

# Modeling & Simulation of Multiphase Interleaved Boost Converter for Grid-connected PV System

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# Modeling & Simulation of Multiphase Interleaved Boost Converter for Grid-connected PV System

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## CERTIFICATE

This is to certify that the project entitled “**Modeling & Simulation of Multiphase Interleaved Boost Converter for Grid-connected PV System**” submitted by **Ms. PreetiKumariSahu (213EE5349)** in partial fulfillment of the requirements for the award of Master of Technology degree in Industrial Electronics, Department of Electrical Engineering at National Institute of Technology, Rourkela is a genuine work carried out by her under my supervision and guidance.

The matter illustrated in this thesis has not been submitted to any other Institute for the award of any Degree to the best of my knowledge.

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## ABSTRACT

A Multiphase Interleaved boost converter with photovoltaic module using Maximum Power Point Tracking (MPPT) technique is the primary objective of this project. Hence at the beginning, the PV module is analyzed in MATLAB using SIMULINK software. Single-diode Photovoltaic model is used here. The surrounding conditions, which really affect the characteristics of PV cells are listed as; Solar Irradiation & Temperature. Generally three boost converters are used in parallel manner to form a three-phase interleaved boost converter. Controlling pulses are coming from the three maximum power point trackers. The MPPT indicates the maximum possible power from the photovoltaic module and supply it to the load via the multiphase interleaved boost converter which boosts up the voltage in high ratio to required magnitude. Then the generated dc output voltage is given back to grid through universal inverter. Before connecting to grid it should be properly synchronized. In this project, simulation & design of a close loop three phase inverter in MATLAB SIMULINK platform is also presented. That is also a part of PV grid connected systems. The inverter utilized here is controlled by the synchronous d-q reference frame. It injects a current into the grid so that both can be synchronized. Phase lock loop technique is used here to lock the grid frequency and phase with inverter ones. Filter is especially designed here at the inverter output terminal to eliminate the high frequency ripple. It's of low pass type. There are many MPPT methods given by the researchers. Among them P&O method and INC method are mostly used. Here P&O algorithm is used because of its advantages over INC method. P&O MPPT algorithm having faster dynamic response and well-regulated PV output voltage than hill climbing algorithm. Since the working procedure of INC algorithm is more complicated than the other two algorithms and also the simulation time spent by INC algorithm is little longer than the other two algorithms.



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# Chapter 1

## INTRODUCTION

- 1.1 Theoretical background
- 1.2 Literature survey
- 1.3 Motivation
- 1.4 Objective
- 1.5 Thesis Outline

## **1.1 Theoretical Background**

Main objective of the project is Photovoltaic module along with Multiphase Interleaved boost converter using Maximum Power Point Tracking (MPPT) technique. Hence in the beginning, the PV module is analyzed in MATLAB using SIMULINK software. Single-diode Photovoltaic model is used here. The surrounding conditions, which really affect the characteristics of PV cells can be listed as; Solar Irradiation & Temperature. Generally three boost converters are used in parallel manner to form a three-phase interleaved boost converter. Controlling pulses are coming from the three maximum power point trackers. The MPPT indicates the maximum possible power from the photovoltaic module and supply it to the load via the multiphase interleaved boost converter which boosts up the voltage in high ratio to required magnitude. Then the generated dc output voltage is given back to grid through universal inverter. Before connecting to grid it should be properly synchronized. In this project, simulation & design of a close loop three phase inverter in MATLAB SIMULINK platform is also presented. That is also a part of PV grid connected systems. The inverter utilized here is controlled by the synchronous d-q reference frame. It injects a current into the grid so that both can be synchronized. Phase lock loop technique is used here to lock the grid frequency and phase with inverter ones. Filter is especially designed here at the inverter output terminal to eliminate the high frequency ripple. It's of low pass type. There are many MPPT methods given by the researchers. Among them P&O method and INC method are mostly used. Here P&O algorithm is used because of its advantages over INC method. P&O MPPT algorithm having faster dynamic response and well-regulated PV output voltage than hill climbing algorithm. Since the working procedure of INC algorithm is more complicated than the other two algorithms and also the simulation time spent by INC algorithm is little longer than the other two algorithms.

## **1.2 Literature Survey**

Now a days one of the important concerns in the generating plant is the hike in load demand. However the energy resources are unavailable to meet the desired load demands utilizing the conventional sources [1], [2]. Increased concerns to deficit of fossil fuel, higher price of oil, increased global warming; harm to environment has increased the renewable energy utilization. Around the world there are many non-conventional energy sources. Among all solar light energy & wind energy are prime resources of energy [3], [5]. They can be used in this regard. Abundance and sustainability for solar radiant energy has made it possible to

utilize it properly. Solar generated energy can be used as grid connected if the grid is nearby or as stand-alone unit. Another benefit of using solar energy is its portability. It can be operated wherever necessary, as solar energy is available in a wide way and entirely free of cost. Because of all these advantages, PV systems have been used in various power applications. As photovoltaic (PV) cells have greater importance in generation of energy, several research and development is being done on finding the maximum possible power, as the characteristics of the PV module is nonlinear in nature [4]. Hence the optimum operating point is needed, where it can show linear performance. That maximum possible operating point is called the maximum power point (MPP) that ensures max possible power generation. There are several MPPT methods available. They are Perturb & Observation Method, Incremental Conductance Method, Parasitic Capacitance Method, Constant Voltage & Constant Current method [8]. Among all the MPPT methods, Perturb & Observation method is utilized here for finding the maximum power for its low cost of operation [6]. This Technique is divided into two parts. In 1<sup>st</sup> part Current iteration makes the PV module functioning at maximum power point. And in 2<sup>nd</sup> part the control circuit identifies the operating point, whether that is max point or not. If not then set the point nearer to max. point [7]. The Choice is to be made according to the need of algorithm and operating conditions. If the required algorithm is very simple and not much effort is given on the reduction of the voltage ripple, then P&O method is suitable. But if the fluctuation decides the maximum power point is to be reduced than INC method is applicable, but it makes the operation complex and more costly [9]. Output generated power of the PV cell can be affected by the factors like solar irradiation & temp. Furthermore its efficiency is very small. So to diminish overall cost of the PV system, high efficient energy processors can be used. This energy processor considers mainly DC-DC converter like buck, boost or buck-boost converter. Hence the DC-DC converter is the primary stage followed by maximum power point tracking controller circuit which gives an uninterrupted operating point [11], [12]. Generally to boost up the voltage level or else we can say to get the output voltage higher than the input, boost converters are used. However when these boost converters are operated for high ratios leading to some difficulties like higher voltage and current stress on the MOSFET & higher voltage. Hence as a solution for this, an interleaving technique for boost converter have been adopted. This approach can be used for higher power applications to produce high voltage gain compared to the simple boost converter [13], [14], [15]. For synchronization with the load, the frequency & output voltage of the inverter must be same as the output voltage & frequency of the Grid [17]. The Grid connected inverter can be

controlled by the pulse width modulated universal inverter. This is most widely used in PV systems. Different control strategies are available to control the current. They are d-q theory & p-q theory with phase lock loop control [16] to [20].

### **1.3 Motivation**

The challenge of the project and the new area of study were the motivations behind this project. The necessity of a non-conventional energy source due to the depreciation of fossil fuel and nuclear power; hence the photovoltaic array has come into the picture. Hence a fast and precise PV array was needed. PV model is one of the most used energy source as it satisfies government's policy to sustainable green energy and generous tariff schemes. The reason for using the specified model is to minimize the reverse effect of temperature and irradiation changes in the PV array. In this method Photovoltaic cells directly convert the sunlight irradiation into electricity by the photovoltaic effect. It has many advantages like clean and no pollution due to solar power generation as it won't release any greenhouse gasses, so it will not pollute the environment.

### **1.4 Objective**

The primary objective of the thesis is to implement a power system that is a photovoltaic generated power. The step by step objectives are,

- To examine and model PV cell, PV array and PV panels.
- To study the characteristic curves PV cells and effect of variation of environmental conditions like temperature and irradiation on them.
- To track the maximum power point of operation the PV panel irrespective of the changes in the environmental conditions of temperature and irradiation.
- To study the Interleaved Boost Converter and analysis its different modes of operations.
- Synchronization with Grid by the help of close loop inverter control.

## 1.5 Thesis Outline

This thesis is manifested in chapter wise as follows:

Chapter 1 explains overview on why we have chosen renewable energy sources for power generation with literature survey. Advantages of solar PV power generation system among all other renewable energy sources are listed. The motivation for this project and the most important thing is mainline objective, which is divided into subparts.

Chapter 2 gives brief discussions on the solar cell, its basic theory, connections, technologies and modeling with proper equivalent circuit and equations.

Chapter 3 gives small introduction on MPPT and its importance in solar PV power generation is presented. The MPPT's requirements and types are discussed.

Chapter 4 is about DC/DC converter especially Interleaved Boost Converter and its need in solar power generation system. Need of interleaving technique is also listed here. Modes of operation of the converter with basic equations are shown.

Chapter 5 is about a close loop inverter with the help of PLL circuit is described here for the proper synchronization with the grid.

Chapter 6 consists of all the required results are listed together for the user convenience.

Chapter 7 gives conclusion and future Scope.

# Chapter 2

## PV ENERGY SYSTEM

2.1 Introduction

2.2 Photovoltaic arrangement

2.2.1 Photovoltaic cell

2.2.2 Photovoltaic cell Connections

2.2.3 Photovoltaic module

2.2.4 Photovoltaic array

2.3 Modeling of PV cell

2.4 Variation of solar irradiation at const. Temperature

2.5 Variation of temperature at const. Irradiation

2.6 Summary



## 2.1 Introduction

This chapter illustrates the PV arrangement. It is the main part of the project from where supply is coming. It gives basic idea on PV cell, module and array, its different types of connection with corresponding circuit diagram. It also explains the modeling of PV array with all relevant equation, & the factors affecting the characteristics of PV cell.

## 2.2 Photovoltaic Arrangement

A photovoltaic energy system is mainly powered by PV cells. The configuration of PV system is explained in following figure 2.1 as shown below.

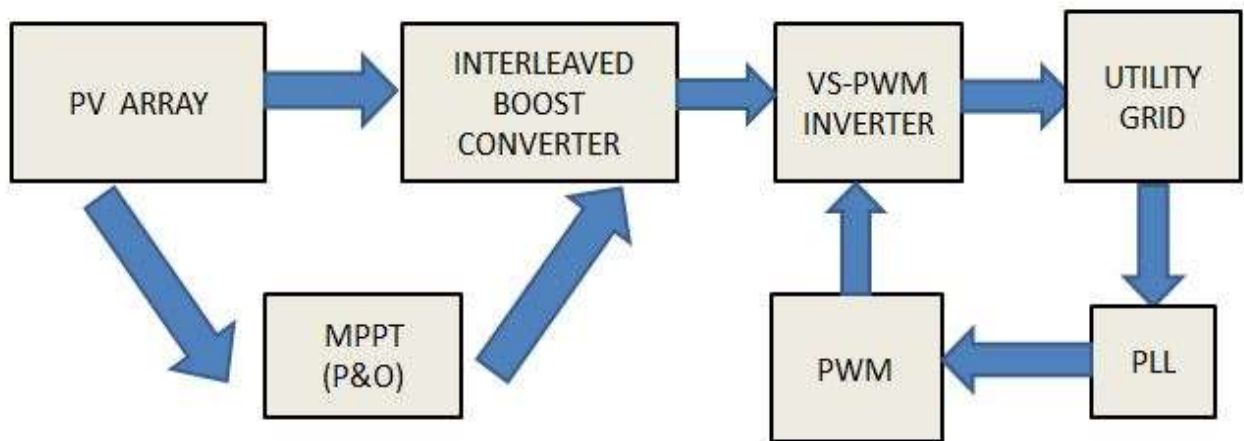


Fig.2.1 Overall block representation of PV energy system

It contains PV modules or Arrays, which convert solar energy in the form of solar irradiation into electric energy. The DC/DC converter changes the value of the input voltage to match it with the overall system. This DC/DC converter may be boost, buck or buck-boost contingent on the required and available voltage levels. Here boost converter with interleaved technique is used. The maximum possible power point tracking system collects the maximum electric power. Then the DC value that is generated from interleaved boost converter is given back to the inverter for grid synchronization purpose. PLL circuit plays an important role for the synchronization.

### 2.2.1 Photovoltaic Cell

Generally PV cells comprise of different types of semiconductors using several manufacturing procedures. Photovoltaic cells consist of a tiny layer of huge Si or a thin Si film attached with electrical ports. To create an electric field, a semiconductor wafer of thin size is specially used for PV cells. From sunlight when light energy falls on the surface of PV cell; charge carriers are generated from the incident light. Because the generated charge carriers, electric current originated provided short path is made through the PV cell. When the energy of the incident light is sufficiently enough, charges can free the covalent electrons of the semiconductor. This mechanism mainly depends upon the given two factors. They are (1) on the Semiconductor material and (2) On the incident light's wavelength.

The rate of originated electric carriers depends upon (1) the flux of incident light and (2) the capacity of absorption of the semiconductor. Furthermore, the absorption capacity depends mainly upon,

- band gap of the semiconductor,
- the extent of reflection of the cell surface,
- the intrinsic concentration of carriers in the semiconductor,
- the mobility of electron,
- the rate of recombination,
- the Temperature

The solar irradiation is comprised of photons of several energies. However energies of the photons that are lower than the band gap energy of the PV cell can't be used and no voltage and current are generated from them. Hence photons with energy higher than the band gap energy, produce electricity. And the remainder of the energy which can't be used for electricity generation dissipated as the heat from the surface of PV cell.

The fabrication process of the only element is economically feasible, that is Si. Other materials may be efficient better than Si, but they are too costly. A PV cell can be either circular or square in shape.

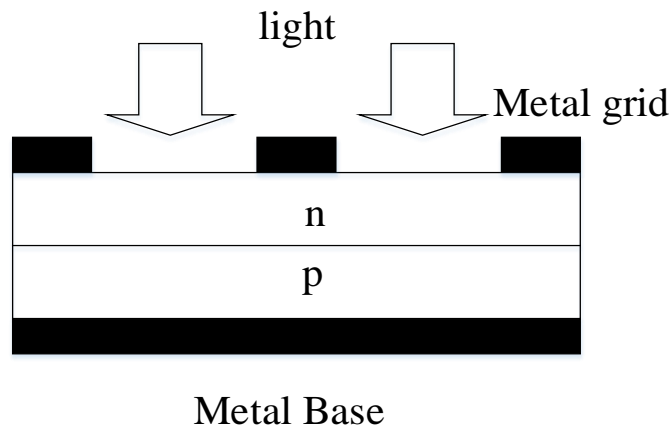


Fig. 2.2 Structure of PV cell

### 2.1.2 Photovoltaic Cell Connections

PV cell connection is just similar to the battery connection. Whenever positive terminal of PV cell is connected to negative terminal of another PV cell, then they form a series connection. In series connection current is same and voltage is added as shown in figure 2.3.

