MODELING AND SIMULATION OF HYBRID WIND/PHOTOVOLTAIC STAND-ALONE GENERATION SYSTEM

A THESIS SUBMITTED IN PARTIAL FULFILLMENT OF THE REQUIREMENTS FOR THE AWARD OF THE DEGREE OF

Master of Technology
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By

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CERTIFICATE

This is to certify that the project entitled "**MODELING AND SIMULATION OF HYBRID WIND/PHOTOVOLTAIC STAND-ALONE GENERATION SYSTEM**" submitted by **Mr. Sandeep Kumar** (212EE5261) in partial fulfillment of the requirements for the award of Master of Technology degree in Industrial Electronics, Department of Electrical Engineering at National Institute of Technology, Rourkela is an authentic work carried out by him under my supervision and guidance.

To the best of my knowledge the matter embodied in this thesis has not been submitted to any other university/Institute for the award of any Degree.

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ABSTRACT

Renewable energy sources have become a popular alternative electrical energy source where power generation in conventional ways is not practical. In the last few years the photovoltaic and wind power generation have been increased significantly. In this study, we proposed a hybrid energy system which combines both solar panel and wind turbine generator as an alternative for conventional source of electrical energy like thermal and hydro power generation. A simple control technique which is also cost effective has been proposed to track the operating point at which maximum power can be coerced from the PV system and wind turbine generator system under continuously changing environmental conditions. The entire hybrid system is described given along with comprehensive simulation results that discover the feasibility of the system. A software simulation model is developed in Matlab/Simulink.

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List of abbreviations

PV	Photo Voltaic
MPPT	Maximum Power Point Tracking
DC	Direct Current
MATLAB	MATrix LABoratory
P&O	Perturb and Observe
IC	Incremental Conductance
Fig	Figure
PMSG	Permanent magnet synchronous generator
MPP	Maximum power point

List of symbols

I_{PV}	Photocurrent current
I_O	Reverse saturation current of diode
V	Voltage across the diode
a	Ideality factor
V_T	Thermal voltage
R_s	Series resistance
R_p	Shunt resistor of the cell
K_I	Cell's short circuit current temperature coefficient
G	Solar irradiation in W/m^2

G_{STC}	Nominal solar irradiation in W/m^2
I_{PV_STC}	Light generated current under standard test condition
I_{0_STC}	Nominal saturation current
E_g	Energy band gap of semiconductor
T_{STC}	Temperature at standard test condition
q	Charge of electrons
I_{SC_STC}	Short circuit current at standard test conditions
V_{OC_STC}	Short circuit voltage at standard test conditions
K_V	Temperature coefficient of open circuit voltage
N_S	Number of series cells
N_P	Number of parallel cells
$\mathrm{P_M}$	Power captured by wind turbine
ρ	Air density
β	Pitch angle (in degrees)
R	Blade radius (in meters)
V	Wind speed (in m/s)
p	The number of pole pair in the generator
V_{ph}	Generator output
f	Frequency of rotor
ϕ	Flux
t	Number of turns
V_0	Output of buck-boost converter
V_W	Input of buck-boost converter
P	Wind power
Ω	Rotor speed

Ω_e	Generator- phase voltage angular speed.
V_W	Rectifier output voltage
D	Duty cycle of converter
C_P	Wind turbine power coefficient
λ	Tip- speed ratio
λ_1	Constant
Ω	Rotor speed of rotation (in rad/sec)

CHAPTER-1

INTRODUCTION TO HYBRID SYSTEM

1.1 INTRODUCTION

Due to the critical condition of industrial fuels which include oil, gas and others, the development of renewable energy sources is continuously improving. This is the reason why renewable energy sources have become more important these days. Few other reasons include advantages like abundant availability in nature, eco-friendly and recyclable. Many renewable energy sources like solar, wind, hydel and tidal are there. Among these renewable sources solar and wind energy are the world's fastest growing energy resources. With no emission of pollutants, energy conversion is done through wind and PV cells.

Day by day, the demand for electricity is rapidly increasing. But the available base load plants are not able to supply electricity as per demand. So these energy sources can be used to bridge the gap between supply and demand during peak loads. This kind of small scale stand-alone power generating systems can also be used in remote areas where conventional power generation is impractical.

In this thesis, a wind-photovoltaic hybrid power generation system model is studied and simulated. A hybrid system is more advantageous as individual power generation system is not completely reliable. When any one of the system is shutdown the other can supply power. A block diagram of entire hybrid system is shown below.

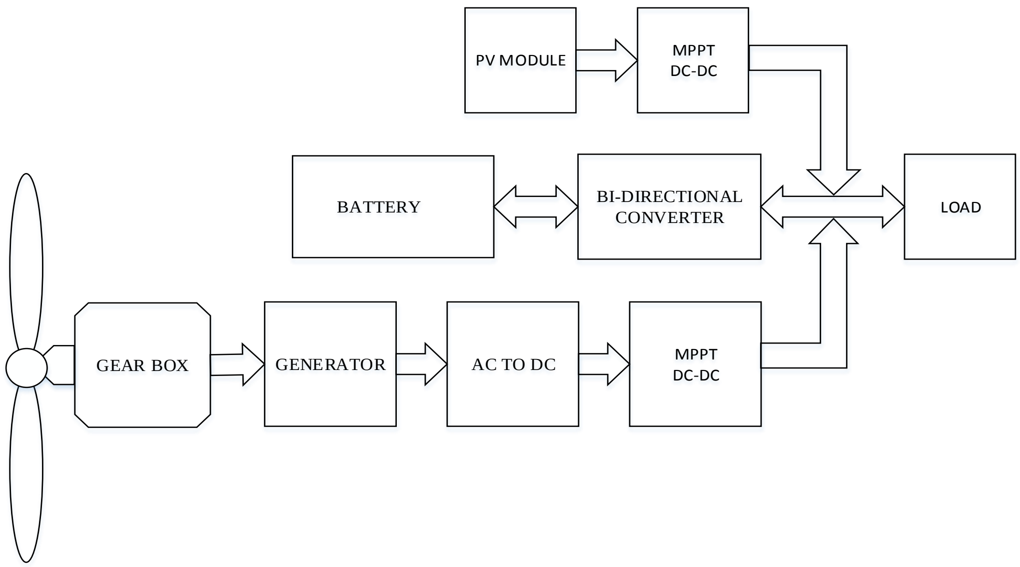

Fig 1.1: Block diagram of hybrid system

The entire hybrid system comprises of PV and the wind systems. The PV system is powered by the solar energy which is abundantly available in nature. PV modules, maximum power point tracing systems make the PV energy system. The light incident on the PV cells is converted into electrical energy by solar energy harvesting means. The maximum power point tracking system with Perturb & absorb algorithm is used, which extracts the maximum possible power from the PV modules. The ac-dc converter is used to converter ac voltage to dc.

Wind turbine, gear box, generator and an AC – DC converter are included in the wind energy system. The wind turbine is used to convert wind energy to rotational mechanical energy and this mechanical energy available at the turbine shaft is converted to electrical energy using a generator. To coerce the maximum power from wind system we used a maximum power point tracing system.

Both the energy systems are used to charge a battery using bi-directional converter. Bidirectional converter and the battery form the common additional load to the wind and PV energy systems.

Hybrid generation systems that use more than a single power source can greatly enhance the certainty of load demands all the time. Even higher generating capacities can be achieved by hybrid system. In stand-alone system we can able to provide fluctuation free output to the load irrespective of weathers condition. To get the energy output of the PV system converted to storage energy, and constant power delivered by the wind turbine, an efficient energy storage mechanism is required, which can be realized by the battery bank.

1.2 LITERATURE REVIEW

Due to high demand of energy and limited availability of conventional energy, non-conventional sources become more popular among researchers. A lot of research work is going on to enhance the power efficiency of non-conventional sources and make it more reliable and beneficial.

Hybrid generation system uses more than one source, so that we can extract energy from different sources at the same time which enhances the efficiency. From [2],[3] the working of PV /Wind hybrid system is understood, different topologies that can be used for the hybridization of more than one system and also about advantages and disadvantages of hybrid system. From [1], [4] and [5] basic details of PV cell, PV module, PV array and their modeling are studied. Also, the behavior of PV modules at varying environmental conditions like solar irradiation and temperature are studied. Behavior of PV module during partial shading condition and also how it’s bad effects can be minimized is explained in [6]-[8]. Different MPPT techniques, their advantages and disadvantages and why MPPT control is required is explained in [9]-[11].The wind energy system, its working and also techniques to extracts the maximum power from the wind energy system is understood from [13]-[17]. From [18]-[20] study about different type of bi-directional converters, their working and how to use them in battery charging and discharging is carried out.

1.3 RESEARCH MOTIVATION

Recently, the availability of power in India has not just increased but also improved, although the demand consistently rose more than the supply. That's why non-conventional sources have become the center of attraction. Among these fast growing non-conventional sources the wind energy system and solar photovoltaic system are very common. Now India has become fifth in installed capacity of both wind and solar power plant. As of 30th September 2013 the installed capacity of wind power in India was 19881MW. But, as the wind is season and region based, it was not so reliable so we go for hybrid system of power generation.

1.4 OBJECTIVES

The main objective of the thesis is to implement a power system that is a hybrid of both Photovoltaic and wind powers. The step by step objectives are

- To study and model PV cell, PV array and PV panels
- To study the characteristic curves and effect of variation of environmental conditions like temperature and irradiation on them
- To study the PV module's behavior under partial shading condition
- To trace the maximum power point of operation the PV panel irrespective of the changes in the environmental conditions
- To study and simulate the wind power system and track its maximum power point
- Implement hybrid system

CHAPTER-2

PHOTOVOLTAIC ENERGY SYSTEM

History

In 1839, a French physicist Edmund Becquerel proposed that few materials have the ability to produce electricity when exposed to sunlight. But Albert Einstein explained the photoelectric effect and the nature of light in 1905. Photoelectric effect state that when photons or sunlight strikes to a metal surface flow of electrons will take place. Later photoelectric effect became the basic principle for the technology of photovoltaic power generation. The first PV module was manufactured by Bell laboratories in 1954.

2.1 PHOTVOLTAIC ARRANGEMENT

A photovoltaic energy system is mainly powered by solar energy. The configuration of PV system is manifested in figure 2.1.

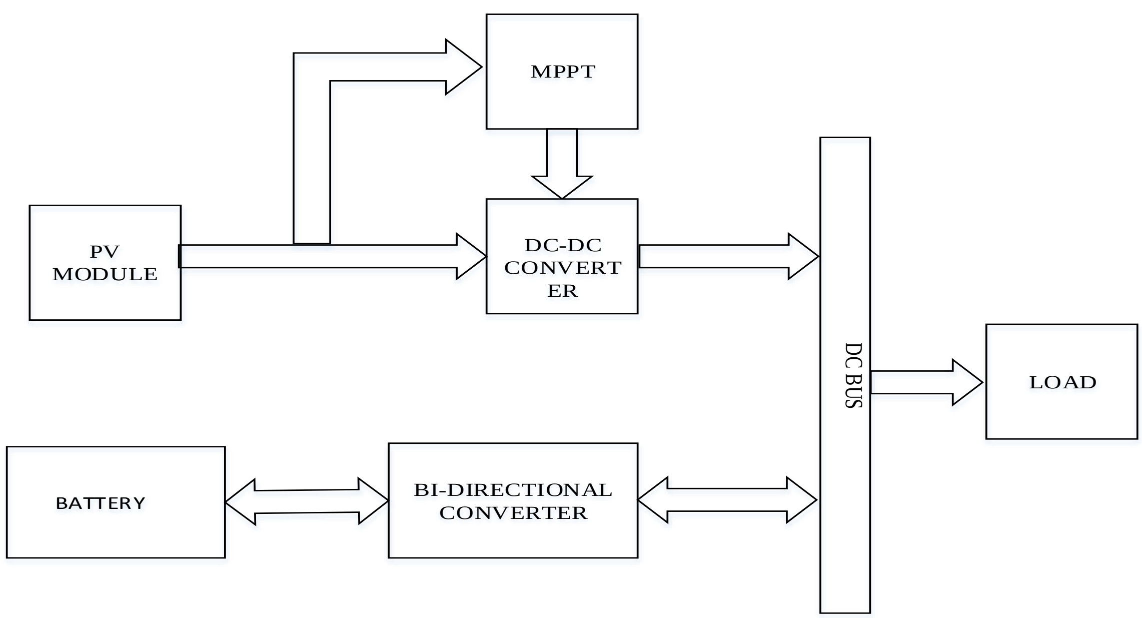

Fig.2.1 Overall block diagram of PV energy system

It contains PV modules or arrays, which convert solar energy in the form of solar irradiation into electric energy. The dc-dc converter changes the level of the voltage to match it with the electrical appliances that are supplied by this system. This DC-DC converter may be either buck or boost or buck-boost contingent on the required and available voltage levels. The maximum power point tracing system coerces the maximum power from the PV modules. A bi-directional converter which is able to supply the current in both the directions is used to charge the battery when there is a power surplus and the energy stored by the battery is discharged into the load when there is a power deficit.

