STUDY OF MPPT TECHNIQUE IN PHOTOVOLTAIC SYSTEM

A Project Report

submitted by

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THESIS CERTIFICATE

This is to certify that the thesis titled **STUDY OF MPPT TECHNIQUE IN PHOTOVOLTAIC SYSTEM** , submitted by **Ravi Kumar**, to the Indian Institute of Technology, Madras, for the award of the degree of **Master of Technology**, is a bona fide record of the research work done by him under our supervision.

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ABSTRACT

KEYWORDS: photovoltaic;MPPT

Solar energy, radiant light and heat from the sun, has been reined by humans since ancient times using a range of ever-evolving technologies. Solar radiant energy accounts for most of the usable renewable energy on earth. Photovoltaic (PV) Power Generation is a method of generating electrical power by converting solar radiation into direct current using semiconductors that exhibit the photovoltaic effect. In this report, the PV array is modeled and its voltage-current characteristics and power-voltage characteristics are simulated . The main encumbrance for the reach of Photovoltaic systems is their low efficiency and high capital cost. Here we intend to examine algorithms to extract maximum obtainable solar power from a PV module for use in a DC application. The concept of Maximum Power Point Tracking is to be implemented which results in appreciable increase in the efficiency of the Photovoltaic System. Different schemes of MPPT algorithms such as Perturb and Observe, Incremental Conductance are studied and implemented. The 5. Mppt algorithm implemented in this work will identify the suitable duty ratio in which the DC/DC converter should be operated to obtain maximum power output.

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ABBREVIATIONS

IITM	Indian Institute of Technology, Madras
MPPT	Maximum Power Point Tracking
PV	Photo Voltaic
P and O	Perturb and Observe

CHAPTER 1

INTRODUCTION

1.1 Solar energy

It's certainly clear that fossil fuels are mangling the climate and that the status quo is unsustainable. There is now a broad scientific consensus that the world needs to reduce greenhouse gas emissions more than 25 percent by 2020 – and more than 80 percent by 2050. The idea of harnessing the solar power has been around for ages. The basic process is simple. Solar collectors concentrate the sunlight that falls on them and convert it to energy. Solar power is a feasible way to supplement power in cities. In rural areas, where the cost of running power lines increases, solar power, a clean renewable resource with zero emission, has tremendous potential which can be harnessed using a variety of devices. With recent developments, solar energy systems are easily available for industrial and domestic use with the added advantage of minimum maintenance. Solar energy could be made financially viable with government tax incentives and rebates. An exclusive solar generation system of capacity 250KWh per month would cost around Rs. 20 lakhs, with present pricing and taxes. Most of the developed countries are switching over to solar energy as one of the prime renewable energy source.

1.2 The need for renewable energy

Renewable energy is the energy which comes from natural resources such as sunlight, wind, rain, tides and geothermal heat. These resources are renewable and can be naturally replenished. Therefore, for all practical purposes, these resources can be considered to be inexhaustible, unlike dwindling conventional fossil fuels. The global energy crunch has provided a renewed impetus to the growth and development of Clean and Renewable Energy sources. Clean Development Mechanisms (CDMs) are being adopted by organizations all across the globe. Apart from the rapidly decreasing reserves of fossil fuels in the world, another major factor working against fossil fuels is the pollution associated with their combustion. Contrastingly, renewable energy sources are known to be much cleaner and produce energy without the harmful effects of pollution unlike their conventional counterparts

1.3 Historical development

Photovoltaic technology in reality goes back over 160 years. The basic science was first came upon in 1839 but the pace of advancement really hastened in two major drives in the 20th century. Bell Laboratories, discovered silicon had photoelectric attributes and quickly developed silicon bases solar cells, achieving 6 percent efficiency and former satellites were the elemental use for these first solar cells. To spur acceptance, Germany and then Japan initiated appreciable subsidy programs and now those markets exist largely without grants. In 2007, California leads the US with a similar 10-year program.[3]

1.4 Applications

Solar technologies are broadly qualified as either passive or active depending on the way they catch, change over and distribute sunlight. Active solar proficiencies use photovoltaic arrays, pumps, and fans to convert sunlight into executable outputs. Passive solar techniques include selecting materials with favorable thermal attributes, and citing the position of a building to the Sun. The standalone PV Systems have been used for solar street lighting, home lighting system, SPV water pumping system. A hybrid system installed with a backup system of diesel generator can be used in remote military installations, health centres and tourist bungalows. In grid connected system the major part of the load during the day is supplied by the PV array and then from the grid when the sunlight is not sufficient.

1.5 Different sources of renewable energy

1.5.1 Wind Power

Wind turbines can be used to harness the energy available in airflows. Current day turbines range from around 600 kW to 5 MW of rated power. Since the power output is a function of the cube of the wind speed, it increases rapidly with an increase in available wind velocity. Recent advancements have led to aerofoil wind turbines, which are more efficient due to a better aerodynamic structure.

1.5.2 Hydro Power

Hydropower installations up to 10MW are considered as small hydropower and counted as renewable energy sources. These involve converting the potential energy of water stored in dams into usable electrical energy through the use of water turbines. Run-of-the-river hydroelectricity aims to utilize the kinetic energy of water without the need of building reservoirs or dams.

1.5.3 Biomass

Biomass works as a natural battery to store the sun's energy and yield it on requirement. Biomass energy is derived from five distinct energy sources; garbage, wood, landfill gases, waste, and alcohol fuels. This way, biomass works as a natural battery to store the sun's energy and yield it on requirement.

1.5.4 Geothermal

Geothermal energy is the thermal energy which is generated and stored within the layers of the Earth. The gradient thus developed gives rise to a continuous conduction of heat from the core to the surface of the earth. This gradient can be utilized to heat water to produce superheated steam and use it to run steam turbines to generate electricity. The main disadvantage of geothermal energy is that it is usually limited to regions near tectonic plate boundaries, though recent advancements have led to the propagation of this technology

1.5.5 Solar

The tapping of solar energy owes its origins to the British astronomer John Herschel who famously used a solar thermal collector box to cook food during an expedition to Africa. Solar energy can be utilized in two major ways. Firstly, the captured heat can be used as solar thermal energy, with applications in space heating. Another alternative is the conversion of incident solar radiation to electrical energy, which is the most usable form of energy. This can be achieved with the help of solar photovoltaic cells or with concentrating solar power plants. As the Photovoltaic module exhibits non-linear V-I Characteristics, which are dependent on solar Insolation and environment factors, the development of an accurate power electronic circuit oriented model is essential to simulate and design the photovoltaic integrated system. In this report, the design of PV system using simple circuit model with detailed circuit modelling of PV module using MATLAB/Simulink and the physical equations governing the PV module is presented.

1.6 Literature Review

A maximum power point tracking algorithm is absolutely necessary to increase the efficiency of the solar panel as it has been found that only 15-20 percent of energy incident is converted into electrical energy. Among all the MPPT methods, Perturb & Observe and Incremental Conductance are most commonly used because of their simple implementation and lesser time to track the maximum power point. Under suddenly changing weather conditions (irradiation level) as MPP changes continuously, P&O takes it as a change in MPP due to perturbation rather than that of irradiation and sometimes ends up in calculating wrong MPP. However this problem is eliminated in Incremental Conductance method as the algorithm takes two samples of voltage and current to compute MPP. However, Instead of being more reliable, the complexity of the algorithm is very high compared to the former one and hence the cost of execution increases.

CHAPTER 2

CHARACTERISTICS OF SOLAR ARRAY

A photovoltaic based generation system uses one or more solar modules or panels to convert solar energy to electrical energy. Basically,2. Its componets include solar panels, power electronic converters, and necessary hardware to provide reliable power to the loads.

2.1 Photovoltaic cell

Solar cells are the building blocks of a PV array. These are made up of semiconductor materials like silicon etc. A thin semiconductor wafer is specially treated to form an electric field, positive on a side and negative on the other. Electrons are knocked loose from the atoms of the semiconductor material when light strikes upon them. If an electrical circuit is made attaching a conductor to the both sides of the semiconductor, electrons flow will start causing an electric current. It can be circular or square in construction.

2.2 Photovoltaic module

The voltage generated by a single solar cell is very low, around 0.5V. So, a number of solar cells are connected in both series and parallel connections to achieve the desired output. In case of partial shading, diodes may be needed to avoid reverse current in the array. Good ventilation behind the solar panels are provided to avoid the possibility of less efficiency at high temperatures

2.3 Photovoltaic array

Again the power produced by a single module is not sufficient to meet the power demands for most of the practical purposes. PV arrays can use inverters to convert the dc output into ac and use it for motors, lighting and other loads. The modules are connected in series for more voltage rating and then in parallel to meet the current specifications. Fig. 2.1 shows a solar cell and different ways of arranging it to obtain solar modules and arrays.

