugged. Hence need low maintenance so it is smart to choose to have PV one of the energy sources in hybrid system. Wave and tidal energy available only at sea shore and need large capital investment and more maintenance, therefore not compatible for household hybrid system. But can be use in large power hybrid system. Corrosion because of seawater is a major drawback. Wind energy source is also a good choice but more preferable for open land hybrid system and status of wind throughout the year is also important. India has monsoon climate hence has enough potential of wind energy. Biomass energy is good option but it needs regular feeding to continuously operate. Biomass with grid hybrid system is broadly used in sugar mill in India. In residential applications, biomass can be used for space heating or for cooking. Businesses and industry use biomass for several purposes including space heating, hot water heating, and electricity generation.

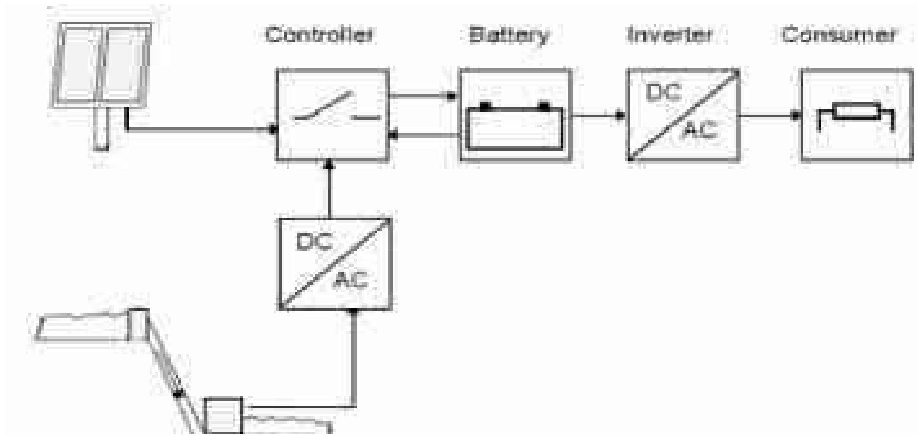
5.2.2 Wind/PV Hybrid System





A typical hybrid energy system consists of solar and wind energy sources. The principle of an open loop hybrid system of this type is shown in Figure. The power produced by the wind generators is an AC voltage but have variable amplitude and frequency that can then be transformed into DC to charge the battery. The controller protects the battery from overcharging or deep discharging. As high voltages can be used to reduce system losses, an inverter is normally in traduced to transform the low DC voltage to an AC voltage of 230V of frequency 50 Hz. The hybrid PV-wind generator system has been designed to supply continuous power of 1.5 kW and should have the following capabilities: Maximizes the electric power produced by the PV panels or by the wind generator by detecting and tracking the point of maximum power stores the electric energy in lead-acid batteries for a stable repeater operation. Control of the charge and discharge processes of the batteries protects wind generator from over speeding by connecting a dummy load to its output.

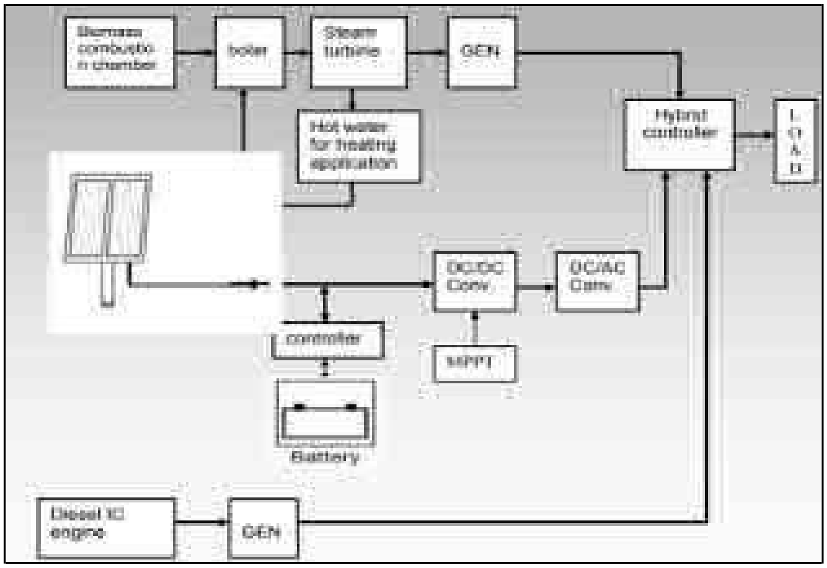
5.2.3 PV/Hydro Hybrid System



The block diagram of hybrid system, which combines PV with hydro system, is shown above. In this system there is a small reservoir to store the water. This type of hybrid system sometimes depends upon the geographical condition where the water at some height is available. System capacity is depends upon at the water quantity and solar radiation. The power supplied by falling water is the rate at which it delivers energy, and this depends on the flow rate and water head. The local water flow and head are limited at this project site, and a relatively simple hydro energy component is used in the project. Hydropower available is may be of runoff river type hence produces variable amplitude and frequency voltage. It can be use to charge the battery after converting it into DC.

5.2.4 Biomass-PV-Diesel Hybrid System

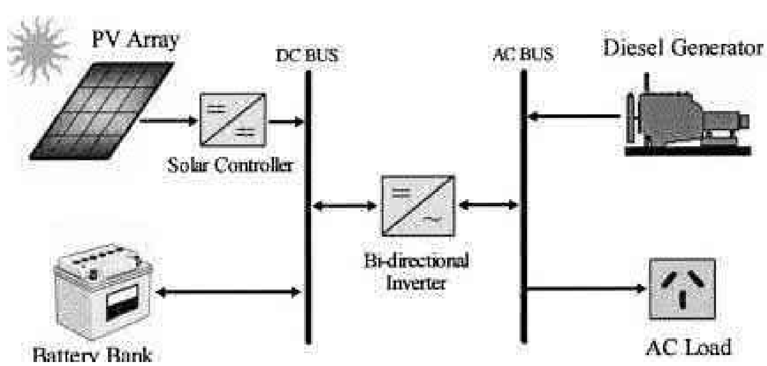
Biomass is matter usually thought of as garbage. Some of it is just substance lying around -- dead trees, tree branches, yard clippings, leftover crops, wood chips and bark and sawdust from lumber mills. It can even include used tires and livestock manure. The waste wood, tree branches and other scraps are gathered together in big trucks. The trucks bring the waste from factories and from farms to a biomass power plant. Here the biomass is dumped into huge hoppers. This is then fed into a furnace where it is burned. The heat is used to boil water in the boiler, and the energy in the steam is used to turn turbines and generators. Other application of Biomass is that it can also be tapped right at the landfill with burning waster products. When garbage decomposes, it gives off methane gas. Pipelines are put into the landfills and the methane gas can be collected. It is then used in power plants to make electricity.



