DESIGN OF CONTROL ALGORITHM FOR RENEWABLE ENERGY RESOURCES

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DESIGN OF CONTROL ALGORITHM FOR RENEWABLE ENERGY RESOURCES

A Thesis submitted in partial fulfillment of the requirements for the degree of Bachelor of Technology *in*
"Electronics & Instrumentation Engineering"

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May-2011

CERTIFICATE

This is to certify that the draft report/thesis titled "**Design of Control Algorithm For Renewable Energy Resources**", submitted to the National Institute of Technology, Rourkela by **Sabyasachi Mohanty (Roll. No.110EI0136)**

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Prof. K.K.Mohapatra
Supervisor

ACKNOWLEDGEMENTS

I would like to express my sincere gratitude towards all the people who have contributed their precious time and efforts to help us in completing this project, without whom it would not have been possible for us to understand and analyze the project.

I would like to thank **Prof. K K Mohapatra**, Department of Electronics & Communication Engineering, our Project Supervisor, for his guidance, support, motivation and encouragement throughout the period this work was carried out. His readiness for consultation at all times, his educative comments, his concern and assistance have been invaluable.

I am also grateful to **Dr. Sukadev Meher**, Professor and Head, Department of Electronics & Communication Engineering, for providing the necessary facilities in the department.

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<u>Dedicated to,</u>

Our Parents & friends who have been…
there for us from genesis to apocalypse…

ABSTRACT

The need for renewable energy sources is on the rise because of the subtle energy crisis in the world today. By the year 2020, India plans to produce atleast a minimum of 20 Gigawatts of Solar power, whereas we have only tapped less than half a Gigawatt of our potential as of March 2010. Solar energy is an important untapped resource in a tropical country like ours. The main obstruction for the penetration and reach of solar PV systems is their high capital cost and low efficiency. In this thesis, we examine a schematic to extract maximum obtainable solar power from a PV module and use the energy for DC and AC application also tackling with the problem of partial shading in PV. This project also uses the concept of Maximum PowerPoint Tracking (MPPT) which significantly increases the efficiency of the solar photovoltaic system.

But in this project our main intention is to interface the PV array with the MPP tracker and process power for dc and ac loads. All simulations are carried under MATLAB/Simulink environment.

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ABBREVIATIONS AND ACRONYMS

MNRE	-	Ministry of New and Renewable Energy
IREDA	-	Indian Renewable Energy Development Agency
PVA	-	Photo Voltaic Array
AC	-	Alternating Current
DC	-	Direct Current
SPV	-	Solar Photo Voltaic
VSI	-	Voltage Source Inverter
PWM	-	Pulse Width Modulation
EMI	-	Electro Magnetic Interference
MATLAB	-	MATrixLABoratory
MPPT	-	Maximum Power Point Tracking
PID	-	Proportional, Integral and Derivative
IC	-	Integrated Circuit
LED	-	Light Emitting Diode
SMPS	-	Switched Mode Power Supply

CHAPTER 1

Introduction

1.1   MOTIVATION:

As the days go by, the demand of power is increasing gradually and on the contrary the resources used for power generation are becoming inadequate. Apart from the reason of inadequate resources, the methods used for power generation by fossil fuels are not even environment friendly and they devote an ultimate reason for global warming and greenhouse effect.

So it is the time to initiate the usage of renewable energy resources on very large scale. The three main available renewable energy resources are (i) Direct Solar Energy, (ii) Hydro Energy and (iii) Wind Energy. Hydro Energy generation and Wind Energy generation are of course two of the main sources of renewable energies, but the main disadvantage in Hydro Energy is that, it is seasonal dependent and in Wind energy is that it is geographical location dependent. On the other hand Solar Energy is prevalent all over the globe and all the time. The amount of irradiance and temperature may vary from place to place and from time to time but under given conditions Solar Energy system can be implemented. Solar Energy or PV energy system is the most direct way to convert the solar radiation into electricity based on photovoltaic effect. Despite of high initial costs, they are already have been implemented in many rural areas. In future the cost of the PV panel also may diminish, because of the advancing technology and also the competition between manufacturers. And therefore, the time is not so far that almost every middle class person can afford his own solar panel at home for at least some basic requirements.

In the perspective of above noted points, it is evident that PV Energy plays a pioneer role in the forthcoming future. So, it is our duty to learn, implement and improvise the idea as fast as we can, so that it becomes prevalent rather than precarious to the future generations.

1.2   PV ENERGY:

1.2.1 Photovoltaics (PV):

Photovoltaics are best known as a method for generating electric power by using solar cells to convert energy from the sun into a flow of electrons. Photovoltaic effect refers to photons of light exciting electrons into a higher states of energy, which allows them to act as charge carriers for

an electric current. The photovoltaic effect was first observed by Alexandre-Edmond Becquerel in 1839.The term photovoltaic refers to the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Practically all photovoltaic devices are some type of photodiode.

Solar cells produce direct current electricity from sun light which can be used to power equipment or to recharge a battery. The first practical application of photovoltaic was to power orbiting satellites and spacecrafts, but nowadays the majority of photovoltaic modules are used for grid connection for the generation of power. In this case an inverter is needed to convert the DC to AC. There is even demand for off-grid power for boats, electric cars, recreational vehicles, roadside emergency telephones, remote sensing and lastly for cathodic protection of pipelines.

Cells require protection from the environment and are usually packaged tightly behind a glass sheet. And if more power is required than a single cell can generate, cells are electrically connected in series and parallel to form photovoltaic modules, aka solar panels. A single module is enough to power an emergency telephone, except for a house or a power plant the modules must be arranged in multiples as arrays.

1.2.2 PV Energy Efficiency:

The output voltage thus obtained from the PV panel is DC. For low power applications, dc-dc converters are employed to step-up or step-down the output DC voltage according to the load requirements. However overall conversion efficiency is very low (typically 6.5 percent). So accurate modeling and design of dc-dc converter is necessary in order to improve the overall system performance with cost effective solution.

As the efficiency of solar panel itself is very less and it is inevitable, so the precaution should be taken such that the efficiency of the converter should be maximum. For the efficient regulation, techniques have been discussed and designed in the project. Various converter topologies have been proposed in the literature.
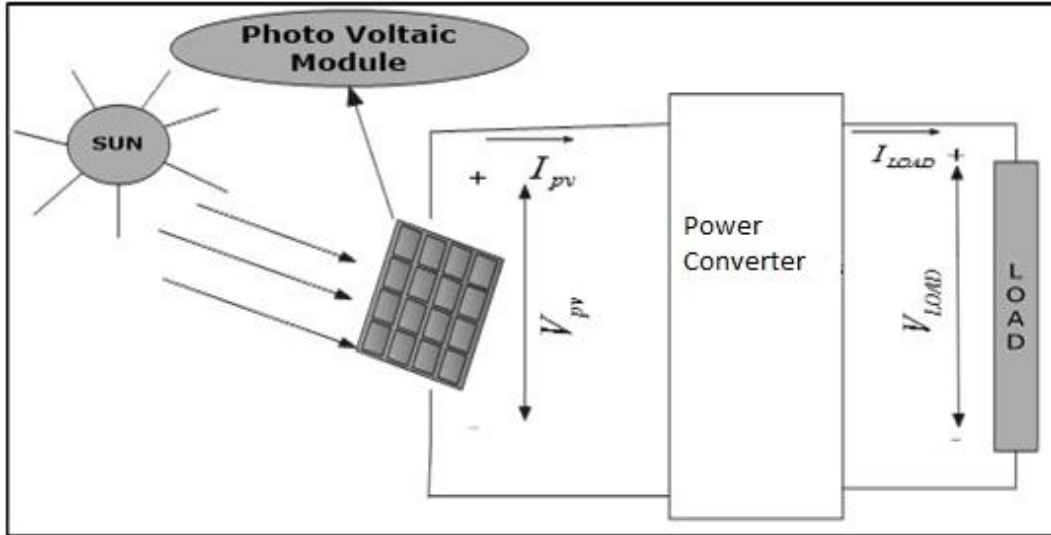
Figure 1: Schematic Diagram of PV Based Converter System.

As shown in the above Figure Fig.1 the dc voltage obtained from the PV array is regulated through dc-dc converter before it is fed to load. As we know the efficiency of solar PV array is very low, so it is of utmost important task of the designer to design dc-dc converter with the appropriate topology to obtain maximum efficiency and also with less cost.

1.3   AN INTRODUCTION:

Solar energy is 100% pollution-free, and infinite and clean, so developing of solar energy power systems can solve the problem of exhausting of fossil fuels. A single-stage PV system has been developed for efficiency improvement and cost reduction. Though the structure of a single-stage PV system is simpler than that of a two-stage PV system, still current sensors, a couple of IGBTs and corresponding drivers are still needed in the power stage. The modeling of a boost converter with an MPPT algorithm was discussed. The proposed PV system conditions real power for ac and dc loads to accommodate different amounts of PV power.

1.4 OVERVIEW OF PROPOSED WORK DONE:

Many literatures are used to carry out the project which includes notes on photovoltaic arrays, PV energy systems, converters topology, variation in the performance of arrays with atmospheric conditions, etc. It tells about the applications of photovoltaic technology and also the converter requirement for photovoltaic applications. Various converter topologies have been proposed in the available literature which describe various such converters available for use.

We later extend our PV design to implement Maximum Power Point Tracking (MPPT) in PV Energy Systems, and also to be implemented in the dc-dc converter.

1.5 THESIS OBJECTIVES:

The objectives are hopefully to be achieved at the end of the project:

1. To study the solar cell model and observe its characteristics.

2. To study the DC-DC converter and its operation.

3. To study the Maximum Power Point Tracking (MPPT) algorithms of PV Energy system and to implement in Simulink Environment.

4. To obtain the simulated results in the MATLAB-Simulink Environment.

1.6   ORGANISATION OF THESIS:

The thesis is organized into six chapters including the chapter of introduction. Each chapter is different from the other and is described along with the necessary theory required to comprehend it.

Chapter No.2 deals with PV Array Characteristics and its modeling. First, the equivalent mathematical modeling of the solar cell is made after studying various representations and simplification is made for our purpose. Then PV and IV characteristics curve for both constant temperature and constant irradiation for the equivalent model is studied in MATLAB-Simulink environment using the equation corresponding to that model.

Chapter No.3 deals with the design of various types of DC-DC Converter such as buck, boost, buck-boost etc., and this section also deals with the comparison between the output waveforms of Buck converter and Boost converter.

Chapter No.4 deals with the study of DC to AC Inverters such as half bridge and Full Bridge VSI's

Chapter No.5 deals with the study of Maximum Power Point Tracking and its significance in PV Energy systems. And later on we adopt Incremental Conductance algorithm in MATLAB/Simulink to design the MPPT controller to track and operate at maximum power point for the proposed PV Energy system. Also concept of Partial Shading in PV arrays, and demerits of it is discussed. And eventually a method is proposed in order to counteract for partial shading in PV array which can be used to design an algorithm to find out the global maximum peak in the V-P curve.

Chapter No.6 is results and discussion section, in which all simulation results such as PV Characteristics, Simulation of dc converters, and Simulation of PV power with MPPT which is compared to without MPPT, operation of inverter, simulation of the current and voltage obtained for AC loads etc., which are obtained in before sections are displayed and explained each result meticulously.

CHAPTER 2

PV-Array Characteristics

2.1   INTRODUCTION:

Learning and analyzing PV Array characteristics plays a vital role when it comes to PV energy generation. These characteristics vary from one model to the other. But, however we in this section study the PV array characteristics for ideal PV Cell, which includes P-V and I-V characteristics during constant temperature and also P-V and I-V characteristics during constant Irradiance. Meticulous study of these characteristics helps us to understand the functioning of PV Cell during the variations of temperature and irradiation which are the pioneer parameters for PV energy generation.

These characteristics obtained, not only helps us in understanding PV system, but also helps in the study of concept Maximum Power Point Tracking (MPPT) and also to obtain that point for maximum efficient operation of System. These topics are discussed in later chapters in detail.

2.2   PV ARRAY MODELING:

The solar cell arrays or PV arrays are usually constructed out of small identical building blocks of single solar cell units. They determine the rated output voltage and current that can be drawn for a given set of atmospheric data. The rated current is given by the number of parallel paths of solar cells and the rated voltage of the array depends on the number of solar cells connected in series in each of the parallel paths. A single PV cell is a photodiode. The single cell equivalent circuit model consists of a current source dependent on irradiation and temperature and a diode that conducts reverse saturation current, and forward series resistance of the cell.

