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FINAL REPORT

MAXIMUM POWER POINT TRACKING OF PHOTOVOLTAIC SYSTEM

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by

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CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

Ngo Tien Dat

Approved:

Dr. Irraivan Elamvazuthi

ABSTRACT

Renewable energy sources plays an important role in electricity generation. Various renewable energy sources like wind, solar, geothermal, ocean thermal, and biomass can be used for generation of electricity and for meeting our daily energy needs.

Energy from the sun is the best option for electricity generation as it is available everywhere and is free to harness. On an average the sunshine hour in Malaysia is about 9 hours annually also the sun shine shines in Malaysia for a whole 12 months in a year. Electricity from the sun can be generated through the solar photovoltaic modules (SPV). The SPV comes in various power output to meet the load requirement.

Maximization of power from a solar photo voltaic module (SPV) is of special interest as the efficiency of the SPV module is very low. Every photovoltaic (PV) array has an optimum operating point, called the maximum power point, which varies depending on cell temperature, the insolation level and array voltage. A peak power tracker is used for extracting the maximum power from the SPV module. The function of MPPT is need to operate the PV array at its maximum power point. The present work describes the maximum power point tracker (MPPT) for the SPV module connected to a resistive load. The simulation studies are carried out in MATLAB/SIMULINK. The design of the MPPT is proposed utilizing a boost-converter topology. Many algorithms have been proposed, however, two algorithms, the perturb-and-observe (P&O) method, and incremental-conductance (IC) claimed by many in the literature to be inferior to others, continues to be by far the most widely used method in commercial MPPT of PV.

ACKNOWLEDGEMENTS

Firstly, I would like to thank my supervisor, Dr. Irraivan Elamvazuthi for his full of support to the completion of this project. His constant guidance, helpful comments and suggestions have helped me not only to complete but also to enhance the expected results of this project. His kindness, valuable advices, friendly approach and patience will always be appreciated.

My enormous thanks to my family members for their priceless support and continuous encouragement. Special gratitude to my Mother for her continuous and unlimited support that kept me going. There is no words can fulfil her effort.

I would like also to express my thanks for the FYP committee for their guidance and management in making all projects run smoothly. A special gratitude to Dr. Zuhairi Baharudin for his effort on monitoring and checking the reports to match the university's standards.

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TABLE OF CONTENTS

LIST OF FIGURES

CHAPTER 1
INTRODUCTION

The generation of energy in our modern industrialized society is still mainly based on a very limited resources: petroleum, gas, and coal. As the world's energy demands rise and new sources for petroleum become scarce, the search for alternative energy resources has become an important issue for our time. A large amount of research has been done not only in the area of nuclear power generation but also in the area of unlimited energy sources such as wind power generation and solar energy transformation.

The most effective and harmless energy source is probably solar energy. For many applications it is so technically straightforward to use. Use of solar energy instead of fuel combustion, particularly for simple application like low and medium temperature water heating, can reduce the load on the environment. Solar energy can be harvested by the use of photovoltaic (PV) array.

Significant projects have been realized and others are still in planning. Most of these new systems are used to generate electrical power which is fed into the public electrical grid to provide energy for businesses and private homes. Every photovoltaic cell array has an optimum operating point, called the maximum power point (MPP), which varies depending on cell temperature and the present insolation level. The goal of project is to design the Maximum Power Point Tracker (MPPT) system connected to PV array to maximize the power acquired and increase efficiency.

Maximum Power Point Tracker (MPPT) is an electronic system operates the Photovoltaic (PV) modules in a manner that allows the PV modules to produce all the power they are capable of. MPPT is not a mechanical tracking system that "physically moves" the modules to make them point more directly at the sun. MPPT is a fully electronic system that varies the electrical operating point of the modules so that the modules are able to deliver maximum available power.

1.1 Literature Review

Most of the installation in Malaysia under the MBIPV project is base on **"plug and play"** basic, where the main components is buy from SOLAMAX and only the installation part is done by our side. This will only limit us as a great technology user but not a contributor to the technology due to lack of knowledge in the solar power controller field.

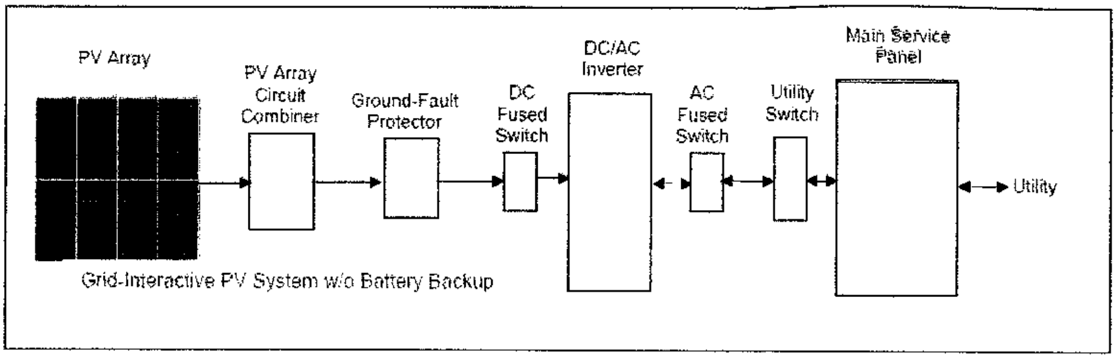


Fig 1: Typical system applied in PV system.

Typical application of Solar system is a combination of a ready make and integrated components, for example the Inverter (DC to AC) integrated with controller and battery charger controller. Most of the system used is fixed and without MPPT tracking devices which can maximize the amount of power generated by solar panel while the Sun is moving.

Therefore, this proposal is to research and develop a low-cost and high-efficiency solar power controllers system that optimize energy extraction from photovoltaic solar panels, in small renewable standalone energy power plants.

The main focus is put on complete solar power systems, from the specification of PV panel, control of MPPT (Maximum Power Point Tracking), converter and inverter.

When I search for local research in Malaysia, most of the solar power R&D are carried out by public university, but focusing on different interest from this proposal:

- Development of solar cell fabrication (USM),
- Development of organic cell by Solar Energy Research Institute, UKM,
- Development of Solar car by UTM and
- Solar thermal system by UKM.
- Development of grid-connected (3KW) inverter by UM.
- Installation of Grid –Connected System by Pusat Tenaga Malaysia.

Searching for research about MPPT of PV system, I got some articles write about this topic. But is seems like each research still did not meet the optimisation, that means the efficiency of the system is still not very high. Those below are some researches from internet:

- 2007, Hannes Knopf, Austra, using P&O: oscillation around MPP, so reduce efficiency.
- 2009, Lee Chong Hun, US, using P&O: smoothly when irradiation change slowly, but MPPT tracks error when irradiation change rapidly.
- 2008, Robert David, Canada, using P&O: MPPT tracks better than Lee Chong Hun's, but still got failure when irradiation change extremely fast.
- 2007, R. Farani, Italy, using IncCond: MPPT tracks fast but still got instability.
- 2010, Arindam.S, India, using IncCond: got instability when MPPT maintains at maximum point.

Many algorithms have been proposed and used for MPPT, but there are five most popular technique are used, which are:

- Constant Voltage (CV)
- Open Circuit Voltage (OV)
- Short Circuit Current (SC)
- Perturb and Observe (P&O)
- Incremental Conductance (IC)

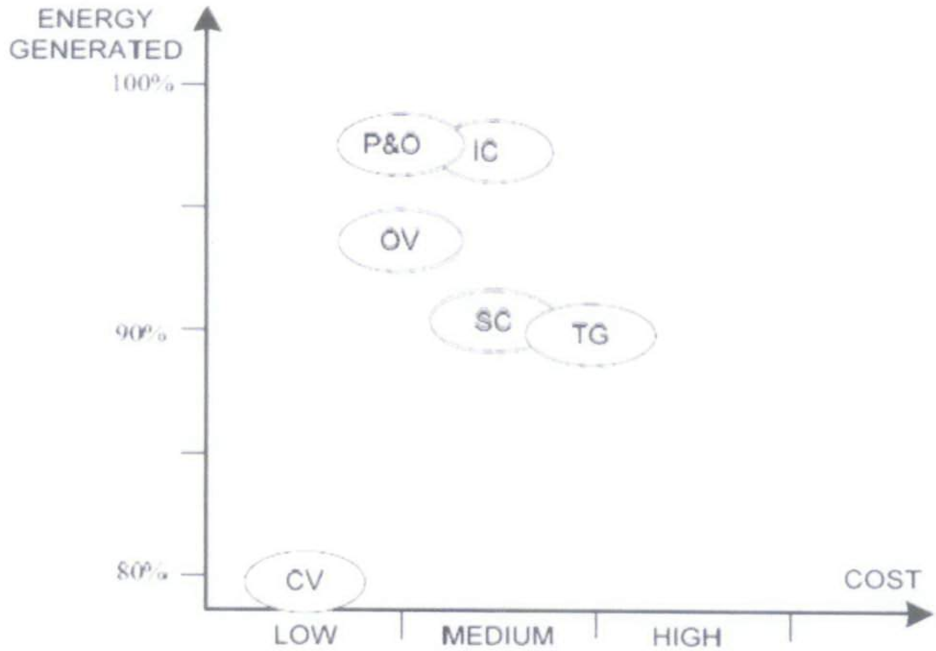


Fig 2: Trishan Esram, and Patrick L. Chapman, " Comparison of PV Array Maximum Power Point Tracking Techniques",2006.

There are some articles choose Perturbation & Observation (P&O) is the best technique, but some researchers say Incremental Conductance (I&C) is the best one. And when they use these techniques, sometimes they face problems with the output power, inconstant and also error tracking.

1.2 Problem Statement

Since many techniques have been used for MPPT, and still some different ideas for which technique is the best. So between two best techniques which are Perturbation & Observation (P&O), and Incremental Conductance (I&C), it needs to be verified which one can have higher efficiency.

Also with these two technique, previous researches show that they still have some problems. Two main problem of P&O are: oscillations around the MPP in steady state conditions, and poor tracking (possibly in the wrong direction, away from MPP) under rapidly-changing irradiations. Problem with IC technique is: output instability due to use of derivative algorithm. So these two techniques need to be tested and improved to have better efficiency.

1.3 Objectives

My research plan is to simulate the PV system with MPPT techniques, using both Perturbation & Observation, and Incremental Conductance algorithms to see which one have better outcome. The simulation tool is used is Matlab/Simulink, which is kind of popular simulation software that is used world-wide recently.

The second thing I also do is to try improving two techniques, then do comparison. My planned system will be built as below:

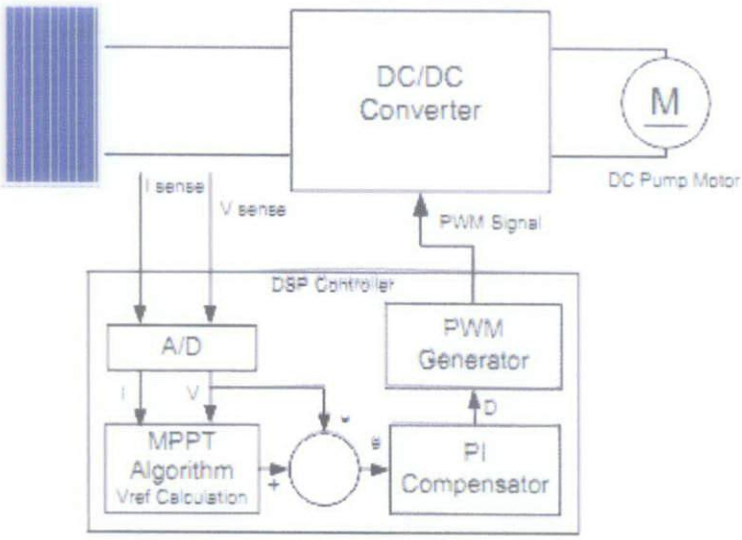


Figure 3: PV system with MPPT

1.4 Scope of Study

The scope of this project consists of research, further testing, analysis and improvement. The research is important for better understanding about Maximum Power Point Tracking for Photovoltaic System. Further testing must be done using simulation tool Matlab Simulink to show the result of work. Analysis of the result and improvement are also included in the scope of this project. Furthermore, implementation on hardware is also to be done in case can find the appropriate devices and components.

CHAPTER 2
BACKGROUND STUDY

This chapter will introduce the various elements of such a photovoltaic power system and derive the mathematical models necessary to represent its behaviour in a complete system simulation.

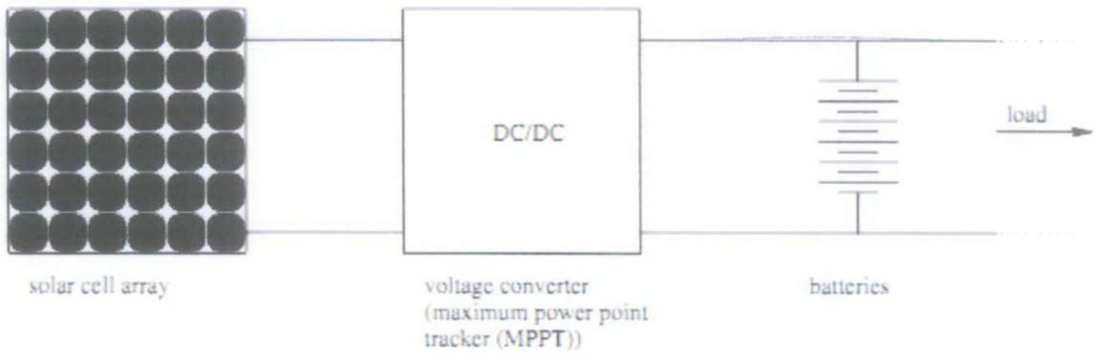


Figure 4: MPPT of simple PV system

MPPT is a circuit that allows extracting Maximum Power Point from PV array independently from the variation of its electrical characteristic that is function of the operative condition (temperature, illumination, and aging). The optimization of the delivered power is delivered by controlling current through the array or the voltage across it, with the best working point (MPP) of the power characteristic.