In hybrid system diesel energy is only work as a backup source. When the demand on its peak, the available sources are insufficient for that then the diesel back is required. There is a controller, which maintains the energy balance during the load variation. It assigns the priority among the energy sources. It also maintains the synchronizing the voltage signal coming from the different sources. Suppose the instantaneous magnitude of voltage signal coming from PV sources is differ from that of coming from other source say biomass. Hence it causes the local circulating power flow.

5.2.5 Hybrid PV diesel system

A photovoltaic diesel hybrid system ordinarily consists of a PV system, diesel gensets and intelligent management to ensure that the amount of solar energy fed into the system exactly matches the demand at that time. Basically the PV system complements the diesel gensets. It can supply additional energy when loads are high or relieve the genset to minimize its fuel consumption.



In the future, excess energy could optionally be stored in batteries, making it possible for the hybrid system to use more solar power even at night. Intelligent management of various system components ensures optimal fuel economy and minimizes CO_2 emissions.

5.2.6 Advantages of a photovoltaic diesel hybrid system

In contrast to power supply systems using diesel gensets, and despite their higher initial cost, PV systems can be amortized in as little as four to five years, depending on the site and system size, and they have low operating costs. In addition, PV systems are flexible and can be expanded on a modular basis as the energy demand grows. Compared to pure gensets systems, a photovoltaic diesel hybrid system provides numerous advantages:

- Lower fuel costs
- Reduced risk of fuel price increases and supply shortages
- Minimal CO_2 .

5.2.7 Components of photovoltaic diesel hybrid system

PV inverters

PV inverters are the central components of the fuel Save Solution. Designed specifically to be used in weak utility grids, they are suitable for high voltage and frequency fluctuations. They also remain extremely productive in harsh ambient conditions such as heat, moisture, salty air, among others. A centralized PV system contains only one string into a central point where direct current is converted to alternating current. In a decentralized PV system, the PV power is divided into many strings, which are converted into alternating current by several inverters.

PV array

The solar power is generated in the PV modules, which can be mounted on the ground or on a roof, depending on local conditions. Inverters are compatible with all PV module types and technologies currently available on the market.

Fuel save Controller

The fuel save controller provides the perfect interface between the gensets, PV systems and loads, managing demand-based PV feed-in into the diesel-powered grid. As the central component of the fuel save solution, it ensures maximum security with reduced fuel costs and minimizes CO_2 emissions.

Diesel Genset

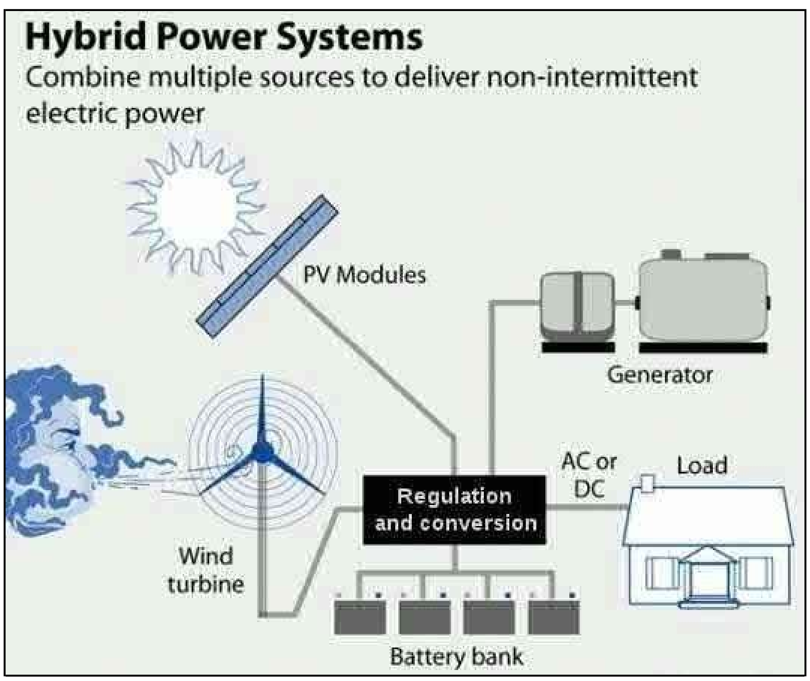
In grid-remote regions, pure diesel systems often provide the energy for industrial applications. They constitute the local grid, ensuring a constant power supply to all connected users. Because the gensets require a constant fuel supply, they are often the system‘s highest operating cost. In regions with weak utility grids, diesel gensets often serve as a backup during grid power outages.

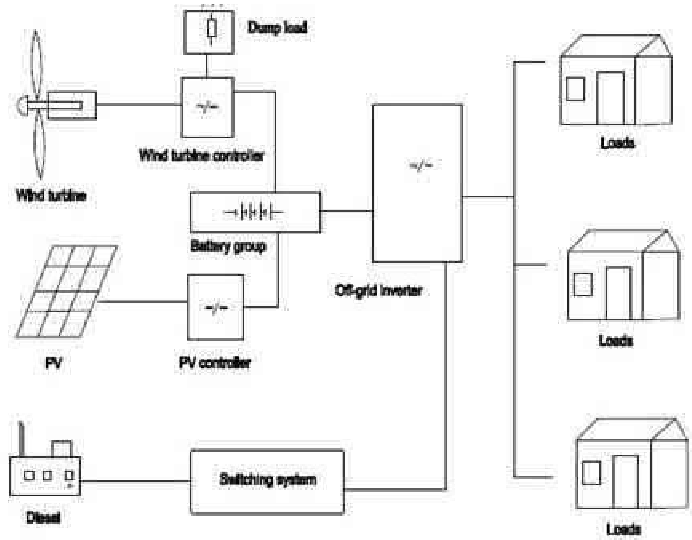
Optional storage batteries

To boost the efficiency of the entire energy supply system, it is advisable to include a storage battery. When solar irradiation is insufficient or energy is needed after dark, the storage battery supplies the required energy, ensuring optimal hybrid system operation.