In the Figure 2, is an approximated version of actual single cell equivalent circuit, the output current (I_{pv}) and the output voltage (V_{pv}) are dependent on the solar irradiation and temperature and also the saturation current of diode. For that single cell, I_{pv} and V_{pv} are calculated by the equations given below:
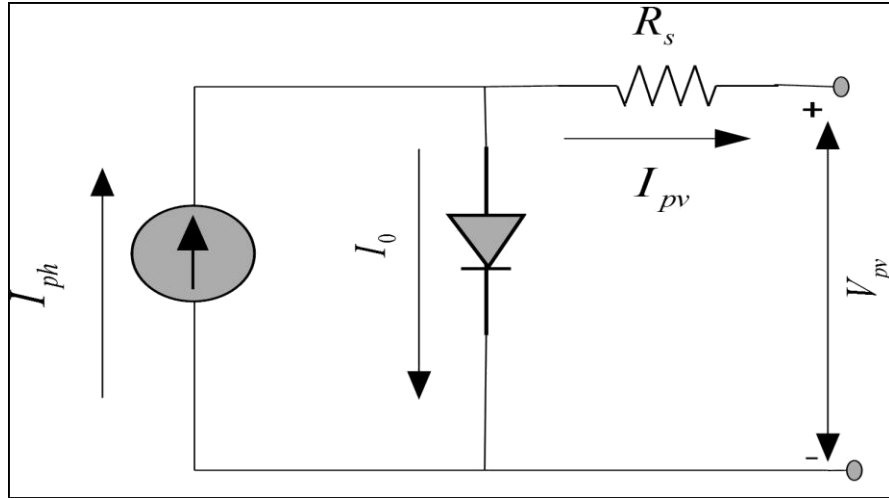
Figure 2: Equivalent Circuit of PV Cell

EQUATIONS:

Module Photo Current:

$$I_{ph} = [I_{SCr} + K_i(T - 298)] * \lambda / 1000 \tag{1}$$

Module Reverse Saturation Current:

$$I_{rs} = I_{SCr} / [\exp(\frac{qV_{OC}}{N_s kAT}) - 1] \tag{2}$$

The module saturation Current I_0 varies with the cell temperature as given by:

$$I_0 = I_{rs} [\frac{T}{T_r}]^3 \exp[\frac{q*E_{g0}}{Bk} \{\frac{1}{T_r} - \frac{1}{T}\}] \tag{3}$$

The Current output of PV Module is:

$$I_{pv} = N_p * I_{ph} - N_p * I_0 [\exp\{ \frac{q*(V_{pv} + I_{pv} R_s)}{N_s AkT} \} - 1] \tag{4}$$

With the help of above equations subsystems are created in MATLAB/Simulink environment to obtain PV cell equivalent subsystem and with the help of obtained subsystem PV Characteristics are obtained.

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The solar array mainly depends up on three factors: (i) Ambient temperature, (ii) Load current and (iii) Solar irradiation. They are observed as,

(i) When load current increases the voltage drops in the PV array.

(ii) When the temperature increases the output power reduces due to increased internal resistance across the cell.

(iii) When irradiation level increases, the output power increases as more photons knock out electrons and more current flow causing greater recombination.

The variation of output power acts as a function of cell voltage and is affected by different operating conditions. Also output I-V characteristics of the single cell model are observed under various conditions of temperature and solar irradiation. The concerned simulations results are obtained under MATLAB-Simulink environment and are given in results and discussion section.

The obtained results are depicted in the RESULTS AND DISCUSSION Section.

CHAPTER **3**

DC DC Converter

3.1 MOTIVATION:

Most research works that focus on howto extract more power more effectively from PV cells are needed.Two common such ways are sun-based tracking and MPPT. Surveys show PV systems with sun tracking collecting30%–40% more energy than does PV systems without sun tracking. Directly connecting a PV module to the load enablesextraction of 31% energy, which increases to 97% through use ofMPPT.The maximum extractable power from PV panels depends notonly on the strength of the solar irradiation but also on theoperating point of the energy conversion system. MPPT is ofparamount importance to the system as it not only maximizessystem efficiency but also minimizes the return of investment onthe PV installation. To ensure maximum extraction of power, the maximum power point (MPP) should first be found before thesystem's operation point is driven to that point. A DC–DCconverter will vary the apparent impedance Ri of a PV module to match with the RMPP value.

DC Converters have two tasks: interface a PV panel and an RE source or the grid (or etc.),and drive the operating point of the PV panel to the MPP.Converter configuration thus matters to optimal performance of aPV system.
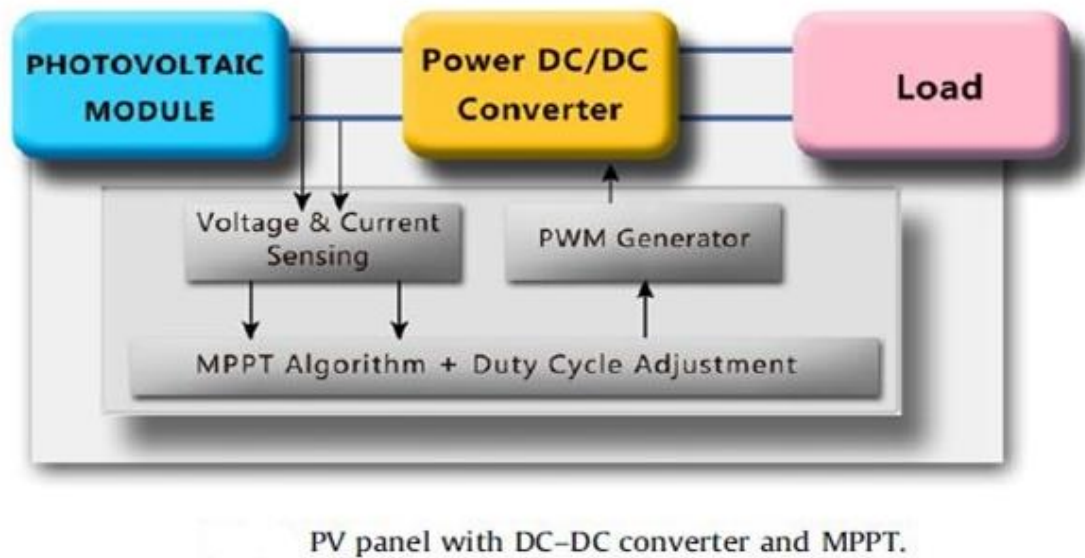
PV panel with DC–DC converter and MPPT.

Figure 3: Schematic of Power Converter which implements MPPT.

3.2   Typess of DC DC Converters:

In order to analyze our system, it is essential to reduce the complexity of the mathematical expressions, as well as to resort to computers for most of the tedious computations necessary in the analysis, state-space approach is best suited for this purpose [10]. In literature this state space averaging is the modeling structure given.

3.2.1 Buck Converter

In DC–DC buck converter or step-down converter, the output voltage magnitude is always lower than the input voltage magnitude, so this topology can be used for connecting high module voltages to low load or battery voltages.

PV apparent impedance Ri is converter input impedance. By changing the duty cycle D, Ri value can be matched with that of the optimum resistance RMPP. Table 1 has the resistance conversion ratio of a buck converter. As D is in the interval [0,1], a buck converter cannot reflect impedances that are smaller than the load impedance and therefore does not achieve values that are near the short-circuit current Isc of the PV module, i.e., a buck converter operates only with Rload <= Rmpp.

A buck converter does not allow tracing of PV I–V curve points that are close to Isc and that when the buck converter is used as MPPT, the MPP will be tracked as if it is restricted to within the operation region. General categories of buck converters are those that modulate the input voltage through PWM to generate the output voltage required for battery charging, and those that cause the PV panel to operate at the MPP.
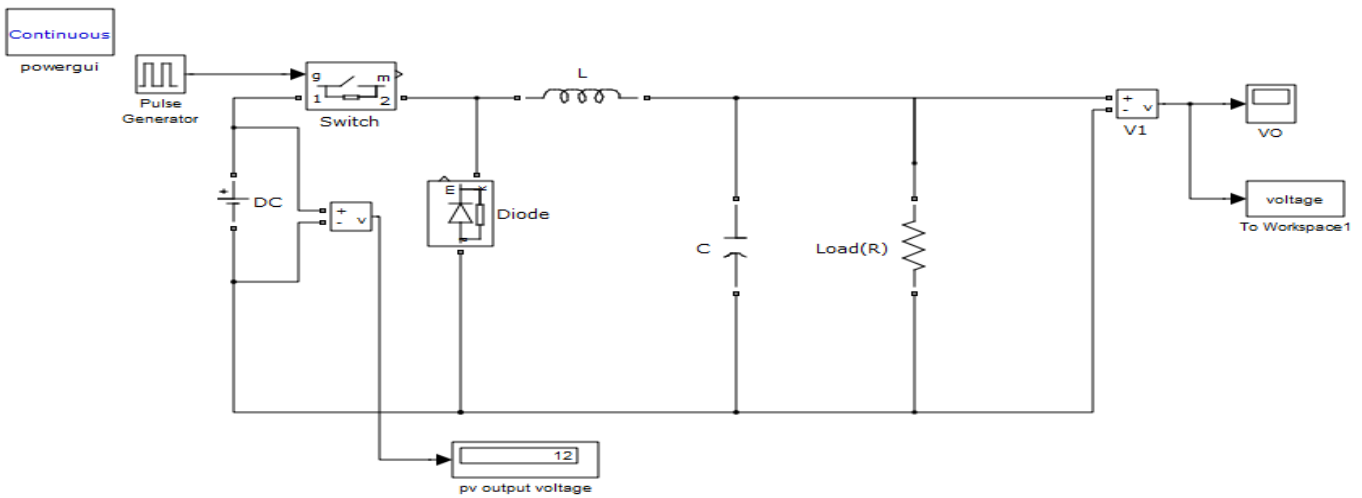
Figure 4: Circuit Diagram of Buck Converter

3.2.2 Boost Converter

In DC–DC boost or step-up converter, the output voltage magnitude is always higher than the input voltage magnitude, so this topology can be used to connect high load/battery voltages and low module voltages. As is theorized of buck converter resistance conversion ratio, because the value of duty cycle is between [0,1], a boost converter cannot reflect impedances that are greater than load impedance and therefore does not achieve values near a module's open-circuit voltage, i.e., boost converter operates only if Rload <= Rmpp. Fig. 4 shows boost converter not following the curve points that are near the open-circuit voltage, and when the boost converter is used as MPPT, the MPP will be tracked as if it is restricted to within the operation region. Note that under low irradiation condition, a boost converter cannot track MPP because the point is in the non-operating region. Many research works have developed applications for DC–DC boost converter in PV systems.
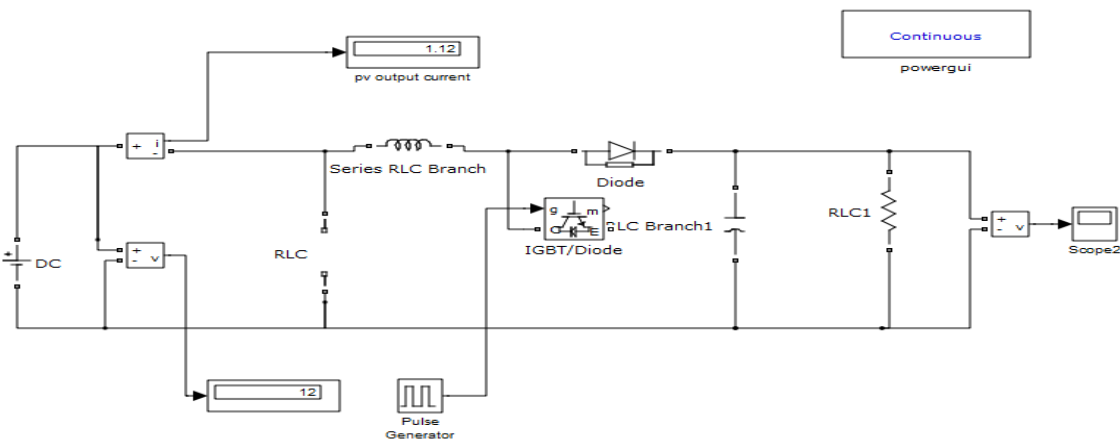

Figure 5: Circuit Diagram of Boost Converter

In our design, we will implement a Boost-Converter and we incorporate MPPT Controller to it and study is carried out in MATLAB-Simulink environment.

A model is designed in MATLAB-Simulink for the boost conversion design along with an MPPT Controller and thus the Maximum Power Point is achieved in the system. This system also includes the PV Array which is designed in Chapter No.2. The obtained results are depicted in RESULTS AND DISCUSSION section.

CHAPTER 4

DC to AC INVERTERS

4.1   Motivation:

An inverter are an essential components in solar modules, they serve the purpose of converting the variable direct current (DC) output of a photovoltaic (PV) solar panel into alternating current (AC) with a frequency required by the utility. So inverters can be used to feed into a commercial electrical grid or can be used by a local, off-grid electrical network. It is an essential component in a photovoltaic system, which facilitates the use of ordinary commercial appliances with solar power. DC to AC Inverters have important functions adapted for use with photovoltaic arrays which includes maximum power point tracking.

