

CHAPTER ONE: INTRODUCTION

1.1 Background of the Study

Solar energy is the energy generated by harnessing the power of the solar radiation. Solar energy is clean and available in abundance [10]. Solar technologies use the sun for provision of heat, light and electricity. These are for industrial and domestic applications.

Nowadays the energy deficiency problems faced by the world, more especially the third world countries, are urging researchers to find an alternative energy source that would complement the conventional fossil fuel. The alternative energy sources include solar, nuclear and wind. Thus it has become an urgent necessity to invest in renewable energy sources that can power the future sufficiently.

The energy potential of the sun is immense. The power from the sun intercepted by the earth is approximately 1.8×10^{11} MW, which are many thousand times larger than the present consumption rate on the earth from all other in-use commercial energy sources [10]. Despite the unlimited resource however, harvesting it presents a challenge because of the limited efficiency of the array cells.

There are two methods for converting solar power into electricity, thermal which is based on concentrating solar power by mirrors or other type of reflectors to produce high temperature to generate water vapour or other liquids with high pressure to rotate turbines to generate electricity or by making use of photovoltaic (PV) effect to convert solar power to electric power directly. A photovoltaic complete system usually consists of the followings: Photovoltaic units or cells, batteries, charging controllers, inverters, load

controllers, circuit breakers and wiring. The best efficiency of the majority of commercially available photovoltaic cells ranges between 10 and 20 percent. Two limiting factors relating to harvesting this abundant solar energy from the solar panels are; conversion efficiency of the panels and power transfer efficiency to the batteries. This shows that there is still room for improvement. This project seeks to identify a way of improving efficiency of solar panels. Three ways of increasing the efficiency of the solar panels are through increase of cell efficiency, maximizing the power output and the use of a solar tracking system.

The use of a solar tracking system and many solar panels are meant to increase the conversion efficiency of the cells which is completely dependent on solar irradiation. As such this method of increasing the efficiency of the cells is retarded by increase in temperature because with increase in temperature, the efficiency of the cells is being decreased [11].

The other method of increasing the efficiency of solar panels is by maximizing the power output to the batteries. This can be done through the use of a maximum power point tracking (MPPT) device that will utilize the solar panel to its maximum potential. This project seeks to design and construct a maximum power point tracking (MPPT) device.

To design an MPPT, there are several DC-DC converter topologies and several algorithms that can be employed. The converter topologies include; buck converter, boost converter, and buck-boost converter while the algorithms that can be employed are; constant voltage algorithm, open circuit voltage algorithm, short circuit current algorithm, incremental conductance (IC) and the perturb and observe (P&O) algorithm [9,4].

1.2 Problem Statement

The major problem relating to the wide spread application of the solar energy is the poor conversion efficiency of the solar panels and poor power transfer efficiency to the batteries.

1.3 Aim And Objectives

The aim of this project is to design and construct a maximum power point tracking (MPPT) device.

This aim can be obtained through the following objectives:

1. To design the electronic circuitry for MPPT.
2. To produce the printed circuit board of the electronic components.
3. To design and construct the necessary packaging.
4. To evaluate the performance of the system in tracking the maximum power point.

1.4 Significance

This project will benefit the environment because it will lead into generating energy that does not cause pollution to the environment. It will provide a cheaper source of power for homes and small scale businesses as it is being used overtime.

1.5 Scope

This research work focuses on the design and construction of a maximum power point tracking system utilizing a buck-boost converter and an incremental conductance algorithm.

CHAPTER TWO: LITERATURE REVIEW

2.1 Introduction

The efficiency of a solar cell is very low. In order to increase the efficiency, methods are to be undertaken to match the source and load properly. One such method is the Maximum Power Point Tracking (MPPT). This is a technique used to obtain the maximum possible power from a varying source. The maximum power point tracking system is a charge controller type that can be used to achieve a maximum power point transfer to the load so as to increase the efficiency of solar cell.

