DESIGN AND SIMULATION OF WIND AND SOLAR HYBRID SYSTEM

Major Project Report

Submitted in Partial Fulfillment of the Requirements

for the Degree of

MASTER OF TECHNOLOGY

IN

ELECTRICAL ENGINEERING

(Electrical Power Systems)

By

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MAY 2016

CERTIFICATE

This is to certify that the Major Project Report entitled **"DESIGN AND SIMULATION OF WIND AND SOLAR HYBRID SYSTEM"** submitted by **Ms. Kartika Dubey (14MEEE07)**, towards the partial fulfillment of the requirements for degree of Master of Technology (Electrical Engineering) in the field of Electrical Power Systems of Nirma University is the record of work carried out by her under my supervision and guidance. The work submitted has in my opinion reached a level required for being accepted for degree. The results embodied in this major project work to the best of my knowledge have not been submitted to any other University or Institution for award of any degree or diploma.

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I, **Kartika Dubey**, Roll . No. **14MEEE07**, give undertaking that the Major Project entitled "**DESIGN AND SIMULATION OF WIND AND SOLAR HYBRID SYSTEM**" submitted by me, towards the partial fulfillment of the requirements for the degree of Master of Technology in Electrical Power Systems of Nirma University, Ahmedabad, is the original work carried out by me and I give assurance that no attempt of plagiarism has been made. I understand that in the event of any similarity found subsequently with any published work or any dissertation work elsewhere; it will result in severe disciplinary action.

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Acknowledgement

I would like to thank Institute of Technology, Nirma University, Ahmedabad, for giving me the opportunity to carry out the project in its premises. With all humbleness, I would like express my sincere gratitude to my project guide Prof. Manisha T. Shah, for her guidance and support during the project work. I am obliged to other faculty members and supporting staff of the department for their support during project duration. I would also like to thank Dr. P. N. Tekwani, I/c Director of Institute of Technology and Head of Electrical Engineering Department, Nirma University, for providing the project work in campus. I am thankful to my classmates for their support. At last, I would like to thank GOD and my parents.

ABSTRACT

The energy demand is increasing now which is forcing us to generate the power using other sources considering conventional and non-conventional sources. Most of the power across nation is generated by means of fossil-fuels resulting into huge amount of carbon emissions in the environment. This suggests the power producers to move towards the Green Power Technology. This thesis supports the different technology for the power generation, i.e., Wind and Solar Hybrid System. The Hybrid System is the integration of two or more energy sources like Photovoltaic (PV) system, wind energy conversion (WECS) system, fuel cells etc. This thesis is aimed at simulation of a hybrid energy system, combining wind energy and solar energy, which is capable to fulfill the need of the power demands usually at remote areas or the power demands in stand alone condition. The system consists of a PV solar panel, Wind turbine, Wind generators, DC-DC Boost converter, inverter and load. The Maximum power point tracking (MPPT) technique is used to track maximum power from individual energy system in order to make entire system more efficient. The simulations are performed in the MATLAB SIMULINK software.

Abbreviations

HAWT .... Horizontal Axis Wind Turbine
IC .... Incremental Conductance
PI .... Proportional Integral
PMSG .... Permanent Magnet Synchronous Generator
P&O .... Perturb & Observe
PV .... Photovoltaic
PWM .... Pulse Width Modulation
MPP .... Maximum Power Point
MPPT .... Maximum Power Point Tracking
SPWM .... Sinusoidal Pulse Width Modulation
VAWT .... Vertical Axis Wind Turbine
WECS .... Wind Energy Conversion System
WPP .... Wind Power Plant

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Chapter 1

Introduction

Mostly the energy demands of the world are supplied by using the fossil fuels, which is the basic cause of generation of carbon emissions in the environment. The modern lifestyle of our society directly leads to the increased consumption of the energy, which results into the increased amount of carbon emissions in the atmosphere and hence is responsible for the unwanted Climatic Change or Global Warming[1].

The developed countries usually consume large energy releasing the unwanted emissions in environment. But the growth of developing countries like India are of more concern. The metropolitan regions are now over populous and they require more amount of generated energy, so the private and public companies have now started to research in the field of renewable energy sources, i.e. environmentally friendly solutions for the power generation problems are becoming more prominent now[2].

The energy that is generated from natural processes and cannot be exhausted, i.e., is continuously restored is called Renewable Energy. There are various other forms of renewable energies also which are used for power extraction. Renewable energy is also called as Green Energy because in the process of energy production the carbon emissions are avoided and the environment does not get polluted.

1.1 Objective of The Work

The power demand by the developing country is increasing day by day. The conventional power generation plants are not enough to supply this demand and also they pollute the environment, so the power is now also generated using renewable sources. The main objective of the work is to develop the Hybrid Energy System (HES). HES consist of interconnection of Solar PV and wind system. The system simulated is capable of supplying the power to the required loads. Both solar and wind are easily available in the system, thus they are used in the current project. The system developed will able to feed ac as well as dc loads.

1.2 Solar Energy

The sun is the vast energy source for the earth, so solar energy is very important form of renewable energy. This energy is freely available in the atmosphere in the vast amount, if efficiently harnessed by the modern technology. All wind, hydro, fossil-fuel and biomass energy have their origins in sunlight.

1.2.1 Types of Solar Energy[4]

The solar energy can be classified into the basic three types mentioned as follows:

- Solar Thermal Energy.
- Concentrated Solar Power.
- Solar Photovoltaic Energy.

1) Solar Thermal Energy

Solar thermal energy is the energy produced by conversion of the sun energy into heat form and it uses flat collector plates to harness the suns energy. This technology is mainly used for environment friendly low-cost generation.

The energy generation process basically concentrates the heat of sun, and that heat is utilized for running a heat engine, which turns on the generator for producing electricity. The working fluid used for heating can be either liquid or a gas like water, oil, air, nitrogen, helium, etc. Different types of efficient engines used are capable of producing 10-100 of megawatts of power.

The basic applications of solar thermal energy are:

- Solar space heating
- Solar water heating
- Solar pool heating
- Solar thermal cooling

2) Concentrated Solar Power (CSP)

In CSP the sunlight is concentrated by means of mirrors or lenses. This concentrated light is converted into heat which is passed through a heat engine (steam turbine) connected to an electrical power generator for electricity production. The CHP have two parts: First part which collects the solar energy and then converts it into the heat, and second part which converts the heat energy into electricity.

3) Solar Photovoltaic Energy

Solar PV is commonly used technology for electricity generation for lower demand. In this technology the sunlight is directly converted into electrical energy. Solar panels basically consist of different solar cells made up of PV material. This technology is already well established in many countries including India, and is about to become one of the key technologies of the 21st century.

These materials have a property known as the photoelectric effect that causes them to absorb photons of light and release electrons. When these free electrons are captured, the flow of electric current occurs which results into the electricity.

1.3 Wind Energy

The flow of a huge amount of air is Wind. It usually flows from a high pressure area to a low pressure area. This is due to the suns radiation, which is differently absorbed on the earths surface. The surface of earth is heated differently by the sun, because of various scenarios like clouds, hills, valleys, water bodies, vegetation and desert lands. Due to this uneven heating, there are various temperature differences on the surface. Air on surfaces having higher temperatures will then begin to rise because it is lighter; creating low atmospheric pressure. Air on surfaces with cooler temperatures sinks; resulting into higher atmospheric pressure. This behaviour of warm gases moving upward and are replaced by particles which are cooler is called Convection and the energy moving during convection is called convectional current. These currents result into the flow of wind.

The terms "wind energy" or "wind power" is the process in which the wind is used to generate electricity or mechanical power. The kinetic energy of the wind is converted into mechanical power by means of wind turbines. This mechanical power can be used for a generator to further convert this mechanical power into electricity.

1.4 Wind and Solar Hybrid Energy Systems

To meet the increasing demand the renewable energy sources are playing an important role producing the Green Energy. Hybrid Renewable Energy Systems (HRES) are now becoming more popular for remote power generation applications.

A hybrid energy system is combination of two or more renewable energy sources which are used together to provide increased system efficiency. We usually prefer solar and wind together because these two are the most important renewable sources and can produce large amount of energy with greater reliability when used in a proper coordinated manner, because we know that whenever sun is not available or its intensity is low, wind will be present and vice-versa.

The hybrid solar and wind system uses, solar panels that collect solar energy and wind turbines that collect wind energy, and then these energies are converted into the usable form by means of suitable converters. Their output is then connected to the grid via transformer.[3] [23]

1.5 Literature Survey

The solar energy is the most clean and inexhaustible form of energy resource and it plays a very important role in power generation. Thus, they are being widely used for power generation. There are various types of materials that can be used for designing of solar panels, resulting into the high efficiency of the system. There are different application areas of solar power generation like solar home and pumps, building integrated systems etc. are also discussed[4].

For obtaining the excellent accuracy of the solar cells and for generating curves required for analysing the performance of cell, the modelling of solar cell can be done. The equivalent circuit of solar cell have a source (photocurrent), a series and shunt resistor and a diode. The modeled cell then predicts the performance of the cell under different environmental and physical conditions or various varying parameters. The output energy produced by a solar cell depends on its intrinsic properties and the solar radiation falling on the panel. It is observed in the analysis that at higher temperature the open circuit voltage decreases and a slight decrease in short circuit current also takes place. Also the lower power output is obtained when solar irradiance falling on the panel is less, i.e., on cloudy day, causing decrease in open circuit voltage and large decrease in short circuit current. Again it is shown that the increase in series resistance will have no effect on short circuit current and open circuit voltage[5].

The Wind/PV Hybrid system is suggested as the best option to feed the loads at the remote areas. By properly estimating the load requirement, the HES can be modeled and is proved to be very reliable for the areas which are off-grid[6].

The hybrid system can also be a grid connected system associated with the Maximum Power Point Tracking (MPPT) to track the maximum power. The tracking of maximum power will result into the higher efficiency of the system. The main advantage of suggested Hybrid system is its lower cost and higher reliability. There are various MPPT methods and implementing the MPPT technique in grid connected system can be done for increasing efficiency. The MPPT technique used is capable to track the maximum power without measuring wind speed in case of wind energy system and without sensing the temperature and irradiance level in case of solar PV system[7].

The PWM technique is used for inverter switching for having a controlled ac output of inverter, by converting the uncontrolled dc voltage at its input (usually constant dc). There are various carrier based modulation techniques for which produce efficient output having minimum harmonic distortion and enhanced output. The gating signals are generated by any of the two carrier signals, i.e., sawtooth carrier wave or triangular carrier wave. These gating signals are used to switch on/off the inverter for having controlled output[8].

There are many MPPT techniques like P&O, IC, Fuzzy Logic, Constant voltage etc out of which, the two most important MPPT techniques are P&O method and IC method. The voltage and current of the panel is sensed and MPPT methods are applied in the Matlab simulink software. These techniques are analysed on standard test specifications of PV module considering the radiation of $1000W/m^2$ and temperature of 25 degree centigrade. Out of different techniques, P&O method is proved to be the best and simplest method for applying MPPT technique. Also the other method are used for other specified applications or conditions[9] [10].

The power generation using wind turbines having PMSG are widely used now for wind power generation. The wind system requires the generator for energy production and PMSG are proved to be the most efficient generator when compared to the other generators. The simulation of wind system will be performed in the Matlab Simulink software under varying wind speed[11] [13].

The output obtained from the system may not be purely sinusoidal having large harmonic contents. The designing of LC filters are done for the system in order to reduce the harmonic content at the output side. The LC filter will simply reduce the dominant harmonic resulting into the reduction in THD at the output side. The application of LC filter will also result into smooth output voltage, which gives the sinusoidal voltage at the output[12].

Chapter 2

Solar Photovoltaic Energy System

The technology of Solar PV is mostly used now-a-days as it converts the solar heat energy directly into the electrical energy by using solar cells (also called photovoltaic cells). PV effect is the process of converting light (photons) to electricity (voltage) that is why the name PV is given.

2.1 Working of Solar PV

A French physicist, Edmund Bequerel found that some materials have a property of producing small amounts of electric current, when exposed to light, in 1839. The first PV module was built by Bell Laboratories in 1954. This principle is used to understand the basic working principle of solar PV system. The basic operation of the Solar PV cell is shown in the Fig. 2.1.

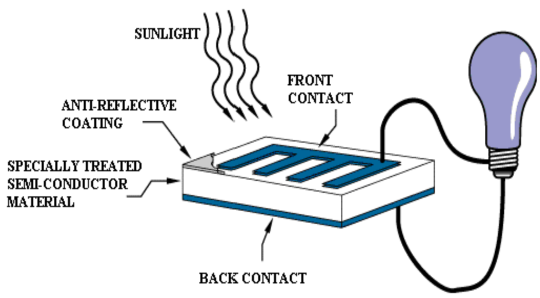

Figure 2.1: Operation of basic photovoltaic cell (Solar Cell)

At normal condition the electrons of the material are present in their valence band. When the sunlight falls on the solar cell, the electrons absorb the photon energy and become free from the atoms in the semiconductor material. So the free electrons can now move into the conduction band resulting into the flow of electrons. If electrical conductors are attached forming a closed electrical circuit, the electrons flow will occur in the system resulting into the flow of electric current. Thus, producing an electric current which can be then used for loads connected.

2.2 Introduction to Solar Cells, Solar Panel and Solar Array

PV modules are the combinations of series and parallel connected solar cells. The combination of solar modules results into the formation of solar array as shown in the Fig. 2.2. The single solar cell will not be able to produce the more power, so we need to use solar array for generating large power in the range. The orientation of PV modules are oriented in the south-east and south-west for the maximum energy extraction. A tracking system is also used with the array for maximizing the production simply by tracking the movement of the sun, throughout the day and the year [9].

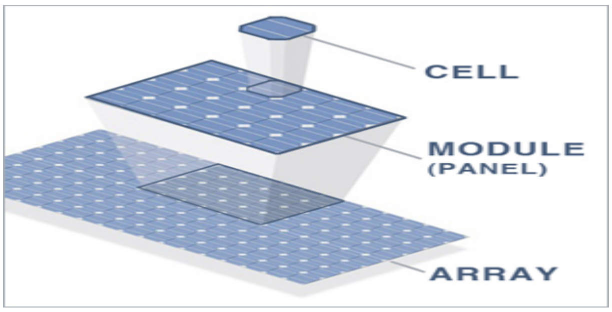

Figure 2.2: Solar cell, Module (Panel) and Solar Array

2.3 Types of Solar Cells [1]

The solar cells require the material which can absorb the energy of photons and is able to generate free electrons for the conduction of current resulting from electron flow. Mostly Silicon (Si) is used as a semiconductor material for making solar cells. Apart from Silicon we can also use Germanium (Ge), Cadmium Sulphide (CdS), Cadmium Telluride (CdTe) and Copper Sulphide (CuS). There are following main types of solar cells:

2.3.1 Single Crystalline (or Monocrystalline) Solar Cells

They are made up from a very pure form of silicon resulting into the most efficient type of cells as compared to all other types of solar cells. Also they are most space-efficient since lesser cells are required per unit of output. Another advantage is that they have longest life of around 25 years amongst all other types.They are highly efficient having efficiency about 20-27%.

2.3.2 Polycrystalline Solar Cells

They are less efficient having 10-15% of efficiency resulting into more space requirement compared to monocrystalline. Due to this reason, they require more space. Another drawback is that they have a lesser heat tolerance than monocrystalline, i.e., they don't perform efficiently with high temperatures. They are cheaper than the single crystalline cells.

2.3.3 Amorphous Solar Silicon Cells (or Thin Films)

They do not have crystalline structure at all resulting into very cheap production of cells. They are made up of thin films and are usually used for bulk power generation because of lower cost of production. Their efficiency is very low around 3-5%.

2.4 Types of PV Systems

PV systems are usually classified according to their functions, operations and how they are connected to other power sources and electrical loads. They are mainly classified into two types: Grid connected system and Stand-alone system.

2.4.1 Grid Connected Solar Power System

Grid-connected PV systems are interconnected with the electric utility grid and supply the electrical power as per the demand when needed. When excess power is generated by the solar panel then a battery is used to store that power. Once the battery is also fully charged at that time the excess power is then supplied to the grid in order to fulfil the demand at some other areas. This configuration is more preferred as it provides higher reliability.

2.4.2 Stand-Alone Solar Power System

The solar panels are not connected to a grid in stand-alone configuration but instead they are used to charge a bank of batteries to store the power produced by the solar panels. Then electrical loads draw power from these batteries. Once the battery if fully charged then excess generated power is simply wasted. So this configuration is usually not preferred.

2.5 Solar PV System Configuration

The solar PV system basically comprises of two components: dc-dc boost converter and inverter for proper working of the system. The output obtained from the panel is of fluctuating value. To obtain constant dc value and to convert it into ac quantity, the above mentioned components are required. The entire operation of these two components used are illustrated below:

2.5.1 DC-DC Converters

The main functions of various dc-dc converters are mentioned as follows:

- To convert the input dc voltage into output dc voltage.
- To reduce voltage ripple on dc output voltage.
- To regulate dc output voltage against load and line variations.
- To provide isolation between input source and the load.

Boost Converter

When the available voltage at the input side is not sufficient then we need to increase the value of the voltage up to the certain required level. For this purpose boost converters are used. Boost converter (or Step-Up Converter) is used to convert the fluctuating dc input voltage into constant dc output voltage, such that the output voltage value will be greater than input voltage value. The converter has an inductor, a switch (usually IGBT or MOSFET), diode and a capacitor as shown in the Fig. 2.3.

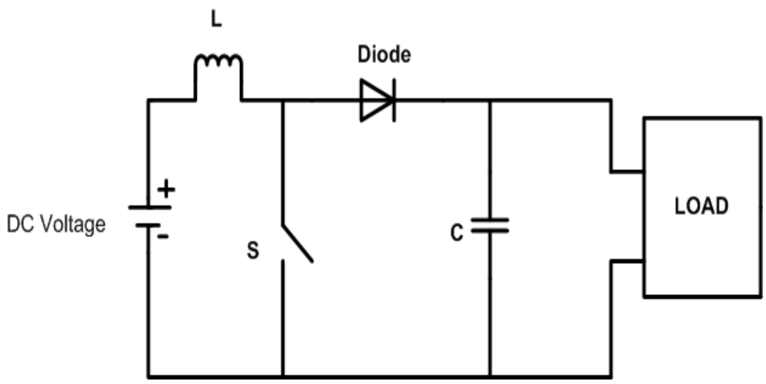

Figure 2.3: Block diagram of dc-dc boost converter

The output voltage of the boost converter is given by equation 2.1:

$$V_0 = \frac{V_i}{1 - D} \tag{2.1}$$

where:

V_0 = Output Voltage

V_i = Input Voltage

D = Duty Ratio (Always between 0 to 1)

The inductor value can be calculated by using equation 2.2:

$$L = \frac{V_{in} * D}{\Delta i_L * f_s} \tag{2.2}$$

where:

L = Inductor

V_{in} = Converter input voltage

D = Duty Ratio (Always between 0 to 1)

Δi_L = Amount or ripple in the current

f_s = Switching frequency

Thus, it is clearly seen that V_0 is always greater than V_i because of the value of duty ratio, which means the output voltage value is boosted.