DC-AC inverters have been widely used in industrial applications such as that of UPS, AC motor drives and static frequency changes. Recently, the inverters are also playing crucial roles in renewable energy applications as they are used to link a photovoltaic or wind system to a power grid. Just like DC-DC converters, the inverters usually operate in a pulse width modulated (PWM) way and switch between a few different circuit topologies, which means that the inverters are nonlinear, specifically piecewise smooth system. In addition, the control strategies used in the inverters are also similar to those in DC-DC converters. For instance, current-mode control and voltage-mode control are usually employed in practical applications.

4.2 Converter Topologies:

Based on the power supply, inverters can be broadly classified into two types: Voltage Source Inverter and Current Source Inverter. A VSI has negligible impedance at its input terminal that is, it has almost a constant dc voltage source, whereas for a CSI, it is fed with adjustable current from a dc source with high impedance in this case. For the purpose of our project, all analysis throughout this paper has been done for Single Phase Voltage Source Inverters (VSI). Single-phase voltage source inverters (VSIs) can be found as half-bridge and full-bridge topologies. Since the power range they cover is the pretty low, so they are widely used in power supplies, single-phase UPSs, etc.

a) Half Bridge:

Figure 6 shows the power topology of a half-bridge Voltage Source Inverter, which requires the use of two large capacitors to provide a neutral point, such that each of the capacitors maintain a constant voltage of magnitude equal to Vi/2. Because the current harmonics injected by the operation of the inverter are low-order harmonics, a set of large capacitors (C+ and C-) is required. The states for the switches S1 and S2 are defined by different modulating technique, which in the case of this project is a carrier-based PWM.For realizing SPWM, a high-frequency triangular carrier wave $V_c$is compared with a sinusoidal reference $_{Vr}$ of the desired frequency.

The intersection of and waves determines the switching instants and commutation of the modulated pulse.
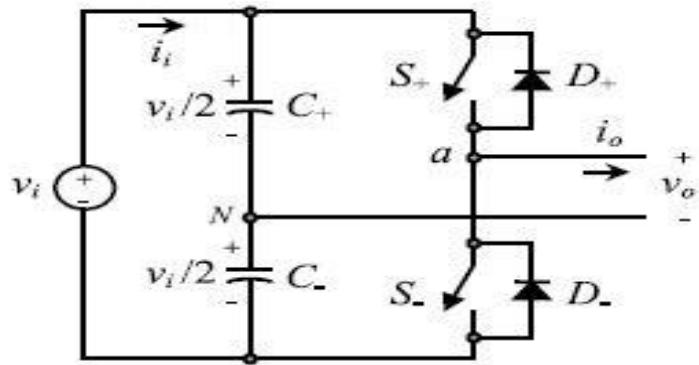

Figure 6: Circuit Diagram of Single Phase Half Bridge Inverter

b) Full Bridge:

The A single-phase inverter in the full bridge topology is as shown in Figure 6, which consists of four switching devices, two on each leg. The full-bridge inverter can produce an output power twice that of the half-bridge inverter with the same input voltage. There are three different PWM switching schemes, which improves the characteristics of the inverter. The main intention is to add a zero sequence voltage to the modulation signals such that they can ensure the clamping of the devices to either the positive or negative dc rail; in the process of which the voltage gain is improved, leading to an increased load fundamental voltage leads to reduction in total current distortion and increased load power factor. In Figure 6, the top devices are assigned to be S1+ and S2+ while the bottom devices as S1- and S2- .
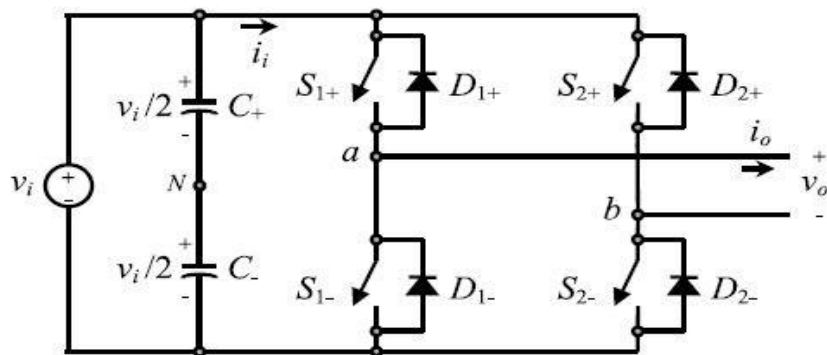

Figure 6: Circuit Diagram of Single Phase Half Bridge Inverter

NOTE: Studying the inverter models presented in Fig. 5 and Fig 6 meticulously, a model is designed in MATLAB-Simulink for the DC to AC conversion. This system also includes the PV Array which is designed in Chapter No.2. The obtained results are depicted in RESULTS AND DISCUSSION section.

CHAPTER **5**

Maximum Power Point Tracking

(MPPT)

5.1   INTRODUCTION:

Maximum power point tracking (MPPT) is a technique that grid tied inverters, solar-battery chargers and similar devices use to draw the maximum possible power from one or more photovoltaic devices, typically solar photovoltaic arrays. Solar cells have a complex relationship between temperature, solar irradiation, and total resistance that produces a non-linear output efficiency which can be analyzed based on the I-V curve. It is the purpose of the MPPT system to sample the output of the cells and apply the proper resistance (load) to obtain maximum power for any given environmental conditions. MPPT devices are generally integrated into an electric power converter system that provides voltage or current conversion, and regulation for driving various loads, including batteries, or motors etc.

Solar cells are devices that absorb sunlight and convert that solar energy into electrical energy. By wiring solar cells in series, the voltage obtained can be increased or if we want to increase the current then cells are connected in parallel. Solar cells are wired together in series and in parallel to form a solar panel. Solar panels can be connected to create a solar array.

The Maximum Power Point Tracker (MPPT) is needed to optimize the amount of power obtained from the solar array to the power supply. The output of a solar array is characterized by a performance curve of voltage versus current, called the I-V curve. See Figures Fig. 8 and Fig. 10. The maximum power point of a solar array is the point along the I-V curve that corresponds to the maximum output power possible for the array. This value can be determined by finding the maximum area under the I-V curve.

MPPT's are used to correct for the variations in the I-V characteristics of the solar cells. The I-V curve will move and deform depending upon such things as temperature and illumination. For the array to be able to draw out the maximum amount of power possible, either the operating voltage or current needs to be controlled.

Since the maximum power point quickly moves with the change in lighting conditions and cell temperature, a device is needed that finds the maximum power point and converts that voltage to a voltage equal to the voltage of the system. A major factor when deciding to utilize solar energy as a source is cost. As one might expect, a purchaser would want to extract the maximum power per rupee spent on an array. Solar arrays do present an interesting problem in the transfer of energy to a load, however. Since the solar array has a unique I-V relationship similar to a silicon diode, the maximum power point must be tracked to extract the most energy possible.

For more explicit explanation, we can say that solar panels have a nonlinear voltage-current characteristic, with a distinct maximum power point (MPP), which depends on different environmental factors, for instance temperature and irradiation. For continuously harvesting the maximum power from the solar panels, they must operate at their MPP inspite of the inevitable changes in the environment. This is why the all photovoltaic systems generally employ some method for maximum power point tracking (MPPT). Over the past decades many MPPT techniques have been published. The three algorithms that where found most suitable for large and medium size photovoltaic (PV) applications are perturb and observe (P and O), incremental conductance (InCond) and fuzzy logic control (FLC). Here in this project we propose P and O method, which overcome the poor performance when the irradiation changes continuously. This model was validated with simulation.
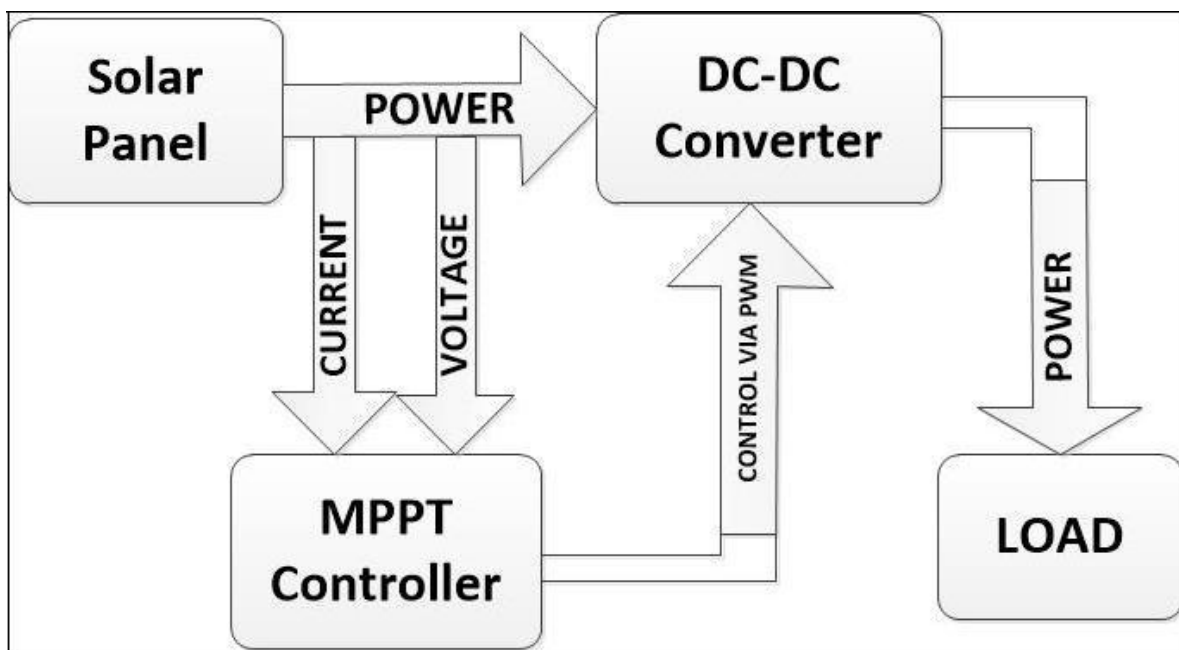
Figure 7: Block diagram of DC-DC converter incorporating MPPT

Above figure Fig. 7 shows a typical feed-forward configuration of DC-DC Converter through MPPT controller which in total aids in tracking Maximum Power Point and makes it evitable for PV Array to operate at Maximum Power Point.

5.2   PERTURB & OBSERVE METHOD:

5.2.1   Motivation:

As previously explained, MPPT algorithms are of utmost importance in PV applications because the MPP of a solar panel varies with the irradiation and temperature, so the use of MPPT algorithms is required in order to obtain the maximum power from a solar array.

Over the past decades many methods to find the MPP have been developed. These techniques vary from each other in many aspects such as required sensors, complexity, cost, effectiveness, speed of convergence, hardware needed for the implementation and lastly correct tracking with irradiation and/or temperature change.

Among these techniques, the P&O and the InCond algorithms are the ones that are most common. These techniques infact have the advantage of an easy implementation but they also have drawbacks, as will be shown later. Other techniques based on different principles are fuzzy logic control, fractional open circuit voltage or short circuit current,neural network, current sweep, etc. Most of these methods results in locating a local maximum and some, like the fractional open circuit voltage or short circuit current, give an approximated MPP, but not the exact one. Its not a problem in normal conditions when the V-P curve has only one maximum. However, for a partially shaded PV array, there are multiple maxima's in these curves. In the next section the most popular MPPT techniques are discussed.

5.2.2   Hill Climbing Techniques:

Both P&O and InCond algorithms are based on the principle of "hill-climbing", which is basically to move the operation point of the PV array in the direction in which power increases. Hill-climbing techniques are the most popular MPPT methods due to their good performance when the irradiation is constant and ease of implementation.

The advantages of both methods are low computational complexity and simplicity. The shortcomings are also well-known: oscillations around the MPP and they can get lost and track the MPP in the wrong direction during rapidly changing atmospheric conditions. These drawbacks will be explained later.

5.2.3 P&O Algorithm Implementation:

The P&O algorithm is also known as the "hill-climbing", but both the names refer to the same algorithm depending on how it is put into effect. Hill-climbing involves introducing a perturbation in the duty cycle of the power converter and in PandO a perturbation in introduced in the operating voltage of the DC link between the PV array and the power converter. In the case of the Hill-climbing, introducing a perturbation in the duty cycle of the power converter implies modifying the voltage of the DC link between the PV array and the power converter, hence both the names refer to the same technique.