Specifically the Power Point Tracker is a high frequency DC to DC converter. They take the DC input from the solar panels, change it to high frequency AC, and convert it back down to a different DC voltage and current to exactly match the panels to the loads. MPPT's operate at very high audio frequencies, usually in the 20-80 kHz range. The advantage of high frequency circuits is that they can be designed with very high efficiency transformers and small components.

2.1 Physical Structure Of Photovoltaic Cell

A solar cell is a semiconducting device that absorbs light and converts it into electrical energy. Today's most common cell is a mass manufactured single p-n junction Silicon (Si) cell with an efficiency up to about 17 %. It consists of a moderately p-doped base substrate and a thin heavily n-doped t op layer. Thin metal contacts on the surface and a plain metal layer on the back connect this photovoltaic element to the load

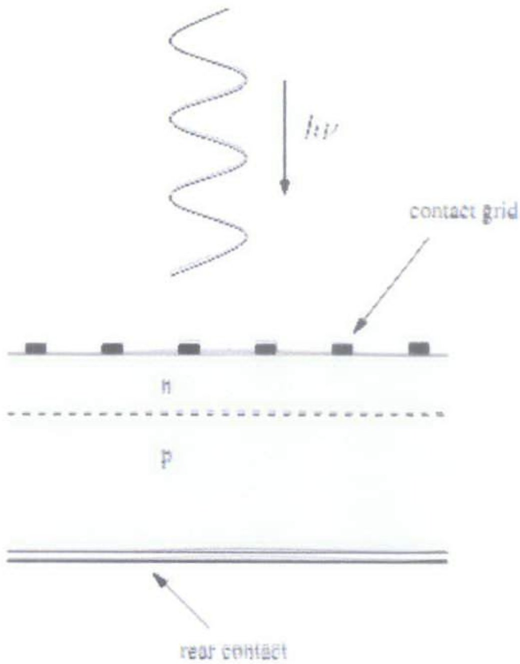


Figure 5: Schematic representation of a standard p-n junction solar cell

If exposed to radiation, electron-hole pairs are created by photons with an energy greater than the band-gap energy of the semiconductor ($h\nu > E_g$). This is called the photovoltaic effect. The newly created charge carriers in the depletion region are separated by the existing electric field. This leads to a forward bias of the p-n junction and builds up a voltage potential called the photo-voltage. As soon as a load is connected to the cell, this voltage will cause a current (called the photo-current) to flow through the load. In addition the forward bias of the p-n junction also leads to a small diode current Id in the opposing direction of the photo-current

The p-n j unction properties and the discussed reaction of the semiconductor to radiation lead to the simplified and idealized equivalent circuit diagram of a photovoltaic cell as shown in Figure 6.

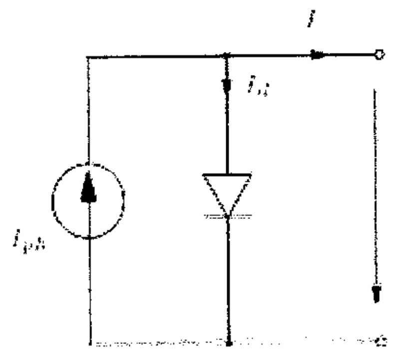


Figure 6: Simple equivalent circuit diagram of a solar cell

2.2 The Solar Panel

In photovoltaic energy system, single cells are combined into solar cell arrays by connecting a number of cells in series. Consideration of the equivalent circuit model lead to the equation for a photovoltaic cell array (commonly called a solar panel or solar array) with z photovoltaic cells in series connection:

$$I = I_{ph} - I_{s_1}\left[e^{\frac{q(V+IzR_s)}{zn_1kT}} - 1\right] - I_{s_2}\left[e^{\frac{q(V+IzR_s)}{zn_2kT}} - 1\right] - \frac{V+IzR_s}{zR_p}.$$

These panels then can be further arranged in series or parallel connections to achieve the desired voltage and current values for the system.

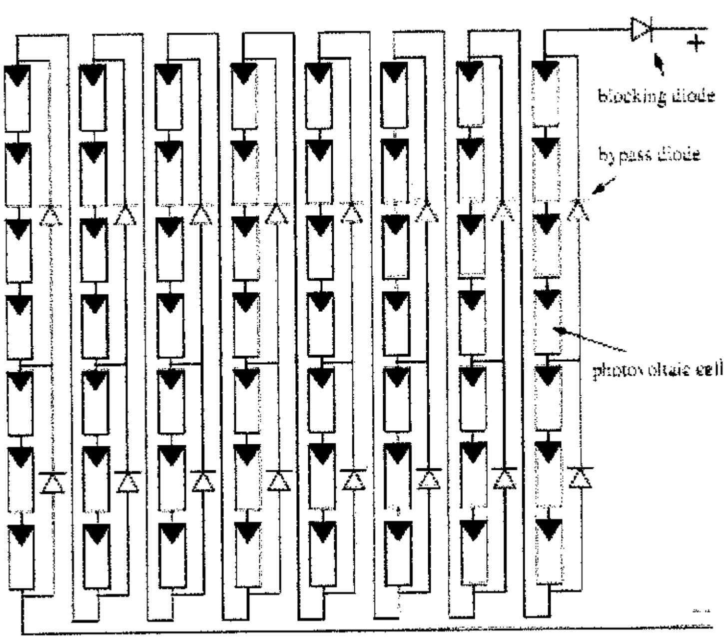


Figure 6: Schematic representation of solar panel

The I -V characteristics of a photovoltaic cell strongly depend on insolation and temperature. This becomes very apparent when evaluating equation for selected values of temperature and irradiance and plotting the results as an I - V graph (Figures 7 and 8). Figure 7 shows that the output current I of an array is greatly influenced by the change in insolation S , whereas the output voltage V stays approximately constant. In contrast, for a changing temperature one can see that the voltage varies widely while the current remains unchanged (Figure 8).
The P -V characteristics for a photovoltaic cell array can be obtained from the I - V characteristics and the relation for the output power P = VI as shown in Figures 8 and 9. These figures clearly show how the dependency of output current I and output voltage V on temperature and insolation translate into a dependency of the output power on the same two parameters.

Figure 9 confirms the expected behavior of a device that converts solar energy into electrical energy: the power output of a solar panel is greatly reduced for a decreasing insolation. It also shows an effect which might not be immediately obvious: the output power is reduced by an increase in panel temperature. This can be explained by the significant temperature dependency of the op e n circuit voltage VOC . The voltage drops due to an increase of the reverse saturation current Is in the diode. The principal temperature variation of Is is a result of the temperature variation of the intrinsic carrier concentration, which yields a higher recombination rate inside the semiconductor

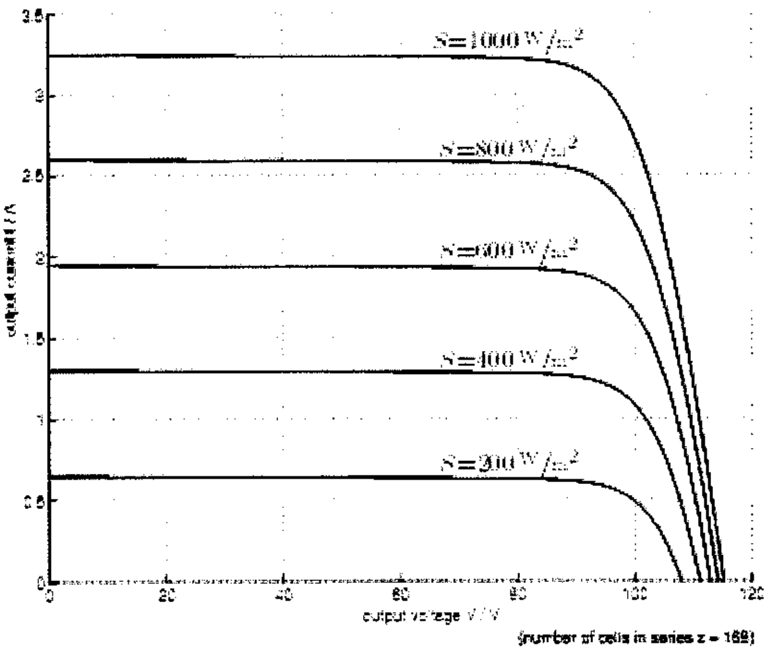


Figure 7: I-V characteristics of PV cell array for various value of irradiance S at a temperature 25 C degree

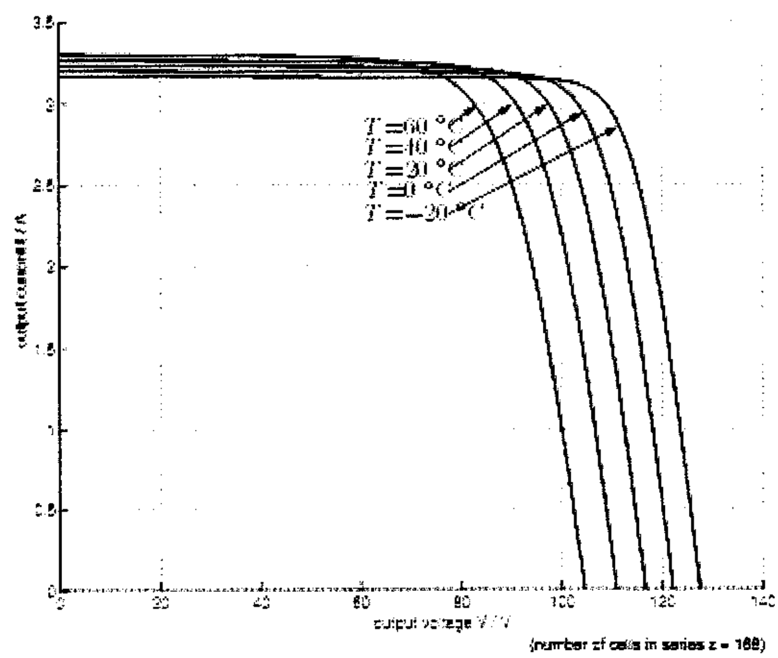


Figure 8: I-V characteristics of PV cell array for various value of temperature T at an irradiance of 1000 W/m2

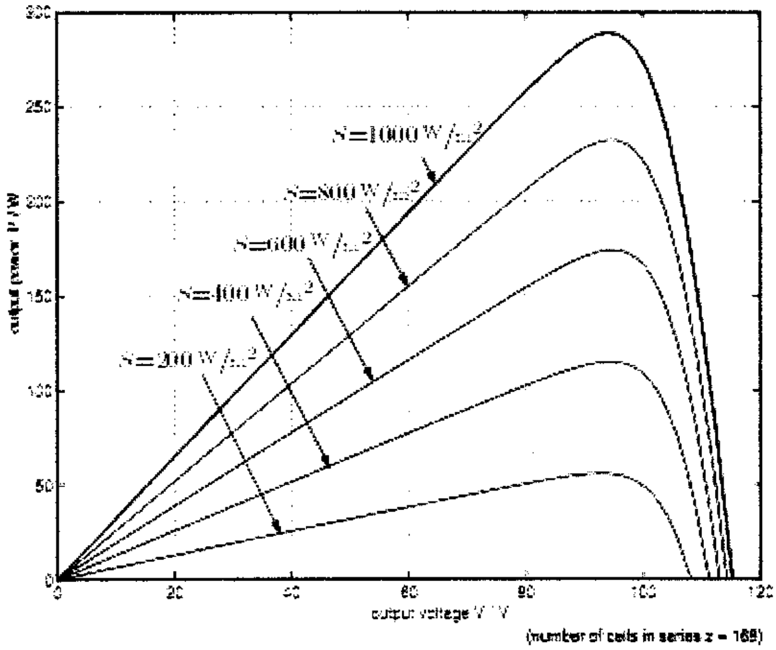


Figure 9: P-V characteristics of PV cell array for various value of irradiance S at a temperature 25 C degree

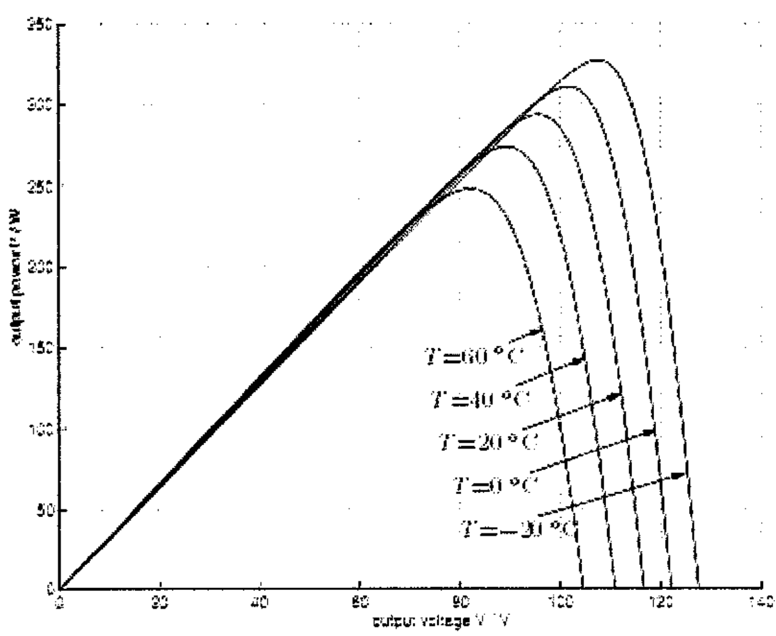


Figure 10: P-V characteristics of PV cell array for various value of temperature T at an irradiance of 1000 W/m2

It can also b e seen that the output power of a solar panel not only depends on temperature and insolation, but also very strongly on its operating voltage V . The point of maximum power indicated as MPP (Maximum Power Point) in Figure 11 is the desired operating point for a photovoltaic array to obtain maximum efficiency.