Calculation of Inductor Value

The calculation of inductor value is very important when we are considering the boost inverter. The calculation is shown below:

Given parameters:

Panel Output Current, I_{panel} = 2A

Input Voltage, V_{in} = 34V

Let us assume:

Switching frequency, f_s = 20KHz

and Duty Ratio, $D = 0.5$

and Δi_L = 10% of I_{panel} = 0.2A

The inductor value can be calculated by using eq.(3.2),

$$\mathrm{L} = 4.25\mathrm{mH}$$

and the value of output voltage for the assumed value of duty ratio can be calculated from eq.(3.1),

$$V_0 = 68\mathrm{V}$$

The output voltage and the output current produced by the boost converter by considering the above values, is shown in the Fig. 2.4 and Fig. 2.5 respectively:

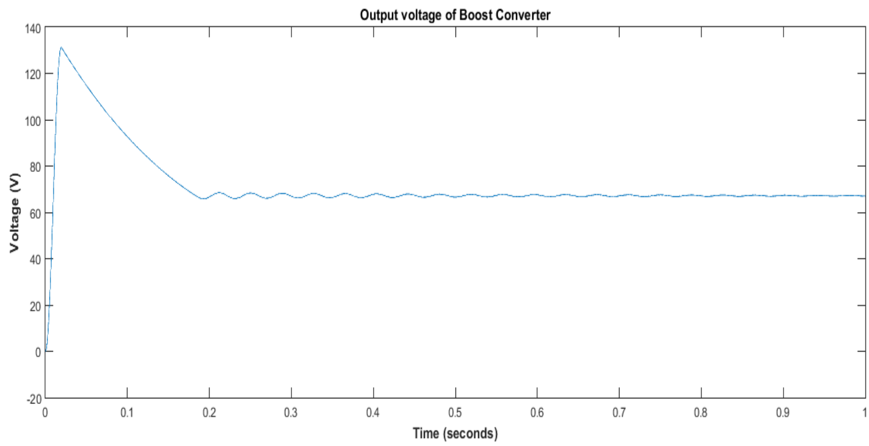

Figure 2.4: Output Voltage of boost converter

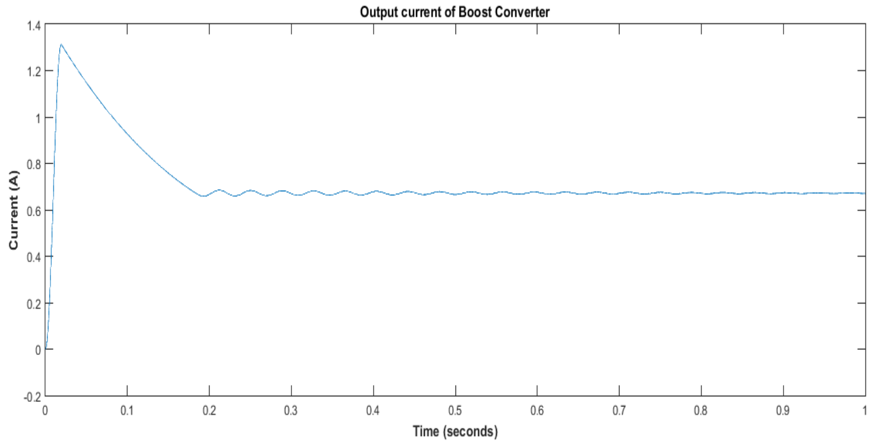

Figure 2.5: Output Current of boost converter

2.5.2 Solar PV Inverters

Solar PV modules always generate dc current and dc voltage. To feed these current and voltage to the grid or some of the ac loads, inverters are needed for converting this dc quantity into ac value. There are different possible configurations of inverters as per their connection with the PV module on how the PV modules. Some of these inverter configurations are discussed below:

a) Central Inverters

This is the simplest configuration having series connected solar PV panel in the parallel for obtaining the desired output as shown in Fig. 2.6. The resulting PV array is then connected to the single inverter, as shown in the figure below. All the PV strings operate on the same voltage which may or may not be the Maximum Power Point voltage for them. The main problem with this configuration is that if different irradiation falls on the strings then they operate individually which makes the MPP tracking difficult and thus results into power loss.

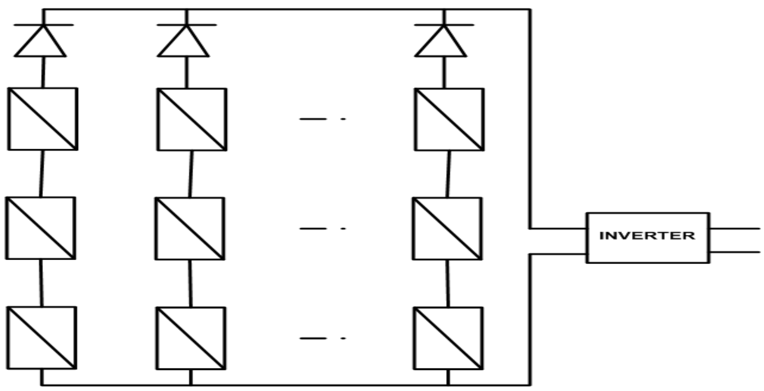

Figure 2.6: Central Inverter configuration

b) String Inverters

In this configuration of inverter, each of the string of PV panels are connected in the series manner and then they are connected to a different inverters, as can be seen in Fig. 2.7. Thus, the tracking of MPP is improved in case of shading, because here each string is allowed to operate at a different MPP leading to lesser power loss. While in the central inverters above, only one operating point is there, which may or may not be the MPP for each string. The main drawback is that the number of the components required in the system is increased resulting into the increase in the installation cost.

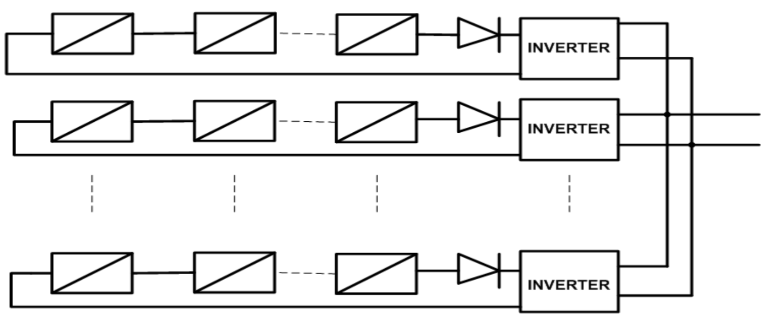

Figure 2.7: String Inverter configuration

c) Multi-String Inverters

In this case, each string of the panel is connected to different individual DC-DC converter and then the converters are connected to a single inverter as shown in Fig. 2.8. The advantage is same as that of string inverter, i.e., each string can have a different MPP operating point. The main disadvantage is increase in the cost of the system as compared to the central inverter because different converter is used for each individual string.

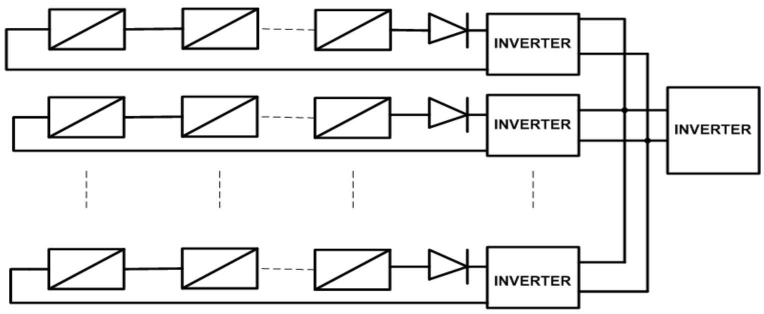

Figure 2.8: Multi-String Inverter configuration

Chapter 3

Maximum Power Point Tracking

Solar PV systems are widely used now and are also encouraged in the world for pollution-free generation of power. The output power from a PV panel mainly depends on the changing environmental conditions, like solar radiation, atmospheric temperature and also on the connected load. Due to this, PV panels have nonlinear I-V and P-V characteristics as shown in the Fig. 3.1 [9] [19].

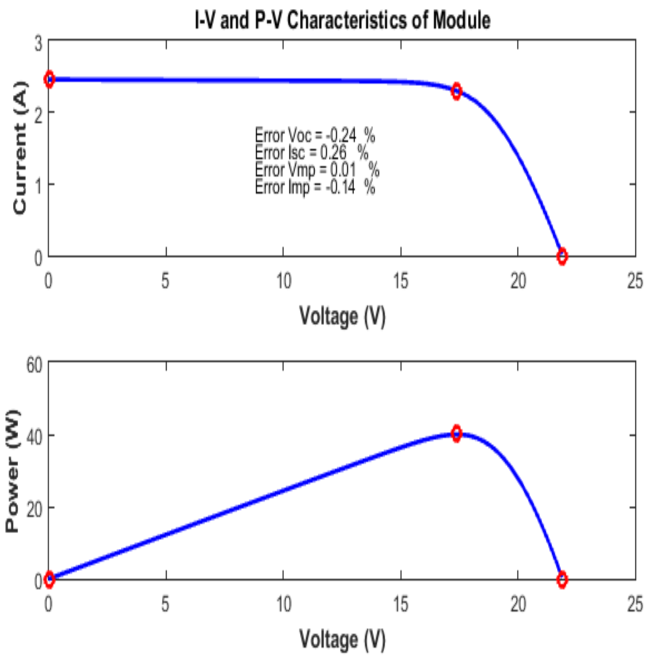

Figure 3.1: I-V and P-V Characteristics of PV Module

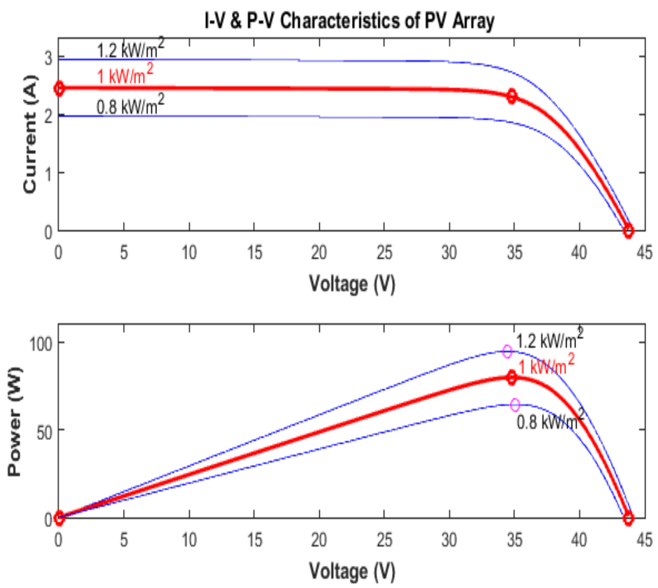

Figure 3.2: I-V and P-V Characteristics of PV Array

From above I-V curve the three important parameters can be obtained:

- Short-circuit Current (I_{sc}): Current that flows through an illuminated cell when the voltage across it is zero or null (i.e., short-circuit condition).
- Open-circuit Voltage (V_{oc}): Voltage across an illuminated cell when the flowing current is null or zero (i.e., open circuit condition).
- Maximum Power Point(MPP): Point of the I-V curve which gives the maximum value of the product between the voltage and current.

There is only one point of maximum power (MPP - Maximum Power Point). The PV power characteristic is nonlinear, which vary as per the level of solar irradiation and temperature, which make the maximum power extraction a complex task considering load variations.

The maximum power P_{max} can be calculated by the product of the maximum power voltage (V_{max}) and the maximum power current (I_{max}) in the I-V curve,

$$P_{max} = V_{max} * I_{max} \tag{3.1}$$

The maximum power current is greatly affected by variation solar irradiance, while it does not considerably affect the maximum power voltage. The variation in temperature causes an opposite behavior having great influence on the maximum power voltage. In other words we can say that, the increase in temperature decreases the open-circuit voltage (V_{oc}) whereas increased intensity of solar radiation improves the short-circuit current (I_{sc}).

The major problems associated with the PV system are its poor overall efficiency of energy conversion and the initial cost of implementation is high. Thus it is necessary to use some techniques to extract the maximum power from these panels, to achieve maximum efficiency in operation by using maximum-power-point tracking (MPPT) techniques.

The basic principal of MPPT technique is to monitor the terminal voltage and/or current continuously and to automatically update the control signal so that the maximum power can be obtained from a PV system.

The basic techniques used for MPPT concept are:

- Perturb and observe method (P&O).
- Incremental conductance(IC).
- Constant voltage(CV).
- Fixed duty cycle.

3.1 Fixed duty cycle method

This is the simplest MPPT approach because it does not require any feedback signal and here the load resistance is adjusted only once for extracting the maximum power from the module. It is basically classified as an off-line technique. This method is not much efficient but it is functional, also it aggregates the appreciable amount of error to the extracted power profile because of voltage variation due to atmospheric variation. This method is not much preferred now.

3.2 Constant voltage(CV) method

This technique uses empirical results to show that the V_{mpp} is about 70-80 percentage of the open circuit voltage across the PV module under STC(Standard Test Conditions) (1000W/m2, 25 degree centigrade). The voltage across the PV panel does not have significant change, even when irradiance changes effectively. Thus, it become bit possible to operate nearer to the MPP by ensuring that the module voltage is approximately constant.

This method demands only one voltage sensor (V_{PV}). The voltage across the PV panel is measured by a voltage sensor and is compared with the set voltage or reference voltage which generates an error signal which is further applied to a pulse width modulator. The duty cycle is generated in the final stage which is used to drive a power electronic converter.

A very basic problem with this method is that the available energy is wasted when the load is not connected to the PV array and another thing is that it is not always necessary that the MPP will be located at 76 percent of the arrays open circuit voltage.

3.3 Incremental conductance(IC) method

Among different MPPT strategies, the incremental conductance (IC) technique is widely used because of its very high tracking accuracy at steady state and also good adaptability for the rapidly changing atmospheric or weather conditions.

The IC method is based on the concept that the slope of the PV array power curve is zero at the MPP, positive on the left side of the MPP, and negative on the right side, as given by,

$$\frac{dP}{dV} = 0, atMPP. \tag{3.2}$$

$$\frac{dP}{dV} > 0, leftofMPP. \tag{3.3}$$

$$\frac{dP}{dV} < 0, rightofMPP. \tag{3.4}$$

Since

$$\frac{dP}{dV} = \frac{d(IV)}{dV} = I + V\frac{dI}{dV} \cong I + V\frac{\Delta I}{\Delta V} \tag{3.5}$$

Now equation 4.2, 4.3 and 4.4 can be rewritten as,

$$\frac{\Delta I}{\Delta V} = I/V, atMPP. \tag{3.6}$$

$$\frac{\Delta I}{\Delta V} > I/V, leftsideofMPPintheP - VandI - Vcharacteristics. \tag{3.7}$$

$$\frac{\Delta I}{\Delta V} < I/V, rightsideofMPPintheP - VandI - Vcharacteristics. \tag{3.8}$$

Thus the MPP can be tracked by comparing the value of instantaneous conductance (I/V) to the value of incremental conductance $(\Delta I/\Delta V)$.

Based on the above comparisons, the corresponding algorithm decides to increase or decrease the voltage value across the PV array, so that system moves nearer to the MPP. This method provides easy and fast response to rapidly changing solar irradiance and so it is usually used.

3.4 Perturb and observe method (P&O)

This is the simplest method resulting into easy implementation for the low cost system. The MPPT algorithm basically compares the power obtained in the previous step with the one obtained in the next step, so that the voltage or current of the system should be increased or decreased as required. Due to change in the reference value (either voltage or current), the operating point is moved towards the MPP, by either increasing or decreasing the value of voltage or current of the array.

The sign obtained in the last perturbation will decide about the next perturbation. If power is incremented, the perturbation will be done in the same direction and if the value of power is decreased, then the next perturbation will be done in the opposite direction.

Based on the above concepts, the algorithm is implemented for this technique. The entire loop is processed and is repeated until the MPP is obtained.

The main disadvantage of this technique is that the output power oscillates about the MPP resulting into the huge power loss in the system.

The performance of this technique can be improved by changing the step size for the converters duty cycle, so that the more accurate tracking can be done. The method suggests that the duty cycle should be multiplied by a dynamic value depending on the previous change in the extracted power. When such concept of variable step size is applied, the method is called as modified P and O technique.[18] [19]

The flowchart of P and O technique is given in Fig. 3.3, which requires the voltage and the current sensors. V and I sensed are the panel voltage and panel current. Delta mentioned in the flowchart is the step size for perturbation.