5.3 PV/SOLAR THERMAL/GRID-CONNECTED HYBRID SYSTEM

The hybrid system that combines wind, solar, and diesel power generation system has become popular because of its advantages over either single system. The main advantages of hybrid systems are fuel saving lower atmospheric contamination, savings in maintenance, silent systems, and connection to other power supplies which enable higher service quality than traditional single-source generation systems. The main components of hybrid systems are: the power sources, the storage devices, the power management center, and monitor and control devices. There are two main advantages of the system compared to others. First, the energy of the proposed system is used wisely and efficiently by monitoring the load power and the available renewable energy to define the quantity of needed power and to select the best available source. Secondly, additional batteries are used as a dumped load in the system, which can be used if there is a shortage in the renewable energy source to minimize the usage of the diesel engine. In addition, a wireless monitoring system will be used to help in self-troubleshooting and a fast alarm system, which will minimize maintenance efforts.





Hybrid Solar Wind Diesel Power Generation system has different schematics that each has its own advantages and implementation. In the scheme illustrated in Figure, the battery is charged directly from the photovoltaic (PV) module and the wind turbine where each has its own charge controller. The load receives its required power from all energy sources via an inverted to convert the DC to AC. The battery is charged in similar way to the first scheme but the only difference is that the load receives its required power via the battery not others. Also, there is no dump load in this case.

The charge controller receives the power from the energy sources (PV module and the wind turbine) and delivers the power to the battery if it is not fully charged, to the dump load if the battery is fully charged. If the battery is not fully charged and the output power from the renewable energy sources is not satisfactory, the diesel engine is turned on to supply the load with the needed power until the battery is fully charged again. The sensors are used for controlling the power flow among the system devices and elements, and troubleshooting purposes. For wind turbine, if the wind sensor reading does not match the proper amount of energy produced by wind turbine, the controller will send a command to the generator housed in the wind turbine to shut off. For the PV module, if the light intensity sensor reading does not match the amount of power produced by the PV module, the controller will send a command to the disconnect the PV module from the charge controller. The system will take the power input from both the wind turbine and solar panel and send them to the charge controller. The charge controller will direct the power to the battery or the dump load battery based on battery voltage input.

When the battery voltage sensor inputs data that the battery is full, the charge controller will switch to dump load. However, when the battery is undercharged, the diesel engine will be switched on to supply the load with the power needed until the battery is charged again.

Moreover, the other sensors will be used for the troubleshooting purpose. For example, the system will be able to identify problem in the wind turbine or the solar panel. Such as when the wind speed and the light intensity sensors reading do not match with the input power given to the system that is read by the voltage and current sensors. Furthermore, the fuel level sensor will sense the diesel engine is running out of fuel.

5.3.1 Case studies of Wind-PV system

Many remote communities around the world cannot be physically or economically connected to an electric power grid. The electricity demand in these areas is conventionally supplied by small isolated diesel generators. The operating costs associated with these diesel generators may be unacceptably high due to discounted fossil fuel costs together with difficulties in fuel delivery and maintenance of generators. In such situations, renewable energy sources, such as solar photovoltaic (PV) and wind turbine generator provide a realistic alternative to supplement engine-driven generators for electricity generation in off-grid areas. It has been demonstrated that hybrid energy systems can significantly reduce the total life cycle cost of standalone power supplies in many off-grid situations, while at the same time providing a reliable supply of electricity using a combination of energy sources. Numerous hybrid systems have been installed across the world, and the expanding renewable energy industry has now developed reliable and cost competitive systems using a variety of technologies. In a report, India‘s gross renewable energy potential (up to 2032) is estimated at 220 GW.

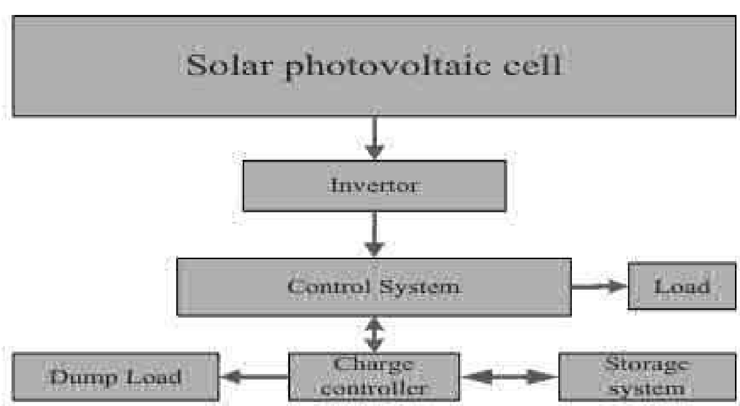
It is likewise noted in the report that, with a renewable energy capacity of 14.8 GW (i.e. 9.7% of the total installed generation capacities of 150 GW as on 30 June 2009), India has barely scratched the surface of a huge opportunity. However, in the last couple of years itself, the share of renewable energy in installed capacity has grown from 5 to 9.7%. This implies an enormous potential in energy generation, which can achieve several hundred GW with current renewable energy technologies. As the cost of building solar PV–wind capacity continues to fall over the next five to ten years; a significant scale-up of renewable generation is a very realistic possibility in the developing world. Thousands of villages across the globe are still being exiled from electricity and energizing these villages by extended grids or by diesel generators alone will be uneconomical. Moreover, with the current resource crunch with government, these villages receive low priority for grid extension because of lower economic return potential. Standalone solar PV–wind hybrid energy systems can provide economically viable and reliable electricity to such local needs.

Many countries with an average wind speed in the range of 5–10 m/s and average solar insolation level in the range of 3–6 KWh/m2 are pursuing the option of wind and PV system to minimize their dependence on fossil-based non-renewable fuels. Autonomous wind systems do not produce usable energy for a considerable portion of time during the year. This is primarily due to relatively high cut-in wind speeds which ranges from 3.5 to 4.5 m/s. In decree to overcome this downtime, the utilization of solar PV and wind hybrid system is advised. Such systems are usually equipped with diesel generators to meet the peak load during the short periods when there is a deficit of available energy to cover the load demand. Diesel generator sets, while being relatively inexpensive to purchase, are generally expensive to operate and maintain, especially at low load levels. In general, the variation of solar and wind energy does not match the time distribution of the demand.