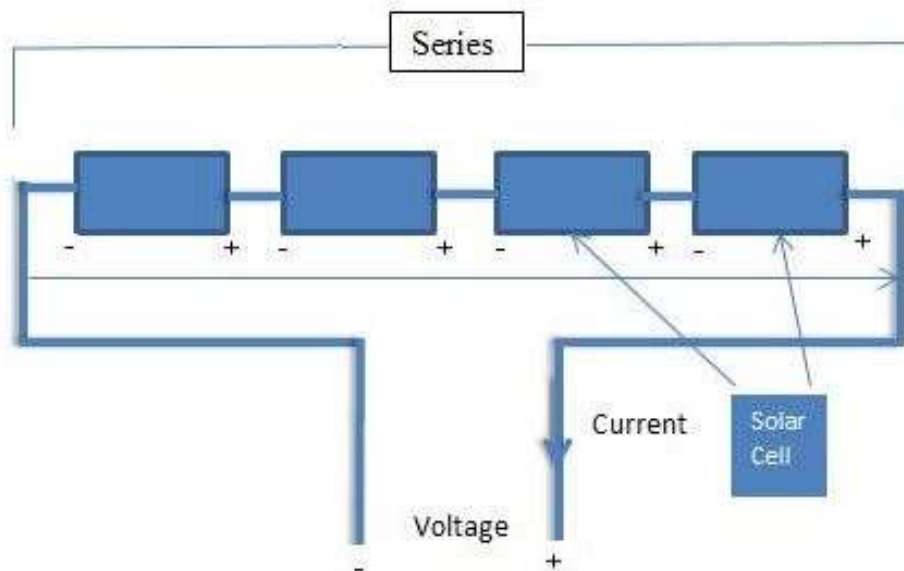


Fig. 2.3 Series connection of solar cell

Whenever all the positive terminals of PV cells are connected to one terminal and all the negative terminals are clubbed together of PV cell to another terminal, then they form a parallel connection. In parallel connection, current is added and voltage is same as shown in figure 2.4.

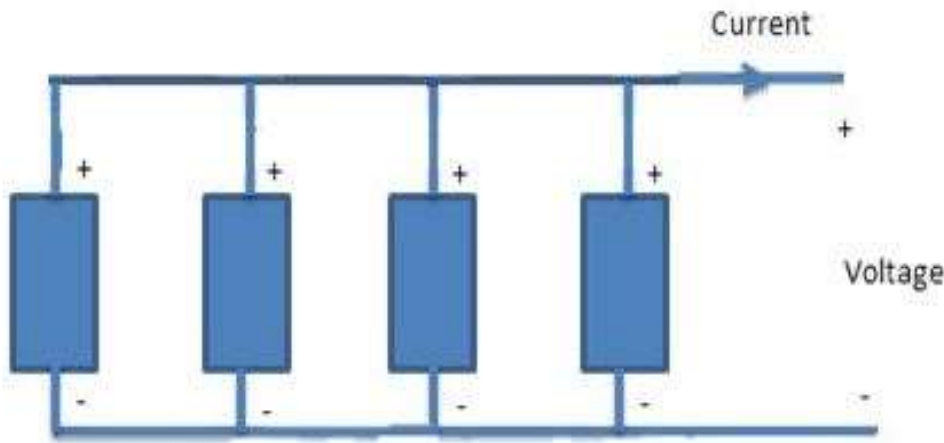


Fig. 2.4 Parallel connection of solar cell

### 2.2.3 Photovoltaic Module

Generally the voltage generated from PV cell is very small approximately 0.5V. Hence for high voltage the different Photovoltaic cells are connected in series manner, & for the higher current several Photovoltaic cells are connected in parallel manner to form a PV module. Several diodes are connected across the circuit to avoid reverse currents in case of the adverse environmental condition. Because of the reverse current arises due to the adverse environmental condition power going to be wasted consequently the surface of the PV. At higher temperatures the efficiency of the PV cells becomes less.

### 2.2.4 Photovoltaic Array

An array is a group of solar PV Modules connected electrically together. They are mounted on a sustainable structure to produce higher amount of desired power. Here in this project the main aim is to design a grid connected power generation system for a load that is connected to the grid.

## 2.3 Modeling of PV Cell

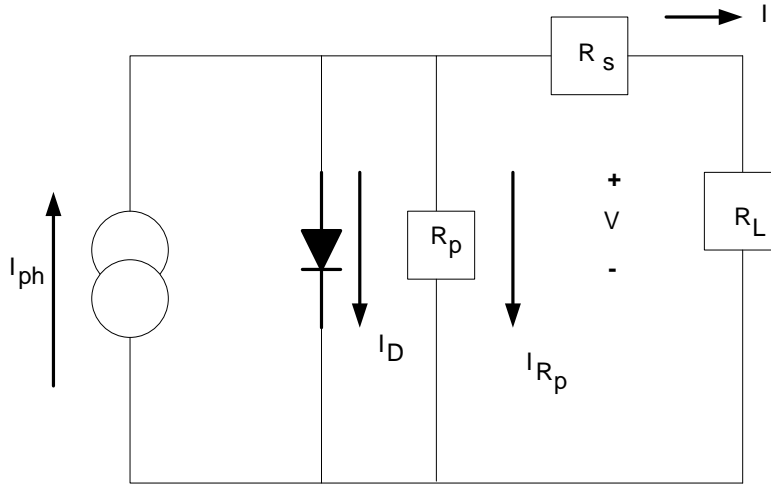


Fig. 2.5: Equivalent circuitual representation of PV cell

A solar PV cell is mainly represented by a current source connected with a diode in parallel fashion. Furthermore a shunt resistance and an intrinsic series resistance are added to the model as shown in figure.

Where,

$R_s$  is the intrinsic series resistance whose value is slight.

$R_p$  is the shunt resistance with very high value.

After applying KCL to the point where  $I_{ph}$ , diode,  $R_s$  and  $R_p$  all meet, we get our expression as,

$$I_{ph} = I_D + I_{Rp} + I$$

If we rearrange the above equation then we get a new equation as,

$$I = I_{ph} - I_{Rp} - I_D$$

$$I = I_{ph} - I_o \left[ e^{\left( \frac{V + I.R_s}{V_T} \right)} - 1 \right] - \left[ \frac{V + I.R_s}{R_p} \right]$$

Where,  $I_{ph}$  =photocurrent

$I$  = Cell current,

$I_0$  = Reverse saturation current

$V$  = Cell voltage

$R_s$  = intrinsic series resistance,

$R_p$  = parallel shunt resistance,

$V_T$  = Thermal voltage

$K$  = Boltzmann constant,

$T$  = Temperature in Kelvin,

$q$  = Charge of an electron.

$$I = n_p I_{ph} - n_p I_{rs} \left[ e^{\left( \frac{q}{kTA} \frac{V}{n_s} \right)} - 1 \right]$$

Where,

$n_s$  = number of cells connected in series

$n_p$  = number of cells connected in parallel

$A$  = p-n junction ideality factor

$I_{rs}$  = cell reverse saturation current.

Factor  $A$  in the equation indicates the cell deviated from the characteristics of ideal p-n junction; its value lies between the range 1-5 and here  $A=2.46$ .

Reverse saturation current of cell  $I_{rs}$  changes with temperature in accordance with the following given equation:

$$I_{rs} = I_{rr} \left[ \frac{T}{T_r} \right]^3 e^{\left( \frac{qE_G}{kA} \left[ \frac{1}{T_r} - \frac{1}{T} \right] \right)}$$

Where,

$T_r$  = Reference temperature of cell.

$I_{rr}$  = reverse saturation current of the cell at temperature  $T_r$ .

$E_G$  = band gap energy of the semiconductor utilized in the cell.

## 2.4 Variation of solar irradiation at const. Temperature

The P-V and I-V characteristics of a PV cell are highly sensitive to solar irradiation. The solar irradiation keeps on fluctuating, due to the fact that environmental conditions changing continuously. However control mechanisms are available which can trace this change and can help the PV cell to meet the desired load demands. Solar irradiation affects the PV input, the more is the irradiation, and consequently more will be the input to the PV cell. As result power value will be increased to the same voltage value. It also affects the open circuit voltage; it varies proportionally with the solar irradiation. This is due to the fact that, when more sunlight incidents on to the surface of PV cell, the electrons are assigned with higher excitation energy, thereby increasing the electron mobility hence more power is generated.

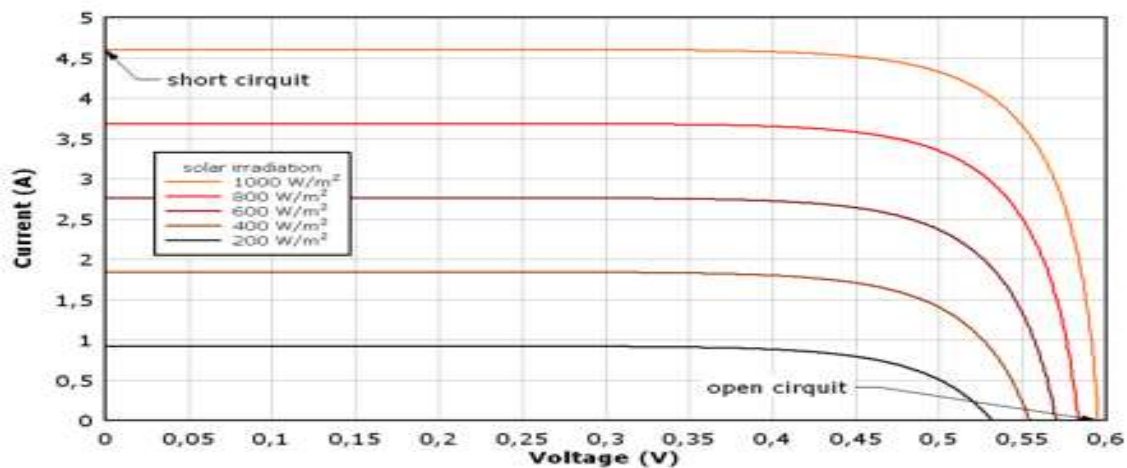


Fig. 2.6: Variation of I-V curve with solar irradiation

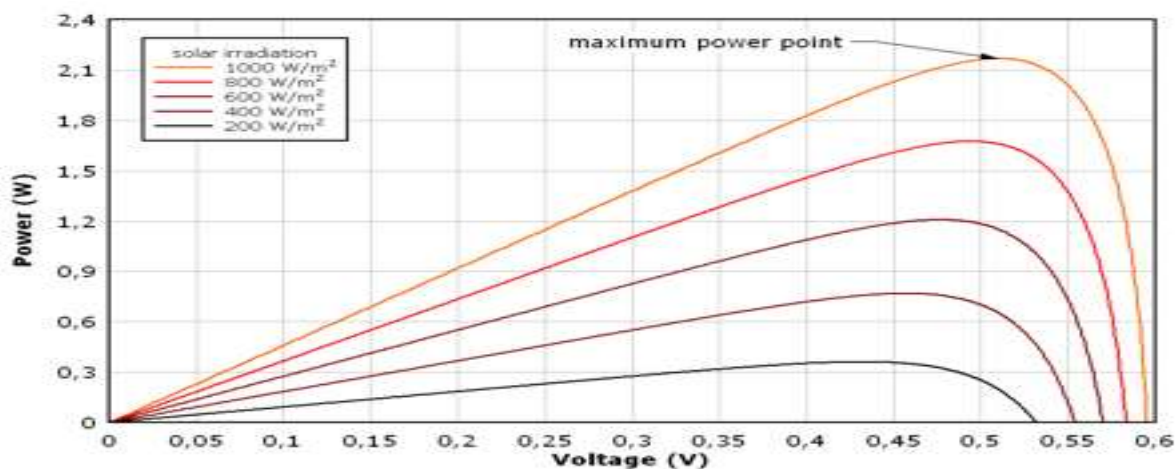


Fig. 2.7: Variation of P-V curve with solar irradiation

## 2.5 Variation of Temperature at const. Solar irradiation

Variation of temperature has a negative impact on PV cell i.e. it affects the power generation capacity. With an increase in temperature, open circuit voltage decreases. Because with the hike in temperature band gap energy of the material increases. Thus more and more energy is required to jump the energy barrier. Hence the efficiency of the solar PV cell decreases. The following two figure show how the P-V & I-V curve changing with the Temp.

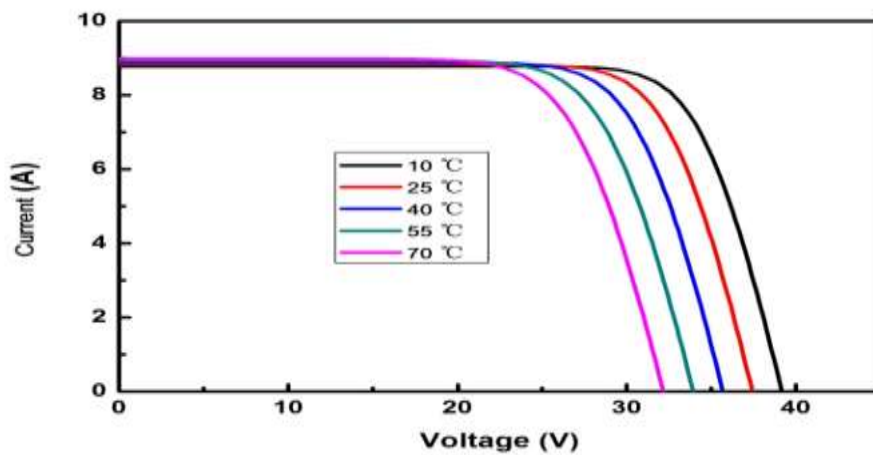


Fig. 2.8: Variation of I-V curve with Temp.

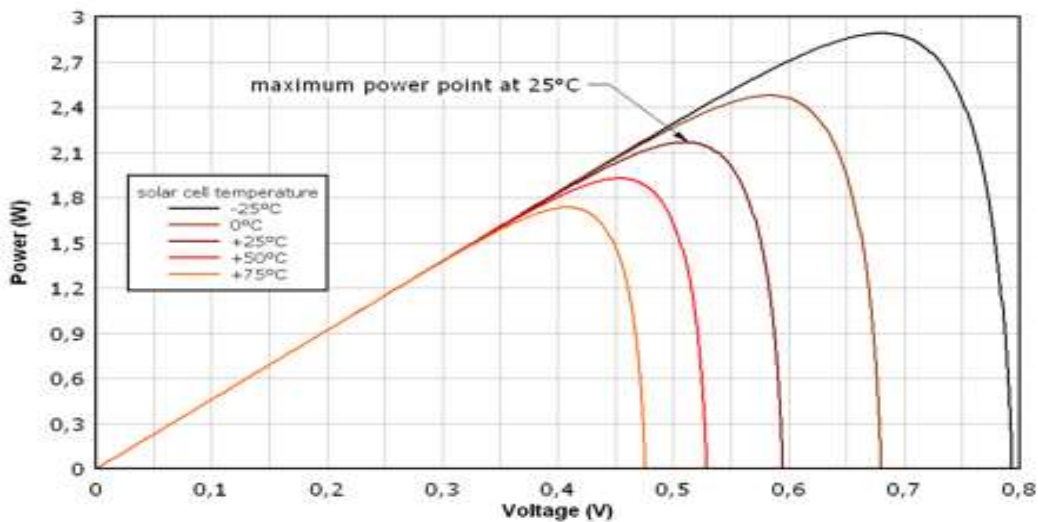


Fig. 2.9: Variation of P-V curve with temp.



## **2.6 Summary**

In this chapter a brief introduction on solar PV cell is illustrated. PV cell is successfully modeled along with all the proposed equation. One equivalent single diode PV cell model also considered for good understanding. Many environmental conditions like temperature and irradiation affect the system. So the effect of varying temp on PV module is explained here with P-V and I-V characteristics. Similarly effect of varying solar irradiation on PV module also properly stated.

