**UNIVERSITI MALAYSIA PAHANG**

## BORANG PENGESAHAN STATUS TESIS♦

**JUDUL:** **PV MODULE MAXIMUM POWER POINT TRACKER(MPPT) USING MICROCONTROLLER**

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# PV MODULE MAXIMUM POWER POINT TRACKER(MPPT) USING MICROCONTROLLER

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This thesis is submitted as partial fulfillment of the requirements for the award of the Bachelor of Electrical Engineering (Hons.) (Electronics)

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*Specially dedicated with lots of loves to*

*My beloved parent*

*Ismail  Salim & Samidah Ab Samad*

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**ABSTRACT**

PV Module Maximum Power Point Tracker(MPPT) , is a photovoltaic system that uses the photovoltaic array as a source of electrical power supply. 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. The function of MPPT is needed to operate the PV array at its maximum power point. The design of a Maximum Peak Power Tracking (MPPT) is proposed utilizing a boost-converter topology. Solar panel voltage and current are continuously monitored by a closed-loop microprocessor based control system, and the duty cycle of the boost converter continuously adjusted to extract maximum power. The design consists of a PV array, DC-DC Boost converters (also known as step-up converters) and a control section that uses the PIC16F877A microcontroller. The control section obtains the information from the PV array through microcontroller's Analog to Digital Converter (ADC) ports and hence to perform )the pulse width modulation (PWM) to the converter through its Digital to Analog Converter (DAC) ports. Many such algorithms have been proposed. However, one particular algorithm, the perturb-and-observe (P&O) method, claimed by many in the literature to be inferior to others, continues to be by far the most widely used method in commercial PV MPPT's.

*(Keywords: Boost Converter, Pulse Width Modulation,PIC16F877A)*

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| | | |
|---|---|---|
| PWM | - | Pulse Width Modulation |
| MPPT | - | Maximum Power Point Tracker |
| PV | - | Photovoltaic |
| DC | - | Direct Current |
| D,d | - | Duty Ratio |
| DCM | - | Discontinuous Current Mode |
| CCM | - | Continuous Current Mode |
| MOSFET | - | Metal Oxide Silicon Field Effect Transistor |

## LIST OF APPENDICES

# CHAPTER 1

# INTRODUCTION

## 1.1 Introduction

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.

The problem faced by MPPT is it not perfectly delivered the output voltage as stated, since the outputs of PV system are depends on the temperature, irradiation, and the load electrical characteristic. So, that's why MPPT is needed to be implementing in the PV system to maximize the PV array output voltage.

## 1.2 Overview of Photovoltaic (PV)

Photovoltaic (PV) is the field of technology and research related to the application of solar cells for energy by converting sunlight directly into electricity. Photovoltaic are generally known as a method for generating solar power by using solar cells packaged in photovoltaic modules, often electrically connected in multiples as solar photovoltaic arrays to convert energy from the sun into electricity. In the simple words the photons from sunlight knock electrons into a higher state of energy, creating electricity. The term photovoltaic denotes the unbiased operating mode of a photodiode in which current through the device is entirely due to the transduced light energy. Virtually all photovoltaic devices are some type of photodiode. Solar cells produce direct current electricity from light, which can be used to power equipment or to recharge a batterylead acid.

PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. These values correspond to a particular resistance, which is equal to V/I as specified by Ohm's Law. A PV cell has an exponential relationship between current and voltage, and the maximum power point (MPP) occurs at the knee of the curve as shown in Figure 1.0, where the resistance is equal to the negative of the differential resistance (V/I = -dV/dI).

## 1.3 Overview of Maximum Power Point Tracker (MPPT)

A maximum power point tracker (MPPT) is a high efficiency DC to DC converter which functions as an optimal electrical load for a photovoltaic (PV) cell, most commonly for a solar panel or array, and converts the power to a voltage or current level which is more suitable to whatever load the system is designed to drive. PV cells have a single operating point where the values of the current (I) and Voltage (V) of the cell result in a maximum power output. Maximum power point trackers utilize some type of control circuit or logic and algorithm to search for this point and thus to allow the converter circuit to extract the maximum power available from a cell.

In short , photovoltaic (PV) arrays are used to provide energy and MPPT are used to correct the variations in the current-voltage characteristics of the solar cells. The Figure 1.0 is an idealized curve with no deformations due to cell damage or bypass diodes kicking in. The point on the current-voltage (I-V) curve of a solar module under illumination, where the product of current and voltage is maximum ($P_{max}$, measured in watts). The points on the I and V scales which describe this curve point are named $I_{mp}$ (current at maximum power) and $V_{mp}$ (voltage at maximum power.).

For a typical silicon cell panel, the maximum power point (MPP) is about 17 volts for a 36-cell configuration. For the array to be able to delivered the maximum possible amount of power, either the operating voltage or current needs to be carefully controlled. This maximum power point is seldom located at the same voltage the main system is operating at, and even if the two were equal initially, the power point would quickly move as lighting conditions and temperature change (varied under the ambient condition). Hence, a device is needed that finds the maximum power point and converts that voltage to a voltage equal to the system voltage.

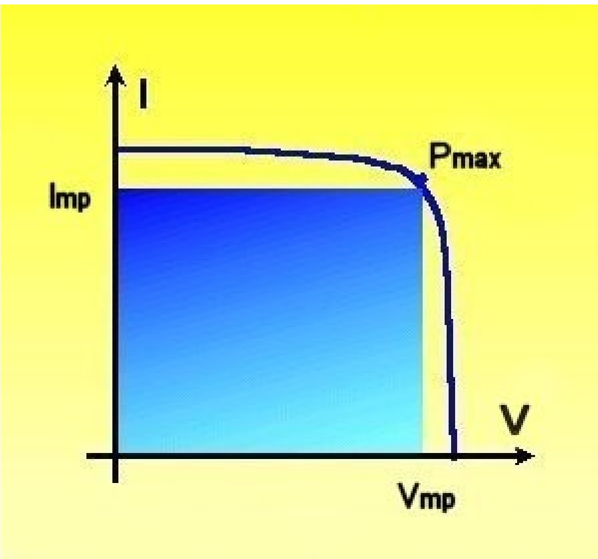


**Figure 1.0 :** MPP characteristic

## 1.4 Objectives

i. Implementation of microcontroller in the MPPT system.
   - The used of the microcontroller to control the D (duty cycle for the boost converter) by the algorithm that has been choosen.

   .

ii. The operation of the PV module should be forced to operate at maximum power point under varying ambient condition.

## 1.5 Scopes of Project

This project relates to a method and a device for implementing the method that tracks the optimal maximum power point in a system that supplies power from a direct-current power source, such as that generated by a solar cell array (photovoltaic generator)

i. The choosing of DC-DC converter based on the desired output voltage from the MPPT in term to ensure the PV module will operate at the maximum point.
   - The DC-CC converter that will be used in this project is the Boost Converter. The power MOSFET in the circuit act as the switching element towards the converter due to its capability in sustaining the high level current and voltage. The PIC will act as the controller of the circuit by giving the signal to the power MOSFET for its switching mode (On and off) to produce the desired voltage.

ii. The implementation of microcontroller (PIC16F877A) to produce PWM.

- PIC16F877A is used to generate PWM by using crystal 20MHz, the maximum PWM frequency value can be generated by PIC16F877A is 208.3 kHz. The duty cycle can be start from 0 to 0.99. [5]

# CHAPTER 2

# THEORY AND LITERATURE REVIEW

## 2.1 MPPT

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.[1]

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.

## 2.2 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.[3] 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 2.1 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.

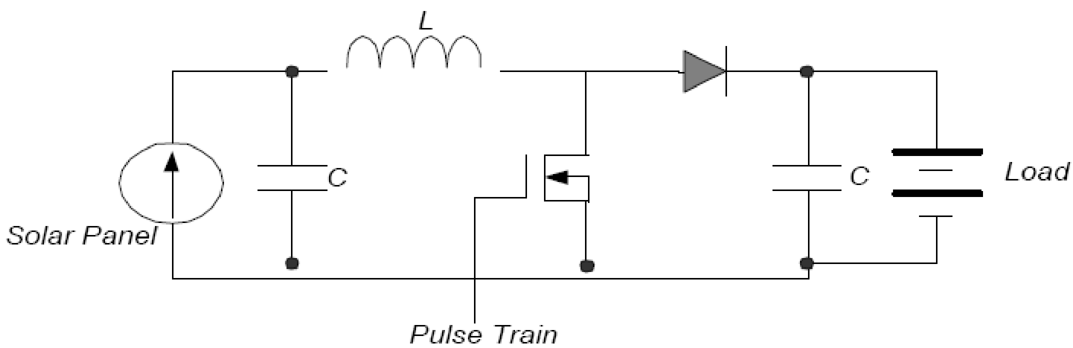


**Figure 2.1 :** Boost Circuit

### 2.2.1 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 2.2 and 2.3.

- In figure 2.2 at the On-state,, resulting in an increase in the inductor current;
- In Figure 2.3 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.

