Grid Synchronization of Hybrid System using PLL

Dissertation submitted in fulfillment of the requirements
of the degree of

Master of Engineering

in

Power Electronics & Drives

Submitted by
Anurag Verma
(Reg. No. 801543001)

Under the Guidance of
Dr. Surya Prakash
Assistant Professor, EIED

Electrical and Instrumentation Engineering Department

Thapar University, Patiala

(Declared as Deemed-to-be-University u/s 3 of the UGC Act., 1956)

Post Bag No. 32, Patiala – 147004

Punjab (India)

Declaration

I hereby certify that the work which is presented in dissertation entitled, "Grid Synchronization of Hybrid System using PLL", in partial fulfillment of the requirements for the award of the degree of Master of Engineering in Electronics & Drives, submitted to Electrical & Instrumentation Engineering Department of Thapar University, Patiala is as authentic record of my own work carried under the supervision of Dr. Surya Prakash. It refers others researcher's work which are duly listed in the reference section. The matter contained in this dissertation has not been submitted, neither in part nor in full to any other degree to any other university or institute except as reported in text and references.

Anurag Verma
Anurag Verma
(801543001)

Place: PATIALA
Date: 25/07/2017

This is to certify that the above statement made by the student is correct and true to the best of my knowledge and belief.

Dr. Surya Prakash
(Assistant Professor)

Date: 25/07/2017

Acknowledgement

First and foremost I take the privilege to offer my deepest sense of gratitude to Dr. Surya Prakash, Assistant Professor, EIED, Thapar University, Patiala for his commendable support and constant motivation throughout this project. With deep humility, I thank him for all the insightful conversations and his valuable comments. His guidance has helped me improve my knowledge and perspective towards the work. I will always be indebted.

I am thankful to Dr. R.S Aggarwal, Associate Professor & head, EIED for constantly encouraging each student to put their best foot forward in whatever field of work they take up and Ms. Manbir Kaur, Associate Professor & PG Coordinator for her motivational approach.

I would like to extend my sincere thanks to Dr. P.S. Rana, for providing valuable guidance in typesetting the text in LaTeX. My sincerest thanks to all the faculty members and staff of Electrical and Instrumentation Engineering Department, Thapar University, Patiala, who have bestowed their guidance at appropriate times without which it would have been very difficult to proceed with my work. I further express heartfelt gratitude to my parents and friends who have constantly helped me keep my morale high all through the work.

(Anurag Verma)
(801543001)

Table of Contents

List of Tables

List of Figures

List of Abbreviation

ΔV_d	Boost converter peak to peak DC output voltage
λ	PV module Illumination
λ	Wind turbine ratio of tip speed
ω_c	Cut-off frequency
ω_m	Angular velocity of shaft
ω_o	Resonant frequency
ρ	Density of air in kg per m^3
A_s	Turbine Swept Area
C_f	Capacitance of Filter
C_p	Coefficient of power
E_{go}	Silicon Band gap energy
f_s	Boost converter switching frequency
I	Current from the PV cell
I_0	Reverse saturation current
I_C	Capacitor current
I_d	Boost converter DC output current
I_d	Current across d-axis
I_d	Diode current

I_L	Inductor current
I_O	Current across Load
I_q	Current across q-axis
I_{scr}	PV module short circuit current
I_{SC}	Short-circuit current
I_{source}	Source current
k	Boltzmann's constant
K_i	Integral controller Gain
K_i	Temperature coefficient of short circuit current
L_f	Inductance of Filter
N_p	Number of cells in parallel
N_s	Number of cells in series
P_m	Wind turbine mechanical power
q	Electron charge
R_L	Load resistance
R_s	PV module series resistance
$S_1, S_2, S_3, S_4, S_5, S_6$	Switches used in inverter
T	p-n junction temperature
T_m	Wind turbine mechanical torque
t_{off}	Boost converter OFF period
t_{on}	Boost converter ON period
T_s	Boost converter switching time
V	Voltage from the PV cell

V_{cap}	Capacitor voltage
V_{dc}	Voltage of DC supply
V_d	Voltage across d-axis
V_d	voltage across the diode terminals
V_{in}	Boost converter input DC voltage
V_{L-L}	Wind generator line to line voltage
$V_{o/p}$	Output voltage
V_{OC}	Open-circuit voltage
V_{out}	Boost converter output DC voltage
V_{p-p}	AC side fundamental rms phase to phase voltage
V_q	Voltage across q-axis
V_w	Wind velocity(m/s)
C	Boost converter capacitance
D	Boost converter duty ratio
M	Modulation index
R	Blade Radius

Abstract

The generated power from conventional energy resources are not able to meet the power demands, so the different renewable energy resources are required to meet the rising power demand. Renewable energy resources are most suitable and best for distribution system and creates less pollution and global warming. In present work the renewable energy sources are taken into account so as to make the hybrid system. The basic circuit equation of the solar cell are used and a model has been developed in matlab including effects of solar irradiation and temperature. This project consist of PMSWG as a wind generator, PV module, DC-DC converter and voltage source inverter. Power control strategy is used to extract the maximum power by maximum power point control using perturbation & observation and incremental conductance method are used and simulated in matlab. The voltage source inverter interfaced with grid. The energy drawn from the wind turbine and PV module is transferred to the grid by keeping common DC link voltage constant. The simulation results shows the control performance and dynamic behavior of the hybrid wind-PV system.

Keywords: Boost converter, Incremental conductance method, Permanent synchronous wind generator(PMSWG), Phase locked loop(PLL), Power supply, Solar cell

Chapter 1

Introduction

1.1 Overview

This project is entirely concerned to meet the rising demand of Electrical energy and to reduce the green-house gas emission from electric power generation system, the best and transparent alternate solution is to go for the energies like renewable, solar, and wind energy etc. To produce green and clean energy without any pollution is PV technologies and likely wind energy with the help of smart innovative methods, the objective are defined with promised deliverable and techniques involved in achieving the goal[1], [2].

Because of increment in the industrialization and the energy utilized by the houses has come about into the expanded request of vitality mostly power. The absence of non-sustainable power source assets increment the fuel cost and risky emanation from the consuming of petroleum products from power era is unsustainable.As we know the Hybrid system is combination of two generation system. Here PV- wind combined together to form Hybrid system of electric generation of power. Solar energy is present only during the day but because of the sun's radiation and unforeseeable adumbration beyond the clouds, flying animals, tress etc.The sun's irradiation level varies. Because of these such type of reasons solar energy is unstable and less in use[3].

The availability of fossil fuel for the electric power generation has limited nowadays. This has led to the urgent search of other alternative sources. Renewable energy sources are those resources that can be used again even after harnessing the energy. The main renewable sources of energy are solar, wind, hydro, biomass etc. The most recently used renewable energy resources are wind energy and solar energy. Wind energy and solar energy are non-infected and onsite dependent source of energy[2], [4]. The Wind is also an scheme of solar intensity. As the unregulated heating of atmosphere due to sun's radiation/intensity wind starts blow. Wind blowing patterns are modified by the earth topography, water bodies and by flora. kinetic energy of the wind is converted into the mechanical power then to electrical energy with help of generator, which convert mechanical power into electrical power.

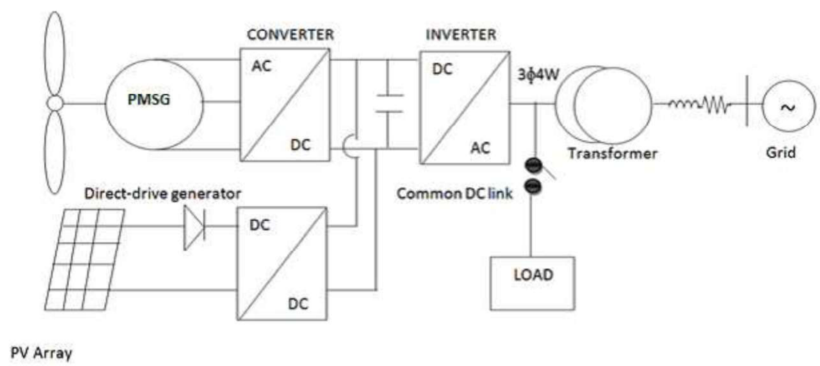

Fig. 1.1: Basic structure of a Hybrid system with Grid-connected
[1]

Because of the unpredictable nature of the wind, wind energy is not reliable one and less in use. But, it holds capability of supplying power in large amount.

So, it is better to go for a hybrid system of electrical generation which is preferable over a lone wind or lone PV system of generation. Extremely it is sophisticated to use hybrid system of generation. In this manner the disadvantages of individual system of generation and also the grid tied of hybrid system is reliable and improves the systems stability in day night both. In the fig.1.1 the system that is hybrid system in which a wind turbine, whose output connected to the permanent synchronous wind generator. The output of this generator is in the form of an ac so we need to convert it into the ac to dc by using ac to dc converter.Likewise in case of PV the output is in the form of DC, the output side of PV array is attached with DC-DC boost converter to boost the output voltage upto a required equivalent output. Now, the output of both the system is connected to common DC link voltage. After this , the output of a common dc link voltage is connected with the DC to AC converter and the output of this DC-AC converter is synchronized with the utility grid. The inverter converts the DC power from PV array to the AC power. It also maintains the volatge and the frequency constant as of the utility grid[5], [6].

1.2 Literature Review

In the most paper the basic idea of modelling and synchronization of grid is discussed and concluded. [1], [7]In these papers author explained the detailed model of PV cell and its mathematical analysis. By taking a diode model of PV cell and explained the each equations of the PV cell by steps by using simulink environment. 36 cell in series and a cell in parallel with 36 Watt power has been chosen. The V-I and P-V characteristics with effect of ir-radiance and the effect of temperature. Now after this the maximum power extraction is taken into the account so, [4] author simulated PV model in this paper. By using different-different MPPT techniques various output characteristics are observed relatively. Author simulated the P&O MPPT and incremental conductance algorithm in simulink environment and compared the results of both the method. Finally, he concluded to make the use of incremental conductance method instead of using P&O because the incremental conductance method is easier, simpler, and require less hardware. This method also gives better results. It's way of synchronization and the techniques of PLL are also discussed in each steps of way of algorithm. Modelling of solar and wind system explained and given by a suitable equations which are used in this project[8], [9].
Now after that many papers suggested, in which the numerical condition of the PV offer is exhibited in a consecutive way.
[2]This paper describes the configuration of PV array with its performance in different-different approaches or methodology and also the connected grid with DC-AC converter methodology presented.[3], [6] In these papers author framed the equations by converting solar cell's equation to a form. It also includes the various effect such as changes in the solar irradiation and the temperature of the solar cell. Novelty of paper is the method used for MPPT , which is very best method. All the work simulated in simulink environment.
The PV electrical generation is the most power effective implementation of utilization of the solar energy, but the conversion efficiency of the system is very low.
Photovoltaic power era framework actualizes a successful usage of sun based vitality, yet by and large has low transformation productivity.[10], [11]Author explained MPPT control is the fundamental to guarantee the yield of photovoltaic power era framework at the greatest power yield as could be expected under the circumstances. Photovoltaic cells model of photovoltaic power era framework and essential control calculation is talked about in the survey.[12], [13] and [14] From thes papers the MPPT control in view of perturbation & observation (P&O) technique

and incremental conductance (Inc.Cond) strategy is individually mimicked in matlab/simulink. The reproduction investigation demonstrates that P&O strategy is straightforward, however has impressive power misfortune. Inc.Conductance strategy has more exact control and speedier reaction, yet has correspondingly higher equipment prerequisite. By and by, keeping in mind the end goal to accomplish most extreme productivity of photovoltaic power era, a sensible and conservative control strategies ought to be picked[15], [8] and [16].