# Chapter 3

## MAXIMUM POWER POINT TRACKING

3.1 Introduction

3.2 Overview on MPPT

3.2 Methods of MPPT Techniques

3.2.1 Perturb and observe Method

3.2.2 Incremental conductance Method

3.2.3 Parasitic capacitance Method

3.2.4 Constant voltage Method

3.2.5 Constant current Method

3.3 Flow diagram of P&O algorithm

3.4 Summary

### **3.1 Introduction**

This chapter mainly deals with the MPPT control technique. Need of MPPT for PV system is discussed here. It also gives some introduction on MPPT, its types and process of controlling and tracking the maximum power.

### **3.2 Overview on Maximum Power Point Tracking**

As we know, efficiency of a PV cell is very small. So to make it efficient, some methods are to be adopted. These methods mainly equalize the load& source impedance. One such mechanism is the Maximum Power Point Tracking (MPPT). It is a technique using which we can get the maximum possible power point from the changing nonlinear source. In PV system the current vs. voltage characteristics is non-linear one. Hence it is very difficult to be used with the load for various applications. So by using MPPT techniques we can change it to linear one, use them smoothly for further operation. A boost converter is also connected followed by the MPPT, whose duty cycle is varied using MPPT control circuit.

A boost converter is used on the load side and a PV panel is used as input to the converter.

### **3.3 Methods of MPPT Techniques**

A lot of MPPT algorithms have been developed by researchers all over the world. Some of them are listed below,

- Perturbation and Observation method.
- Incremental Conductance method.
- Parasitic Capacitance method.
- Constant Voltage.
- Constant Current.

Mainly in MPPT technique, we have to get the condition,  $dP/dV=0$ , to find the maximum possible power point of the P-V characteristics.

The difference among all the techniques is the process used to meet the above-mentioned condition.

### 3.3.1 Perturbation and Observation Method

Perturb & Observation method shortly known as P&O is commonly used algorithm to get the maximum possible power because of its easy procedure and lesser required components. This technique finds the maximum possible power point of the PV modules by using three main functions: at first it will perturb, then observe and finally compare the power generated from the PV modules in an iterative manner.

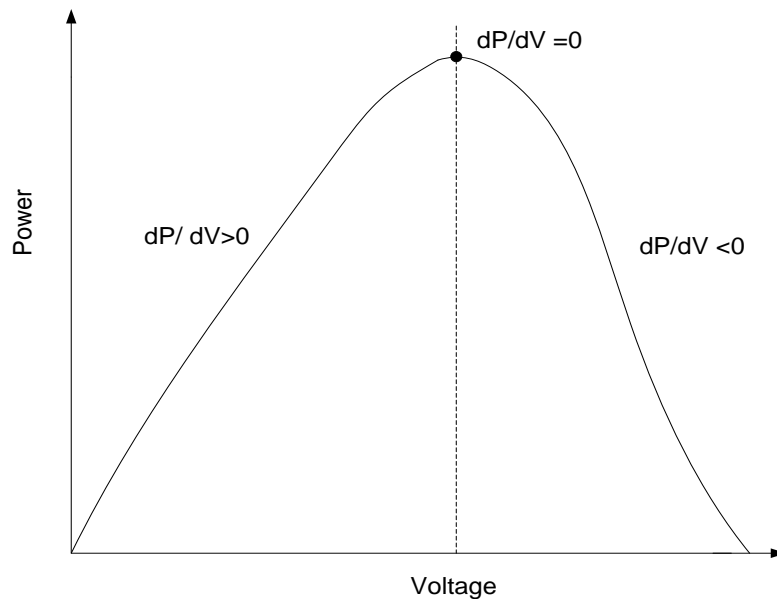


Fig. 3.1: P-V characteristics of PV module

The benefits of the P& O technique are:

- ease in structure
- ease in implementation and
- Required components are less.

The process of the P& O method can be listed as below:

- (a) The generated power which is traced by the P&O method will oscillate and then perturb up and down beside the maximum possible power point. The magnitude of variations of the output voltage decides the extent of oscillation and its magnitude.
- (b) P&O method doesn't work when the weather conditions change in rapid manner.

In this method very less number of sensors are used.

If  $dP/dV$  is positive, then the algorithm increases the magnitude of the voltage towards the maximum power point till  $dP/dV$  is negative. This iteration is continued until the algorithm finally reaches the Maximum Power Point.

### 3.3.2 Incremental Conductance Method

In Incremental Conductance method mainly we compare incremental conductance and instantaneous conductance. It will decide the different direction of the terminal voltage for PV modules by calculating and then it compares the two factors; they are incremental conductance and instantaneous conductance. If the magnitude of incremental conductance is equal to that of instantaneous conductance, then it represents that point as maximum power point.

The basic theory is manifested as shown in below figure.

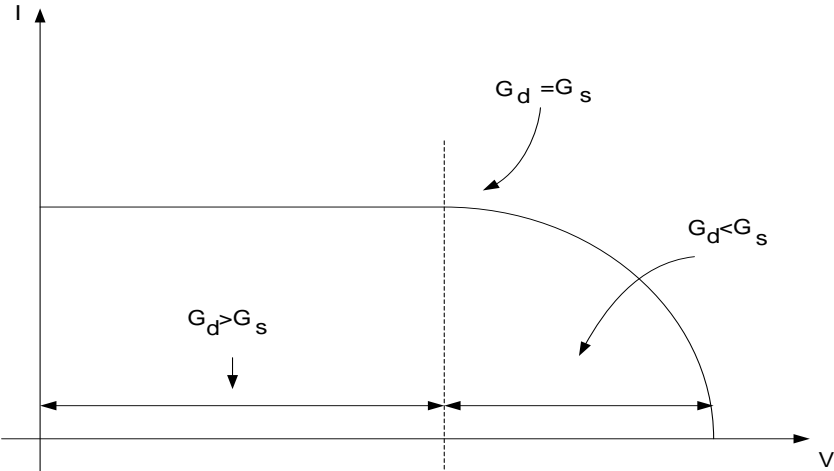


Fig. 3.2: The schematic diagram of the INC method.

The generated output power is directly in proportion with the terminal voltage condition applied, when the operating region of PV module is within the constant current area. Here we are focusing on the slope i.e.  $(dP/dV)$ .

As the generated output power increases linearly with the terminal voltage, slope of the power curve,  $(dP/dV) > 0$ .

When the traced operating point passes through the maximum power point, it shows similar behavior as constant voltage. Hence output decreases linearly with the terminal voltage, so the slope is negative in this case. i.e.  $(dP/dV) < 0$ .

When the traced operating point is exactly lies on the maximum power point, slope is turned to zero. i.e.  $(dP/dV) = 0$ .

It can be further expressed as,

$$\frac{dP}{dV} = \frac{d(VI)}{dV} = I \frac{dV}{dV} + V \frac{dI}{dV} = I + V \frac{dI}{dV}$$

By the relation  $\frac{dP}{dV} = 0$ , the above equation can be rearranged as follows,

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

$dI$  and  $dV$  indicates the current error and voltage error before and after the increment respectively. Static conductance ( $G_s$ ) & dynamic conductance ( $G_d$ , incremental conductance) of PV modules are defined as follows,

$$G_s = -\frac{I}{V}$$

$$G_d = \frac{dI}{dV}$$

The maximum power point (operating voltage is  $V_m$ ) can be found when

At  $V=V_m$ ,

$$G_d = G_s$$

### **3.3.3 Parasitic Capacitance Method**

This method is improved version of incremental conductance method. Here one parasitic capacitor is included into the voltage calculation.

### **3.3.4 Constant Voltage Method**

This method is not so much used because, the losses during the operation depends on the relation between the open circuital voltage and the voltage at which maximum power occur. The ratio of these two voltages is mainly constant for a PV cell around 0.76.

### **3.3.5 Constant Current Method**

Like the constant voltage method, this method also depends on the relation between the open circuit current and current at which maximum power occurs. The ratio of these mentioned two currents is basically constant for a PV cell, i.e. approximately 0.95. Thus the short circuit current is obtained experimentally and the operating current is adjusted to 95% of this value.

The Choice is to be made according to the need of algorithm and operating conditions. If the required algorithm is very simple and not much effort is given on the reduction of the voltage ripple, then P&O method is suitable. But if the fluctuation decides the maximum power point is to be reduced than INC method is applicable, but it makes the operation complex and more costly.

Here in my project, P&O method is adopted; hence the flowchart for the above-mentioned method is illustrated below.

### 3.5 Flow Diagram of P & O Algorithm

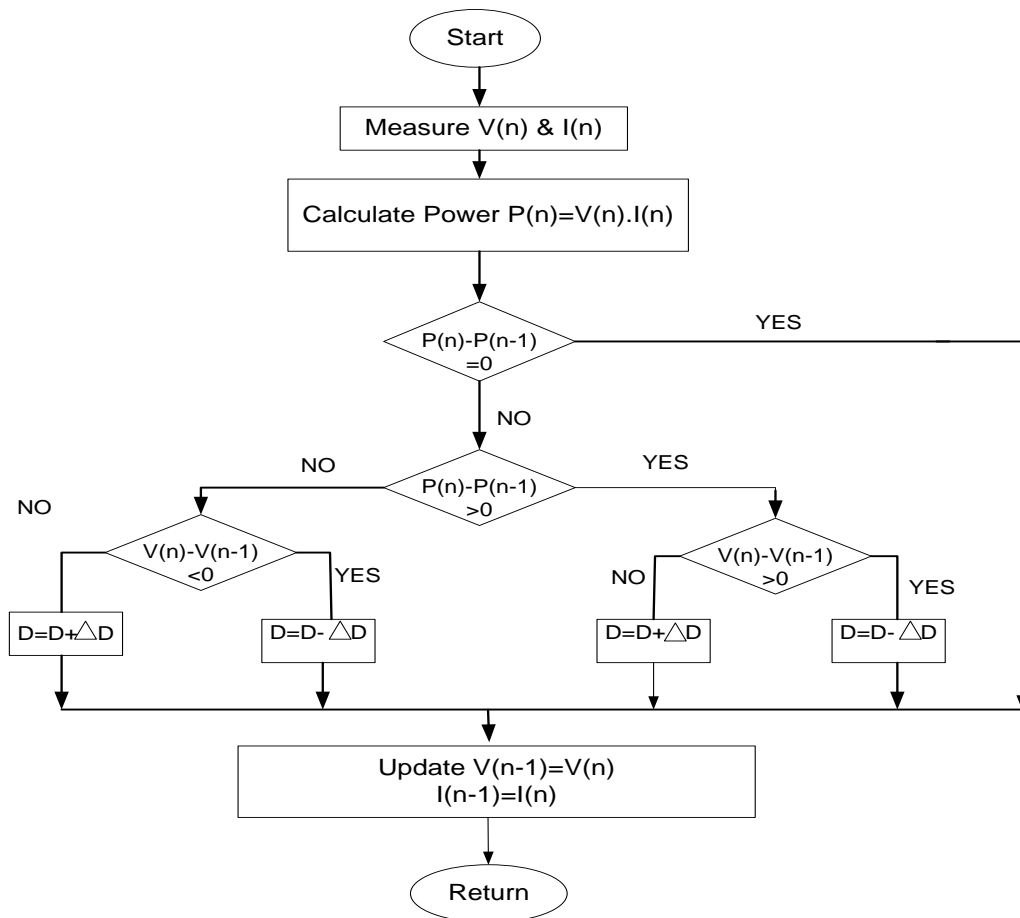


Fig. 3.3 Flow diagram representation of P&O algorithm

### 3.6 Summary

In this chapter Maximum Power Point Tracking technique is explained. Basically the I-V and P-V characteristics obtained from PV module are nonlinear. Hence we can't do further operation with fluctuating parameter. So as the solution to this problem MPPT controller circuit used here. Types of MPPTs with brief descriptions are illustrated. P & O method is used here for its cost effectiveness. The flow diagram of P & O is manifested showing the working principle.



# Chapter 4

## **MULTIPHASE INTERLEAVED BOOST CONVERTER**

- 4.1 Introduction
- 4.2 Overview on DC-DC converter
- 4.2 Modes of operation of Boost Converter
- 4.3 Interleaving technique
- 4.4 Basic circuit and operating principle
- 4.5 Theoretical waveforms
- 4.6 Summary

## 4.1 Introduction

This chapter gives the view on DC–DC converter. It explains the types of the converter with circuit diagram. Mode of operation of Boost converter and proposed interleaved boost converter is manifested here. It also presents theoretical waveforms of the multiphase boost converter according the operation intervals.

## 4.2 Overview on DC-DC Converter

Basically the conversion efficiency of the PV array is very small, so as to increase the efficiency, high energy processors are required. This processor mainly adopts DC-DC converter. Here in my project I have used Boost converter to boost up magnitude of the input voltage to a desired level without any use of transformer. The prime parameters of the boost converter are: an inductor, a diode, and a high-frequency MOSFET switch. The control mechanism lies in the manipulation of the duty pulse given to the MOSFET, depending upon which voltage will change.

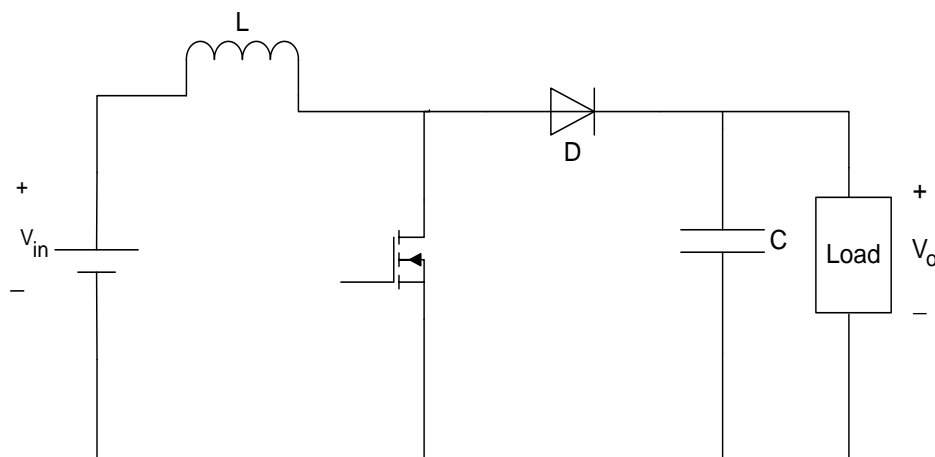


Fig 4.1: A Boost Converter

## 4.3 Modes of Operation of Boost Converter

There are two modes of operation. They depend upon the closing and opening of the switch. In the 1<sup>st</sup> mode of operation switch is closed; this is called as charging mode of operation. In the 2<sup>nd</sup> mode the switch is open; this is called as discharging mode of operation.

### **4.3.1 Charging Mode**

In this mode of operation; 1<sup>st</sup> the MOSFET is closed, then inductor is charged by the supply through the switch. That current flowing through the inductor is exponentially charging but for the convenience purpose we are considering as linearly varying. At this mode diode is in off state, so the current can't flow through this. Hence the load demand is met by the discharging of the capacitor.

### **4.3.2 Discharging Mode**

In this mode; when the MOSFET is OFF, the diode is forward biased. Now the inductor gradually discharges. Furthermore, it charges the capacitor and meets the load demands. The load current changes in a slow manner, hence assumed to be constant.