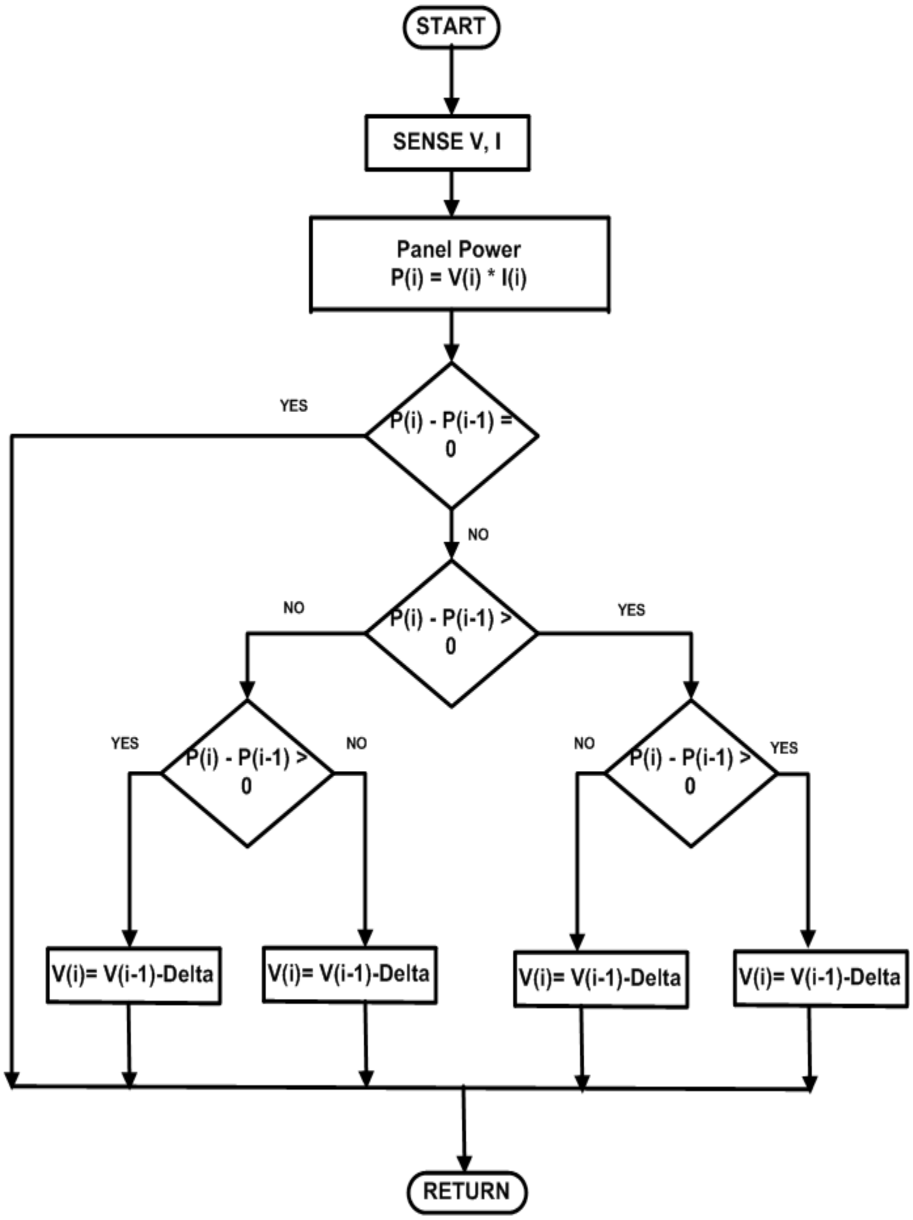

Figure 3.3: Flowchart of P and O technique for MPPT

3.5 Comparison of Different MPPT Techniques

The comparison of different MPPT techniques are shown in the Table 3.1 [14][15][16][17]:

Table 3.1: Comparison of Various MPPT Techniques

Methods	**Advantages**	**Disadvantages**
Fixed Duty Cycle Method	(i) Simplicity. (ii) Use of a PWM method to drive the dc-dc converter. (iii) No feedback signal is required, thus less complexity.	(i) Considerable amount of error is present in the system. (ii) Low efficiency in terms of the extracted power. (iii) Method is not much used now.
Constant Voltage Method	(i) Easily implemented. (ii) Use of a single voltage sensor.	(i) Appreciable steady-state error due to the difference between VPV and OC. (ii) Energy is wasted when no load is connected to the array.
Incremental Conductance Method	(i) Operation close to the MPP. (ii) High tracking accuracy.	(i) Relative complex implementation. (ii) Require two sensors (voltage and current).
Perturb and Observe Method	(i) Variable step size. (ii) Fast and precise technique. (iii) Modification of this technique provides more accurate result.	(i) Requirement of two sensors (voltage and current). (ii) Complex implementation dueto calculation of derivatives. (iii) Lack of fast response in case of rapidly changing radiation. (iv) Oscillation of power takes place around MPP, resulting into power loss.

Chapter 4

Wind Energy Conversion System

Wind energy conversion system (WECS) mainly converts the kinetic energy of the wind, i.e. wind energy, into other usable form of energy or electricity, by means of wind turbines. These wind turbines are connected to the electrical generators for generation of electrical power.

Wind energy is the low quality energy because it has random motion of the wind particles. The wind particles are free to move in any of the direction, i.e. they may move either with the resultant wind direction or in opposite direction.

4.1 Wind Energy

Wind energy is most exploitable form of renewable energy sources. It is simply the form of solar energy which is produced by heating of the surface of earth.

The wind energy is being harnessed over the centuries. In olden times wind mills are used for the wind energy extraction. The blades of the wind mills were oriented to the direction of the wind so that when wind strikes the blades, the blades will move in the direction of wind. They worked on the thrust principle.[21]

The wind speed is very important factor responsible for the amount of energy which a wind turbine can extract. At the earths surface, wind speed is always zero because the sum of the movements of the wind particles moving in different direction is zero. The wind speed increases with the increase in height.

4.2 Power in the Wind

The kinetic energy contained in the wind is turned into the electrical power by the wind power plants. The wind speed is responsible factor for wind power.

The power of the wind at a specified height is specified as Power Density (W/m^2) and the energy in the wind that pass through a vertical area of $1m^2$ during one year (KWh/m^2) is Energy Content in wind[20]

The power in the wind turbine is given by equation 4.1,

$$P_w = \frac{1}{2} * \rho A V^3 \tag{4.1}$$

where:
ρ = Density of air (kg/m^3)
A = Area of cross section of wind parcel (m^2)
V = Speed of wind (m/s)

The value of ρ varies with the height above sea level and temperature. But the standard value of $\rho = 1.25\ kg/m^2$ is usually taken.

From the above equation we can see that wind power is directly proportional to the cube of wind speed, which shows that as wind speed is increased twice the power will be increased by factor eight.

4.3 Wind Turbine

Wind turbines play a very important role in converting the kinetic energy of the wind into the usable form, i.e. electrical form. All wind turbines work on the principle of aerodynamics, i.e. principle of lift forces. The Cut-in speed of wind is 4-5 m/s in the modern wind turbines. When the wind speed exceeds the cut-out speed, i.e. 22-25 m/s approximately, the turbines must be stopped, otherwise overloading may occur and it will damage the turbines component.

4.3.1 Components of wind turbines

- **Tower:** The tower is used to provide the foundation to the entire wind conversion system. The tower should be strong enough to carry the weight of nacelle and the rotor blades. Usually a concrete or steel is used to make tower. As per the rated power of the system which is to be carried by turbines, the rotor diameter and the tower height is chosen.

- **Rotor and Rotor Blades:** The rotor converts the energy in the wind into rotary mechanical movement. Mostly, three blade horizontal axis rotors are used and they are mainly made up of glass-fibre or carbon-fibre. The rotor blades are designed in the specific shape so that the air is forced to flow through them. There is the pressure difference between the upside and downside of the blades which causes the movement of the blade and hence the rotor rotates.

- **Nacelle:** It contains all the machines of turbine, i.e. generator, gearbox etc. and is connected at the top of the tower via bearings.

4.3.2 Types of Wind Turbine

a) Horizontal Axis Wind Turbine (HAWT):

The blades of the turbines rotate on an axis parallel to the ground. They consists of the main rotor shaft and generator at the top of a tower. They contains a gearbox, which increases the rotation of the blades into a faster rotation to drive an generator. The advantages & disadvantages of HAWT are given in table 4.1.

Table 4.1: Advantages and Disadvantages of HAWT

Advantages	**Disadvantages**
Higher efficiency	The generators and its gearbox are mounted on a tower, resulting in difficult servicing.
Lower cost-to-power ratio	More complex design because yaw is needed.

b) Vertical Axis Wind Turbine (VAWT):

The turbines have blades rotating on an axis perpendicular to the ground. They have the main rotor shaft arranged vertically. The generator and gearbox can be placed near the ground, improving accessibility for maintenance. Their advantages & disadvantages are given in table 4.2.

Table 4.2: Advantages and Disadvantages of VAWT

Advantages	**Disadvantages**
Maintenance is simple for generators which are ground mounted.	Not self-starting,thus,require generator to run in motor mode at start.
Wind from any direction is extracted.	Difficulty in controlling blade over-speed.
Blade designing is simple.	Lower efficiency.

4.3.3 Classification of WPP

The WPP are classified as Type A, Type B, Type C and Type D. The different types of WPP are compatible for different working speeds with different types of generators used as the speed range. The classification in tabular manner is given in table 4.3 showing the type of generators used for specified speed range.

Table 4.3: Classification of Wind Power Plants (WPPs)

S.No.	Type of WPPs	Speed Range	Type of Generator Used
1	A	Constant speed (1%, 2 % variability)	Squirrel cage induction Generator (SCIG).
2	B	Narrow range variable speed (0% 10 % variability)	Wound rotor Induction Generator (WRIG).
3	C	Limited range variable speed (-40% - 30% variability)	Doubly-fed Induction Generator (DFIG).
4	D	Wide range variable speed (2.5 times the rated speed)	Permanent Magnet Synchronous Generator (WRIG).

4.3.4 Permanent Magnet Synchronous Generator (PMSG) based Wind Energy Conversion System (Type-D)

A permanent magnet synchronous generator is a type of synchronous generator, where the field is excited by using permanent magnet in place of a coil. The rotor and stator magnetic field rotates with the same speed; hence they are referred under the category of synchronous machines. The synchronous speed is given by,

$$N_s = \frac{120 * f}{P} \tag{4.2}$$

where:

f = frequency of electric supply (50 Hz)

P = Total number of poles of machine per phase.

Advantages of using PM in synchronous Generator:

- No external dc supply is required for the excitation circuit.
- Slip rings are avoided, so it have simple construction, maintenance free.
- No condensers are required for maintaining pf.

Disadvantages of using PM in Synchronous Generator:

- Using large PM will result into costly system.
- The performance of PMs gets affected by heat.

PMSG is now playing much attention in the wind energy applications because of its self-excitation capability which leads to high power factor of system and results into the high efficiency operation. The permanent magnets are mounted on the rotor. The air gap between the stator and rotor is reduced for increasing the efficiency and for minimising the amount of magnetic materials needed. PMSGs are mostly used for low power, low cost requirements.[22]

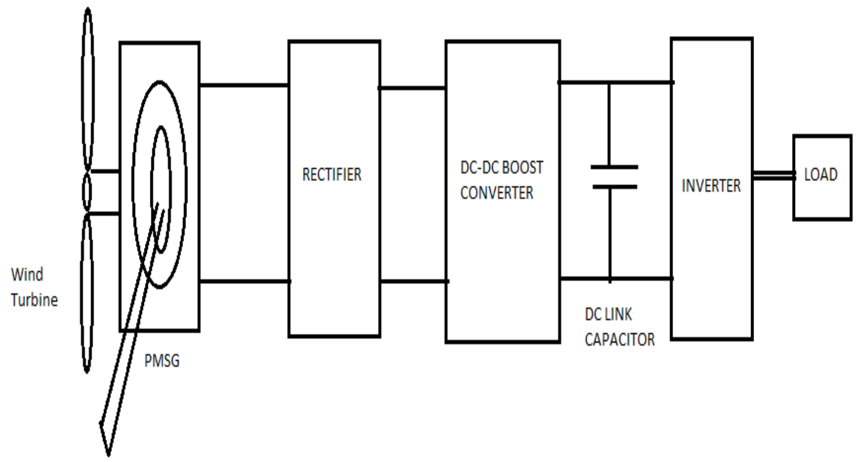

Figure 4.1: Basic block diagram of stand-alone wind system

The figure above shows the basic block diagram of WPP. It consists of a wind turbine converting the kinetic energy of the wind into the form acceptable by PMSG. The output of PMSG is rectified by means of uncontrolled rectifier which converts the ac into dc form and the output of rectifier is again fed to the dc to dc boost converter for obtaining constant dc voltage. The ripple in the dc link voltage is controlled by means of dc link capacitor. This approximately constant dc voltage is converted back into to the fixed ac by inverter and is connected to the appropriate load.

Chapter 5

Hybrid Energy System

Since the global warming is increasing day by day, so the concern regarding environmental issues are increased which results into the evolution of generation of green power. The hydro power is most useful and vast source used for the production of clean energy but other than these sources, wind and solar are the two most common sources to meet the required demands. Both the solar and wind can produce the sufficient amount of power but their behaviour can not be easily predicted and hence using them alone is bit unreliable. But by combining them together as hybrid system and applying the MPPT technique will result into the more efficient system[23].

The basic block diagram of wind and solar PV hybrid system is shown in Fig.5.1. Both the solar and wind energy systems are connected in parallel having their individual dc boost converters. The output of the two dc boost converters are connected in parallel and supplied to the common inverter. The output of inverter is fed to the load. This common inverter configuration will result into the reduced cost of the system. The output of the inverter is made smoother and sinusoidal by means of LC filter at the output end.

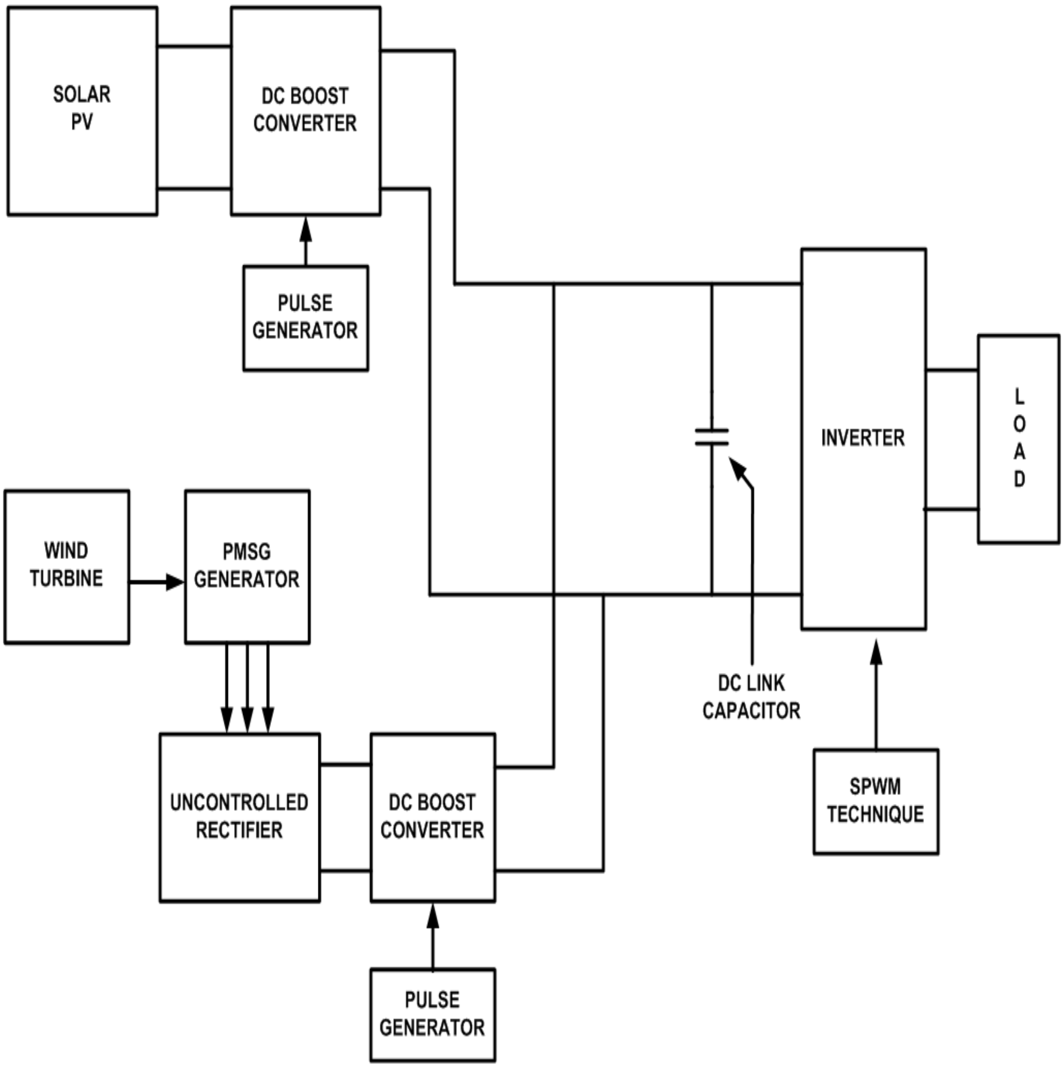

Figure 5.1: Block diagram of hybrid system

Chapter 6

Simulation and Results

The Wind and PV Hybrid Energy System contains the simulation of entire wind and solar PV systems together in MATLAB simulink software.

6.1 PV system without applying MPPT Technique

The combined system consists of boost converter and the inverter. The gating signal of boost converter is given by pulse generator. The output of the boost converter, i.e., the dc link voltage is to be maintained at constant value, which will act as a input to the inverter. The inverter gating is controlled by the SPWM technique having triangular wave as a carrier wave.

Considering close loop system the variable load will cause the fluctuations in the dc link voltage resulting into the huge voltage fluctuations at the inverter output. To reduce such voltage fluctuations at the load side, the output of dc link is compared to its reference value and the error is passed through the PI controller. The main function of the PI controller is to reduce the error and to tune the system for taking care of any load variations. The output of the PI is then combined with the gating signals of the inverter resulting into the proper ac output.

In this system the input side variations are not considered. The system may or may not operate on the maximum power offered by the panel. The efficiency of the system will be less.