2.2 Charge Controller

A charge controller is a device whose core function is to maintain the battery at highest possible state of charge so when the PV module charges the battery the charge controller shields the battery from overcharge and detaches the load to prevent deep or full discharging [12]. In other words it simply performs the necessary function of ensuring that the batteries cannot be damaged by overcharging by effectively cutting off the current from the PV panels when the battery voltage reaches a certain level. So basically a Maximum Power Point Tracking Solar Charge Controller performs an extra function to improve the system efficiency.

The efficiency loss in a basic system is due to a miss-match between voltage produced by the PV panels and that required to charge the batteries under certain conditions. Ideally, charge controller directly controls the state of charge of the battery. Without charge control, the current from the module will flow into a battery proportional to the 'IRRADIANCE' (the radiant power received by a surface per unit area), whether the

battery needs to be charging or not. If the battery is fully charged, unregulated charging will cause the battery voltage to reach exceedingly high levels, causing electrolyte loss, internal heating and also might lead to grid corrosion. So we can basically say that a charge controller maintains the health and extends the lifetime of the battery. Hence the necessity of having such a type of charge controller has immense advantage while using solar panels. This work done by the controller has a very complex mechanism where the main components are a converter and sensor. There are certain algorithms assigned to the system in order to compare and decide on that right voltage and power which makes the whole system a truly smart and further efficient [7]. So from the sunlight captured by the PV panels are then turned into current which is later sent to these controllers for further modifications.

2.3 Battery

The battery's main responsibility is to store the charge modified from the solar charge controller for later use. Since solar energy is concerned selecting the right type of battery is the most important thing. So in this case, the deep cycle type battery is preferred for its efficiency.

Basically deep cycle batteries are energy storing units in which chemical reactions occurs that generates voltage hence generates electricity. The reason it is called deep cycled because it works in two cycles; charging cycle and discharging cycle.

The methodology followed by the deep cycle batteries is very interesting. While a car battery is designed to supply an instant bulk of energy to start up, a deep cycle battery is designed to provide power at a balanced rate slowly powering up the load.

2.4 Photovoltaic Modules/Array

The basic building blocks of solar or PV system are the solar or PV cells. These individual cells are quite small producing about 1 or 2 KW of power. In order to boost this power output of the PV cells they have to be connected together forming larger units called modules. These modules however can be connected to form arrays which are interconnected to produce more power. By connecting these cells or modules in series the voltage can be increased. On the other hand by connecting the cells or modules in parallel the output current can reach higher values.

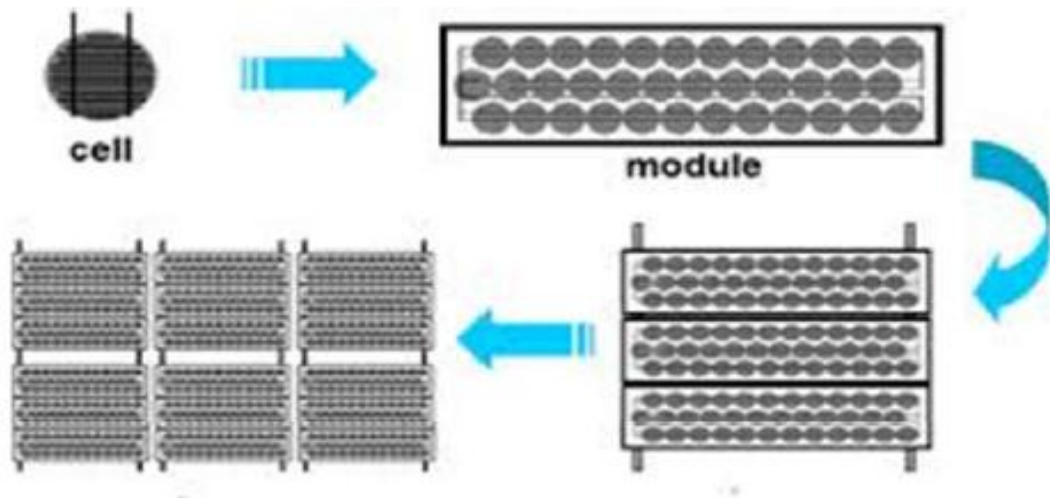


Fig: 2.1 The formation of a PV system from cell to array.