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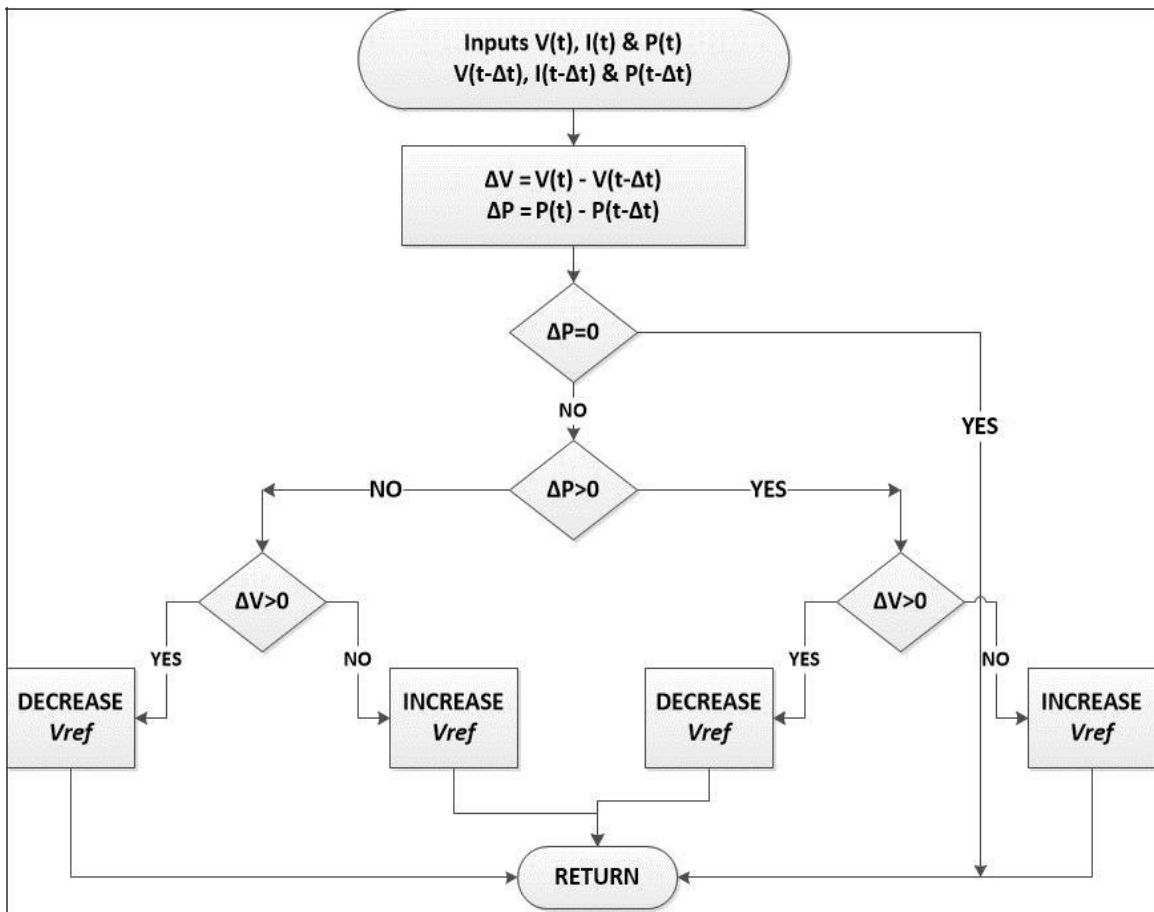
Figure 8: Flow Chart of P&O Algorithm.

In this method, the sign of the last perturbation and the sign of the last increment in the power are used to decide what the next perturbation should be. As shown in the flow chart above in figure Fig. 8, on the left of the MPP incrementing the voltage increases the power whereas on the right decrementing the voltage increases the power.

If there is an increment in the power, the perturbation should be continued in the same direction and if the power decreases, then the next perturbation should be introduced in the opposite direction. The algorithm is implemented using these facts. The above process is repeated till the MPP is reached. Then the operating point of the energy conversion system oscillates about the MPP. This problem is common also to the InCond method, as was mention earlier. A scheme of the algorithm is shown in Figure Fig. 8. In both P and O and InCond algorithms, how fast the MPP is reached depends on the size of the increment of the reference voltage. The drawbacks of these techniques are mainly two. The first and main one is that they can easily lose track of the MPP if the irradiation changes rapidly. In case of step changes they track the MPP almost perfectly, because it changes instantaneously and moreover the curve remains steady. However, when the irradiation changes continuously, so the curve on which the algorithms are based changes continuously with the irradiation, so the changes in the voltage and current are not only due to the perturbation of the voltage. As a result it is not possible for the algorithms to determine whether the change in the power is due to the change in the irradiation or due to its own voltage increment.

5.3   Effects of Partial shading on Maximum Power Point

Photovoltaic modules are connected in series and parallel to form a PV array in order to match the power requirements in terms of voltage and current. However the total power in such an array is lower than the sum of the individual rated power of each module. This can be accounted for a lot of different reasons. But the main reason is 'partial shading'. In a series connected solar photovoltaic module if the cells are not equally illuminated then there can be a serious performance hit. The same current is forced though all the cells even though a few cells under shade produce less photon current. It may happen that the shaded cells get reverse biased and acting as loads and further draining power from fully illuminated cells which results in an undesirable condition. If the system is not appropriately protected against partial shading, then hotspot problem can arise and in some cases, the system can be damaged beyond repair. The PV plants which are built today in a fixed series-parallel configuration and the single module is equipped with bypass diodes included in different configurations as show in Fig. This is used to bypass the single module when it is slightly radiated in order to avoid that the single module current may reduce the current of the whole photovoltaic array. On one hand the proposed solution is easily adoptable and allowed to improve the energy production from the whole PV array but on the other hand it imposes to neglect the energy produced by the module which is bypassed by the diode

The functioning of a photovoltaic array is impacted by solar insolation, temperature, shading, and array configuration. Often, the PV arrays get shadowed by the moving clouds or by shadowing from adjacent buildings and towers, trees, utility etc. This in case of big PV installations such as those used in distributed power generation systems gains especial interest. Under partly shaded conditions, the PV characteristics get more complicated with more than one peaks in the I-V curve. Yet, it is very important

to understand and predict them in order to draw the maximum possible power out of the PV system.
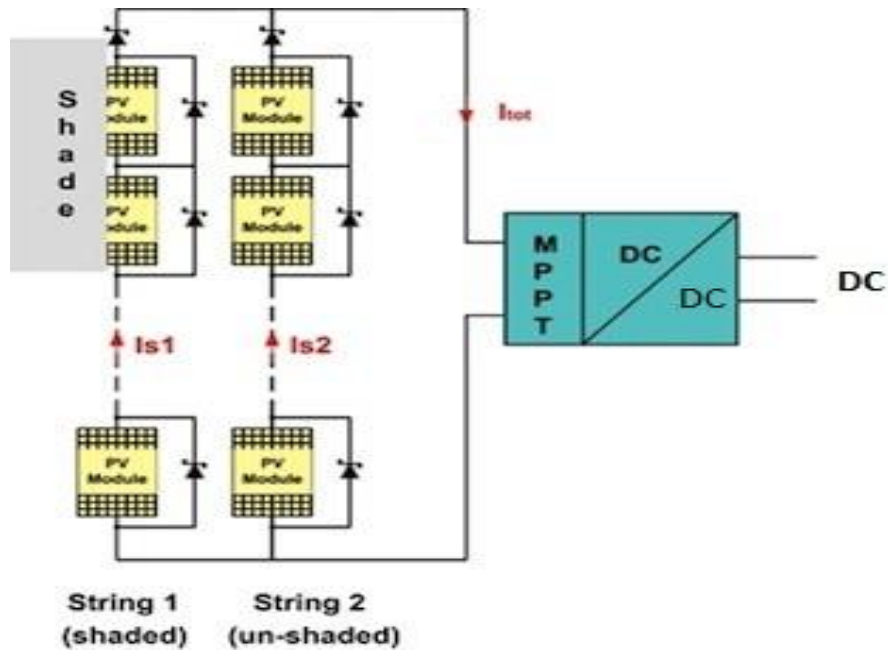

Figure 9: PV array Configuration to counter for Partial Shading

When a solar array is used at a source of power, it is necessary to use a maximum power point tracker in ensure minimal energy loss. The maximum power point tracker is implemented to track the maximum power point. This needs to be tracked since due to temperature and illumination the maximum power point will be continuously moving on the I-V curve. In our design, we will implement a Boost-Converter and we incorporate MPPT Controller to it and study is carried out in MATLAB-Simulink environment.

Also, a MATLAB-based modeling and simulation scheme desirable for studying the I-V and P–V characteristics of a photovoltaic array under a non-inhomogeneous insolation due to partial shading is presented. It can also be further used for acquiring and assessing new MPPT methods, especially for partially shaded conditions. It can also be used to study the effects of shading patterns on PV panels which may not be having similar forms. For a set of PV modules, the array configuration (refers to the number of series and parallel connections) importantly bears on the maximum usable power under partially shaded conditions. This is yet another view to which the acquired model can be applied.

Studying the algorithm presented in figure Fig. 8 meticulously, a program is designed in MATLAB-Simulink for the design of MPPT Controller and thus the Maximum Power Point is achieved in the system. This system also includes the PV Array which is designed in Chapter No.2. The obtained results are depicted in RESULTS AND DISCUSSION section.

CHAPTER **6**

Results & Discussions

6.1 PV System:

In order to verify the proposed study of small scale PV system is considered. This section reveals the simulation results of PV array using the equations depicted in last section in MATLAB/Simulink environment. In this section we will explore the characteristics of PV array with the change in irradiance and temperature and we will observe the changes in output power and current.

Fig.8 depicts the variation of Module current with Module Voltage with the variation of irradiance on the module at the constant temperature i.e. of 25°C.
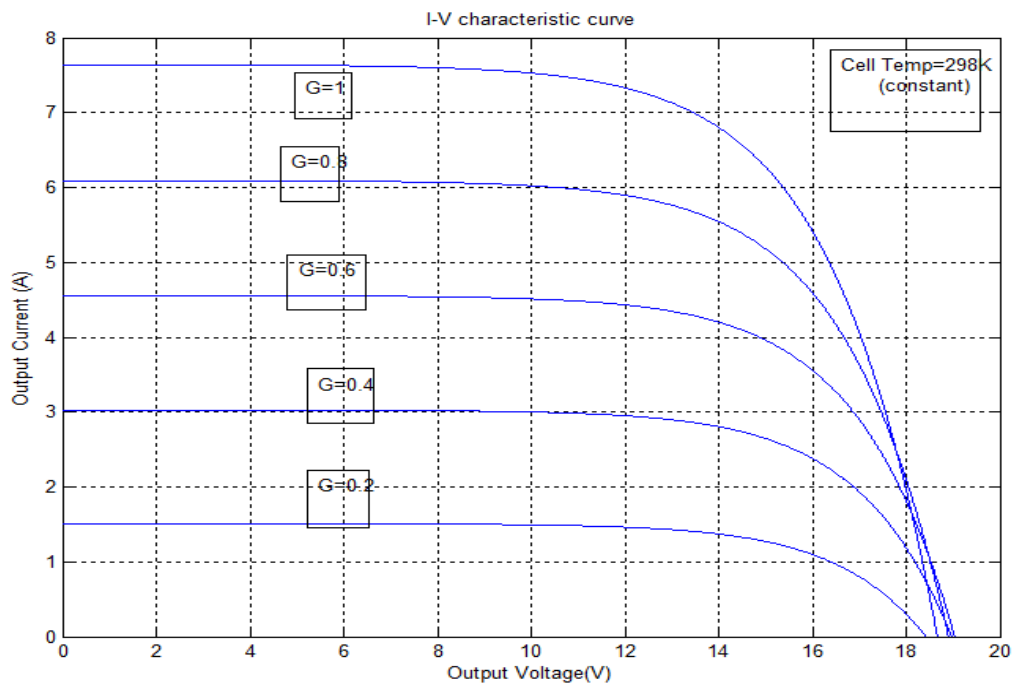
Fig.10 I-V Characteristics at constant temperature.