5.4 DESCRIPTION OF HYBRID RENEWABLE ENERGY SCHEMES

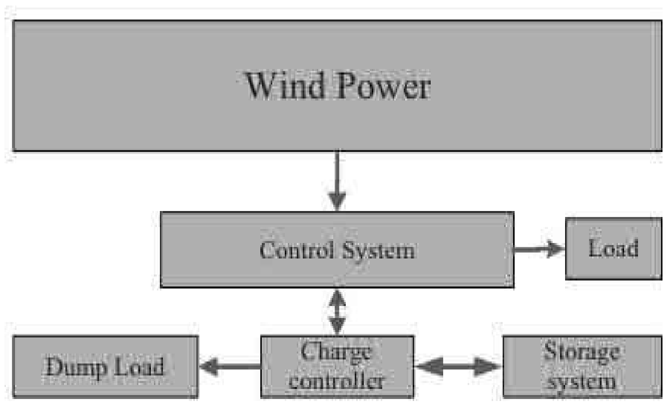
A hybrid renewable PV–wind energy system is a combination of solar PV, wind turbine, inverter, battery, and other addition components. A number of models are available for PV–wind combination as a PV hybrid system, wind hybrid system, and PV–wind hybrid system, which are employed to satisfy the load demand. Once the power resources (solar and wind flow energy) are sufficient excess generated power is fed to the battery until it is fully charged. Thus, the battery comes into play when the renewable energy sources (PV–wind) power is not able to satisfy the load demand until the storage is depleted. The operation of hybrid PV–wind system depends on the individual element. In order to evaluate the maximum output from each component, first the single component is modeled, thereafter which their combination can be evaluated to meet the require dependability. If the electric power production, though this type of individual element, is satisfactory the actual hybrid system will offer electrical power at the very least charge.

5.4.1 Hybrid photovoltaic system



Solar energy is one of the site-dependent, non-polluting energy sources, and is available in great quantity. It is a potential source of alternative/renewable energy and utilization of solar radiation for power generation reduces the dependence on fossil fuel. Solar PV power generation unit consists of PV generator, diesel generator, and inverter and battery system. For improved performance and better control, the role of battery storage is very important. The necessary condition for the design of the hybrid PV systems for maximum output power is hot climate. This type of system is cost effective and reliable, especially for those locations where the power supplies though the grid is not suitable and the cost of the transmission line is very high such as remote and isolated areas. Designed a system for computing production cost associated with hybrid PV battery method in which the size associated with PV method is calculated on such basis as electrical requirements not attained. For standalone hybrid PV system, analysis of reliability is determined in the term of loss of load (LOL) probability.

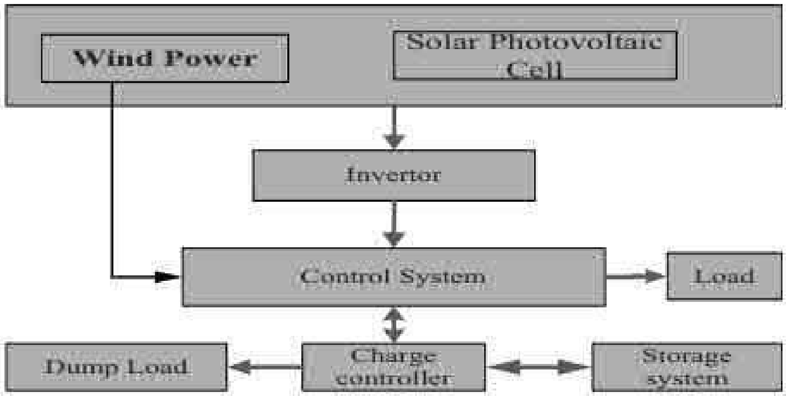
5.4.2 Hybrid wind energy system



For the design of a reliable and economical hybrid wind system a location with a better wind energy potential must be chosen. Optimal sizing of a hybrid wind system and forecasting of a hybrid system based on several optimization techniques are obtained based on the application. A methodology is obtained for identifying the wind turbine generator parameters as capacity factor which relates to identically rated available wind turbine and capacity factor calculated on the basis of wind speed data at different hours of the day of many years. Hybrid wind system performance, reliability, and reduction in the cost of energy (COE) can be obtained by using a battery backup system. When the hybrid system generated power is in surplus, this power is used for loading the batteries for backup security and this charge battery power is used when the load requirement is not supplied by design hybrid system. Figure shows the architecture of wind hybrid energy system.

5.4.3 Hybrid photovoltaic/wind energy system

PV and wind system, both depending on weather condition, individual hybrid PV and hybrid wind system does not produce usable energy throughout the year. For better performance of the standalone individual PV combination or wind combination need battery backup unit and diesel generator set results to increase the hybrid system cost.



The main objective of the design is to obtain a cost-effective solution. Different artificial techniques are available for the optimal size of the hybrid system to minimize total annual cost. A couple of renewable energy sources—PV panels and wind turbines—are viewed as, together with traditional diesel generators in order to optimally design ability as well as functioning, preparing of the hybrid system. An optimization is used to match hourly supply and demand problem had been resolved to have sparse matrices and also the linear programming algorithm.