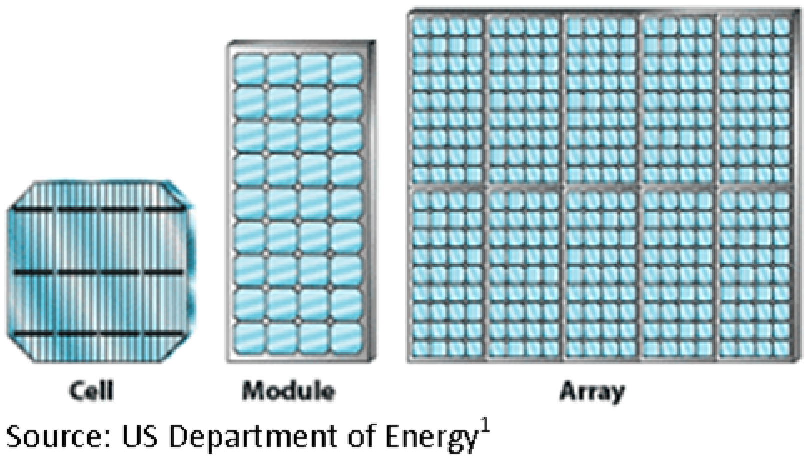


Figure 2.1: Different Solar Modules

CHAPTER 3

PV MODELLING

Typically a solar cell can be modelled by a current source and an inverted diode connected in parallel to it. It has its own series and parallel resistance. Series resistance is due to hindrance in the path of flow of electrons from n to p junction and parallel resistance is due to the leakage current. When irradiance hits the surface of solar PV cell, an electrical field is generated inside the cell. As seen in Fig.3.1 this process separates positive and negative charge carriers in an absorbing material (joining p-type and n-type). In the presence of an electric field, these charges can produce a current that can be used in an external circuit. This generated current depends on the intensity of the incident radiation. The higher the level of light intensity, the more electrons can be unleashed from the surface, the more current is generated.

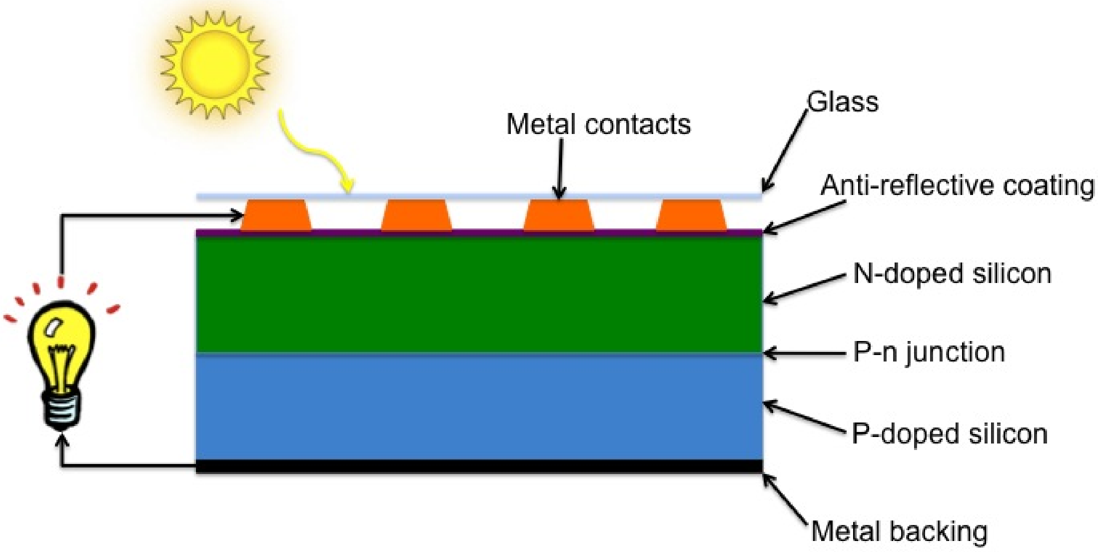


Figure 3.1: cell diagram

The most important component that affects the accuracy of the simulation is the PV cell model. Modelling of PV cell involves the estimation of the I-V and P-V characteristics curves to emulate the real cell under various environmental conditions. An ideal

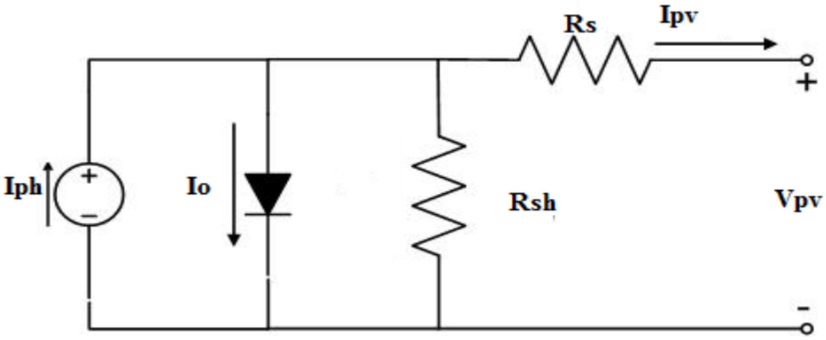


Figure 3.2: solar cell circuit diagram

solar cell is modelled by a current source in parallel with a diode. However no solar cell is ideal and thereby shunt and series resistances are added to the model as shown in the Fig 3.2

The current source I_{ph} represents the cell photo current, R_{sh} and R_s are used to represent the intrinsic series and shunt resistance of the cell respectively. Usually the value of R_{sh} is very large and that of R_s is very small, hence they may be neglected to simplify the analysis. The PV mathematical model used to simplify our PV array is represented by the equations 3.1 - 3.4 .[2]

Module Photo Current

$$I_{ph} = \frac{\lambda}{1000}[I_{scr} + K_i(T - 298)] \tag{3.1}$$

Module Reverse Saturation Current

$$I_{rs} = \frac{I_{scr}}{\exp(\frac{qV_{oc}}{NskAt}) - 1} \tag{3.2}$$

Module Saturation Current

$$I_s = I_{rs}\left[\frac{T}{Tr}\right]^3 \exp\left(q * \frac{Ego}{Bk}\right)\left(\frac{1}{Tr} - \frac{1}{T}\right) \tag{3.3}$$

The Current Output of PV module is

$$I_{pv} = N_p \times I_{ph} - N_p \times I_s \left[\exp\left(q * \frac{V_{pv} + I_{pv} R_s}{NskAt} \right) - 1 \right] \tag{3.4}$$

Where

$V_{pv}$is output voltage of a PV module (V)

$I_{pv}$is output current of a PV module (A)

$T_r$is the reference temperature = 298 K

T is the module operating temperature in Kelvin

$I_{ph}$is the light generated current in a PV module (A)

$I_s$is the PV module saturation current (A)

A = B is an ideality factor = 1.6

k is Boltzmann constant = 1.3805 X $10^{-23} J/K$

q is Electron charge = 1.6 X 10^{-19} C

R_s is the series resistance of a PV module

I_{scr} is the PV module short-circuit current at 25 oC and $1000W/m^2$= 2.55A

K_i is the short-circuit current temperature co-efficient at $I_{scr} = 0.0017A/°C$

λ is the PV module illumination $(W/m^2) = 1000W/m$

E_{go} is the band gap for silicon = 1.1 Ev

N_s is the number of cells connected in series

N_p is the number of cells connected in parallel

Table 3.1: Electrical Characteristics Data of Green SolarIndia 37W (AT-37) PV Module

Parameter	Value	Units
Maximum power - P_{max}	36.917	W
Voltage at Pmax -V_{mp}	17.905	V
Current at Pmax -I_{mp}	2.062	A
Short-circuit current - I_{sc}	2.226	A
Open-circuit voltage - V_{oc}	21.425	V
Total number of cells in series N_s	36	
Total number of cells in parallel N_p	1	

3.1 MATLAB simulink model of photovoltaic cell

3.1.1 Temperature Conversion ($^\circ$ C to $^\circ$ F)

Trk=273+25(ref.temp.)

Tak=273+Top(operating Temp.)