## **4.4 Interleaving Technique**

Generally to boost up the voltage level or else we can say to get the output voltage higher than the input, boost converters are used. However when these boost converters are operated for high ratios leading to some difficulties like higher voltage and current stress on the MOSFET & higher voltage. Hence as a solution for this, an interleaving technique for boost converter have been adopted. This approach can be used for higher power applications to produce high voltage gain compared to the simple boost converter. Output of the PV module is acting as input to these converters. For the switches pulses are generated from the MPPT controller circuit so that they can be used in an efficient manner. However at the high power application, the vast reverse-recovery current from the diode cause again a problem. The problems may be extra switching losses & rigorous electromagnetic interference noise. When the MOSFET is switched on, the diode cannot be immediately switched off. Consequently, the output side capacitor is connected to ground; at that instant of time very large current spikes arise both at the switch & at the rectifier, which will cause EMI noise & extra switching losses. Reverse-recovery problem of diode is affected by its forward current, reverse voltage, temperature & slew rate of the current etc. One efficient way to remove this problem is to switch off the diode smoothly so that the  $di/dt$  can be controlled during that period.

## 4.5 Equivalent circuit and Operating Principle

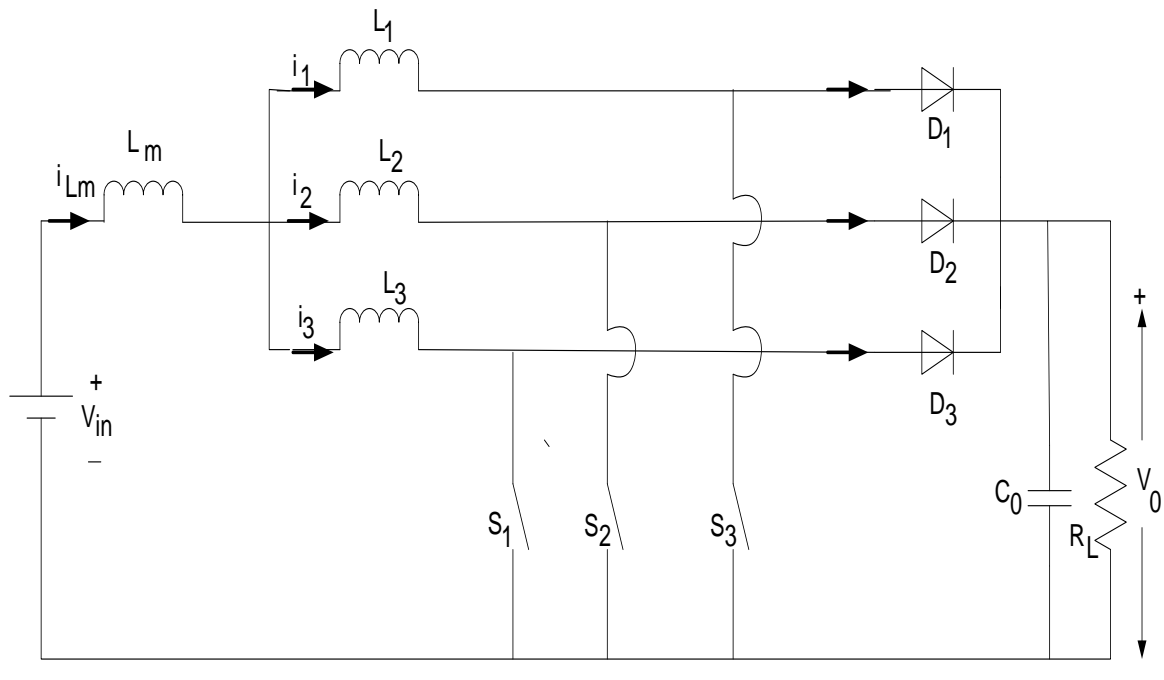


Fig. 4.2: circuitual representation of three phase interleaved boost converter

The equivalent circuit of interleaved boost converter is shown in Fig. 4.2.

Where,

$L_m$  = inductor of main boost converter.

$i_{Lm}$  = current flowing through  $L_m$ .

The current is flowing continuously and has very small ripple. This given converter has mainly three phases:

$L_1, S_1, D_1$  represents phase 1

$L_2, S_2, D_2$  represents phase 2

$L_3, S_3, D_3$  represents phase 3

Hence it is called as three-phase Interleaved Boost Converter.

$L_1, L_2,$  and  $L_3,$  are not used as three separate inductors, they just tied on a single core of magnetic material.  $T_1, T_2,$  &  $T_3$  are ideal transformers.

To analyze the working procedure, certain assumptions are taken for the simplicity,

- 1) Initially converter is in steady-state condition and the inductor current  $i_{Lm}$  is continuous in nature.
- 2) The given integrated inductors have no leakage inductance.
- 3)  $L_1, L_2, L_3$  all are equal to  $L$ .
- 4) The magnitude of output side capacitor  $C_0$  is sufficiently high to smooth out the output voltage ripples and  $V_0$  is assumed to be constant within a cycle period.

## Modes of operation

Operation of multiphase interleaved boost converter comprises of 3 modes. Mode 1 from time duration  $t_0$  to  $t_1$ , mode 2 from time duration  $t_1$  to  $t_2$  and the final mode that is mode 3 from  $t_2$  to  $t_3$ . Three modes with circuit diagram and relevant equation are described below.

### Mode-01

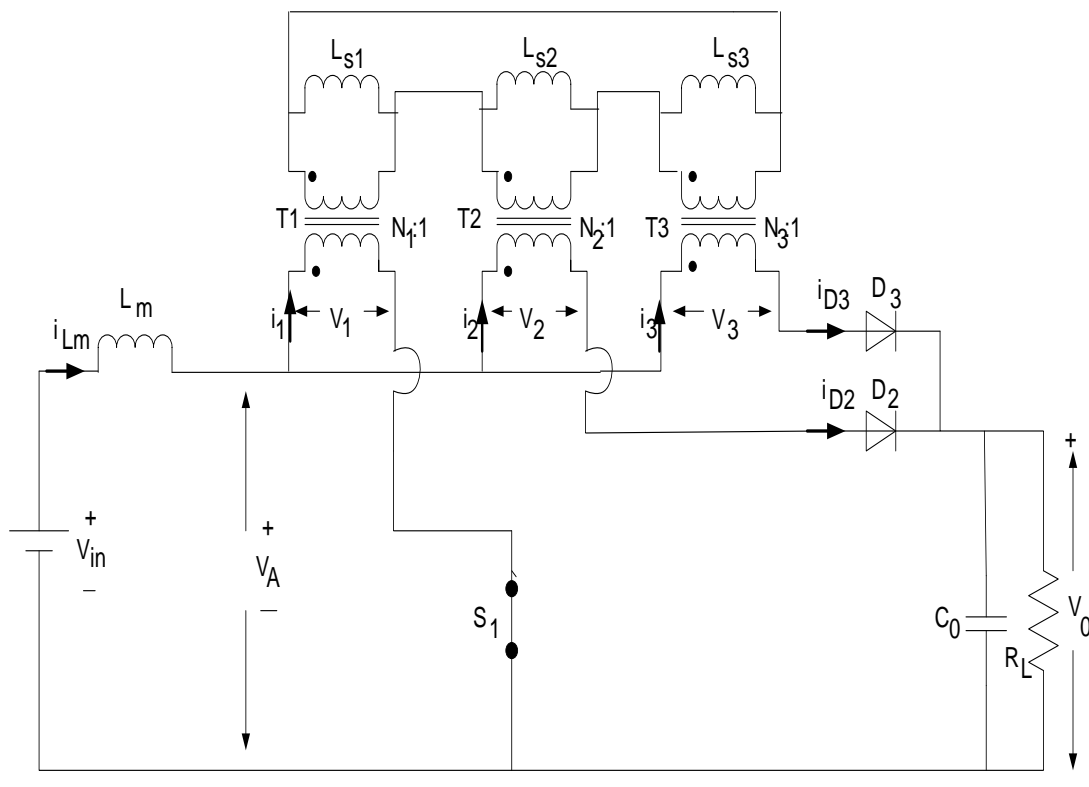


Fig 4.3: circuit diagram for mode 1

This stage has time duration  $t_0$  to  $t_1$ .

Before time  $t_0$ , diode current  $i_{D1}$  falls to zero.

At time  $t = t_0$  instant, switch  $S_1$  is turned on. Because of the inductive currents  $i_2$  and  $i_3$ , diodes D2 and D3 are forward biased.

The primary voltage of the transformer,  $T_1$  is  $V_A$ .

Similarly, primary voltage of the transformer  $T_2$  &  $T_3$  is  $(V_A - V_O)$ .

$V_{DS}$  of both the switches S2 and S3 is  $V_O$ .

$V_A$  at this mode can be expressed as,

$$V_A = \frac{2}{3} V_O$$

$\dot{i}_{Lm}$  (Sum of  $i_1, i_2$  &  $i_3$ ) vary at the following rate,

$$\frac{di_{Lm}}{dt} = \frac{V_{in} - V_A}{L_m} = \frac{V_{in} - 2V_O/3}{L_m}$$

$\dot{i}_1$  Increase at the rate of,

$$\frac{di_1}{dt} = \frac{1}{3} \left( \frac{V_{in} - 2V_O/3}{L_m} + \frac{2V_O}{L} \right)$$

Both  $i_2$  and  $i_3$  decrease at the rate of,

$$\frac{di_2}{dt} = \frac{di_3}{dx} = -\frac{1}{3} \left( -\frac{V_{in} - 2V_O/3}{L_m} + \frac{V_O}{L} \right)$$

This mode terminates when  $\dot{i}_2$  (&  $\dot{i}_{D2}$ ) reduces to zero, which removes the reverse-recovery problems of the diode.

## Mode-02

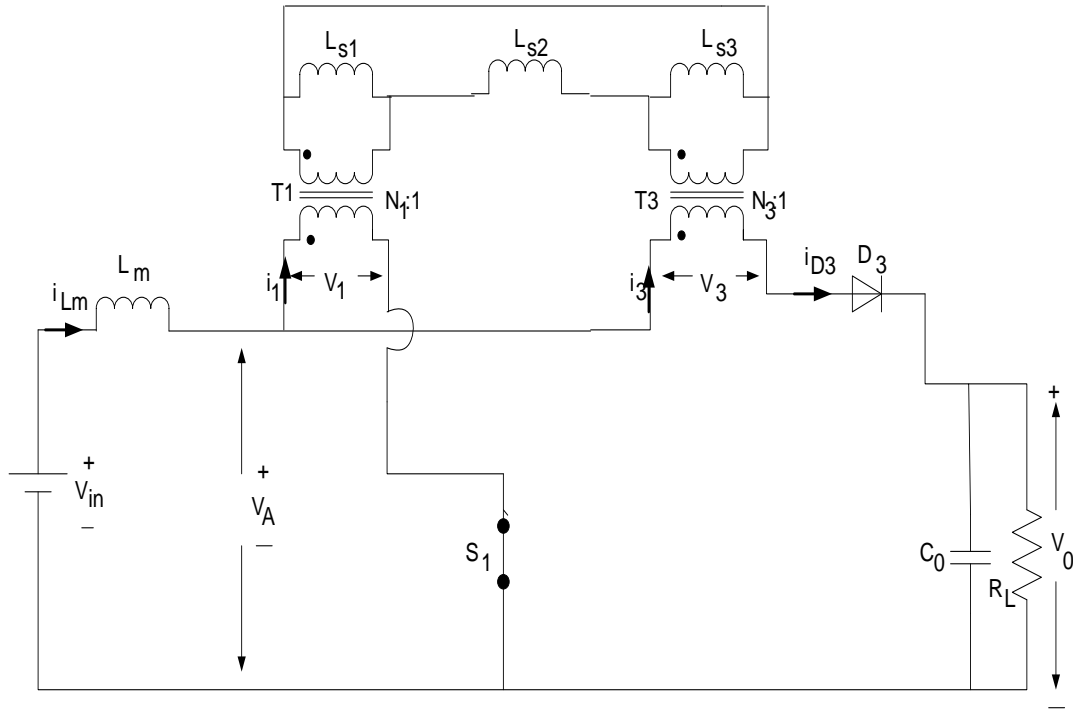


Fig 4.4: circuit diagram for mode -2 of operation.

This mode starts with the time duration ( $t_1$  to  $t_2$ ).

In mode 1,  $i_2$  falls to zero,  $D_2$  achieves its turn OFF state naturally.

$V_A$  at this mode is given as,

$$V_A = \frac{LV_{in} + 3L_m V_o}{L + 6L_m}$$

Reverse voltage of the diode  $D_2$  can be obtained as,

$$\text{Reverse voltage of } D_2 = (V_o - V_A) - (2V_A - V_o)$$

$$= \left( \frac{2LV_o - 3LV_{in} + 3L_m V_o}{L + 6L_m} \right)$$

$i_1$  &  $i_3$  will vary according to the following equation,

$$\frac{di_1}{dt} = \left( \frac{3LV_{in} - LV_o + 3L_m V_o}{L(L + 6L_m)} \right)$$

$$\frac{di_3}{dt} = - \left( \frac{2LV_o - 3LV_{in} + 3L_m V_o}{L(L + 6L_m)} \right)$$

-ve sign indicates current  $i_3$  is decreasing.

$i_{Lm}$  (the total sum of  $i_1$  &  $i_3$ ) will change accordingly,

$$\frac{di_{Lm}}{dt} = \frac{d(i_1+i_3)}{dt} = \frac{6V_{in}-3V_o}{L+6L_m}$$

### Mode-03

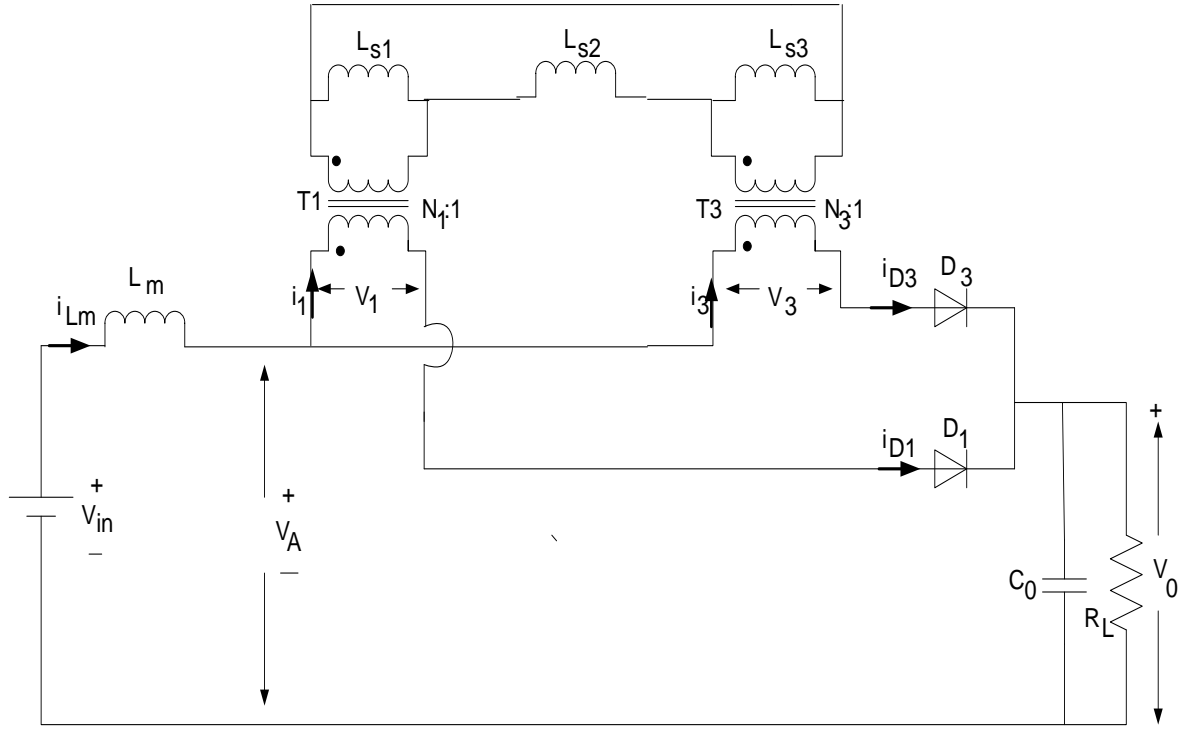


Fig 4.5: circuit diagram for mode-03 of operation.