Fig.10 depicts the variation of Module power with Module Voltage with the variation of irradiance on the module at the constant temperature i.e. of 25°C.
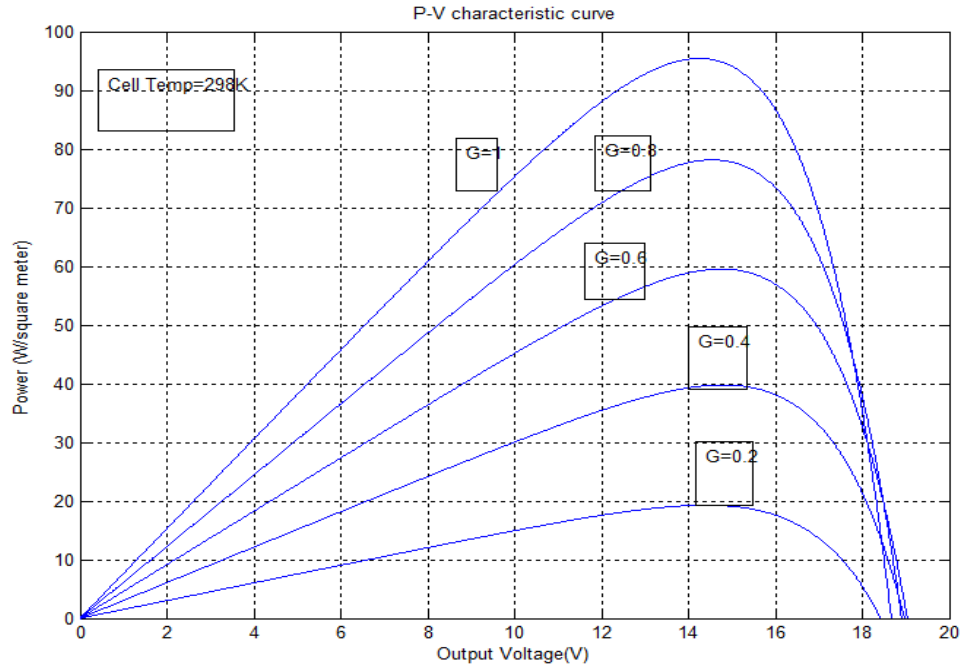
Fig .11: P-V Characteristics at constant temperature

Fig.11 depicts the variation of Module current with Module Voltage with the variation of temperature on the module at the constant irradiance i.e. of 1 kW/m^2.
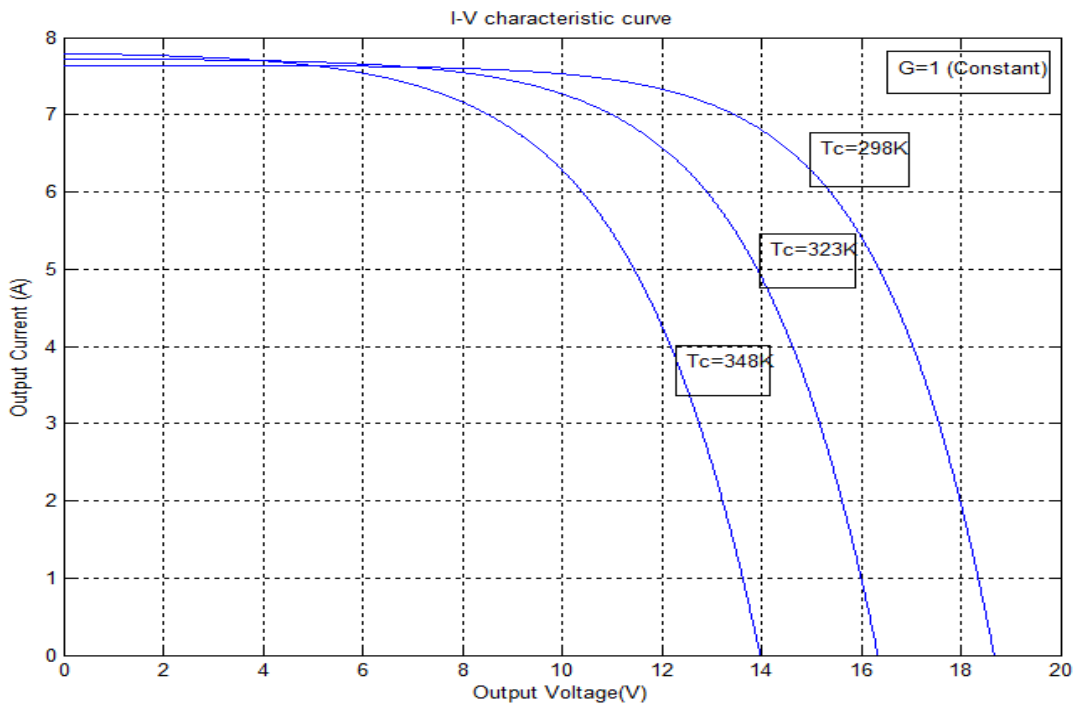
Fig 12. I-V Characteristics at constant irradiance

Fig.12 depicts the variation of Module Power with Module Voltage with the variation of temperature on the module at the constant irradiance i.e. of 18W/m^2.
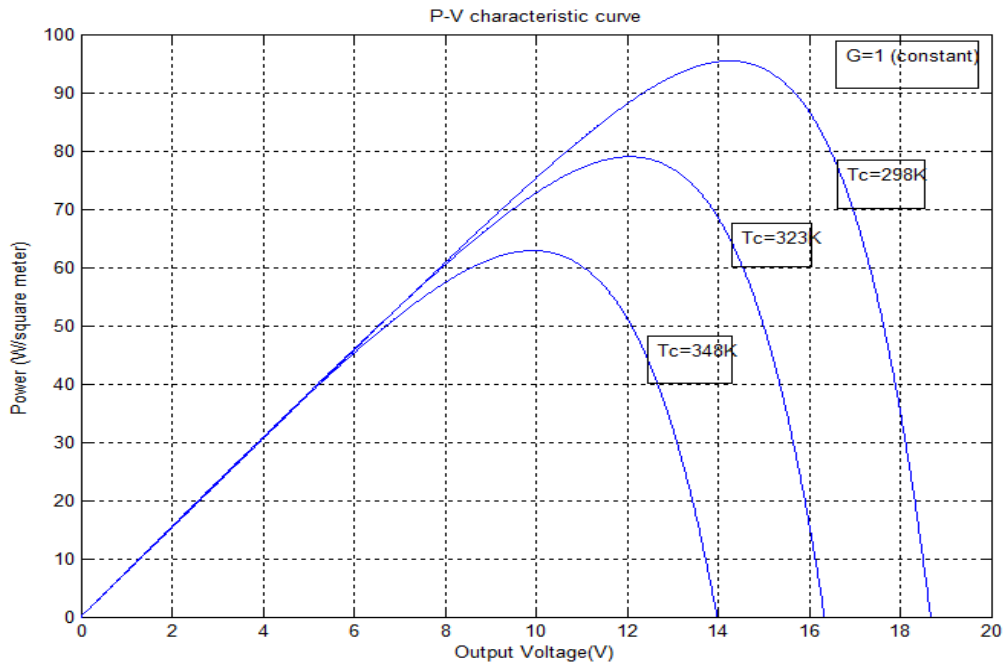
Fig.13. P-V Characteristics at constant irradiance

6.2   Boost Converter:
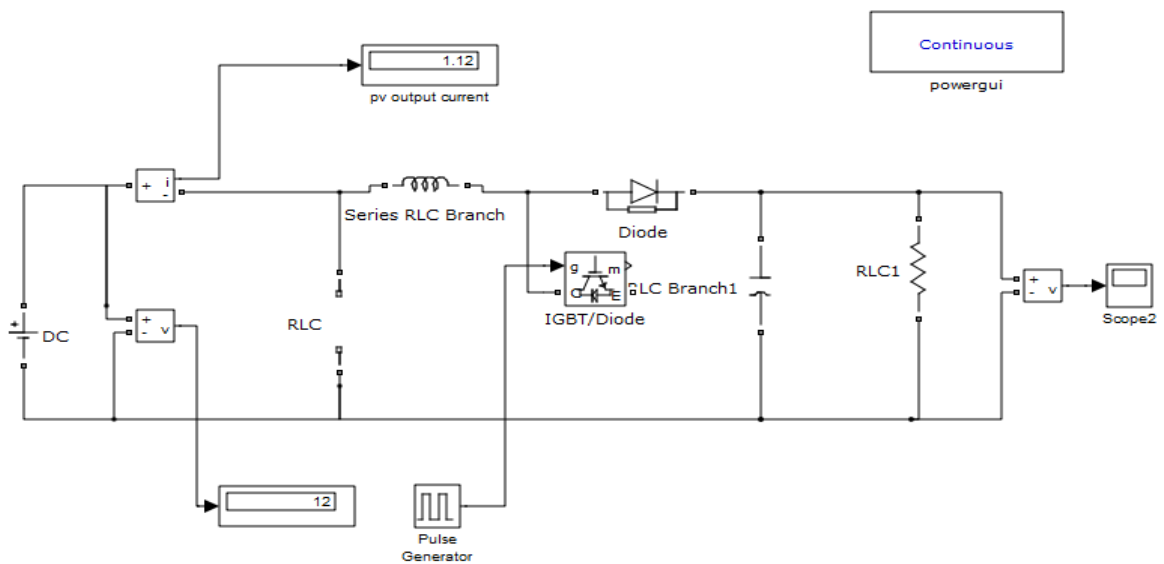
Fig.14(a).MATLAB Simulink Model for Boost Converter

For Vin=12V, Switching Cycle Duty Cycle= 50, C = 70e-6F, L = 6e-6H, R = 10ohms

Output Voltage waveform obtained is
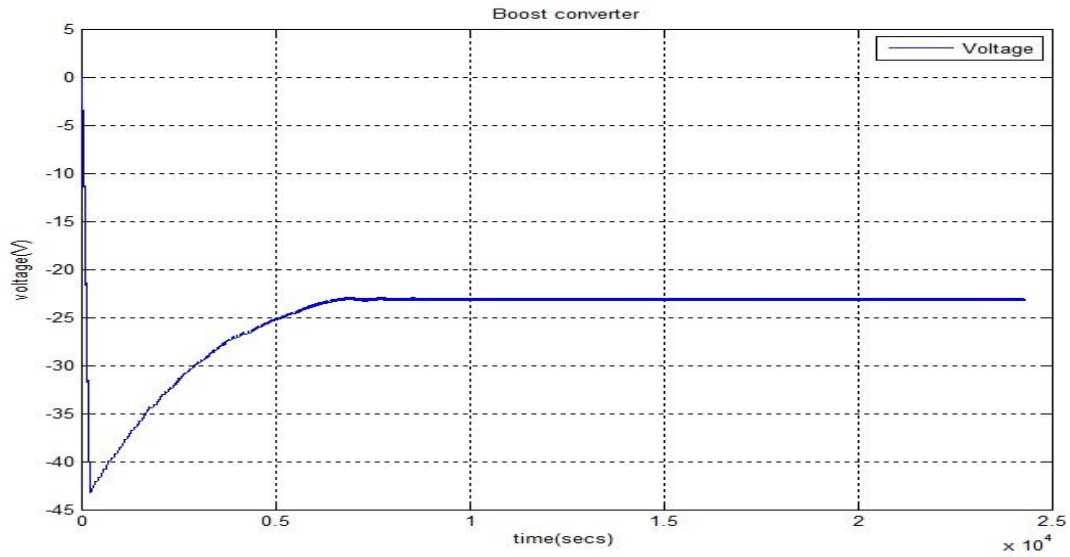
Fig.14(b).Simulation results for Boost Converter

6.3   Buck Converter:
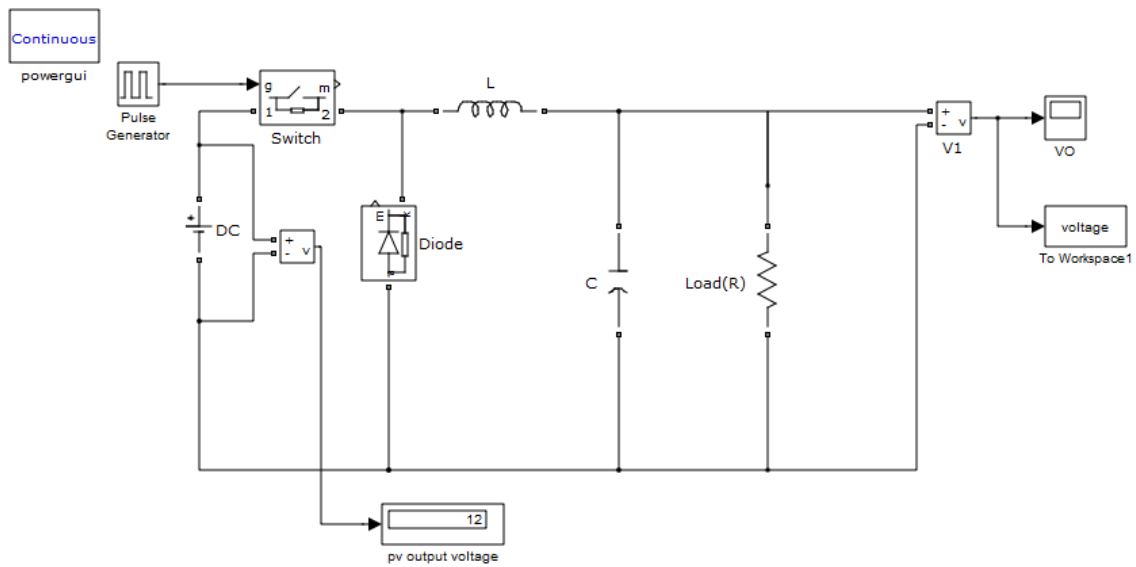
Fig.15(a).MATLAB Simulink Model for Buck Converter

For, Vin=12V, Switching signal duty cycle = 66.67, C = 35 e-6 F, L = 27e-6 H Load(R) = 10ohms