Designs of a DC micro grid system basically based upon the two interdependent sources which are wind source and solar. [17]This paper also describes a micro grid well-structured block diagram. For designing the corresponding controller according to the types of distributed energy, the different approaches are used. Nowadays in the increased number of distributed power generation system connected to the grid. First and foremost important problem of distributed power generation system connected to grid or network is basically synchronization. For the control of distributed power generation, detecting the positive order voltage constituent frequency at fundamental value. The phase angle and its magnitude in positive order voltage is used during the synchronization of the converter output members or the transforming variables for reference in the respect of it[18], [19]. Despite of the technique using in the detection of system i.e. By using a ZCD or a PLL, the amplitude and the phase angle of the positive order component must be quick and exactly obtained, even if the practical distortion in voltage or unbalanced[4], [20]. Amid of these techniques for the voltage zero-crossing is the simplest and one of the mostly and the phase-locked loop (PLL)-based techniques.[18], [15] and [3]The power can be provided even to the remote locations. Hybrid system is very much useful in continuous energy generation. The wind energy conversion system converts the input wind to AC power which is directly fed to the grid. The PV system converts the input solar radiation into DC power

1.3 Research Motivation

- Now a days the hybrid wind-solar system connecting to a grid are the scorching field of research.
- Wind energy is an economical in nature on the other hand, PV provides additional advantages over the other renewable source since they are eco-friendly and require less maintenance.

- The combination of both the wind power source and solar power source provides economical form of electrical power generation.
- The main challenge is to implement the project work by simulating in matlab/simulink environment and the new research area to study the motivations of this project.

1.4 Objective of the Work

The power era is to a great extent subject to the need of the customer i.e. the heap end prerequisite.

- To develop the model of hybrid system by using solar and wind system.
- To develop the control algorithm and design of PLL.
- To synchronize the developed model with utility Grid.

1.5 Organization of the Dissertation

The work carried out in this project has been coordinated in 7 chapters.

Chapter 1 deals with Introduction and Literature Review

Chapter 2 deals with the study of solar cell and its modelling, effect of variation of Solar Irradiation on output.

Chapter 3 deals with the Boost converter and various different operating modes of charging and discharging in different states of switching.

Chapter 4 deals with wind turbine, permanent magnet synchronous wind generator.

Chapter 5 deals with the control scheme.

Chapter 6 deals with the simulation results and discussion

chapter 7 deals with conclusion and future scope of the work, References

Chapter 2

Solar Cell

This chapter covers the all necessary details of the solar cell. It covers: basic physics of semiconductors in photovoltaic devices; physical models of solar cell operation; characteristics and design of common types of solar cell; and approaches to increasing solar cell efficiency.

2.1 Introduction

Solar cell or photovoltaic cell is the elemental component of PV panel. It is made by the silicon and a commonly a p-n junction. The p-n junction is made by two different layers by doping some impurities to it. A PV cell, which is the basic unit of the complete photovoltaic system is a electrical device that converts light energy with the help of photoelectric effect, generally a physical and chemical phenomenon. Number of solar cells together combined to form PV panels or modules. Similarly,number of PV panels combined together to form PV arrays. These modules can be connected in series or parallel to form large solar arrays.

Due to rise in the cost of electrical energy, conventional sources of energy are degrading day by day. In India, the primary energy resources are used on the large scale which results into the various emission effects that causes serious environmental problems. To avoid these environmental pollution and its related problems, we goes for an alternative sources of energy. These renewable energy provides electrical energy to remote areas (rural electrification) where the main utility gird is not present.

Three basic attributes for the operation of photovoltaic (PV) cell which are as follows:

1. Generation of electron-hole pairs or excitons is takes place when the solar cell absorbs some light.

2. Opposite charge carriers creates the separation.
3. The separate eradication of those carriers to an extraneous circuit.

Photovoltaic system of generation has many advanatges like upkeep, buzz free, and eco-friendly in nature. Because of these advantages it is very commonly use in today as a valuable renewable energy resource[1].

To connect the PV generation system to a utility grid the main stages are PV array, DC to DC converter, DC to AC converter. The solar cell equation is interpreted by including various effects of changes in sun intensity and the temperature. DC-DC converter is interfaced with PV array for the control of the output.

The two stages are used for injecting the power into the grid through the PV array. The DC-DC converter is used here to increase the voltage level of connected PV array. Maximum power point theorem is used to extract maximum power from the PV array for achieving maximum power point curve. Now, if we talk about the second stage of the grid connected DC-AC converter, in this stage the control operation is done while the conversion of DC power into AC power[2].

The connected PV array and its injected current to grid, controlled by the same method. The performance of the PV array depends upon the various standard test conditions like

1. Irradiance = $1,000\frac{w}{m^2}$
2. Solar Spectrum AM = 1.5
3. Normal Operating Temperature = 25^0C

2.2 Solar Cell Modelling

By combining the solar cell in parallel and series the array formed is called PV array. In diagram it is shown that the single cell equivalent circuit diagram. To improve the efficiency of the cell, the cells are combined in two ways i.e series and parallel. By connecting cell in series the output obtained is greater and by combining the cells in parallel the output current is increased. So,the PV array combine din different different manner to increase the current and voltage rating and performance of the module.

PV module photo current:

$$I_{ph} = [I_{scr} + k_i(T - 298)] * \frac{\lambda}{1000} \tag{2.1}$$

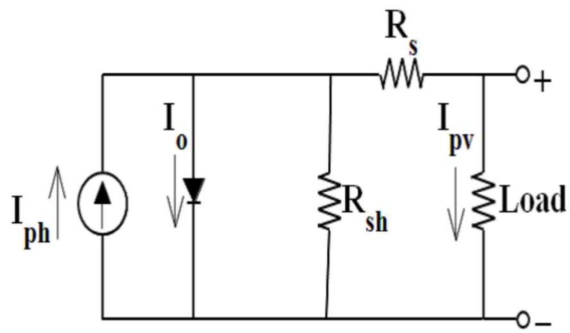

Fig. 2.1: A PV cell circuit diagram
[5]

Module current in terms of reverse saturation:

$$I_{ro} = \frac{I_{scr}}{\exp(\frac{qV_{oc}}{N_s kAT})} - 1 \tag{2.2}$$

PV Module saturation current:

$$I_o = I_{ro}[\frac{T}{T_r}]^3 \exp\frac{qEg_o}{BK}[\frac{1}{T_r} - \frac{1}{T}] \tag{2.3}$$

PV module output current:

$$I_{pv} = N_p * I_{ph} - N_p * I_{ro}[\exp\frac{q * V_{pv} + I_{pv}R_s}{N_s AKT} - 1] \tag{2.4}$$

When this equation is simulated in simulink environment, the results obtained shows the various non-linear behavior and its characteristics also same. At various different irradiations and temperature.

The above two graphs giving the general idea of the current-voltage (I-V) characteristics of a normal PV cell made up of silicon that is operated under standard test conditions as discussed in the section 2.1. The output power that is found from a PV cell is the general product of the current and the voltage $(I * V)$.

During open circuit condition, it means that it is not connected to any load. In this case the obtained current is minimum(zero) and the obtained output voltage is maximum. So, the known

Table 2.1: PV module specifications

PV module (36 w) specification	
Rating	37.08 w
Peak Value of Current	2.25 A
Peak Value of Voltage	16.56 V
Current at Short Circuit	2.55 A
Voltage at Open Circuit	21.24 V
Parallel No. of Cells	1
No. of total cells in series	36

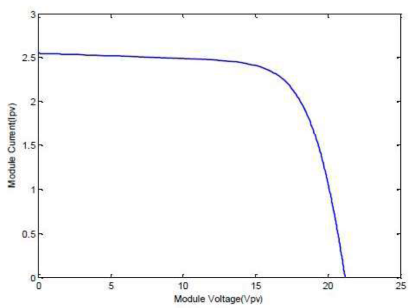

Fig. 2.2: I-V Characterstics of a 36W PV module

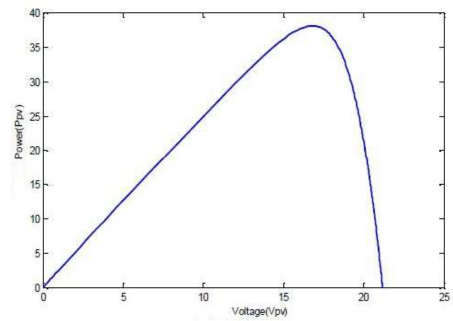

Fig. 2.3: P-V Characterstics of a 36W PV module.

current and the voltage is called as open circuit current and open circuit voltage. But, when we see during the load connected PV cell the obtained current is maximum and the voltage is minimum(zero). In this case the known current is called as short circuit current(I_{sc}) and reach upto maximum point[21], [3].

At that point the traverse of the sun based cell I-V qualities bend ranges from the short circuit current (Isc) at zero yield volts, to zero current at the full open circuit voltage (Voc). As it were, the most extreme voltage accessible from a cell is at open circuit, and the greatest current at short circuit. Obviously, neither of these two conditions creates any electrical power, however there must be a point some place in the middle of were the sun oriented cell produces most extreme power[9], [22].

In any case, there is one specific blend of current and voltage for which the power achieves its most extreme esteem, at Imp and Vmp. At the end of the day, the time when the cell produces most extreme electrical power and this is appeared at the upper right region of the green rectangle. This is the "greatest power point" or MPPT. Consequently the perfect operation of a photovoltaic cell (or board) is characterized to be at the most extreme power point[2], [12].

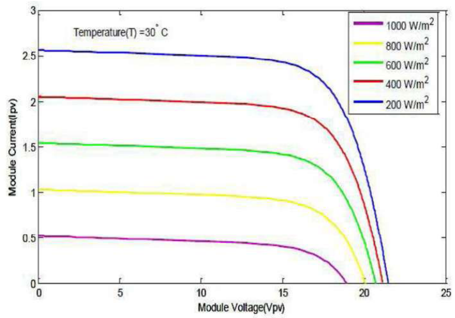

Fig. 2.4: Characterstics of V-I at various Irradiation level.

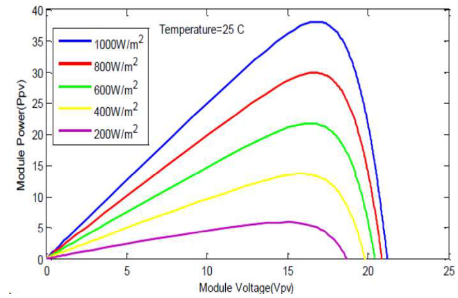

Fig. 2.5: Characterstics of P-V at various Irradiation level.

The greatest power point (MPPT) of a sun based cell is situated close to the twist in the I-V qualities bend. The comparing estimations of Vmp and Imp can be evaluated from the open circuit voltage and the short out current: Vmp = (0.8–0.90)Voc[23] and Imp = (0.85–0.95)Isc. Since sun based cell yield voltage and current both rely on upon temperature, the genuine yield power will differ with changes in encompassing temperature. Up to this point we have taken a gander at Solar Cell I-V Characteristic Curve for a solitary sun powered cell or board. In any case, numerous photovoltaic exhibits are comprised of littler PV boards associated together. At that point the I-V bend of a PV cluster is only a scaled up adaptation of the single sun based cell I-V characterstic bend as appeared.

2.3 Solar Irradiation's Effect

Solar Irradiation mainly affects the voltage, current, and power $i.e$ Voltage v/s Current curve and the Voltage v/s Power Curve as show in the figure 2.2 and 2.3 in section 2.2[24]. Any changes in the atmoshphere it may be temperature, humidity, etc. all affects the maximum power because of change in the solar irradiation. Therefore, for maximum power we need maximum power point tracking algorithm to extract maximum power from the PV cell and make it constant throughout our need. Any change in the solar irradiation level ignored by the MPPT. The open circuit voltage increases in the increase of solar irradiation level. During the increase in the solar irradiation level the magnitude of voltage increases which results into higher magnitude of power.As, we all know that when the sunlight falls on the PV cell is more the emitted energy will be more because the emitted electrons will be more which produce more energy and results into the higher current[4], [14].

2.4 Effect of Temperature on PV module

The output of the PV cell vary by varying the temperature. This effect can be seen from the figure 2.6. Increase or decrease in temperature changes the output power which is the product of voltage and current as discussed earlier in the section 2.3. When the temperature increases, the band gap energy of the cell also increases which need more energy to jump the generated barrier or gap. This results in the decrease in the efficiency of the solar cell[7].