This mode has the time duration, ( $t_2$  to  $t_3$ ).

At the instant  $t_2$ , switch  $S_1$  is turned off; then the capacitor is getting charged up by the inductor current across switch  $S_1$ .

Consequently  $D_1$  is forward-biased and starts conducting.

At this mode,  $V_A$  is expressed as,

$$V_A = \frac{LV_{in}+6L_mV_o}{L+6L_m}$$

The reverse voltage across diode,  $D_2=(V_o - V_A)-2(V_A - V_o)$

$$= \frac{3L(V_o-V_{in})}{L+6L_m}$$



Both  $i_1$  &  $i_3$  will vary accordingly,

$$\frac{di_1}{dt} = \frac{di_3}{dt} = -\frac{3(V_o - V_{in})}{L + 6L_m}$$

$i_{L_m}$  (sum of  $i_1$  &  $i_3$ ) will change accordingly,

$$\frac{di_{L_m}}{dt} = \frac{d(i_1 + i_3)}{dt} = -\frac{6(V_o - V_{in})}{L + 6L_m}$$

The voltage of switch  $S_2$  at this mode is found to be,

$$\begin{aligned} V_{D(S_2)} &= V_A + 2(V_A - V_o) \\ &= \left( \frac{3LV_{in} + 2(3L_m - L)V_o}{L + 6L_m} \right) < V_o \end{aligned}$$

Compared with the simple boost converter, voltage across the switch before its turning on, the voltage across the switch is suppressed using interleaved boost converter by the mutual coupling between opposite polarity of the integrated inductors. Such a technique would encourage to reduce the switching losses.

In the next mode of operation, the switch  $S_2$  got turned on. With this, new switching cycle begins. As the mode of operation in  $t_3-t_6$  and  $t_6-t_9$  are same as that of  $t_0-t_3$ , hence only the working of the first 3 modes is analyzed here.

## 4.6 Theoretical Waveforms

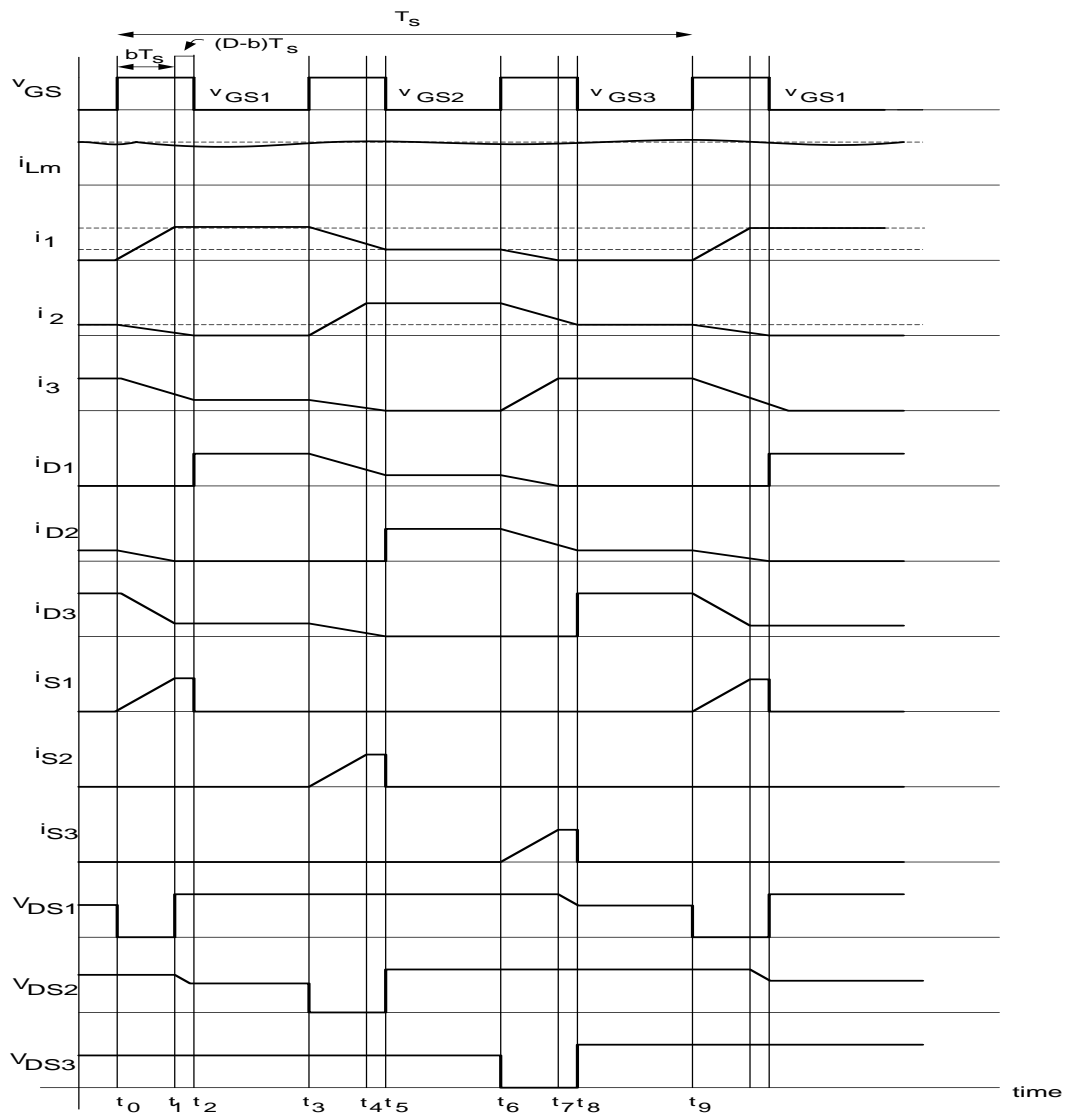


Fig. 4.6 Theoretical waveforms according to operation intervals

## 4.7 Summary

Need of Boost converter for PV module is depicted here. Modes of operation of Simple Boost and interleaved boost converter are illustrated showing how it is different from the simple one. Theoretical current and voltage waveforms are explained symbolizing each interval of modes of operation. Proposed equivalent circuit of the multiphase interleaved boost converter is drawn with all the equations explaining each mode.

# Chapter 5

## GRID SYNCHRONIZATION

5.1 Introduction

5.2 Overview on Grid Synchronization

5.3 Design Details of the system

5.2.1 Inverter and Transformer

5.2.2 LC Filter

5.3 Control strategy

5.4 Phase Lock Loop (PLL)

5.5 Summary

## 5.1 Introduction

This chapter explains the synchronization of grid with the PV system. It gives a brief introduction on control strategy adopted for grid synchronization. The basic components required for controlling the grid parameter are discussed here.

## 5.2 Overview on Grid Synchronization

Grid is a voltage source of infinite capacity. For synchronization with the load, the frequency & output voltage of the inverter must be same as the output voltage & frequency of the Grid. The Grid connected inverter can be controlled by the pulse width modulated universal inverter. This is most widely used in PV systems. Different control strategies are available to control the current. They are d-q theory & p-q theory with phase lock loop control. Here synchronously rotating d-q reference frame technique is adopted along with the PLL circuit. Phase lock loop mechanism is utilized to synchronize the grid with PV.

## 5.3 Design Details of the System

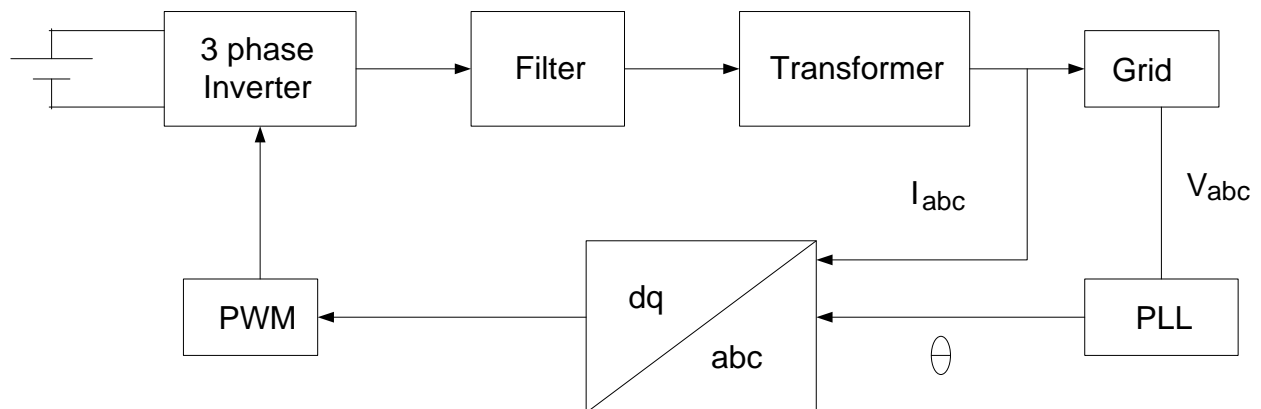


Fig 5.1 Block diagram of the system

### 5.3.1 Inverter & Transformer

The block diagram representation of the overall grid-connected system is shown in Fig 5.1. Given three-phase Bridge inverter is the most commonly used configuration in three-phase power systems. Here the inverter is chosen as universal bridge inverter. Input to the inverter is represented as battery as shown in the block diagram for understanding purpose. But in the overall system, the input is the dc output coming from the converter. The magnitude of the output voltage is required to be 380V rms across the grid. Transformer boosts up the output

of the inverter to the desired value. Besides this, the main function of the transformer is that, it ensures isolation and avoids injection of dc current into the grid. Normally delta-star configuration of the transformer is utilized in grid connected system. As the 3rd harmonic current will be circulated in delta connection and it won't make any harm to the grid. Hence the transformer rating is chosen as 1250VA with the secondary voltage as 415 volt (L-L).

### **5.3.2 LC Filter**

For grid connection, output voltage should be synchronized with the voltage across the grid. Hence the PWM inverter is needed, so that it will give controlled pulse to the switch of the inverter. But it injects ripple current into the grid. Here the function of LC filter is to nullify all these high switching frequency parameters from the inverter output current. The value of L is chosen in such a way that, current ripple should be minimum, because small ripple current results in lower switching and conduction losses. .

### **5.4 Control Strategy**

The control strategy discussed here consists of 2 control loops. One is inside control loop whose work is to control grid current. Another one is outside voltage loop whose function is to control the dc link voltage. The control technique applied for inverter comprises of two control loops. Usually the inner current control loop deals with the power quality issues like low Total Harmonic Distortion & good power factor. And the outer voltage control loop responsible for balancing the power flow in the system.

Here the control technique adopts the synchronous reference frame control technique that is also called as d-q control technique. It normally utilize a reference frame transformation i.e. abc to d-q which changes the grid current and voltages into d-q frame. The transformed voltage detects the phase and frequency of the grid and the transformed current controls the grid current. So we got a control variable as dc values, hence filtering and controlling becomes easier.

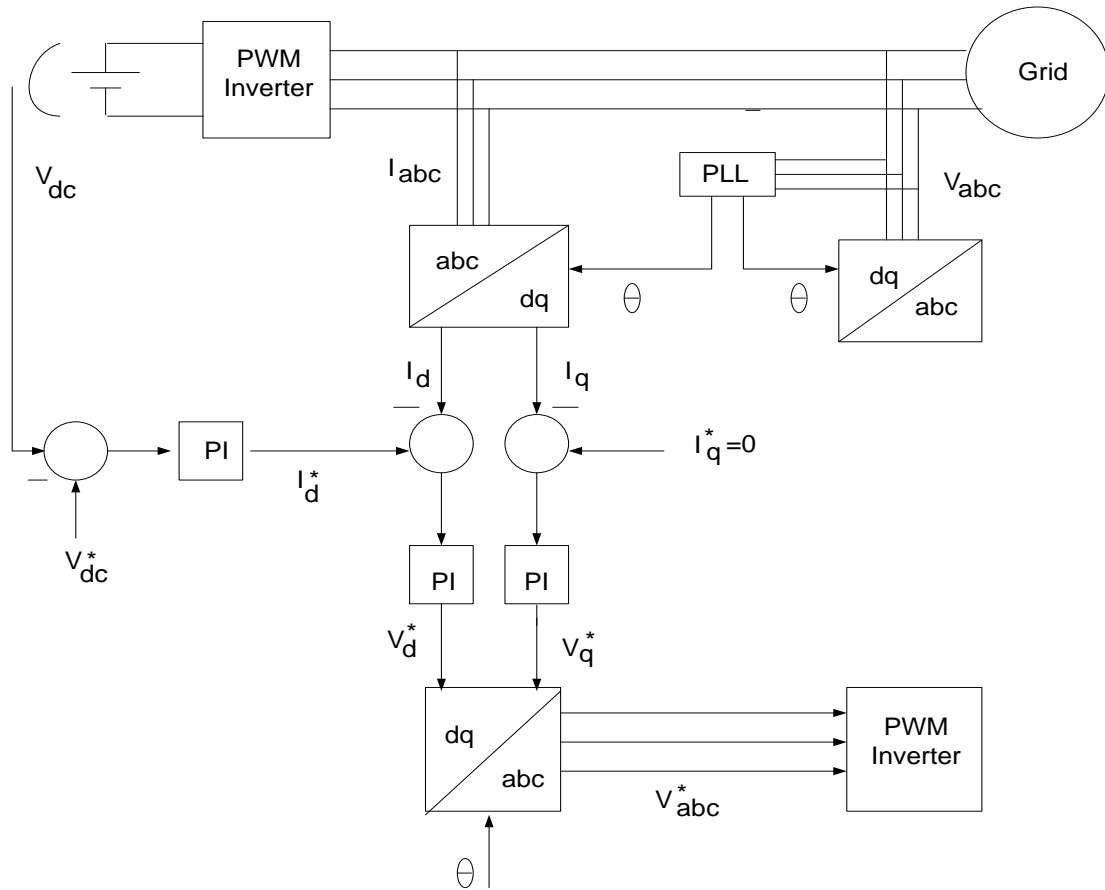


Fig 5.2 General structure for control circuit

The main working of the d-q control is shown as block diagram in Fig.5.2. The DC voltage is actually fed from the boost converter. But for the ease of understanding, battery is used as input to the inverter. The reference for the control of active power is set to DC voltage. And the control for the reactive power is not considered here.

### 5.5 Phase Lock Loop (PLL)

Grid synchronization is very important for grid connected systems. Inverter Phase & frequency must be synchronized with the grid phase and frequency. Here an output signal synchronized with already set reference input signal both in frequency and phase. In 3-phase grid connected system, PLL is implemented using d-q transformation. Fig.5.3 shows the block diagram of a 3-phase PLL. Here  $V_{abc}$  is the grid voltage which is transformed into DC components using transformation technique from abc to d-q. The PLL said to be locked by keeping  $V_d^*$  to zero. The loop filter PI is acting as low pass filter. Generally it suppresses the high frequency factor. It gives the DC controlled signal to voltage controlled oscillator (VCO). VCO acts as an integrator. It integrates the output of the PI controller that is the inverter output frequency to obtain inverter phase angle  $\theta$ . When the difference between grid

and inverter phase angle is reduced to zero PLL becomes active, as a result synchronously rotating voltages  $V_d = 0$  and  $V_q$  gives magnitude of grid voltage.