The simulation is done under the MATLAB SIMULINK software. The block diagram of the PV system having no PI controller is shown in Fig. 6.1 and the simulation results are shown below:

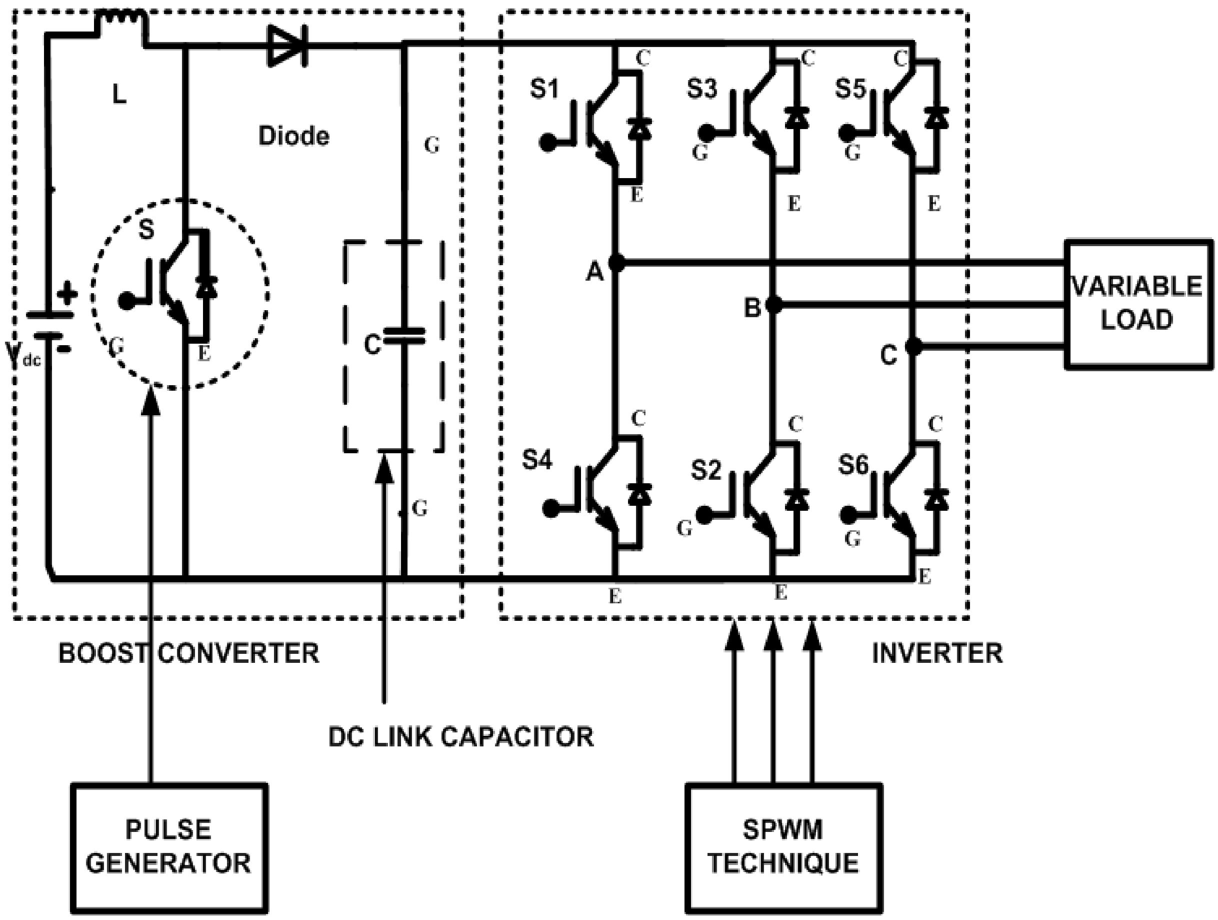

Figure 6.1: Block diagram of PV system with variable load without PI

The load is changed at 2sec and 4sec. With the change in load the output current also changes as shown in Fig. 6.2:

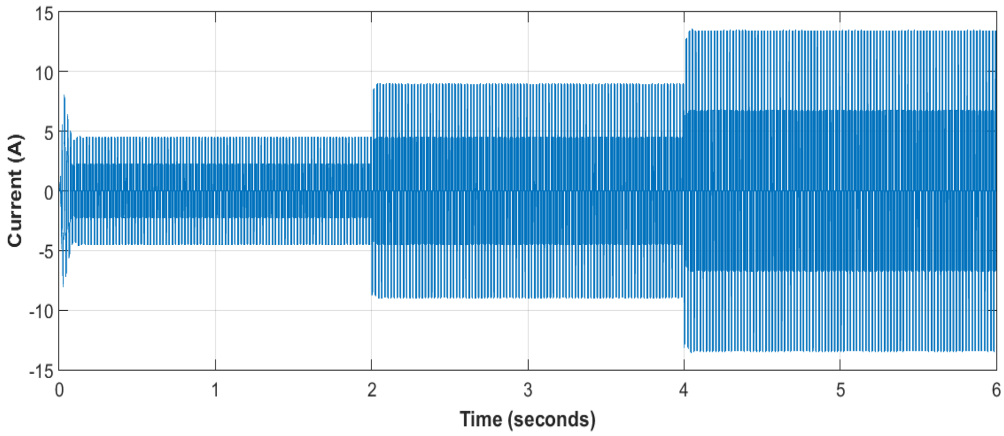

Figure 6.2: Load current of PV system without PI

As the load changes, the dc link voltage is getting disturbed and is not maintained at the constant value when the PI controller is not used in the system. This variable dc link voltage waveform in shown in Fig. 6.3:

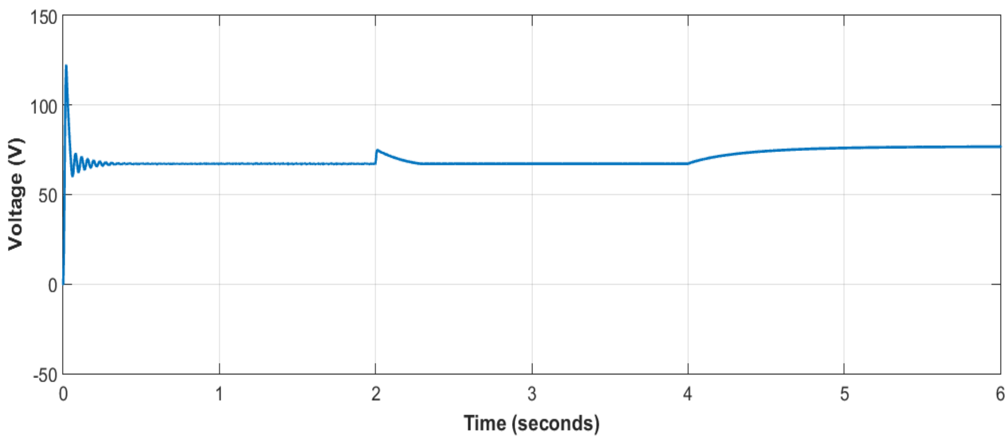

Figure 6.3: Change in DC Link voltage of PV system without PI

The output phase voltage of the combined system is also changing with change in load. The simulation result of the same is shown in Fig. 6.4:

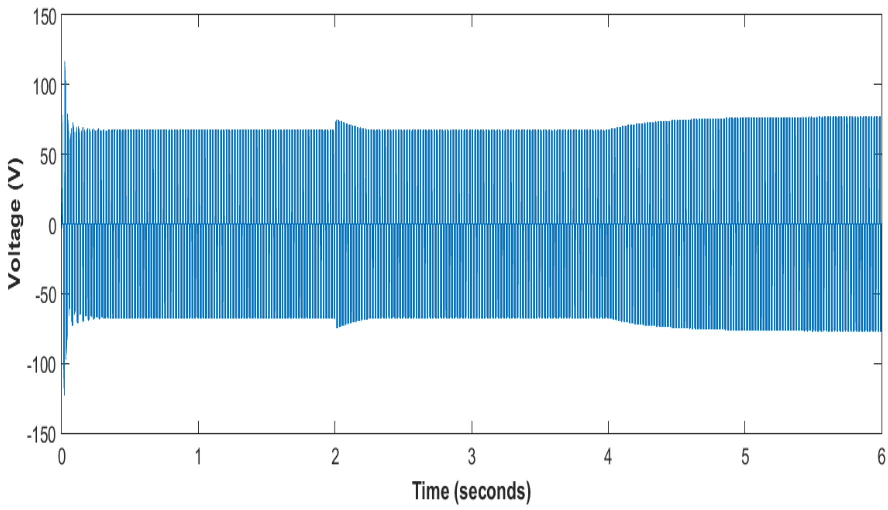

Figure 6.4: Output phase voltage of PV system without PI

To make this variable dc link voltage to a constant value, PI controller is used is the system in the output loop, which is tuned in such a way that the dc link voltage should always have constant voltage irrespective of load variations. The block diagram of the system having PI implementation is shown in Fig. 6.5.

The error signal is generated by comparing the reference value of dc link to the actual value obtained in the system. This error is subjected to the input of the PI controller. The PI tuning is done in order to reduce this error to approximate zero value.

The pulse generator is used to generate the pulses for the switch used in boost converter. The inverter switching is generated by using SPWM technique for all the three legs of two level inverter used in the system.

The small oscillations will be observed in the voltage waveforms of the boost converter and inverter output at the instant of the load change, but it will automatically settle down to the steady state value because of the tuned PI controller. The main objective of PI controller used at the output side of the system, is for maintaining the boost converter output and inverter output voltage at constant value.

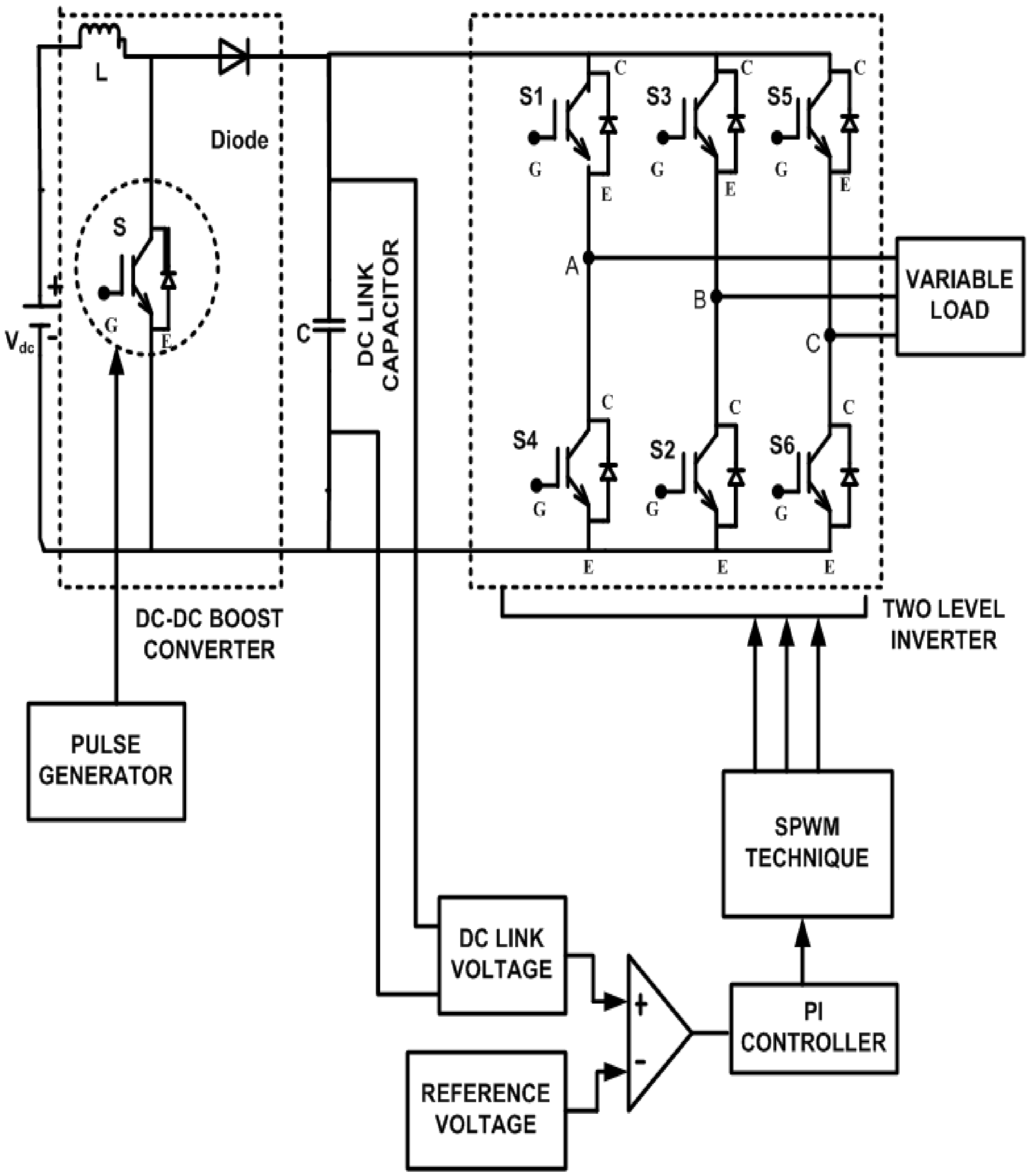

Figure 6.5: Block diagram of PV system connected to the variable load having PI

The block diagram of control scheme used for generating the pulses of the inverter switches for one leg is shown in the Fig. 6.6. The generation of gate signals are done by using SPWM technique. The actual dc link voltage sensed, is compared to the reference value set. The error signal thus generated will be given to the PI controller. Pi controller will generate the dc value. The output dc value obtained is then multiplied by the sin component with zero degree phase shift, resulting into the sinusoidal wave. Thus, the obtained sin wave is then compared with the triangle for generation of gate pulses. Similarly, the gate pulses are obtained for the two other legs by shifting the sin component by 120^0 and 180^0 respectively.

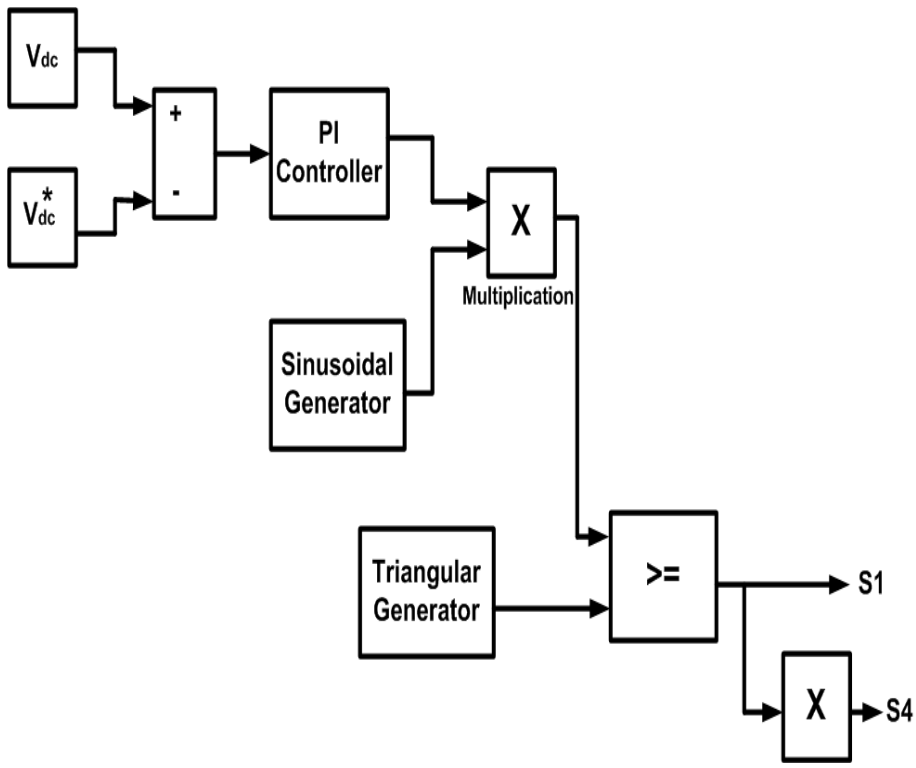

Figure 6.6: Block diagram of control scheme for inverter switches for Leg-A

The dc link voltage after the PI implementation is almost constant as shown in Fig. 6.7 irrespective of the load variations in the system.

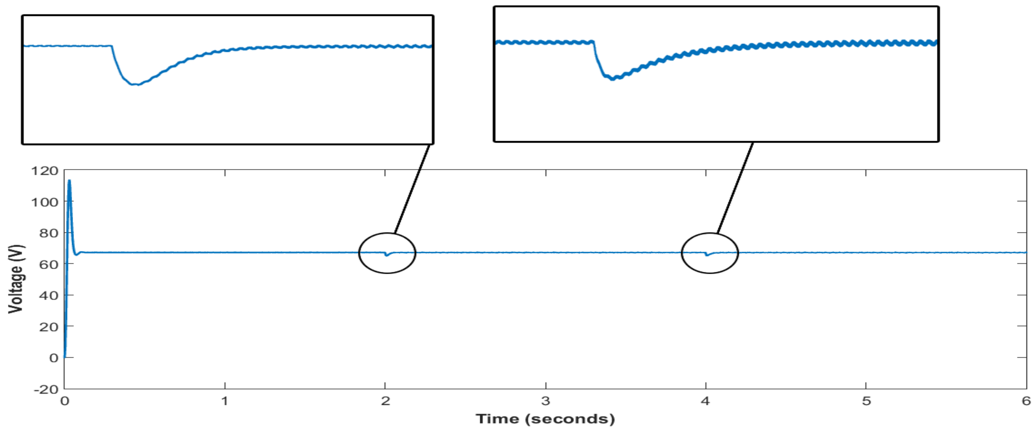

Figure 6.7: Capacitor voltage (dc link voltage) with PI implementation

The output phase voltage waveform at steady state of the combined system, after the PI implementation is shown in Fig. 6.8:

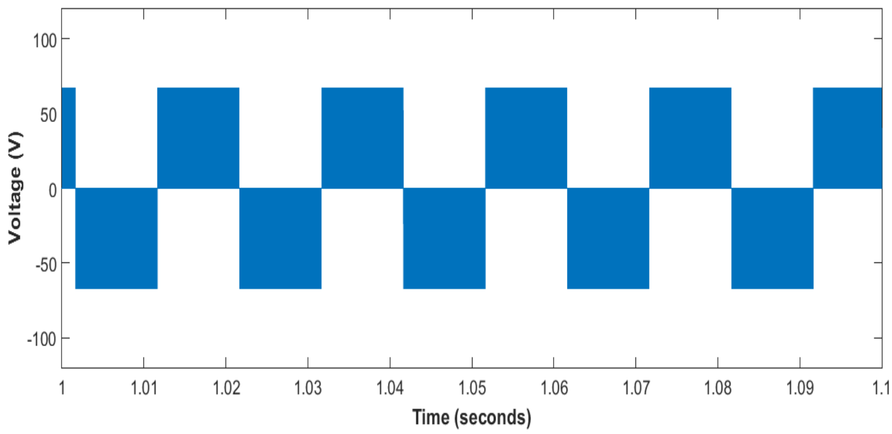

Figure 6.8: Output phase voltage with PI

6.2 PV system along with the MPPT Technique

The MPPT technique is used to extract the maximum power from the PV panel so that the panel work with its full efficiency. For simulation results, PV panel is connected at the input side of the system. The output of the panel is connected to the boost converter. The gating signal of the boost converter is now being controlled by the output provided by MPPT. Simply we can say that the duty cycle of converter is managed by MPPT technique.