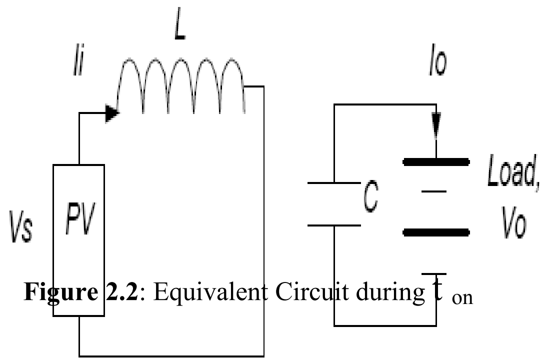



**Figure 2.2**: Equivalent Circuit during $t_{on}$

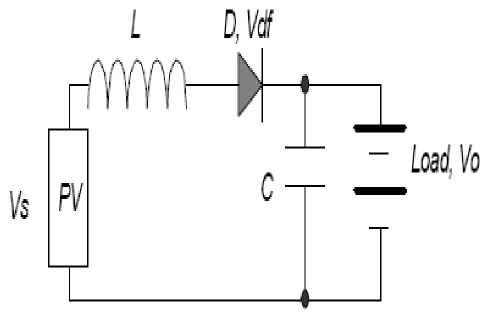


**Figure 2.3**: Equivalent Circuit during $t_{off}$

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 ($I_L$) never falls to zero. Figure 2.4 shows the typical waveforms of currents and voltages in a converter operating in this 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 ($V_i$) appear across the inductor, which causes a change in current ($I_L$) flowing through the inductor during a time period (t) by the formula:

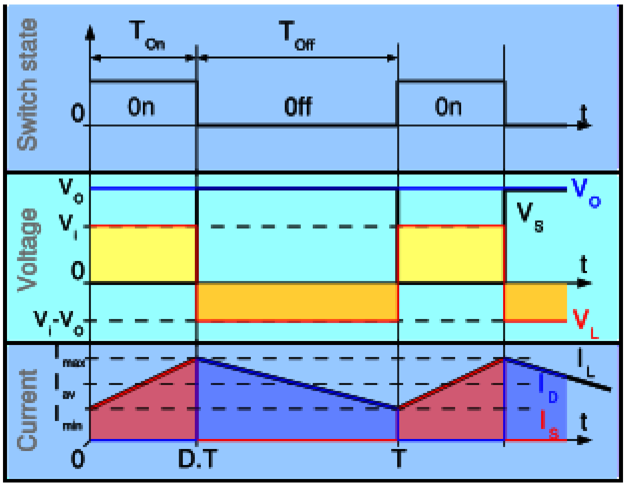



**Figure 2.4**: Waveforms of current and voltage in a boost converter operating in continuous mode

$$\Delta I_L / \Delta t = V_i / L \quad (1)$$

At the end of the On-state, the increase of $I_L$ is given by:

$$\Delta I_{L\,on} = (Vi\,.D.\,T) / L \quad (2)$$

D is the duty cycle. It represents the fraction of the commutation period T during which the switch is On. Therefore D ranges between 0 (S is never on) and 1 (S is always on). During the Off-state, the switch S is open, so the inductor current flows through the load. By considering there was zero voltage drops in the diode, and a capacitor large enough for its voltage to remain constant, the derivation of $I_L$ is:

$$\mathbf{V_i - V_o = L\, dI_L / dt} \qquad (3)$$

Therefore, the variation of $I_L$ during the Off-period is:

$$\Delta \mathbf{I}_{\mathbf{L\,off}} = \mathbf{(Vi\text{-}Vo)(1\text{-}D)\ T] / L} \qquad (4)$$

As we consider that the converter operates in steady-state conditions, the amount of energy stored in each of its components has to be the same at the beginning and at the end of a commutation cycle. In particular, the energy stored in the inductor is given by:

$$\mathbf{E = 0.5L \,.\, I_L^{\,2}} \qquad (5)$$

Therefore, the inductor current has to be the same at the beginning and the end of the commutation cycle. This can be written as

$$\Delta \mathbf{I}_{\mathbf{L\,on}} + \Delta \mathbf{I}_{\mathbf{L\,off}} = \mathbf{0} \qquad (6)$$

Substituting $\Delta \mathbf{I}_{\mathbf{L\,on}}$ and $\Delta \mathbf{I}_{\mathbf{L\,off}}$ by their expressions yields:

$$\Delta \mathbf{I}_{\mathbf{L\,on}} + \Delta \mathbf{I}_{\mathbf{L\,off}} = [(Vi\ .D.T) / L] + [(Vi\ \text{-}Vo).(1\text{-}D)T] / L = 0 \qquad (7)$$

This can be written as:

$$\mathbf{V_o / V_i = 1/(1\text{-}D)} \qquad (8)$$

Which in turns reveals the duty cycle to be:

$$\mathbf{D = 1\text{-}\ (V_i / V_o)} \qquad (9)$$

From the above expression it can be seen that the output voltage is always higher than the input voltage (as the duty cycle goes from 0 to 1), and that it increases with D, theoretically to infinity as D approaches 1. This is why this converter is sometimes referred to as a step-up converter.

While during the discontinuous mode occurs, the amount of energy required by the load is small enough to be transferred in a time smaller than the whole commutation period. In this case, the current through the inductor falls to zero during part of the period. The only difference in the principle described above is that the inductor is completely discharged at the end of the commutation cycle see waveforms in Figure 2.5. The difference has a strong effect on the output voltage equation. It can be calculated as follows:

As the inductor current at the beginning of the cycle is zero, its maximum value $I_{L\,max}$ (at t=D.T) is

$$\mathbf{I_{L\,MAX} = (V_i.\ D.T) / L} \tag{10}$$

During the off-period, $I_L$ falls to zero after δ.T:

$$\mathbf{I_{L\,MAX} + [\ (Vi\ Vo).\ \Delta.T] / L = 0} \tag{11}$$

Using the two previous equations, δ is:

$$\mathbf{\delta = (\ Vi\ .D) / (Vo-Vi)} \tag{12}$$

The load current $I_o$ is equal to the average diode current ($I_D$). As can be seen on figure 4, the diode current is equal to the inductor current during the off-state. Therefore the output current can be written as:

$$\mathbf{I_o = I_D = (I_{L\,MAX} / 2)\ .\ \delta} \tag{13}$$

Replacing $I_{Lmax}$ and δ by their respective expressions yields:

$$\mathbf{I_o = (Vi^2\ .\ D^2\ .\ T) / 2L\ (V_o - V_i)} \tag{14}$$

Therefore, the output voltage gain can be written as :

$$\mathbf{V_o / V_i = 1 + [(V_i . D^2.T) / (2L .I_o)} \qquad (15)$$

Compared to the expression of the output voltage for the continuous mode, this expression is much more complicated. Furthermore, in discontinuous operation, the output voltage gain not only depends on the duty cycle, but also on the inductor value, the input voltage, the switching frequency, and the output current.

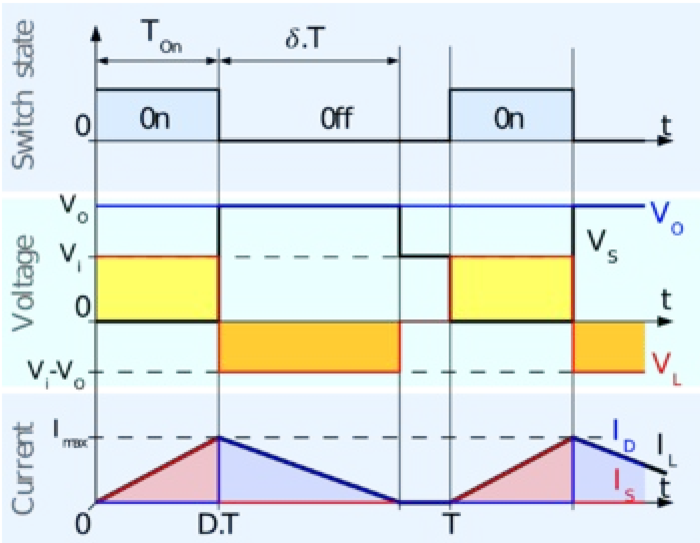



**Figure 2.5**: Waveforms of current and voltage in a boost converter operating in Discontinuous mode

## 2.3 MOSFET Driver

A gate voltage ($V_{G)}$ is always needed to control the switching of the MOSFET, enabling it to behave as a switch in the boost converter. This voltage $V_G$, 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).[5]

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.

### 2.4 Pulse Width Modulation (PWM)

Pulse width modulation (PWM) is a powerful technique for controlling analog circuits with a processor's digital outputs. PWM is employed in a wide variety of applications, ranging from measurement and communications to power control and conversion. By controlling analog circuits digitally, system costs and power consumption can be drastically reduced. What's more, many microcontrollers and DSPs already include on-chip PWM controllers, making implementation easy.

Shortly, PWM is a way of digitally encoding analog signal levels. Through the use of high-resolution counters, the *duty cycle* of a square wave is modulated to encode a specific analog signal level. The PWM signal is a digital because, at any given instant of time, the full DC supply is either fully on or fully off. The voltage or current source is supplied to the analog load by means of a repeating series of on and off pulses. The on-time ($T_{on}$) is the time during which the DC supply is applied to the load, and the off-time ($T_{off}$) is the period during which that supply is switched off. Given a sufficient bandwidth, any analog value can be encoded with PWM.

Figure 2.6 shows three different PWM signals. Figure 2.6a shows a PWM output at a 10% duty cycle. That is, the signal is on for 10% of the period and off the other 90%. Figures 2.6b and 2.6c show PWM outputs at 50% and 90% duty cycles, respectively. These three PWM outputs encode three different analog signal values, at 10%, 50%, and 90% of the full strength. If, for example, the supply is 9V and the duty cycle is 10%, a 0.9V analog signal results. Common modulating frequencies range from 1 kHz to 200 kHz.