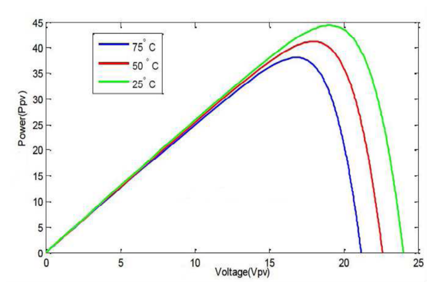

Fig. 2.6: Effect of Varitaion of temperature on P-V curve

Chapter 3

Design and Analysis of Boost converter

3.1 Introduction

These topics which are mentioned below covered in this chapter.

- Step-up Principle
- Modes of operation of Boost Converter
- Waveform of Boost Converter
- Mathematical analysis of Boost Converter

3.2 Step-up Principle

3.2.1 Boost converter

A device that takes a dc as a input voltage and gives as a required output voltage is known as DC-DC converter. The output voltage is at various level in comparison with the input voltage. There are basically three types of DC-DC converter which are as follows :[21]

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

The basic circuit diagram of boost converter is shown in the figure. As, the switch S closed for time t_1, current through the inductor L increased & the stored energy in the inductor also rises. But, when the switch S is opened during time t_2, transfer of energy takes place through the connected load via diode D and the level of the current falls down[1].

If we talk about the transformer, it steps up and steps down the level of voltage level from a level to different level. Also, the losses are more. So, to avoid these losses DC-DC converter are used for a required output voltage which consists of an inductor(L), diode(D), switch(S), capacitor(C) and supply voltage(V_s).Because of this type of methodology of source voltage is increased upto a desired level as per our need. Change in the duty cycle of the switch the output voltage is changed[25].

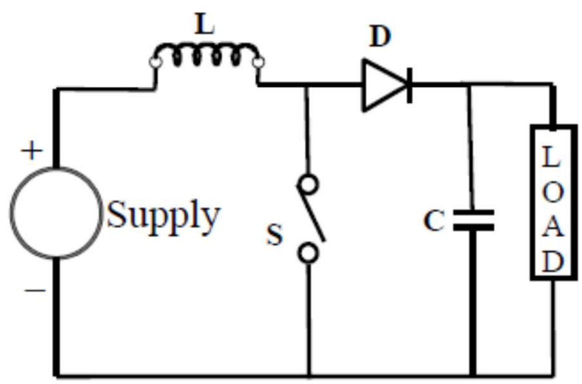

Fig. 3.1: Boost Converter Circuit Diagram

3.3 Modes of Operation of Boost Converter

In boost converter there are generally 2 modes of operation. These two modes of operation lean on the load connected and switching at high frequency. During the switch closed, charging of inductor takes place also discussed earlier in the section 3.2. This mode of operation is called as mode of charging.

Equivalently the second mode of operation takes place when the switch is opened and the inductor is discharging in this mode of operation. Therefore this mode of operation is called as discharging mode of operation[1].

3.3.1 Mode of operation I

In this mode of operation the switch is closed and the inductor(L) starts charging by the supply through the switch(S). The diode which is used in this boost converter restrain the flow of current[26].

Mode I is valid during $0 \leq t \leq DT$, where **D** is the duty ratio and **T** is the switching period.

Switch closed, the voltage across inductor

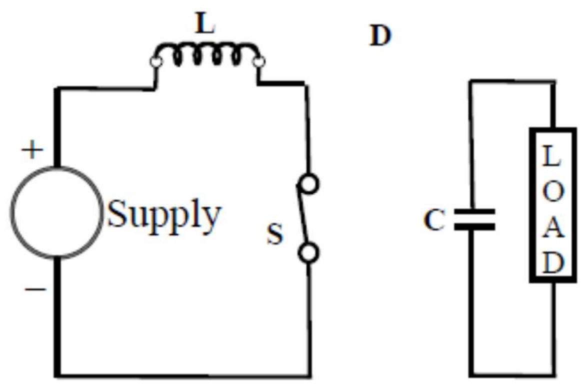

Fig. 3.2: I Mode of Operation

$$V_L = L\frac{di}{dt} \tag{3.1}$$

Ripple current i.e peak to peak given in the equation 3.2

$$\Delta I = \frac{V_s}{L}T_1 \tag{3.2}$$

The average output voltage is given by

$$V_o = V_s + L\frac{\Delta I}{T_2} = V_s(1 + \frac{T_1}{T_2}) = V_s\frac{1}{1-D} \tag{3.3}$$

3.3.2 Mode of operation II

In the first mode of operation, the switch is open and the diode act as a short circuited. As during the first mode of operation inductor charged at a level. Now , in this mode of operation same inductor starts discharging through the capacitor. Current across the load assumes as fixed through the whole operation since, it is very small.

Mode II is valid for $DT \geq t \geq T$

where **D** = duty ratio and **T** = switching period. Equation of voltage in this mode

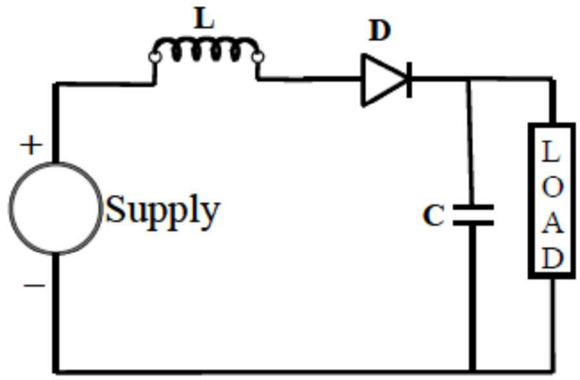

Fig. 3.3: II Mode of Operation

$$V_s = Ri_2 + L\frac{di_2}{dt} \tag{3.4}$$

Equation of current in this mode

$$i_2(t) = \frac{V_s - E}{L}(1 - \exp\frac{Rt}{L}) + I_2 \exp\frac{-Rt}{L} \tag{3.5}$$

3.4 Mathematical Analysis of the Boost converter

During the time t_1 as seen from the waveform, inductor current linearly rises from I_1 - I_2, then

$$V_s = L\frac{I_2 - I_1}{t_1} = L\frac{\Delta I}{t_1} \tag{3.6}$$

$$t_1 = \frac{\Delta IL}{V_s} \tag{3.7}$$

Discharging of inductor i.e linearly fall in current from $I_2 - I_1$ for time t_2

$$V_s - V_a = -L\frac{\Delta I}{t_2} \tag{3.8}$$

$$t_2 = \frac{\Delta IL}{V_a - V_s} \tag{3.9}$$

$$\Delta I = I_2 - I_1 = \frac{(V_a - V_s)t_2}{L} \tag{3.10}$$

from equation (3.7) and (3.9)

$$V_a = \frac{V_s}{1-k} \tag{3.11}$$

$$k = 1 - \frac{V_s}{V_a} \tag{3.12}$$

For an ideal condition(lossless circuit)

$$V_s I_s = V_a I_a \tag{3.13}$$

Hence, Peak to Peak ripple current:

$$\Delta I = \frac{V_s(V_a - V_s)}{fLV_a} \tag{3.14}$$

$$= \frac{V_s k}{fL} \tag{3.15}$$

also, the Peak to Peak ripple voltage:

$$\Delta V_c = \frac{I_a(V_a - V_s)}{V_a fC} \tag{3.16}$$

$$= \frac{I_a k}{fC} \tag{3.17}$$

3.5 Input and Output Waveforms

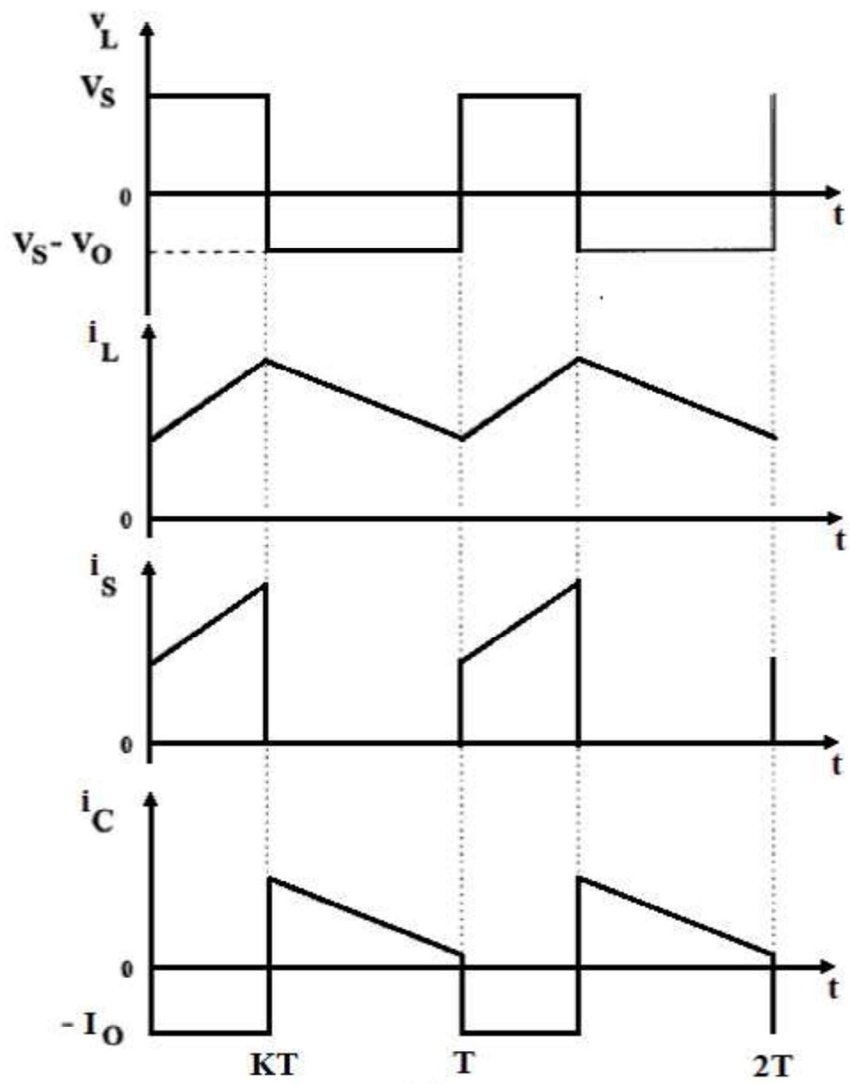

Fig. 3.4: Input & Output waveforms of the Boost converter

Chapter 4

Permanent Synchronous Wind Generator

4.1 Introduction

- Wind Turbine
- Solidity
  Ratio of Tip Speed, λ
  Coefficient of Power, C_p
- Wind Turbine Characterstics
- Permanent Magnet Synchronous Wind Generator

4.2 Wind Turbine

Turbine and the generator together placed to form as wind energy system. The generator are often either induction or synchronous. The most ordinarily used generator within the energy conversion system today is static magnet synchronous generator. The PMSWG will turn out power in comparison to different machines. The 3 inputs area unit the generator speed in chemical element of the nominal speed of the generator produce efficient power when compared to other machines[27], [10].The three inputs area are the generator speed in pu of the nominal speed of the generator, & the pitch angle in degrees and the wind speed in m/s. The tip speed ratio λ in p.u of λ_{nom} is obtained by the division of the rational speed in p.u of the base rotational speed and the wind speed in pu of the base wind speed. The output is the torque applied to the generator shaft. The power extracted from the wind is given by, Where, C_p is called the power coefficient of the rotor or it is also called as efficiency of rotor. The value of C_p is lie between 0.4 and 0.5 for high speed, two blade turbines and between 0.2 and 0.4 for low-speed turbines with more than two blades[5].

Availability of wind is everywhere. The wind is another form of energy called solar energy. Wind always blows in the direction where the atmospheric pressure is high to low pressure. This process occurs due to the non-uniform heat generated by the solar energy and because of the earth rotation. Furthermore, the wind energy is avilable in the form of a kinetic energy by air having some velocity.

Wind energy may be converted into many form of energies as per our need. For example electricity is generated by the help of wind turbine, also for the water pumps to lift up the water, and in the propelling of ships. Wind energy is the best form of fossil fuels and also an alternative that is available in plenty of amount in the nature. In the generation of electricity with the help of wind turbine, there is no green house gas is emitted and also non polluted alternative sources of energy.