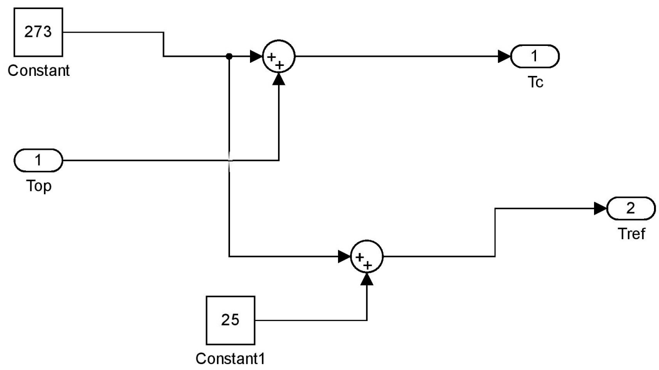


Figure 3.3: Block for temp conversion

3.1.2 Module Photo Current

$$I_{ph} = \frac{\lambda}{1000}[I_{scr} + K_i(T - 298)]$$

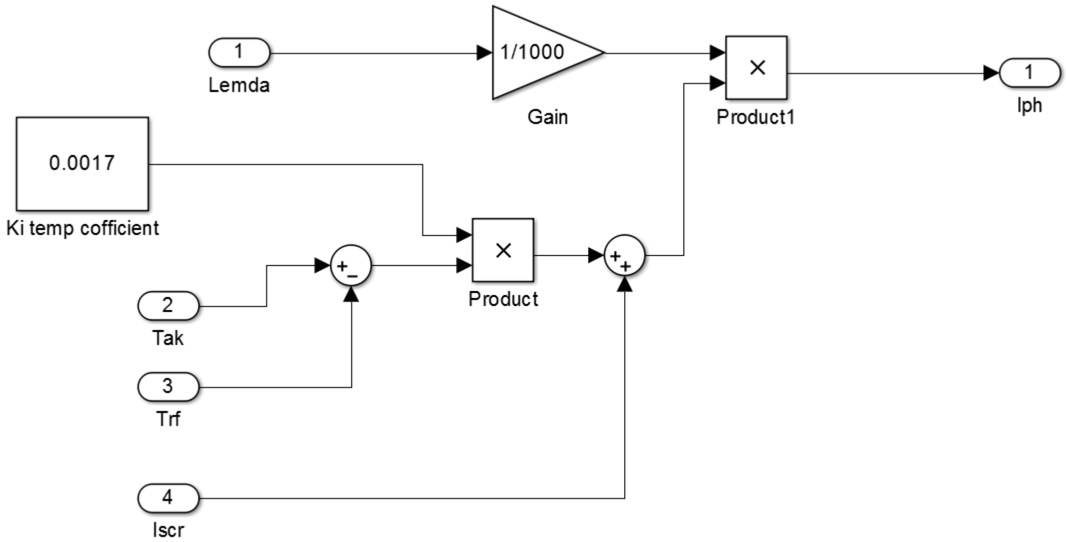


Figure 3.4: Block For Module Photo Current

3.1.3 Module Reverse Saturation Current

$$I_{rs} = \frac{I_{scr}}{\exp(\frac{qV_{oc}}{NskAt}) - 1}$$

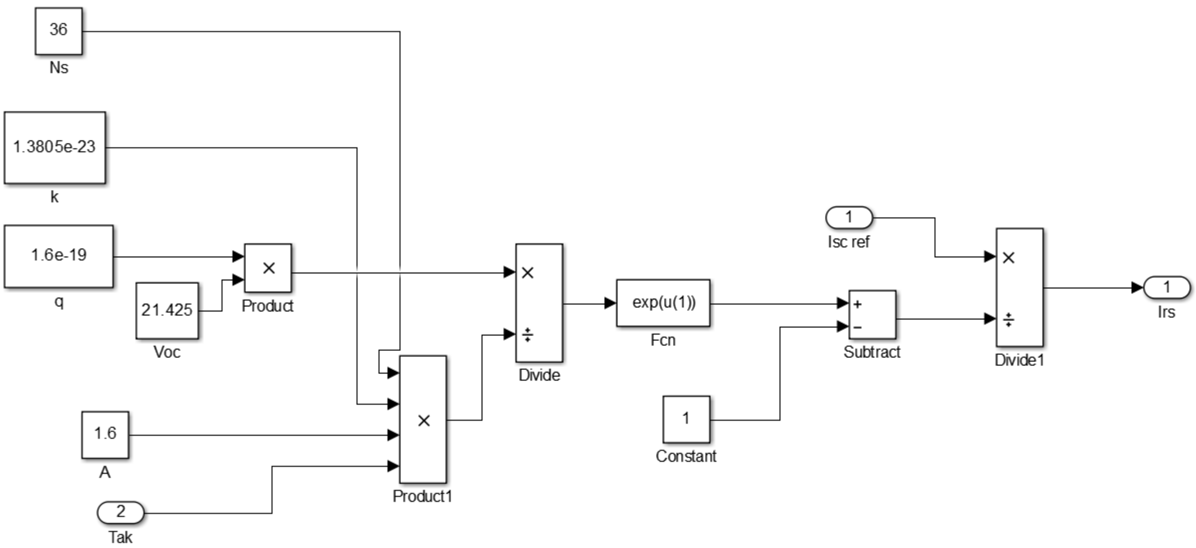
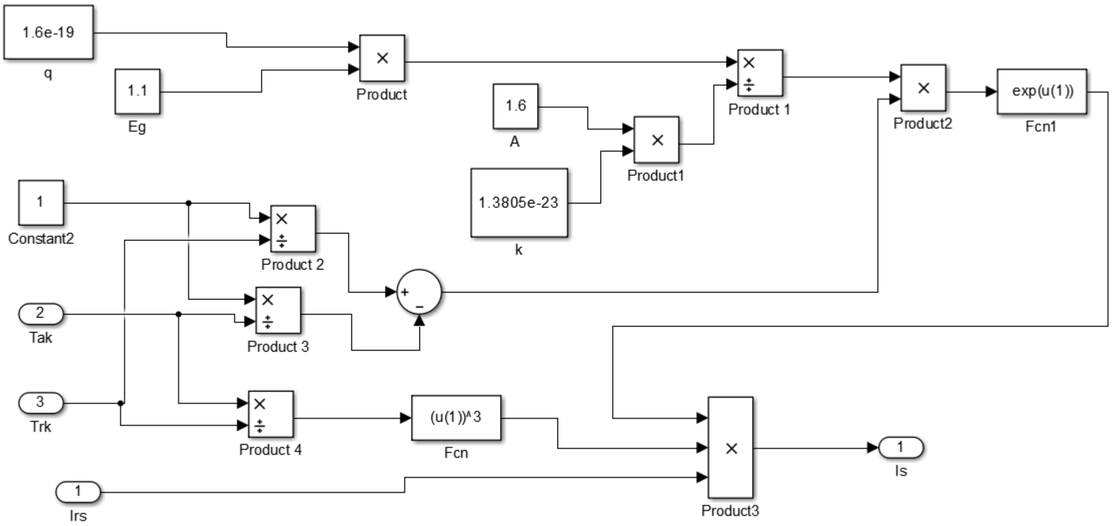


Figure 3.5: Block For Module Reverse Saturation Current

3.1.4 Module Saturation Current

$$I_s = I_{rs}\left[\frac{T}{Tr}\right]^3 \exp\left(q * \frac{Ego}{Bk}\right)\left(\frac{1}{Tr} - \frac{1}{T}\right)$$



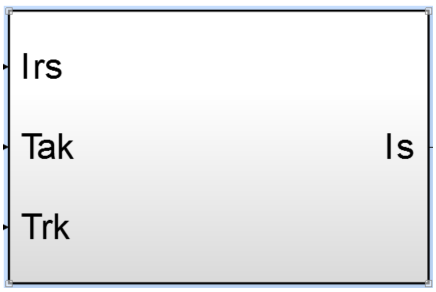


Figure 3.6: Block For Module Saturation Current

3.1.5 Module output Current

$$I_{pv} = N_p \times I_{ph} - N_p \times I_s \left[\exp\left(q * \frac{V_{pv} + I_{pv} R_s}{NskAt} \right) - 1 \right] \tag{3.5}$$