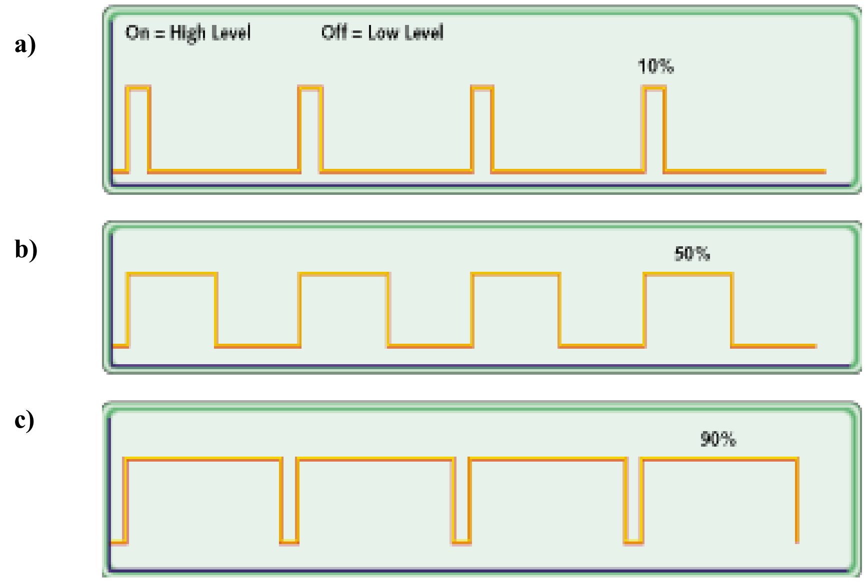



**Figure 2.6:** PWM signals of varying duty cycles

### 2.5 PIC16F877A

The function of PIC in this project to generate the PWM, according to the datasheet there is some steps need to be considered during the programming of the PIC :

1. Setting the PWM period
2. Setting the duty cycle.
3. select the output pin and enable timer
4. enable the PWM controller.

### 2.6 **MPPT Algorithm**

In developing MPPT there are many algorithm has been used, the most that has been used is P&O (Perturb and Observation) and INC (Incremental Conductance Technique). The P&O algorithms are widely used in MPPT because of their simple structure and the few measured parameters required. By referring to Figure 2.7 it operate by periodically perturbing (i.e. incrementing or decrementing) the array terminal voltage and comparing the PV output power with that of the previous perturbation cycle. If the power is increasing the perturbation will continue in the same direction in the next cycle, otherwise the perturbation direction will be reversed. This means the array terminal voltage is perturbed every MPPT cycle; therefore when the MPP is reached, the P&O algorithm will oscillate around it resulting in a loss of PV power, especially in cases of constant or slowly varying atmospheric conditions. This problem can be solved by improving the P&O algorithm's logic for comparing the parameters of two preceding cycles. If the MPP is reached, the perturbation stage is bypassed

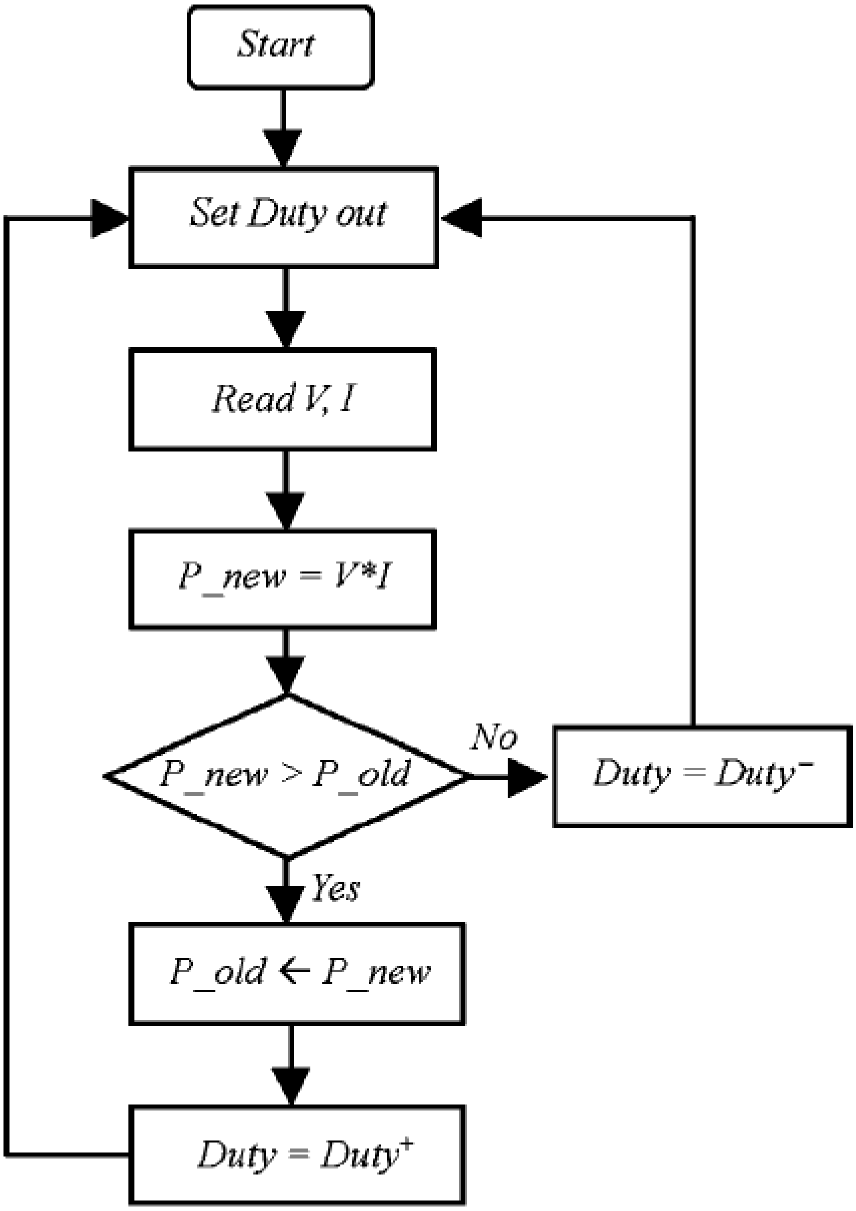



**Figure 2.7:** P&O Algorithm Flow Chart

# CHAPTER 3

# METHODOLOGY AND DESIGN

## 3.1 Introduction

This chapter will cover the steps to design the MPPT and the specifically explains each part of the MPPT. Including the hardware and software implementations during the designing process. Generally the MPPT design can be divided into two parts hardware and software. The software used in this project are P Spice for the circuit design, the importance of this process part to ensure all the values of the components that has been calculated can be ideally implement in the real hardware. The other one is Microcode Studio for Microcontroller programming.

## 3.2 System Design

In designing process of the project the system has been designs separately by parts software and hardware. In Figure 3.1 its shown the general overview of the MPPT project.

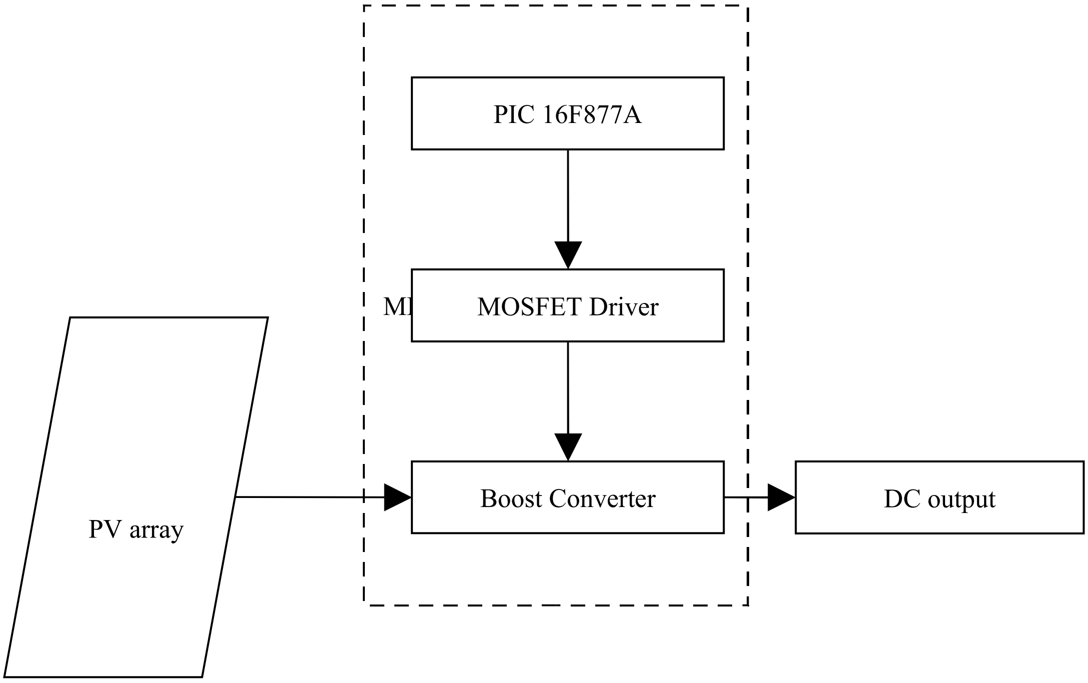



**Figure 3.1:** Block Diagram of MPPT Interface with the PV Array

Figure 3.1 Block diagram descriptions:

**A/D converter** : Convert the voltage value (analog) in digital signal to be process in microcontroller.

**Microcontrolle**r: Will be implement with the algorithm (PAO) to control the PWM or D value. Simply said as the brain of the circuit.

**Boost converter**: The main item of the project, function to ensure the PV panel will be able to deliver the maximum value with any restriction condition such as cloudy day , shadow and etc. controlled by PWM value from the microcontroller.

**Load** : Will be the DC load as the output are the step up DC voltage.

The MPPT was designed to ensure the PV panel will operate at the maximum power point to delivered the maximum output power. The optimum voltage of the PV panel is 17.4 volt, so without affected by any disturbances its will ensure the output power will at 80Watt.