2.1.1 PV CELL

Photovoltaic cell is the building block of the PV system and semiconductor material such as silicon and germanium are the building block of PV cell. Silicon is used for photovoltaic cell due to its advantages over germanium. When photons hit the surface of solar cell, the electrons and holes are generated by breaking the covalent bond inside the atom of semiconductor material and in response electric field is generated by creating positive and negative terminals. When these terminals are connected by a conductor an electric current will start flowing. This electricity is used to power a load.

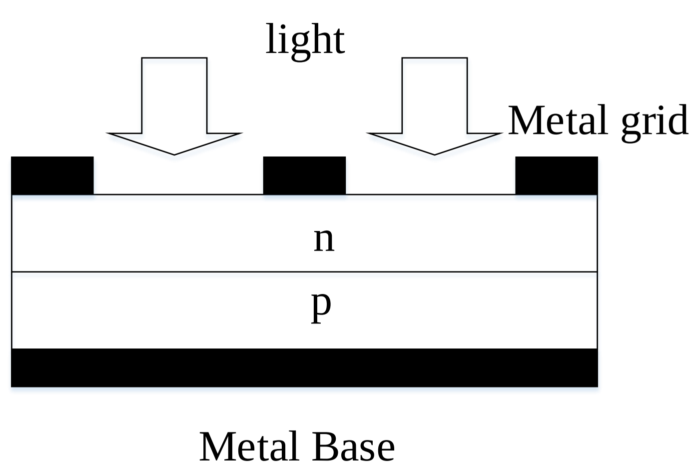

Fig.2.2 Structure of PV cell

2.1.2 PV MODULE

A single cell generate very low voltage (around 0.4), so more than one PV cells can be connected either in serial or in parallel or as a grid (both serial and parallel) to form a PV module as shown in fig.3.2. When we need higher voltage, we connect PV cell in series and if load demand is high current then we connect PV cell in parallel. Usually there are 36 or 76 cells in general PV modules. Module we are using having 54 cells. The front side of the module is transparent usually buildup of low-iron and transparent glass material, and the PV cell is encapsulated. The efficiency of a module is not as good as PV cell, because the glass cover and frame reflects some amount of the incoming radiation.

2.1.3 PV ARRAY

A photovoltaic array is simply an interconnection of several PV modules in serial and/or parallel. The power generated by individual modules may not be sufficient to meet the requirement of trading applications, so the modules are secured in a grid form or as an array to gratify the load demand. In an array, the modules are connected like as that of cells connected in a module. While making a PV array, generally the modules are initially connected in serial manner to obtain the desired voltage, and then strings so obtained are connected in parallel in order to produce more current based on the requirement.

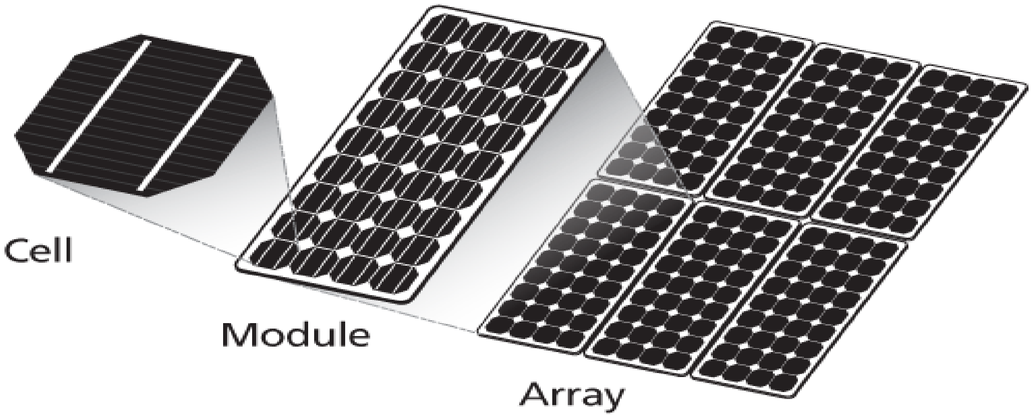

Fig.2.3 Photovoltaic system

2.2 WORKING OF PV CELL

The basic theory involved in working of an individual PV cell is the Photoelectric effect according to which, when a photon particle hits a PV cell, after receiving energy from sunbeam the electrons of the semiconductor get excited and hop to the conduction band from the valence band and become free to move. Movement of electrons create positive and negative terminal and also create potential difference across these two terminals. When an external circuit is connected between these terminals an electric current start flowing through the circuit.

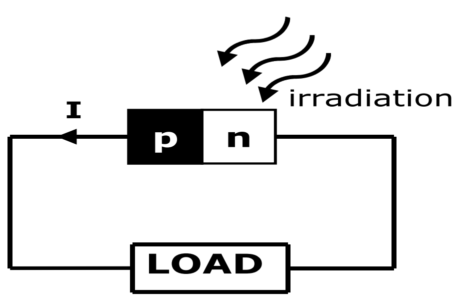

Fig 2.4 Working of PV cell [1]

2.3 MODELING OF PV CELL

The photovoltaic system converts sunlight directly to electricity without having any disastrous effect on our environment. The basic segment of PV array is PV cell, which is just a simple p-n junction device. The fig.2.4 manifests the equivalent circuit of PV cell [1]. Equivalent circuit has a current source (photocurrent), a diode parallel to it, a resistor in series describing an internal resistance to the flow of current and a shunt resistance which expresses a leakage current. The current supplied to the load can be given as.

$$I = I_{PV} - I_O\left[\exp\left(\frac{V + IR_S}{aV_T}\right) - 1\right] - \left(\frac{V + IR_S}{R_P}\right) \tag{2.1}$$

Where

I_{PV}–Photocurrent current,

I_O–diode's Reverse saturation current,

V–Voltage across the diode,

a– Ideality factor

V_T –Thermal voltage

R_s– Series resistance

R_p–Shunt resistance

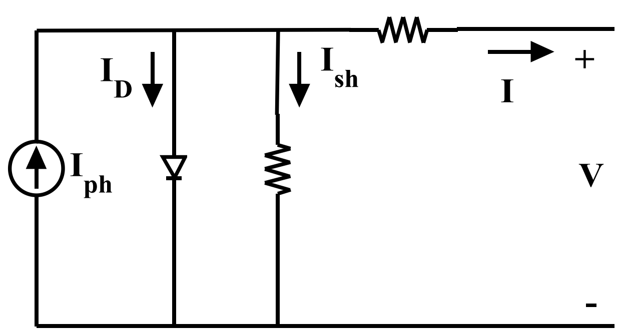

Fig 2.5 Equivalent circuit of Single diode modal of a solar cell

PV cell photocurrent, which depends on the radiation and temperature, can be expressed as.

$$I_{PV} = \left(I_{PV\_STC} + K_I \Delta T\right)\frac{G}{G_{STC}} \tag{2.2}$$

Where

K_I– cell's short circuit current temperature coefficient

G–solar irradiation in W/m^2

G_{STC}–nominal solar irradiation in W/m^2

I_{PV_STC}– Light generated current under standard test condition

The reverse saturation current varies as a cubic function of temperature, which is represented as

$$I_O = I_{O\_STC}\left(\frac{T_{STC}}{T}\right)^3 \exp\left[\frac{qE_g}{aK}\left(\frac{1}{T_{STC}} - \frac{1}{T}\right)\right] \tag{2.3}$$

Where

I_{0_STC}– Nominal saturation current

E_g – Energy band gap of semiconductor

T_{STC}–temperature at standard test condition

q – Charge of electrons

The reverse saturation current can be further improved as a function of temperature as follows

$$I_O = \frac{\left(I_{SC\_STC} + K_I \Delta T\right)}{\exp\left[\frac{\left(V_{OC\_STC} + K_V \Delta T\right)}{aV_T}\right] - 1} \tag{2.4}$$

I_{SC_STC}– short circuit current at standard test condition

V_{OC_STC}– short circuit voltage at standard test condition

K_V– temperature coefficient of open circuit voltage

Many authors proposed more developed models for better accuracy and for different purposes. In some of the models, the effect of the recombination of carriers is represented by an extra diode. Some authors also used three diode models which included influences of some other effects that are not considered in previous models. But due to simplicity we use single diode model for our work.

Efficiency of a PV cell does not depend on the variation in the shunt resistance R_p of the cell but efficiency of a PV cell greatly depends on the variation in series resistance R_s. As R_p of the cell is inversely proportional to the shunt leakage current to ground so it can be assumed to be very large value for a very small leakage current to ground.

As the total power generated by a single PV cell is very low, we used a combination of PV cells to fulfill our desired requirement. This grid of PV cells is knows as PV array. The equations of the PV array can be represented as

$$I = I_{PV}N_P - I_O N_P\left[\exp\left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S}\right) - 1\right] - \left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{R_P\left(\frac{N_S}{N_P}\right)}\right) \tag{2.5}$$

N_S– Number of series cells

N_P– Number of parallel cells

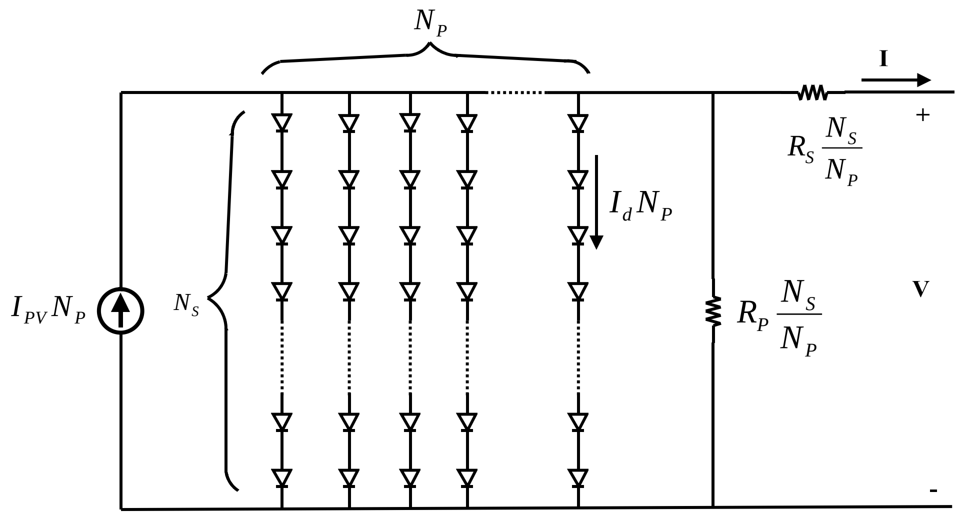

Fig.2.6 Representation of PV module

A small change in series resistance can affect more on the efficiency of a PV cells but variation in shunt resistance does not affect more. For very small leakage current to ground, shunt resistance assumed to be infinity and can be treated as open. After considering shunt resistance infinity, the mathematical equation of the model can be expressed as.

$$I = I_{PV} N_P - I_O N_P \left[\exp\left(\frac{V + IR_S\left(\frac{N_S}{N_P}\right)}{aV_T N_S} \right) - 1 \right] \tag{2.6}$$

I-V and P-V characteristics of PV module are shown in figures 2.7 and 2.8 respectively.

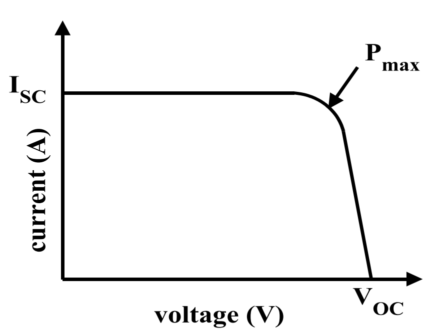

Fig. 2.7 IV characteristics

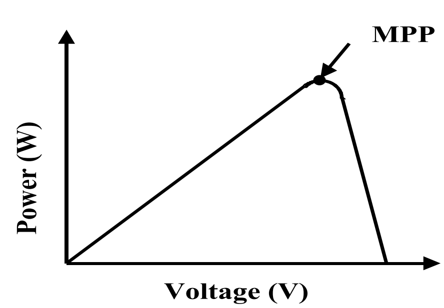

Fig. 2.8 PV characteristics

The two key parameters which are used to relate the electrical performance are the open-circuit voltage of the cell V_{OC} and short-circuit current of the cell I_{sc}.

The maximum power can be stated as

$$P_{max} = V_{max} I_{max} \tag{2.7}$$

The parameters used for the modeling of PV module are shown in table 2.1 [2]

Sl.no.	**Parameter**	**Value**
1	I_{mp}	7.61 A
2	V_{mp}	26.3 V
3	I_{sc}	8.21 A
4	P_{max}	200.143 W
5	V_{oc}	32.9 V
6	K_v	-0.1230 V/K
7	K_i	0.0032 A/K
8	N_s	54
9	N_p	4

TABLE 2.1

Parameters of the PV array at 25^0C, 1000w/m^2

2.4. SHADING EFFECT

When a module or a part of it is shaded it starts generating less voltage or current as compared to unshaded one. When modules are connected in series, same current will flow in entire circuit but shaded portion cannot able to generate same current but have to allow the same current to flow, so shaded portion starts behaving like load and starts consuming power. When shaded portion starts to act as load this condition is known as hot-spot problem. Without appropriate protection, problem of hot-spot may arise and, in severe cases, the system may get damaged [6]. To reduce the damage in this condition we generally use a bypass diode [8]. Block diagram of PV array in shaded condition is shown below.