Output Voltage Signal obtained is
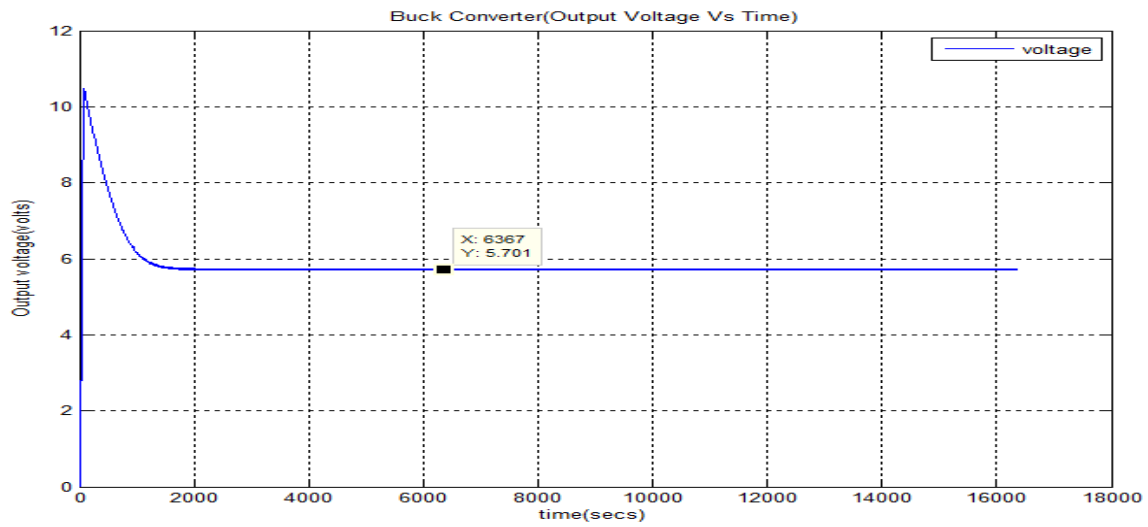
Fig.15(b).Simulation results for Buck Converter

6.3.1   Power Obtained from solar panel:
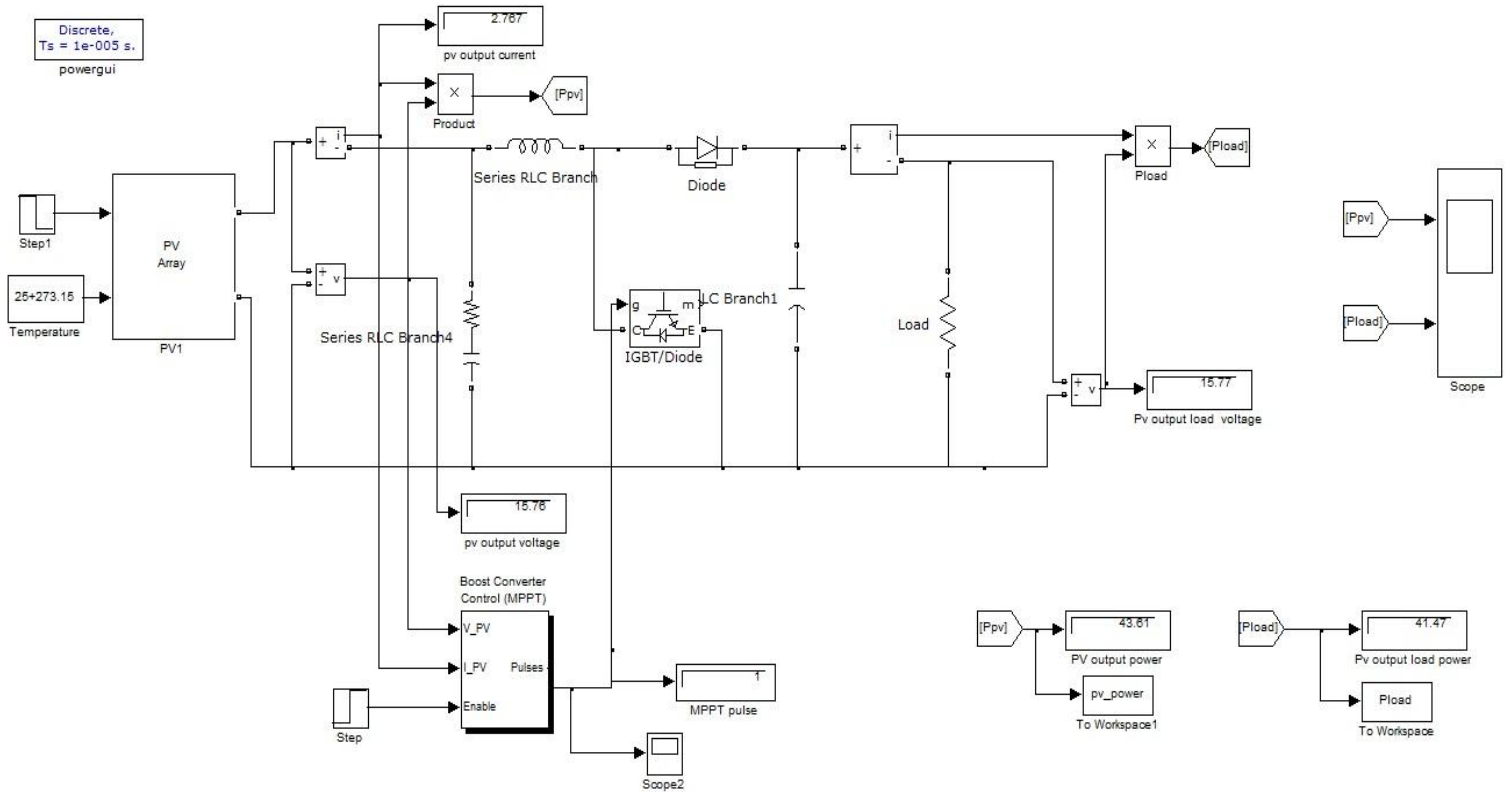
Fig.16. MATLAB-Simulink Model of PV module implemented along with Boost Converter and MPPT module

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Fig.13 depicts the Simulink model of a PV module along with a Boost Converter for constant load. From Fig.13 (a), one can be see that, the load draws 19.9watts at G=1 and 12.61watts at G=0.8 from the solar module.Fig.13 (a) doesn't include a MPPT module. But as previously calculated the maximum power point at G=1 and Temp=301K, Pmpp=55.1watts and the maximum power point at G=0.8 and Temp=301K is 43watts.Fig.13 (b) has a MPPT module which is based on InCond algorithm. The corresponding output power is shown in Fig.13 (b)
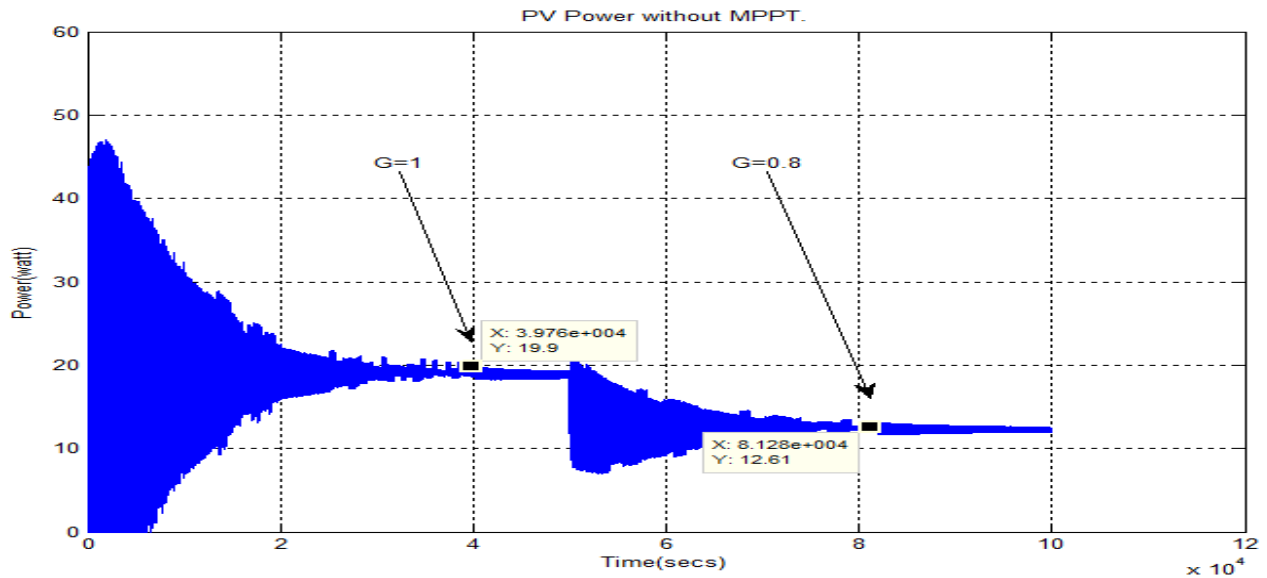
Fig.17. Power drawn from the PV module implemented without the MPPT module
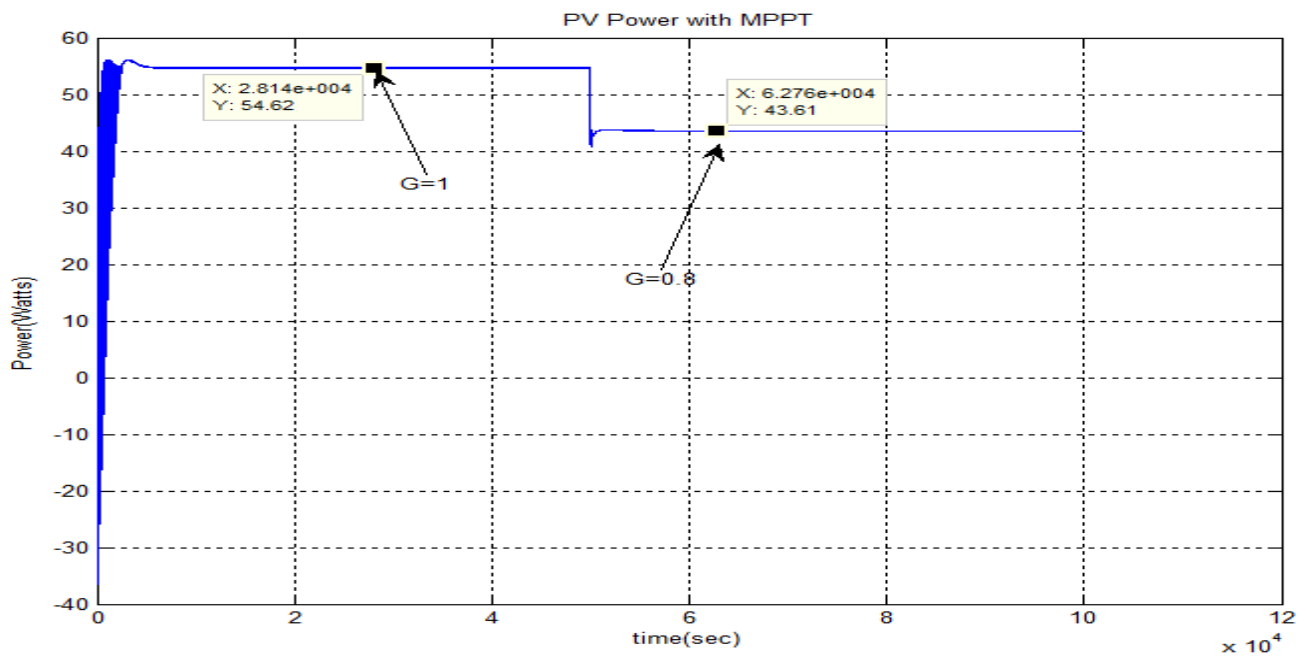
Fig.18. Power drawn from the PV module implemented with MPPT module for a DC load