The corresponding values for voltage and current are called V mp and I mp , respectively

The P -V curve shown in Figure 11 shares the temperature and insolation dependencies shown in Figures 7; as a result the value for the optimum operating voltage V mp will vary constantly with changes in these environmental conditions. In these circumstances a maximum power point tracking (MPPT) mechanism can help to significantly increase the power output of a solar power system by adjusting the system load in such a way that the operating voltage V will always b e approximately equal to the optimum operating voltage Vmp :

$V = Vmp + \epsilon$, with ϵ being as small as possible

The importance of keeping the operating voltage as close as possible to Vmp is illustrated in Figure 11. If the operating voltage differs from V mp by about 10 % as indicated by V1 , it will result in a output power reduction of almost 25 %. Comparison of systems with and without maximum power point tracking devices shows that units with a MPPT output 80-90 % o f their theoretical maximum power, whereas units without a MPPT only operate at 30 % of their maximum power output

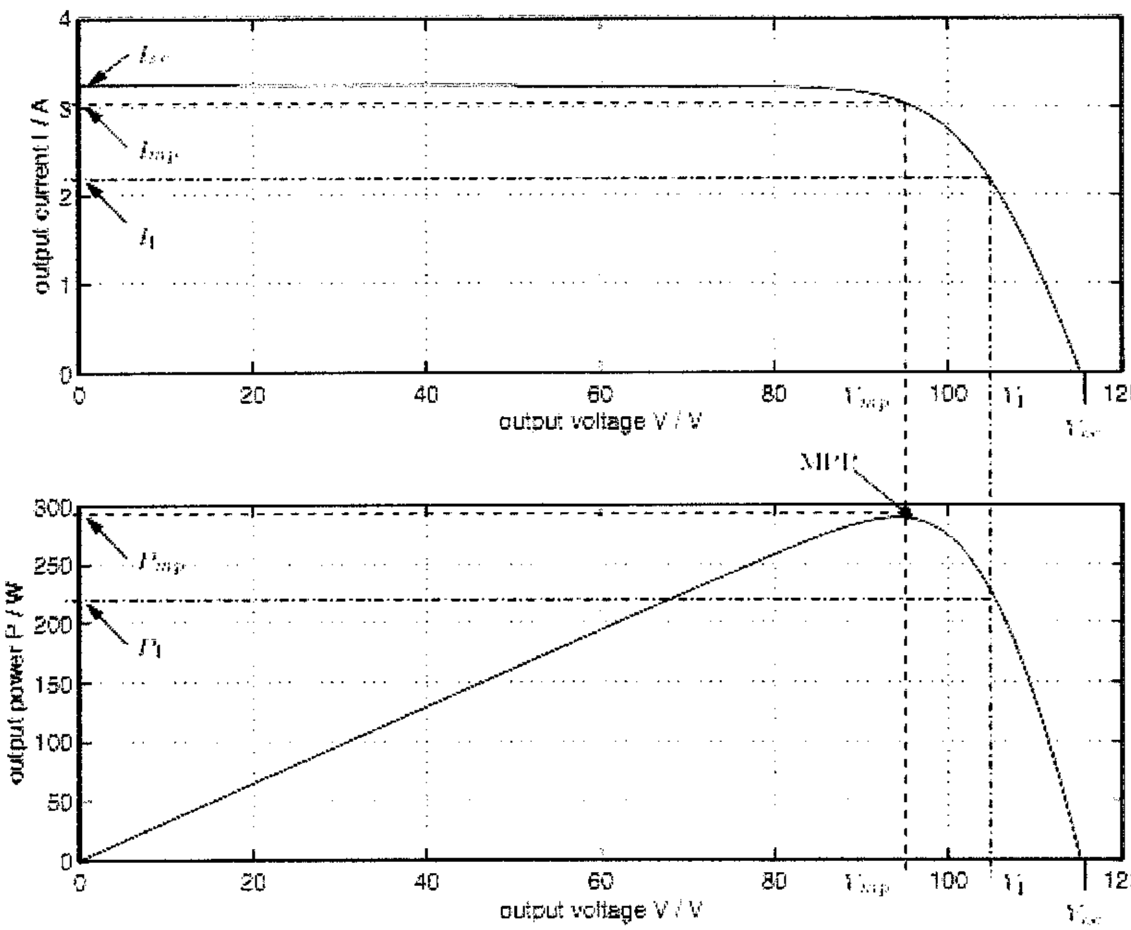


Figure 11: Maximum Power Point MPP and the correspondent voltage Vmp and current Imp for a photovoltaic cell array with 168 cells series operating at STC.

2.3 DC-DC Boost Converter

The need of converter in the MPPT system is to maximize the varied input of DC voltage. In term of maximized the output voltage by step up the input voltage the boost converter is ideally to be choose in the MPPT design compared to the Buck converter since the Boost converter can always track the maximum power point. By referring to the input of the both topologies the Buck converter input voltage is always greater or equal to its output voltage so the output panel must exceed the battery voltage for power to flow. The maximum power point of 12V commercial PV module is above 13V for most combinations of insolation and temperature. So buck converter can operate at the MPP undermost but not at all condition. While for the Boost converter input voltage must lie between the zero and output voltage so that's why, Boost converter will always be able to operate at the panel's MPP. In term of simplicity a buck converter with a MOSFET switch still requires an additional diode or MOSFET's to block the reverse current flow when the panel voltage drops below the battery voltage, as an advantages of Boost converter naturally it has this devices as part of its structure , which eliminates an additional source of voltage drop and power loss.

A boost converter has been employed in this application to regulate the power output to the load. It consists of an inductor, a logic level, Power MOSFET switch, a Schotky diode and capacitors. Figure 12 shows a typical connection of a boost converter. The basic Boost converter containing at least two semiconductor switches (a diode and a transistor) and one energy storage element. Filters made of capacitors (sometimes in combination with inductors) are normally added to the output of the converter to reduce output voltage ripple.

A 15 to 18volt from the solar panel will be the target operation point of the solar panel. In this case we will extract a current of 4.6 Amp from the device, which will then give us a maximum power from the PV array.

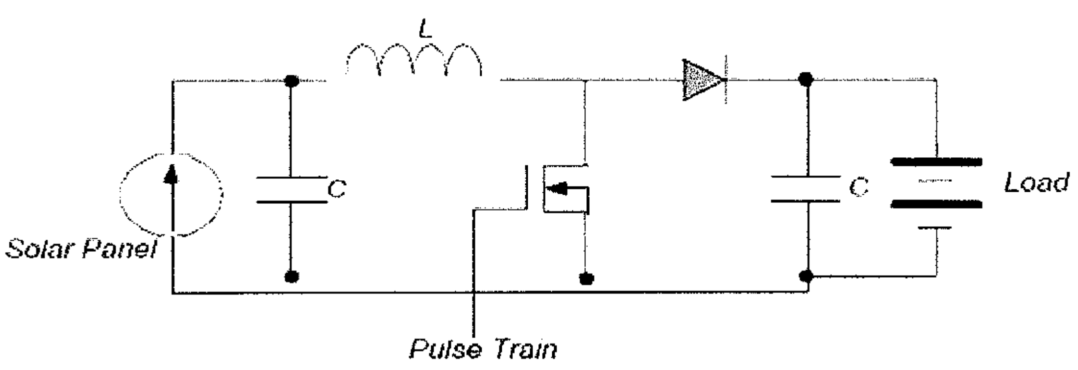


Figure 12: Boost circuit

2.4 Operation of Boost Converter

As known, a boost converter is capable of providing an output voltage that is greater than the input voltage. The key principle that drives the boost converter is the tendency of an inductor to resist changes in current. When being charged it acts as a load and absorbs energy like a resistor), when being discharged, it acts as an energy source (like a battery). The voltage it produces during the discharge phase is related to the rate of change of current, and not to the original charging voltage, thus allowing different input and output voltages. The basic principle of a Boost converter consists in 2 distinct states as in Figure 13 and 14.

• In figure 13 at the On-state,, resulting in an increase in the inductor current;

• In Figure 14 at the Off-state, the Transistor (switch) is open and the only path offered to

inductor current is through the flyback diode D, the capacitor C and the load R. This result in transferring the energy accumulated during the On-state into the capacitor.

• The input current is discontinuous, stepping between a very high inductor current and 0. The

large ripple usually requires a large input bypass capacitor to reduce the source impedance.

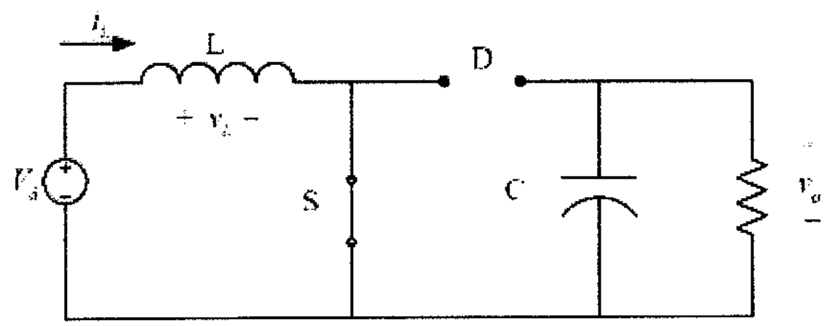


Figure 13: Boost converter at ON-stage

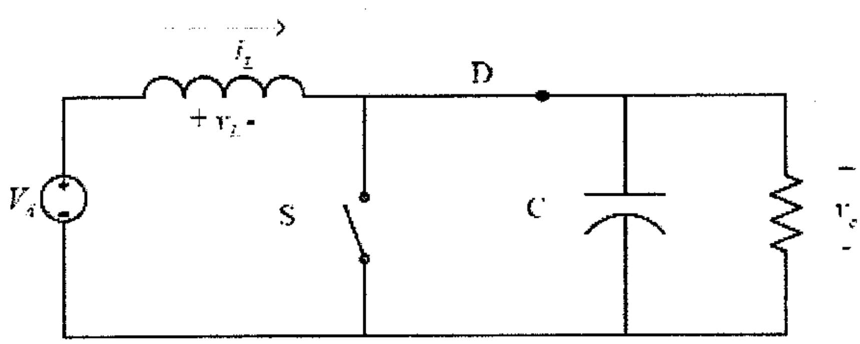


Figure 14: Boost converter at OFF-stage

The operation of a boost converter can be divided into two modes the Continuous Current Mode and the Discontinuous Current Mode. Depending on the switching actions of the switching device (like MOSFET). During the Continuous Current Mode the current through the inductor (IL) never falls to zero. Figure 15 shows the typical waveforms of currents and voltages in a converter operating in this mode.

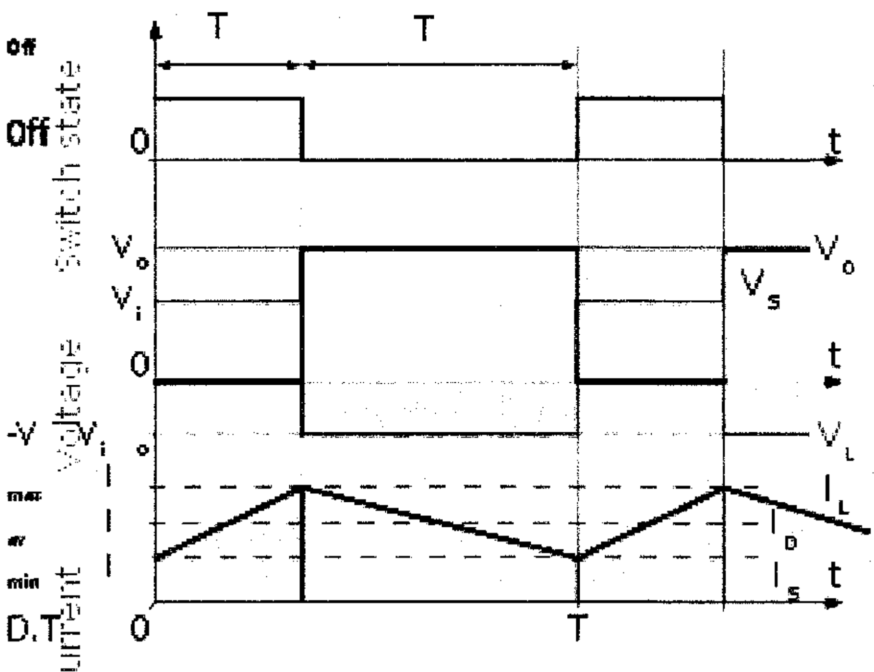


Figure 15: Waveforms of current and voltage in a boost converter operating in continuous mode

The output voltage can be calculated as follows, in the case of an ideal converter (i.e. using components with an ideal behavior) operating in steady conditions. During the On-state, the switch S is closed, which makes the input voltage (Vi) appear across the inductor, which causes a change in current (IL) flowing through the inductor during a time period (t) by the formula

2.5 MOSFET Driver

A gate voltage (VG) is always needed to control the switching of the MOSFET, enabling it to behave as a switch in the boost converter. This voltage VG, directly affects the turn on and turns off time delay of the MOSFET as a switching device. As a result, a drive circuit will be needed to enhance the performance of the MOSFET, thus the overall efficiency of the MPPT circuit. The important characteristics of the MOSFET is to turn it on, the gate terminal value at least 10 volts greater than the source terminal (about 4 volts for logic level MOSFET's). The circuit driver should be able to supply a reasonable current to ensure the stray capacitance can be charged up as soon as possible. Since the large stray capacitance between the gate and the terminal is one of the important characteristic of MOSFET. Because of this characteristic the capacitance needs to be charged up before the gate voltage reaches the desired voltage.