Nowadays the demand is increasing day by day so the customer is required huge amount of electrical energy. In the wind turbine the blades are used may be two or three for the best electrical generation[11], [15] and [6]. An electrical generator is used to generate the electricity from the wind power. Gearbox is attached with the rotating blades. The speed is adjusted with the help of these gear box. The adjusted speed is used for the generation of the useful form of energy. There is wind generator feed with the transformer that changes the form of level to another level. The useful form is 33kV.

Extracting wind turbine's kinetic energy by the area swept by the blades of the wind turbine. Therefore the wind's kinetic energy related to power in terms of air flowing(mass per unit time).

$P_o = \frac{1}{2}(\text{mass of air in per unit time})(\text{velocity of wind})^2$

$$= \frac{1}{2}(\rho A V_w)(V_w)^2 \tag{4.1}$$

$$= \frac{1}{2}\rho A V_w^3 \tag{4.2}$$

Available power in the wind is written in the form of mathematical equation which is shown in equation (4.1) & (4.2).The power that is transferred by the wind turbine is somehow different from these equations. Available power and the transformed power is differ in the factor that is given as the coefficient of power (C_p).

Therefore the generated power from the wind turbine is given in the form of mathematical equation[28].

$$P = \frac{1}{2}\rho A C_p V_w^3 \tag{4.3}$$

where the symbols has usual meanings as:
ρ = Density of air in $\frac{kg}{m^3}$
A = Turbine swept area
V_w = velocity of wind in $\frac{m}{sec}$

$$C_p(\frac{\lambda}{\beta}) = C_1(\frac{C_2}{\lambda_i} - C_3\beta - C_4)\exp^{-}\frac{C_5}{\lambda_i} + C_6\lambda \tag{4.4}$$

where,

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \tag{4.5}$$

here the, C_1 = 0.5176, C_2 = 116, C_3 = 0.4, C_4 = 5, C_5 = 0.0068
these terms are generally used in the energy of wind for calculation.

4.2.1 Speed Solidity

The ratio between the area projected by the blade and to the intercepting wind area is known as Solidity. The area projected by the blade is equal to the wind's projected area direction. There is a direct relationship between the speed solidity and the the torque. Rotors having high solidity best suitable for lifting up the water due to high torque and speed as low. Rotors having low solidity best suitable for the generation of electrical power due to high speed and torque of low magnitude[8], [29].

4.2.2 Ratio of tip speed, λ

Tip speed ratio of wind turbine is mathematically defined as,

$$\lambda = \frac{W_T R}{V_W} \tag{4.6}$$

where the symbols have their usual meanings
λ- Non-Dimensional
W_T - Wind turbine rotational speed

N = Rotational speed of wind turbine in revolutions per second

R = Radius of Blades

4.2.3 Coefficient of Power

Coefficient of power(C_p) in the wind turbine is defined as

$$C_p = \frac{Wind\ turbine\ output\ power}{Power\ in\ the\ wind}$$

The coefficient of power is different as to the wind turbine due in the case of losses of transmission occurred by the mechanical and the generation of electrical.

C_p is dimensionless and is help in used for describing the rotor size.

4.3 Wind Turbine Characteristics

Power transfer by mechanical work to the shaft of the rotor is defined as:

$$T_m = \frac{P_m}{\omega} \tag{4.7}$$

Maximum torque is given by :

$$T_{max} = 0.5 C_{p-opt} \pi (\frac{R^5}{\lambda_{opt}^3}) \omega^2 \tag{4.8}$$

Table 4.1: Specifications of the Wind turbine

specifications of the wind turbine	
Rating in kW	1000 W
Diameter of the wind turbine	8 m
Blade numbers	3
Wind speed(cut-in)	3 m/s
Wind speed(cut-off)	25 m/s
Rated wind speed	10 m/s
Density of air	1.225 kg/m^3

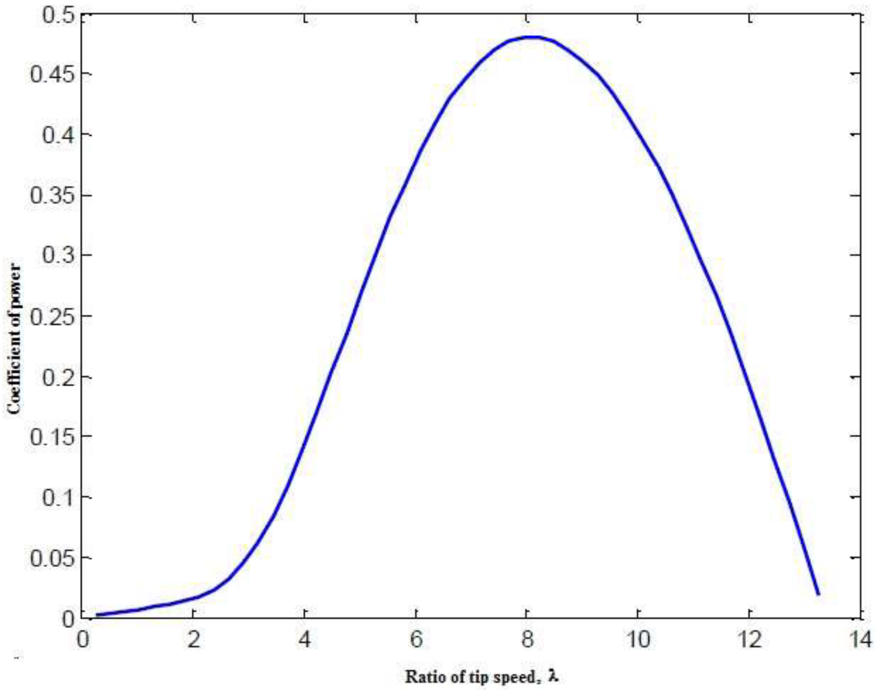

Fig. 4.1: Characteristics of Power Coefficient and T.S.R

4.4 Permanent Magnet Synchronous Wind Generator

Permanent magnet synchronous generator is a generator whose field is excited with the help of magnet called permanent magnet. Here the word used as synchronous, it means that the magnetic and rotor field rotate as having the speed same as both.

permanent magnet synchronous generators are the mainly resource for the generation of electrical energy i.e.commercial

The main thing is the design considerations taken into the account which is shown in the figure 4.1. In the most of the designs the assembly of rotating is in the mid-point of the generator. The moving part rotor connected with the magnet magnetically whereas the stator which is stationary which is connected with the load electrically. In the diagram it is shown that the component of the stator field which is perpendicular in space affects the component of torque which is parallel also affects the voltage. Voltage is determine by the load attached.

Chapter 5

Control Methodology

In this chapter the control methodology of the PV, voltage source inverter, how the maximum power is extracted from the PV by using incremental conductance method?, and the phase locked loop for thr synchronization is discussed in detail.

5.1 Maximum Power Point Tracking

These topics which are mentioned below are covered in this section.

- Maximum Power Point Tracking (MPPT)
- Perturbation Observation Method (P&O)
- Flowchart of P&O algorithm
- Incremental Conductance Method
- Comparison of two MPPT methods
- Incremental Conductance Algorithm Flowchart

In PV modules the maximum power is extracted with the help of the MPPT. It is used in between PV module and the DC-DC boost converter. This arrangement can be seen in the below figure. By adjusting the duty cycle of the DC-DC Boost converter a peak power is obtained. Change in the irradiance and the effect of temperature vary the maximum power point in the PV module. Therefore we need MPPT techniques to extract the maximum power from the PV module. Earlier different method and techniques are used to achieve MPP, they are developed and published. There are many aspects in which the MPP must be kept in mind which are as

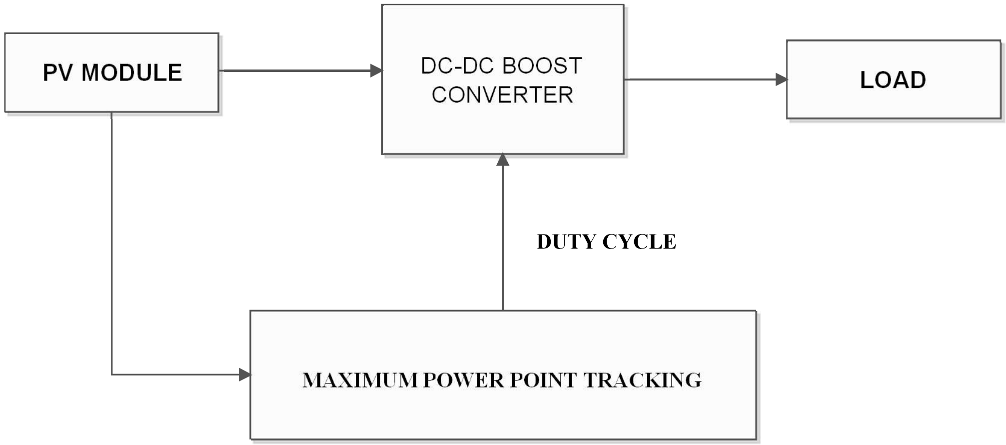

Fig. 5.1: MPPT arrangement in the Circuit

follows:

1. Sensors
2. Complexity
3. Effectiveness range
4. In accordance with the speed,
5. Cost
6. Irradiation
7. Temperature
8. Effectiveness Tracking

There are generally nineteen techniques, from that only two techniques are best in use. Generally, we use P&O method and incremental conductance method. These method are simple and require less hardware.

5.2 Perturbation and Observation Technique

Whenever the change in the power is seen the perturbation control is appropriated in the account of the methodology used in the circuit [17]. If the change occur in the power that is positive then the the increase in the voltage will be seen in R.H.S. Correspondingly, if the change occurs in the power is negative then the decrease in the voltage will be seen in the left side of the equation. PWM control signal can be controlled by change in the voltage with the help of perturbation.

Accordingly this algorithm works, and the maximum peak overshoot generated and after that it falls down linearly and achieve steady state. This action can be control by the output power, reaching maximum value.

5.3 P&O Algorithms Flowchart

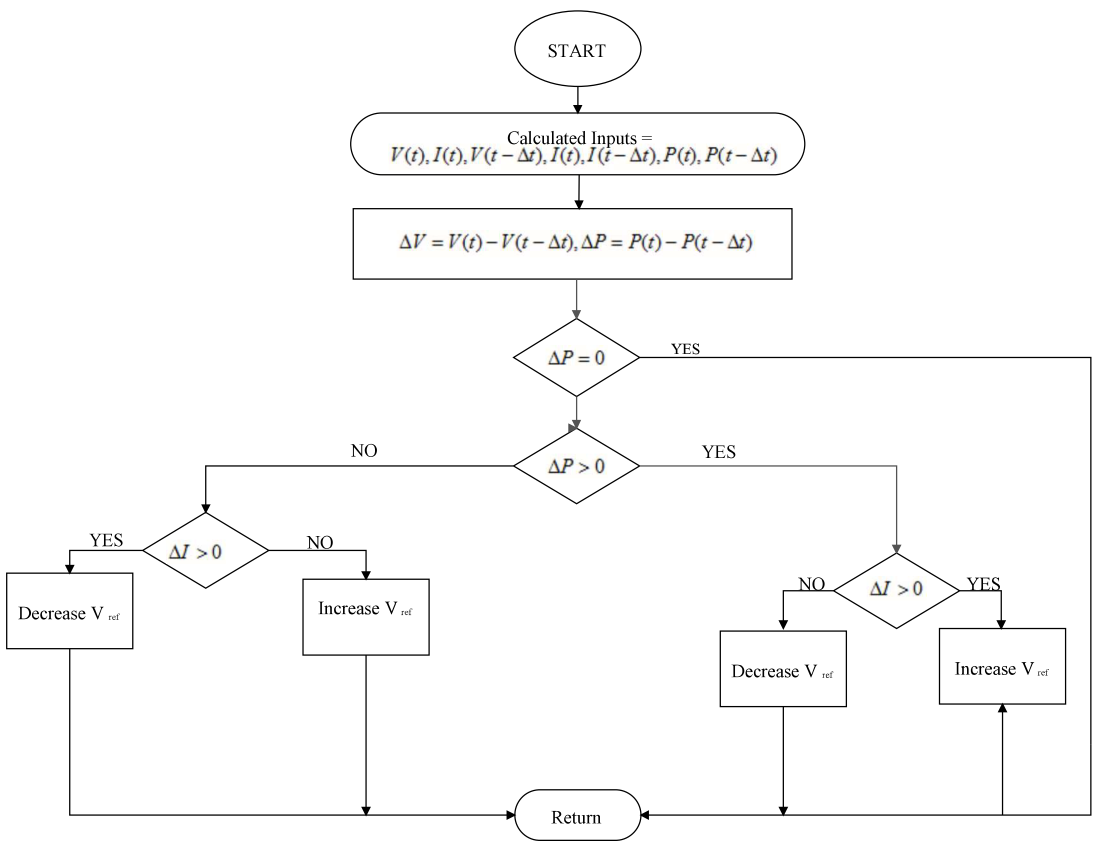

Fig. 5.2: Perturb and Observe Algorithm Flowchart

From the above flowchart following observations are made:
when the $dP > 0$ and $dV > 0$, it shows the power in left part of the equation is the maximum power point.
whenever, the $dP < 0$ and $dV > 0$, it shows the power in right side negative
At $dP = 0$ Maximum Power Point is achieved.