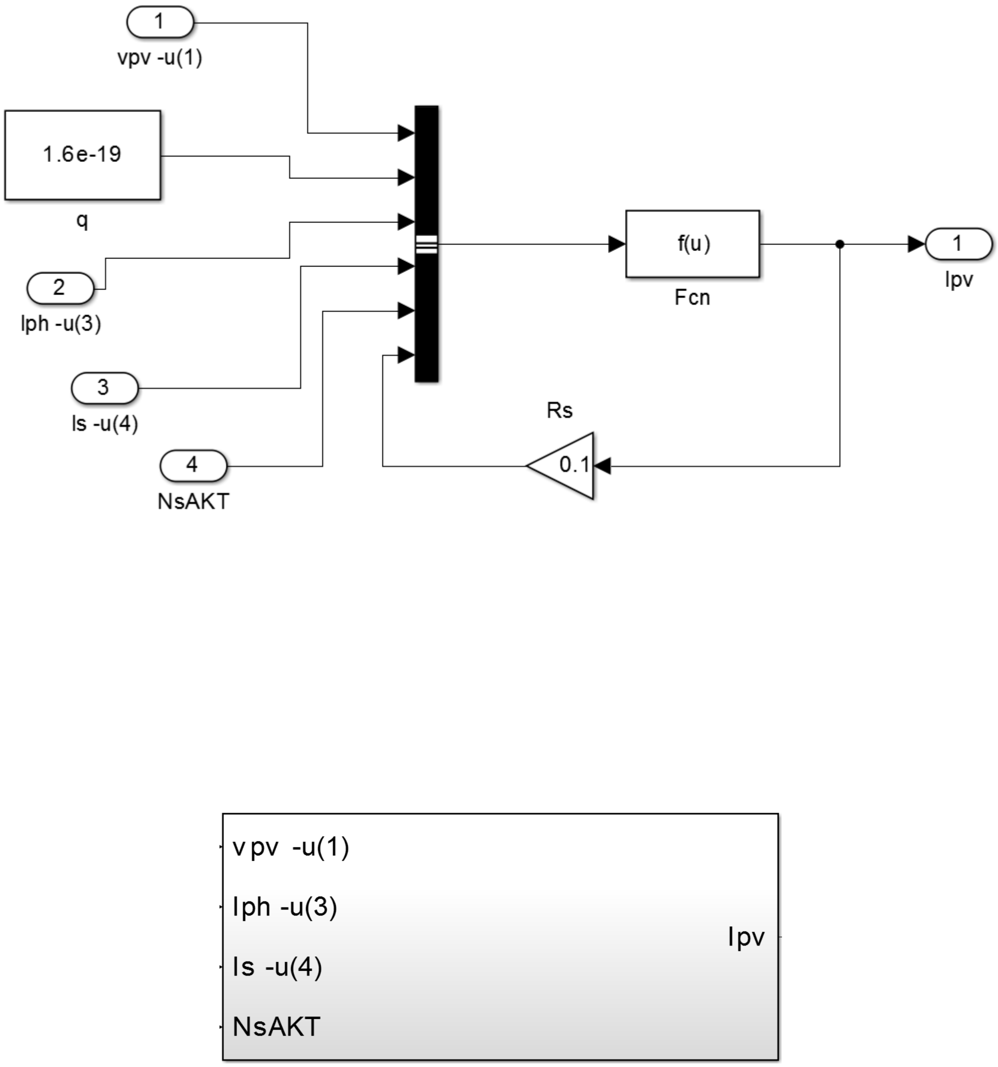


Figure 3.7: Block For Output Current

3.1.6 NsAkT

The NsAkT Will Be Prepared As Show Below

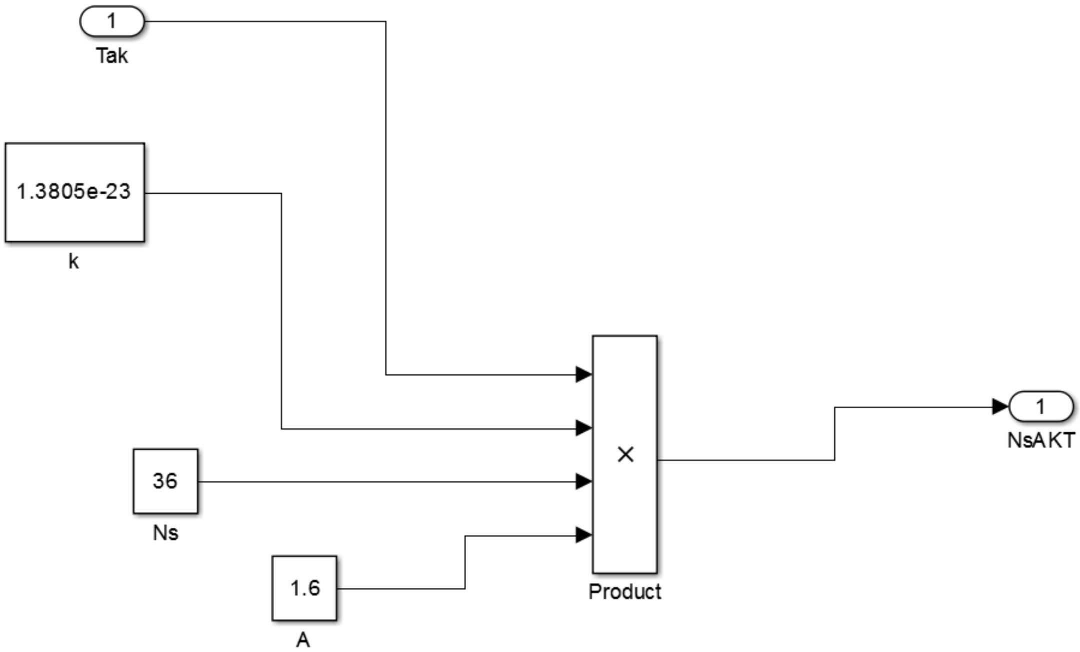


Figure 3.8: NsAkt

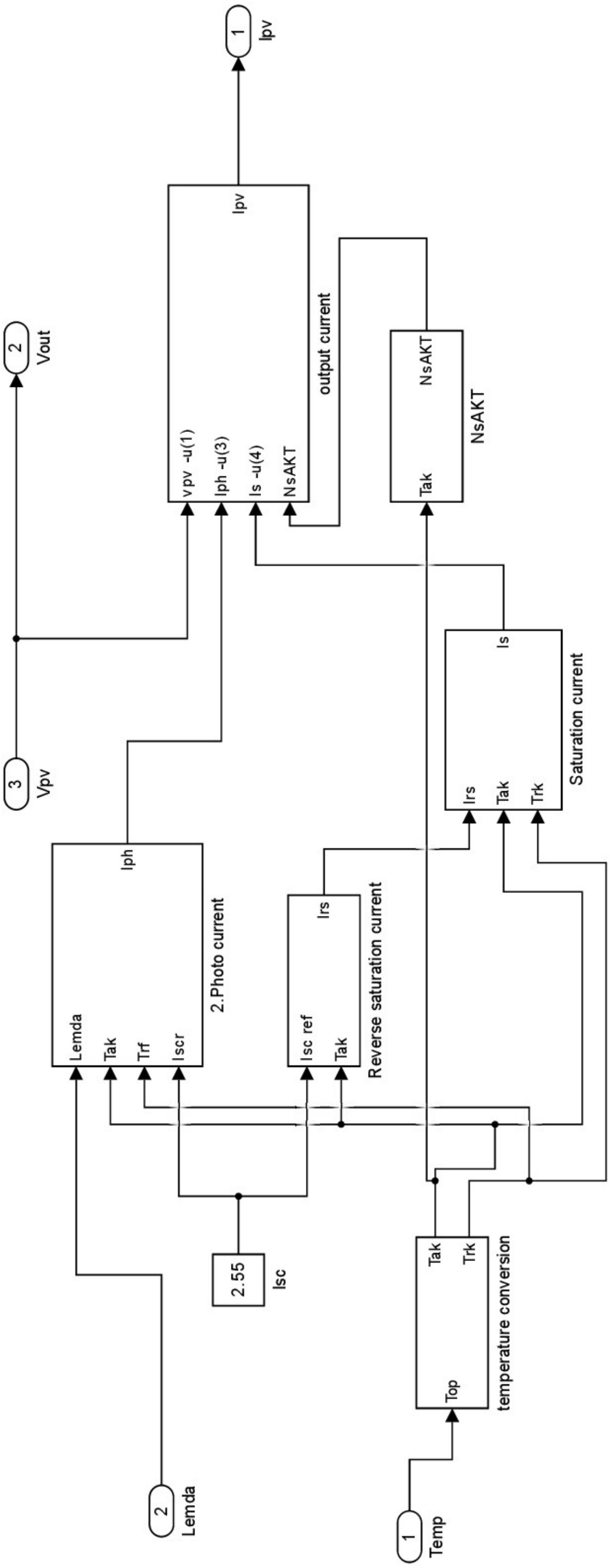


Figure 3.9: complete PV module

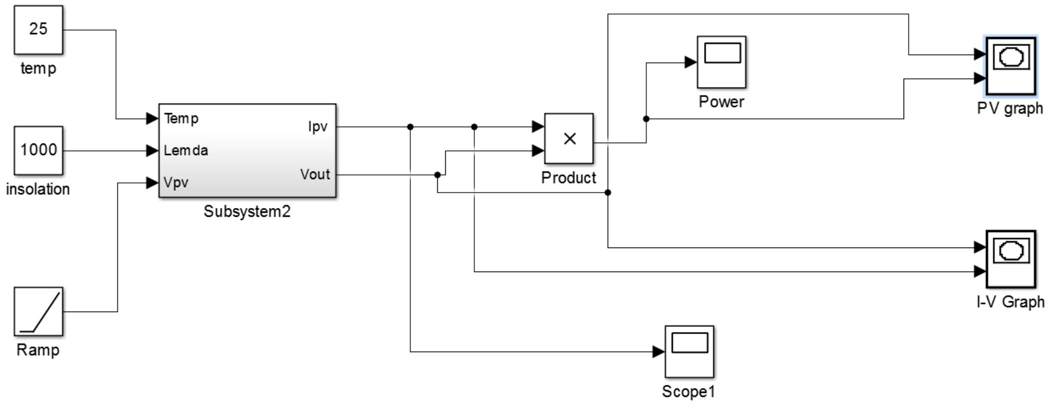


Figure 3.10: circuit model for PV Module

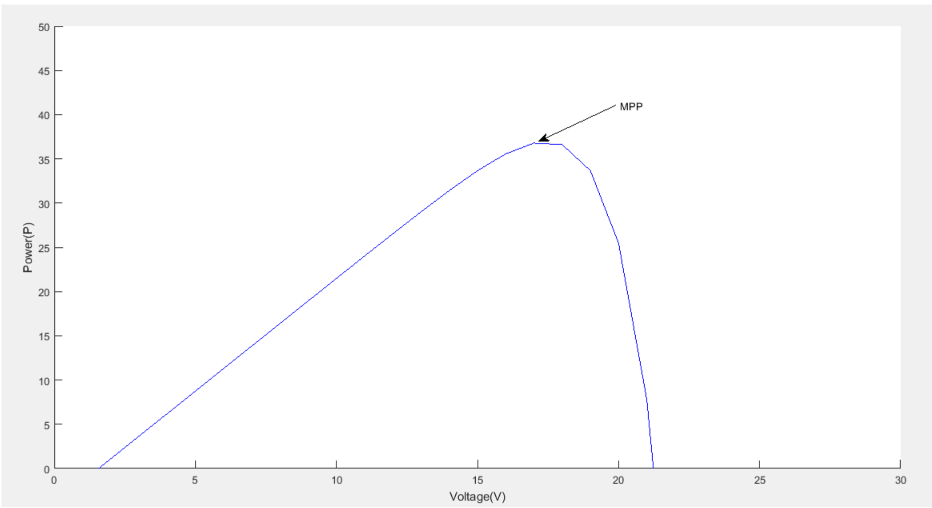


Figure 3.11: PV Curve

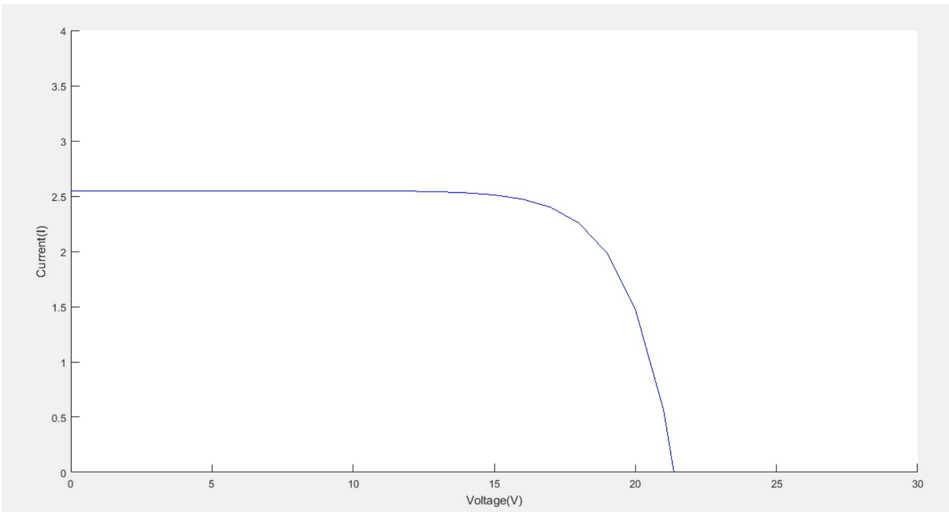


Figure 3.12: IV Curve

3.2 Characteristics of tata solar power panel

In this section,IV and PV characteristics of Tata BP solar panel(ID-141023) are shown. As we can see nature of fig 3.13 and fig 3.14 is similar to nature of fig 3.11 and fig 3.12.