2.6 Battery

A battery is a device capable of storing electrical energy by means of a reversible chemical reaction. There are several different battery types, discerned by size, use and construction. The most common battery is the lead-acid battery, but nickel-cadmium nickel-iron and nickel-hydride are also available, among others. For most solar applications the lead-acid battery is the best choice.

a) General battery chemistry

A lead-acid battery contains sulfuric acid (H2SO4), water (H2O), lead (Pb) and lead-oxide (PbO2). The electrolyte is the solution of sulfuric acid in water. A battery
consists of a series of cells, connected in series, to provide the desired output voltage. The output of a lead-acid cell is a little over 2 V and also depending on the state of charge. Therefore, for a 12 V lead acid battery there are 6 cells connected in series. A battery stores electrical energy by forcing electrons into positions in which they contain more energy by applying a voltage on the battery connectors. The storage is realized by the following chemical reactions:

On the positive electrode:

PbO2 + HSO4- + 3 H+ + 2 e → PbSO4 +H2O

On the negative electrode:

Pb + HSO4- → PbSO4 + H+ + 2 e-

Overall reaction:

Pb + PbO2 + 2 H+ + 2 HSO4- → 2 PbSO4 + 2 H2O

When a load is connected to the battery, the reaction is reversed, and the electrons release the stored energy. The capacity of a battery (how much energy it can store) is measured in AH (Amp Hour).

b) Starting and Deep-cycle batteries

Basically there are two types of batteries, they are namely starting and deep cycle batteries. Different use asks for different battery designs. A starting battery, as used in most cars, is designed to deliver a large current during a short time. A deep cycle batteries that can withstand deep discharges. It has less instant energy but greater long-term energy delivery. The main difference between the two batteries is the plate-thickness. The plates of the deep-cycle batteries are up to 35 times thicker than those of starting batteries. Hence deep cycle batteries can survive a number of discharge cycles and it is suitable for use in application where power supply standby is needed.

c) Battery charging

Batteries are best charged in 3 different steps, bulk charge, absorption charge and float charge. During bulk charge, the highest charge current is sent to the batteries until the battery is 80-90% charged. During absorption charge, current is limited as internal resistance of the battery increases. The applied voltage is a little higher. Absorption charge lasts until the battery is fully charged. During float charge, voltage is reduced. The purpose of float charge is to keep a charged battery from discharging, thus enhancing battery life.

d) Battery life

Since the storage and release of energy in batteries involves solving and dissolving the plates in the electrolyte, batteries do not last forever. Batteries are rated for a certain number of cycles to a certain depth of discharge. When taken careof, batteries can last for decades, while when mistreated, they can die prematurely.Main causes for premature battery death are overcharging, charging with a too high charge current, and sulfating. The first two causes can be prevented by a charge controller. Sulfating is the formation of large lead sulfate on the battery plates, and occurs when the battery is left in a low- or uncharged state for a longer period of time. Sulfating is sometimes (partially) reversible by controlled charging of the battery. In a well-designed system that's being used the way it was designed for, these problems will not occur, and the batteries will provide reliable and convenient energy storage for years or decades, depending on battery quality.

2.7 Perturbation & Observation (P&O) Technique

The P&O method is a widely used approach to MPPT. It employs a micropro-cessor with the values for panel voltage V and panel current I as its input values and the desired operating voltage Vref as its output value. The notation used for the desired operating voltage Vref alludes to the fact that this system can then be inserted in the already discussed voltage-feedback controller t o supply Vref.

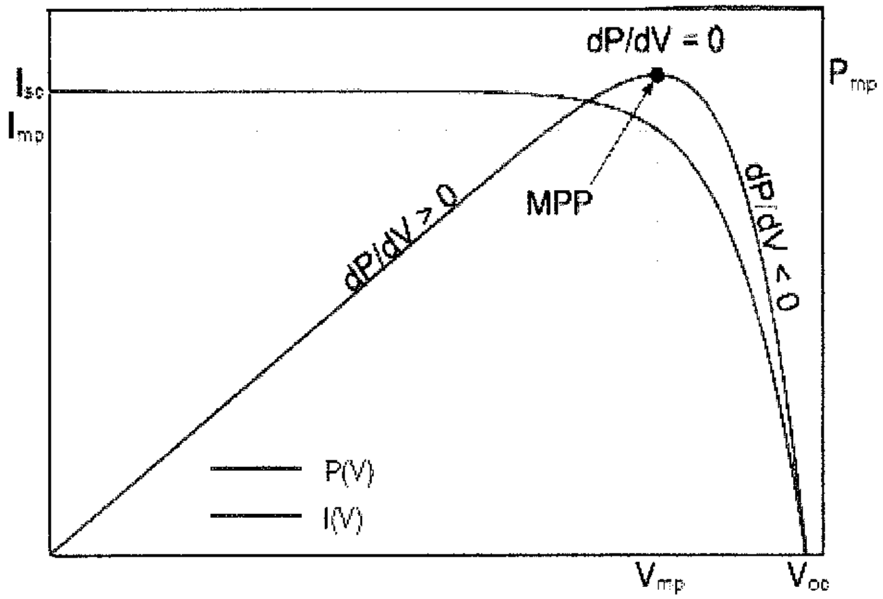


Figure 16: P&O technique

Another possible configuration is to have the microprocessor directly controlling the d c-to-dc converter's PWM input variable d . This makes the extra voltage control feedback loop dispensable.

As the name of the P&O method states, this process works by perturbing the system by increasing or decreasing the array operating voltage and observing its impact on the array output power. Figure 17 shows a flowchart diagram of the P&O algorithm as it is implemented in the controlling microprocessor. As can be seen in Figure 16, V and I are measured to calculate the current array output power P(k). This value for P(k) is compared to the value obtained from the last measurement P(k-1). If the output power has increased since the last measurement, the perturbation o f the output voltage will continue in the same direction as in the last cycle. If the output power has decreased since the last measurement, the perturbation of the output voltage will b e reversed to the opposite direction of the last cycle.

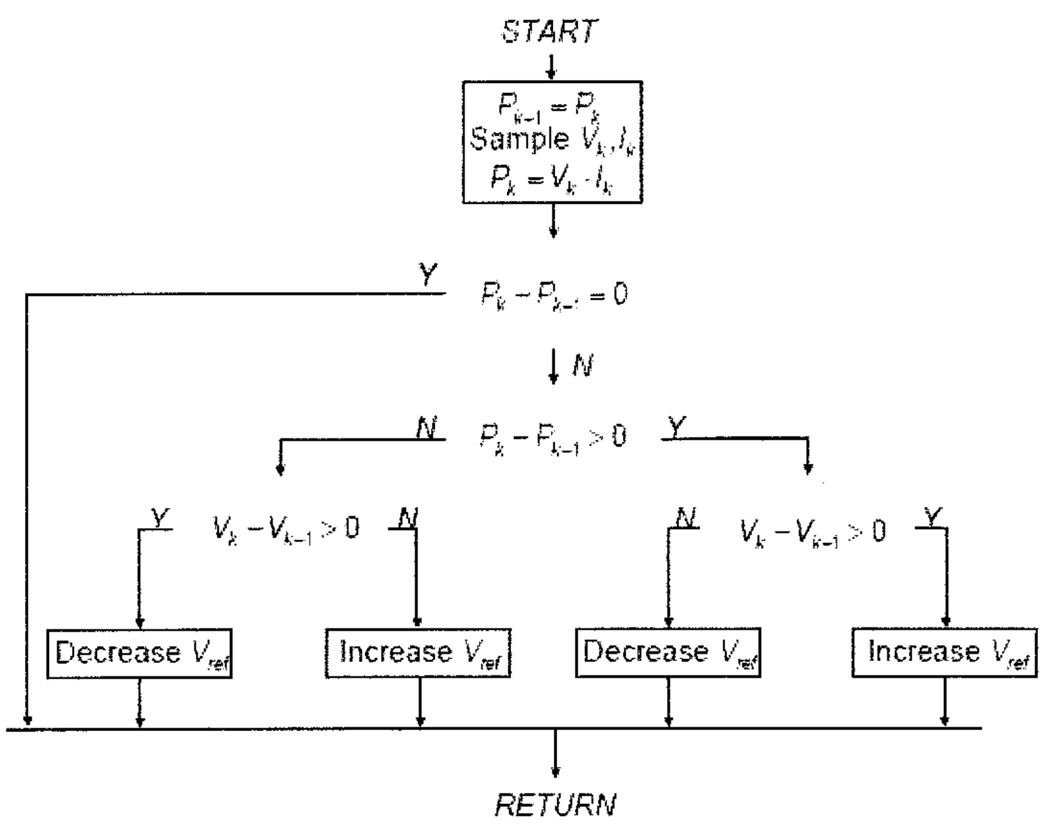


Figure 2.2: *The flowchart of the P&O algorithm*

Figure 17: Flowchart of P&O algorithm

With this algorithm the operating voltage V is perturbed with every MPPT cycle. As soon as the MPP is reached, V will oscillate around the ideal op e rating voltage Vmp . T his causes a power loss which depends on the step width of a single perturbation. If the step width is large, the M PPT algorithm will be responding quickly to sudden changes in operating conditions with the trade off of increased losses under stable or slowly changing conditions. If the step width is very small the losses under stable or slowly changing conditions will b e reduced, but the system will b e only able to respond very slowly to rapid changes in temperature or insolation. The value for the ideal step width i s system dependent and needs to be determined experimentally.

2.8 Incremental Conductance (IC) Technique

It is based on the fact that the derivative of the output power P with respect t o the panel voltage V is equal to zero at the maximum power point (MPP). The solar panel's P -V characteristics in Figure 3.4 show further that the derivative is greater than zero to the left of the MPP a nd less than zero to the right of the MPP.

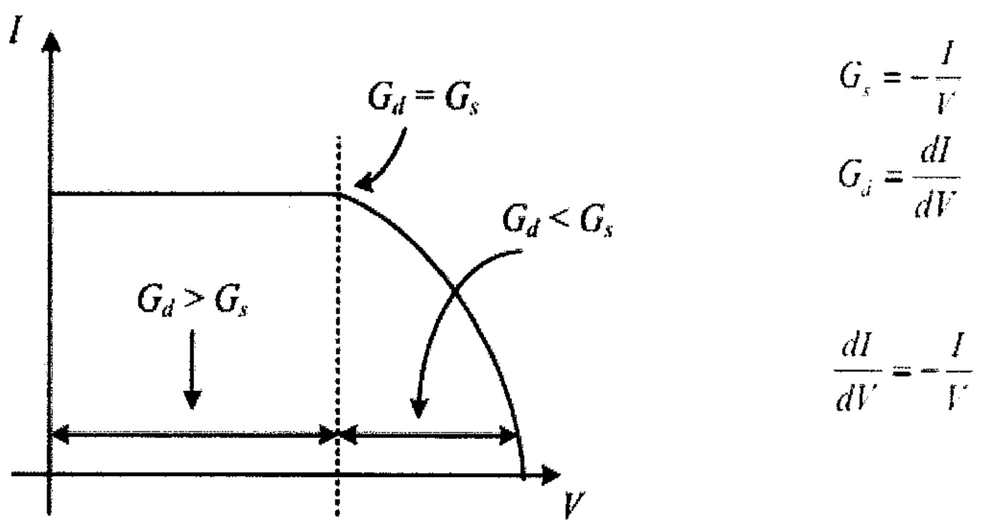


Figure 18: The schematic of IC technique

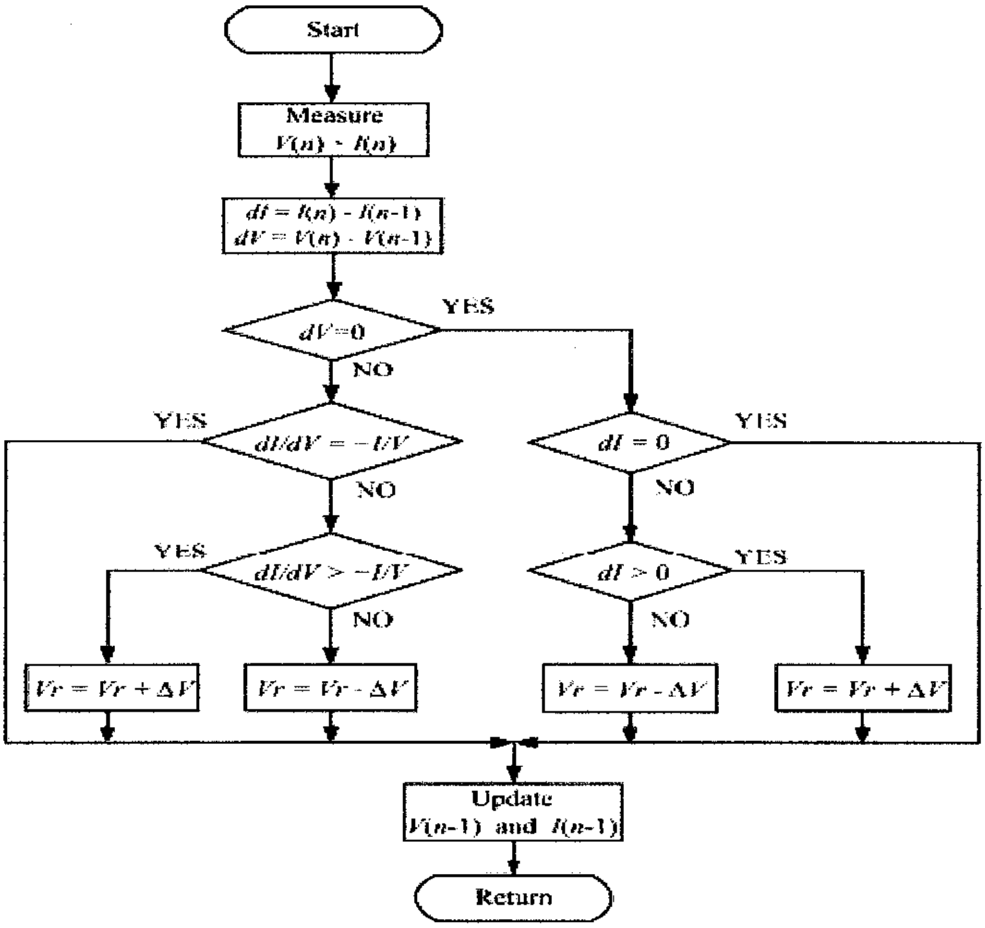


Figure 19: Flowchart of IC technique

CHAPTER 3
METHODOLOGY

This project will be conducted according to this methodology to meet the objective. The objective of this project is to design the Maximum Power Point Tracking for Photovoltaic system. This topic has already been done by some people, but there is still a lot improvement needed. That is to compare two techniques P&O and IC, and also try to improve these two technique to get a better efficiency.