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6.4 Modeling of an Inverter
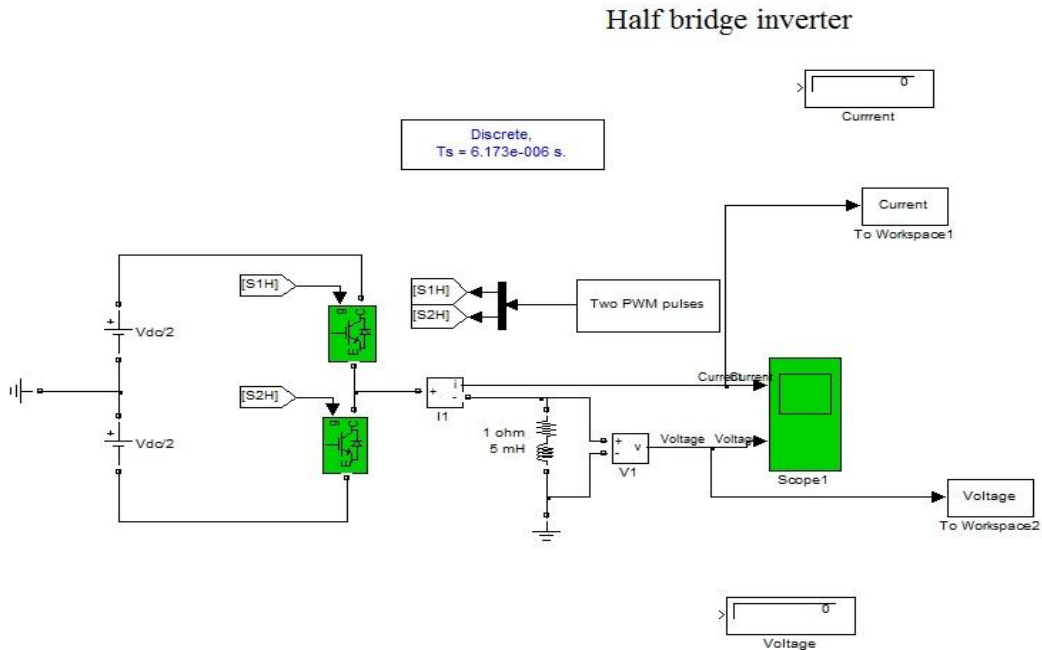
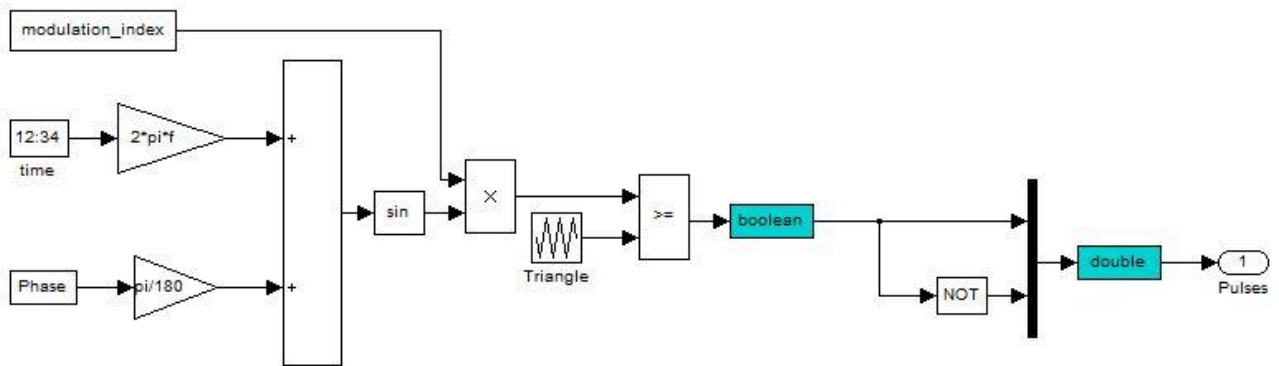Fig.19(a). MATLAB Simulink model of a Half Bridge Inverter

Fig.19(b). Generation of switching Signals for the Half Bridge inverter

Fig.19(a) depicts the Simulink model of an half bridge inverter and Fig 19(b) denotes the switching signals used to operate the inverter. The corresponding output voltage and current waveform is shown in Fig.19 (c)
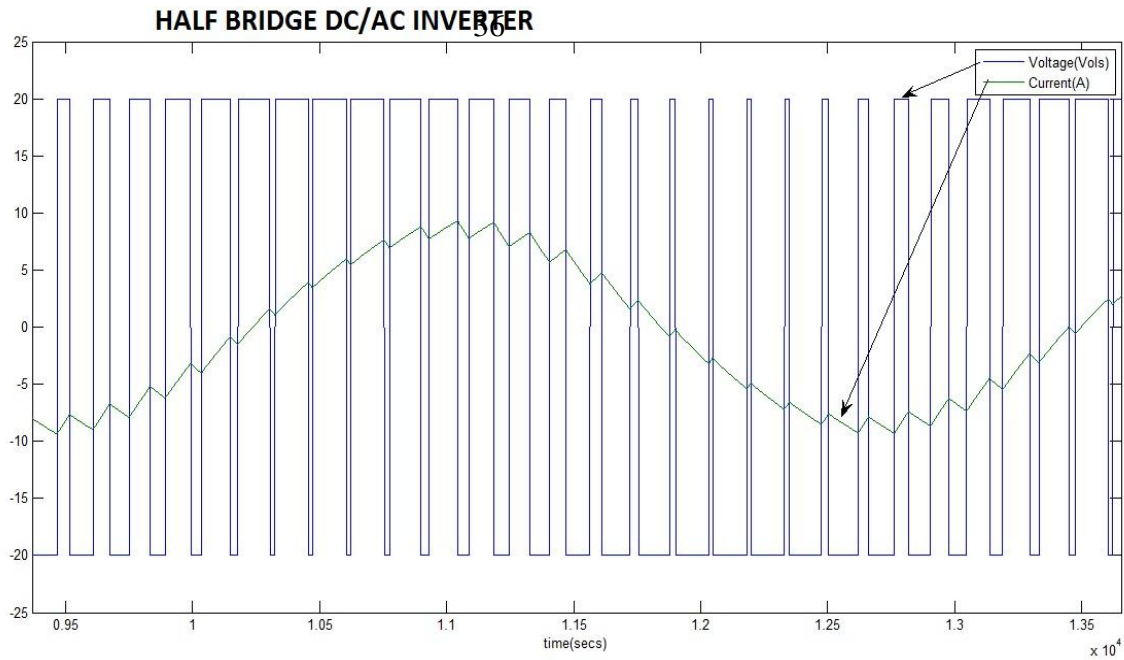
HALF BRIDGE DC/AC INVERTER

Fig.19(c). Current and Voltage waveforms generated by the inverter

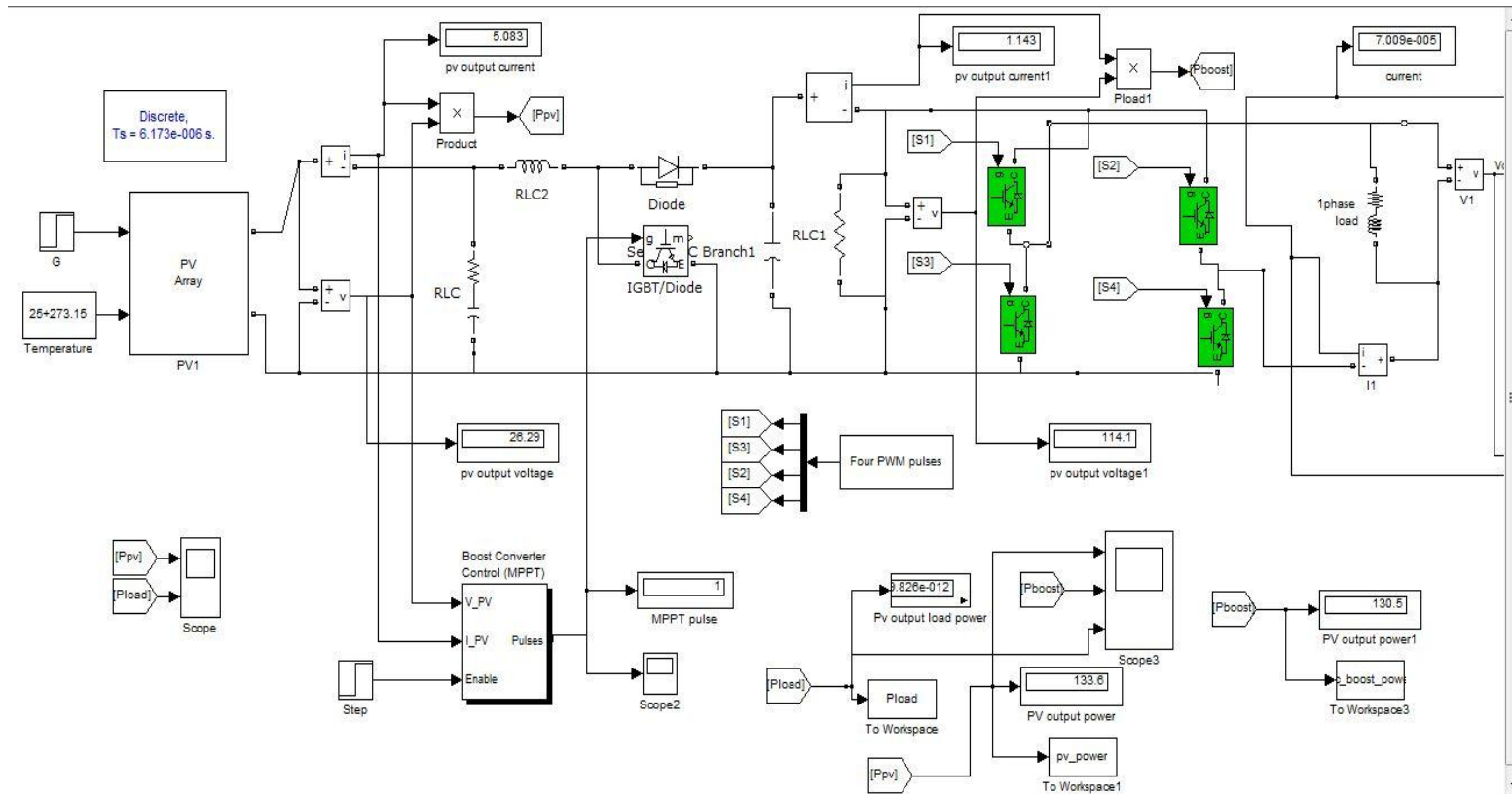## 6.5 PV Module with Boost Converter and Full Bridge Inverter