The MPPT technique is applied at the input side in order to control the input side variations as shown in the Fig 6.9, while the PI is tuned at the output side of the inverter which is useful for controlling the variations in the load. The converter and inverter are connected via DC link, whose voltage is to be maintained constant by means of PI tuning.

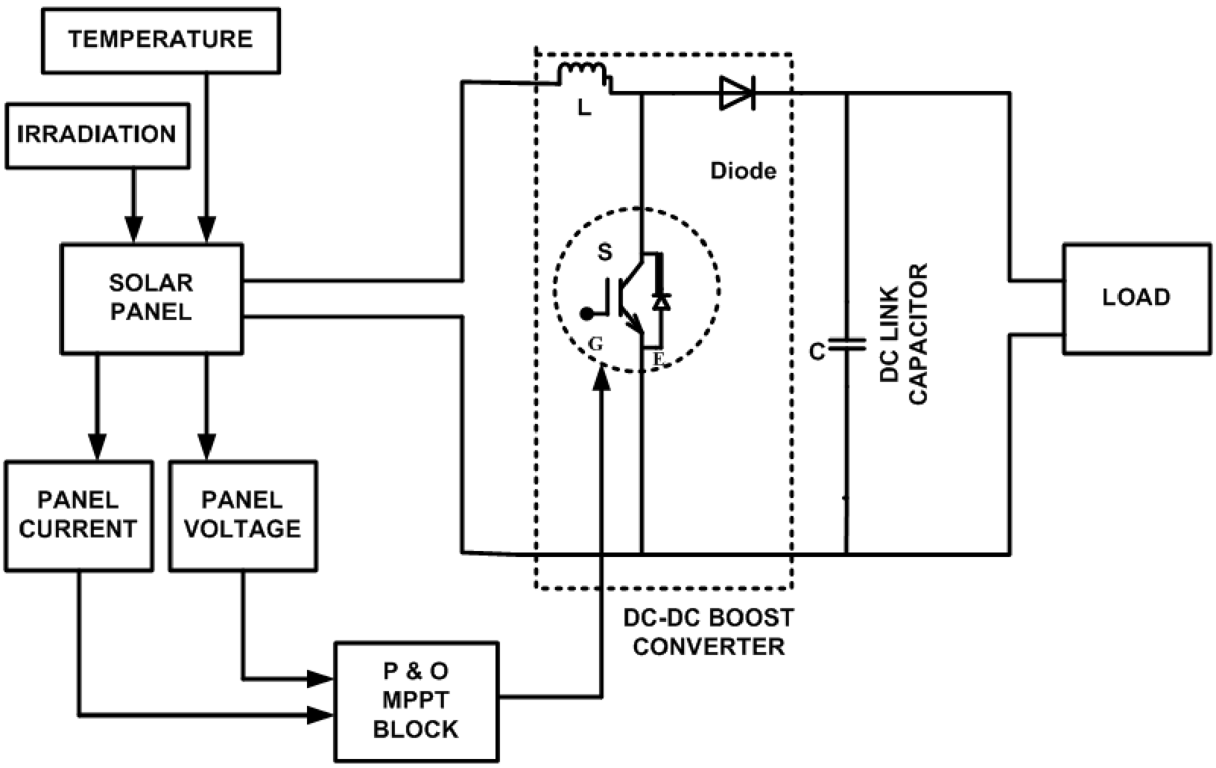

Figure 6.9: Block diagram of boost converter with MPPT technique

The panel used for the simulation purpose have rated power of 40W. The rated voltage and rated current mentioned are 17.40 V and 2.30 A respectively. The output produced by the solar PV panel is a dc value. Fig. 6.10 and Fig. 6.11 shows the waveform of panel voltage and panel current obtained when the two PV panels are considered to be connected in parallel.

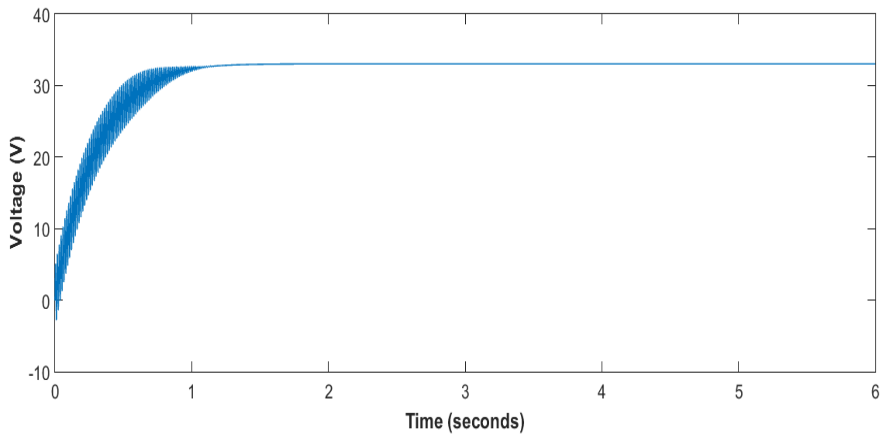

Figure 6.10: Output Voltage of the Solar PV Panel

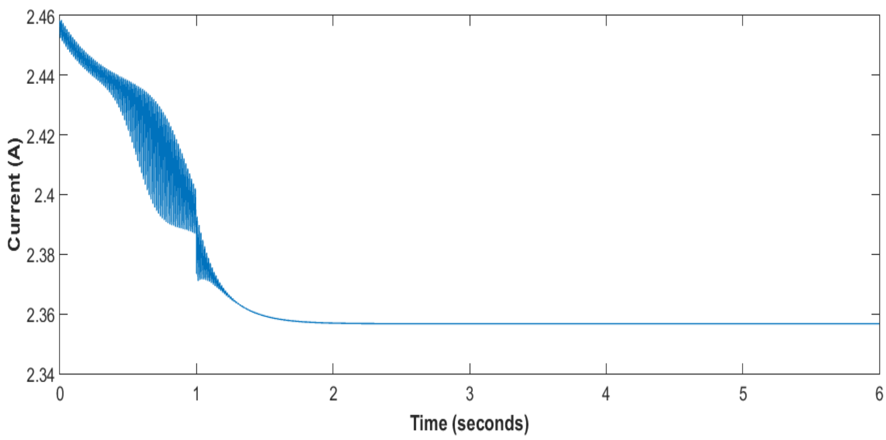

Figure 6.11: Output Current of the Solar PV Panel

The maximum power rating of the panel used is 80W. After applying the MPPT technique it can be seen in the Fig 6.12 that the output power received by the panel is approximately 80W, i.e. the maximum power is extracted from the system by means of P&O MPPT method. The input side variations are constant, i.e. steady state condition. Also the DC link voltage obtained is a constant value as shown in Fig. 6.13, so the converter is boosting the input voltage applied to the system.

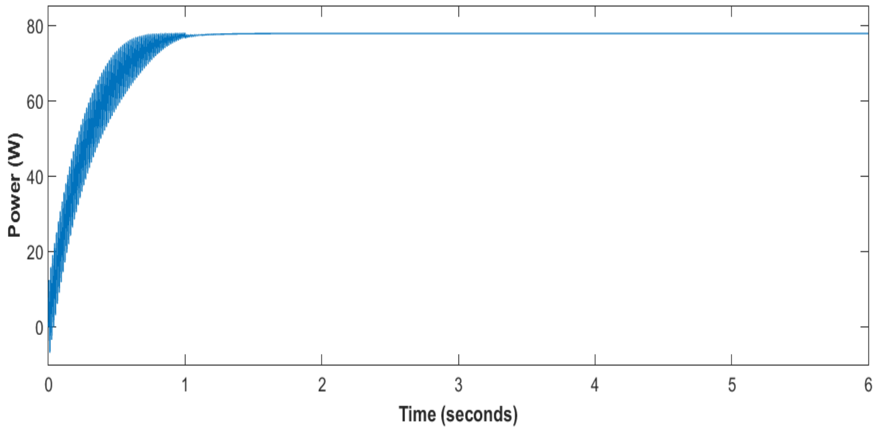

Figure 6.12: Panel output power after applying MPPT (for converter only)

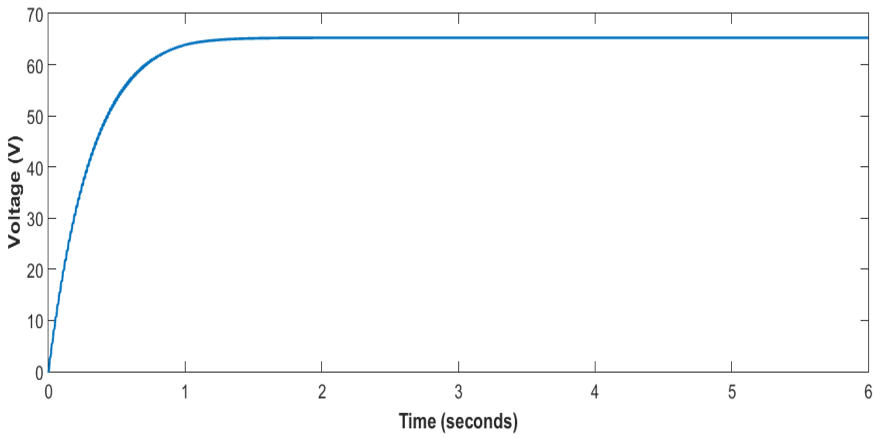

Figure 6.13: Constant DC Link voltage with MPPT technique (for converter only)

The boost converter is connected to the inverter for converting the obtained dc value into ac value along with the MPPT technique as shown in Fig. 6.14. The system is operated at steady state condition, i.e. the input atmospheric parameters are not varied and also the load considered is fixed. The RL load is considered for simulation. The maximum power is extracted from the system resulting into the efficient output of the system.

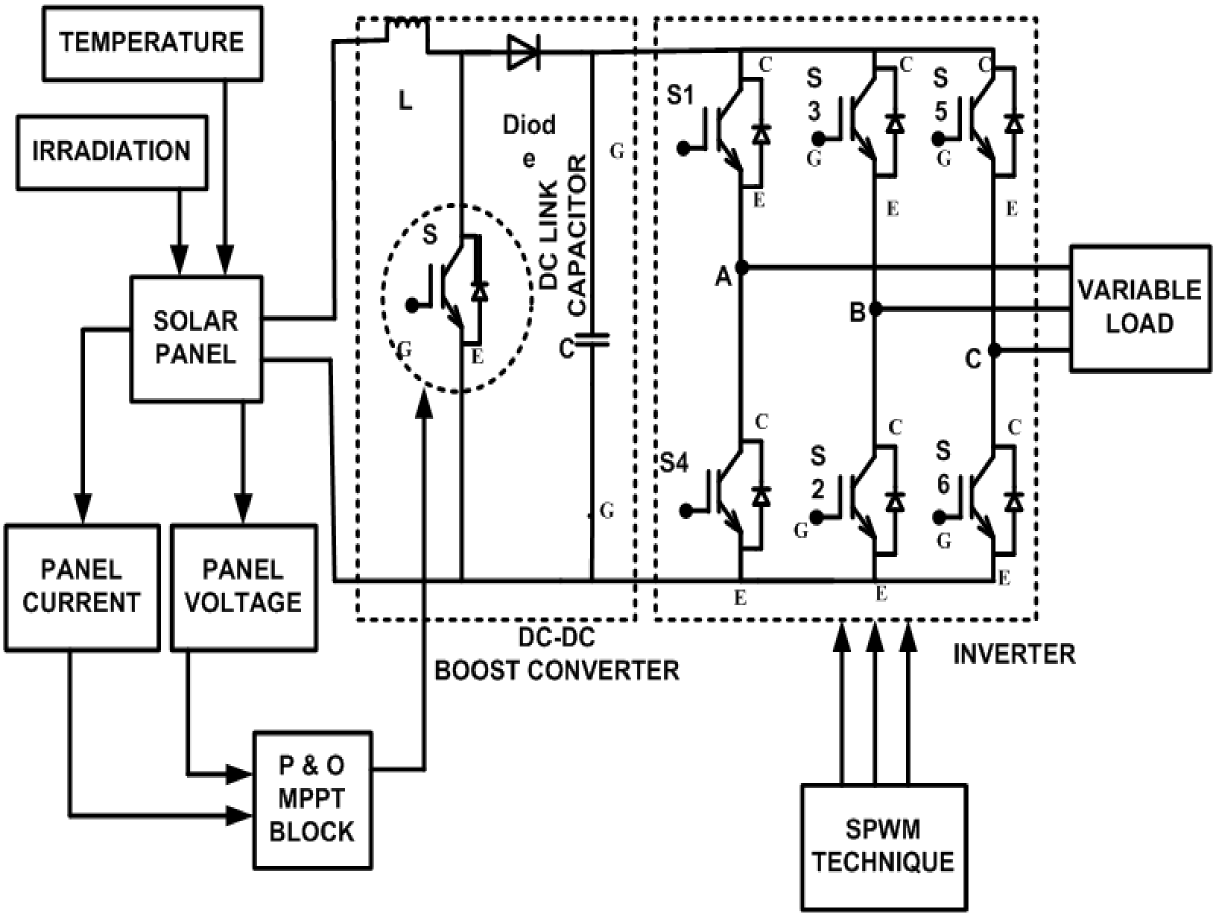

Figure 6.14: Block diagram of PV system with MPPT technique having RL load at steady state

The output voltage and output current produced by the panel is shown in the Fig. 6.15 and Fig. 6.16 respectively.

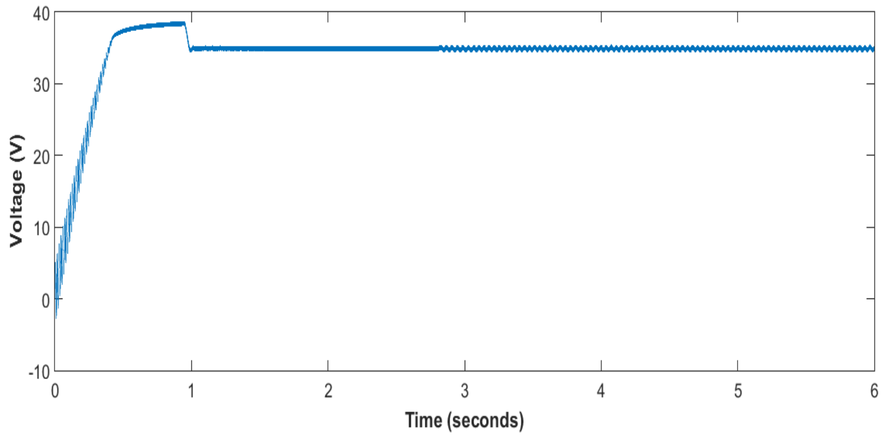

Figure 6.15: Output voltage of PV panel

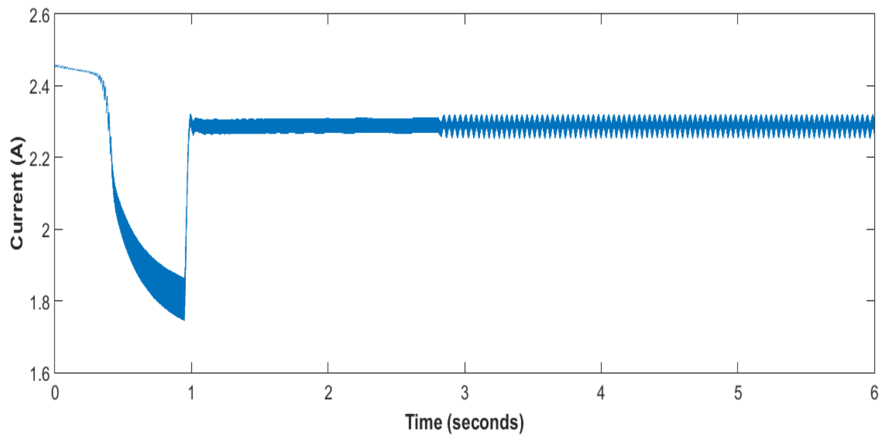

Figure 6.16: Output current of PV panel

After the application of MPPT technique, the power extracted from the panel is approximately equal to the rated value, i.e. 80W, as shown in Fig. 6.17, showing that the maximum power is extracted from the system.

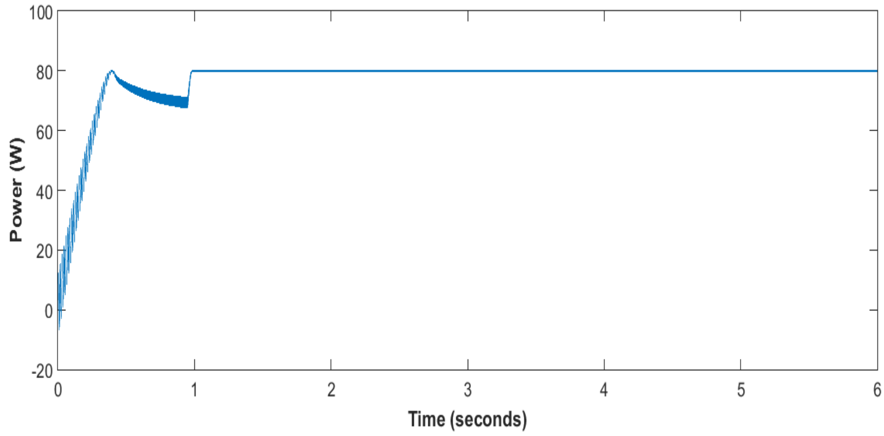

Figure 6.17: Panel output power of PV system with MPPT having RL load

The MPPT technique used, is suppose to control the duty cycle of the boost converter. The dc link voltage is suppose to have value approximately equal to 67 V, which is not coming. Thus, MPPT is not able to control the duty cycle properly. The dc link voltage is shown in Fig. 6.18:

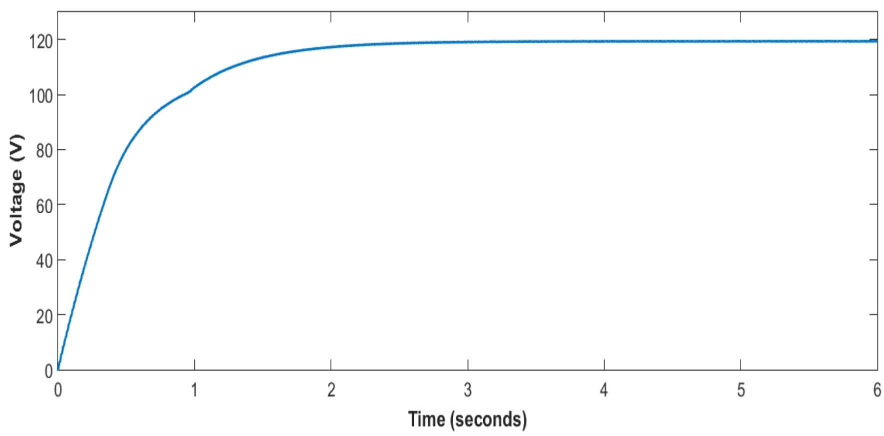

Figure 6.18: Constant DC Link voltage of PV system with MPPT technique having RL load

The waveform of output phase and line voltage is shown in Fig. 6.19 and Fig. 6.20, having RL load associated with the MPPT technique. The constant voltage is being obtained at the output of the system.