5.5 POWER ELECTRONICS TOPOLOGIES AND CONTROL FOR HYBRID SOLAR PV-WIND SYSTEMS

5.5.1 Power electronics topologies and control for Grid-connected system

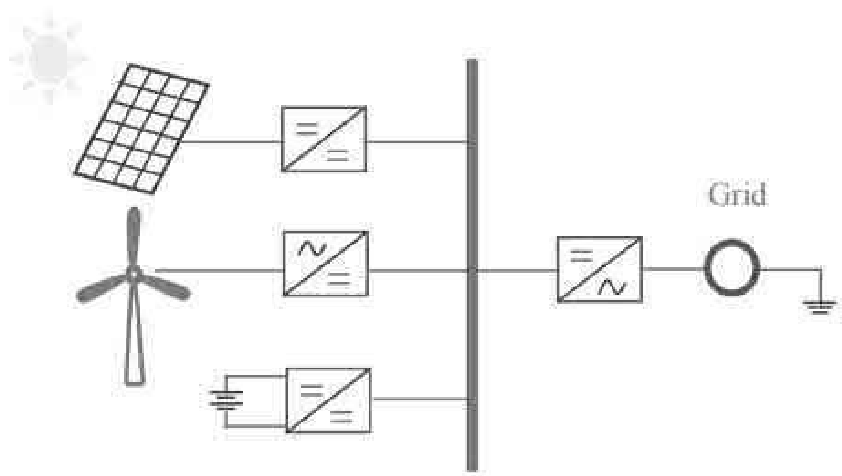


Figure 1: Grid-connected hybrid system at common DC bus

There are two topologies for grid-connected solar PV and wind hybrid system as can be seen from Figure 1 and 2. Figure 1 shows that the DC outputs‘ voltages from individual solar PV, wind and battery bank stream, through individual DC/DC and AC/DC units, are integrated on the DC side and go through one common DC/AC inverter which acts as an interface between the power sources and the grid to provide the desired power even with only one source available. Hence, the renewable energy sources act as current sources and can exchange power with the grid and the common DC/AC inverter controls the DC bus voltage. The individual units can be employed for maximum power point tracking (MPPT) systems to have the maximum power from the solar PV and wind systems and the common DC/AC inverter will control the DC bus voltage. The battery bank is charged when there is an extra power and discharged (by supplying power) when there is shortage of power from the renewable energy sources.

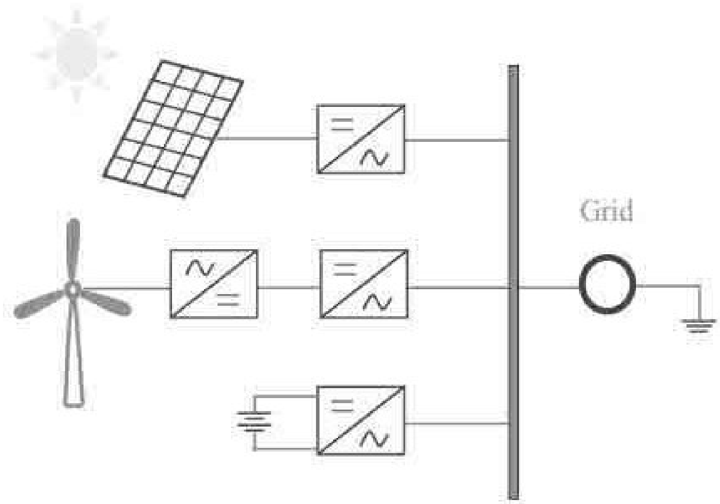


Figure 2: Grid-connected hybrid system at common AC bus

On the other hand, Figure 2 shows that renewable energy sources are injecting power directly to the grid through individual DC/AC and AC/DC-DC/AC units. Many modules have proposed and presented experimental results of PV-wind-battery hybrid systems along with power management schemes and control systems. Such systems were capable to operate in different modes of operation and able to transfer from one mode to another easily. The voltage converters play an important role in controlling the amount and the type of voltage whether AC or DC and the duty cycle of those converters can be used to improve the quality of power. The response of the duty cycle of a DC/DC converter is relatively fast in MPPT control process. Numerous intelligent techniques are used for grid-connected hybrid PV/FC/battery power system to control flow of power via DC/DC and DC/AC converters.

5.5.2 Power electronics topologies and control for standalone system

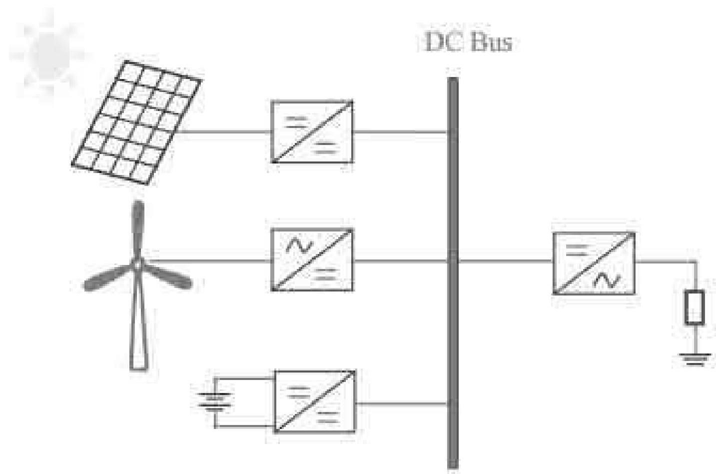


Figure 1: Stand-alone hybrid system at common DC bus

Figure 1 shows a stand-alone solar PV and wind hybrid system with DC common bus. One of its main advantages is to include DC interface bus for coupling different generation sources, which do not have to operate at a constant frequency and in synchronism. The DC bus line output voltage from all streams is set to be fixed and the output current from each source is controlled independently. The DC outputs‘ voltages from individual solar PV, wind and battery bank stream, through individual DC/DC and AC/DC units, are integrated on the DC side, combined in parallel and go through one common DC/AC inverter which acts as an interface between the power sources and the loads to provide the required power to the load by regulating the AC output voltage. The battery bank is interfaced by a DC/DC converter which regulates the DC-link bus voltage by charging (in case of extra power) or discharging the battery (in case of shortage of power). The renewable energy sources act as current sources and supply directly the loads. The interface common unit regulates the magnitude of the load‘s voltage. The individual AC/DC and DC/DC units can be employed for MPPT systems to have the maximum power from the solar PV and wind systems and the common DC/AC inverter will control magnitude of the load‘s voltage. The battery bank acts as a voltage source to control the common DC bus voltage by charging or discharging. In the conventional way for controlling the complete hybrid system, power electronics converters are used for maximum energy extract from solar and wind energy resources. In addition, advanced controlling techniques can remove the power fluctuations caused by the variability of the renewable energy sources.