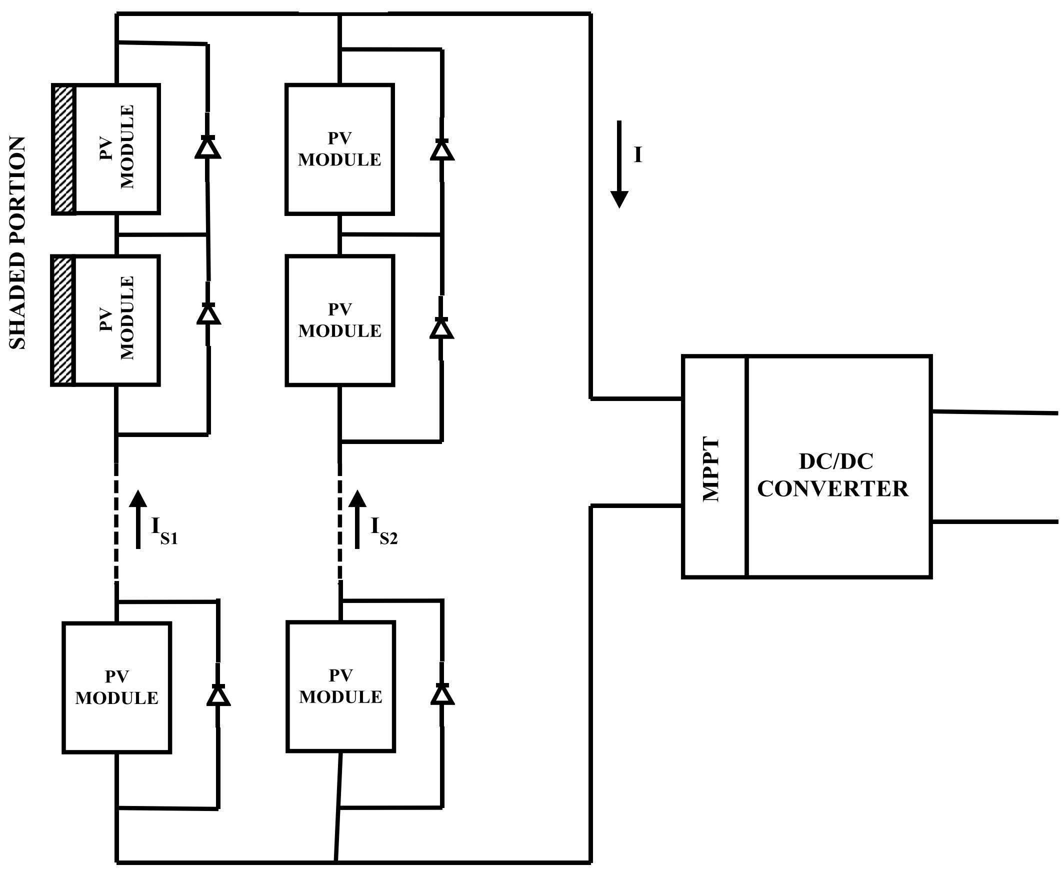

Fig 2.9 PV Array in Shaded condition

Due to partial shading or total shading PV characteristic become more non-linear, having more than one maximum power point [7]. So for this condition tracking of the maximum power point become very tedious. We can easily see the effect of shading on PV characteristics in the fig shown below.

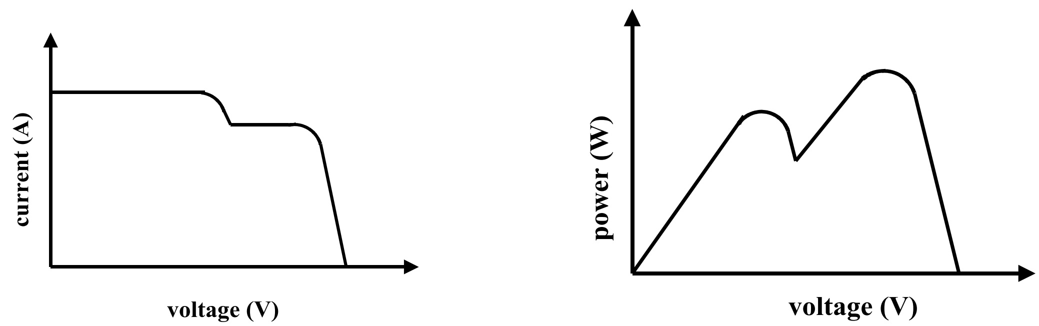

Fig. 2.10 Effect of partial shading on I-V & P-V characteristics

There is wastage of power due to the loss contributed by reverse current which results in overheating of shaded cell.

2.5 MAXIMUM POWER POINT TRACKING

Maximum power point tracing (MPPT) system is an electronic control system that can be able to coerce the maximum power from a PV system. It does not involve a single mechanical component that results in the movement of the modules changing their direction and make them face straight towards the sun. MPPT control system is a completely electronic system which can deliver maximum allowable power by varying the operating point of the modules electrically [9].

2.5.1 NECESSITY OF MAXIMUM POWER POINT TRACKING

In the Power Vs Voltage characteristic of a PV module shown in fig 2.8 we can observe that there exist single maxima i.e. a maximum power point associated with a specific voltage and current that are supplied. The overall efficiency of a module is very low around 12%. So it is necessary to operate it at the crest power point so that the maximum power can be provided to the load irrespective of continuously changing environmental conditions. This increased power makes it better for the use of the solar PV module. A DC/DC converter which is placed next to the PV module extracts maximum power by matching the impedance of the circuit to the impedance of the PV module and transfers it to the load. Impedance matching can be done by varying the duty cycle of the switching elements [10].

2.5.2. MPPT algorithm

There are many algorithms which help in tracing the maximum power point of the PV module. They are following:

a. P&O algorithm

b. IC algorithm

c. Parasitic capacitance

d. Voltage based peak power tracking

e. Current Based peak power tracking

2.5.3. Perturb and observe

Each and every MPPT algorithm has its own advantages and disadvantages. Perturb and observe (P&O) method is widely used due its simplicity. In this algorithm we introduce a perturbation in the operating voltage of the panel. Perturbation in voltage can be done by altering the value of duty-cycle of dc-dc converter.

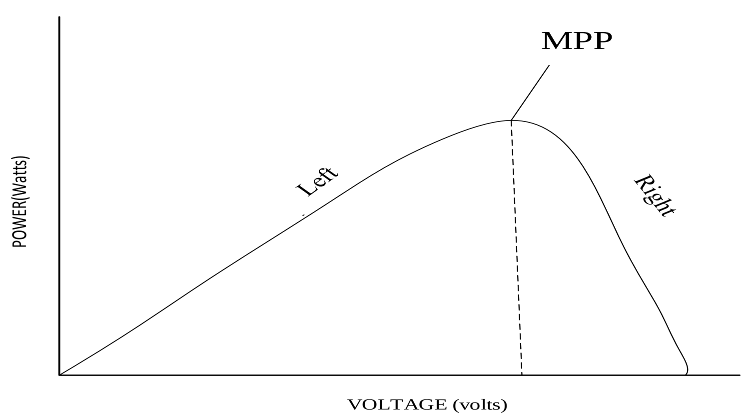

Fig. 2.11 P-V characteristics (basic idea of P&O algorithm)

Fig 2.11 show the p-v characteristics of a photovoltaic system, by analyzing the p-v characteristics we can see that on right side of MPP as the voltage decreases the power increases but on left side of MPP increasing voltage will increase power. This is the main idea we have used in the P&O algorithm to track the MPP [11]. The flow chart of P&O algorithm is manifested in figure 2.12.

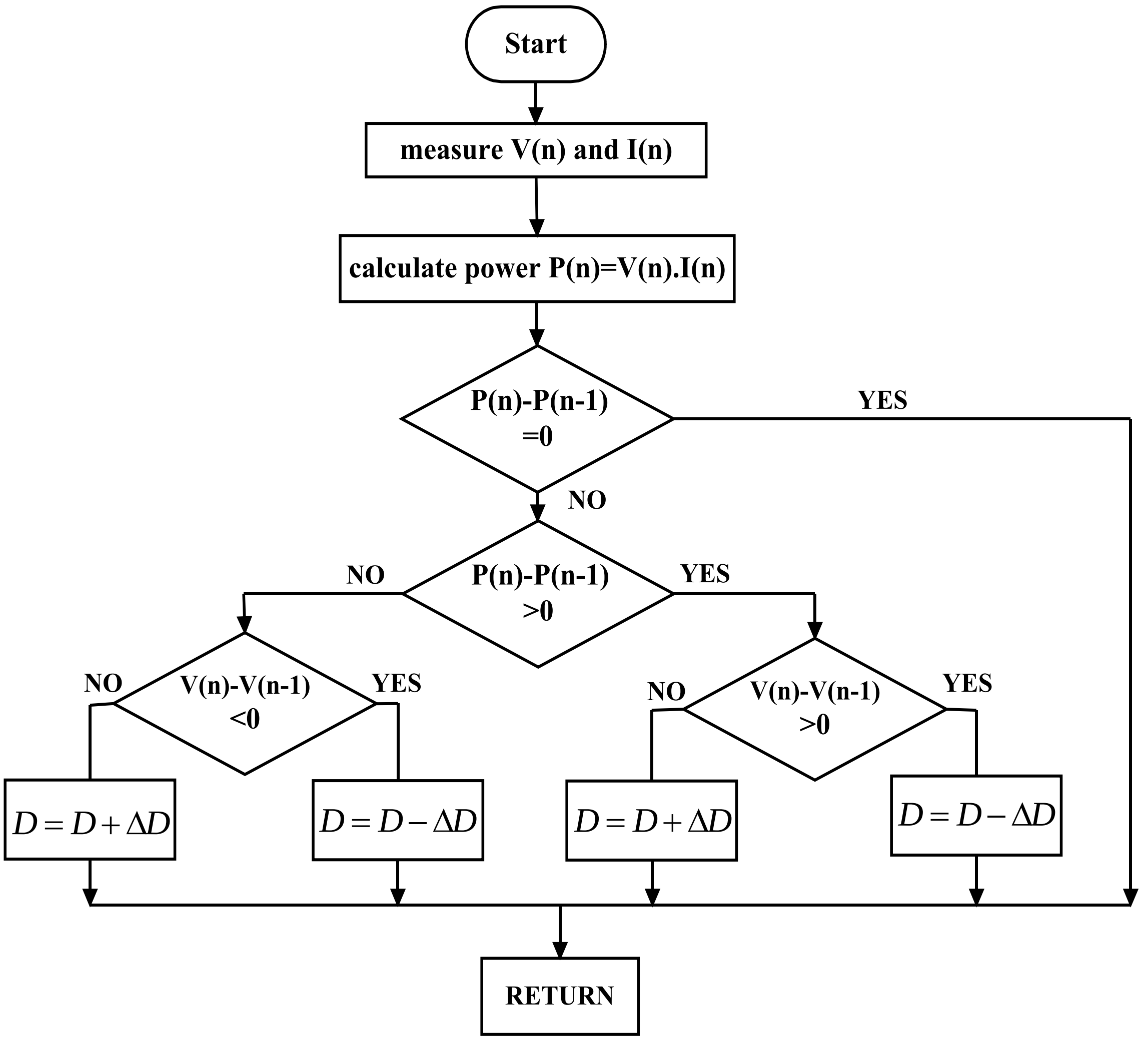

Fig.2.12 Flowchart of Perturb & Observe MPPT algorithm

As we can see from the flow chart first of all we measure voltage and current, by using these values we calculate power, calculated power is compared with previous one and accordingly we increase or decrease the voltage to locate the Maximum Power Point by altering the duty cycle of converter.

CHAPTER-3

DC-DC CONVERTER

3.1 TYPES OF DC-DC CONVERTER

DC-DC converter is an electrical circuit whose main application is to transform a dc voltage from one level to another level. It is similar to a transformer in AC source, it can able to step the voltage level up or down. The variable dc voltage level can be regulated by controlling the duty ratio (on-off time of a switch) of the converter.

There are various types of dc-dc converters that can be used to transform the level of the voltage as per the supply availability and load requirement. Some of them are discussed below.

1. Buck converter
2. Boost converter
3. Buck-Boost converter

Each of them is explained below.

3.1.1 Buck converter:

The functionality of a buck converter is to reduce the voltage level. The circuit diagram of the buck converter is manifested in figure 3.1.

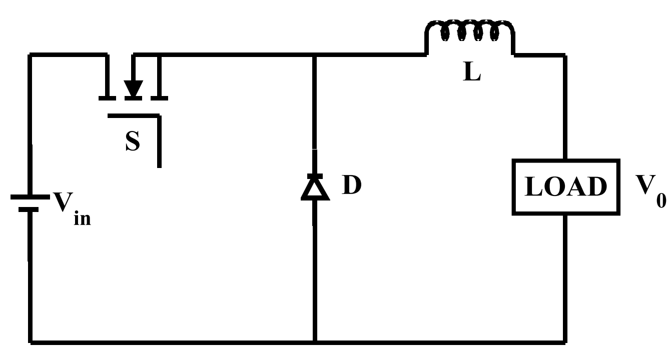

Fig. 3.1 circuit diagram of buck converter

When the switching element is in state of conduction the voltage appearing across the load is V_{in} and the current is supplied from source to load. When the switch is off the load voltage is zero and the direction of current remains the same. As the power flows from source side to load side, the load side voltage remains less than the source side voltage. The output voltage is determined as a function of source voltage using the duty ratio of the gate pulse given to the switch. It is the product of the duty ratio and the input voltage

3.1.2 Boost converter:

The functionality of boost converter is to increase the voltage level. The circuit configuration of the boost converter is manifested in figure 3.2.