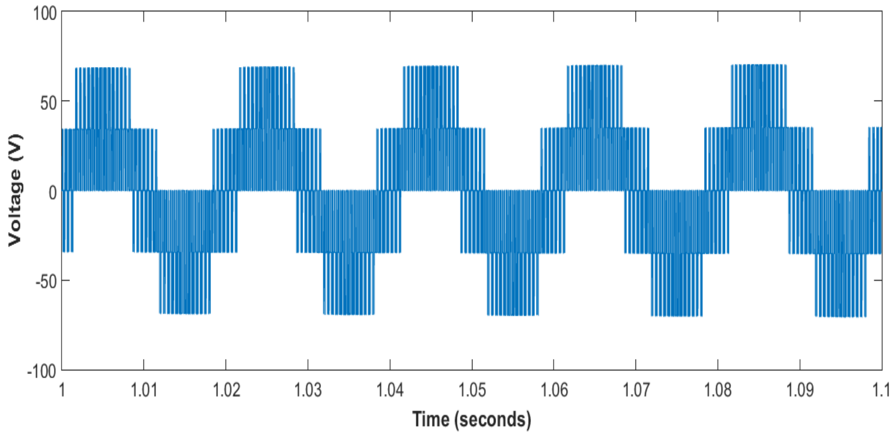

Figure 6.19: Output phase voltage of PV system with MPPT having RL load

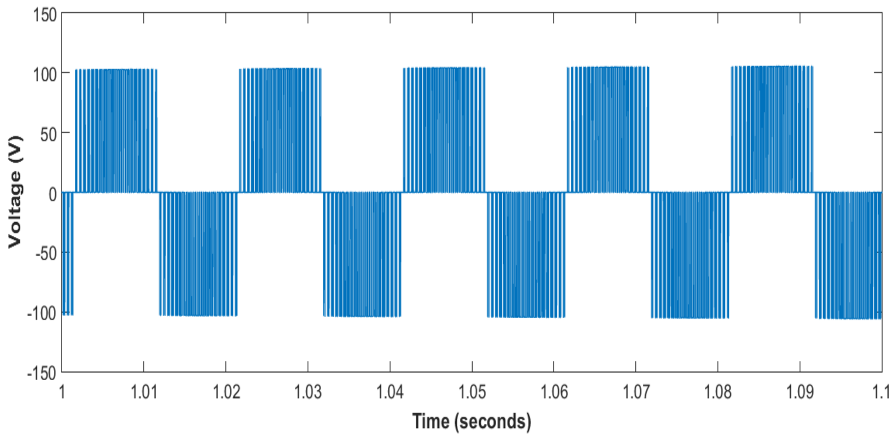

Figure 6.20: Output line voltage of PV system with MPPT having RL load

The waveform shown in the Fig. 6.21, shows the output load current. The sinusoidal current is being obtained due to the inductive part of the load having current ripples in tolerable limits. The ripples can also be reduced by properly setting the resistor and the inductor value or by using the filter at the output of the system if required.

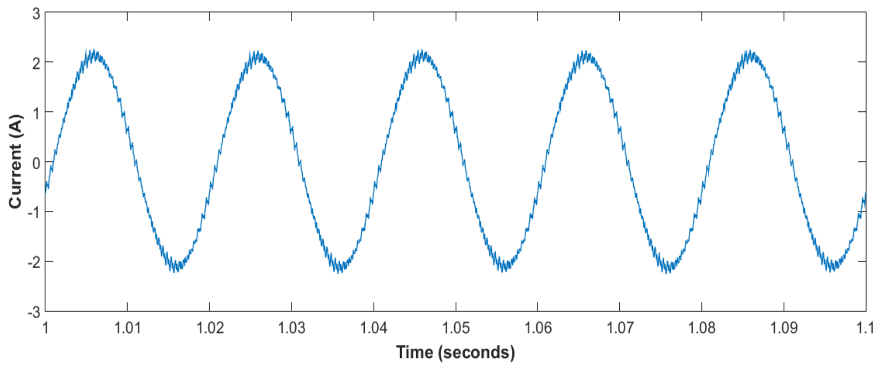

Figure 6.21: Output current of PV system with MPPT having RL load

Currently the MPPT technique is working for the steady state condition only, i.e., when the irradiation and temperature at the input side remains constant. The FFT analysis of output load current is also done showing that the THD is 4.18%. The THD should be lower than the 5% according to the IEEE standards. The FFT window is shown in Fig. 6.22:

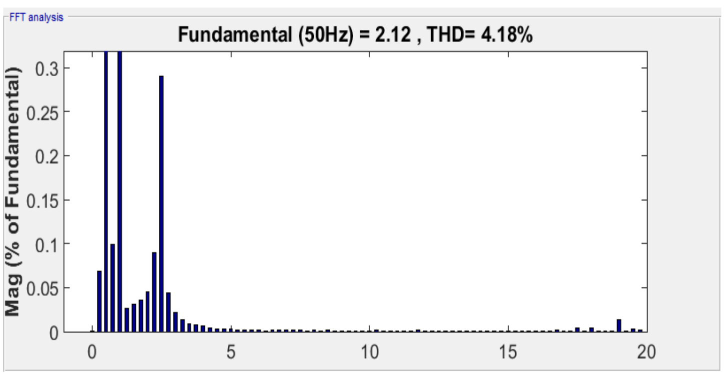

Figure 6.22: FFT analysis of output load current of PV system with RL load

6.3 Input Loop Controlling of Solar PV System using PI Controller

The inverter output obtained by the PV system should always have a constant value. The inverter output either varies due to the variation in the input parameters, i.e. solar irradiation and temperature, or variation in the output load end. The output load variation is taken care, by tuning the PI at the output side. To maintain the dc link constant another PI controller is used at the input side to fix the dc link voltage value as required. The block diagram of input loop controlling having PI is shown in the Fig. 6.23.

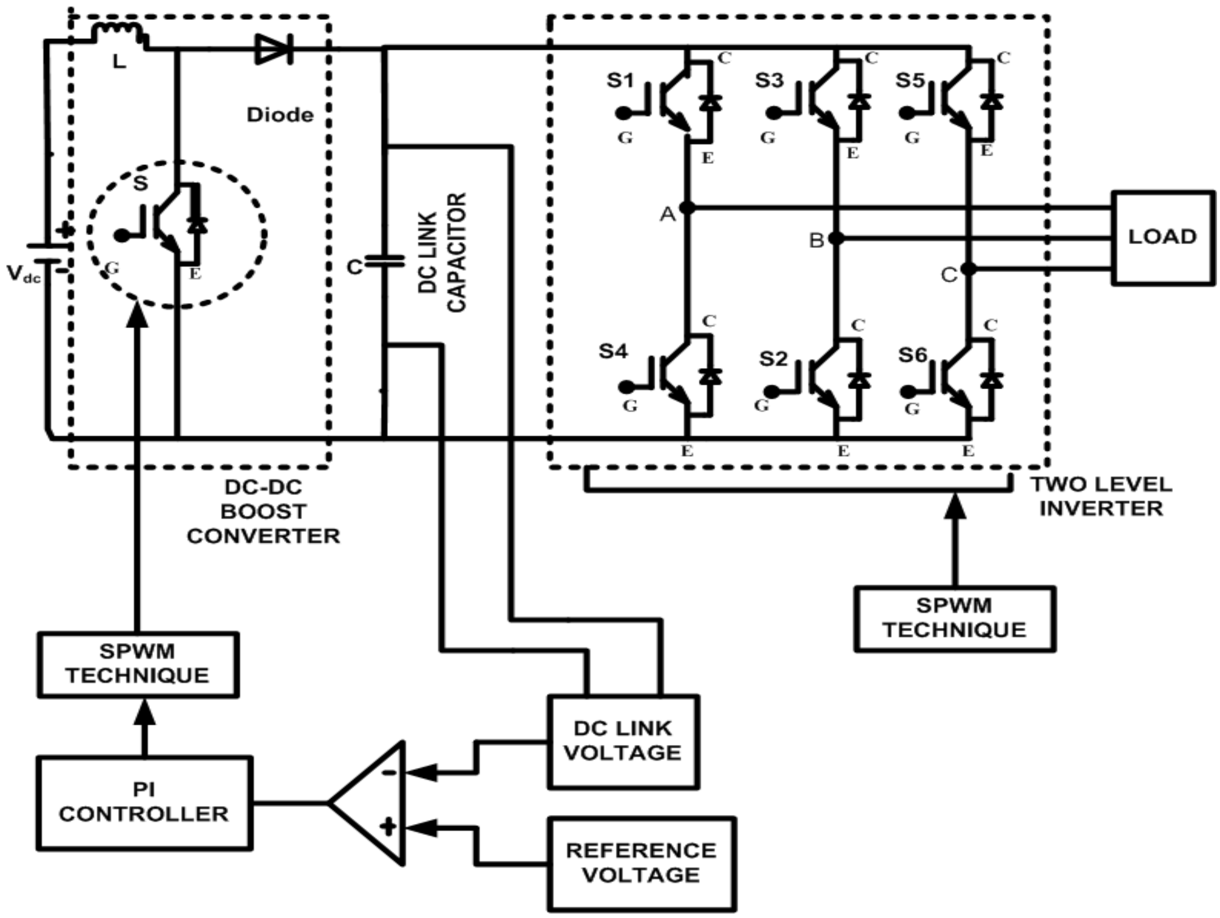

Figure 6.23: Block diagram of PV system having PI in the input loop

The output of the boost converter obtained have a fixed dc value. The dc link voltage is shown in the Fig. 6.24, having PI controller.

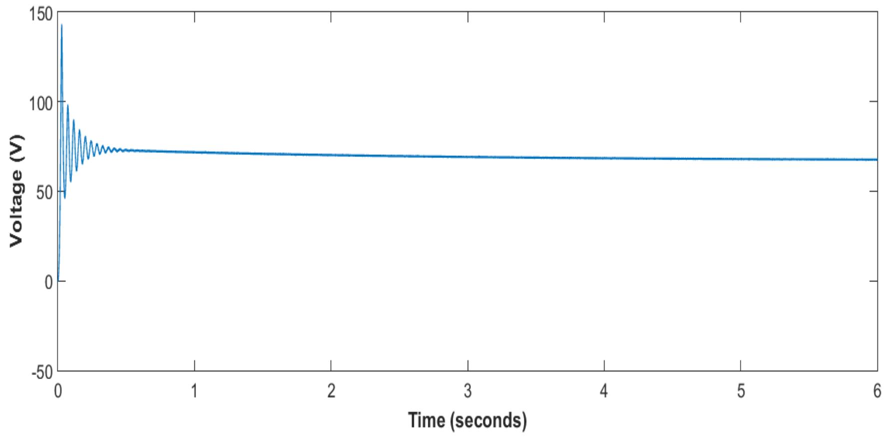

Figure 6.24: DC Link voltage with PI controller having RL load

The inverter output voltage obtained is shown in the Fig 6.25:

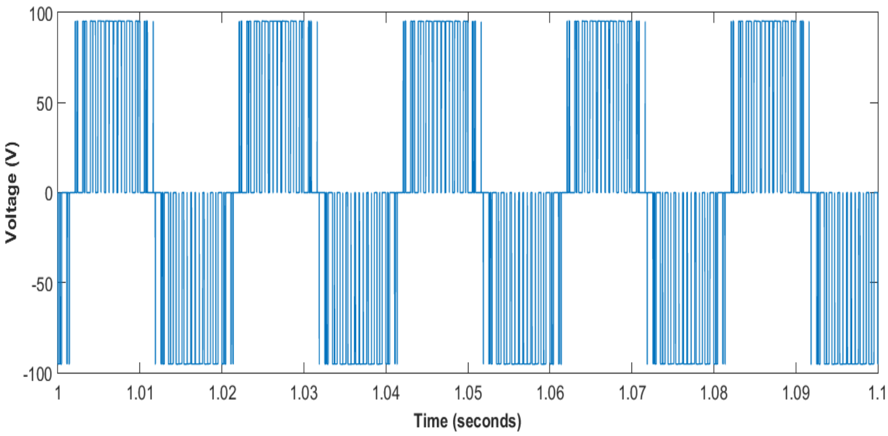

Figure 6.25: Inverter Output Voltage with PI controller having RL-load

The inverter output current obtained is shown in the Fig 6.26:

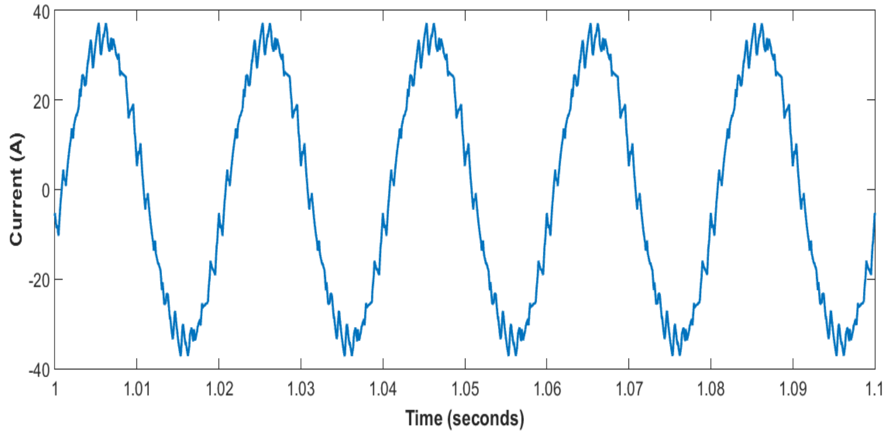

Figure 6.26: Inverter Output Current with PI controller having RL-load

The FFT analysis of the load current is shown in the Fig 6.27, having THD approximately equal to 7%. This value can be reduce to less then 5% as per the norms of the IEEE by using the filters. It is clearly shown that the 19^{th} order harmonic is the dominant harmonic in the system, which can be reduced by designing the filter properly.

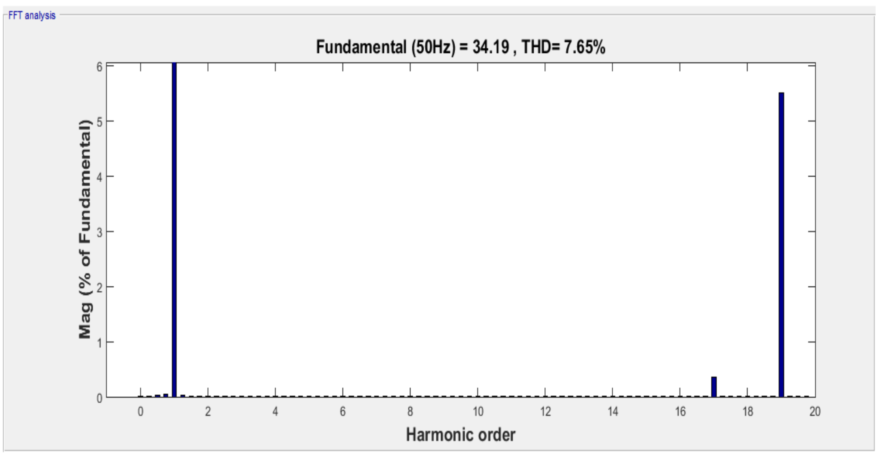

Figure 6.27: FFT analysis of load current of Solar PV system having PI controller

6.4 Wind System

Wind energy conversion system consist of a wind turbine, PMSG, rectifier, dc-dc boost converter and inverter. The generator speed and wind speed are the inputs to the turbine, also we can input the pitch angle of the blades. The output of the turbine will be generated as per the entered data which is per unit torque (equal to the power generated, because pu torque is equal to pu power). This power is entered into the PMSG producing three phase voltage which is given to the uncontrolled rectifier. The rectifier output is passed through the dc-dc boost converter to obtain the constant dc voltage which is fed to the inverter. The inverter is connected to resistive load in this simulation.

The electrical and technical specifications which are used for the simulation purpose of the wind system are mentioned in the Table 6.1 and Table 6.2.