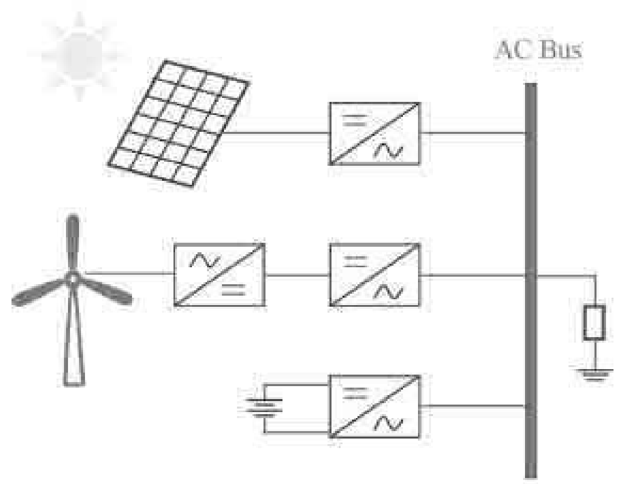


Figure 2: Stand-alone hybrid system at common AC bus

Figure 2 shows stand-alone solar PV and wind hybrid system with AC common bus. The form of pure AC bus bar system is widely used worldwide with lot of advantages, such as simple operation, plug and play scenario, low cost and easy extension according to the load's requirement. On the other hand, controlling AC voltage and frequency and energy management are some of the challenges for this type of topology. In this topology, the AC outputs' voltages from individual solar PV, wind and battery bank stream, through individual DC/AC and AC/DC-DC/AC units, are feeding the loads directly. The renewable energy sources can act as current sources provided that the battery bank exists as a voltage source to control the common AC bus voltage by charging or discharging. Hence, the individual units can be employed for MPPT systems to have the maximum power from the solar PV and wind systems provided that the battery bank exists as a voltage source to control the common AC bus voltage by charging or discharging. The battery bank is charged when there is an extra power and discharged and can supply power in case of shortage of power from the renewable energy sources. Droop control is normally applied to generators for frequency control and sometimes voltage control in order to have load sharing of parallel generators. It can also be used to perform proper current sharing in a micro-grid. With droop control, decentralized control for each interfacing converter is achieved. At the same time, no communication or only low bandwidth co mmunication, such as power line communication, can be used in AC systems. Power flow was controlled using frequency and voltage drooping technique in order to ensure seamless transfer between grid connected and stand-alone parallel modes of operation.

5.6 MAXIMUM POWER POINT TRACKING (MPPT)

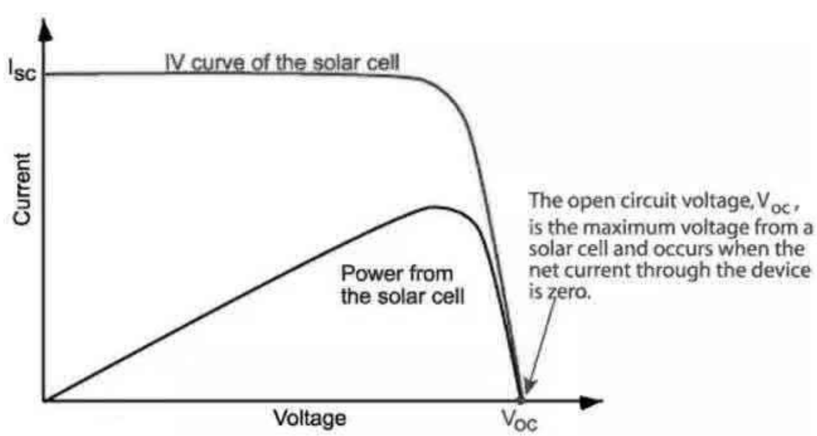
5.6.1 Maximum Power Point Tracking

MPPT is a technique used commonly with wind turbines and photovoltaic (PV) solar systems to maximize power extraction under all conditions. Although solar power is mainly covered, the principle applies generally to sources with variable power: for example, optical power transmission and thermo-photovoltaic. PV solar systems exist in many different configurations with regard to their relationship to inverter systems, external grids, battery banks, or other electrical loads. Regardless of the ultimate destination of the solar power, though, the central problem addressed by MPPT is that the efficiency of power transfer from the solar cell depends on both the amount of sunlight falling on the solar panels and the electrical characteristics of the load. As the amount of sunlight varies, the load characteristic that gives the highest power transfer efficiency changes, so that the efficiency of the system is optimized when the load characteristic changes to keep the power transfer at highest efficiency. This load characteristic is called the **maximum power point** and **MPPT** is the process of finding this point and keeping the load characteristic there. Electrical circuits can be designed to present arbitrary loads to the photovoltaic cells and then convert the voltage, current, or frequency to suit other devices or systems, and MPPT solves the problem of choosing the best load to be presented to the cells in order to get the most usable power out.

5.6.2 Working of MPPT

Maximum Power Point Tracking (MPPT) is a technology approach used in solar PV inverters to optimize power output in less-than-ideal sunlight conditions. Most modern inverters are equipped with at least one MPPT input.

An MPPT tracker is analogous to a thumb placed over a garden hose. If you put your thumb over part of the opening of the hose (adding resistance to the circuit), the pressure (voltage) goes up and the stream flies faster, but less water (current) is getting through. If you completely cover the opening, nothing gets through. If you remove your thumb entirely, the maximum flow rate gets through, but the stream falls limply at your feet.



That is the basic mechanism of the MPPT tracker which varies resistance in the circuit to modify current and voltage. Now imagine that there are hundreds of pumps (solar panels) upstream of the hose and they are delivering water (energy) to you. Further complicating things, some of these pumps go offline at certain parts of the day (partial shading of the array). So the force behind the delivery of water will be constantly varying.

5.7 MAXIMUM POWER POINT TRACKING ALGORITHMS

MPPT algorithms are necessary in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array. Over the past decades many methods to find the MPP have been developed and published. These techniques differ in many aspects such as required sensors, complexity, cost, range of effectiveness, convergence speed, correct tracking when irradiation and/or temperature change, hardware needed for the implementation or popularity, among others. The different MPPT algorithms are discussed below.

5.7.1 Hill-climbing techniques

Algorithms are based on the ―hill-climbing‖ principle, which consists of moving the operation point of the PV array in the direction in which power increases. Hill-climbing techniques are the most popular MPPT methods due to their ease of implementation and good performance when the irradiation is constant. The advantages of these methods are the simplicity and low computational power they need.