5.4 Incremental Conductance Method

Incremental conductance method is most commonly used method for the extraction of maximum power i.e. Maximum power point algorithm. Presenting this technique according to P-V graph gives a unique peak point and maximum power point found where

$$\frac{dP}{dV} = 0 \tag{5.1}$$

where $P = V * I$, Now from the Incremental conductance method,

$$\frac{dP}{dV} = \frac{d}{dV}(V * I) = 0 \tag{5.2}$$

$$= I + \frac{dI}{dV} = 0 \tag{5.3}$$

i.e,

$$\frac{dI}{dV} = -\frac{I}{V} \tag{5.4}$$

the above equation represents Maximum Power Point

$$dP = P(k) - P(k-1) \tag{5.5}$$

$$dI = I(k) - I(k-1) \tag{5.6}$$

$$dV = V(k) - V(k-1) \tag{5.7}$$

$$= V(k)I(k) - V(k-1)I(k-1) \tag{5.8}$$

here k is present condition & (k-1) is before condition.
Supposing that ,

$$\frac{dI}{dV} < -\frac{I}{V} \tag{5.9}$$

Hence, the Maximum operating point of MPP is in equation at R.H.S and the above condition for the output voltage of PV module gets decreased.
Similarly if

$$\frac{dI}{dV} > -\frac{I}{V} \tag{5.10}$$

Hence the point of operation is seen in the equation at L.H.S of Maximum power point, Here Output voltage of PV module gets rises.
With the help of above discussion, we found that,
when $(V = V_{max})$, then

$$\frac{dI}{dV} = -\frac{I}{V} \tag{5.11}$$

Now, when $(V > V_{max})$

$$\frac{dI}{dV} < -\frac{I}{V} \tag{5.12}$$

As, when $(V < V_{max})$, then

$$\frac{dI}{dV} > -\frac{I}{V} \tag{5.13}$$

For extracting maximum power from the PV module the relationship between the $\frac{dI}{dV}$ and $\frac{I}{V}$ can be adjusted and the operating voltage also gets adjusted.

5.5 Comparison of two MPPT Methods

The MPPT techniques which are used in this project are Perturbation Observation technique and the Incremental Conductance technique. These two techniques are used in the extracting maximum power from the PV module as MPPT. Perturbation and Observation method is simply in operation and require very less hardware in comparison of other methods. But if we talk about the power loss, the loss of power is little more in the P&O method is more as compared to others. Because it has reason that the output of the PV module oscillate around the peak value. Some similarities can be seen in the Incremental Conductance method which are least oscillation in comparison to P&O method and the control is better. In the Inc. Cond. method requirement of hardware is more. The steady state value achieved in case of Inc. Cond. method is fast as compare to that of P&O method. These methods has many advantages and many disadvantages also. By simulating the model in matlab/simulink by using the both technique, results obtained are approximately equal. Therefore Perrturbation and observation method is used for the synchronization of grid due to its simple and effortless application.

5.6 Incremental Conductance Algorithm Flowchart

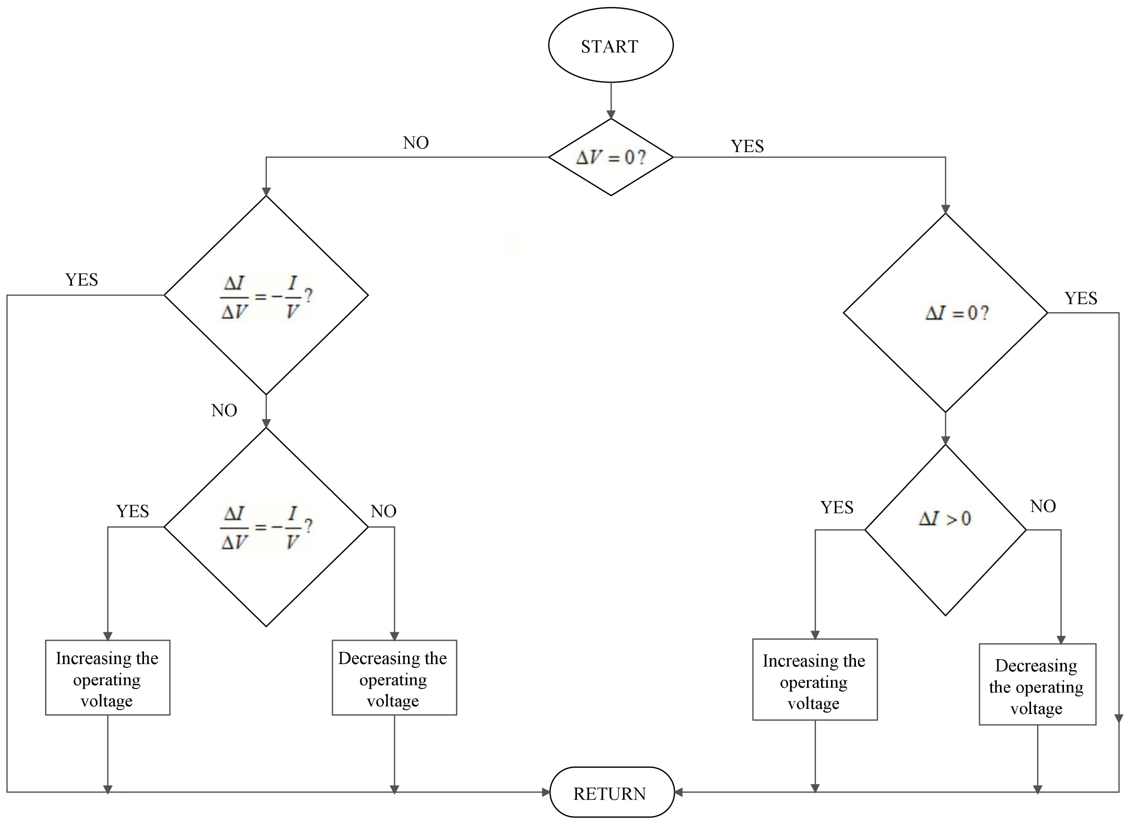

Fig. 5.3: Incremental Conductance Method Flowchart

5.7 Three Phase Voltage Source Inverter

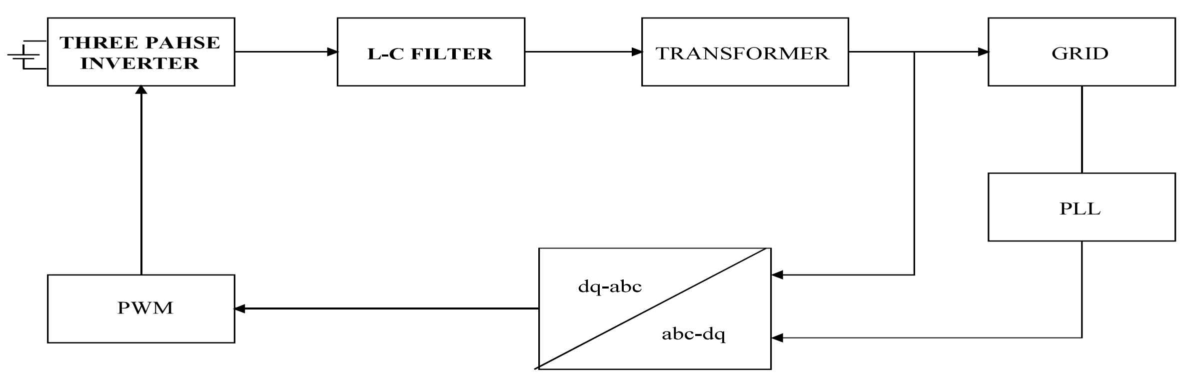

Fig. 5.4: Block diagram of the system.

Three phase VSI is interface between AC and DC system for the distribution of power. During the distribution of the power, control of power also required i.e active power and reactive power. The methodology used here to control the VSI connected with 3 phase grid. These days emerging power electronics widely used in all applications for control. It is widely employed because of the non-linearity in the system which is linearized by the switching. In this VSI the LC filter is considered for the modelling.

5.7.1 Phase Locked Loop

The strategy control of the Hybrid system synchronized with the grid is done by the PLL[16]. PLL which is known as 'Phase-Locked Loop'[30]. It is basically a control system which is

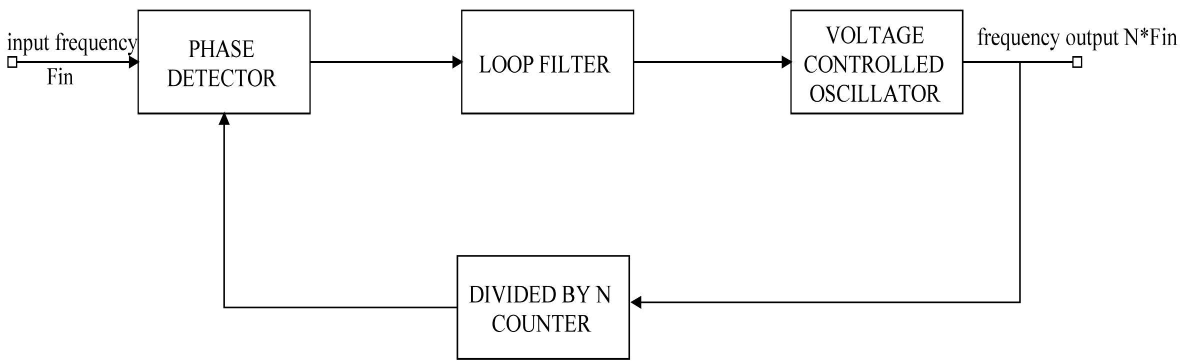

Fig. 5.5: Block diagram of PLL

closed loop, controls the frequency, who's functioning is generally based upon the sensitive detection of phase difference between the input and output signal of the controlling oscillators (CO). The Phase Locked Loop method of frequency synthesis is now the most commonly used method of producing high frequency oscillations in modern communications equipment. The frequency and the phase angle of the input system should match with that of the grid requirements. The synchronization process is done by PLL. It matches the frequency of the input system with that of the grid. Thus, it reduces the error and improves the efficiency[20]. The basic block diagram of PLL is shown in Fig.5.5. To connecting grid with hybrid system the most important part is synchronization of grid with the hybrid system. Frequency and the phase sequence of the grid is synchronized with the inverter with the help of PLL. This PLL minimizes the error from the obtained output current and the reference current from the controller. The two input signal locked by the PLL through feedback signal and shifted into the single phase. It also compares the two input frequencies and results into the same as input frequency. The mathematical equation of PLL is given by:

$$\omega = k_p V_q + K_i \int V_q dt \tag{5.14}$$

$$\theta = \int \omega dt \tag{5.15}$$

5.7.2 Pulse Width Modulation

Configuration of power stages in DC-DC converter depends on output voltage. So, it requires methodology to control the power. The methodology used in this project to control the power for the better efficiency is Pulse width modulation. PWM is the methodology for the control of average power to the load by controlling the input voltage.
Average output voltage is given by:

$$V_{avg} = \frac{T_{ON}}{T} * V_{in} \tag{5.16}$$

From the equation it is clear that, at constant T
if T_{ON} is decreased, the output voltage is also gets reduce.
V_{avg} - output of the converter in voltage.
V_{in} - input of the converter in voltage.
T_{ON} - on time for switch in seconds.
T - switching time of device in seconds.
The average value for the modulation is given by:

$$\bar{y} = \frac{1}{T} \int_0^T f(t) dt \tag{5.17}$$

In PWM technique the term modulation is used for the switching. Modulation index is defined as the ratio of the switching frequency to the reference signal frequency. Mathematically it is given by:

$$m = \frac{f_s}{f_r} \tag{5.18}$$

It is always less than 1 for the better result and to control the harmonic content.