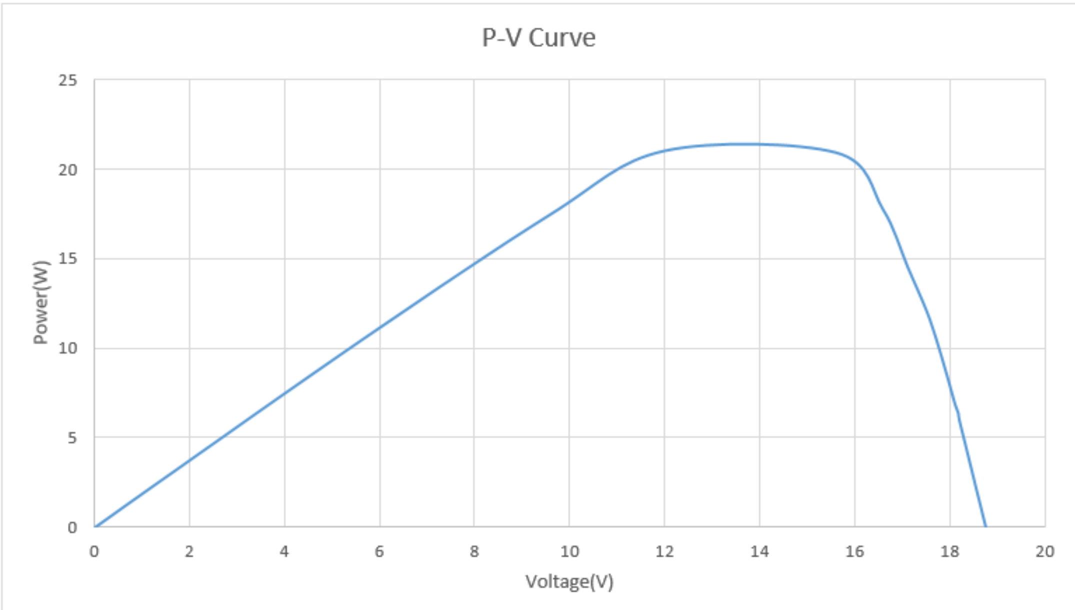


Figure 3.13: PV Curve

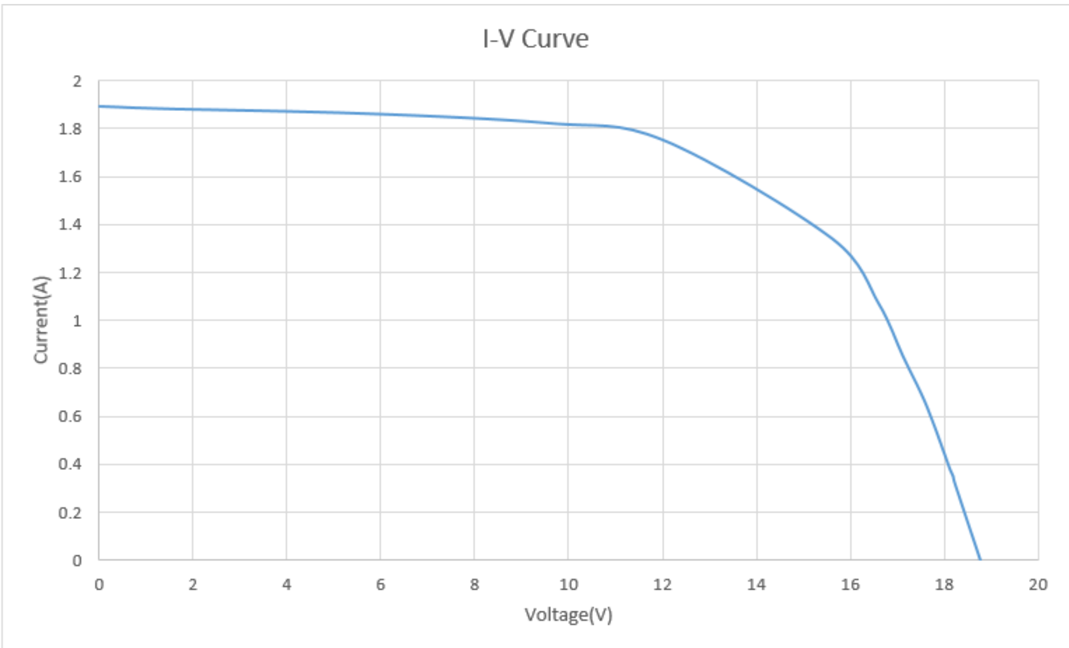


Figure 3.14: IV Curve

CHAPTER 4

BOOST CONVERTER

4.1 Theory

The maximum power point tracking is essentially a load matching problem. A DC to DC converter is required for changing the input resistance of the panel to match the load resistance by varying the duty cycle. There are different topologies for the DC to DC regulators: boost converter, buck converter, buckboost converter. Since our project work deals with the boost converter, further discussions will be centered on this one.

Boost converter steps up the voltage. That is, Vo > Vs. The circuit diagram is shown below:

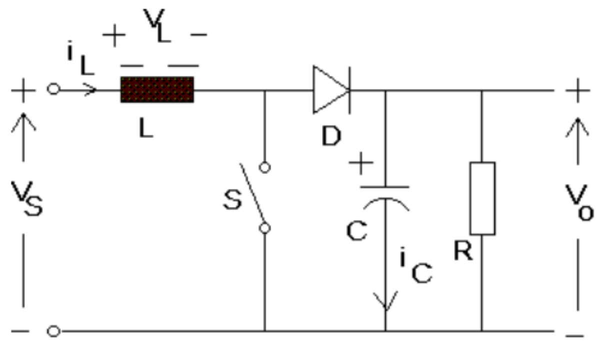


Figure 4.1: Boost Converter

4.2 Operation of boost converter

4.2.1 Mode 1

When the switch is closed the inductor gets charged through the battery and stores the energy. In this mode inductor current rises (exponentially) but for simplicity we assume that the charging and the discharging of the inductor are linear. The diode blocks the current flowing and so the load current remains constant which is being supplied due to the discharging of the capacitor.[5]

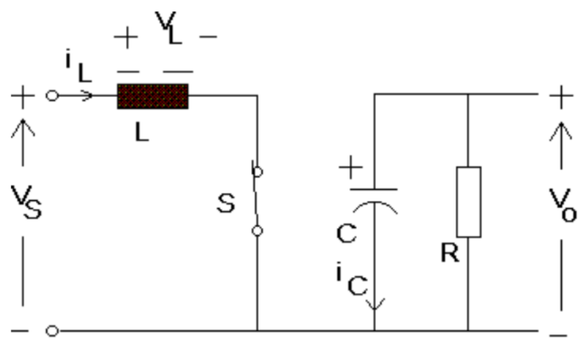


Figure 4.2: Mode 1

4.2.2 Mode 2

In mode 2 the switch is OFF and diode is ON. The energy stored in the inductor gets discharged which charge the capacitor and supply power to load. The load current remains constant throughout the operation.[5]

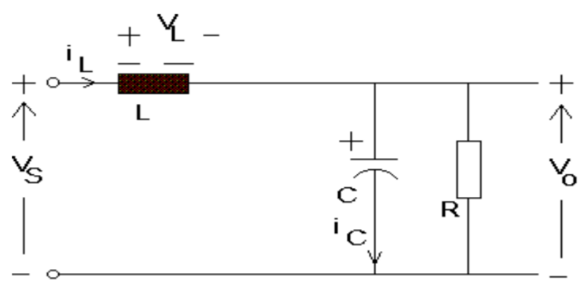


Figure 4.3: Mode 2

CHAPTER 5

MPPT ALGORITHM

5.1 Perturb and observe

Perturb and Observe (P & O) is the simplest method for MPPT implementation. Both P & O and incremental conductance algorithms are based on the "hill-climbing" principle, which consists of moving the operation point of the PV array in the direction of maximum power. It utilizes only one sensor, that is the voltage sensor, to sense the PV array voltage and so the cost of implementation is less and hence easy to implement. 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. If there is an increment in the power, the perturbation should be kept in the same direction and if the power decreases, then the next perturbation should be in the opposite direction. Based on these facts, the algorithm is implemented. The process is repeated until the MPP is reached. The time complexity of this algorithm is very less but on reaching very close to the MPP the algorithm does not stop at the MPP and keeps on perturbing on both the directions. When this happens, the algorithm has reached very close to the MPP and an appropriate error limit can be set or a wait function can be used which ends up increasing the time complexity of the algorithm. However, the method does not take account of the rapid change of irradiation level (due to which MPP changes) and considers it as a change in MPP due to perturbation and ends up calculating the wrong MPP. To avoid this problem incremental conductance method can be used.Basic details are provided in [1]. Flowchart for the above algorithm is shown in fig 5.1.