5.7.2 Perturb and observe

The Perturb and observe (P&O) algorithm is also called ―hill-climbing‖, but both names refer to the same algorithm depending on how it is implemented. Hill-climbing involves a perturbation on the duty cycle of the power converter and P&O a perturbation in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, perturbing the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, so both names refer to the same technique. In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide the next perturbation.

5.7.3 Incremental conductance

The incremental conductance algorithm is based on the fact that the slope of the curve power vs. voltage (current) of the PV module is zero at the MPP, positive (negative) on the left of it and negative (positive) on the right. It can be written as

$$\frac{\Delta V}{\Delta P} = 0 \left(\frac{\Delta I}{\Delta P} = 0\right) at\ the\ MPP$$
$$\frac{\Delta V}{\Delta P} > 0 \left(\frac{\Delta I}{\Delta P} < 0\right) on\ the\ left$$
$$\frac{\Delta V}{\Delta P} < 0 \left(\frac{\Delta I}{\Delta P} > 0\right) on\ the\ right$$

By comparing the increment of the power versus the increment of the voltage (current) between two consecutives samples, the change in the MPP voltage can be determined.

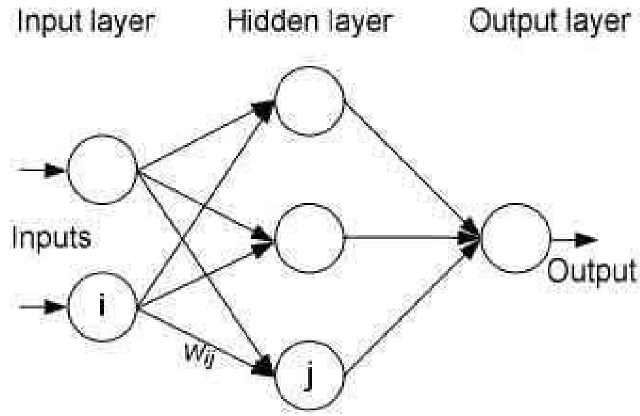
5.7.4 Fuzzy logic control

The use of fuzzy logic control has become popular over the last decade because it can deal with imprecise inputs, does not need an accurate mathematical model and can handle nonlinearity. The fuzzy logic consists of three stages: fuzzification, inference system and defuzzification. Fuzzification comprises the process of transforming numerical crisp inputs into linguistic variables based on the degree of membership to certain sets. The number of membership functions used depends on the accuracy of the controller, but it usually varies between 5 and 7. In some cases the membership functions are chosen less symmetric or even optimized for the application for better accuracy

The rule base, also known as rule base lookup table or fuzzy rule algorithm, associates the fuzzy output to the fuzzy inputs based on the power converter used and on the knowledge of the user. The last stage of the fuzzy logic control is the defuzzification. In this stage the output is converted from a linguistic variable to a numerical crisp one again using membership functions. There are different methods to transform the linguistic variables into crisp values.. The advantages of these controllers, besides dealing with imprecise inputs, not needing an accurate mathematical model and handling nonlinearity, are fast convergence and minimal oscillations around the MPP.

5.7.5 Neural networks

Another MPPT method well adapted to microcontrollers is Neural Networks [8]. They came along with Fuzzy Logic and both are part of the so called ―Soft Computing‖. The simplest example of a Neural Network (NN) has three layers called the input layer, hidden layer and output layer, as shown in Figure. More complicated NN‘s are built adding more hidden layers. The number of layers and the number of nodes in each layer as well as the function used in each layer vary and depend on the user knowledge. The input variables can be parameters of the PV array such as V_{OC} and I_{SC}, atmospheric data as irradiation and temperature or a combination of these. The output is usually one or more reference signals like the duty cycle or the DC-link reference voltage



To execute this training process, data of the patterns between inputs and outputs of the neural network are recorded over a lengthy period of time, so that the MPP can be tracked accurately. The main disadvantage of this MPPT technique is the fact that the data needed for the training process has to be specifically acquired for every PV array and location, as the characteristics of the PV array vary depending on the model and the atmospheric conditions depend on the location.

5.7.6 Fractional open circuit voltage

This method uses the approximately linear relationship between the MPP voltage (V_{MPP}) and the open circuit voltage (V_{OC}), which varies with the irradiance and temperature.

$$V_{MPP} \approx K_1 V_{OC}$$

Where k_1 is a constant depending on the characteristics of the PV array and it has to be determined beforehand by determining the V_{MPP} and V_{OC} for different levels of irradiation and different temperatures. Once the constant of proportionality, k_1, is known, the MPP voltage V_{MPP} can be determined periodically by measuring V_{OC}. To measure V_{OC} the power converter has to be shut down momentarily so in each measurement a loss of power occurs. Another problem of this method is that it is incapable of tracking the MPP under irradiation slopes, because the determination of V_{MPP} is not continuous. One more disadvantage is that the MPP reached is not the real one because the relationship is only an approximation.

5.7.7 Fractional short circuit current

Just like in the fractional open circuit voltage method, there is a relationship, under varying atmospheric conditions, between the short circuit current I_{SC} and the MPP current, I_{MPP}, as is shown by

$$I_{MPP} \approx K_2 I_{SC}$$

The coefficient of proportionality k_2 has to be determined according to each PV array, as in the previous method happened with k_1. Measuring the short circuit current while the system is operating is a problem. It usually requires adding an additional switch to the power converter to periodically short the PV array and measure I_{SC}.

5.7.8 Current sweep

In this method the V-I characteristic curve is obtained using a sweep waveform for the PV array current. The sweep is repeated at fixed time intervals so the V-I curve is updated periodically and the MPP voltage (V_{MPP}) can be determined from it at these same intervals. On the other hand, the sweep takes certain time during which the operating point is not the MPP, which implies some loss of available power. Strictly speaking, it is not possible to track the MPP under irradiation slopes, because the MPP varies continuously. Only if the sweep is instantaneous the global MPP could be found, but that is impossible. Furthermore, the implementation complexity is high, the convergence speed is slow and both voltage and current measurements are required.