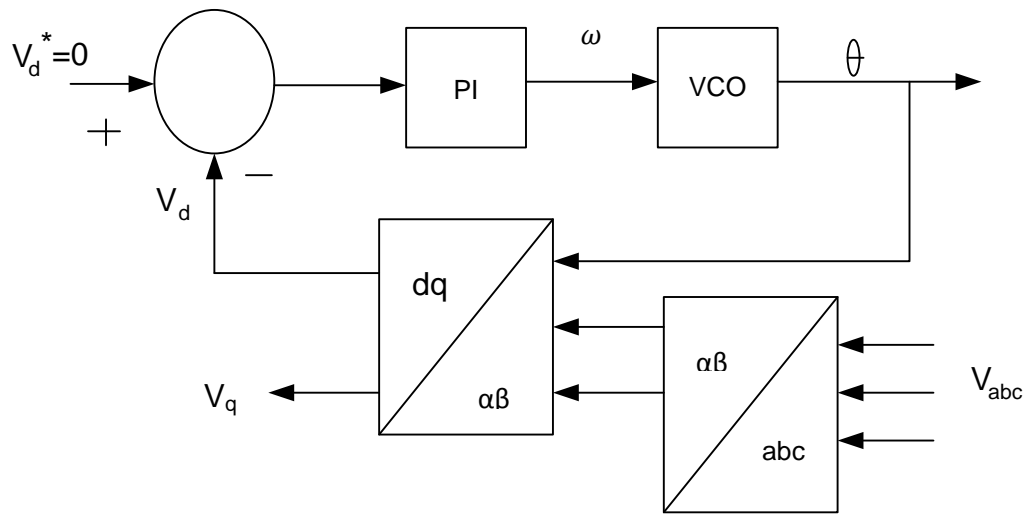


Fig 5.3 General structure of 3-phase d-q PLL

## 5.6 Summary

Grid synchronization is explained in this chapter. The proposed block diagram is considered here showing how the grid synchronization done and what components are required for the synchronization. Basically LC filter and transformer plays important role for compensation. PLL circuit is illustrated with block diagram. Here synchronous d-q reference frame technique is adopted.

# Chapter 6

## SIMULATION RESULTS

- 6.1 Introduction
- 6.2 Simulation results of PV module Before MPPT
- 6.3 Effect of variation of solar irradiation
- 6.4 Effect of variation of Temperature
- 6.5 Simulation results of Interleaved boost converter
- 6.6 Simulation results of Converter after MPPT
- 6.6 Simulation results of PLL circuit
- 6.7 Grid side Simulation results
- 6.8 Summary



## 6.1 Introduction

This chapter presents all the simulated results which are simulated in MATLAB Simulink environment. Simulation results of PV system considering P-V & I-V curve, Interleaved boost converter & output of grid after synchronization are given here.

## 6.2 Simulation results for PV module before MPPT

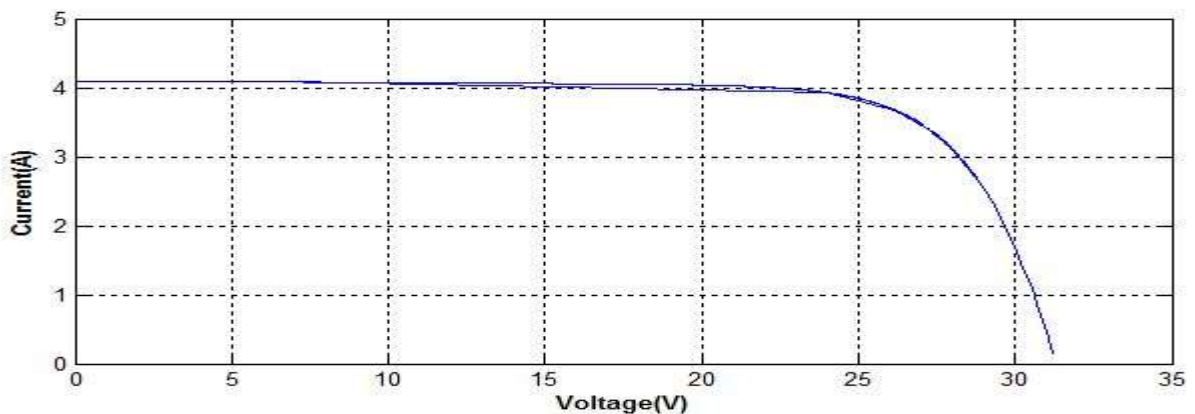


Fig 6.1 Current vs. Voltage curve of PV module

The above figure illustrates the current vs. voltage characteristics of PV panel. The characteristic is taken at 25°C temperature &  $500 \frac{W}{m^2}$  irradiation. We can conclude from the characteristics that, current is constant for some extents then with increase in voltage it suddenly falls and drops to zero.

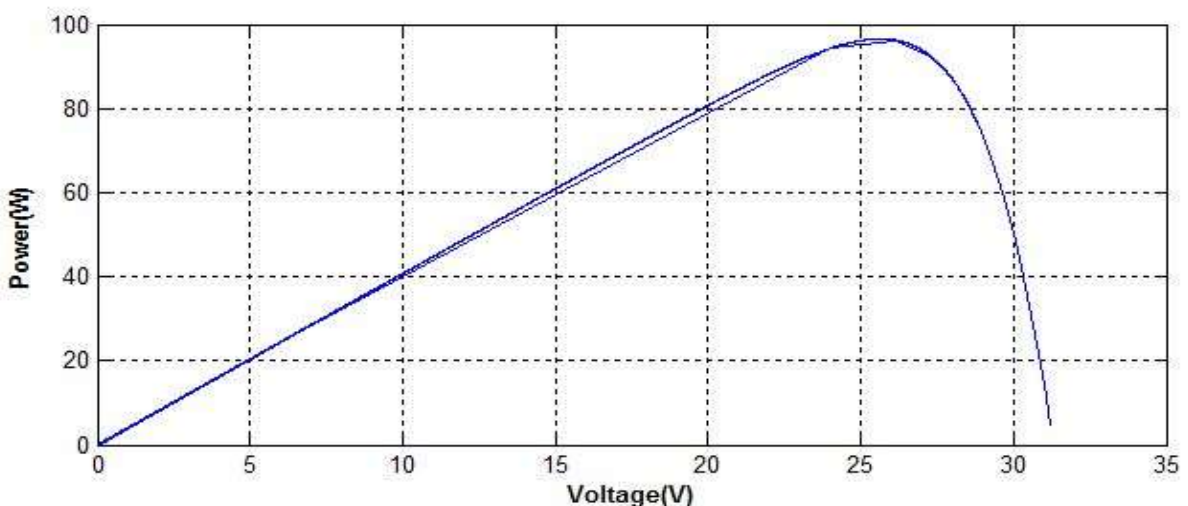


Fig 6.2 Power vs. Voltage curve of PV module

From the figure 6.2, it is clearly visible that, up to some extents power is directly proportional to voltage; however with increase in voltage power suddenly changes and drops to zero. The above characteristic is taken at 25°C temperature &  $500 \frac{W}{m^2}$  irradiation.

### 6.3 Simulation results of PV module at constant temp and varying irradiation

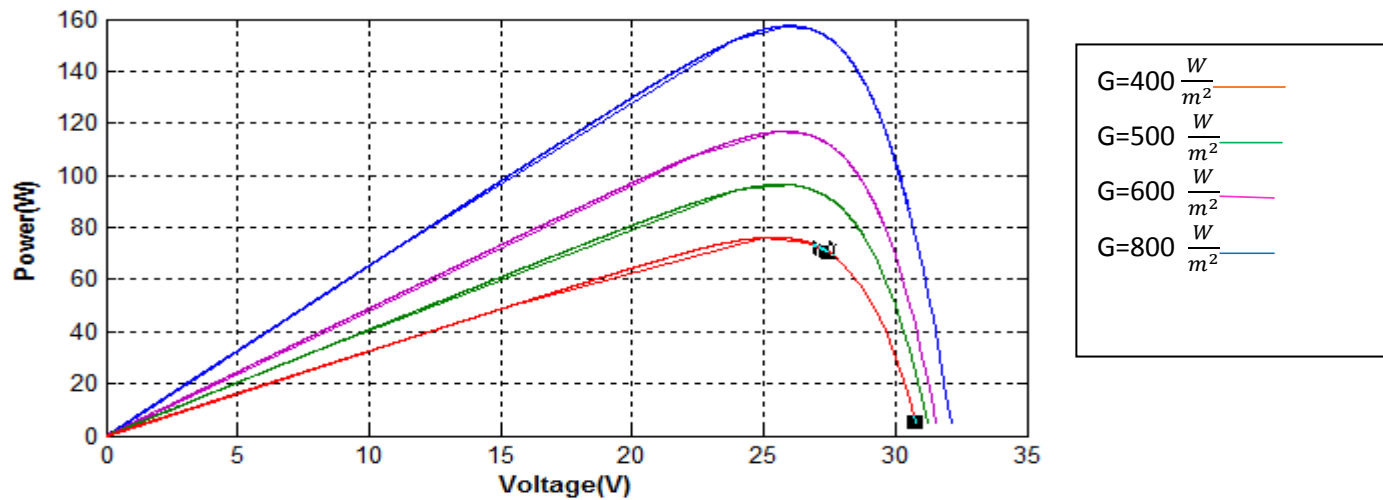


Fig 6.3 Effect of variation of irradiance on P-V curve

The figure numbered 6.3 shows the effect of varying solar irradiation on P-V characteristics keeping temp constant. With increase in solar irradiation maximum level goes on increasing. P-V characteristics are plotted at constant temp 25°C and with solar irradiation  $400 \frac{W}{m^2}$ ,  $500 \frac{W}{m^2}$ ,  $600 \frac{W}{m^2}$ ,  $800 \frac{W}{m^2}$ .

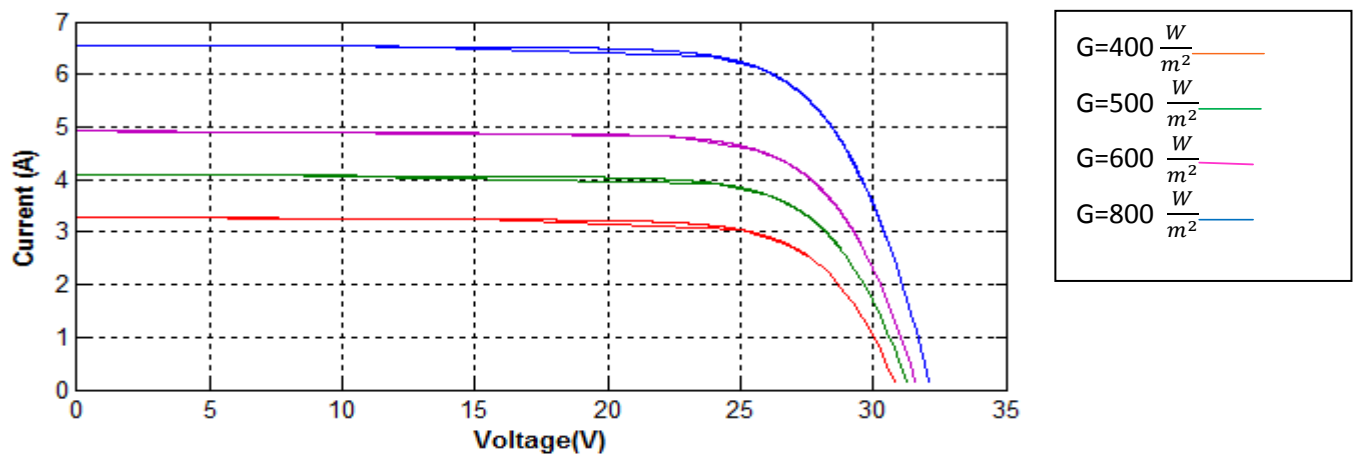


Fig 6.4 Effect of variation of irradiance on I-V curve

Similarly in figure 6.4 effect of varying solar irradiation on I-V characteristics keeping temp constant. Here also with increase in solar irradiation current level goes high. Constant temp is kept at 25°C and solar irradiation varies from  $400 \frac{W}{m^2}$  to  $800 \frac{W}{m^2}$ .

### 6.4 Simulation results of PV module at constant irradiation and varying temperature

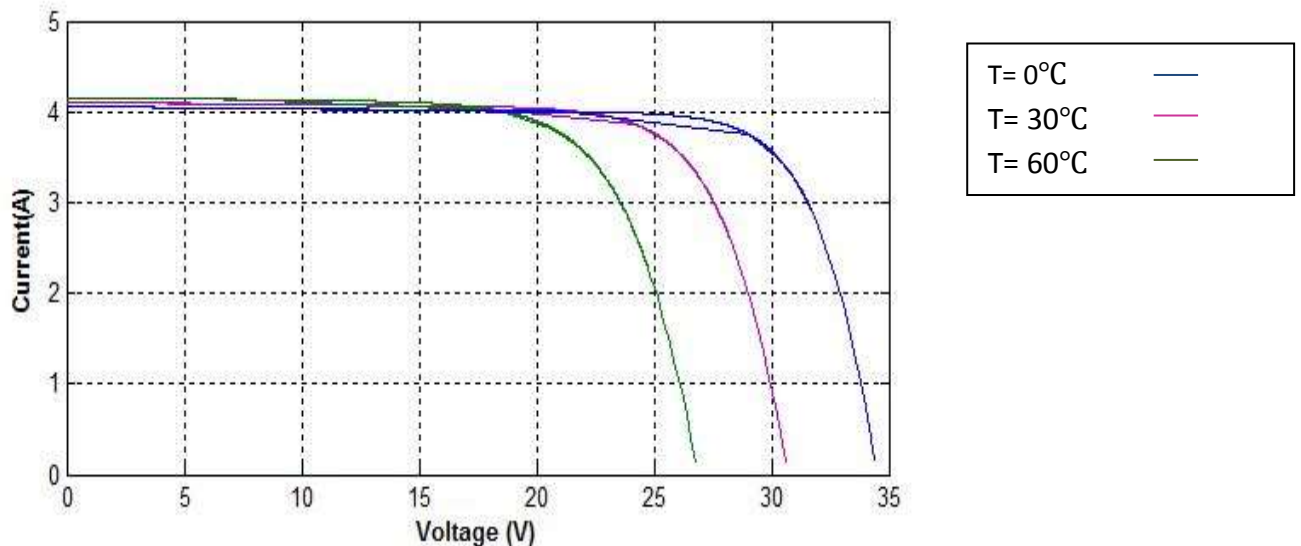


Fig.6.5 Effect of variation of temperature on P-V curve

The figure numbered 6.4 shows the effect of varying temperature on I-V characteristics keeping solar irradiation constant. With increase in temperature, current is approximately constant but voltage decreases. I-V characteristics are plotted at constant solar irradiation  $500 \frac{W}{m^2}$  and with temperatures 0°C, 30°C, 60°C.