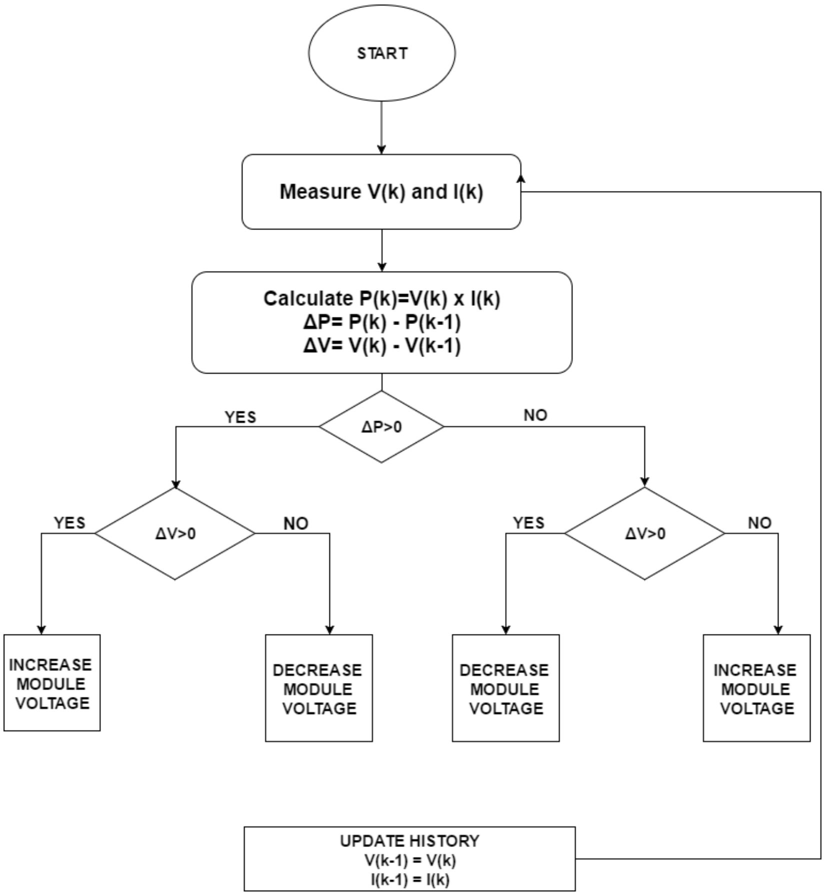


Figure 5.1: Perturb and Observe MPPT algorithm

5.2 Details of Perturb and observe

The Perturb & Observe algorithm states that when the operating voltage of the PV panel is perturbed by a small increment, if the resulting change in power P is positive, then we are going in the direction of MPP and we keep on perturbing in the same direction. If P is negative, we are going away from the direction of MPP and the sign of perturbation supplied has to be changed. Figure 5.2 shows the plot of module output power versus module voltage for a solar panel at a given irradiation. The point marked as MPP is the Maximum Power Point, the theoretical maximum output obtainable from the PV panel. Consider A and B as two operating points. As shown in the figure 5.2, the point A is on the left hand side of the MPP. Therefore, we can move towards the MPP by providing a positive perturbation to the voltage. On the other hand, point B is on the right hand side of the MPP. When we give a positive perturbation, the value of P becomes negative, thus it is imperative to change the direction of perturbation to achieve MPP.

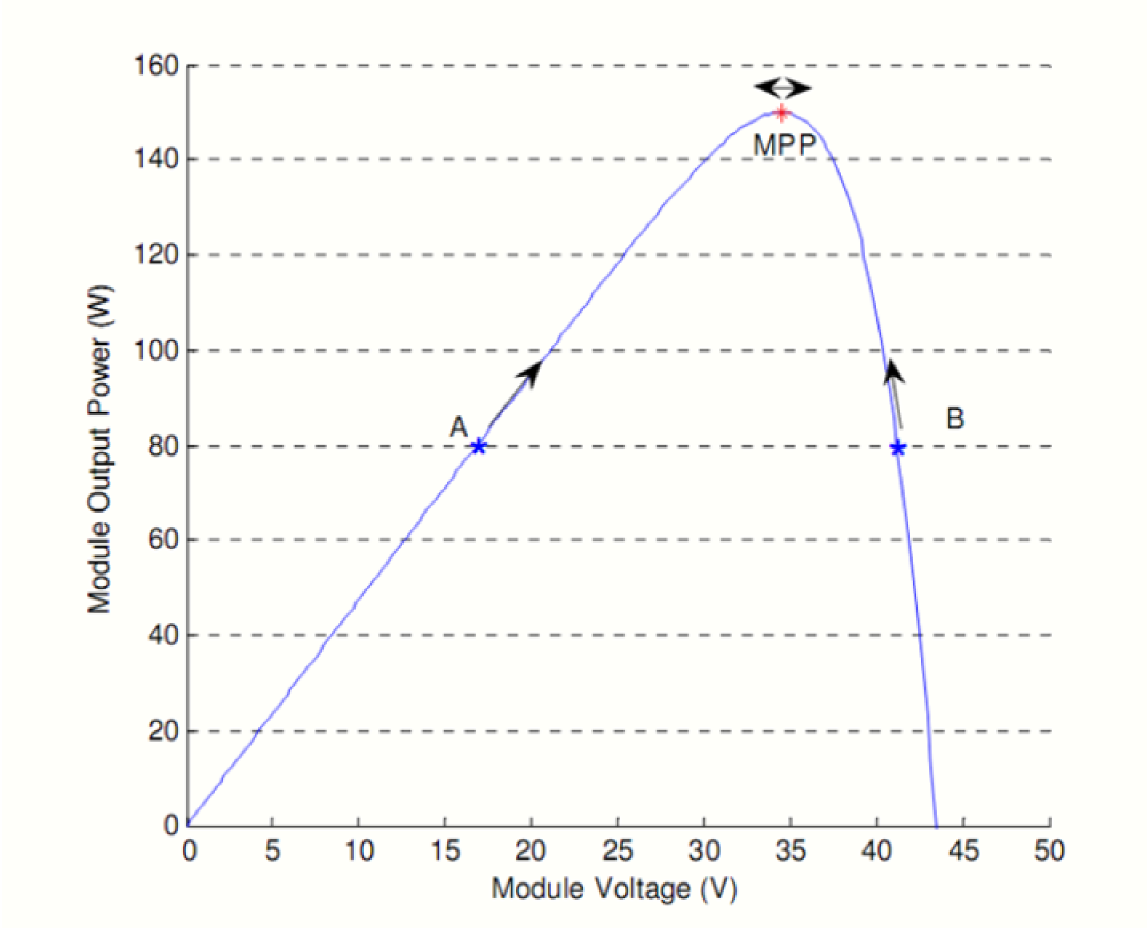


Figure 5.2: A general Solar Panel Characteristics Showing MPP And Operating Points A and B

at MPP

$$\frac{\Delta V}{\Delta P} = 0$$

at point A

$$\frac{\Delta V}{\Delta P} > 0$$

at point B

$$\frac{\Delta V}{\Delta P} < 0$$

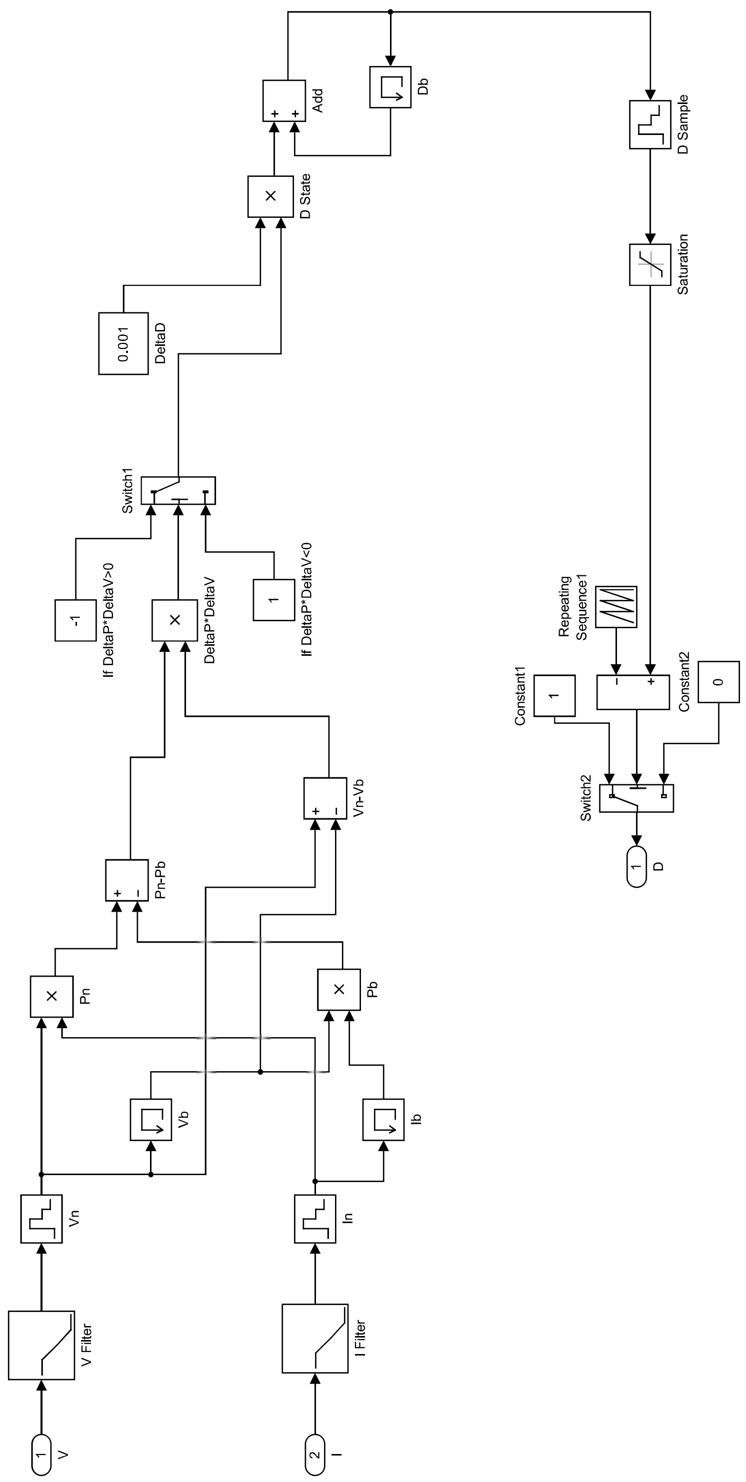


Figure 5.3: perturb and observe simulation diagram

5.3 Effects of irradiance and temperature on PV Array Characteristics

5.3.1 Effects of Irradiance Variation

The term Irradiance is defined as the measure of power density of sunlight received at a location on the earth and is measured in watt per metre square, where as irradiation is the measure of energy density of sunlight .The term Irradiance and Irradiation are related to solar components.Irradiance is to power as insolation is to energy. As the solar insolation keeps on changing throughtout the day similarily I-V and P-V characteristics varies.With the increasing solar irradiance both the open circuit voltage and the short circuit current increases and hence the maximum power point varies.Effects of Irradiance Variation is shown in fig 5.4[4].