Fig.20. Current and Voltage waveforms generated by the inverter

Fig.20 (a) depicts the Simulink model of an PV interfaced which can produce power for DC as well as AC loads and Fig 19(b) denotes the switching signals used to operate the inverter. The corresponding output voltage and current waveform is shown in Fig.19 (c)
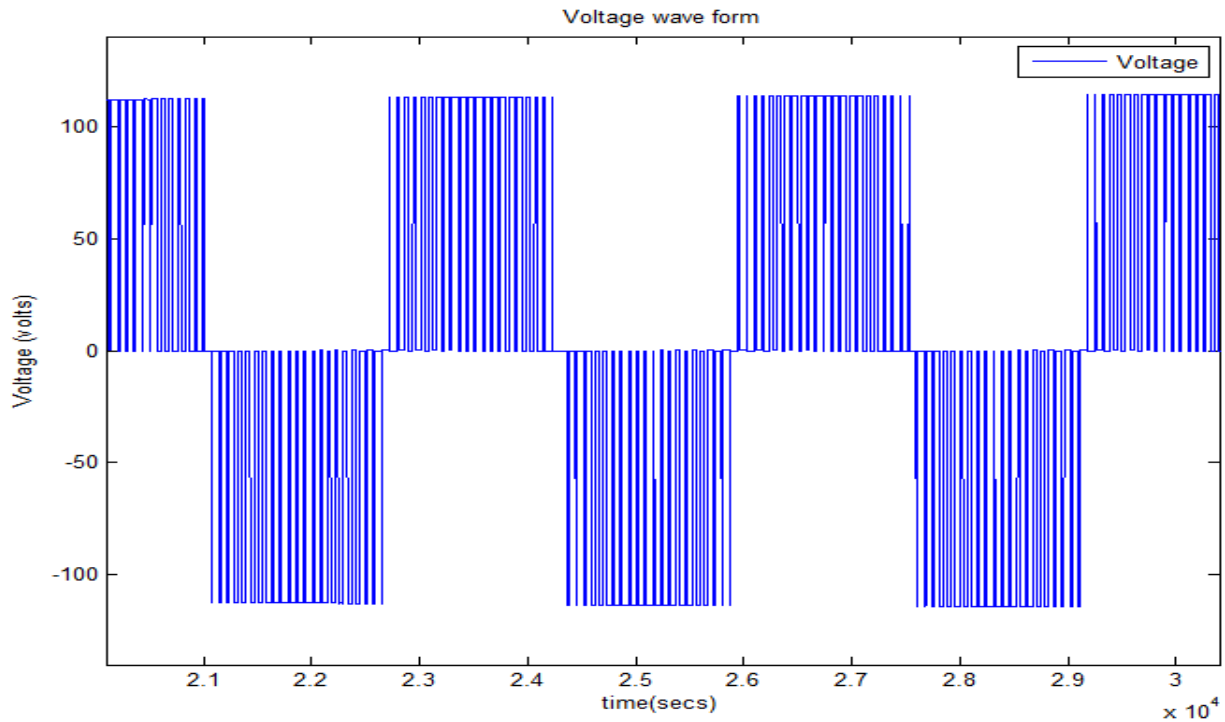
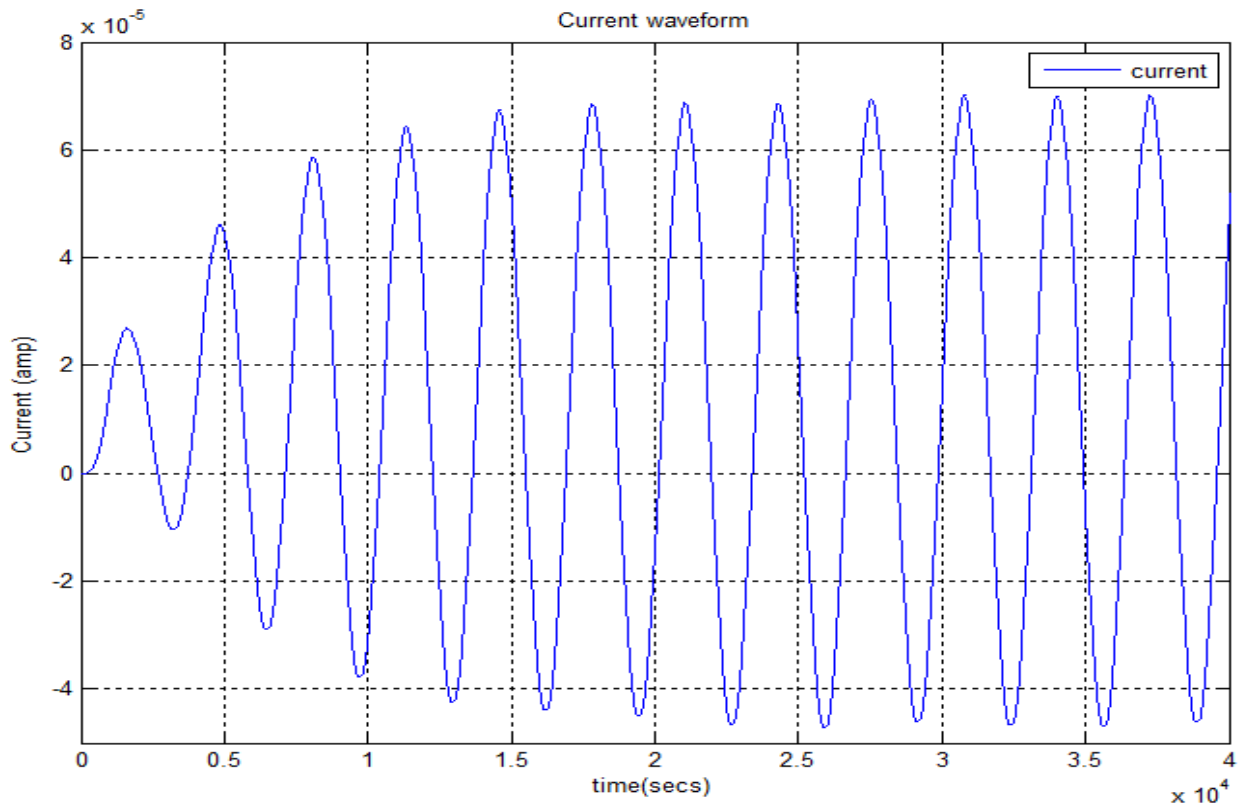

Fig.20(a). Voltage waveforms generated by the inverter

Fig.20(b). Current waveforms generated by the inverter
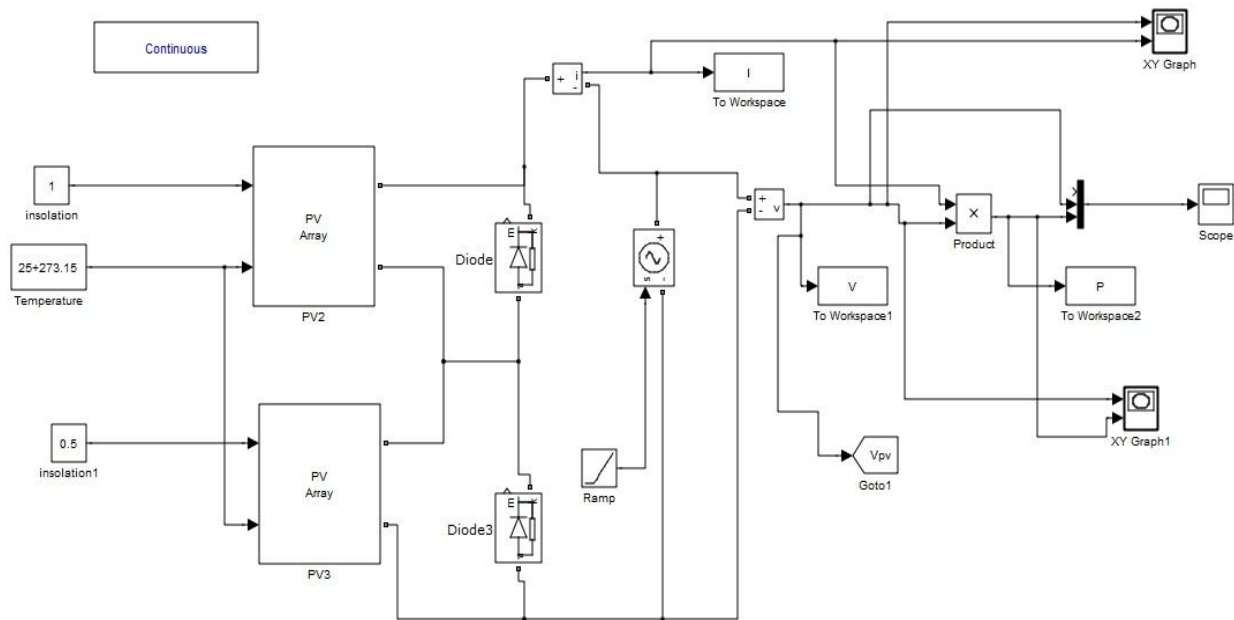
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6.6 PV Model in case of Partial Shading

Fig.21. Modelling partial shading modules

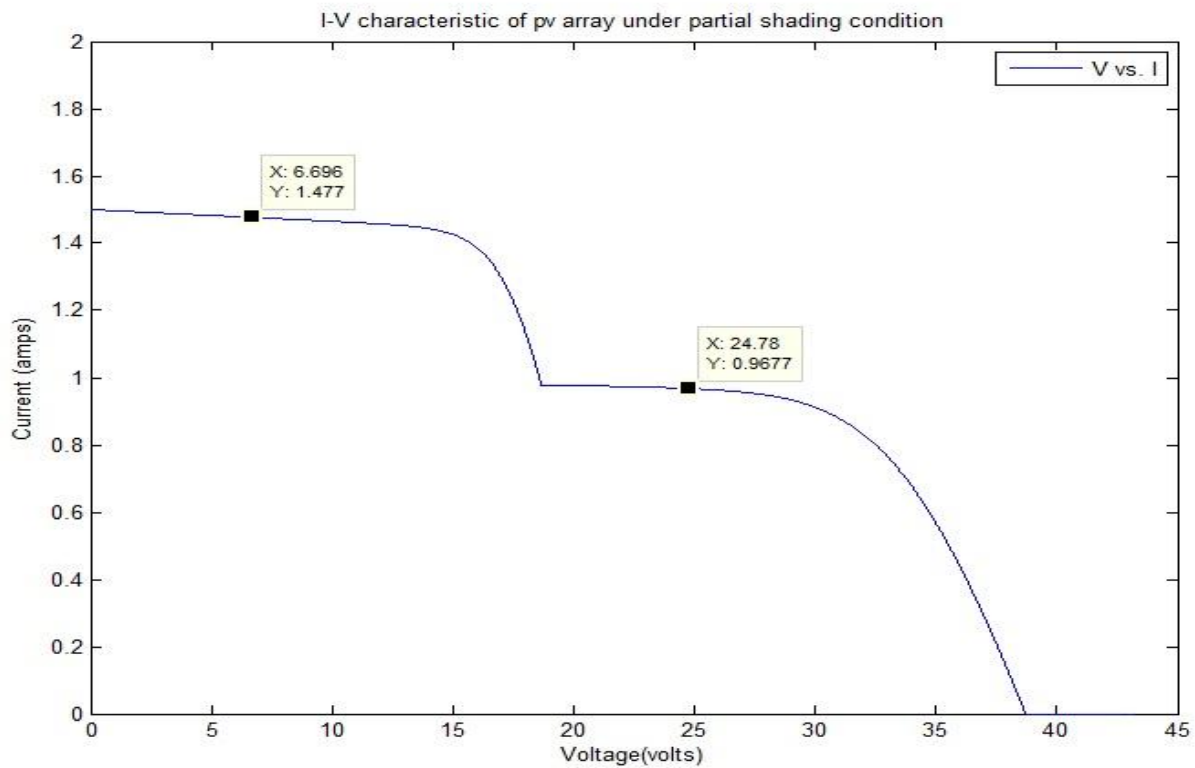## 6.6.1 I-V Characteristics in case of Partial Shaded Modules

Fig.21(a).I-V Characteristic of solar array under partial shading condition

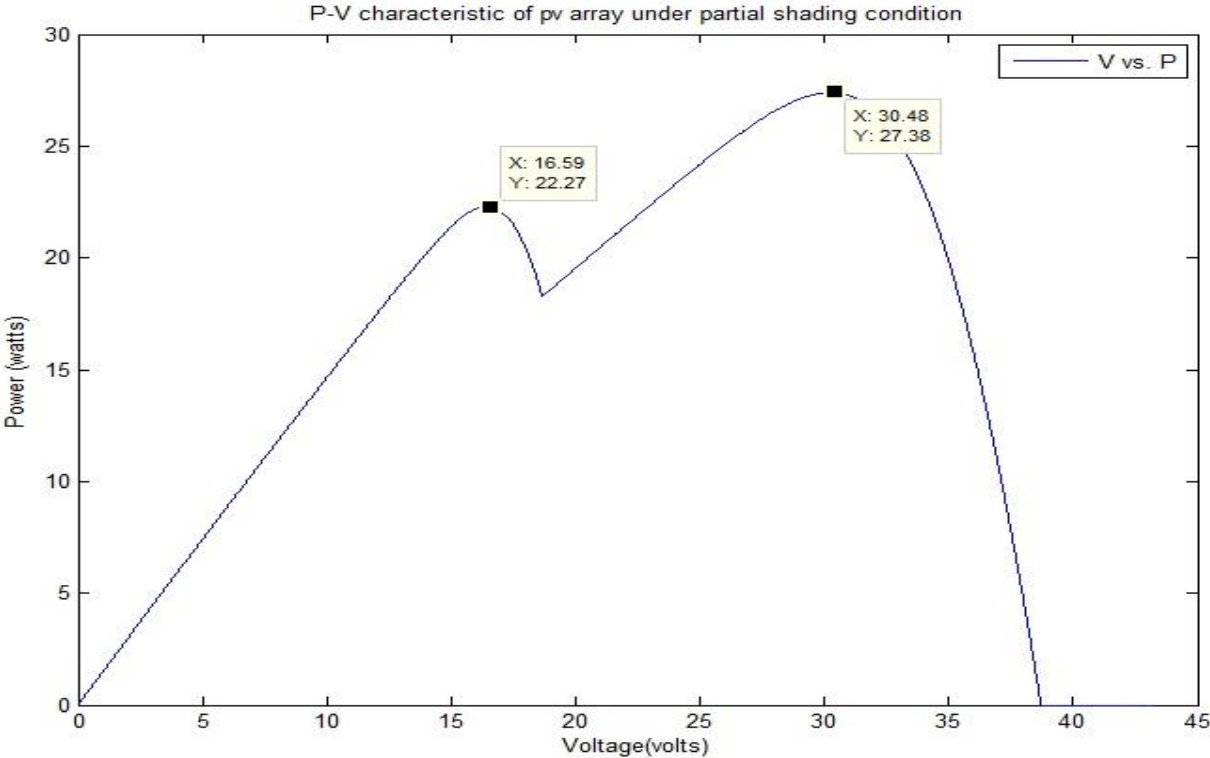## 6.6.2 P-V Characteristics in case of Partial Shaded Modules

Fig.21(b). P-V Characteristic of solar array under partial shading condition

CONCLUSIONS

In this project, a mathematical modeling and design of a photovoltaic energy system is presented. As solar array is used as a source of power, it is necessary to use a maximum power point tracker to ensure minimal energy loss. The maximum power point tracker is implemented to track the maximum power point in our boost converter design. The core idea of the project is to use to track the maximum power and to condition it for single phase ac loads. Moreover, the circuit structure is simpler and much cheaper compared to other control mechanisms where large number of components is needed.

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