Firstly, I spent time to collect articles and information from internet that related to this topic. Then I filter what necessary information and do the literature review for extended proposal. In this literature review will introduce about background theory of related topics. From information and data collected, I will research more and try to do simulation using Matlab/Simulink tool, this simulation will help to show the result of system that designed, from then can make ways to improve and adjust. Two results from simulation P&O and IC will be compared, then efficiency will be calculated to see how much they can improve from system without MPPT. Finally, the implementation with hardware will be conducted to achieve the goal. Hopefully I will get appropriate equipment to support for this project.

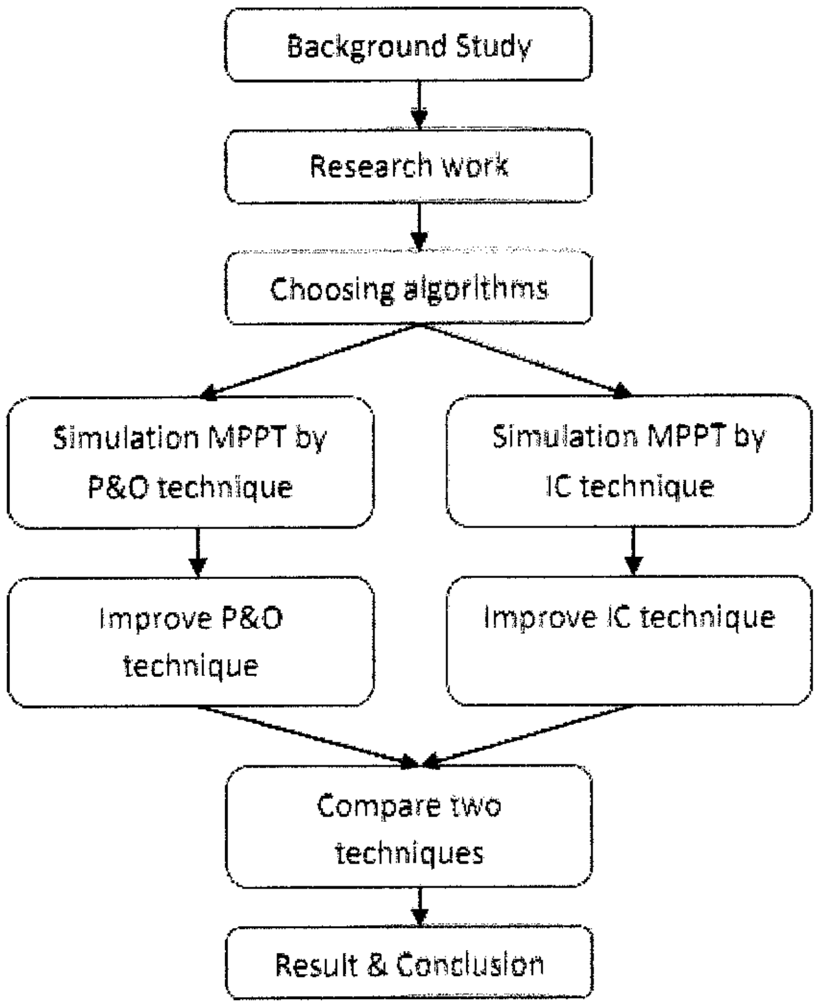


Figure 20 : The flow chart of methodology

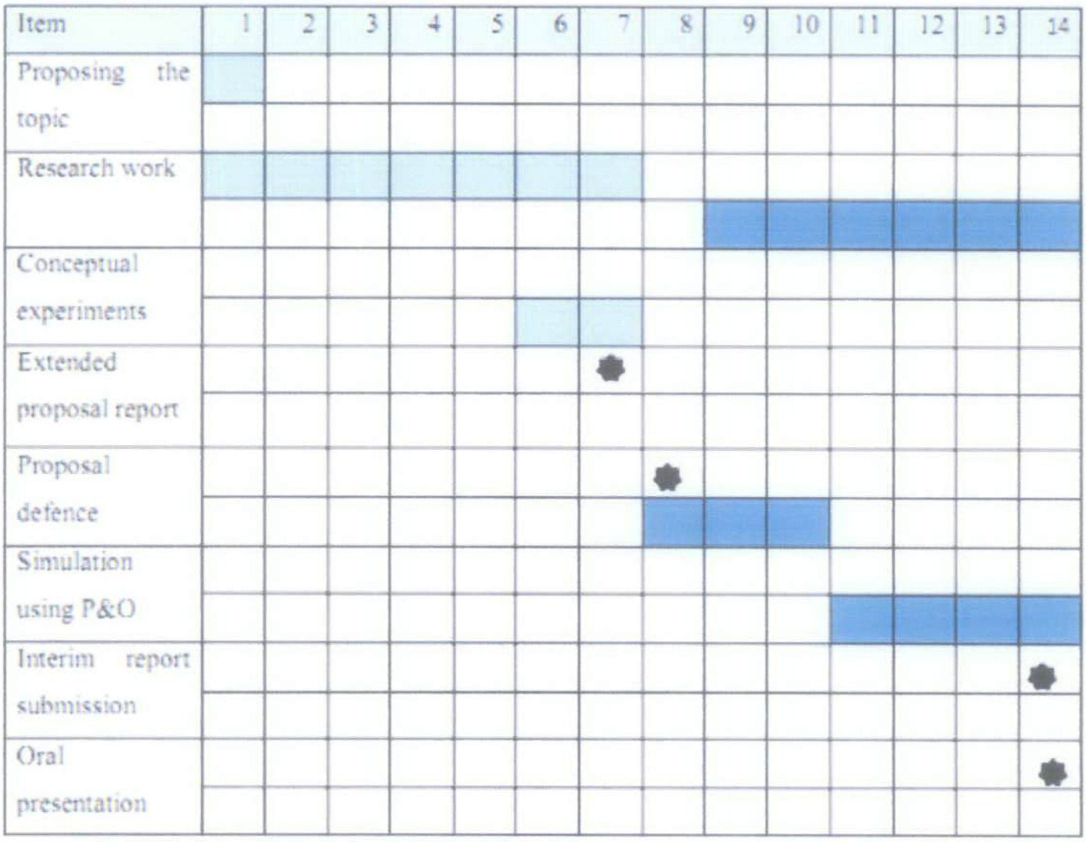


Figure 21: Grant chart for FYP 1

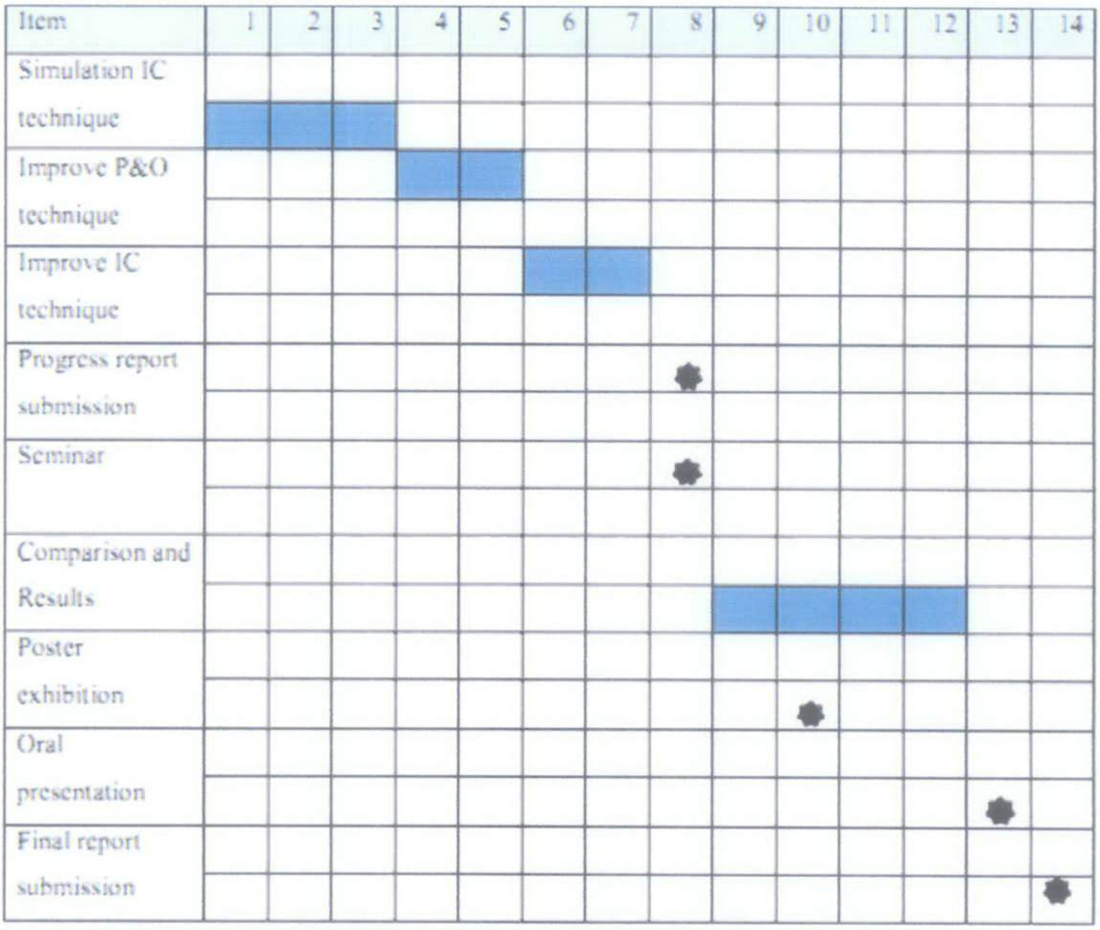
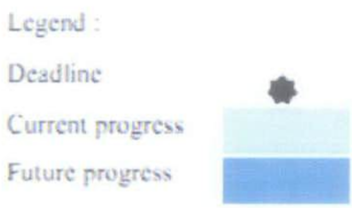


Figure 22: Grant chart for FYP 2



CHAPTER 4
SIMULATIONS AND RESULTS

For simulation, I plant to construct the closed-loop whole system as in figure 22 below. I will do simulation for each part first, then connect all together and run simulation to get result.

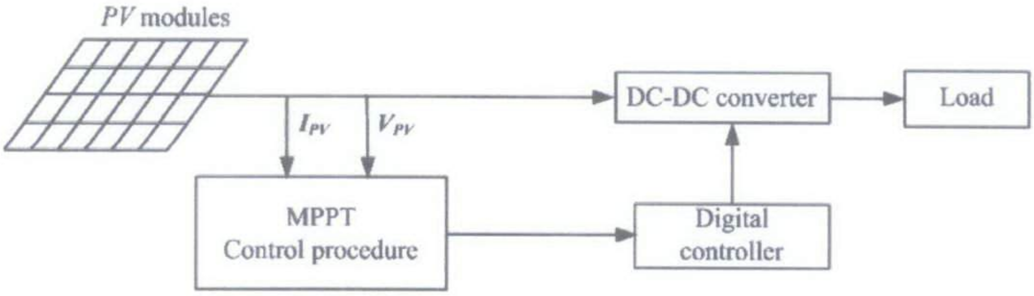


Figure 23: Structure of PV system with MPPT

4.1 PV Cells Behaviour

Using Matlab/Simulink, I build the PV cells sytem in order to test and present its behaviour.