The PV devices can be made using different types of semiconductor materials and they can be arranged in various structures. There are mainly three types of materials used for solar cells which are silicon, polycrystalline thin films, and single crystalline thin film.

2.5 MPPT Charge Controller

Maximum power point tracker (MPPT) is a system that optimizes voltage input and voltage output matching between the PV panel and the battery to achieve maximum panel efficiency. Using current sensors and voltage sensors to detect the operating conditions of the PV panel, various sampling algorithms can be used to calculate the MPP [7]. To perform many simple MPPT algorithms, the four following parameters are measured to operate controllers and are typically provided in PV datasheets:

1. V_{OC} – open circuit voltage
2. I_{SC} – short circuit current
3. V_{MPP} – max power point voltage
4. I_{MPP} – max power point current

The open circuit voltage is the maximum output voltage of the panel with no power drawn. The short circuit current is the absolute maximum current provided by the panel. These two values can be used to calculate their respective MPPT values without a microcontroller. Maximum power point voltage, V_{MPP} , is linearly dependent on the open circuit voltage under varying irradiance and temperature conditions [4]. V_{MPP} determines the maximum power point by periodically disconnecting the system from the load to measure V_{OC} and can be calculated using Equation 1, where the constant k_v represents the configuration of the PV panel.

$$V_{MPP} = k_v \times V_O \quad \dots (2.1)$$

This method of calculating the maximum power point, or fractional open circuit voltage, typically causes temporary loss of power and is not typically advised to use as an MPPT method. Similarly, there is a fractional short circuit method in which the maximum power point current is linearly dependent on the short circuit current and can be calculated using Equation 2:

$$I_{MPP} = k_i \times I_{SC} \quad \dots (2.2)$$

2.6 MPPT Algorithms

There are many ways to maximize the power of a PV system such as using a simple method of voltage relationships to complicated sample based analysis. Most commonly implemented MPPT algorithms include; the constant voltage (CV), perturb & observe (P&O), incremental conductance (INC), open-circuit voltage (VOC), and short-circuit current (ISC) methods. The type of method chosen for a system is typically based on the level of expected irradiance [8]. For instance, methods such as VOC and ISC are better for low levels of irradiance and are usually more immune to noise. The open circuit voltage is being discussed in this research work.

2.6.1 Open circuit voltage method

The open circuit method is similar to the constant voltage method but an improvement to it. The open circuit voltage method uses V_{oc} to calculate V_{MPP} . Once the system obtains the