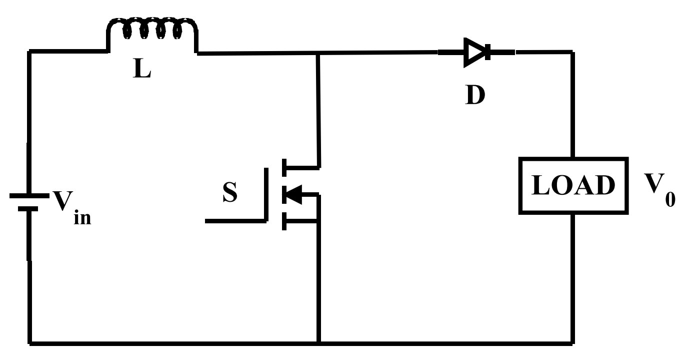

Fig. 3.2 circuit diagram of boost converter

The current carried by the inductor starts rising and it stores energy during ON time of the switching element. The circuit is said to be in charging state. During OFF condition, the reserve energy of the inductor starts dissipating into the load along with the supply. The output voltage level exceeds that of the input voltage and is dependent on the inductor time constant. The load side voltage is the ratio of source side voltage and the duty ratio of the switching device.

3.1.3 Buck-Boost converter:

The functionality of a buck-boost converter is to set the level of load side voltage to either greater than or less than that of the source side voltage. The circuit configuration of the buck-boost converter is manifested in figure 3.3.

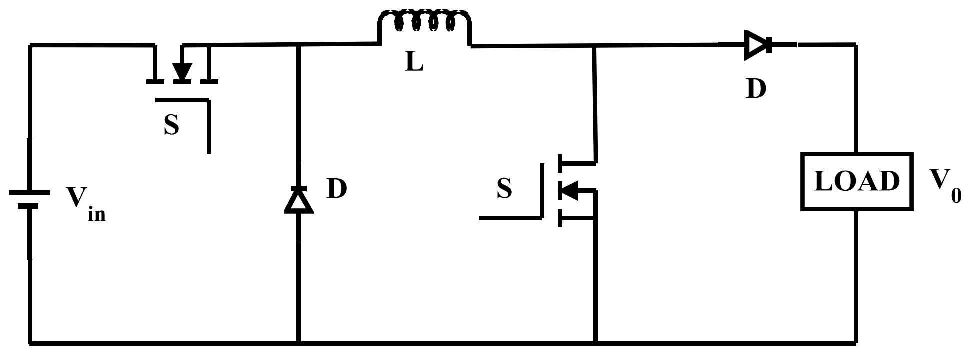

Fig. 3.3 circuit diagram of buck-boost converter

When the switches are in the state of conduction, the current carried by the inductor starts rising and it stores energy. The circuit is said to be in charging state. While the switches are in the OFF state, this stored energy of the inductor is dissipated to the load through the diodes. The output voltage can be varied based on the On-time of the switches.

The buck-boost converter acts as both buck and boost converters depending on the duty cycle of the switches. For the duty ratio less than 50% it acts as a buck converter and for the duty ratio exceeds than 50% it acts as boost converter.

As the voltage can be stepped both up and down, we use buck-boost converter for our convenience in our work.

CHAPTER-4

WIND POWER SYSTEM

4.1 HISTORY

Some 5000 years ago, firstly wind power was used to navigate ships in the Nile. The Europeans used it to pump water and grind grains in 1700s and 1800s.The first windmill which generated electricity was installed in 1890 in U.S. A grid connected wind turbine generator with a capacity of as 2 MW was commissioned in 1979 on Howard Knob Mountain nearby Boon. A 3-MW turbine was commissioned in 1988 on Berger Hill in Orkney, Scotland [14]. The electric power developed from wind is used in lighting the buildings which are at remote places and not connected to the grid. Today wind power generators are available in small size suitable for standalone system and larger utility-generators that could be connected to the electricity grids. In 2003, the worldwide wind power capacity was about 39,294 MW and India wind power capacity was 1550 MW [15].

4.2 SYSTEM CONFIGURATION

The schematic diagram of the wind energy system is manifested in figure below.

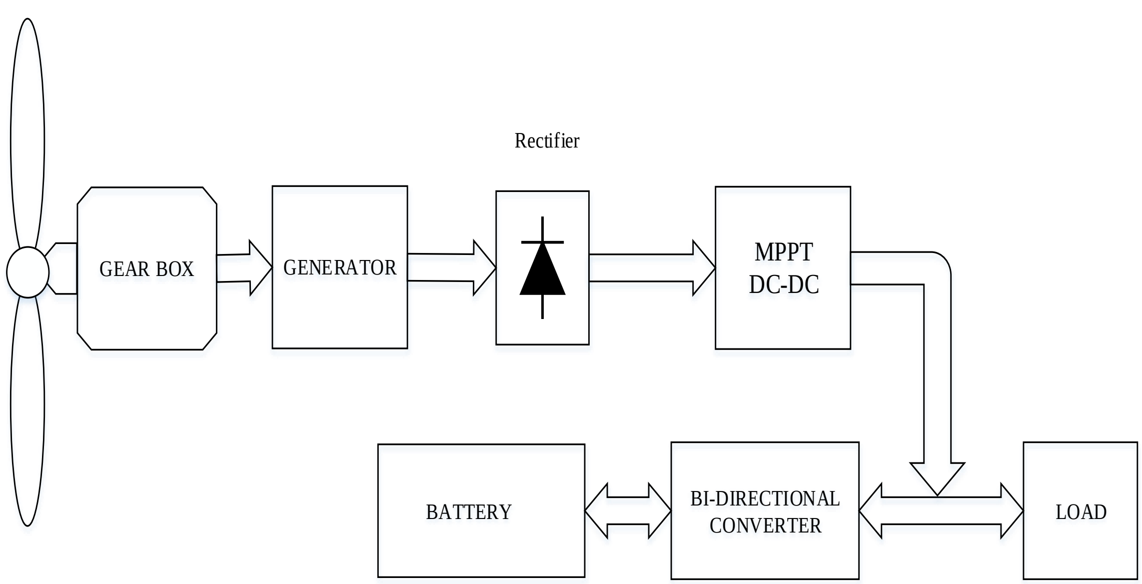

Fig. 4.1 Overall Block diagram of wind energy system

This system comprises of a wind turbine which transforms wind's kinetic energy into rotating motion, a gear box to match the turbine speed to generator speed, a generator which converts mechanical energy into electrical energy, a rectifier which converts ac voltage to dc, a controllable dc-dc converter to trace the maximum power point, a battery is charged and discharged through bi-directional converter.

4.3 WIND TURBINE

Generally a wind turbine consists of a set of rotor blades rotating around a hub, a gearbox-generator set placed inside the nacelle. The basic components of a wind turbine system are shown in figure below.

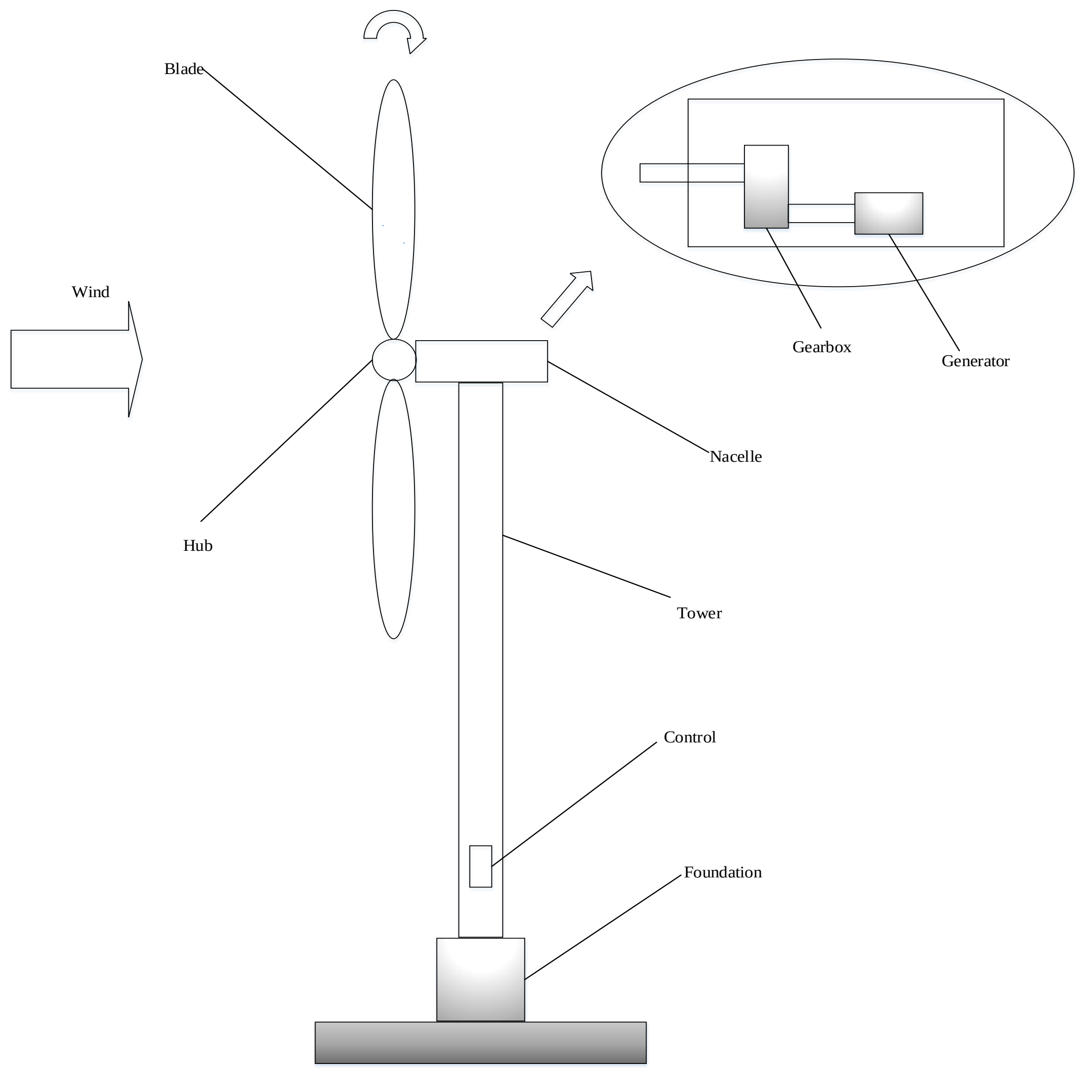

Fig. 4.2 Major turbine components [21]

Based on axes the wind turbines are categorized into two kinds: the vertical axis wind turbine and the horizontal axis wind turbine [21].

4.3.1 MODELING OF WIND TURBINES

A wind turbine converts kinetic energy of air i.e. wind power into mechanical power i.e. rotating motion of the turbine that can be used directly to run the machine or generator. Power captured by wind turbine blade is a concomitant of the blade shape, the pitch angle, speed of rotation, radius of the rotor [21]. The equation for the power generated is shown below.

$$P_M = \frac{1}{2}\pi\rho C_P(\lambda, \beta)R^2V^3 \tag{4.1}$$

Where

P_M– Power captured by wind turbine

ρ –Air density

β –Pitch angle (in degrees)

R– Blade radius (in meters)

V– Wind speed (in m/s)

The term λ is the tip-speed ratio, given by the equation

$$\lambda = \frac{\Omega R}{V} \tag{4.2}$$

Where

Ω - Rotor speed of rotation (in rad/sec)

C_P can be expressed as the function of the tip-speed ratio (λ)

$$C_P = \frac{1}{2}\left(\frac{116}{\lambda_1} - 0.4\beta - 5\right)\exp^{\frac{-16.5}{\lambda_1}} \tag{4.3}$$

$$\lambda_1 = \left(\frac{1}{\frac{1}{\lambda + 0.089} - \frac{0.035}{\beta^3 + 1}} \right) \tag{4.4}$$

Where

C_P – Wind turbine power coefficient

λ –Tip- speed ratio

λ_1 –Constant

4.4 GENERATOR

The shaft of the wind turbine is mechanically coupled to the rotor shaft of the generator, so that the mechanical power developed by the wind turbine (by kinetic energy to mechanical energy conversion) is transmitted to the rotor shaft. This rotor structure has a rotor winding (either field or armature). In both the cases, we get a moving conductor in a stationary magnetic field or a stationary conductor in moving magnetic field. In either case, electric voltage is generated by the generator principle.