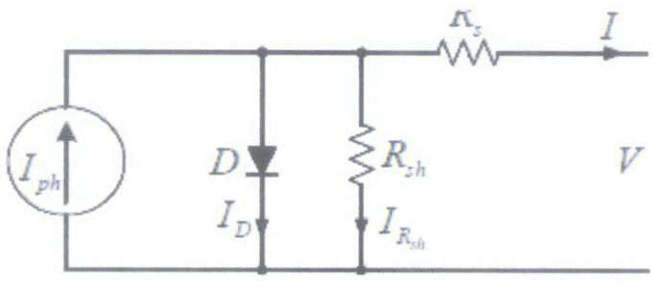


Figure 24: Solar cell diagram

$$I = I_{SC} - I_0\left[e^{38.9(V+IR_S)} - 1\right] - \frac{1}{R_P}(V + IR_S) \qquad \text{at } 25^{\circ}\text{C} \qquad (8.18)$$

Simplify it, we get,

$I = Isc - I_1$, Where,

I_1 = 1e-9*(exp(38.927*(V+I*Rs))-1)+(V+I*Rs)/Rp

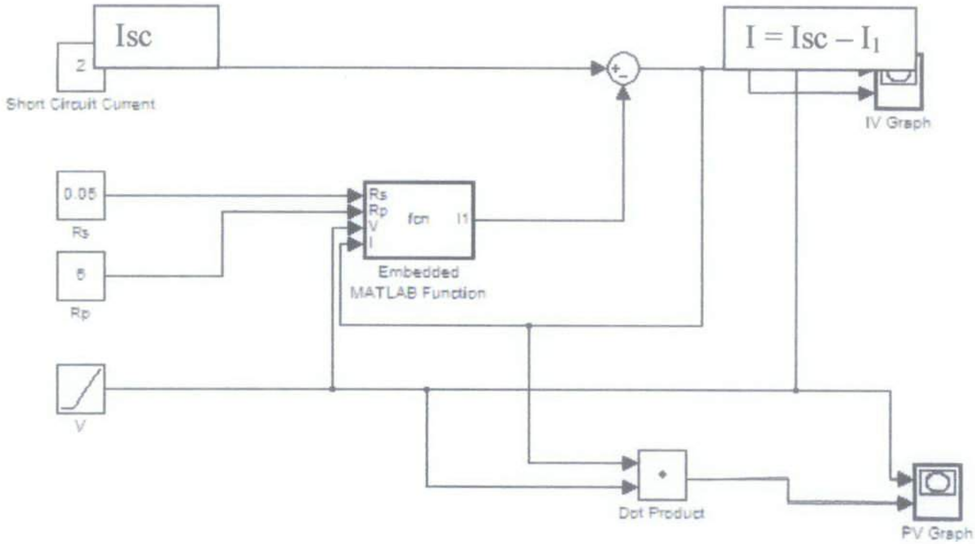
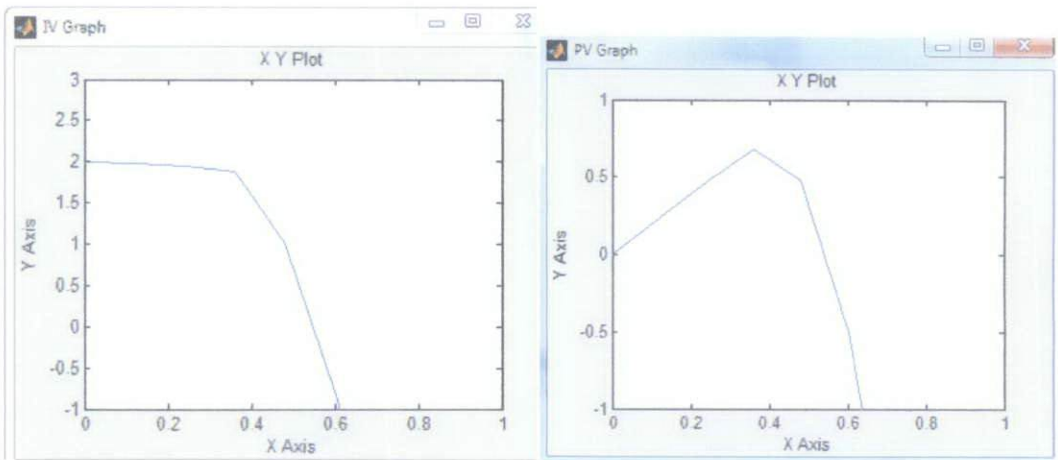


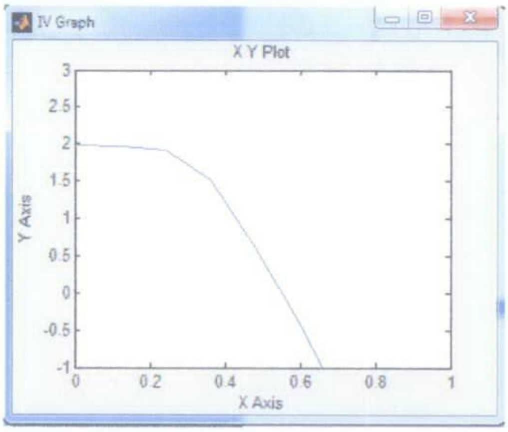
Figure 25: PV cells Simulink

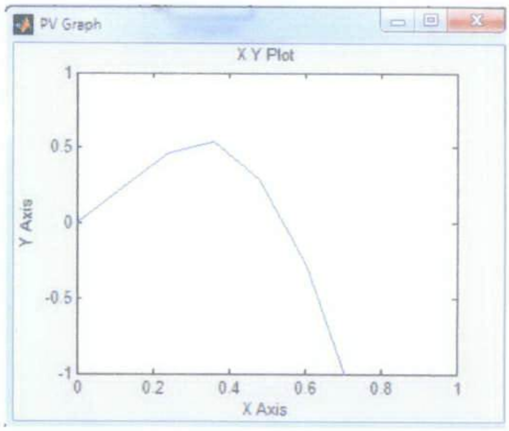
Increasing Rs

Rs = 0.05, Rsh = 6

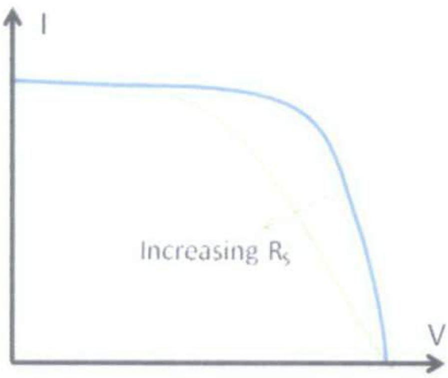


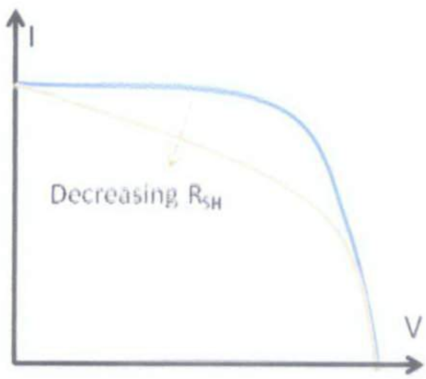
Rs = 0.1, Rsh=6





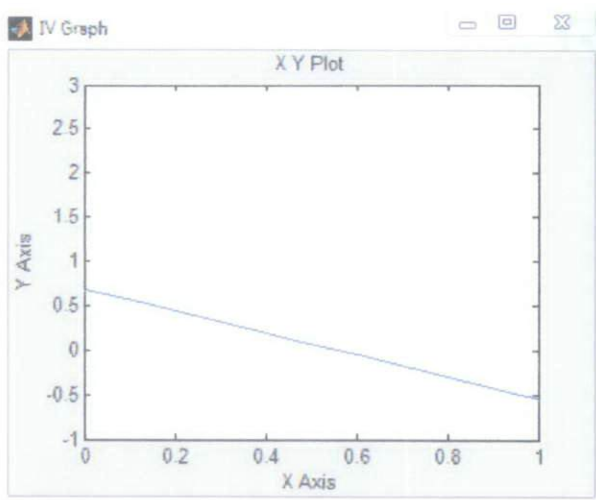
Compare with theory :