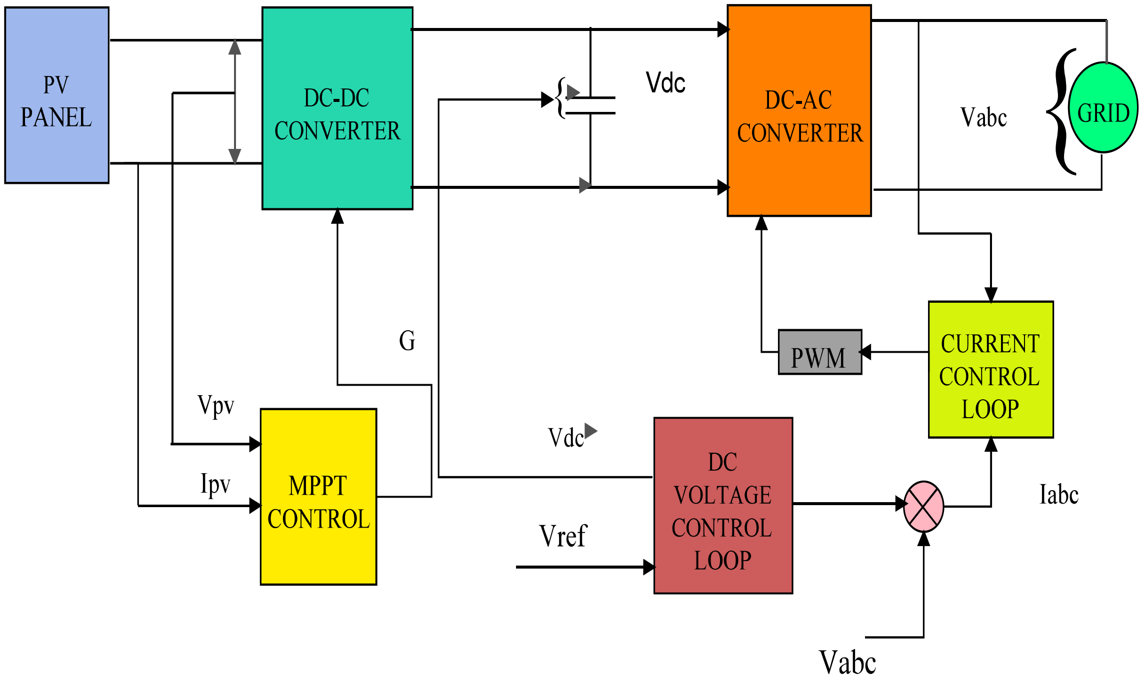

Fig. 5.6: Block digram of control of PV system

5.8 Control Methodology for the PV system

MPPT will recieve the PV voltage and the PV current. According to this voltage and current the reference is set up and deliver to PWM. Now, the MPPT gives the gate signal(G) to DC-DC converter.

On the other hand, other control methodology is the inverter control. In inverter control methodology the two loops are used:-

1. Outer loop(DC voltage control loop)
2. Inner loop(DC current control loop)

By doing so, the DC voltage maintained at constant and DC power is converted to the AC before feeding to the utility grid. For the control of PV output, two control schemes is used in this project. Out of these circuits first one is to regulate the DC-DC converter for extracting maximum power from the PV module and another control circuit is a current controlled PWM in d-q synchronous frame which maintains the DC link voltage of the inverter at constant reference level and also control the active and reactive currents injected to the grid.

Chapter 6

Results and Discussion

In this chapter the obtained results of the project work are explained and discussed with their specification and parameters.

6.1 Introduction

- Matlab Model
- Specification of the Parameters
- Discussion & Results

6.2 Matlab Model

Fig. 6.1 shows the project model in simulink environment.

By simulating the matlab/simulink model of the hybrid system in the simulink environment following results are discussed which are presented in the tabular form[13], [31] and [26].

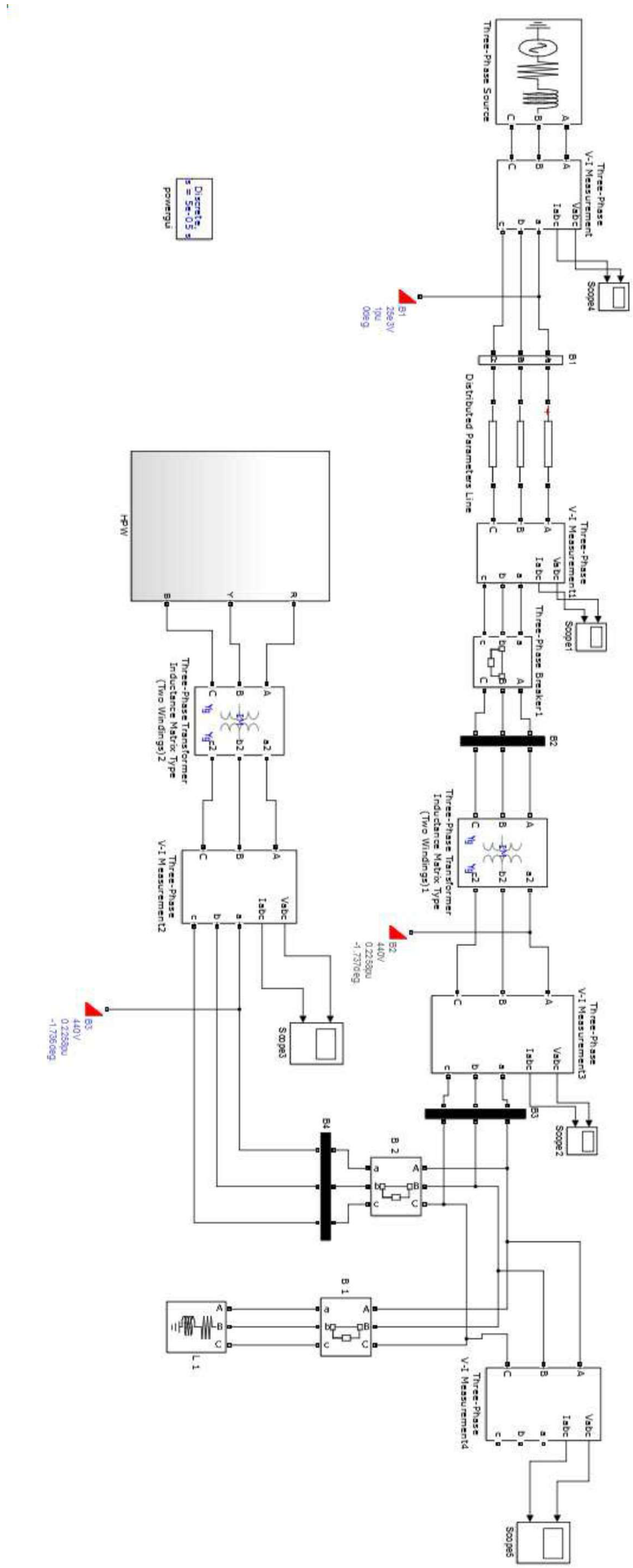

Fig. 6.1: Complete project Model in Simulink Environment

Table 6.1: Specification of the PV module

specification of the PV module	
Rating	8.6 kW
Module Rating	36 W
Number of module in series	21
Number of module in parallel	11
Open circuit voltage	446 V
Short circuit current	28 A
Peak Voltage	348 V
Peak Current	24.75 A

Table 6.2: Specification of the Wind generator

specification of the Wind generator	
Armature resistance	0.425 Ω
Magnetic flux leakage	0.433 wb
Stator Inductance	8.4 mH
Inertia constant	0.012

Table 6.3: Specification of the Grid

specification of the Grid	
Level of short circuit	30 mV
Base Voltage	25 kV
Ratio of X/R	7

6.3 Results

This section discussed about the results obtained in the dissertation work. Following are the parameters are shown in the table 6.4. These are further also explained with the simulation waveform.

Table 6.4: Table of results

Table of Results		
Parameter	**Voltage**(r.m.s)	**Current**(r.ms.)
3-Phase source	14555 volt	3.3 amp
Bus 1	14555 volt	3.3 amp
Bus 2	29 volt	720 amp
Bus 3	29 volt	695 amp
HPW output	29 volt	695 amp
Grid side output	28.5 volt	15.5 amp

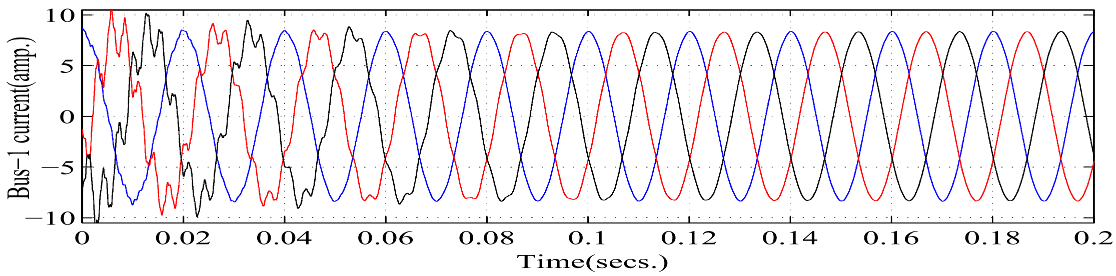

Fig. 6.2: Bus-1 current at source side

Fig.6.2 represents the bus-1 current from the three phase source which are distinguished as bus-1, bus-2, bus-3. Regarding these buses voltage and current are measured and verified with standard parameters. At starting some distortions are seen in the waveform which are because of inductor value at source side. Fig.6.3 represents the bus-1 voltage at three-phase source

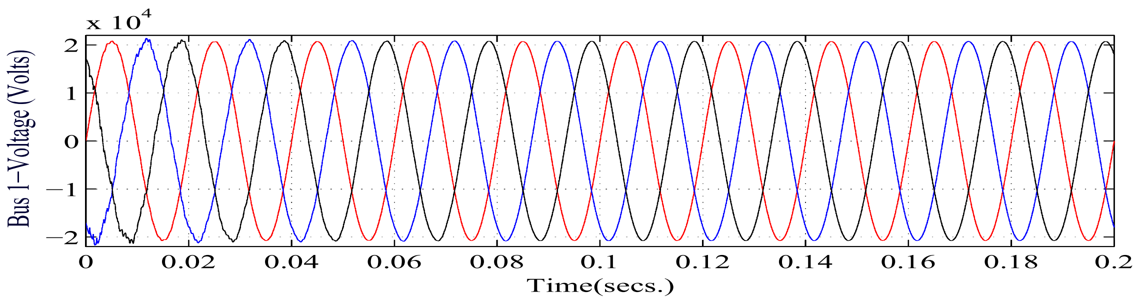

Fig. 6.3: Bus-1 voltage at source side

side can be seen from matlab model. Fig.6.4 represents the bus-2 current from the three phase

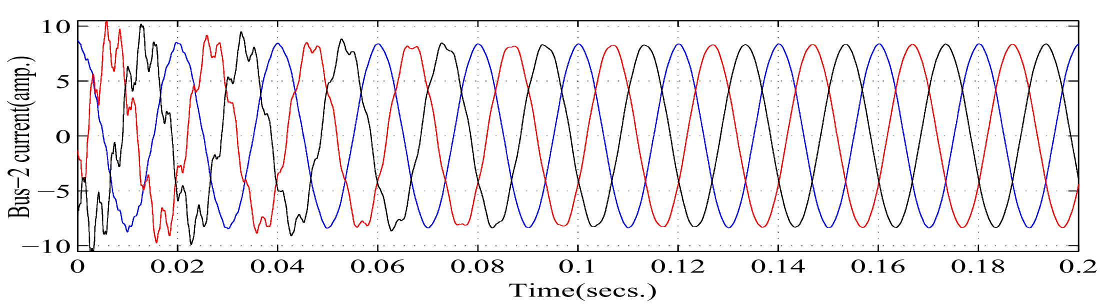

Fig. 6.4: Bus-2 current

source at different parameters. This can be seen from the matlab model. Fig.6.5 represents the