4.4.1 TYPES OF GENERATORS

Generators can be basically classified on the type of current. There are alternating current generators and direct current generators. But in either case, the voltage generated is alternating. By adding a commutator, we convert it to direct current. So for convenience, we go for alternating current generator.

In the AC generators, we can further classify them based on the rotor speed. There are synchronous generators (constant speed machine) and asynchronous generators (variable speed machine or the induction machine).

In the synchronous generators we have salient pole rotor and the cylindrical (non-salient pole) rotor. Based on the speed requirement/availability, we can go for cylindrical rotor for high-speeds and salient pole rotor for low speeds.

Another classification is based on the magnetic field. The magnetism can be done by either permanent magnet or an electro-magnet. In order to reduce the supply requirement, we go for the permanent magnet synchronous generator (PMSG) for the power generation using wind energy.

An induction motor running with negative slip can operate as an induction generator. But this generator is not self-exciting and this has to be excited by a source of fixed frequency. It already needs an exciter for stator. So this machine has to be fed by two supplies and hence it is called doubly fed induction machine or generator.

So doubly fed induction generator (DFIG) and permanent magnet synchronous generator (PMSG) are suitable for wind power generation. We are using PMSG in our work.

4.4.2 PERMANENT MAGNET SYNCHRONOUS GENERATOR

A synchronous machine generates power in large amounts and has its field on the rotor and the armature on the stator. The rotor may be of salient pole type or cylindrical type.

In the permanent magnet synchronous generator, the magnetic field is obtained by using a permanent magnet, but not an electromagnet. The field flux remains constant in this case and the supply required to excite the field winding is not necessary and slip rings are not required. All the other things remain the same as normal synchronous generator.

The EMF generated by a synchronous generator is given as follows

$$E = 4.44 \cdot f \cdot \phi \cdot t$$

Where,

F is the frequency

Φ is the flux

t is the number of turns

4.5 MPPT OF WIND POWER

Wind power verses wind speed characteristics of wind power system is shown in fig below

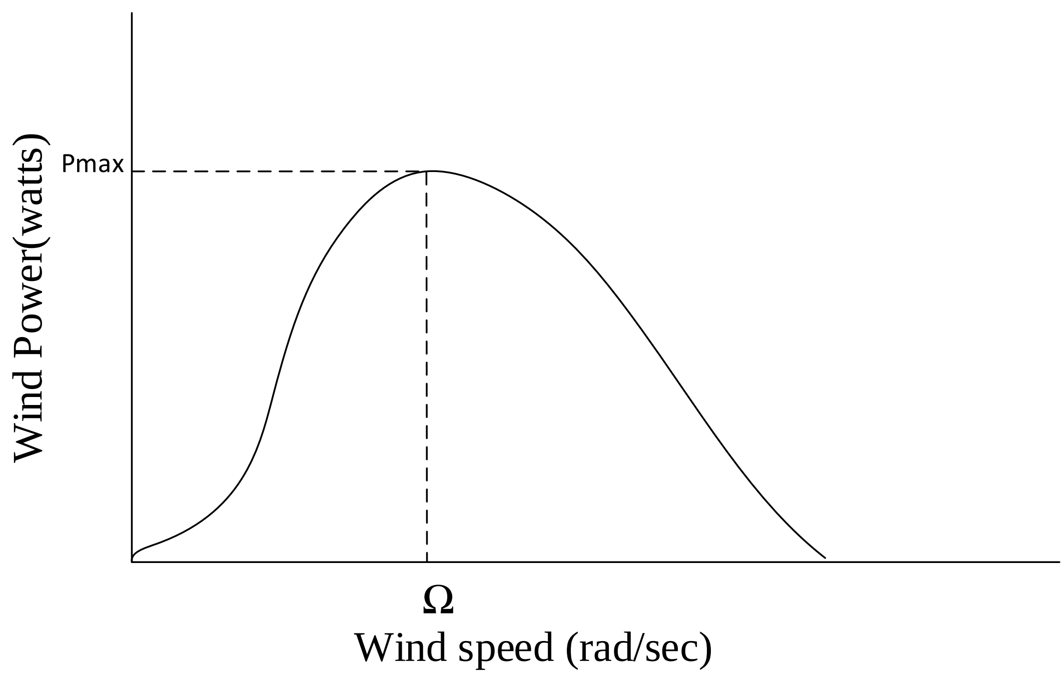

Fig. 4.3 Power vs. speed characteristics of wind turbine

At maximum power point

$$\frac{dp}{d\Omega} = 0 \tag{4.5}$$

From chain rule

$$\frac{dP}{d\Omega} = \frac{dP}{dD} \times \frac{dD}{dV_W} \times \frac{dV_W}{d\Omega_e} \times \frac{d\Omega_e}{d\Omega} \tag{4.6}$$

Where

P– Wind power

Ω– Rotor speed

Ω_e – Generator- phase voltage angular speed.

V_W– Rectifier output voltage

D– Duty cycle of converter

For buck-boost converter

$$V_0 = \frac{D}{1-D} V_W \tag{4.7}$$

Where

V_0 –Output of buck-boost converter

V_W – Input of buck-boost converter

From equation (4.7) we can write

$$\frac{dD}{dV_W} = -\frac{D^2}{V_0} \neq 0 \tag{4.8}$$

As we can see from equation (4.8) that $\frac{dD}{dV_W}$ having negative and non –zero value

The rotor speed of the wind turbine can be correlated with the generator-phase voltage angular speed as follows:

$$\Omega_e = p \cdot \Omega$$

$$\frac{d\Omega_e}{d\Omega} = p > 0 \tag{4.9}$$

Where

p– Number of pole pairs in the generator

From equation (4.9) we observe that $\frac{d\Omega_e}{d\Omega}$ is positive and non-zero value.

The output voltage of the rectifier which is proportional to the output voltage of generator can be written as

$V_{ph} = 4.44 \cdot f \cdot \phi \cdot t$

And $f \propto \Omega_e$

So

$\frac{dV_{ph}}{d\Omega_e} > 0$ As $V_{ph} \propto V_W$

$$\frac{dV_{ph}}{d\Omega_e} \approx \frac{dV_W}{d\Omega_e} > 0 \tag{4.10}$$

Where

V_{ph} – Generator output

f – Frequency of rotor

ϕ – Flux

t – Number of turns

From equation (4.8), (4.9), (4.10) we see that $\frac{dD}{dV_W}$, $\frac{d\Omega_e}{d\Omega}$ and $\frac{dV_W}{d\Omega_e}$ are non-zero value. So $\frac{dp}{d\Omega} = 0$ can be possible if and only if $\frac{dP}{dD}$ becomes zero. From the above equations we can concludes that the operating point at which the crest power can be coerced is traced by varying the duty- cycle of converter [13].

CHAPTER-5
BATTERY CHARGING

5.1 INTRODUCTION

Battery is a storage device which is stores the excess power generated and uses it to supply the load in addition to the generators when power is required. Both PV and wind energy systems (described in the previous chapters) are integrated i.e. connected to a common DC bus of constant voltage and the battery bank is also connected to the DC bus. Any power transfer whether from generator to battery bank or generator to load or from the battery bank to the load takes place via this constant voltage DC bus. As the power flow associated with the battery is not uni-directional, a bidirectional converter is needed to charge and/or discharge the battery in case of excess and/or deficit of power respectively.

5.2 BI-DIRECTIONAL DC-DC CONVERTERS

Bi-directional DC-DC converters are called so due to their ability of allowing the power flow in both the directions, depending on the requirement. There are many applications for the bidirectional converter such as Hybrid Vehicles, Uninterruptable Power Supplies (UPS) and also storage systems powered by Fuel cells and also renewable energy systems.

5.2.1 CLASSIFICATION

Based on the isolation between the input and output side, the bidirectional converters are classified into two types. They are

1. Non Isolated type
2. Isolated type

5.2.1.1 NON-ISOLATED BI-DIRECTIONAL DC-DC CONVERTERS

A basic non-isolated bidirectional converter can be derived from the unidirectional converters by using bi-directional switches. Basic buck and boost converters do not allow the bidirectional power flow due to the presence of the diodes that are unidirectional devices. This problem can be solved by using a MOSFET or IGBT with an anti-parallel diode which allows flow of current in both the directions [18].

The various non-isolated type bidirectional DC-DC converters are

1. Multilevel converter
2. Switched capacitor converter
3. Cuk/Cuk type
4. Sepic/Zeta type
5. Buck-Boost converter
6. Coupled inductor converter
7. Three-level converter

5.2.1.2 ISOLATED BIDIRECTIONAL DC-DC CONVERTERS

The isolated type converters can operate in wide power ranges. The electrical isolation is achieved by using a power transformer in the circuit. But the transformer operates only for AC supply. Introducing AC link in the circuit increases the complexity of the circuit.

Based on the configuration, the isolated bidirectional DC-DC converters can be categorized into two types:

1. A current fed isolated bidirectional DC-DC converter
2. A voltage fed isolated bidirectional DC-DC converter

The various isolated type bidirectional converters are:

1. Fly-back converter
2. Forward fly-back converter
3. Half bridge converter
4. Full bridge converter

5.2.2 BI-DIRECTIONAL CONVERTER FOR BATTERY CHARGING

As mentioned earlier, the bidirectional converter has many applications and here in the work, the converter is used for charging and discharging the battery based on the surplus and deficit of the power respectively.

When there is a surplus of energy, i.e. the supply is greater than demand then the battery is charged, allowing the converter to operate in forward direction. When there is a deficit in power i.e. the supply is less than demand then the battery starts discharging supplying the deficit of power to the load. This requires the converter to operate in reverse direction. Charging/discharging of the battery is done by the help of a bidirectional converter [20].