5.8. PARTICLE SWARM OPTIMIZATION BASED MPPT ALGORITHM FOR PV SYSTEM

This algorithm is used to reduce the steady state oscillation to practically zero once the maximum power point is located. Furthermore, it has ability to track the MPP for the extreme environmental conditions like large fluctuations of insolation and partial shading condition. The MPP tracker based on Particle Swarm Optimization for photovoltaic module arrays is capable of tracking global MPPs of multi-peak characteristic curves where the fixed values were adopted for weighing within the algorithm, the tracking performance lacked robustness, causing low success rates when tracking the global MPPs. Though the MPPs were tracked successfully, the dynamic response speed is low. The PSO based MPPT controller algorithm for various environmental conditions like fully shaded conditions and partially shaded conditions to find new global MPP with re-initialization of particles can be observed. The PSO has simple structure, easy implementation, and fast computation capability. It is able to locate the MPP for any type of P-V curve regardless of environmental variations and also to track the PV system as the search space of the PSO reduced and the time required for the convergence can be greatly reduced. The PSO based MPPT can be used to predict the I-V and P-V characteristics curves during partial shading condition also to evolve and ratify the photovoltaic system design encompassing the power converter and MPPT controller.

5.9 MAXIMUM POWER POINT TRACKING IN HYBRID PHOTO-VOLTAIC AND WIND ENERGY CONVERSION SYSTEM

5.9.1 Introduction

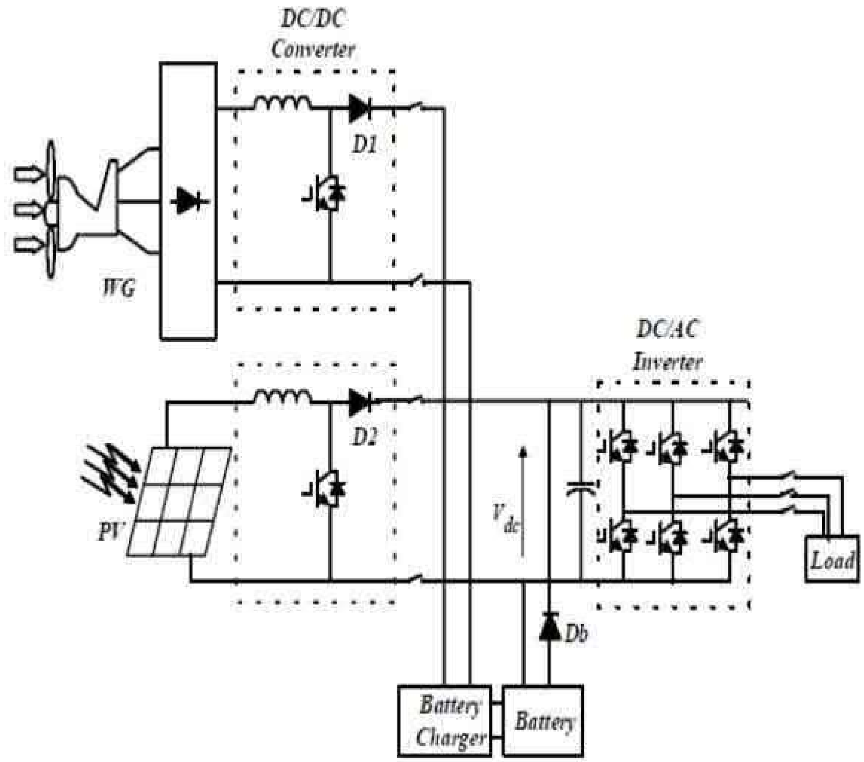
With exhausting of traditional energy resources and increasing concern of environment, renewable and clean energy is attracting more attention all over the world to overcome the increasing power demand. Out of all the renewable energy sources, Wind energy and solar energy are reliable energy sources. However, the renewable energy generation has a drawback that the change of the output characteristic becomes intense because the output greatly depends on climatic conditions, including solar irradiance, wind speed, temperature, and so forth. In this paper, combining the photovoltaic generation with wind power generation, the instability of an output characteristic each other was compensated. Photovoltaic generation and wind generation use Maximum Power Point Tracker (MPPT).

The Wind-solar complementary power supply system is a reasonable power supply which makes good use of wind and solar energy. This kind of power supply system can not only provide a bargain of low cost and high dependability for some inconvenient regions. In addition, the Wind/Solar complementary generation is more economical than a single PV or wind power generation in terms of both the cost and the protection of energy storage components. In stand-alone systems, sizing is extremely important since an adequate design lead to an efficient operation of the components with a minimum investment.

5.9.2 Modeling of Photo-Voltaic Hybrid Energy Conversion System

The construction of PV cell is very similar to that of the classical diode with a p-n junction formed by semiconductor material. When the junction absorbs light, the energy of absorbed photon is transferred to the electron-proton system of the material, creating charge carriers that are separated at the junction. The charge carriers in the junction region create a potential gradient, get accelerated under the electric field, and circulate as current through an external circuit. The solar cell is the basic building of the PV power system it produces about 1 W of power.

To obtain high power, numerous such cell are connected in series and parallel circuits on a panel (module), The solar array or panel is a group of a several modules electrically connected in series-parallel combination to generate the required current and voltage. The PV array must operate electrically at a certain voltage which corresponds to the maximum power point under the given operating conditions, i.e. temperature and irradiance. To do this, a maximum power point tracking (MPPT) technique should be applied. If the array is operating at voltage V and current I the operation point toward the maximum power point by periodically increasing or decreasing the array voltage, is often used in many PV systems. The configuration of hybrid wind and PV system is shown in Figure. This configuration is fit for stand-alone hybrid power system used in remote area. Wind and solar energy are converted into electricity and then sent to loads or stored in battery bank. The topology of hybrid energy system consisting of variable speed wind turbine coupled to a permanent magnet generator (PMG) and PV array. The two energy sources are connected in parallel to a common dc bus line through their individual dc-dc converters. The load may be dc connected to the dc bus line or may include a PWM voltage source inverter to convert the dc power into ac at 50 or 60 Hz. Each source has its individual control.



The output of the hybrid generating system goes to the dc bus line to feed the isolating dc load or to the inverter, which converts the dc into ac. A battery charger is used to keep the battery fully charged at a constant dc bus line voltage. When the output of the system is not available, the battery powers the dc load or discharged to the inverter to power ac loads, through a discharge diode. A battery discharge diode is to prevent the battery from being charged when the charger is opened after a full charge.