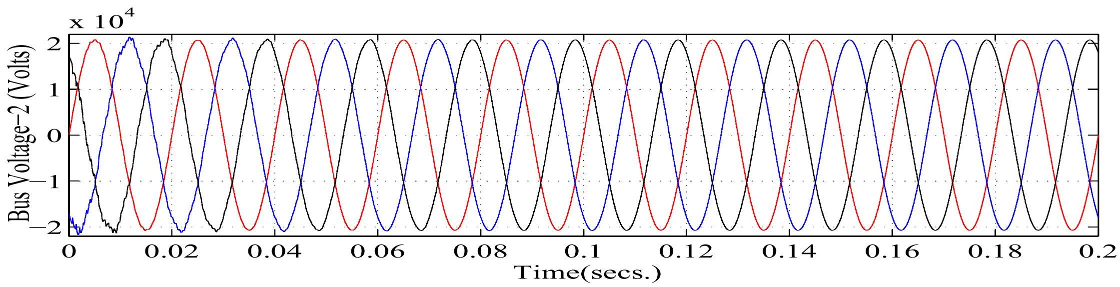

Fig. 6.5: Bus-2 voltage

bus-2 voltage from the three phase source at different parameters. This can be seen from the matlab model and the obtained waveform from the scope of bus-2. Fig.6.6 represents the bus-3

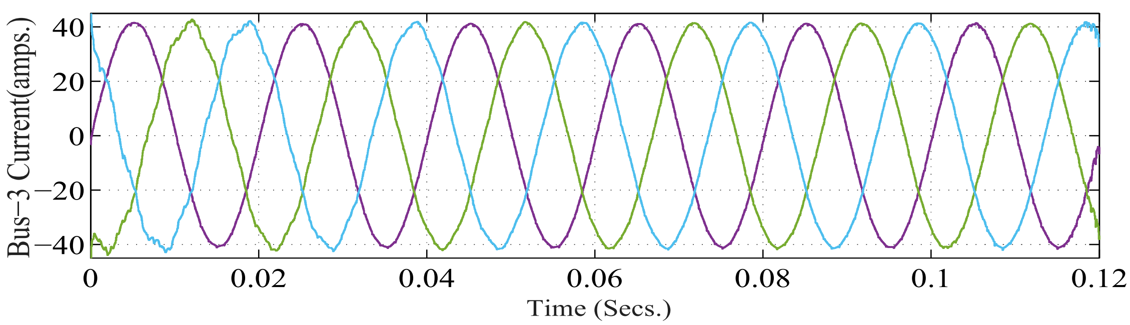

Fig. 6.6: Bus-3 current

current from the three phase source at different parameters. This can be seen from the matlab model. Fig.6.7 represents the bus-3 voltage from the three phase source at different parameters.

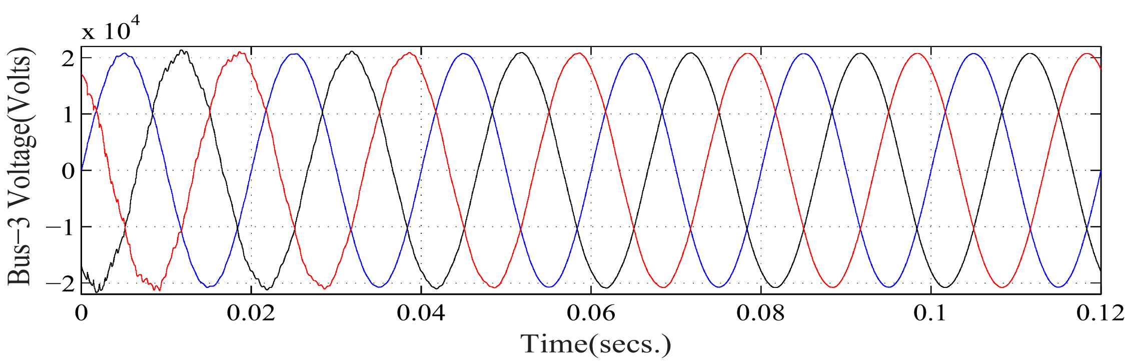

Fig. 6.7: Bus-3 voltage

This can be seen from the matlab model and the obtained waveform from the scope of bus-3.

Fig.6.8 represents the source voltage generated by three phase source which is nearly 20 KV

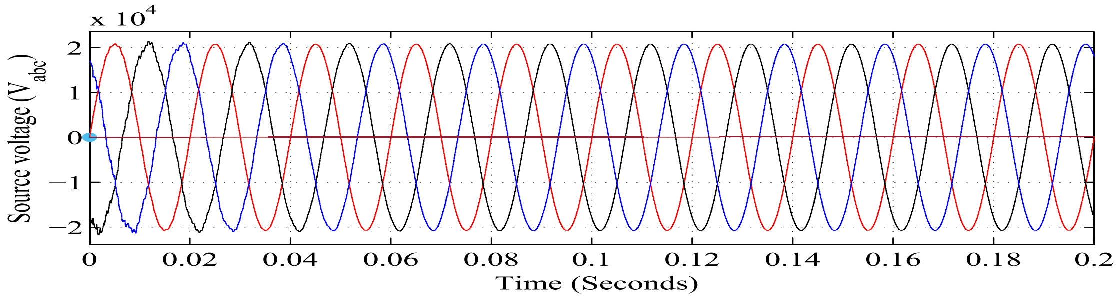

Fig. 6.8: Three-phase source voltage

can be seen from waveform. This source voltage is further measured by V-I measurement and the 3 buses are arranged. Phase to phase to r.m.s voltage is $25 * 10^3$ and the internal connection is star ground. 3-phase short-circuit level at base voltage(VA) is $100 * 10^6$. Fig.6.9 represents

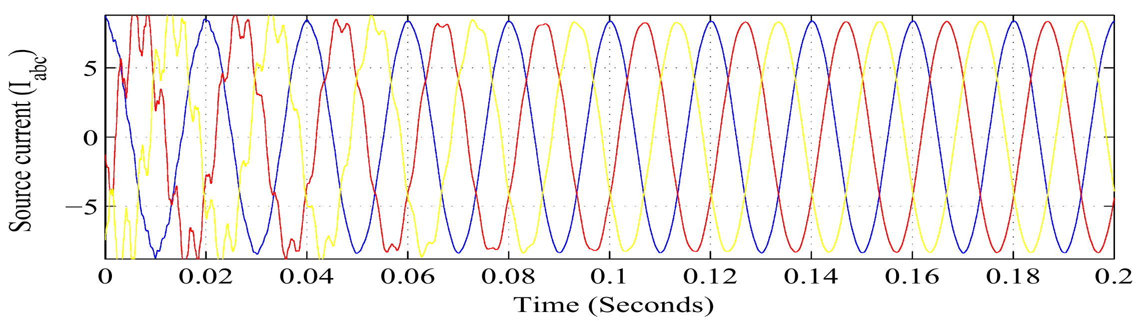

Fig. 6.9: Three-phase source current

the three phase source current generated by the three phase source.

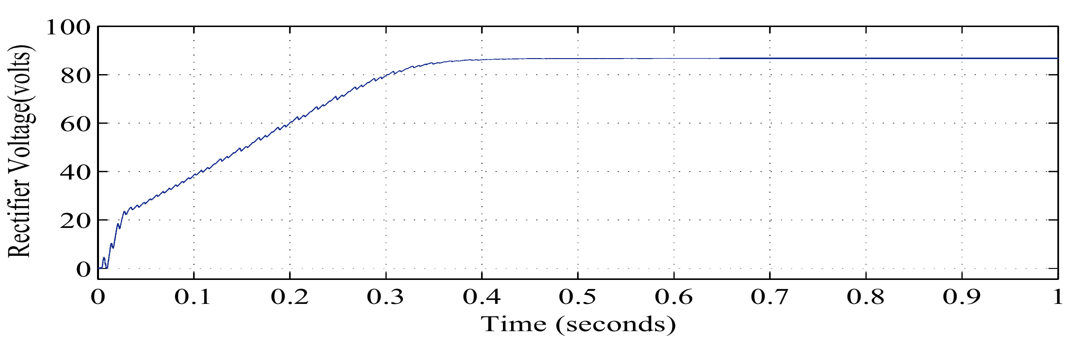

Fig. 6.10: Output Power of the PMSG

Fig.6.10 represents the output power from the permanent synchronous generator rectified by the rectifier AC-DC. Fig.6.11 represents the output voltage waveform of the hybrid system

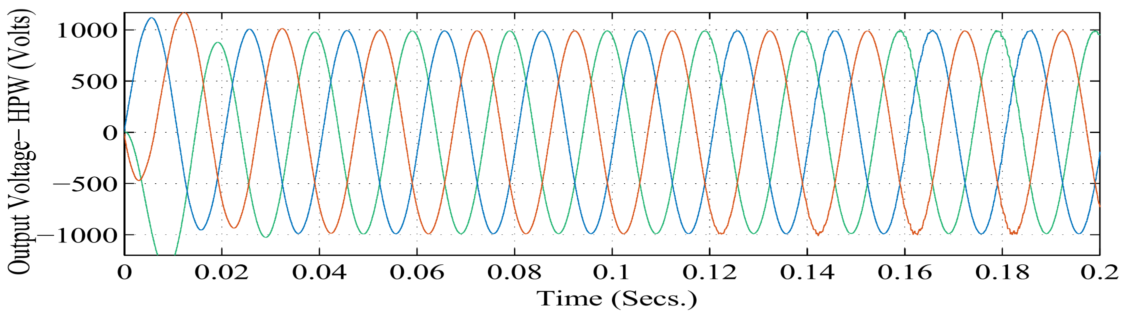

Fig. 6.11: Hybrid system voltage

which consists of solar and wind. This output voltage further synchronize with the grid as shown in the matlab model and also from the synchronized voltage waveform.

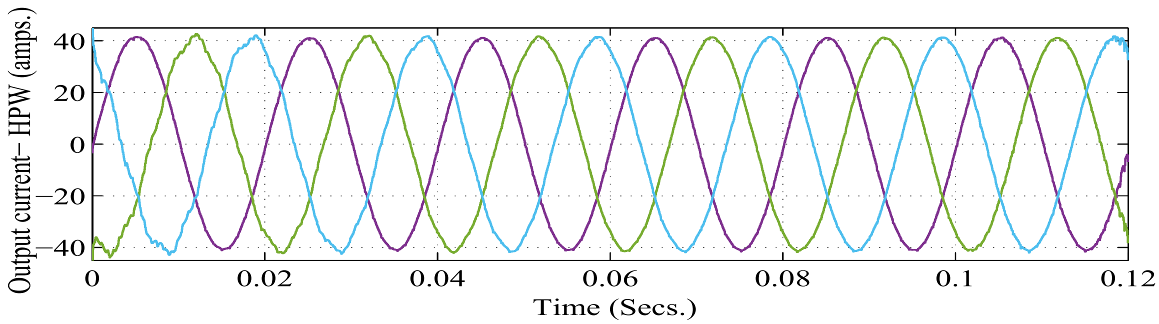

Fig. 6.12: Hybrid system current

Fig.6.12 represents the output current from the hybrid system which consists of solar and wind. This output current further synchronize with the grid as shown in the matlab model and also from the synchronized current waveform.

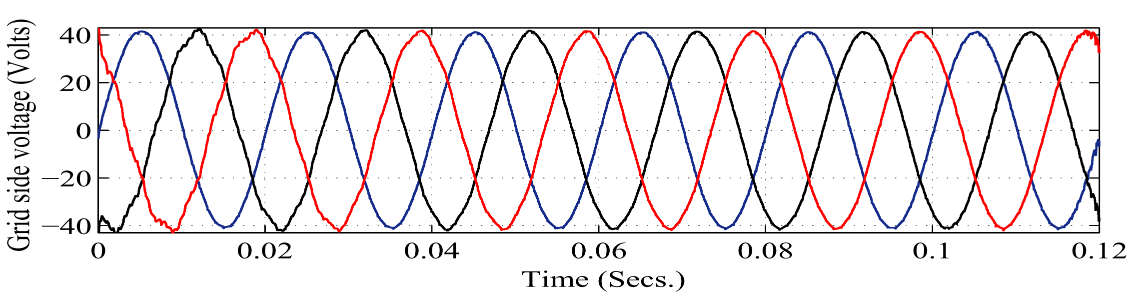

Fig. 6.13: Grid side output Voltage waveform

Fig.6.13 represents the synchronized grid side output voltage waveform.