The ultimate part is the Boost circuit to ensure the voltage output will be at the maximum operating point. The circuit will Boost the input voltage according to the duty cycle of the PWM. The PIC wills continuously operate to produce PWM towards the MOSFET as it as switch of the converter. The MOSFET IRFP150PN is used because the sustainable of high inputs voltage and current 100 volt and 44 A.

The second part is the PIC16F877A act as the prior controller of the Boost circuit, the PWM will produced towards the MOSFET continuously and directly regulate the duty cycles to ensure the V out at the maximum level. The ADC converter will ranging the $V_{in}$ and some calculation will be done through simple algorithm to regulate the duty cycle of the PWM.

The last part is the MOSFET driver circuit. This circuit function to turn on the MOSFET IRFP150N, with minimum voltage is 20 volt.

## 3.3 PV ARRAY SW 80 mono/R5E

The Figure 3.2 show the PV Array that being used in this project. The Sunmodule SW 80 mono/R5E is used in this project since it is ideally suitable for the requirements of applications of any kind to be performed off-grid. The highest demands with regard to manufacturing quality and the many years of Solar World's practical experience guarantee the solar power module’s long life span at high levels of performance, even under extreme conditions. Table 3.1 shows the Electrical characteristic of the SW 80 mono/R5E.

**Figure 3.2:** Sunmodule SW 80 mono/R5E

. The module is suitable for industrial applications such as the power supply of telecommunication systems at off-grid locations as well as for a number of applications that have to do with supplying power in remote rural areas. Because of its compact dimensions and the solid workmanship of its aluminum frame, it can be mounted easily and flexibly. The water repellent junction box allows the modules to be connected easily and safely and facilitates a simple and quick installation process. The junction box is equipped with four grommets and cable terminals inside of the box. Series connection of modules for systems with higher system voltage is just as possible as is a parallel connection for systems with higher operating current.

| | |
|---|---|
| Maximum power $P_{max}$ | 80 Wp |
| Open circuit voltage $V_{oc}$ | 21.9 V |
| Maximum Power Point voltage $V_{mpp}$ | 17.5 V |
| Short circuit current $I_{sc}$ | 5.00 A |
| Maximum power point current $I_{mpp}$ | 4.58 A |

**Table 3.1**: Specification of the SW 80 mono/R5E

### 3.4 Boost Circuit

Since the DC Converter is the most important part of the system, so in designing the circuit there is a lot of things need to be considered. As being stated this project will use Boost Converter as the DC converter, the detail about the converter will be discussed in details in the next subchapters.

#### 3.4.1 Why Boost?

An MPPT in a photovoltaic system may be based on Buck or Boost converters The output voltage of a Buck converter is lower than the input voltage, conversely, the Boost converter steps up the input voltage. If the required voltage of the MPPT based on the Boost converter is higher than the desired output voltage one may use a Buck converter as the second stage to lower the voltage and still obtain a higher energy efficiency than for the case if the MPPT would be based on the Buck converter. Only for duty-cycles approaching 100% the Buck converter approaches the energy efficiency of the Boost converter. However in this case the control capability (controlling the duty-cycle) is very limited whereas for the Boost converter the energy efficiency varies slightly with the duty-cycle.

#### 3.4.2 Boost Design

The boost circuit was design by referring to the basic boost circuit as in Figure 3.3, after doing the calculation to determine the values of each components the circuit has been simulate through the P Spice to get the best value of each components in order to achieve the great result in the real circuit.

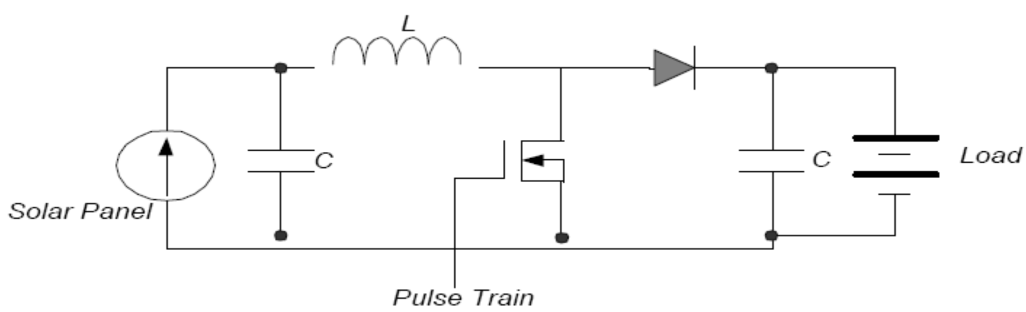


**Figure 3.3:** Boost Circuit

Generally the purpose of using the Boost Converter is to ensure the output voltage will be at maximum operating point of the PV panel 17.1Volt. the voltage output supposedly not be affected by the ambient situation or an cause that can the deteriorating the performance of the PV array.

Determination of minimum values of each component in the circuit. :

Assumption in Calculation: R = 50 ohm

Ripple = <1%

F=100 kHz

Applying the possible minimum values of $V_O$ and $V_S$ to determine D value

Using $D = 1 - \frac{V_i}{V_o}$ , so:

D = 1- $(V_i / V_O)$

D= 1- (10/17)

**D = 0.41**

Determine the inductor minimum value:

$$L_{min} = [D(1-D)^2R]/2f$$

L= $[0.41(0.59)^2 50] / 2*100k$

**$L_{min}$ = 36.0uH**

For C :

D / RCF < 0.01

C > 0.41 / [50*100k* 0.01]

**C >8.2 uFarad**

In order to get the best performance of Boost Circuit a few simulation has been proceed to determine the values of the capacitor, inductor and resistor. Below are the simulation result using the difference value of L and C. Figure 3.4 was being applied with 8.2 uF Capacitor and 36uH Inductor while for Figure 3.5, 680 uF Capacitor and 47uH Inductor. Figure 3.5 shown the very great ripple compare to Figure 3.4 because the differences of the components values. Both simulations have the same value of $V_{in}$ = 7volt .So the highest value of Capacitor and inductor is chosen. Since the highest value of capacitor effectively reduced the ripple.

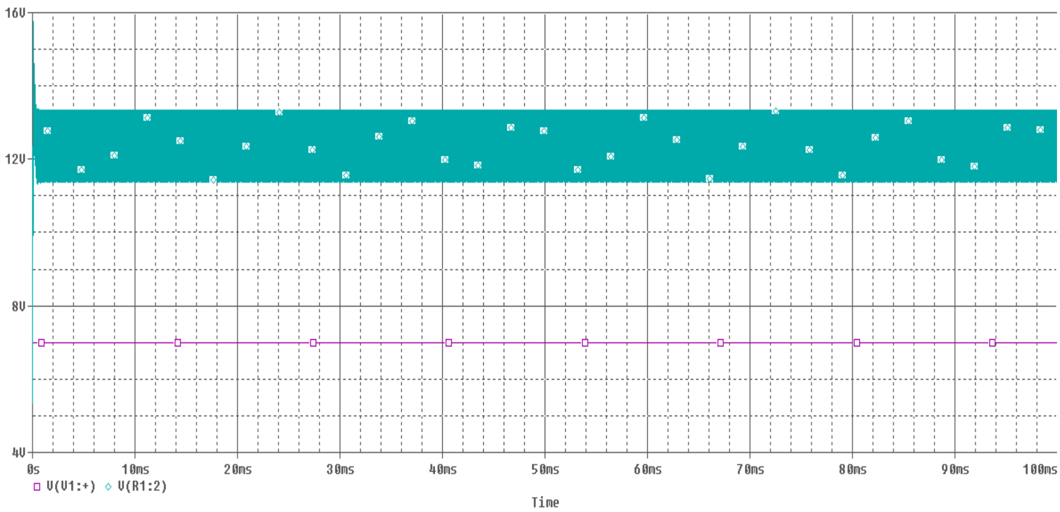



**Figure 3.4:** Simulation result using L= 36uH C=8.2uF

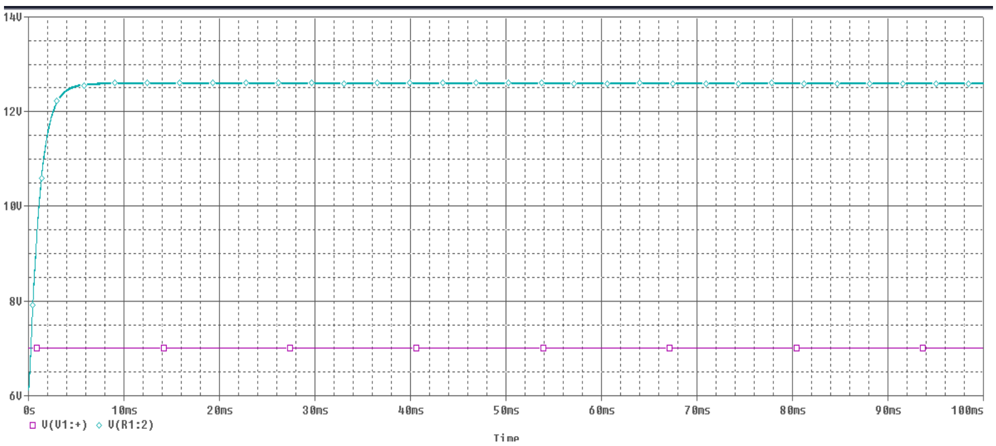



**Figure 3.5:** Simulation result using L= 47uH C=680uF

Hence the circuit has been finalized after considering the suitable values of the Inductor and Capacitor from the simulation result previously. The value are 680uF for the Capacitor and 47uH for inductor. Figure 3.6 show the circuit that will be used in the real hardware :