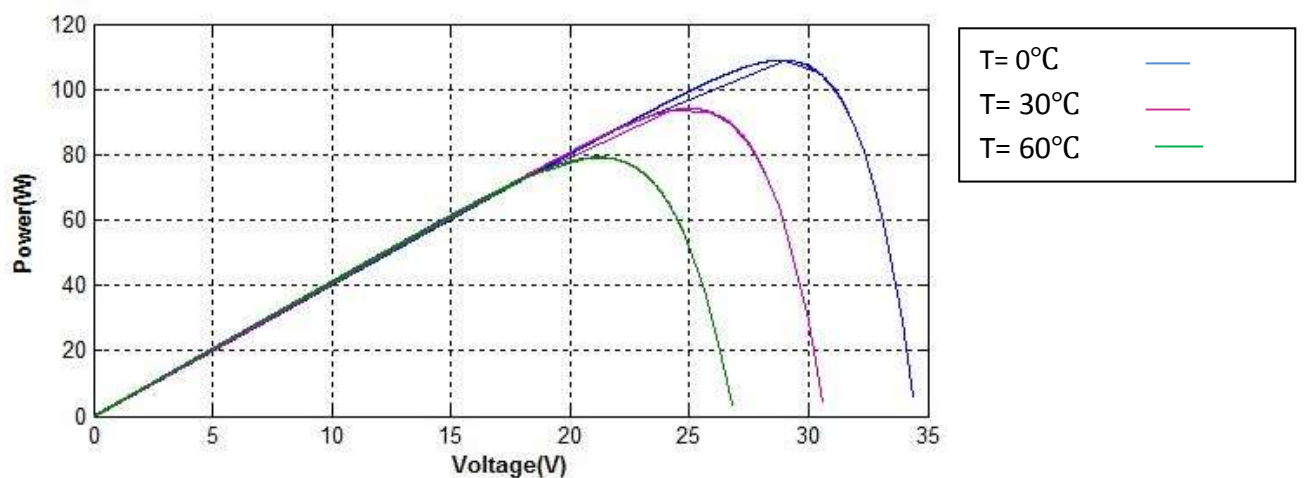


Fig.6.6 Effect of variation of temperature on P-V curve

Similarly in figure 6.6 effect of varying temperature on P-V characteristics keeping irradiation constant. Here with increase in temperature max. power level goes on increasing. Constant irradiation is kept at  $500 \frac{W}{m^2}$  and temperatures vary from  $0^{\circ}C$  to  $60^{\circ}C$ .

### 6.5 Simulation Results for Interleaved Boost Converter

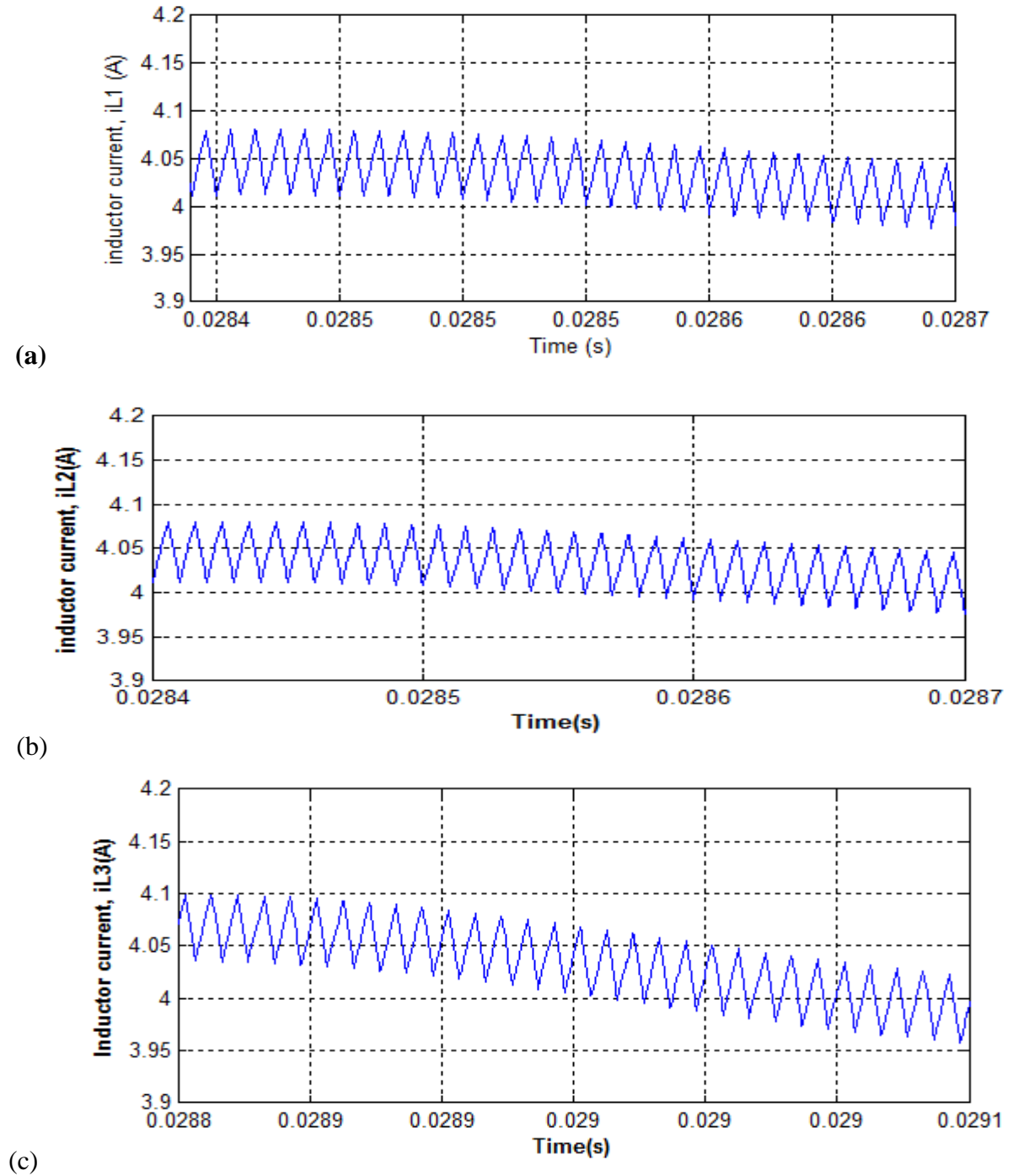


Fig 6.7(a), (b), (c) Inductor current of Interleaved boost converter for phase 1, 2 & 3 respectively.

We know, in multiphase interleaved boost converter three different boost converters represents three individual phases. Figure 6.7 presents 3 different inductor currents.

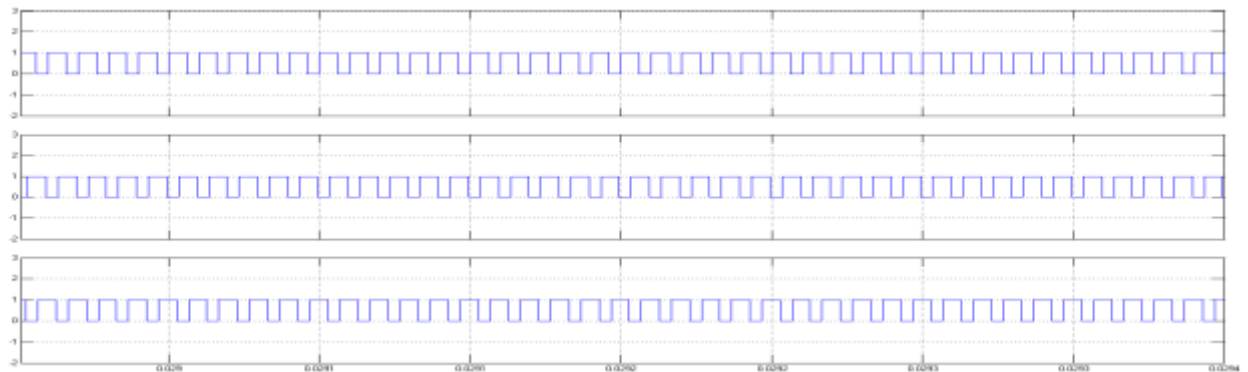


Fig 6.8 pulses for Interleaved boost converter showing phase

In multiphase boost converter three switches are there & their operating phase difference is  $120^\circ$ .

That phase difference is shown in above figure. Hence pulses for 3 different switches are clearly visible.

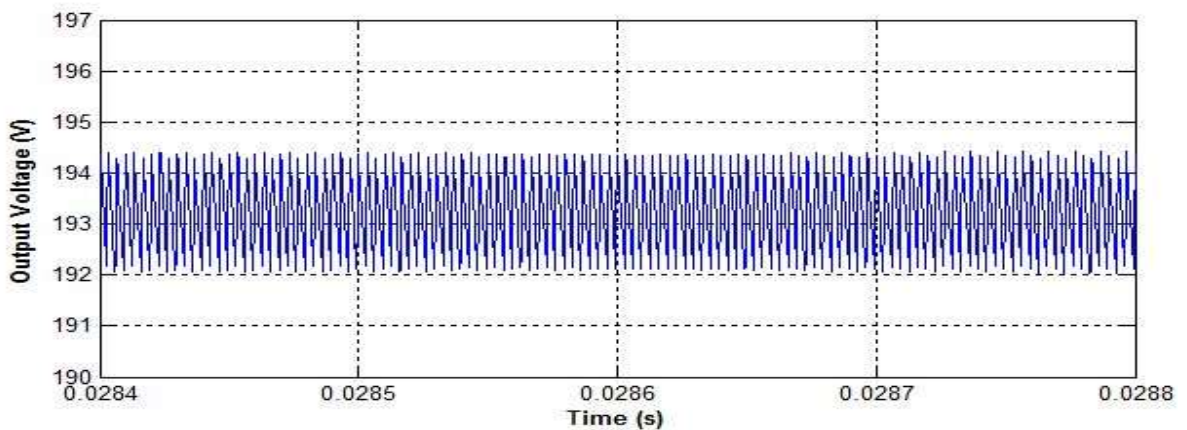
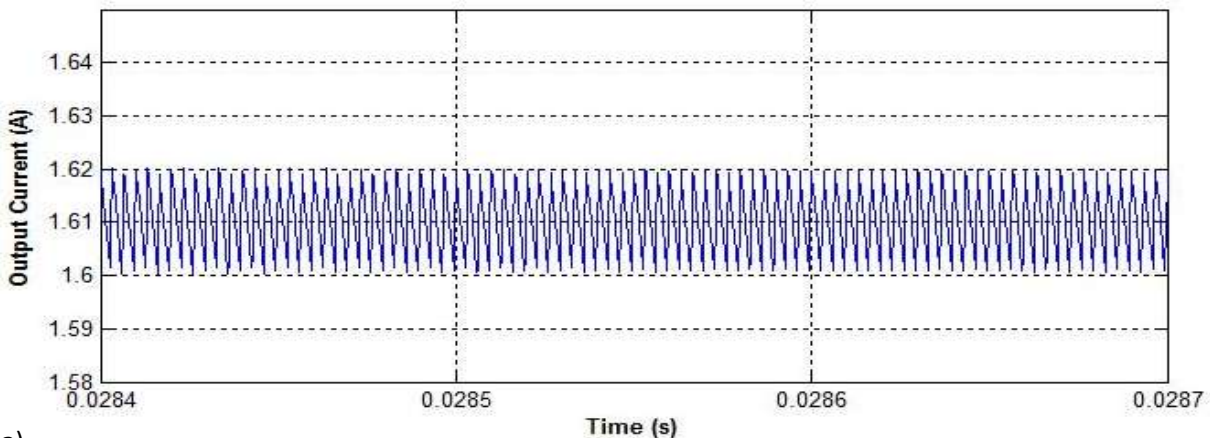


Fig 6.9 (a) & (b) Output voltage& current of Interleaved boost converter

Above figures 6.9 (a) & (b) illustrate output voltage and current of proposed multiphase interleaved boost converter. Here input voltage for the converter is 30V; accordingly, it boosts up the voltage level to 193.5 V as shown in figure. Hence is concluded that interleaved boost converter yields high output voltage with low output current.

### 6.5 Simulation Results of converter after MPPT

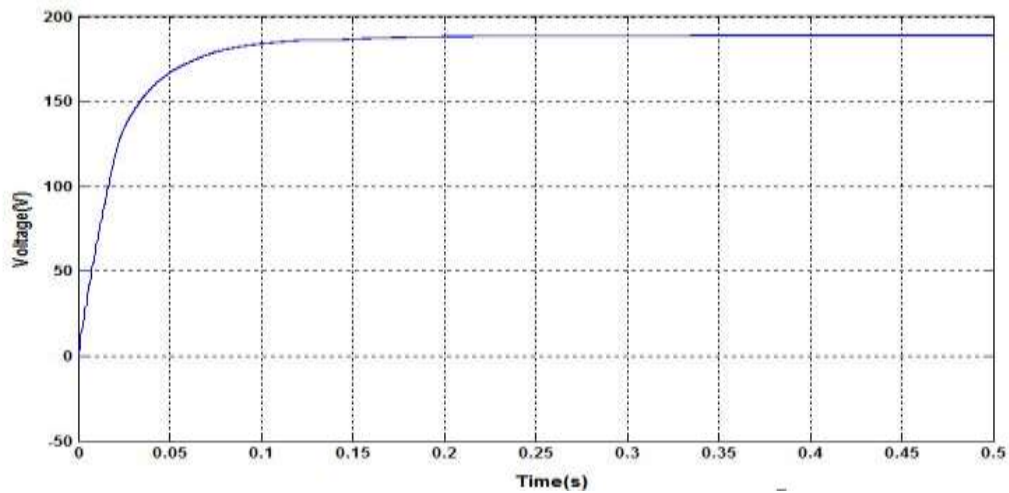


Fig. 6.10 Output voltage after MPPT control

Figure 6.10 shows the maximum output voltage of the interleaved boost converter after connecting it to the MPPT controller circuit. So it can be concluded that, MPPT controller circuit successfully tracks the maximum voltage and give it as 190 V.

### 6.6 Simulation Results of PLL circuit

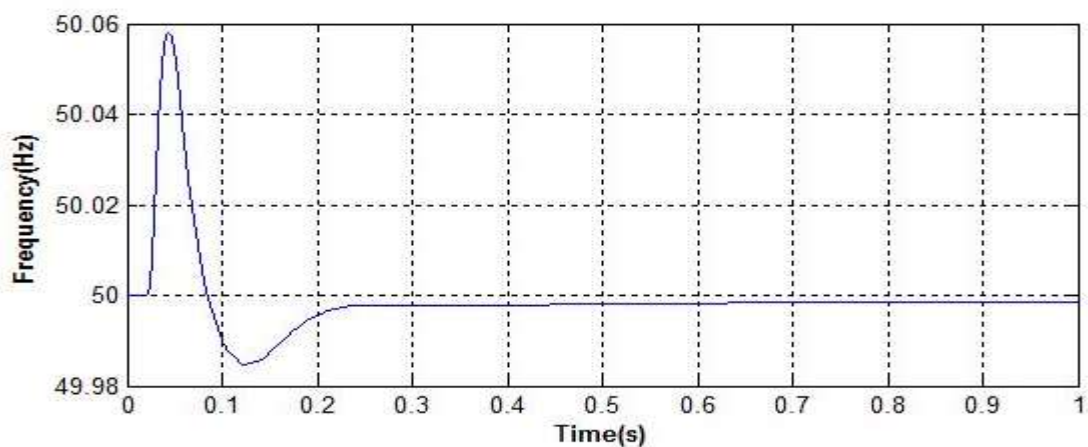


Fig. 6.11 Output frequencies obtained from PLL

PLL circuit is used here to ensure the synchronization process with grid. Mainly inverter frequency should be synchronized with that of grid. Hence the result clearly shows the output frequency as 49.998 Hz nearly same as that of grid frequency.