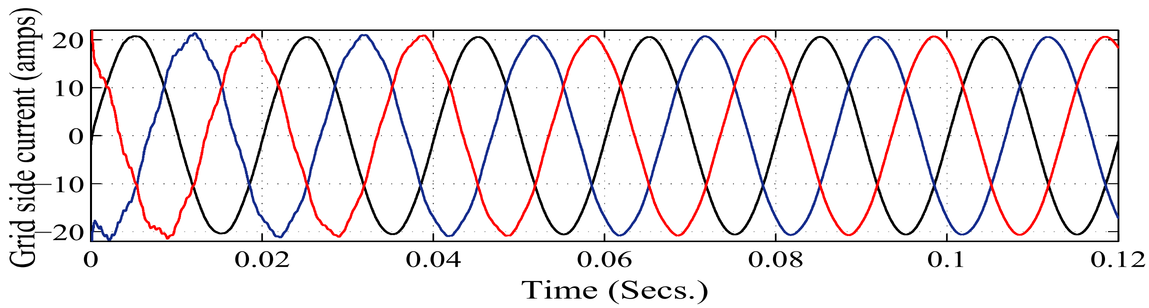

Fig. 6.14: Grid side output current waveform

Fig.6.14 represents the synchronized grid side output current waveform. These waveform obtained after interfacing the grid with VSI and the RL load is connected at grid side which is R= 10 Ω , L= 5 mH. The transformer is of ratio 1:1 i.e unity transformer because of this reason, the output voltage& current of HPW & bus 3 are same.6

Chapter 7

Conclusions & Future Scope

7.1 Conclusions

In this entire dissertation work the PV module with 100 W capacity has been modeled with varying irradiation and temperature and the wind model with 1 kW capacity has developed and simulated in matlab/simulink environment. A boost converter is designed and simulated. MPPT algorithm has designed to control the gate pulse of the high frequency switch of the boost converter.

In this dissertation work both the MPPT methods are used. As the perturbation& observation is simple in operation and required less hardware as compared to incremental conductance method. From the simulation results as shown in the fig. 6.11 and 6.12 it has been observed that both the methods gave nearly same result. So, the perturbation& observation method is chosen for the grid synchronization purpose because of its simplicity and easy implementation. PMSG has used in this dissertation work as a wind generator because of its self excitation capabilities and it also require less maintenance. A gird side VSI has been used to synchronize the wind-PV hybrid system. The various waveform are obtained in matlab environment which are discussed in the chapter 6.

7.2 Scope of Future Work

The future work of this project can be enlarged by using the smart devices like microprocessor's and PLC's to maximize the output power. By doing so, the performance of the system will be better than conventional energy sources. This will reduce the cost and also economic in nature. In future we can also combine other hybrid system with this existing one like fuel cell or battery system can be added and analyzed by the matlab software.

References

[1] S.-K. Kim, E.-S. Kim, and J.-B. Ahn, "Modeling and control of a grid-connected wind/pv hybrid generation system," in *2005/2006 IEEE/PES Transmission and Distribution Conference and Exhibition*, May 2006, pp. 1202–1207.

[2] N. Pandiarajan and R. Muthu, "Mathematical modeling of photovoltaic module with simulink," in *2011 1st International Conference on Electrical Energy Systems*, Jan 2011, pp. 258–263.

[3] J. G. Slootweg, H. Polinder, and W. L. Kling, "Representing wind turbine electrical generating systems in fundamental frequency simulations," *IEEE Transactions on Energy Conversion*, vol. 18, no. 4, pp. 516–524, Dec 2003.

[4] L. Lu and P. Liu, "Research and simulation on photovoltaic power system maximum power control," in *2011 International Conference on Electrical and Control Engineering*, Sept 2011, pp. 1394–1398.

[5] M. Fatu, L. Tutelea, I. Boldea, and R. Teodorescu, "Novel motion sensorless control of stand alone permanent magnet synchronous generator (pmsg): harmonics and negative sequence voltage compensation under nonlinear load," in *2007 European Conference on Power Electronics and Applications*, Sept 2007, pp. 1–10.

[6] T. M. U. N. Mohan and W. P.Robbins, *Power Electronic: Converters,Application, and Design*. Wiley, 2002.

[7] K. Ding, X. Bian, H. Liu, and T. Peng, "A matlab-simulink-based pv module model and its application under conditions of nonuniform irradiance," *IEEE Transactions on Energy Conversion*, vol. 27, no. 4, pp. 864–872, Dec 2012.

[8] W. D. Kellogg, M. H. Nehrir, G. Venkataramanan, and V. Gerez, "Generation unit sizing and cost analysis for stand-alone wind, photovoltaic, and hybrid wind/pv systems," *IEEE Transactions on Energy Conversion*, vol. 13, no. 1, pp. 70–75, Mar 1998.

[9] S. C. Teja and P. K. Yemula, "Energy management of grid connected rooftop solar system with battery storage," in *2016 IEEE Innovative Smart Grid Technologies - Asia (ISGT-Asia)*, Nov 2016, pp. 1195–1200.

[10] T. F. Chan and L. L. Lai, "Permanent-magnet machines for distributed power generation: A review," in *2007 IEEE Power Engineering Society General Meeting*, June 2007, pp. 1–6.

[11] M. E. Haque, K. M. Muttaqi, and M. Negnevitsky, "Control of a stand alone variable speed wind turbine with a permanent magnet synchronous generator," in *2008 IEEE Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy in the 21st Century*, July 2008, pp. 1–9.

[12] D. Sera, L. Mathe, T. Kerekes, S. V. Spataru, and R. Teodorescu, "On the perturb-and-observe and incremental conductance mppt methods for pv systems," *IEEE Journal of Photovoltaics*, vol. 3, no. 3, pp. 1070–1078, July 2013.

[13] S. K. Singh, A. Kumar, P. Bharti, and M. Ansari, "Grid connected pv system based fault analysis," *International journal of Current Engineering and Technology*, vol. 3, pp. 1080–1090, July 2013.

[14] E. M. Natsheh, A. Albarbar, and J. Yazdani, "Modeling and control for smart grid integration of solar/wind energy conversion system," in *2011 2nd IEEE PES International Conference and Exhibition on Innovative Smart Grid Technologies*, Dec 2011, pp. 1–8.

[15] M. E. Haque, M. Negnevitsky, and K. M. Muttaqi, "A novel control strategy for a variable-speed wind turbine with a permanent-magnet synchronous generator," *IEEE Transactions on Industry Applications*, vol. 46, no. 1, pp. 331–339, Jan 2010.

[16] R. Chedid and S. Rahman, "Unit sizing and control of hybrid wind-solar power systems," *IEEE Transactions on Energy Conversion*, vol. 12, no. 1, pp. 79–85, Mar 1997.

[17] D. K. Sharma and G. Purohit, "Advanced perturbation and observation (p amp;o) based maximum power point tracking (mppt) of a solar photo-voltaic system," in *2012 IEEE 5th India International Conference on Power Electronics (IICPE)*, Dec 2012, pp. 1–5.

[18] D. C. Huynh, T. A. T. Nguyen, M. W. Dunnigan, and M. A. Mueller, "Maximum power point tracking of solar photovoltaic panels using advanced perturbation and observation algorithm," in *2013 IEEE 8th Conference on Industrial Electronics and Applications (ICIEA)*, June 2013, pp. 864–869.

[19] B. B. Alagoz, C. Keles, and A. Kaygusuz, "Towards energy webs: Hierarchical tree topology for future smart grids," in *2015 3rd International Istanbul Smart Grid Congress and Fair (ICSG)*, April 2015, pp. 1–4.

[20] L. Hadjidemetriou, E. Kyriakides, Y. Yang, and F. Blaabjerg, "A synchronization method for single-phase grid-tied inverters," *IEEE Transactions on Power Electronics*, vol. 31, no. 3, pp. 2139–2149, March 2016.

[21] M. Kumar and M. Singh, "Simulation and analysis of grid connected photovoltaic system with mppt," in *2012 IEEE Fifth Power India Conference*, Dec 2012, pp. 1–6.

[22] S. Soori, S. A. S. Hasari, A. Salemnia, and S. Khosrogorji, "An improved method for power management and voltage control of pv unit in dc microgrid," in *2016 7th Power Electronics and Drive Systems Technologies Conference (PEDSTC)*, Feb 2016, pp. 326–331.

[23] D. Sera, R. Teodorescu, and P. Rodriguez, "Pv panel model based on datasheet values," in *2007 IEEE International Symposium on Industrial Electronics*, June 2007.

[24] T. Esram and P. L. Chapman, "Comparison of photovoltaic array maximum power point tracking techniques," *IEEE Transactions on Energy Conversion*, vol. 22, no. 2, pp. 439–449, June 2007.

[25] I. Laird, H. Lovatt, N. Savvides, D. Lu, and V. G. Agelidis, "Comparative study of maximum power point tracking algorithms for thermoelectric generators," in *2008 Australasian Universities Power Engineering Conference*, Dec 2008, pp. 1–6.

[26] E. Nazeraj, O. Hegazy, and J. V. Mierlo, "Modeling and control of interleaved dc/dc boost converters via energy factor approach," in *2017 Twelfth International Conference on Ecological Vehicles and Renewable Energies (EVER)*, April 2017, pp. 1–8.

[27] H. Polinder, F. F. A. van der Pijl, G. J. de Vilder, and P. J. Tavner, "Comparison of direct-drive and geared generator concepts for wind turbines," *IEEE Transactions on Energy Conversion*, vol. 21, no. 3, pp. 725–733, Sept 2006.

[28] F. Valenciaga, P. F. Puleston, and P. E. Battaiotto, "Power control of a solar/wind generation system without wind measurement: a passivity/sliding mode approach," *IEEE Transactions on Energy Conversion*, vol. 18, no. 4, pp. 501–507, Dec 2003.

[29] K. Kurozumi, T. Tawara, T. Tanaka, Y. Kawagoe, T. Yamanaka, H. Ikebe, K. Shindou, and T. Miyazato, "A hybrid system composed of a wind power and a photovoltaic system at ntt kume-jima radio relay station," in *INTELEC - Twentieth International Telecommunications Energy Conference (Cat. No.98CH36263)*, 1998, pp. 785–789.

[30] L. K. Gan, D. E. Macpherson, and J. K. H. Shek, "Synchronisation control and operation of microgrids for rural/island applications," in *Power Engineering Conference (UPEC), 2013 48th International Universities'*, Sept 2013, pp. 1–6.

[31] N. Femia, G. Petrone, G. Spagnuolo, and M. Vitelli, "Optimizing sampling rate of p o mppt technique," in *2004 IEEE 35th Annual Power Electronics Specialists Conference (IEEE Cat. No.04CH37551)*, vol. 3, June 2004, pp. 1945–1949 Vol.3.

List of Publications

[1] Anurag Verma, Surya Prakash and Shweta Agarwal, ”Grid Synchronization of the Hybrid System Using PLL”, *published in* ”International Journal of Computer Applications”(0975 8887)

anuragthesis1

ORIGINALITY REPORT

%15	%8	%8	%9
SIMILARITY INDEX	INTERNET SOURCES	PUBLICATIONS	STUDENT PAPERS

PRIMARY SOURCES

1	Submitted to Madan Mohan Malaviya University of Technology Student Paper	%1
2	Submitted to Universiti Teknologi Malaysia Student Paper	%1
3	Submitted to University of Newcastle upon Tyne Student Paper	%1
4	Submitted to Indian School of Mines Student Paper	%1
5	ethesis.nitrkl.ac.in Internet Source	%1
6	Green Energy and Technology, 2015. Publication	%1
7	irdindia.in Internet Source	%1
8	ijettcs.org Internet Source	<%1