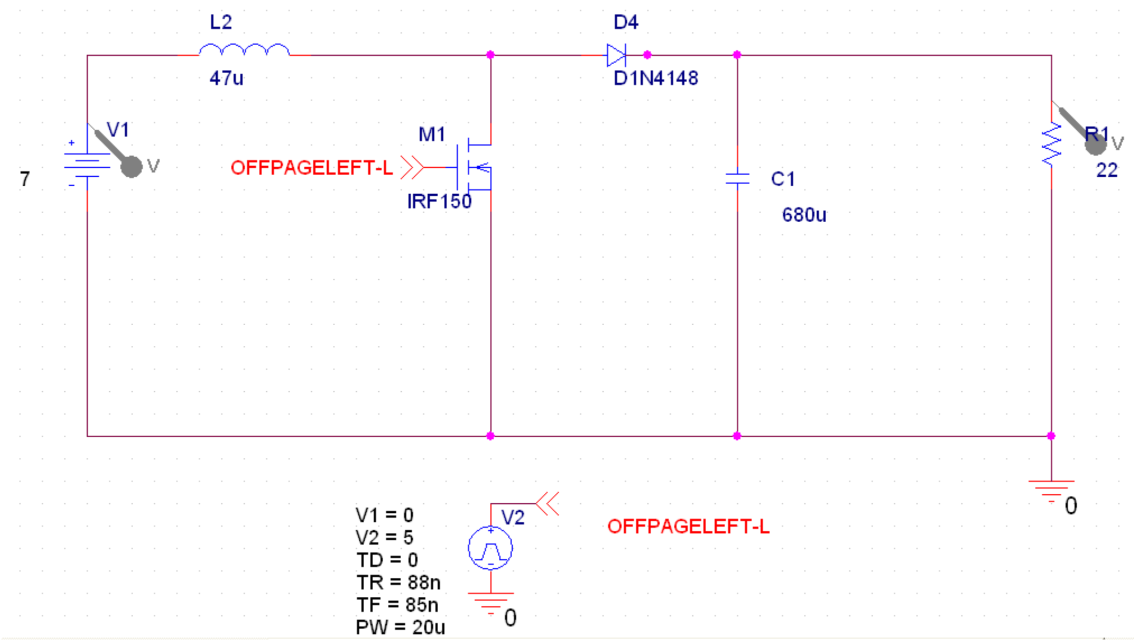



**Figure 3.6:** Final Circuit to Implement

### 3.5 PIC16F877A

PIC16F877A is one of the PIC microcontroller with PWM pins and ADC build in. 5 volt is needed to turn on the PIC the pins needs to supply with 5 volts are $V_{pp}$(1) and $V_{dd}$ (11and 32). The value from input voltage are taken from pin 2 as the Vin changing the value of duty cycle also being range by the controller and the PWM output connect directly towards to the driver. The assembly language is used to program the PIC. Figure 3.7 show the PIC16F877A pins:

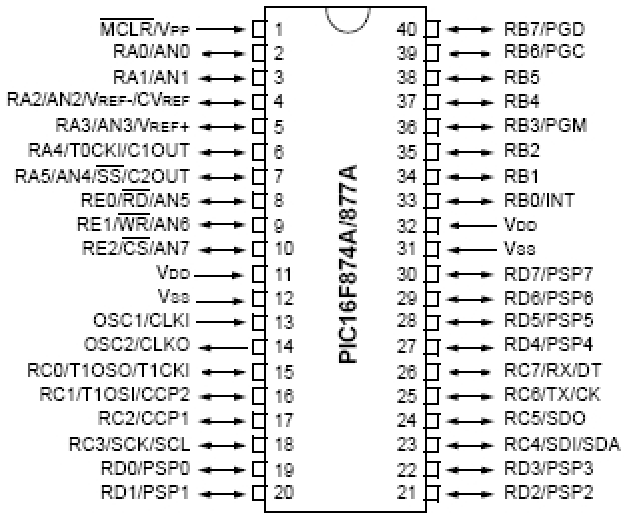
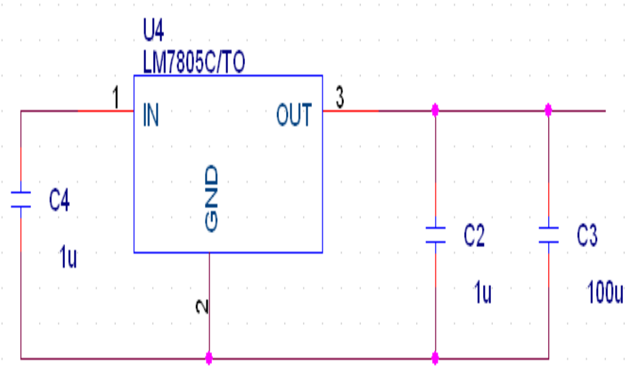



**Figure 3.7 :**PIC16F877A pins

Since PIC16F877A generally need 5 volt to turn on so the 5 volt power supply circuit is being used by using LM7805 voltage regulator to ensure only 5 volt was supply to the PIC to avoid over voltage and cause damage to the PIC.the connection as in Figure 3.8 The clock circuit in Figure 3.9 is used with the 8 MHz crystal oscillator to produce 100 kHz frequency from the PIC.



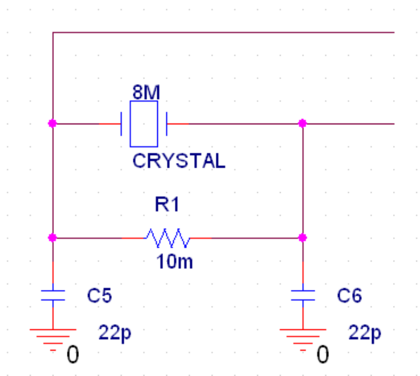




**Figure 3.8:** 5 volt DC Power S

5 volt dc power sup

**Figure 3.9:**Clock Circuit

After the both circuit has been implemented the PWM output was been observed by using the oscilloscope. Figure 3.10 and Figure 3.11 shows the output waveforms results of differences value of D(varied using the variable resistor) the differences clearly seen in the positive width in the waveform .

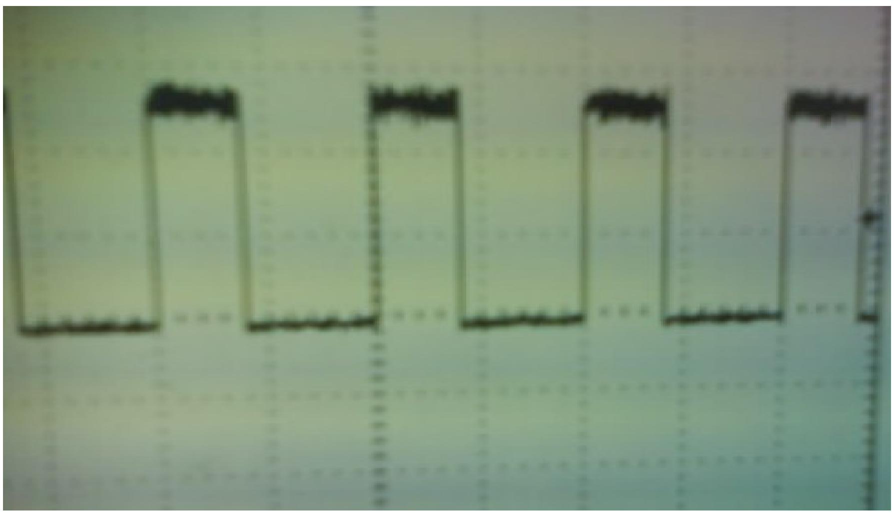


**Figure 3.10:** The PWM output with D=0.4

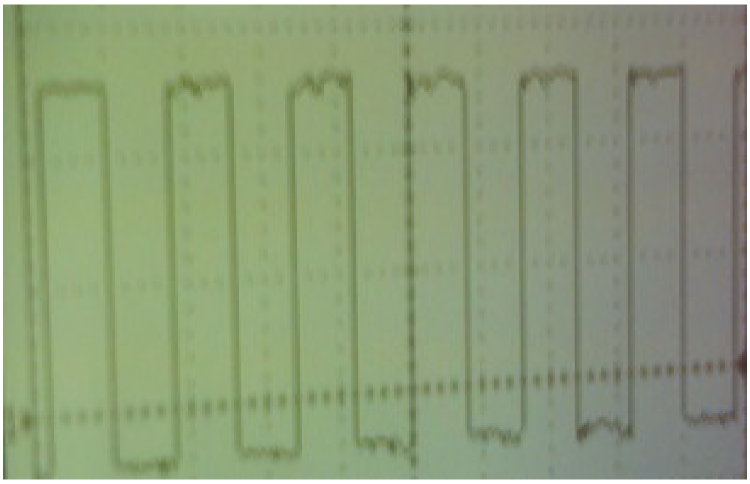


**Figure 3.11:** The PWM output with D=0.5

## 3.6 MOSFET Driver

To turn on the MOSFET, its gate must be supplied with minimum 10 volt. The figure below shows the connection of low IR2109 driver. The MOSFET gate is connected through the LO pin since it is the low side MOSFET. The V cc is directly supply from power supply with 15 volt dc.The connections as in Figure 3.12.