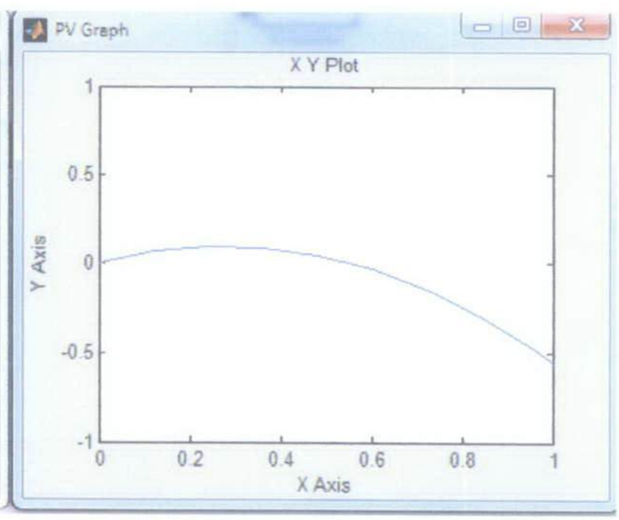




While increasing R_S excessively can cause I_{SC} to drop instead

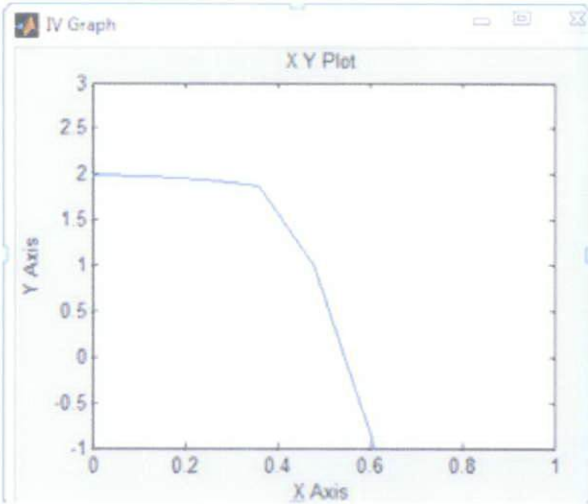
Rs =0.8, Rsh=6

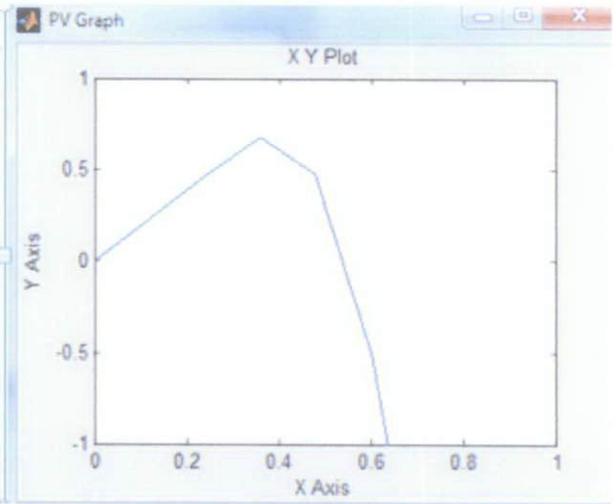




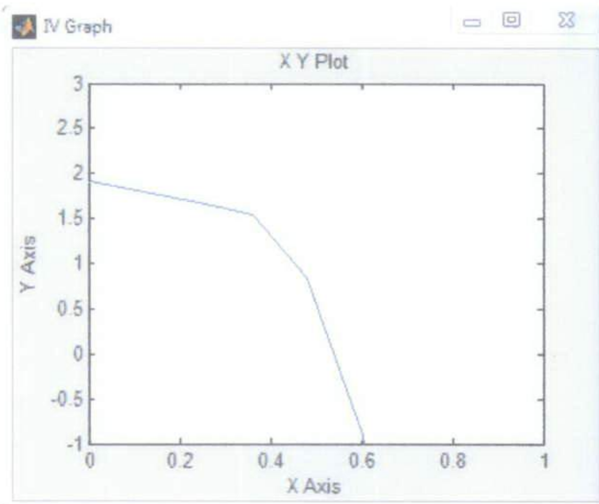
Decreasing Rsh

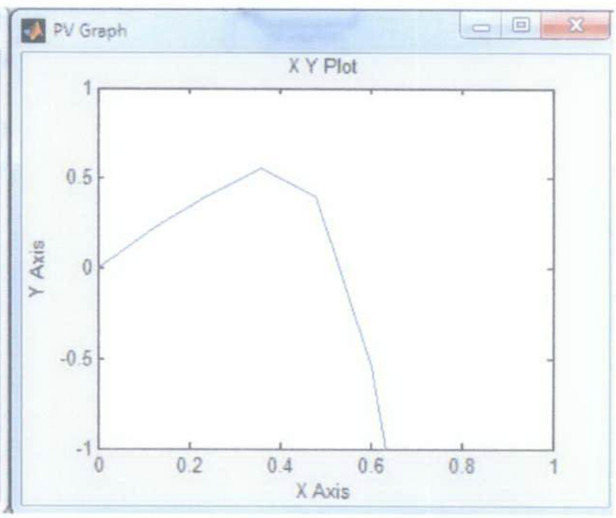
Rs=0.05, Rsh=6

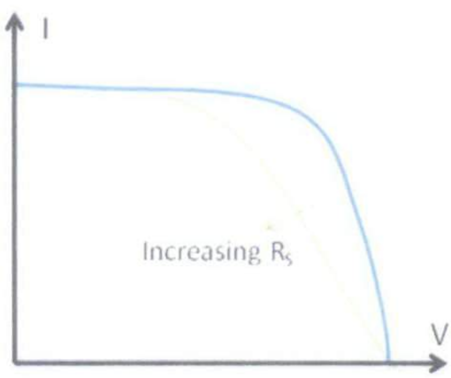


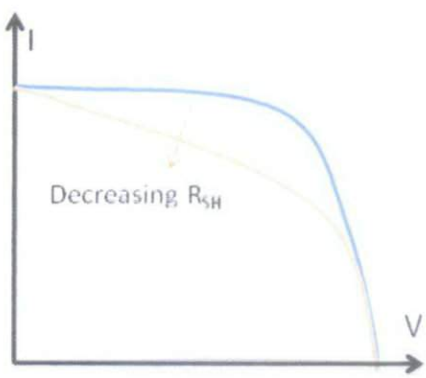


Rs=0,05, Rsh=1









4.2 PV Cells Current And Voltage Characteristic

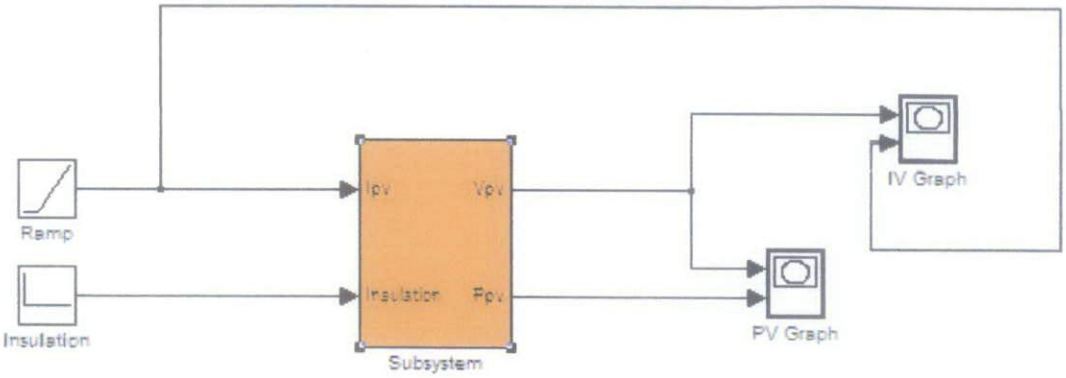


Figure 26: PV cell with one level of insolation

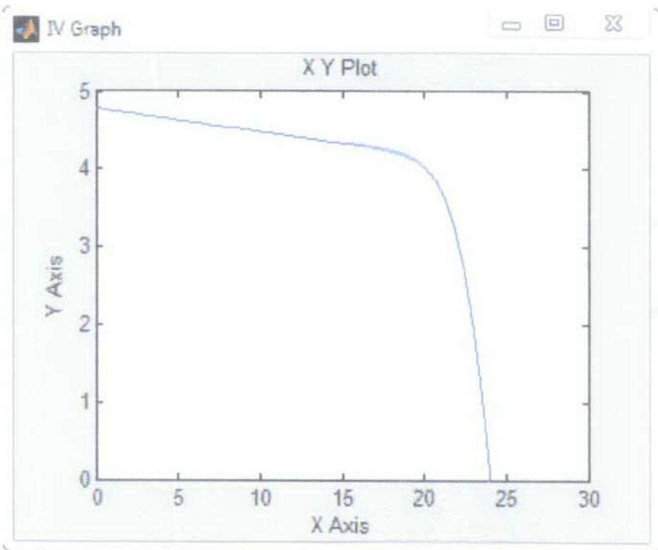


Figure 27: IV characteristic of PV cell with one level of insolation

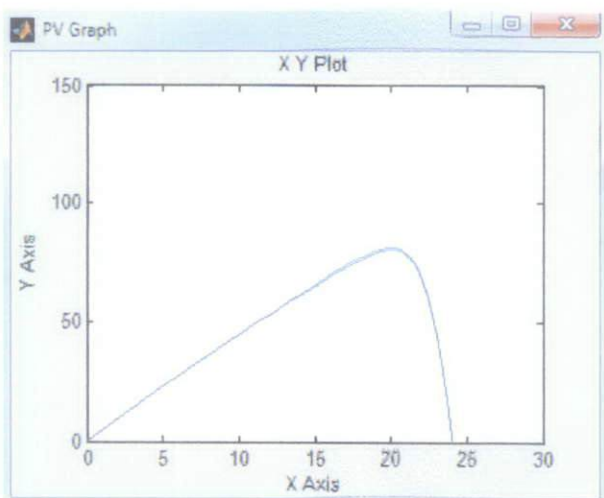


Figure 28: PV characteristic of PV cell with one level of insolation

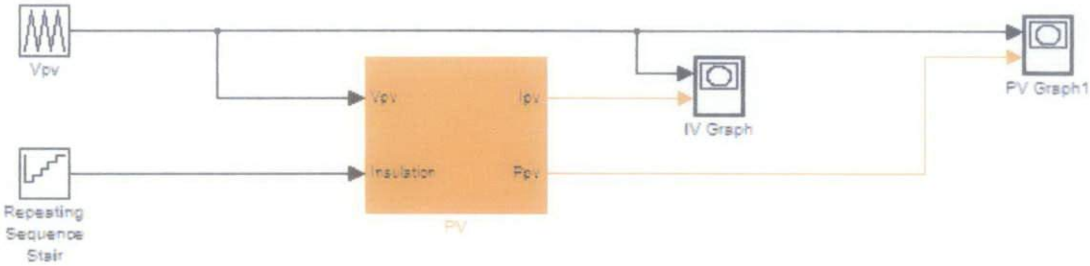


Figure 29: PV cell with variation of level insolation

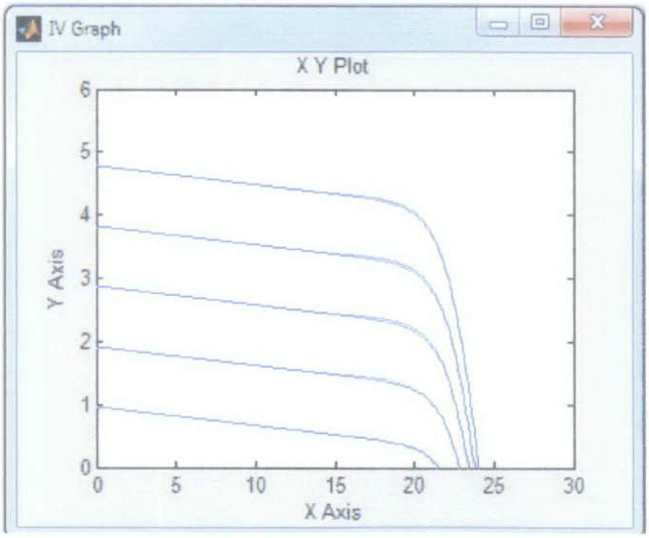


Figure 30: IV characteristic of PV cell with variation of level insolation

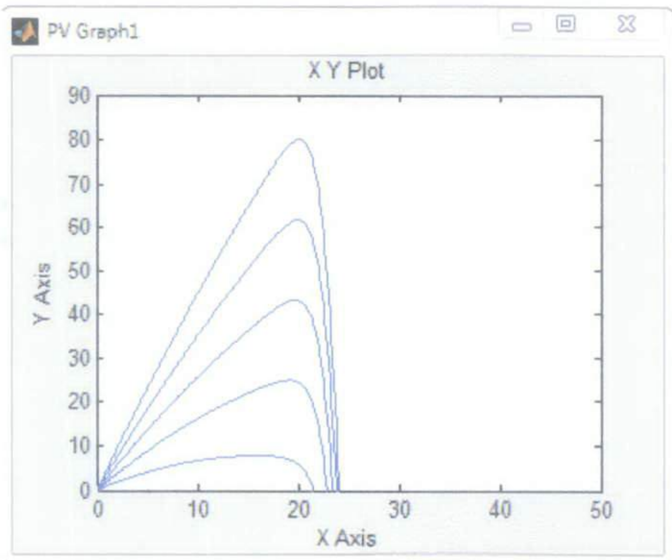


Figure 31: PV characteristic of PV cell with variation of level insolation

4.3 DC-DC Boost Converter

For buck-boost dc-dc converter, we control the output voltage Vo by changing the duty cycle D. With the conversion for buck-boost converter as following equation:

$$\frac{V_o}{V_i} = \frac{-D}{1-D}$$

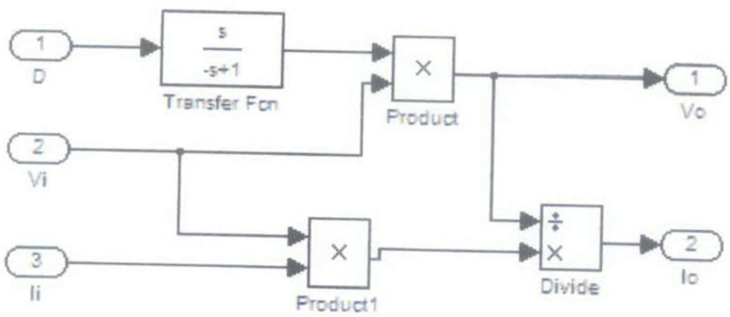


Figure 32: Buck-boost dc-dc converter

Using PWM to control voltage output, along with PID controller, the output voltage will be achieved same as Vref input to PID controller, this is showed in figure 32. In figure 33 is output voltage from PID controller when input voltage is set to 25V. We can see that the controller give a constant output value with high accuracy.