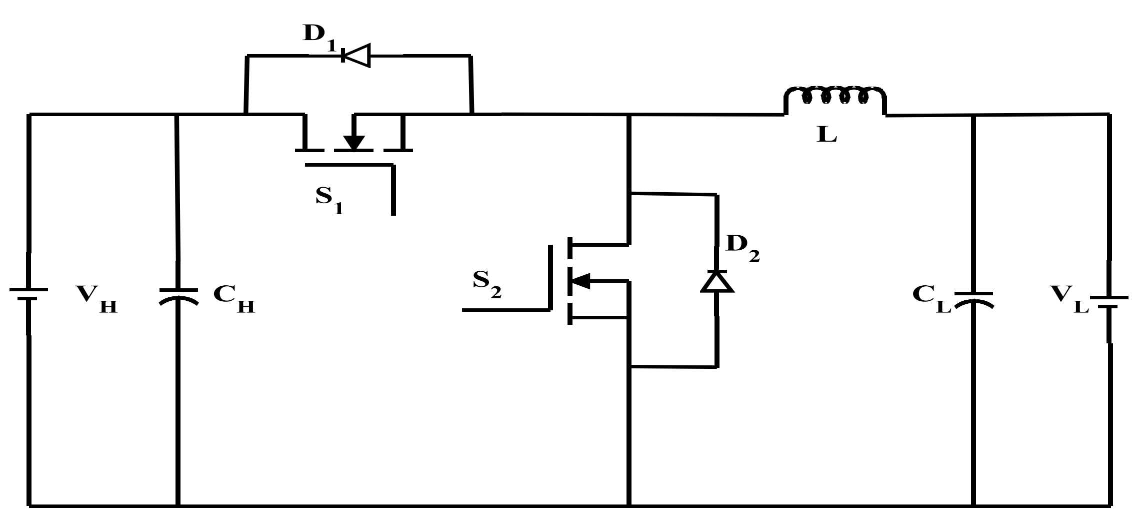

Fig. 5.1 Circuit diagram of the bidirectional converter

CHAPTER-6

RESULTS AND DISCUSSIONS

6.1 RESULTS

Simulation results of PV module

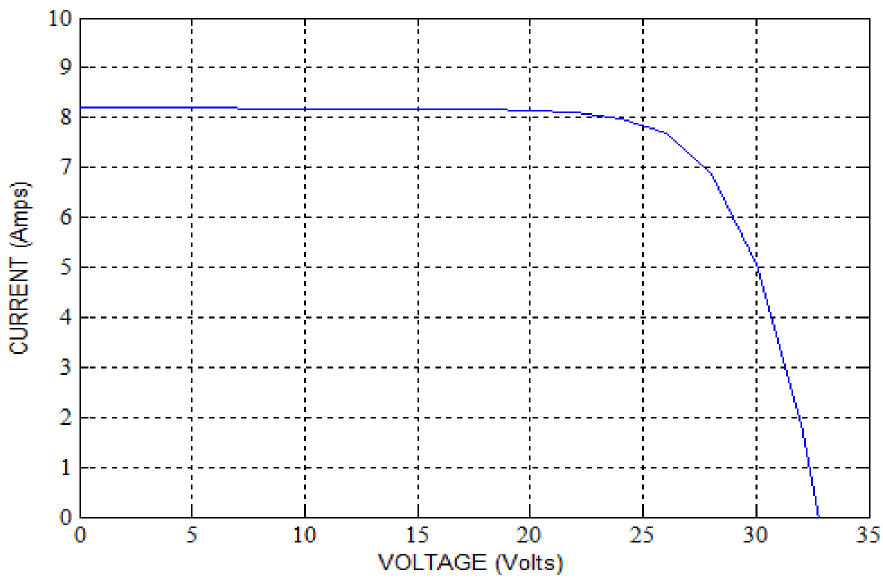

Fig. 6.1 V-I curve of PV module

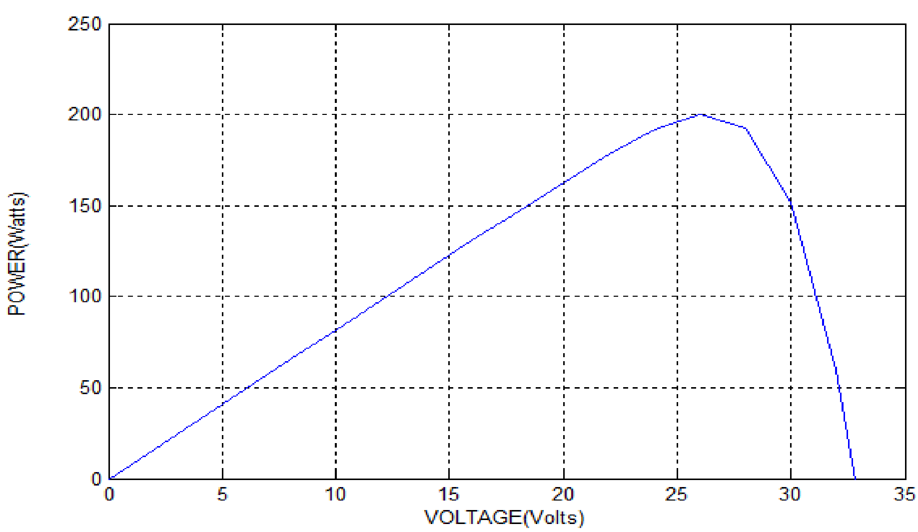

Fig. 6.2 P-V curve of PV module

Fig 6.1, 6.2 represent the I-V and P-V characteristics of a PV module. From fig 6.1 we can see that short circuit current (I_{sc}) of PV module is approximately 8.2A and open circuit voltage (V_{oc}) is approximately 32.9 volts. From fig 6.2 we can observe that maximum power is approximately 200W and it occurs at a current of 7.61A and voltage at 26.3V approximately.

Effect of variation of irradiation

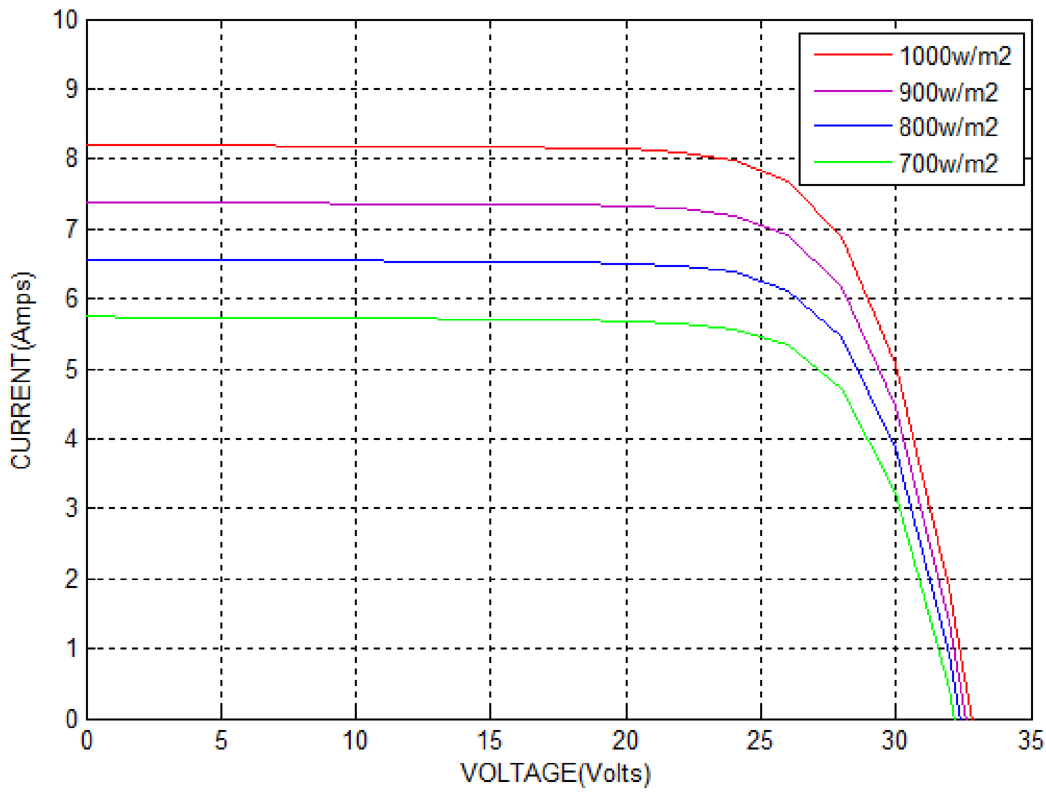

Fig. 6.3 Effect of variation of irradiation on I-V characteristics

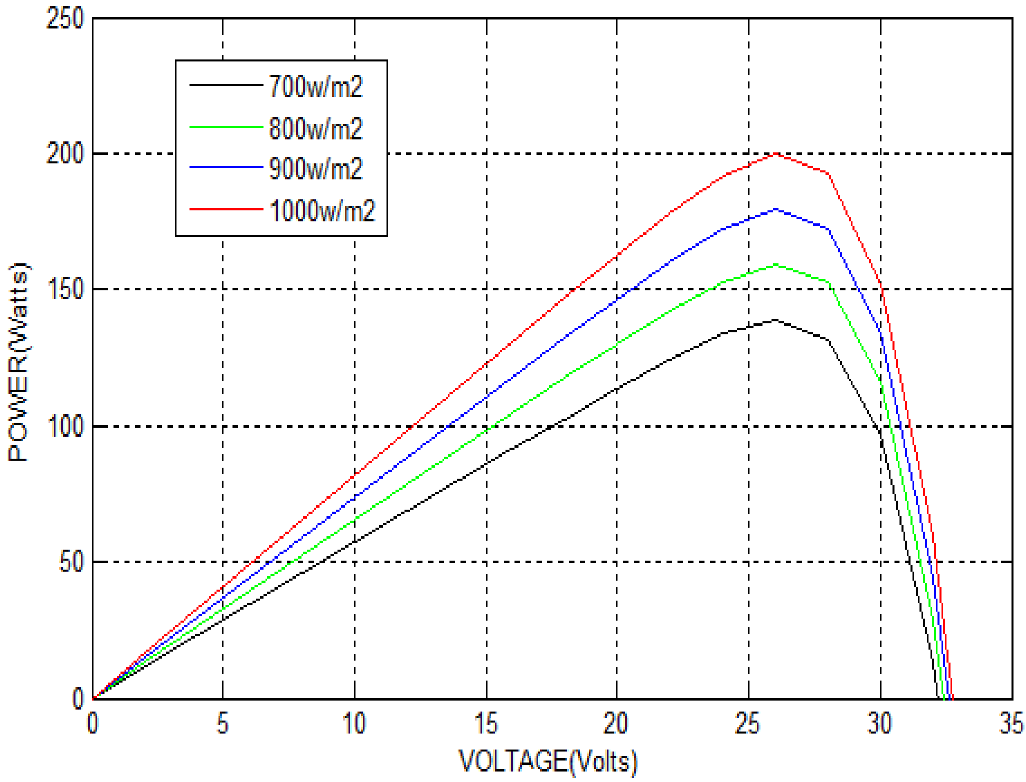

Fig. 6.4Effect of variation of irradiation on P-V characteristics

In fig 6.3, 6.4 we can see the effect of change in solar irradiation on PV characteristics. From fig 6.3 we observe that as we increase the solar irradiation short circuit current increases. Variation in Solar irradiation effects mostly on current, as we can observe from fig 6.3 as we increase solar irradiation from 700 w/m^2 to 1000 w/m^2 current increases from 5.7A to 8.2A approximately but effect of variation of solar irradiation on voltage is very less. Fig 6.4 shows the effect of variation of solar irradiation on P-V characteristics. As solar irradiation increases, power generated also increases. Increase in power is mainly due to increment in current.

Effect of variation of temperature

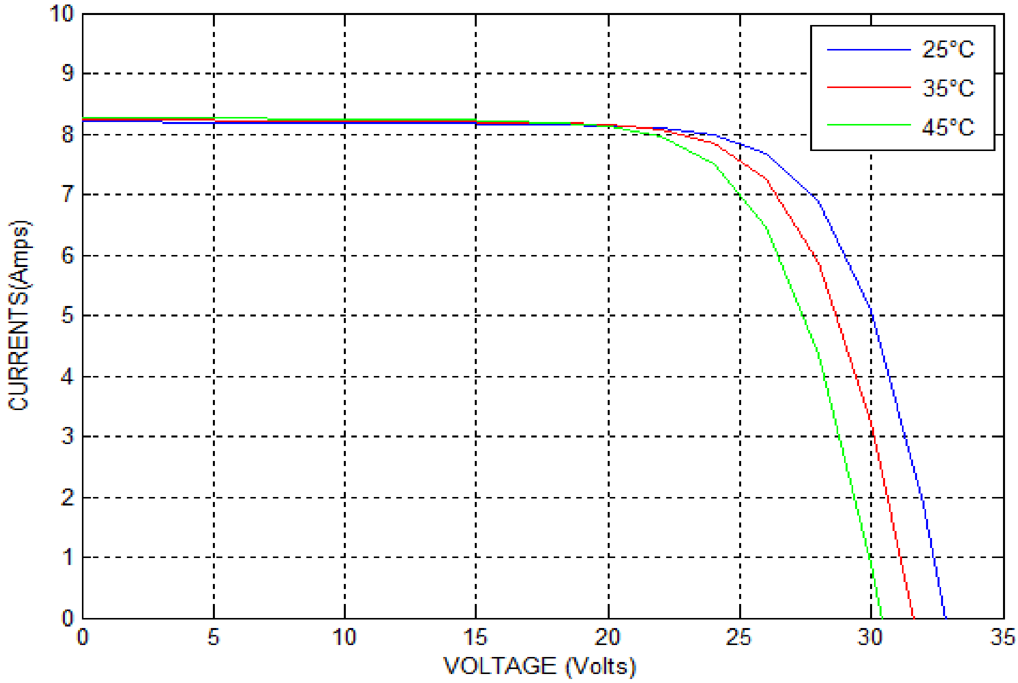

Fig. 6.5 Effect of variation of temperature on I-V characteristics

The outcome of variation of temperature on I-V characteristics is shown in the fig 6.5. From the fig 6.5 we can see the variation of temperature mostly effects voltage, as we increase the temperature voltage decreases but current remains almost unaltered. Fig 6.6 shows effect of temperature variation on the P-V characteristics. As temperature increases power generated decreases, because on increment of temperature voltage decreases.