Table 6.1: Technical specifications of wind turbines of 600 W

Parameters	Data
No. of blades	2
Diameter	2m
Material	Fiber-glass & Carbon fiber
Direction of rotation	Anti-clockwise
Control System	Electronic regulator

Table 6.2: Electrical specifications of wind turbine of 600 W

Parameters	Data
Alternator	Three phase permanent magnet
Magnet	Ferrites
Nominal Power	600 W
Nominal Speed	1000 rpm
Regulator	12 V, 60 A

The entire simulation for the system is done by taking the above data. The block diagram of the proposed wind system is shown in Fig. 6.28:

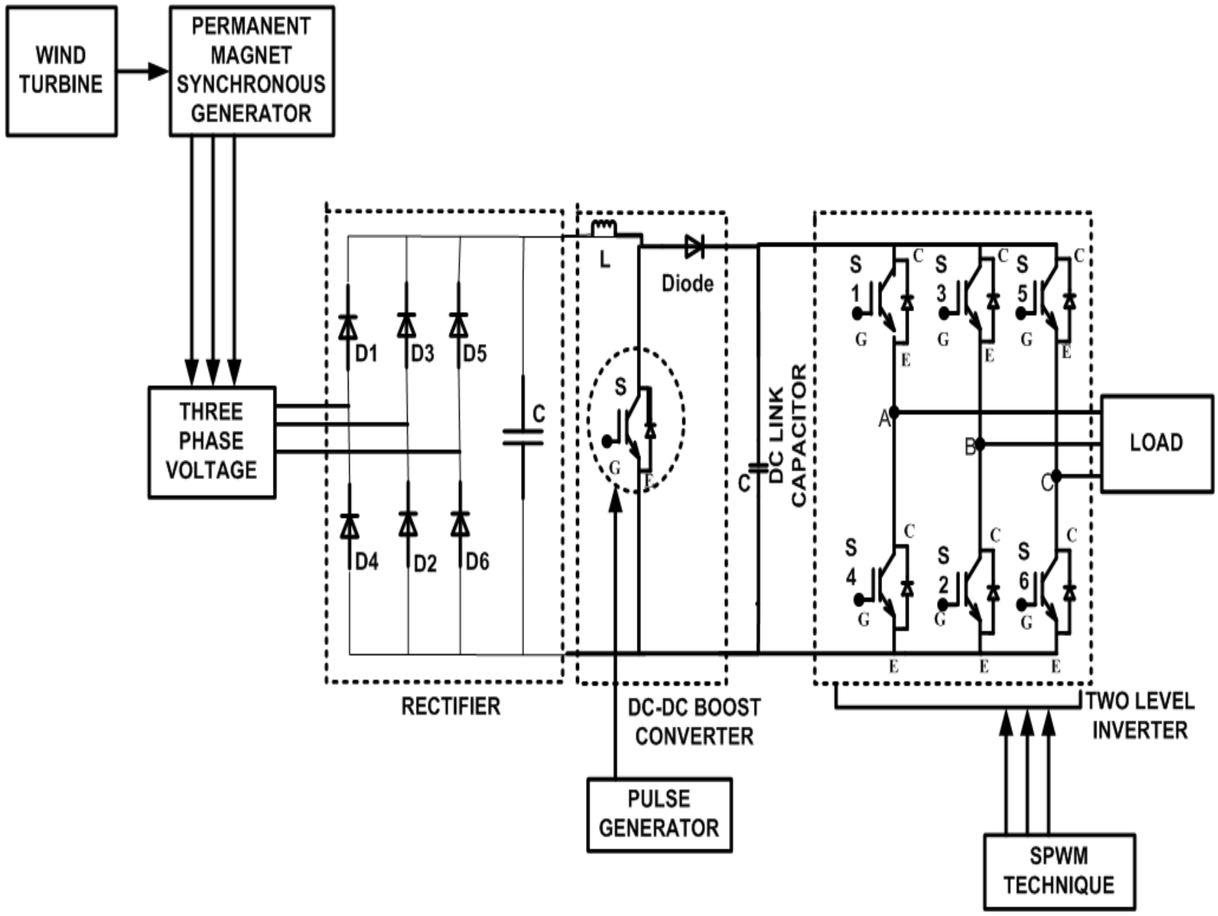

Figure 6.28: Block diagram of wind system

The wind plant produce the ac output which is first converted into fluctuating dc value by means of uncontrolled rectifier used. This fluctuating dc value is then converted into the fixed dc by using dc to dc boost converter. The output of the boost converter is fed to the two level inverter producing the ac output. The inverter output is then fed to the ac loads.

The PMSG is used in the simulation considering all the above parameters. The waveform of rotor speed considering wind speed of 12m/s is shown in the Fig. 6.29:

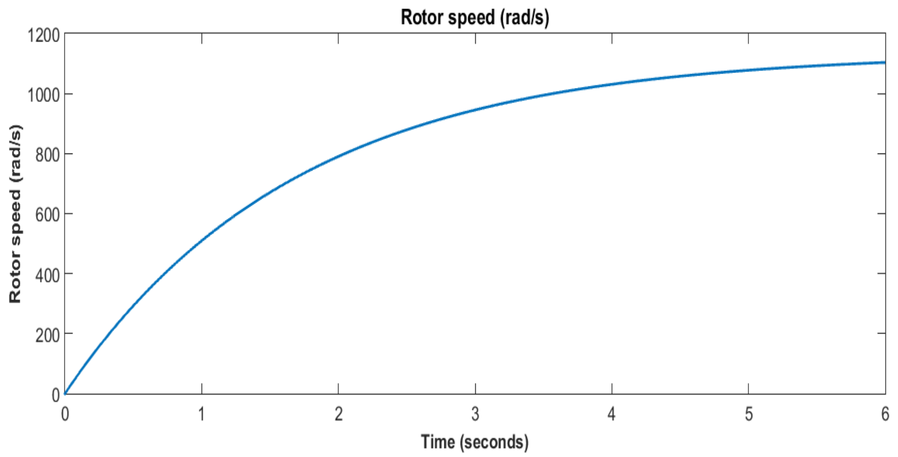

Figure 6.29: Rotor speed at Wind speed of 12m/s

The output voltage produced by the PMSG is shown in Fig. 6.30. The voltage produced is not perfect sin wave but its is alomost of sinusoidal nature. This three phase voltage is fed to the rectifier to produce fluctuating dc value.

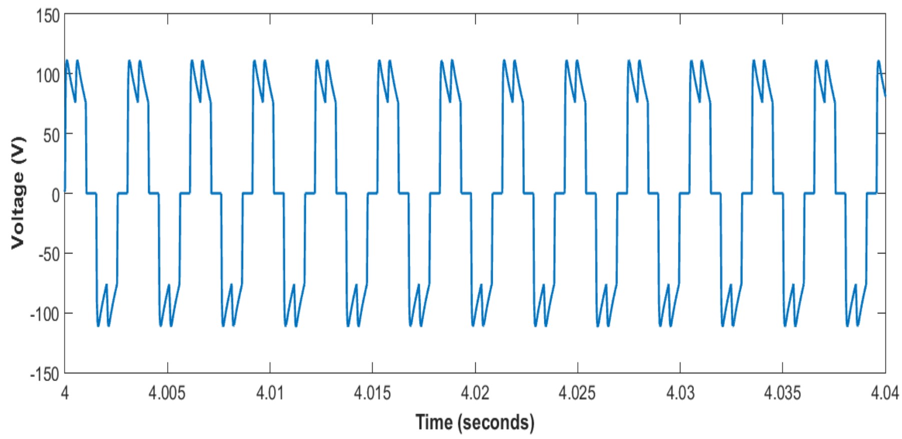

Figure 6.30: Output voltage produced by PMSG

The output produced by the rectifier is of fluctuating value as shown in the Fig. 6.31:

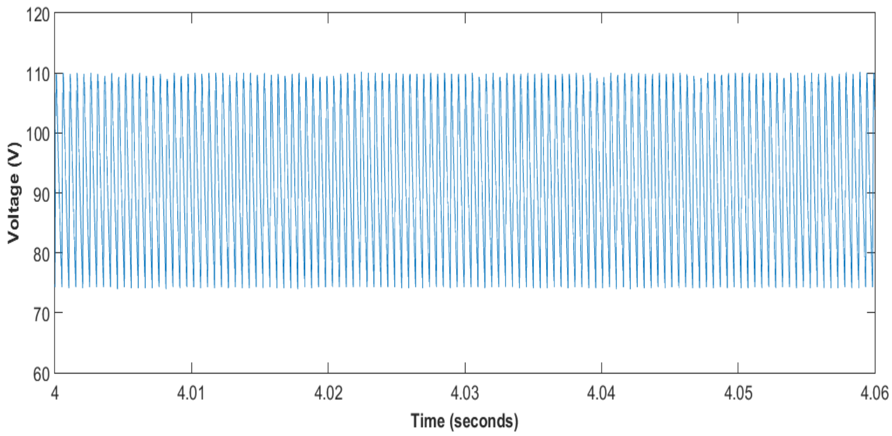

Figure 6.31: Rectifier output voltage of wind system

The output produced by dc to dc boost converter is shown in Fig. 6.32:

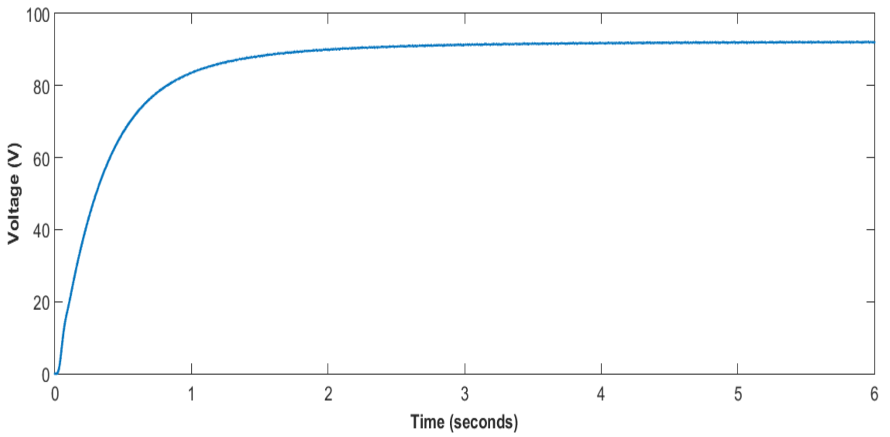

Figure 6.32: Constant DC Link voltage of wind system

For ac loads, the output is converted into ac quantity. The output waveform of the inverter with resistive load is shown in Fig. 6.33:

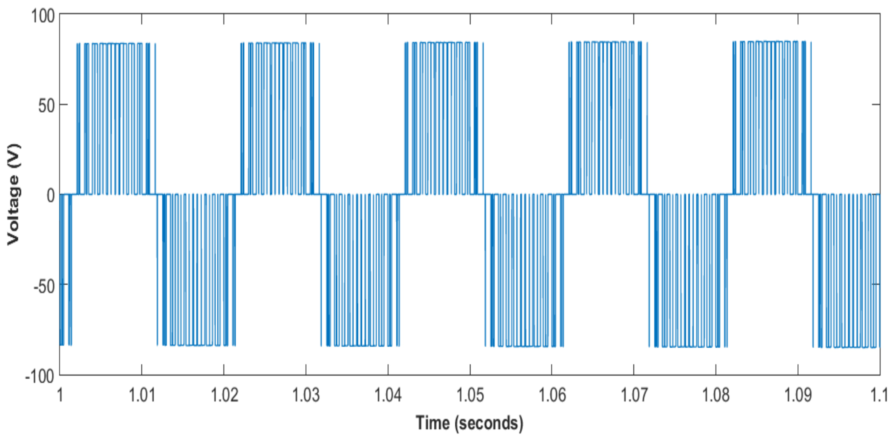

Figure 6.33: Output voltage of inverter of wind system

6.5 Wind & Solar Hybrid System

The hybrid system is basically the interconnection of both wind system and solar system in parallel mode. Both the systems have their own individual boost converters, for maintaining their dc link constant. If the dc link is maintained to a constant value, then it will be easy to interconnect both the systems in parallel to that constant voltage node, i.e. the wind plant and solar plant is interconnected at this common dc link. The common inverter configuration is used in the system at the output end, in order to reduce the cost of the hybrid system. The entire block diagram of the hybrid system is shown in Fig. 6.34:

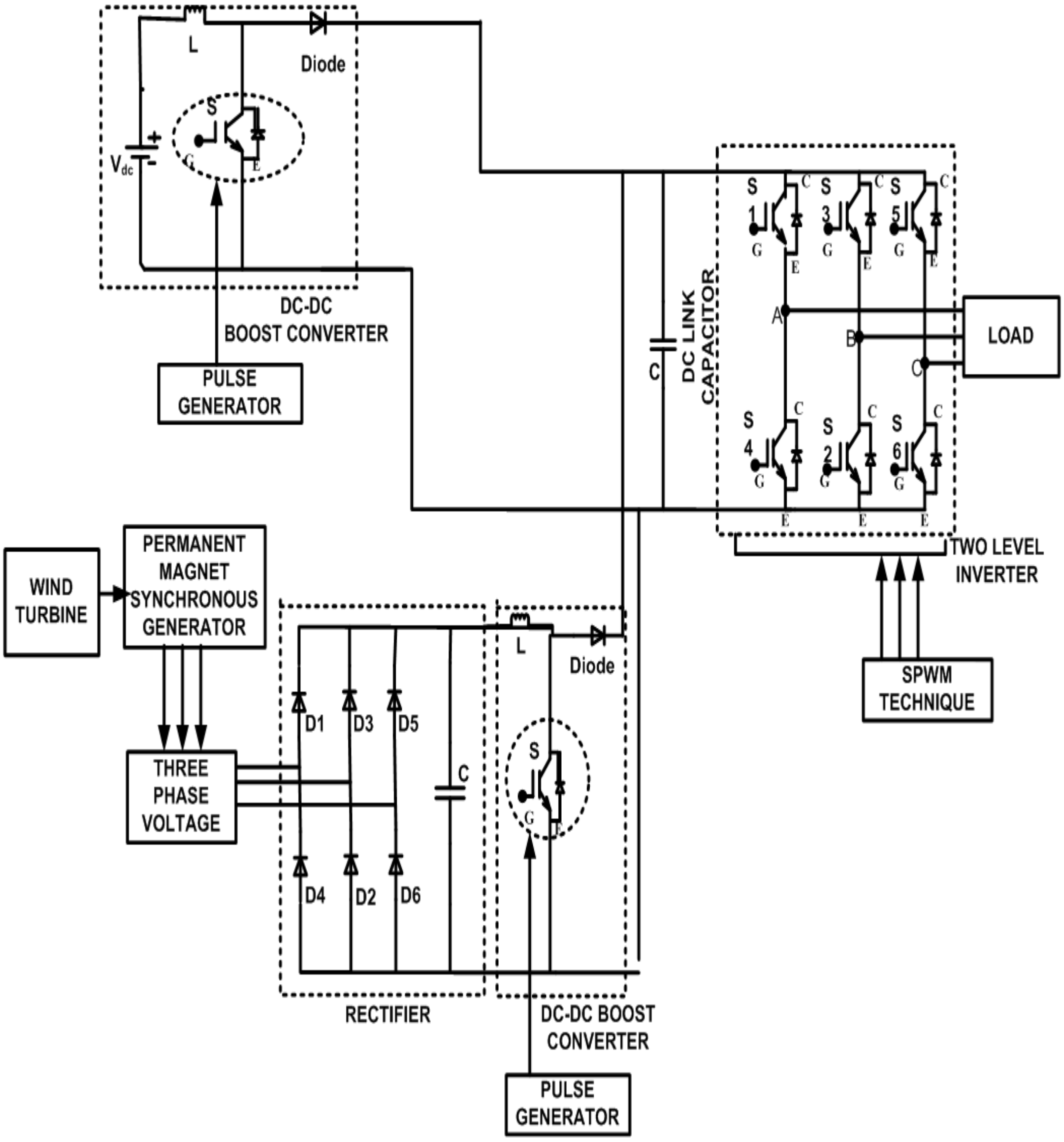

Figure 6.34: Block diagram of wind and solar PV hybrid system

The common dc link voltage produced having a constant dc value as shown in Fig. 6.35. Since both solar PV system and wind system are connected in parallel, so this voltage will be always equal for their individual dc links.

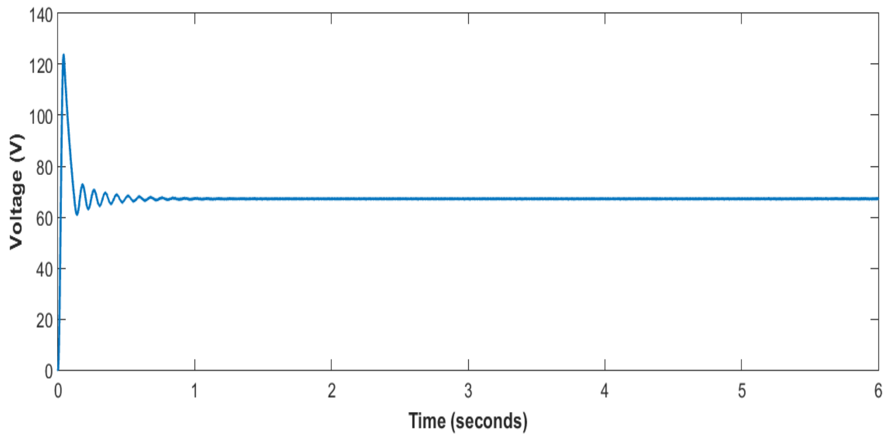

Figure 6.35: Constant Common DC Link voltage of hybrid system

The inverter output current waveform is given in the Fig. 6.36:

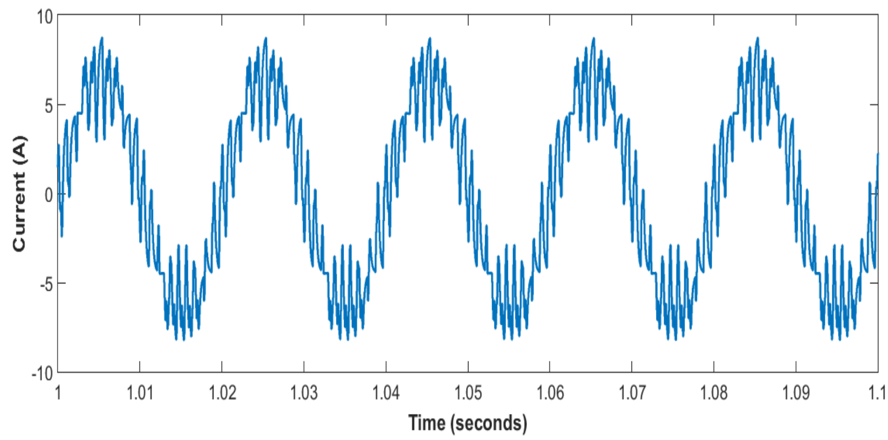

Figure 6.36: Output current of inverter of hybrid system

The inverter output phase voltage waveform is given in the Fig. 6.37:

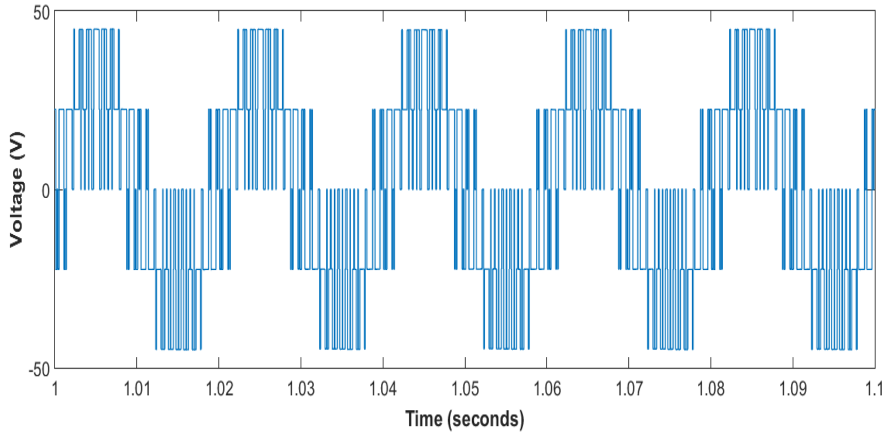

Figure 6.37: Output phase voltage of inverter of hybrid system

The inverter output line to line voltage waveform is given in the Fig. 6.38, considering resistive load:

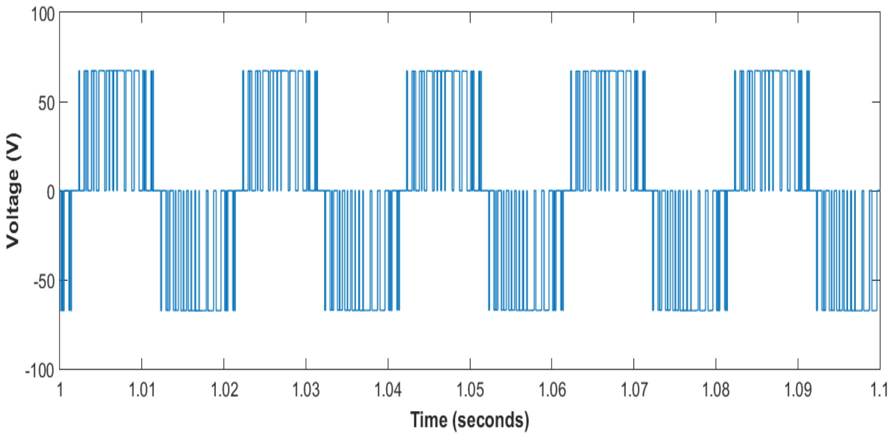

Figure 6.38: Output line voltage of inverter of hybrid system

The FFT analysis of the output voltage waveform of the hybrid system is shown in Fig. 6.39, having R-load. The FFT analysis shows that the THD is about 70% which is not acceptable. From the FFT window it is observed that the most dominant harmonic in the system is of 19^{th} order. In order to reduce this dominant harmonic, LC filter is designed for this system.