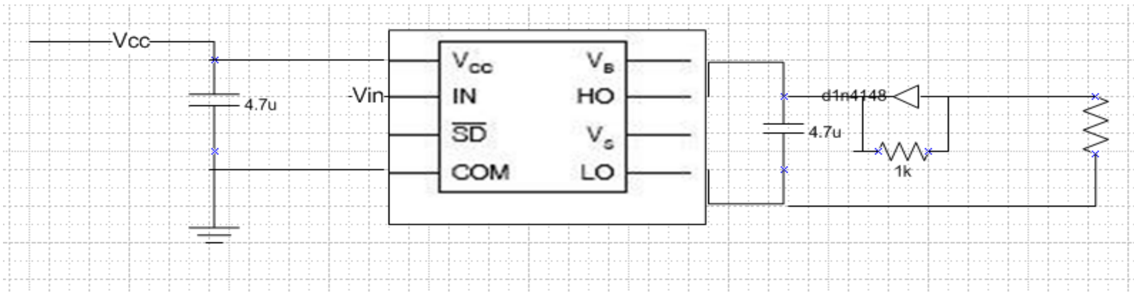



**Figure 3.12:** The Connection of IR2109

### 3.7 Summary

The operation of the MPPT worked part by part. The $V_{in}$ from PV array will connected through the Boost circuit in Figure 3.13 and in the same time the PWM from the PIC with D=0.4 will be get through the MOSFET's gate via the driver circuit in figure 3.14. The whole circuit shown in Figure 3.16

Supposedly the $V_{in}$ from the PV array will be feed back to the PIC to regulate the D value to ensure the maximum output power from the optimum power point of the PV array. This procedure need to be done by implementing the P&O algorithm, since its not successful to be developed in this project, the duty cycle its controlled manually using variable resistors as the input to ADC in PIC. The changing in the variable resistor will directly change the D value as can be seen in Figure 3.10 and 3.11.

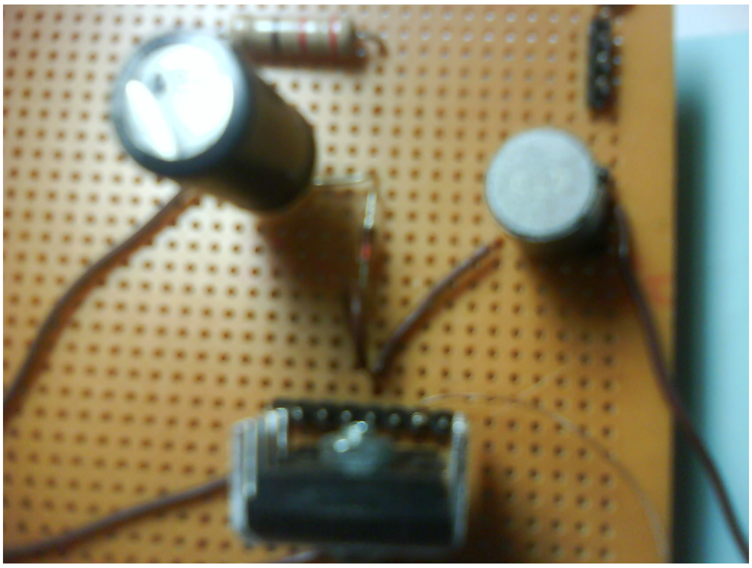


**Figure 3.13:** The Boost Circuit

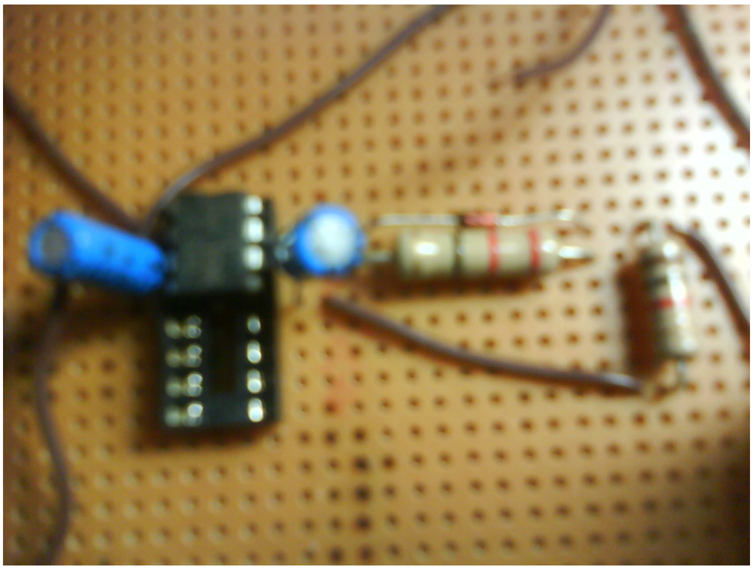


**Figure 3.14:** Mosfet Driver

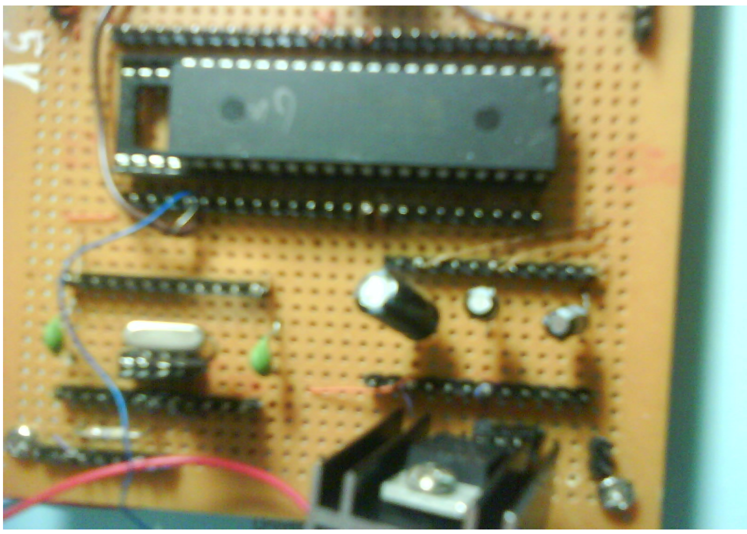


**Figure 3.15:** PIC circuit

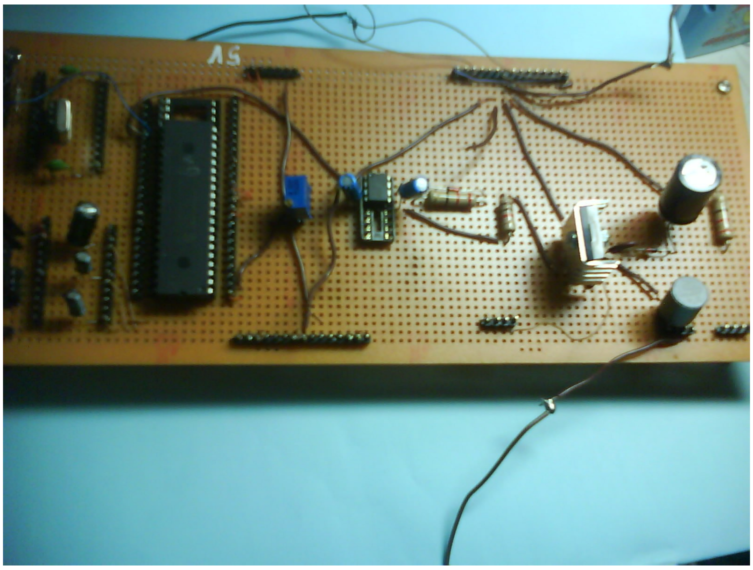



**Figure 3.16:** MPPT Hardware

# CHAPTER 4

# RESULT AND ANALYSIS

## 4.1 Introduction

This chapter will present the results of the MPPT circuit. For the better analysis results the analysis is been done using the P Spice and the real hardware. The analyzing using P Spice is to get the expected result of the Boost converter from the hardware.

## 4.2 Analyzing Using P Spice

By using P Spice the Boost Converter was simulated using the varying value of $V_{in}$ the result as tabulate in Table 4.1, and for better analyzing it was plotted in graph as Figure 4.2. The circuit in Figure 4.1 that has been designed before has been simulating. From the graph in Figure 4.2 it's shown that the $V_{out}$ are proportionally increased with the $V_{in}$. This is the real result of the Boost Converter which the $V_{out}$ will be higher than the $V_{in}$. So this showed the components value is effectively implemented in the converter circuit.

But in this MPPT we need the $V_{in}$ will be step up until the limited value at the MPP of the PV array. This situation occur since there is no feedback control of the $V_{in}$ to the controller (PIC), supposedly the D will be regulated via the feedback from the $V_{in}$. Which when the $V_{in}$ is lower the D should be decreased and vice versa.

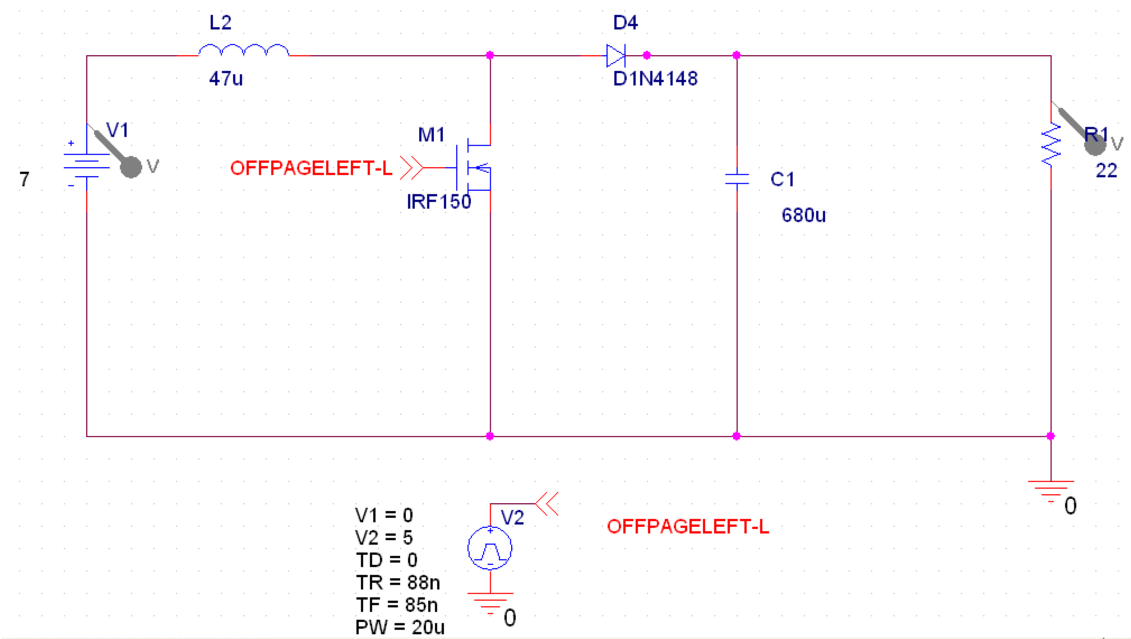


**Figure 4.1:** Boost circuit in Pspice Simulation

**Table 4.1**: Result of varying in $V_{in}$

| Vin | 6.8 | 8 | 10 | 12 | 14 | 16 | 17 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| Vout | 12 | 15 | 18 | 22 | 25.4 | 29 | 31 | 33 | 37 |