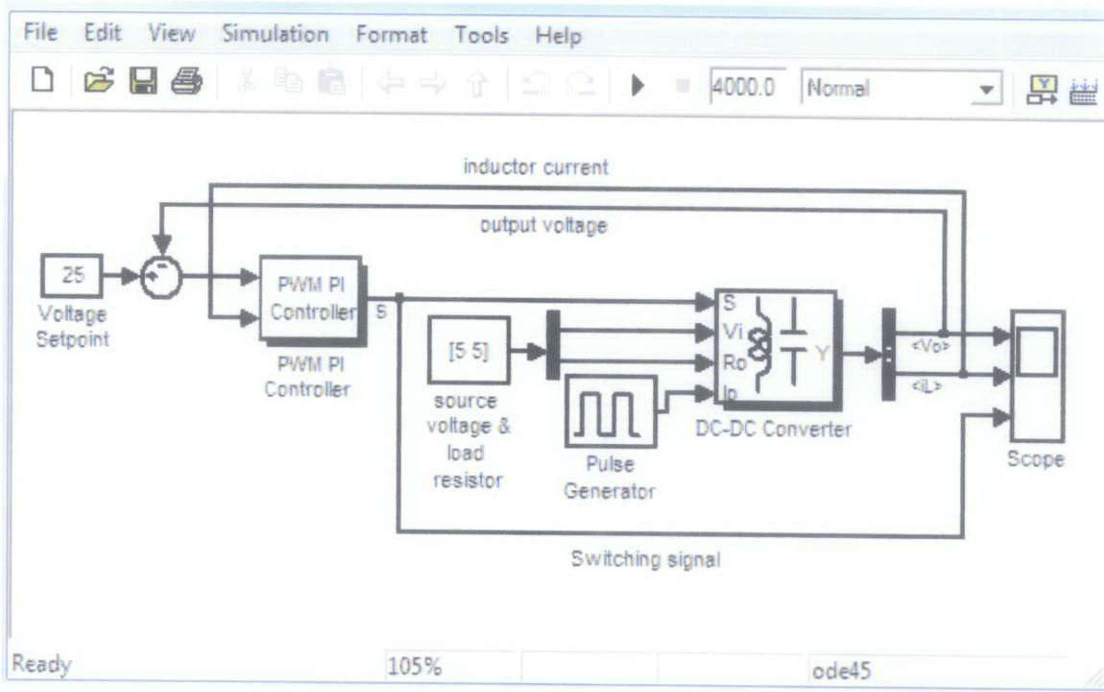


Figure 33: DC-DC boost converter with PWM controlled by PID

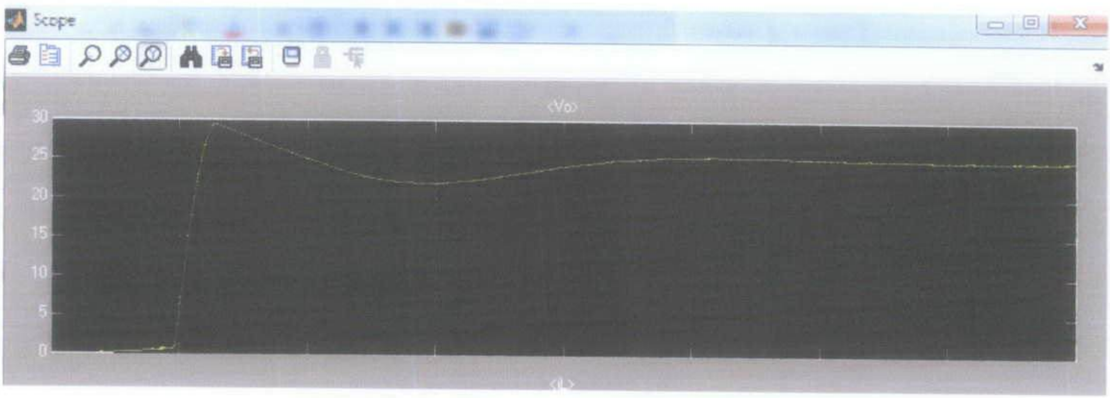


Figure 34: Output of dc-dc converter

4.4 PV System Using P&O Technique

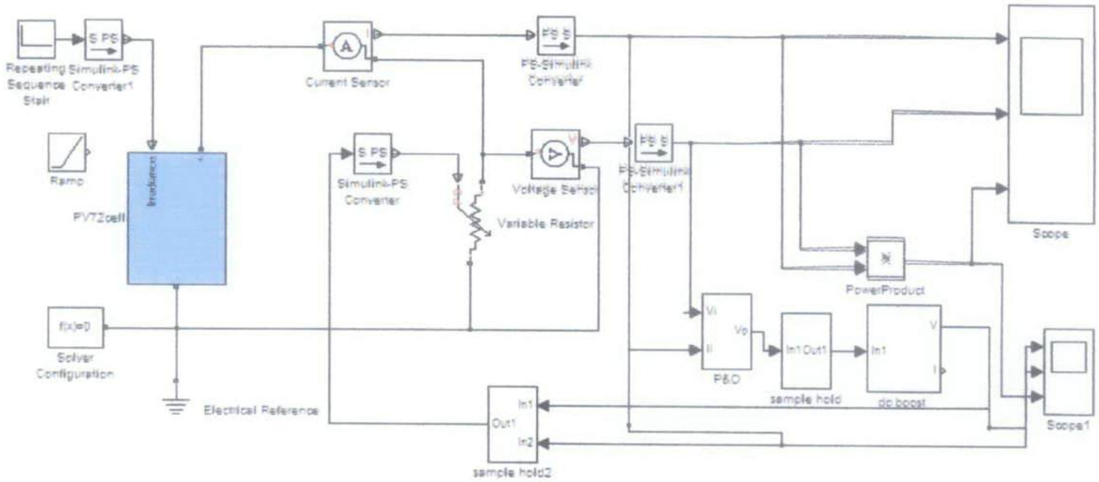


Figure 35: System with P&O technique

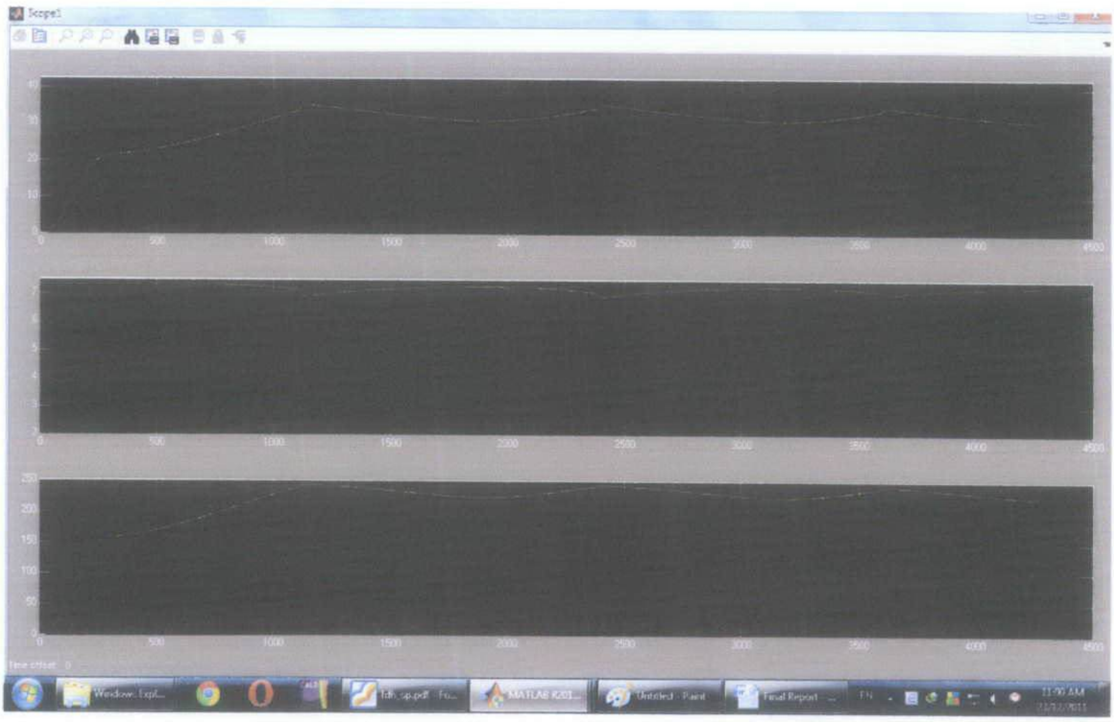


Figure 36: Result of voltage-current-power from top to bottom of the graph

4.5 PV System Using IC Technique

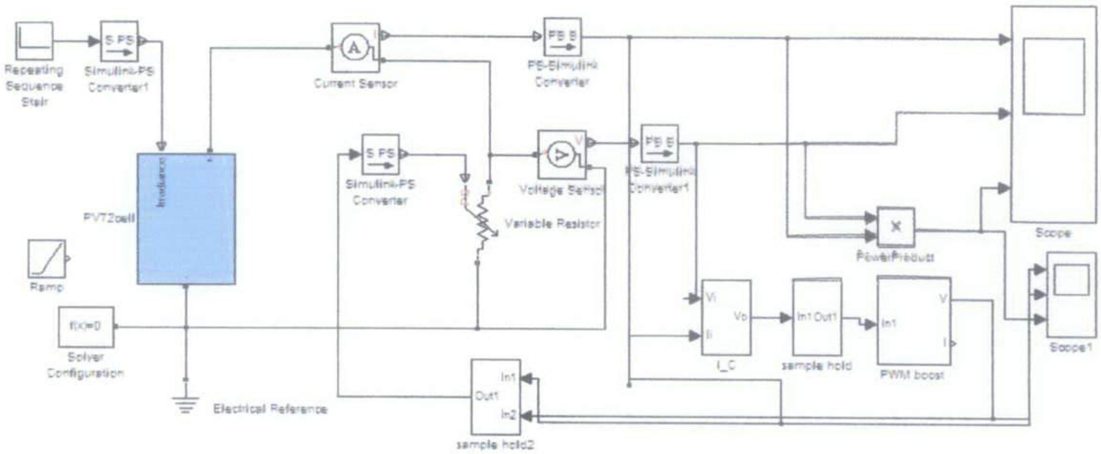


Figure 37: System with IC technique

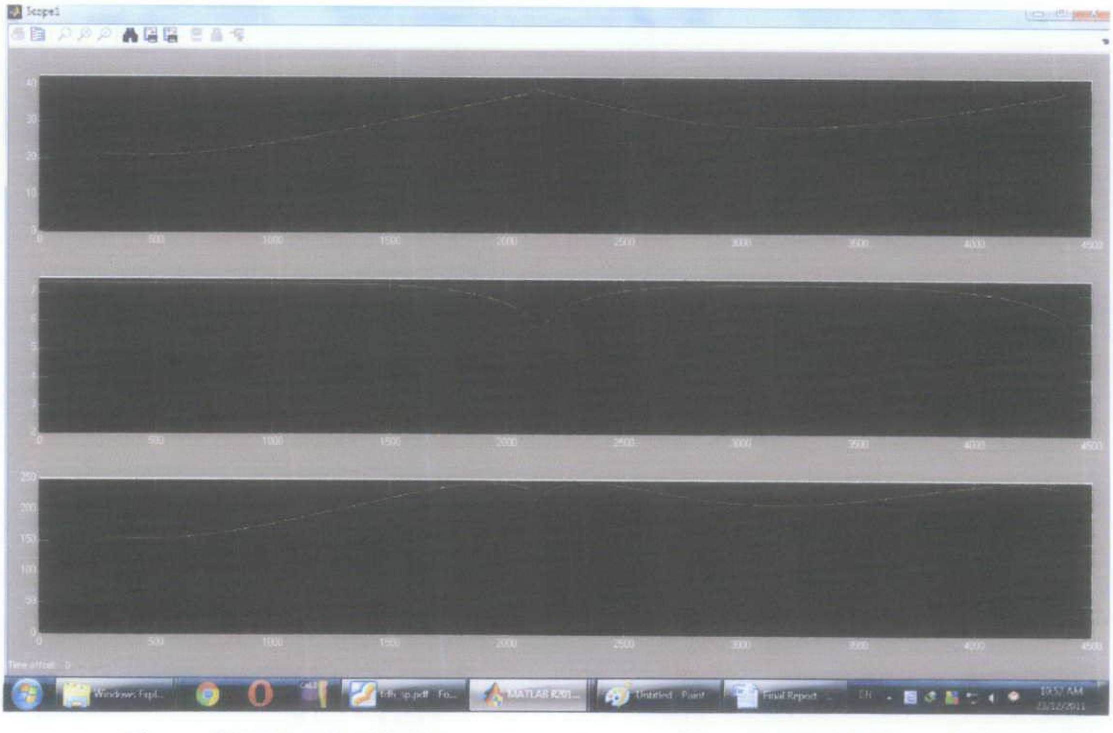


Figure 38: Result of voltage-current-power from top to bottom of the graph

4.6 System Without MPPT

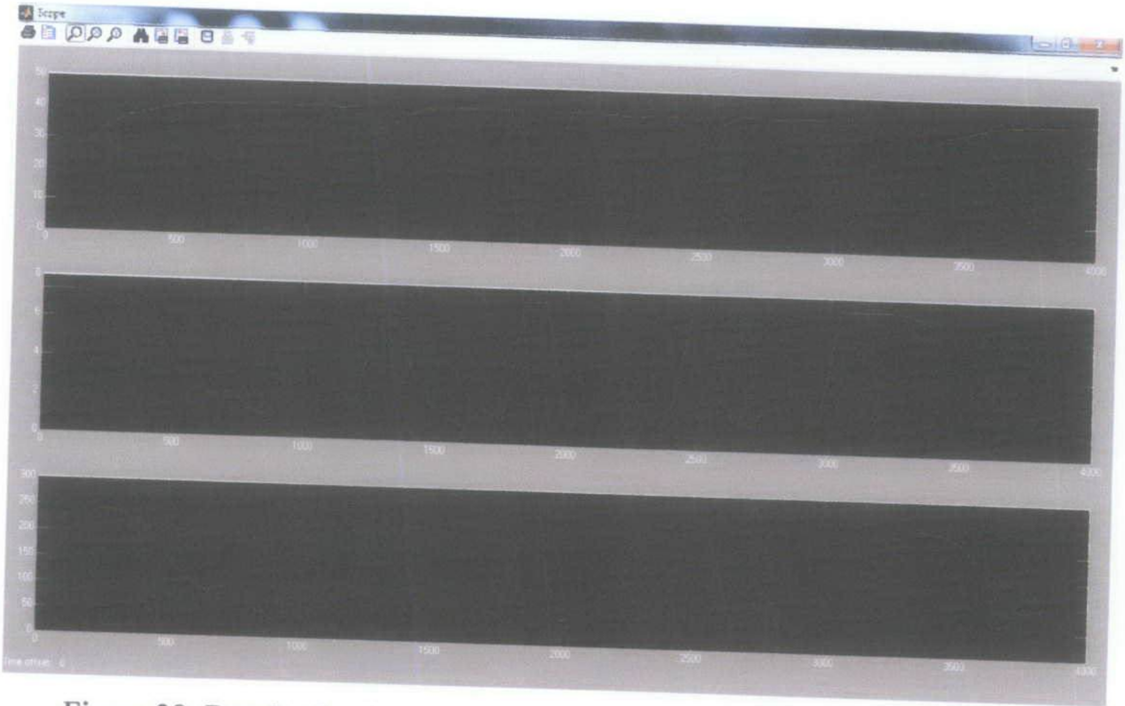


Figure 39: Result of voltage-current-power from top to bottom of the graph

4.7 Comparing Results & Calculate Efficiency

From two graphs we get when using P&O and IC, we can see that P&O can track to the maximum power point faster than IC does, with less oscillation and maintain at higher range of maximum power. When P&O can maintain power output at range 225-250W after reach the maximum power point, the IC only varies at range 200-250W, it means P&O give the higher efficiency.

In this simulation, I also improve P&O to track MPP faster by expand the delta-V (the step change of voltage). This can help to track faster but also my lead to more oscillation, but in my result it turns out well and smoothly.

Calculate efficiency:

Based on data values from Matlab, we get parameters:

a) System without MPPT

   The average power acquired: P= 156W

b) System with P&O technique

   The average power acquired: P= 239W

The efficiency improved: $\frac{239-156}{156} \times 100 = 53.21\%$

c) System with IC technique

The average power acquired: P= 226W

The efficiency improved: $\frac{226-156}{156} \times 100 = 44.87\%$

From the calculations, using MPPT techniques can improve efficiency of PV system. With tracking the maximum power point, the power acquired is much more higher than the ordinary system. The system with P&O technique can increase 53.21% power, and the system with IC technique increases 44.87% power, compared to the ordinary PV system. That is a very big improvement, we can conclude that MPPT should be applied to PV system. And among MPPT techniques, P&O currently is the best technique with the highest performance.

CHAPTER 5
CONCLUSION & FUTURE WORK

In conclusion, MPPT for PV system is very practical and significant nowadays. Since new sources of energy are being encouraged to be used, and among them solar energy is one of most clean and harmless. So developing this system can contribute a lot for research as well as in industry. In this project I has been trying to do simulation this system, in order to find the way to improve and gain efficiency. The two best techniques have been used to test the output power. The Perturbation & Observation (P&O) technique shows the better result compare to Incremental Conductance (IC) technique, with faster tracking and maintain at higher range of MPP.

The future work after done with simulation will be do implementation using hardware. The P&O technique also needs to improve to get higher efficiency. The implementation prototype might face some difficulties because of lacking equipment, in-accurate equipment.Hopefully with effort and tries, the implement will be done and show a good result.

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