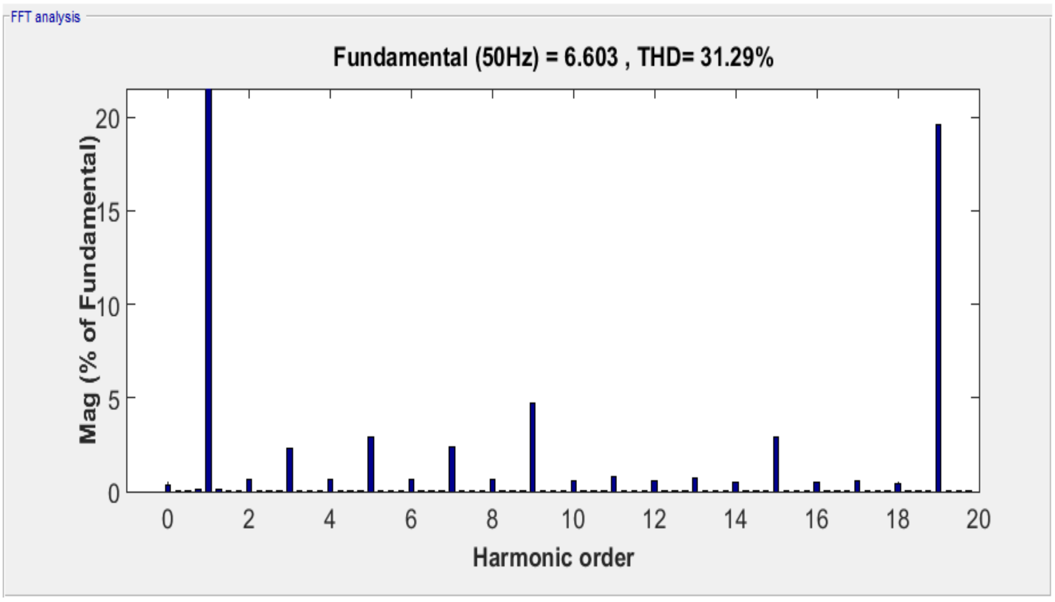

Figure 6.39: FFT analysis of inverter output voltage waveform

6.6 Wind & Solar Hybrid System with LC Filter

6.6.1 Designing of LC Filter

To obtain the sinusoidal output the filter is used for reducing the harmonic contents in the output. These harmonics are present mainly due to the power electronic devices used in the system. The basic block diagram of LC filter is shown in the Fig. 6.40:

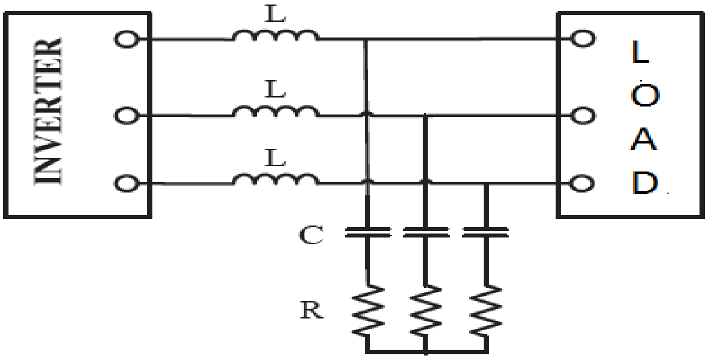

Figure 6.40: Block diagram of LC filter

The parameters of LC filter are choosed on the basis of level of output voltage drop which is acceptable and the switching frequency of the power electronic switches of the inverter.

Given parameters:
DC Link voltage (V_{dc}) = 67 V.
Switching frequency of inverter (f_{sw}) = 5.05 kHz.
Required output frequency (f_{out}) = 50 Hz.
Assuming Inductor Ripple current ($\triangle I_L$) = 10% , i.e. 0.1

The value of L is calculated by using following equation:

$$L = \frac{2 * V_{dc}}{\sqrt{2} * 2\pi * f_{sw} * 3 * \triangle I_s} \tag{6.1}$$

Thus, $L = 9.95$ mH

After calculating the inductor value, the capacitor is now calculated by choosing the most appropriate value of resonant frequency (f_{res}). The resonant frequency range is defined by the following equation:

$$(10 * f_{out}) < (f_{res}) < (\frac{1}{2} * f_{sw}) \tag{6.2}$$

Thus the range for f_{res} for our system will be:

$$500 < (f_{res}) < 2525 \tag{6.3}$$

Choosing $f_{res} = 2520$

The equation for calculation of capacitor is:

$$C = \frac{1}{4 * \pi^2 * f_{res}^2 * L} \tag{6.4}$$

Thus, $C = 0.4$ microfarad.

Now the L & C values are calculated. We will now calculate the value of resistor required. The equation for quality factor is given by,

$$Q = \frac{Z_0}{R} \tag{6.5}$$

Where,
Z_0 = Natural impedance of filter.
R = Damping resistor of the filter.

The natural impedance is calculated by,

$$Z_0 = \sqrt{\frac{L}{C}} = 153.4 ohm \tag{6.6}$$

The range for Q is 5 to 8, for having sufficient attenuation in the system.
Thus, Q = 8.

Now from equation(6.5), we can calculate the value of R, R = 19.2 ohm.

Thus, we have all the three values of required parameters.

$L = 9.95$ mH

$C = 0.4$ microfarad.

R = 19.2 ohm.

The filter is connected after the inverter output so that the smoother sinusoidal waveform is obtained to fed the load. The block diagram of the hybrid system along with the filter is shown in Fig. 6.41:

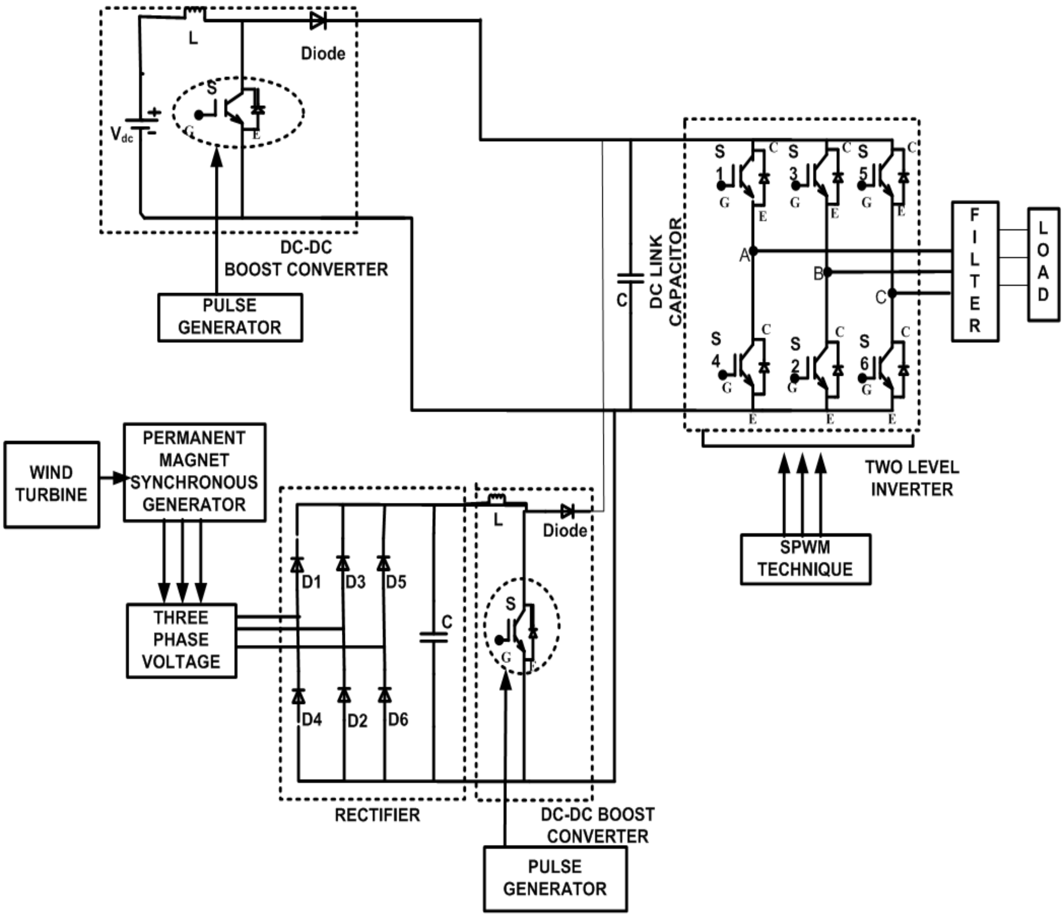

Figure 6.41: Block diagram of hybrid system with LC filter

The voltage at the common dc link obtained, have a constant dc value as shown in Fig. 6.42:

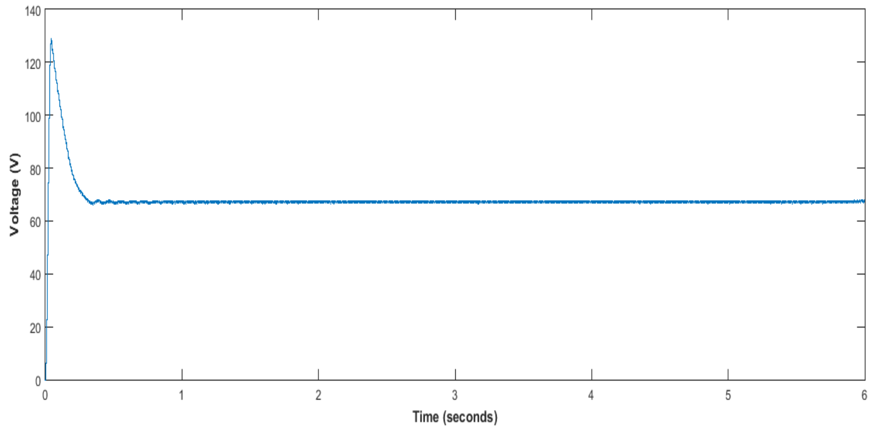

Figure 6.42: Constant Common DC Link voltage

After the implementation of the LC filter, the output voltage obtained is of sinusoidal nature. The output voltage waveform of the system after the LC filter is shown in the Fig. 6.43:

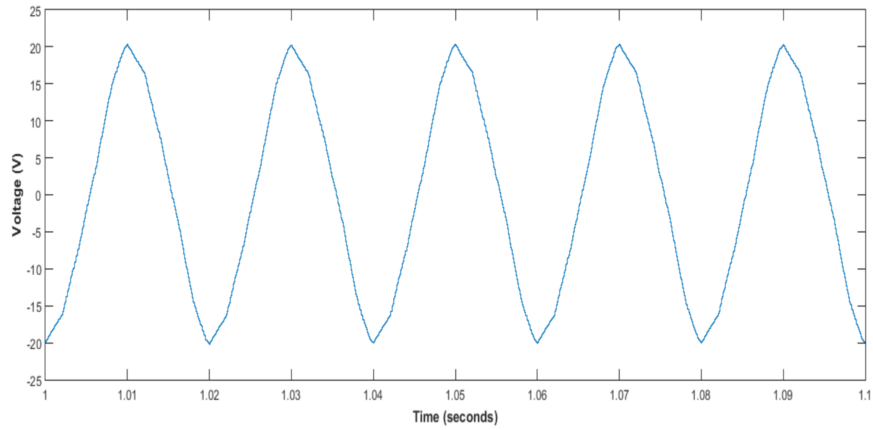

Figure 6.43: Output voltage of hybrid system after using LC Filter

The output current of the system obtained is also sinusoidal after the implementation of LC filter is shown in Fig. 6.44:

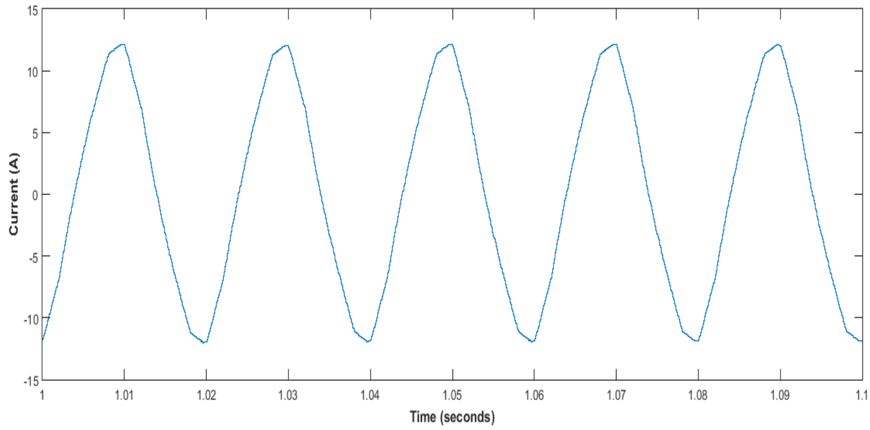

Figure 6.44: Output current of hybrid system after using LC Filter

The FFT analysis of the output voltage waveform after implementing LC filter, is shown in the Fig. 6.45. The FFT analysis shows that the THD is now reduced to about 4.89% which is acceptable as per the standards. The most dominant harmonic in the system was of 19_{th} order before when the filter was not used. But the dominant harmonic magnitude is now reduced by using the filter. Thus, the sinusoidal output is now obtained which is compatible for the loads.

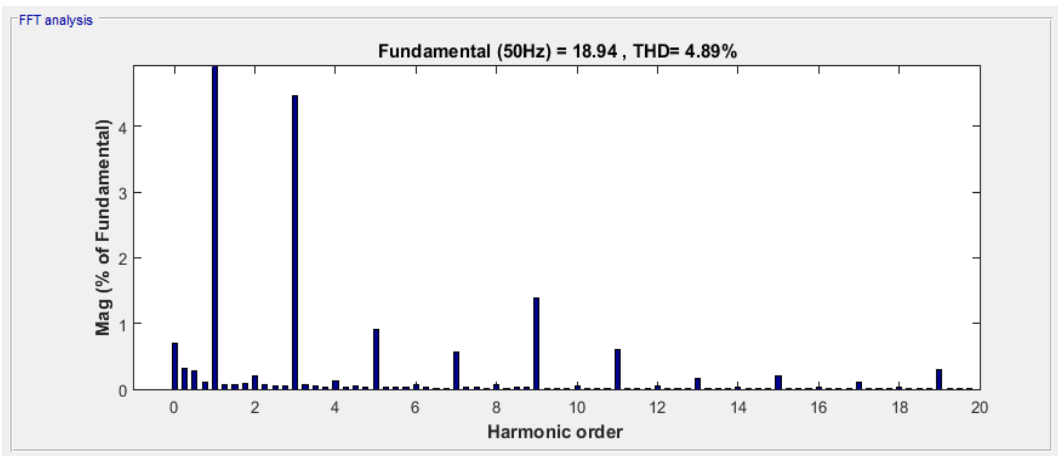

Figure 6.45: FFT analysis of output voltage waveform

Chapter 7

Conclusion and Future Scope of Work

7.1 Conclusion

In this report the solar and wind systems are developed individually in the MATLAB SIMULINK software. Also they are combined together as a hybrid system in parallel arrangement. The entire system is yet developed for the steady state condition, no transients are considered at the input side of the system.

The solar PV system consisting of boost converter and inverter is developed. Also the effect of load variations are observed on the output side of inverter as well as on the dc link voltage. To overcome that effect the PI controller is used which helps in maintaining the dc link voltage constant and the gating sequence of the inverter is modified which will take care of any load variations causing voltage fluctuations at the load side. The MPPT technique for the steady state condition is obtained which is resulting into the extraction of maximum power from the system.

The wind system is also developed consisting of rectifier, boost converter and inverter. The LC filters are used at the output of the inverter in order to get the sinusoidal output.

Both the solar and wind systems are interconnected together and hybrid system is obtained. The dc link of the hybrid system should be kept constant as the solar and wind systems are connected in parallel arrangement. For that the close loop is required individually in both solar and wind systems. The input side controlling of the solar and wind systems is done by using simple PI controllers to make dc link constant.

7.2 Future Scope of Work

The input solar radiation as well as wind is not constant, they keeps on changing according to the change in weather. So we need to take care of the input side of the hybrid system. Also we need to extract the maximum power from the wind and solar PV systems, for this the MPPT technique can be applied to both the systems individually. Now the MPPT technique will be applied for the changing input conditions. The current system obtained is of standalone condition. In future the grid connected system can be designed to feed the required amount of power to the grid.

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