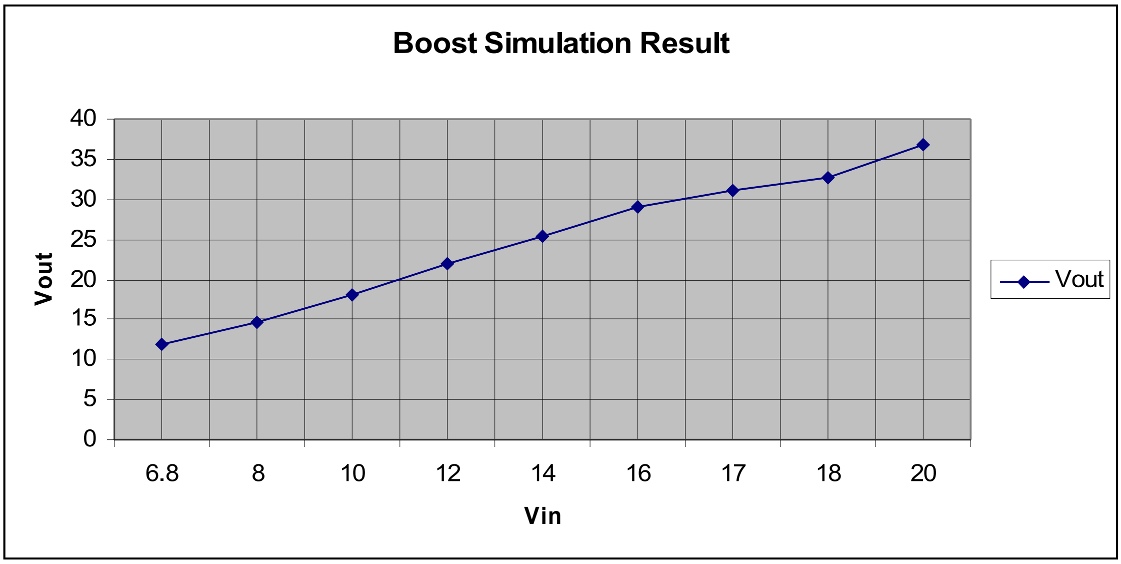



**Figure 4.2:** Boost Simulation Result from data in Table 4.2

## 4.3 Analyzing with Hardware

For the better analyzing there are several steps has been taken to determine the ability and efficiency of the MPPT hardware performance.

### 4.3.1 MPPT CIRCUIT INTERFACE WITH SOLAR PANEL

The result of interfacing MPPT with Solar Panel was taken during a day with ambient condition. The varying $V_{in}$ is the depending on the nature weather ( ambient condition), As seen in the table the input voltage goes low to 6.8volt (cloudy day) and the 16 volt (a portion of panel shadowed for a while) and 20.1volt (sunny day) is the maximum voltage delivered by the panel. For the better analysis the result of the hardware interfaced with the PV array is being compared with the result of hardware that used Power Supply also with the simulated before as seen in Table 4.2.

Clearly shown from the result has been plotted in Figure 4.3. In the Figure 4.3 for the both that has been tested with the hardware, it show a very big differences with the simulation result. The real result is not same as the simulation and the worse case when the real hard ware is interfaced with the PV array the $V_{out}$ is lower compare to the hardware used the DC Power Supply

This situation occurs since there is clearly seen problem on the hardware caused by the inductor, since its getting hot as the voltage increased. So that's why compare to output voltage from power supply and the panel V out from panel drastically drop because the suddenly increasing temperature towards the inductor makes the efficiency deteriorate immediately. This problem will discuss in the next subchapter

**Table 4.2:** $V_{out}$ using the Difference Power Supplies

| $V_{out}$\ $V_{in}$ | 6.8 | 16 | 20.1 |
|---|---|---|---|
| Solar panel | 2.8 | 4 | 2.6 |
| DC Power supply | 2.32 | 4.87 | 5.96 |
| Simulation | 12 | 29 | 36.8 |

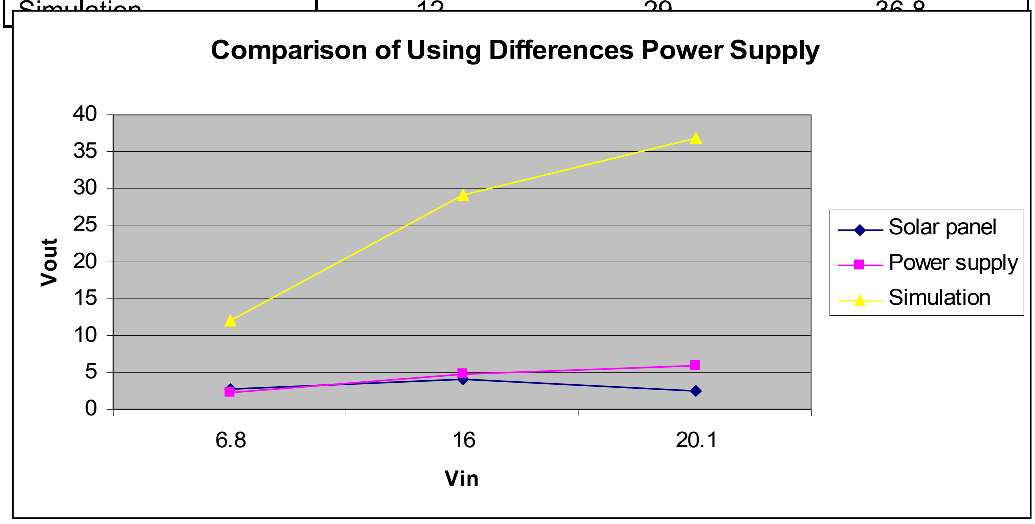


**Figure 4.3:** Comparison towards Vout of MPPT circuit using Difference Power Supply and Simulation Result

### 4.3.2 Effect of Inductor Towards The Output Voltage

Previously the Inductor is stated as the cause of the ineffective Boost Circuit, so to prove this statement the hardware efficiency had been tested by using the different types and values of inductor, this was done by observing the $V_{out}$. Table 4.3 show the types of inductor that had tested and the result of the $V_{out}$ . By observing the results it shows that there were no value of Vout for the Axial Inductor 1uH during Vin=20 volt and the same situation goes to Coil inductor 68uH during Vin more than 17 volt eventhough both of them give the better performance compare to the Silicone.

**Table 4.3:**Vout using difference Inductors

| $V_{out}$\ $V_{in}$ (V) | 6.8 | 8 | 10 | 12 | 14 | 16 | 17 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| **Axial Inductor(1 uH)** | 5.16 | 7.61 | 9.2 | 11.28 | 13.1 | 15.6 | 16 | 16.6 | - |
| **Silicone (47uH)** | 2.32 | 2.73 | 3.3 | 3.86 | 4.42 | 4.87 | 4.92 | 4.98 | 5.96 |
| **Coil (68uH)** | 5.5 | 6.8 | 9.26 | 10.26 | 11.59 | - | - | - | - |

From the Figure 4.4 the better performance gives by Axial Inductor 1uH, since from the others it delivered the highest $V_{out}$ even though it responds to limited $V_{in.}$ This condition cause by the limited current conduction of the Axial Inductor which is limit to 4 Ampere. While for Coil Inductor was limited by the $V_{in}$ since it only can conduct $V_{in}$ less than 15 volt. But for the Silicone Inductor it was be able to resist the high current and voltage rating, but the ineffectiveness comes, since it can hold for the high temperature.

So, for continuing this project the Silicone Inductors is being chosen to be implementing in the hardware, to ensure the performance of the MPPT can be tested at the maximum voltage. Even it has the lowest value of the $V_{ou}$t.