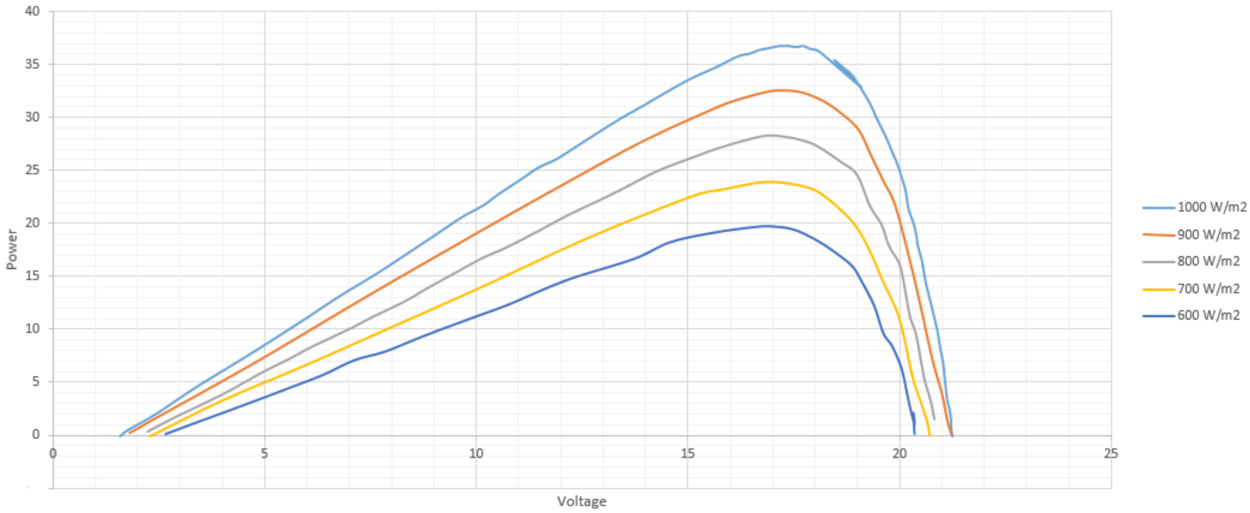


Figure 5.4: Effect on MPP due to insolation

5.3.2 Effects of temperature Variation

Temperature plays another major factor in determining the solar cell efficiency.As the temperature increases the rate of photon generation increases thus reverse saturation current increases rapidly and this reduces the band gap.Hence this leads to marginal changes in current but major changes in voltage.The cell voltage reduces by 2.2Mv per

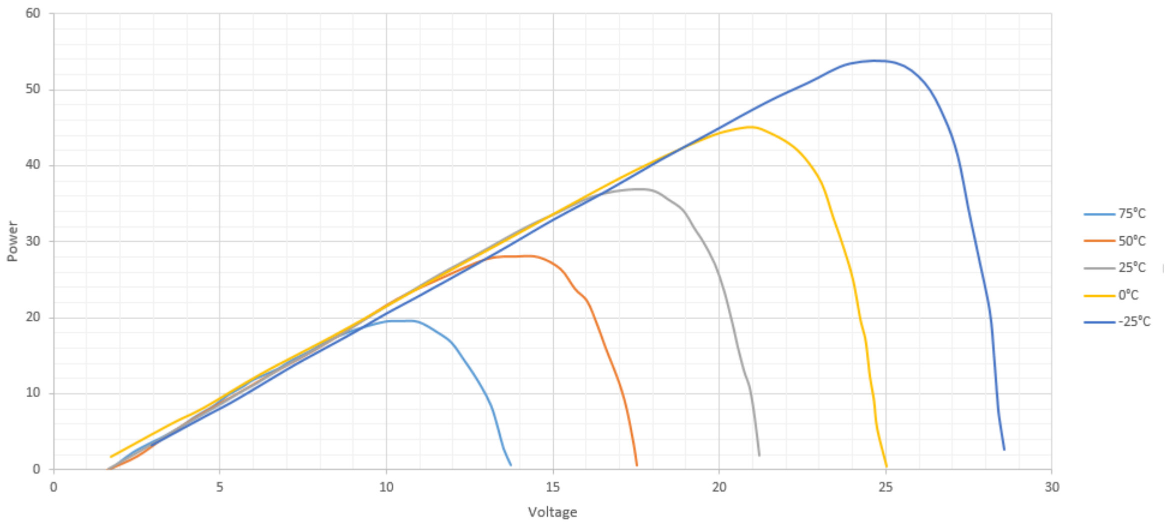


Figure 5.5: Effect on MPP due to temperature

degree rise of temperature.Temperature acts like a negative factor affecting solar cell performance.Therefore solar cells give their full performance on cold and sunny days rather on hot and sunny weather. Now a days Solar panels are made of non-silicon cells as they are temperature insensitive.Thus the temperature remains close to room temperature.Effects of temperature Variation is shown in fig 5.5.[4]

CHAPTER 6

RESULTS AND DISCUSSION

The fig 6.1 shows the basic block diagram of the complete circuit.The fig 6.2 shows circuit diagram. This includes the PV module, boost converter and MPPT control circuit. The modeling and simulation of the whole system has been done in MATLAB-SIMULINK environment. The plots obtained in the different scopes have been shown in fig 6.3 and fig 6.4 .The simulation was first run without MPPT controller.It was seen that when we do not use an MPPT controller, the power obtained at the load side is less than when we use MPPT controller.Perturb and observe algorithm technique is used to increase efficiency of system.The DC/DC converter is widely used in MPPT circuit for the main purpose of matching the load impedance with the panel impedance by changing its operating duty cycle.MPPT technology uses that DC-DC converter for regulating the solar input voltage i.e. MPP and provides impedance matching from source to load for the maximum power transfer to the load.