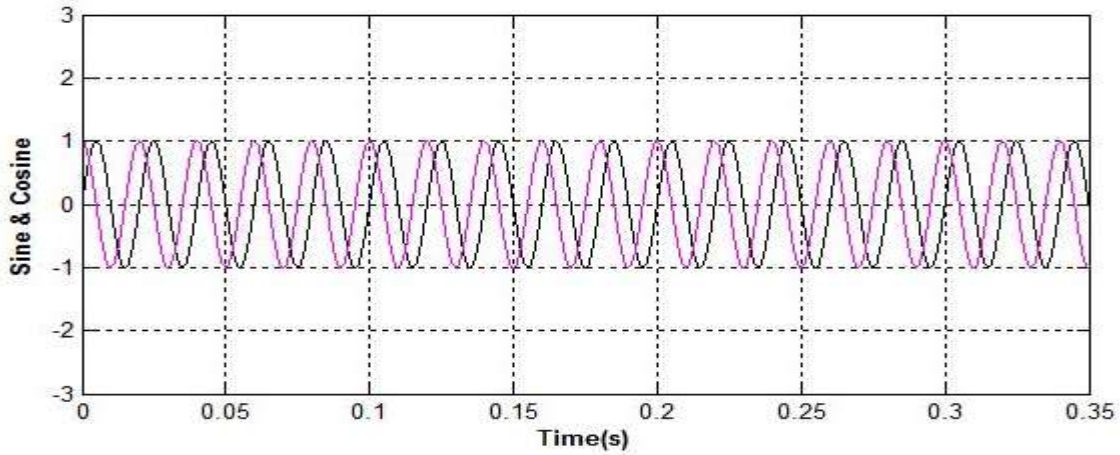


Fig. 6.12 sine and cosine waveform obtained from PLL

### 6.7 Grid Side Simulation Results

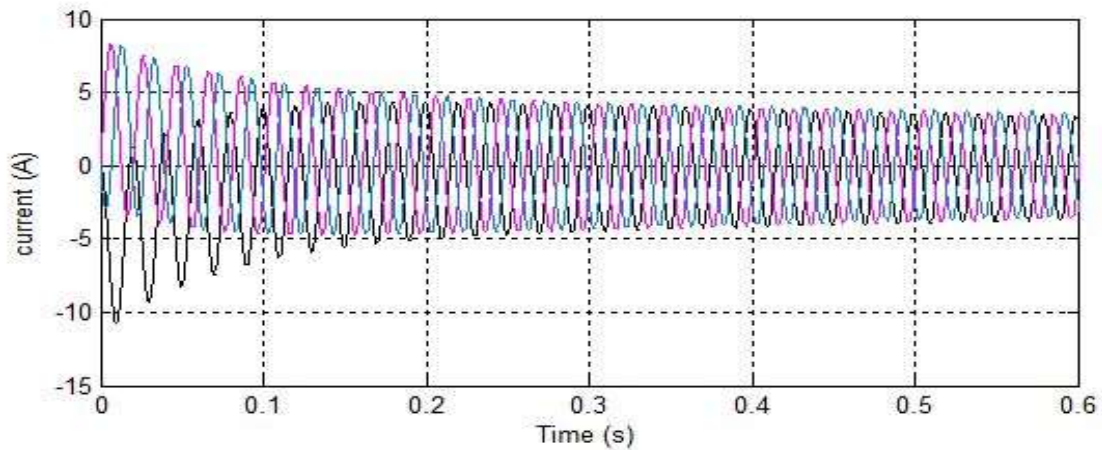


Fig. 6.13 Grid side three phase output current

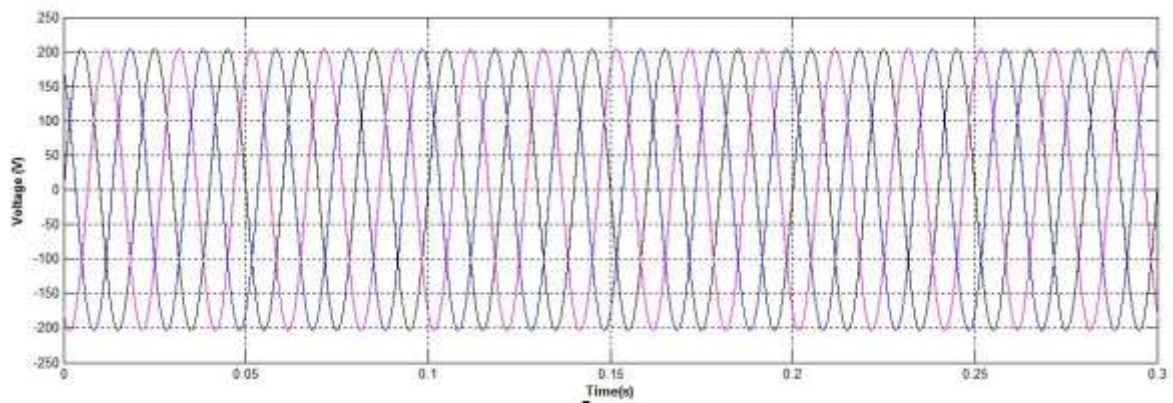


Fig. 6.14 Grid side three phase output voltage

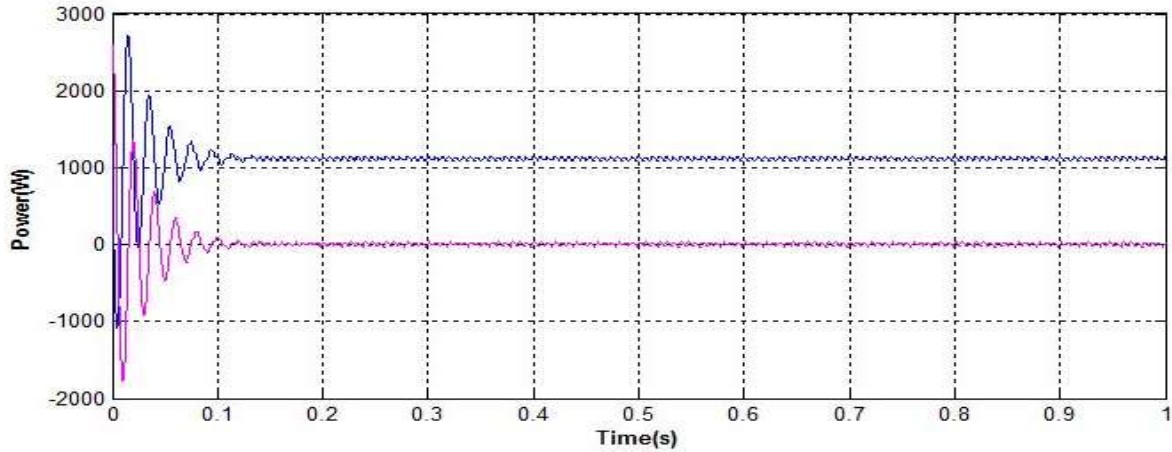


Fig 6.15 Grid side Active and Reactive power component

Figure 6.14, 6.15 & 6.16 show grid side results like three phase output current, voltage and power component. Reactive power is coming as zero and active power is coming as 1198 W. so we can say it is approximately 1.2 kW grids. Grid voltage is maintained at 380V ph-ph rms value. Hence multiphase interleaved boost converter is successfully utilized here for high power application.

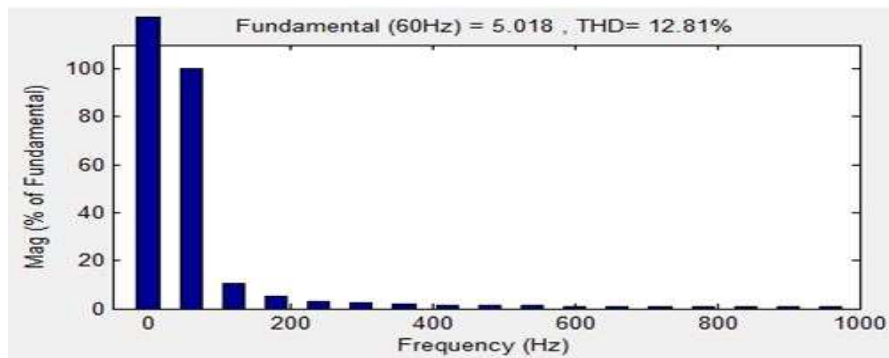


Fig 6.16 Total harmonic distortion of output current

Figure 6.13, shows the harmonic content in grid side output voltage. And it is coming as 12.8%. Harmonic must be come below 5%. But it is 12.8%. If shunt active power filter will be designed properly then harmonic may reduce.

## 6.7 Summary

With the end of this chapter, it can be concluded that all the PV characteristics are properly plotted using MATLAB. Constant temp is maintained at 25°C and solar irradiation is maintained at  $500 \frac{W}{m^2}$ .



# Chapter 7

## CONCLUSION AND FUTURE SCOPE

7.1 Conclusion

7.2 Future Scope

## 7.1 Conclusion

- Multiphase interleaved boost converter for PV application with all the simulation results and equivalent circuit has been presented here. As seen one PV cell gives a very low voltage, which is insufficient for further work, hence more PV cells are connected together to form one PV array.
- However the characteristics of the PV array are nonlinear, it contains lot of harmonics. So to avoid this problem we have used here one maximum power point tracker, known as MPPT. MPPT algorithms are straightforward and simple enough. Here MPPT uses P&O algorithm because of its ease of implementation and simple algorithm. It also does not require any current sensor.
- To boost up the voltage level boost converter is adopted with interleaving technique. It has added some advantages like, can be used for high ratios, also for high power application. Three boost converters are connected in parallel manner, they are studied and simulated properly and presented here with all the required results.
- Since the generated voltage from the above mentioned entire system is DC, hence we need one inverter for converting it to AC. So that it can be given back to the grid. Before connected it to the grid, the frequency and phase of the inverter should be properly synchronized with the grid. So that things also presented here using PLL circuit and synchronous rotating d-q frame. And all the required 3 phase results are listed all together.

## 7.2 Future Scope

Further work in this area may be possible like, there are many MPPT methods are available till date. Hence they can also be implemented here for increasing efficiency in fast changing environmental conditions. One shunt active power filter also can be added after grid current to reduce the harmonic content hence making it smooth. It can also be done considering the partial shading effect into the PV cell.

## REFERENCES

- [1] S. Shongwe, M. Hanif, “Comparative Analysis of Different Single-Diode PV Modeling Methods”, *IEEE Journal of Photovoltaics*, vol.5, no.3, pp.938-946, February, 2015.
- [2] T. Salmi, M. Bouzguenda, A. Gagtli, “MATLAB/Simulink based modeling of solar photovoltaic cell,” *International Journal of Renewable Energy Research*, vol.2, no.2, pp. 55-59, March, 2012.
- [3] K. Ding, X. Bian, H. Liu, T. Peng, “A MATLAB-Simulink-Based PV Module Model and Its Application under Conditions of Non-uniform Irradiance”, *IEEE Transactions on Energy Conversion*, vol.27, no. 4, pp. 864-872, September, 2012.
- [4] N. Femia, G. petrone, G. Spagnuolo, M. Vitelli, “Optimization of perturb and observe maximum power point tracking method”, *IEEE Transactions on power electronics*, vol.20, no. 4, pp. 963-973, July, 2005.
- [5] M. Villalva, J. R.Gazoli, “Comprehensive approach to modeling and simulation of photovoltaic arrays,” *IEEE Transaction on Power Electronics*, vol.24, no.5, pp. 1198-1208, May 2009.
- [6] S.K. Kollimalla, M.K. Mishra, “A Novel Adaptive P&O MPPT Algorithm Considering Sudden Changes in the Irradiance”, *IEEE Transactions on Energy Conversion*, vol.29, no. 3, pp. 602-610, May, 2014.
- [7] M. A. G. Brito, L. Galotto, L. P. Sampaio, C.A. Canesin, “Evaluation of the Main MPPT Techniques for Photovoltaic Applications”, *IEEE Transactions on Industrial Electronics*, vol. 60,no.3, pp. 1156-1167, May, 2012.
- [8] B. Subudhi, R. Pradhan, “A Comparative Study on Maximum Power Point Tracking Techniques for Photovoltaic Power Systems”, *IEEE Transactions on Sustainable Energy*, vol.4, no.1, pp. 89-98, July, 2012.
- [9] F. Wang, X. Wu, Z. Wang, “Analysis of unified output MPPT Control in subpanel of PV converter system”, *IEEE Transaction on Power Electronics*, vol.29, no. 3, pp. 1275-1284, May, 2013.

- [10] C. M. Lai, C. T. Pan, M.C. Cheng, "High-Efficiency Modular High Step-Up Interleaved Boost Converter for DC-Micro-grid Applications", *IEEE Transactions on Industry Applications*, vol. 48, no. 1, pp. 161-171, January, 2012.
- [11] H. Breuninger, S. Pettersson, G. Escobar, "A Comparative Performance Study of an Interleaved Boost Converter Using Commercial Si and SiC Diodes for PV Applications", *IEEE Transactions on Power Electronics*, vol. 28, no. 1, pp. 289-299, May, 2012.
- [12] K. C. Tsenga, C. C. Huang, "High Step-Up High-Efficiency Interleaved Converter with Voltage Multiplier Module for Renewable Energy System", *IEEE Transactions on Industry Applications*, vol. 61, no. 3, pp. 1311-1319, May, 2013.
- [13] X. Kong, A. M. Khambadkone, "Analysis and Implementation of a High Efficiency, Interleaved Current-Fed Full Bridge Converter for Fuel Cell System", *IEEE Transactions on Power Electronics*, vol. 22, no. 2, pp. 543-550, March, 2007.
- [14] G. A. L. Henn, R.N.A.L Silva, "Interleaved-Boost Converter with High Voltage Gain", *IEEE Transactions on Power Electronics*, vol. 25, no. 11, pp. 2753-2761, April, 2010.
- [15] M. E. ropp, S. Gonzalez, "Development of a MATLAB/Simulink Model of a Single-Phase Grid-Connected Photovoltaic System", *IEEE Transactions on Energy Conversion*, vol. 24, no. 1, pp. 195-202, March, 2009.
- [16] S. K. Kollimalla, M. K. Mishra, "A Novel Adaptive P&O MPPT Algorithm Considering Sudden Changes in the Irradiance", *IEEE Transactions on Energy Conversion*, vol. 24, no. 1, pp. 195-202, May, 2014.
- [17] M. Cespedes, J. Sun, "Impedance Modeling and Analysis of Grid-Connected Voltage-Source Converters", *IEEE Transactions on Power Electronics*, vol. 29, no.3, pp. 1254-1261, May, 2013.
- [18] D. Dong, B. Wen, D. Boroyevich, "Analysis of Phase-Locked Loop Low-Frequency Stability in Three-Phase Grid-Connected Power Converters Considering Impedance Interactions", *IEEE Transactions on Industry Applications*, vol. 62, no. 1, pp. 310-321, July, 2014.

- [19] P. Rodriguez, A. Luna, R. Teodorescu, "A Stationary Reference Frame Grid Synchronization System for Three-Phase Grid-Connected Power Converters Under Adverse Grid Conditions", *IEEE Transactions on power electronics*, vol. 27, no. 1, pp. 99-112, June, 2011.