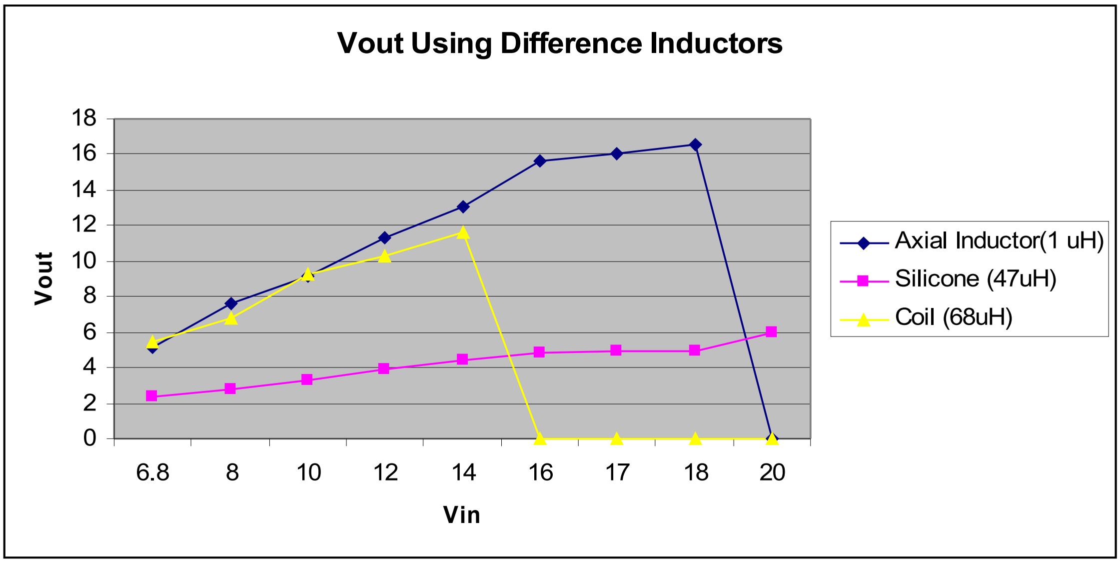



**Figure 4.4:**Vout using difference Inductors

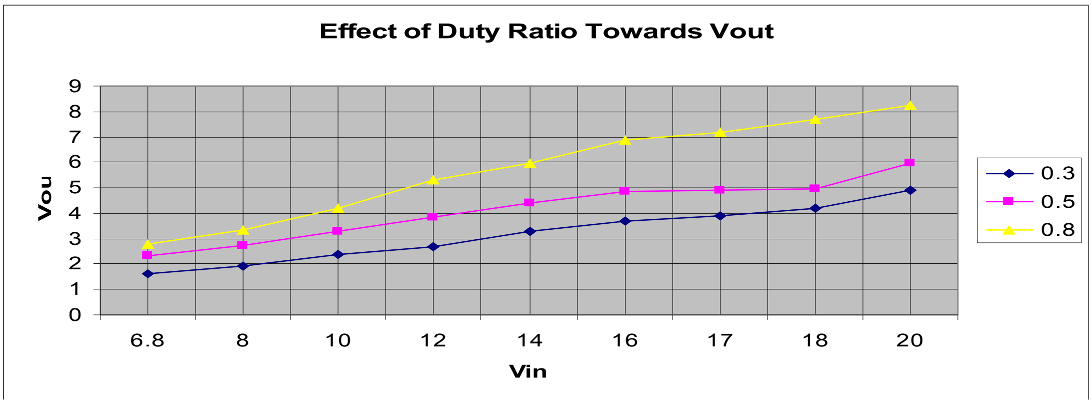
### 4.3.3 The Effect of D Value

As been informed before this, MPPT project is not perfectly working out since there is no implementation of any algorithm to ensure the MPPT work with the high efficiency. The importance of the algorithm is to regulate the D value to ensure the Vout delivered is as the desired value. Since there is a lot of restriction to apply the algorithm in this project, the effect of the D value is being observed by manually varied the value using the variable resistor.

The general principle of varied the D value through the variable resistor is by varied the resistance value. According to the Ohm's Lam as the resistance and voltage value is proportional to each other. So by supplying 5 volts to the resistor it was respond to the input of the ADC pin in PIC's in the range from 0 to 5 volt. As being programmed in the coding (Coding in Appendix 1) the input voltage at the ADC's pin will affect the value of D. The principle is as the $V_{in}$ lower the higher D value will produce to deliver the desired output voltage.

Table 4.4 shows the result of $V_{out}$ by varying the D value through the variable resistor. While for Figure 4.5 the relations between the D can be made. From the table a show that the highest value of D is supposedly to be used for the lower input value. This is supposedly being done continuously and automatically of the controller by using the P&O algorithm which the output voltage from the Boost Converter should be feedback to the controller to find out the suitable value of D to ensure the right and perfect PWM being supplied to the MOSFET

**Table 4.4:** Vout Responds towards the difference value of D




| Vin/D | 6.8 | 8 | 10 | 12 | 14 | 16 | 17 | 18 | 20 |
|---|---|---|---|---|---|---|---|---|---|
| **0.3** | 1.6 | 1.9 | 2.4 | 2.7 | 3.3 | 3.7 | 3.9 | 4.2 | 4.9 |
| **0.5** | 2.32 | 2.73 | 3.3 | 3.86 | 4.42 | 4.87 | 4.92 | 4.98 | 5.96 |
| **0.8** | 2.8 | 3.33 | 4.21 | 5.3 | 5.96 | 6.89 | 7.18 | 7.7 | 8.26 |

**Figure 4.5:** Vout Responds towards the difference value of D

## 4.4 Summary

After doing the several analyzing there were several problems that has been recognized as the causes of the ineffectiveness of the MPPT hardware. Which are:

- Inductor implementing

Inductor act as the crucial part towards the hardware performance as being observed. In most designs the input voltage, output voltage and load current are all denoted by the requirements of the design, whereas, the Inductance and ripple current are the only free parameters. It can be seen from the equation below, that the inductance is inversely proportional to the ripple current. In other words, to reduce the ripple, then use a larger inductor. Thus, in practice a ripple current is decided upon which will give a reasonable inductance.

$$\Delta I_{L_{On}} = \int_0^{D \cdot T} \frac{V_i}{L} dt = \frac{V_i \cdot D \cdot T}{L}$$

Large ripple current means that the peak current $I_{pk}$ greater, and the greater of saturation of the inductor, and more stress on the transistor. So when choosing an inductor is need to ensure the saturation current of the inductor is greater than $I_{pk}$. Likewise, the transistor should be able to handle peak current greater than $I_{pk}$. The inductor should also be chosen such that it can handle the appropriate rms current $I_{rms}$.

It should be noted that when there is a light load the circuit can slip into discontinuous mode, where the inductor becomes fully discharged of its current each cycle. When a load is reapplied the inductor needs to recharge, and so the transistor's duty cycle(D) increases pulling the inductor towards ground, and because of the increased D, $V_{out}$ decreases when we really want it to increase. This causes an instability, which is well known for boost converters.

One way to remove this instability is to choose a large enough inductor so that the ripple current is greater than twice the minimum load current. When this condition is met then the inductor is always in continuous mode. This can be expressed as follows :

$$L = \frac{(V_{out} - V_{in} + V_D)(1 - D)}{\min(i_{load}) f} \qquad (16)$$

- The importance of algorithm

Since from the variable of D value results, its really shows that the D value is very important in order to achieve the desired value of $V_{out}$. So the important of algorithm implementation is to ensure that the D value can be regulate and the right value can be produce in responds to the $V_{ou}$t.

# CHAPTER 5

# CONCLUSION AND RECOMMENDATION

## 5.1 Conclusion

From the analysis of the MPPT hardware its shown that its not working out perfectly, since the major problem of the inductor in the boost circuit. And the efficiency of the PWM is caused by the inefficient in regulating the value of D, since the failure to implement the algorithm. The output voltage is not simultaneously change since the D is fix.

Generally shown from the D value analysis, D value is the important parts of the MPPT PWM. And the components choosement can't be taking easily, every characteristics need to be considered. The D value also can be regulate efficiently by using feedback circuit from the $V_{out}$ of the Boost Circuit to the PIC.

## 5.2 Recommendation

In the future to improve this project, first the implementation of the suitable and great algorithm to ensure the maximum power point of the PV array can be achieved. In term of hardware the inductor should be replace with the doughnut type inductor and the addition of the voltage sensing circuit for the feedback voltage from the Boost Output, the purpose to ensure that the circuit will only delivered the optimum power from the PV array.

## 5.3 Costing and Commercialization

This subchapter will describe the overall cost of the MPPT Project and the ability to commercialize the hardware in the industry.

### 5.3.1 Project Costing

| Device | Quantity | Model | Spec. | Manufacturer | Unit Cost (RM) | Extended Cost (RM) |
|---|---|---|---|---|---|---|
| MOSFET | 1 | IRFP150N | | | 5.00 | 5.00 |
| Capacitor | 1 | | 35V/ 680uF | | 4.00 | 4.00 |
| Capacitor | 2 | | 22pF | | 0.50 | 1.00 |
| Capacitor | 4 | | 50V/ 4.7uF | | 0.50 | 2.00 |
| Capacitor | 1 | | 680uF/35v | | 2.00 | 2.00 |

**Total Cost** **RM 66.70**

| | | | | | | |
|---|---|---|---|---|---|---|
| PIC16F1877A | 1 | | | Microchip | 25.00 | 25.00 |
| LM7805 | | | | | 1.00 | 1.00 |
| Heat Sink | 2 | | | | 0.55 | 1.10 |
| Variable Resistor | 1 | | 5V\ 5ohm | | 5.00 | 5.00 |
| Resistor ¼ watts | 2 | | 22 ohm | | 0.10 | 0.20 |
| Resistor ¼ watts | 1 | | 1 k ohm | | 0.10 | 0.10 |
| Crystal | | | 8 Mhz | | 4.00 | 4.00 |
| MOSFET Driver | 1 | | IR2109 | International Rectifier | 8.00 | 8.00 |
| Diode D1n4148 | 2 | | | | 2.00 | 4.00 |
| Inductor | 1 | | 47uH | | 3.00 | 3.00 |
| IC base | 1 | | 40 pins | | 0.20 | 0.20 |
| IC base | 1 | | 8 pins | | 0.10 | 0.10 |
| Vero Board | 1 | | | | 3.00 | 3.00 |

### 5.3.2 Commercialization

The project takes cost as RM 66.70, its price still lower and affordable. Practically it will be more secure and nice if the size can be reduced using the Printed Circuit Board  PCB. Since the MPPT will be used together with PV array which located and exposed to the nature weather so it is needed to put the devices in the reliable box that resist towards the weather in any condition. This is important to protect the components being damage by the weather and surrounding conditions

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