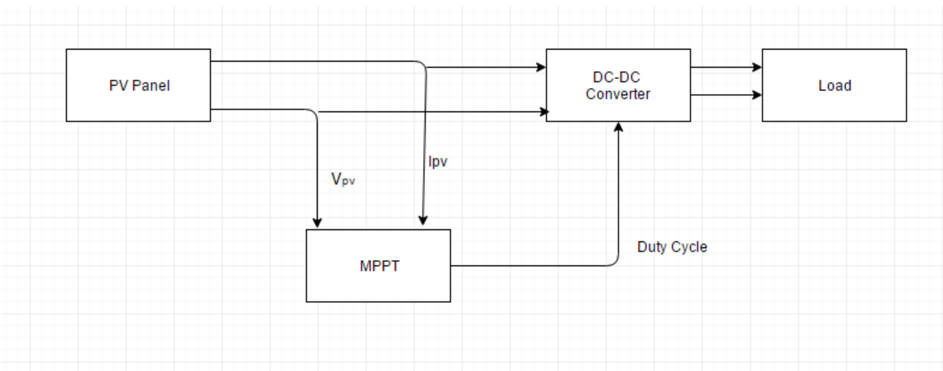


Figure 6.1: Block diagram

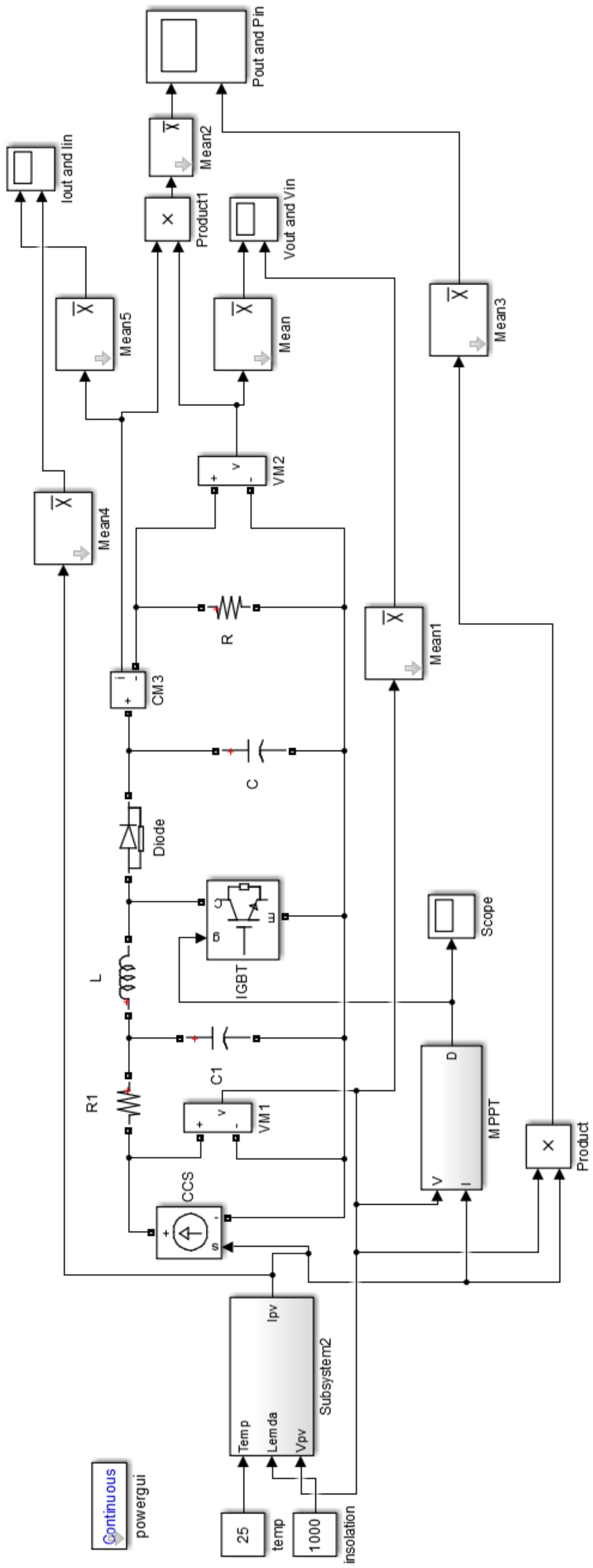


Figure 6.2: circuit diagram

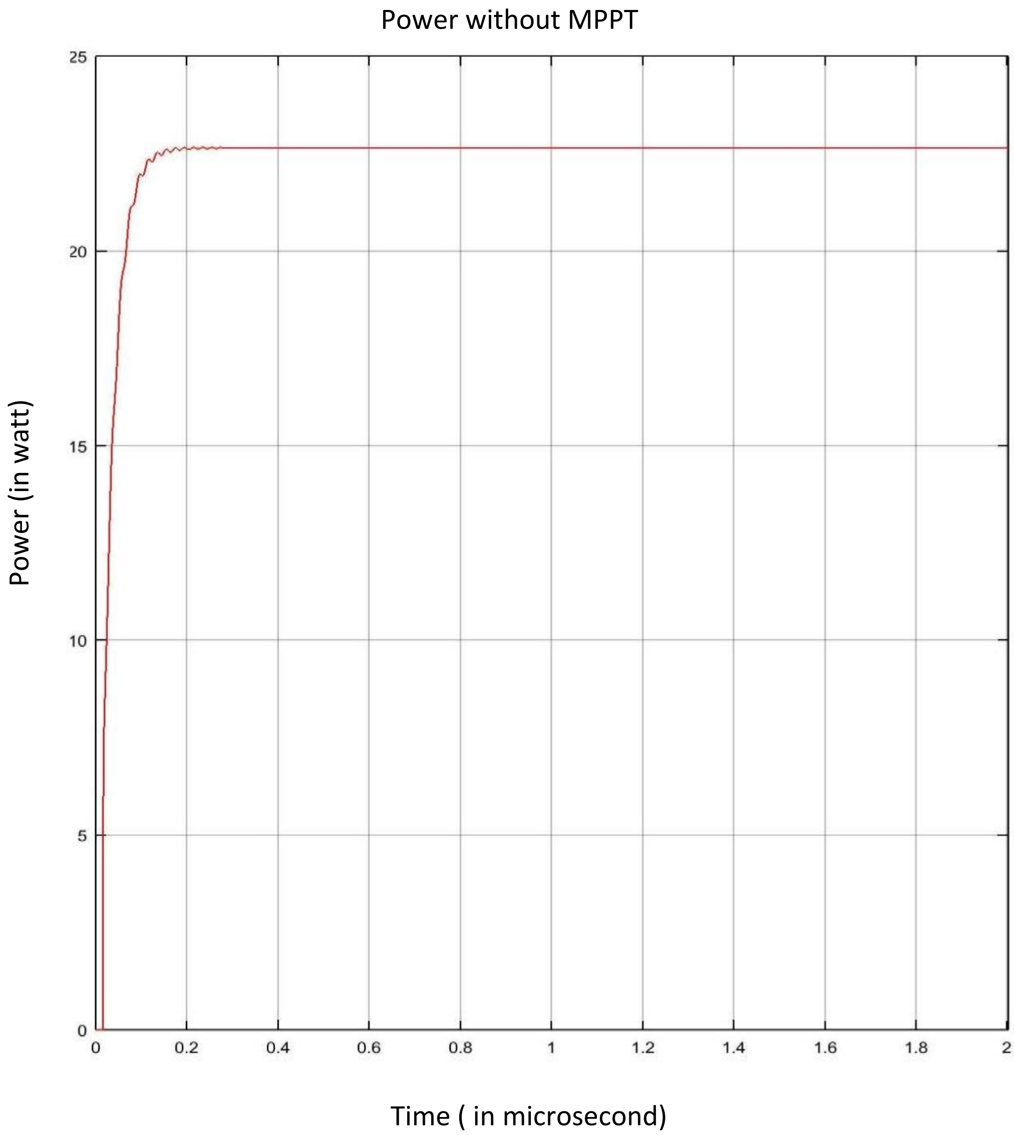


Figure 6.3: output Power without MPPT

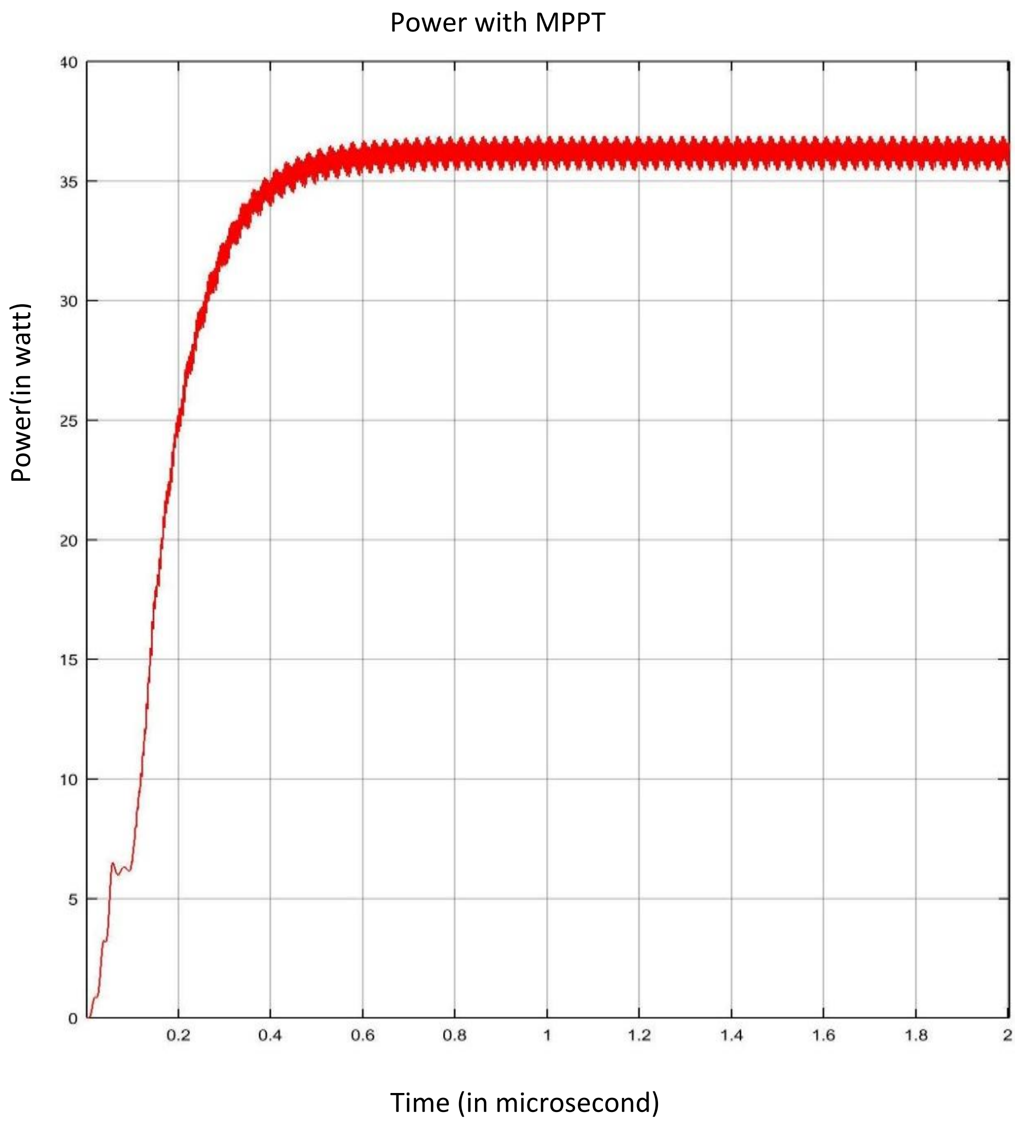


Figure 6.4: output Power with MPPT

CHAPTER 7

SUMMARY AND CONCLUSION

Simulink model of photovoltaic module is designed and P-V,I-V curves are obtained from the simulation.DC-DC Converters are used for load matching and operation of boost converter is discussed.Perturb and observe algorithm is explained.Effect of insolation and temperature on MPP is discussed and PV characteristics are obtained by varying insolation and temperature.we can observe the increase in efficiency after using MPPT controller in fig 6.3 and fig 6.4.

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