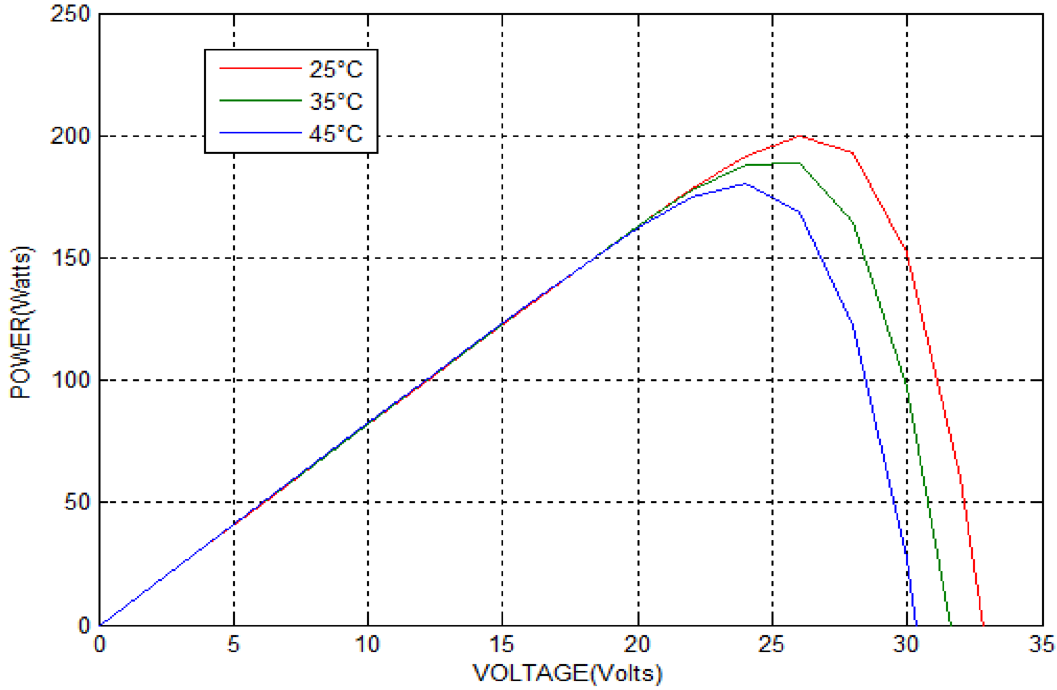

Fig. 6.6 Effect of variation of temperature on P-V characteristics

Shading effect on PV array

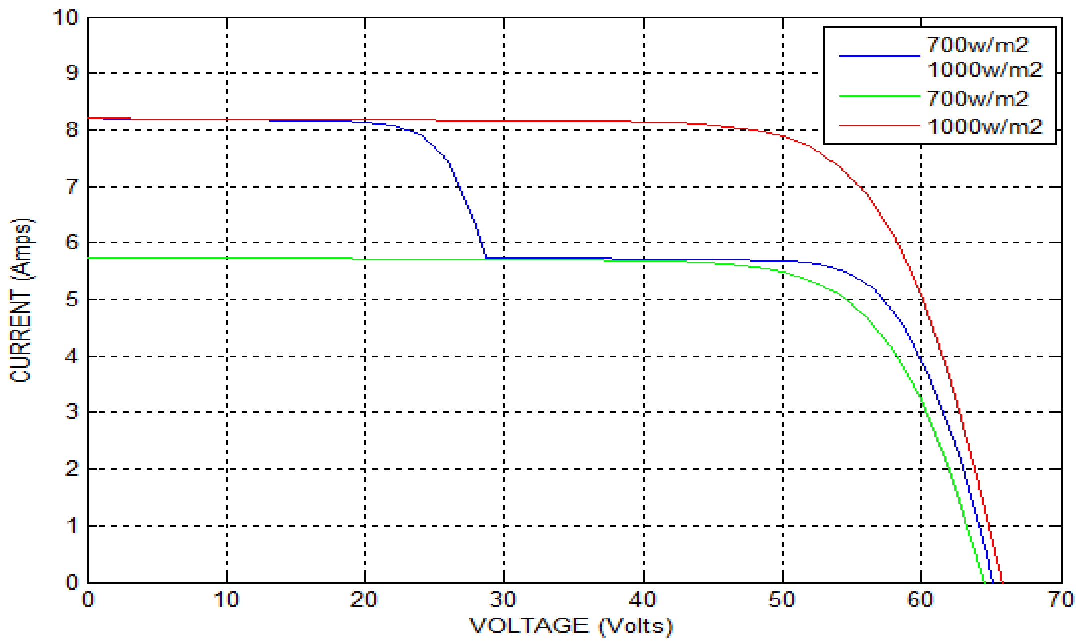

Fig. 6.7V-I characteristics in partial shading condition

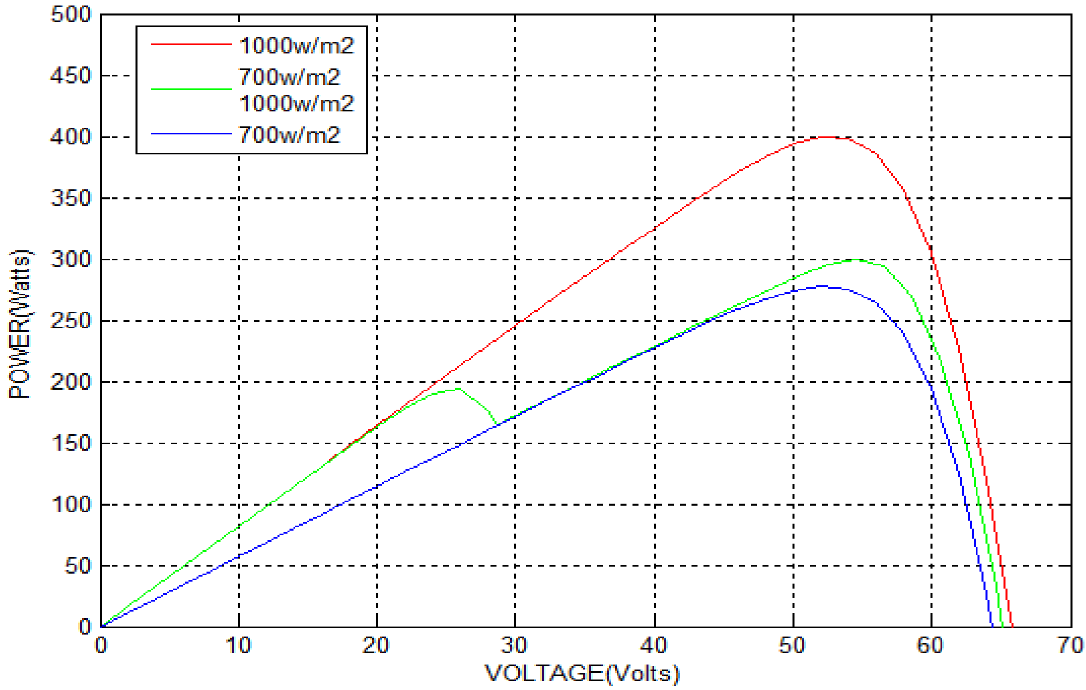

Fig.6.8 P-V characteristics in partial shading condition

I-V, P-V characteristics of a PV array in shading condition can be seen in fig. 6.7 and fig 6.8. As we can observe from fig 6.6 partially shaded PV modules generate less current than the unshaded module. Under partially shading condition we can observe more than one maximum power picks from fig 6.8.

Outputs after MPPT

Output power and output voltage after maximum power point tracing are manifested in the figures 6.9 and 6.10 respectively. As we observe from the fig 6.2, maximum power is achieved at voltage 26.3 volts; from fig 6.10 we can see we are able to track the output voltage where we can get the maximum power which is approximately 26.3 volts. From fig 6.9 we can see the maximum power which is approximately 200 watts can be tracked.

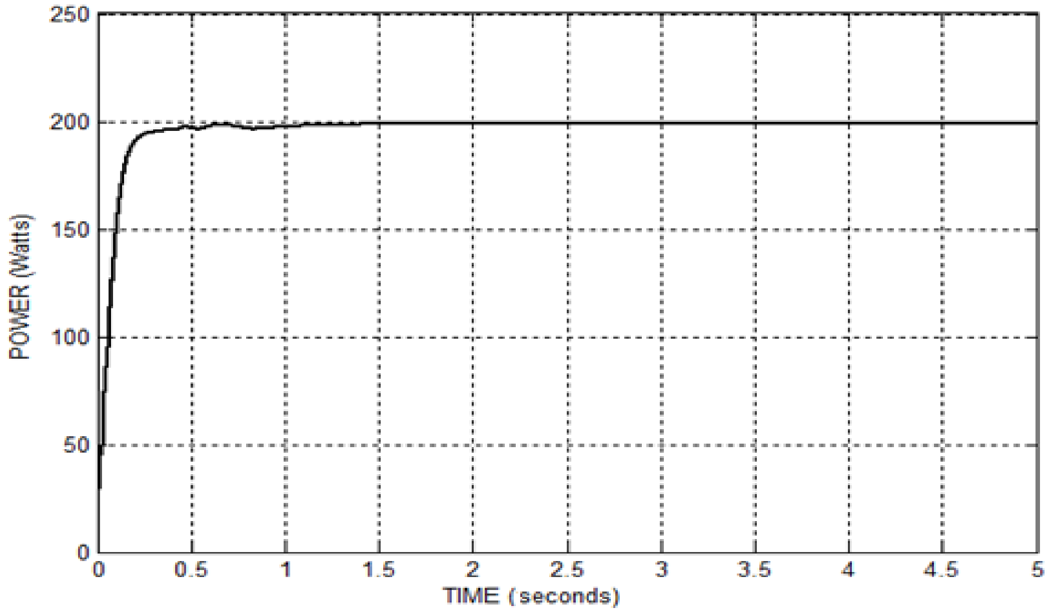

Fig. 6.9 Output power of PV module after MPPT

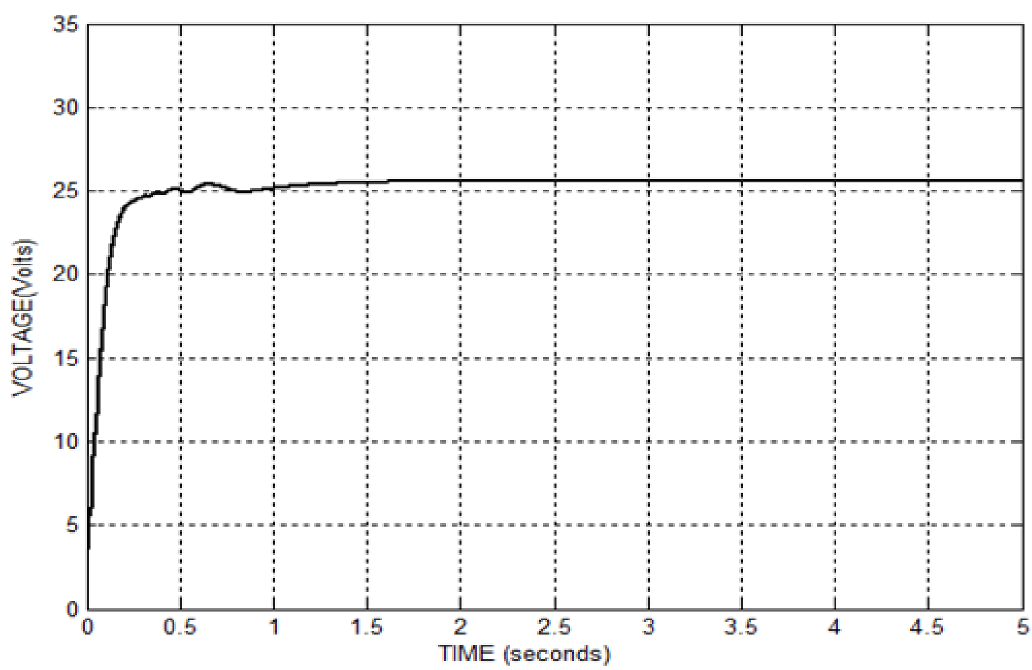

Fig. 6.10 Output voltage of PV module after MPPT

Simulation result of wind energy system

Fig 6.11 shows turbine power characteristics at different wind speed. From the fig 6.11 we can observe that as wind speed increases turbine output power also increases.

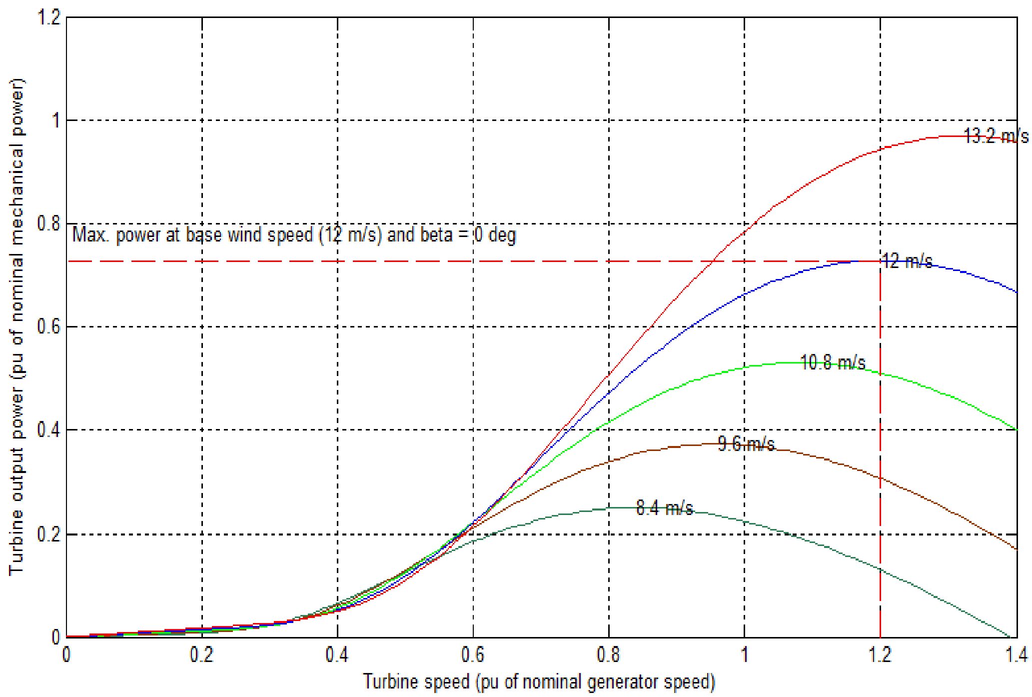

Fig 6.11 Turbine Power characteristics (pitch angle beta=0°)

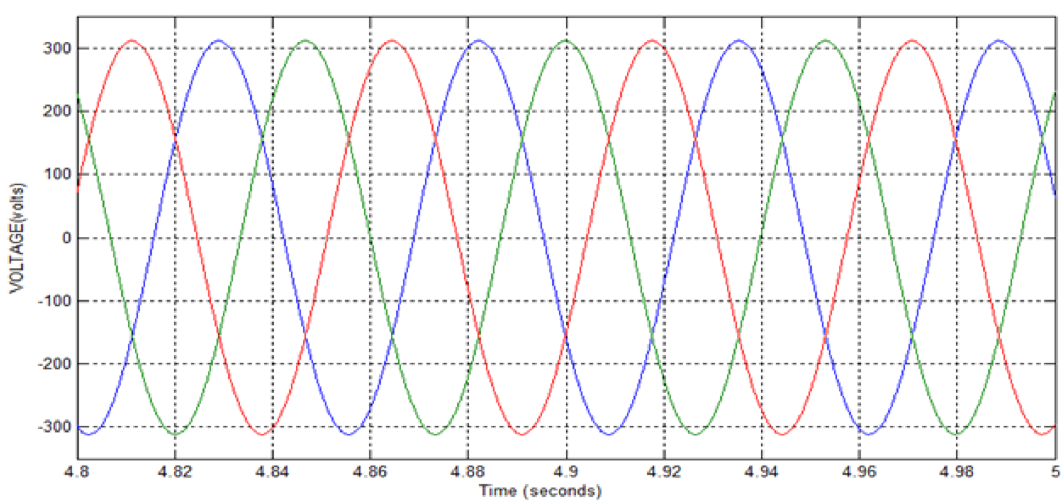

Fig 6.12 Three phase line output voltage of PMSG

PMSG output is shown in the fig 6.12.The point of operation of crest power of wind generator output is traced by a maximum power point tracing system is shown in the fig 6.13 given below. Output Voltage of wind generator at which maximum power is achieved is shown in the fig 6.14.

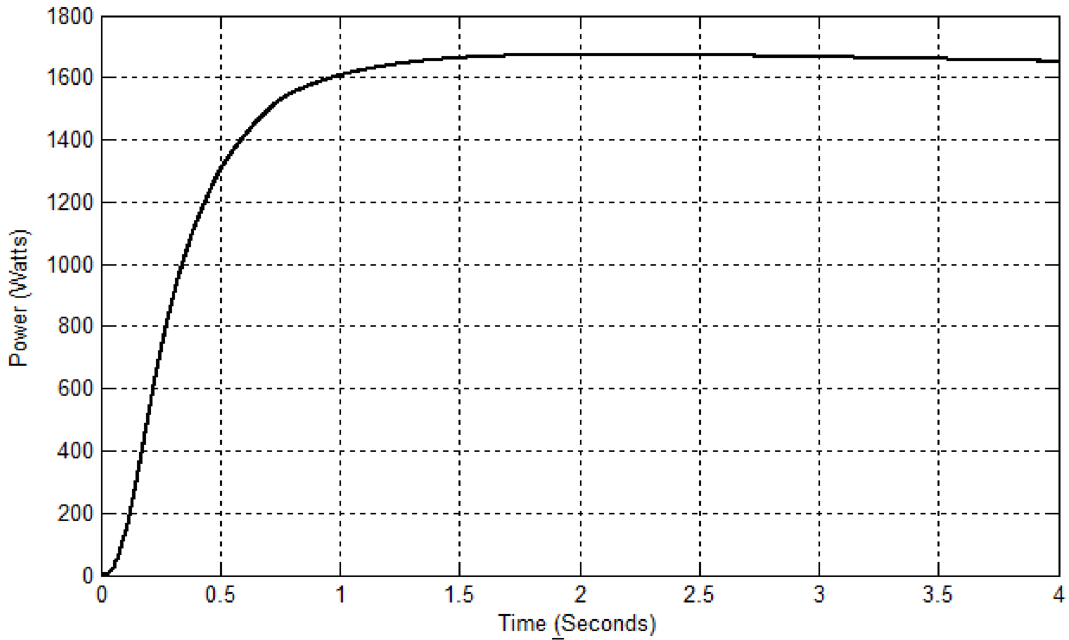

Fig 6.13 Output power of wind system after MPPT

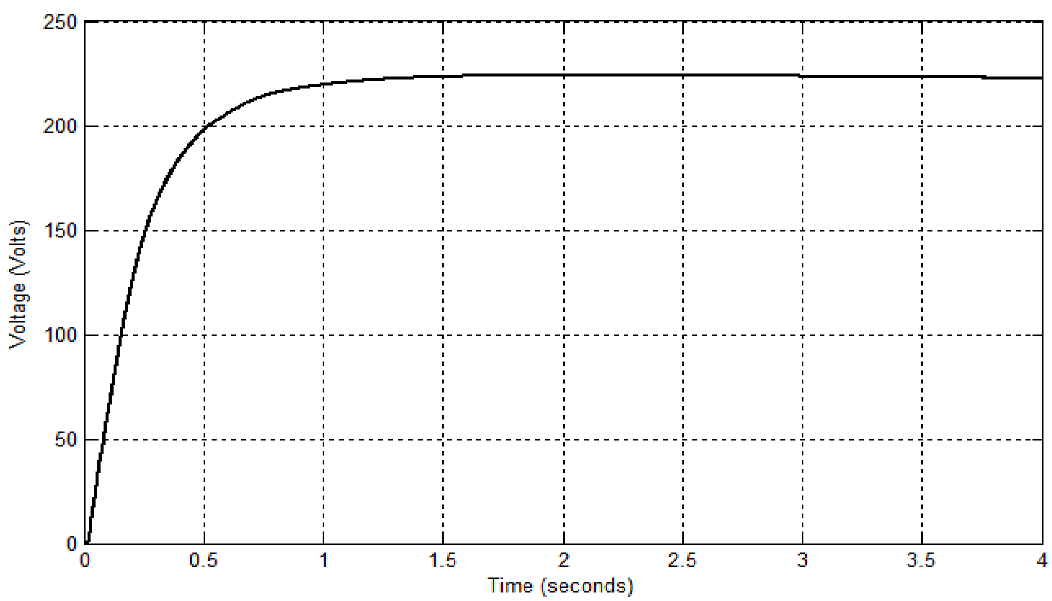

Fig 6.14 Output voltage of wind system at MPP

Simulation results of charging/ discharging

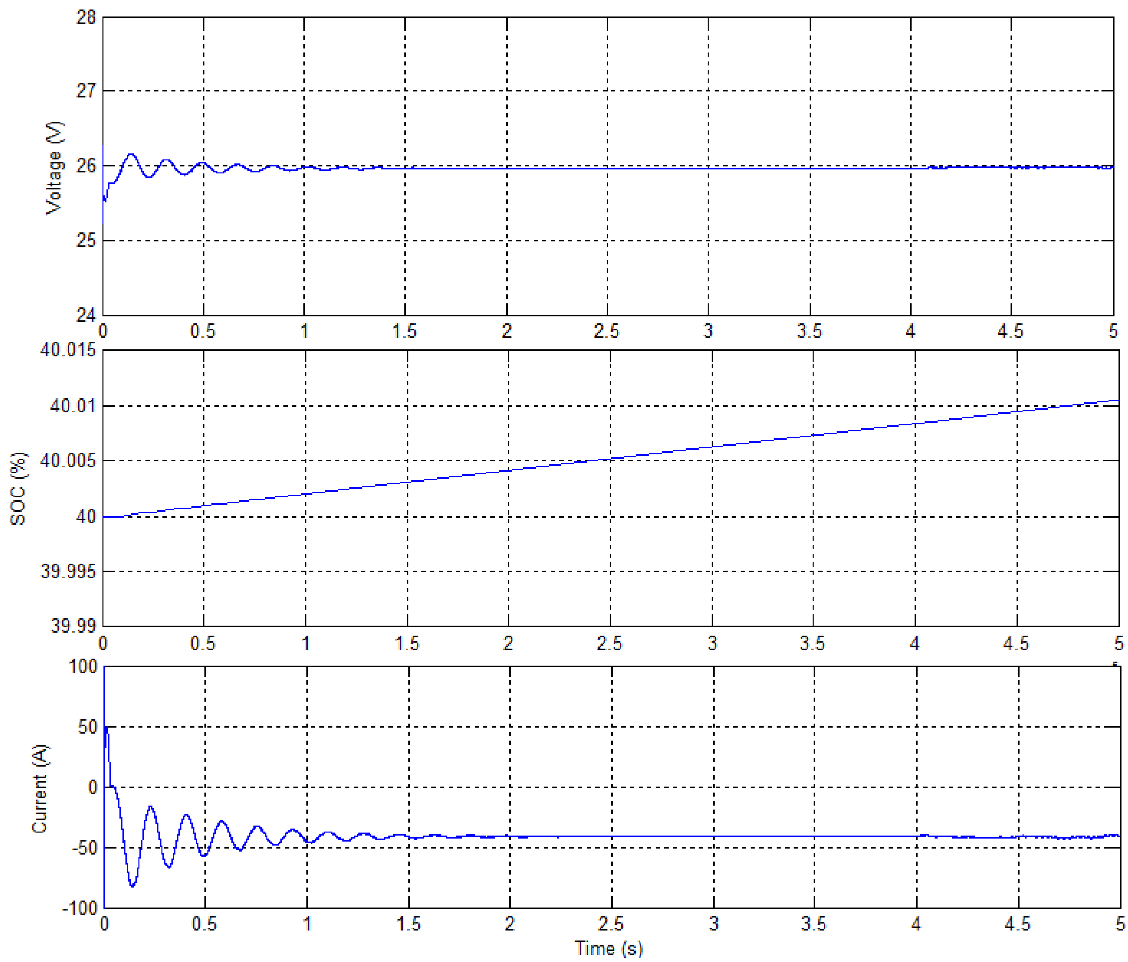

Fig 6.15 charging characteristics of battery

From fig 6.15 we can observe that during charging state of charge (SOC) of the battery is gradually increasing and also during charging current is negative. We can observe at 40% SOC battery voltage is around 26 volts, as state of charge of battery is increased battery voltage exceeded its nominal voltage.

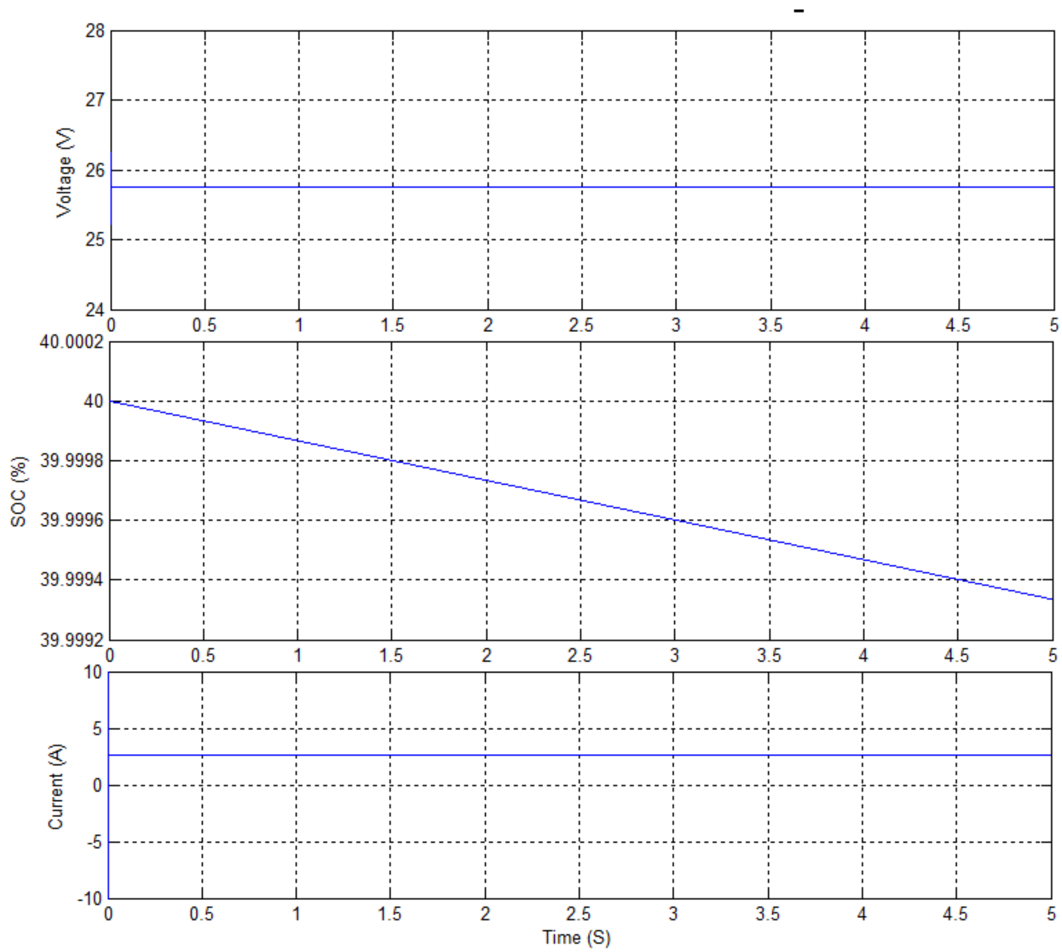

Fig 6.16 Discharging characteristics of battery

From fig 6.16 we can see during discharging, battery start supplying constant voltage and state of charge start decreasing and also during discharging current become positive, which shows battery is supplying the power to the load.

6.2 CONCLUSIONS

- PV cell, module and array are simulated and effect of environmental conditions on their characteristics is studied

- Wind energy system has been studied and simulated

- Maximum power point of operation is tracked for both the systems using P&O algorithm

- Both the systems are integrated and the hybrid system is used for battery charging and discharging

6.3 FUTURE SCOPE

- MPP can be tracked using different algorithms
- Battery charge controller can be designed for more reliable operation and better battery life

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