V_{oc} value, V_{MPP} is calculated by,

$$V_{MPP} = K_V \times V_{oc} \quad \dots(2.3)$$

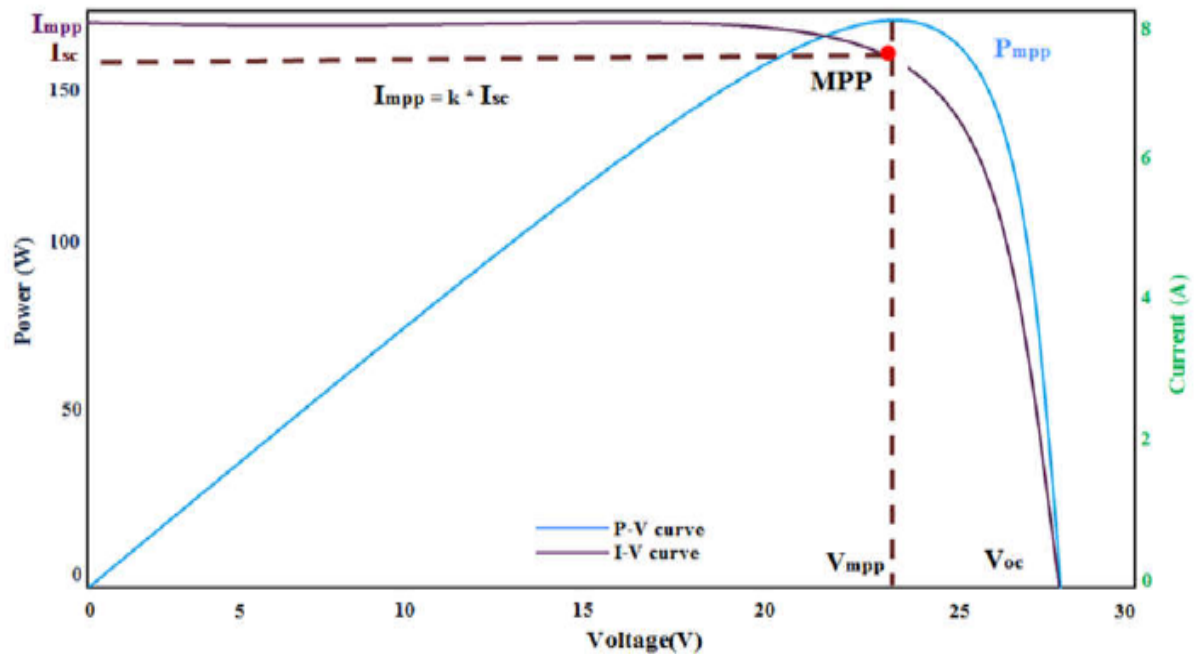


Fig. 2.2 I-V and P-V characteristics of open circuit voltage method

The V_{oc} is the open circuit voltage of the PV Panel. The k value is typically between 0.7 to 0.8 as it is always less than unity (commonly used as 0.76). It is necessary to update V_{oc} occasionally to compensate for any temperature change. Sampling the V_{oc} value can also help correct for temperature changes and to some degree changes in irradiance. Monitoring the input current can indicate when the V_{oc} should be re-measured. The k value is a function of the logarithmic function of the irradiance, increasing in value as the irradiance increases [7].

Benefits of the open circuit voltage method include;

- I. The cost is relatively low.
- II. It is a much simpler method and easy to implement.

Drawbacks of the open circuit voltage method include;

- I. It is not a very accurate method and may not operate exactly at the Maximum PowerPoint.
- II. The open circuit of the solar PV module varies with temperature so the open circuit voltage needs to be measured continuously for temperature variations.

2.6.2 Short circuit current method:

This technique is also referred to as the constant current method. The short circuit current method uses a value of I_{SC} (Short Circuit Current) to estimate I_{MPP} (Maximum power point current). The I_{SC} is the short circuit current of the PV panel.

$$I_{MPP} = k_i \times I_{SC} \quad \dots(2.4)$$

This method uses a short load pulse to generate a short circuit condition. During the short circuit pulse, the input voltage will go to zero, so the power conversion circuit must be powered from some other source. The k values are typically close to 0.9 to 0.98 (always smaller than 1) [7].

Benefits of the short circuit current method include;

- I. It is simple and implementation cost is low.
- II. No input is required for this method.

Drawbacks of the short circuit current method include;

- I. In most cases the irradiation is never exactly at the MPP due to variations on the array that are not considered (it is not always accurate).
- II. Data varies under different weather conditions and locations.

- III. It has low efficiency. In these two methods we have to choose the right constant k value carefully, to accurately calibrate the solar panel.

2.6.3 Perturbation and observation method:

This method is a widely used approach to determine the MPP. In this method the controller adjusts the voltage by a small amount from the array and measures power, if the power increases, then there are further adjustments made in the direction until power no longer increases. This is called the Perturb and Observe Method. This method works by perturbing the system by increasing or decreasing the PV module operating voltage and observing its impact on the output power supplied by the module [8].

The voltage to a cell is increased initially, if the output power increase, the voltage is persistently increased till the point until the output power starts declining. Once the output power starts decreasing, the voltage to the cell is decreased until the point when the maximum power is reached. This process is continued until the MPPT is attained. This results in an oscillation of the output power around the MPP. The PV module's output power curve is a function of the voltage (P-V curve), at the constant irradiance and the constant module temperature, it is also assumed that the PV module is operating at a point which is away from the maximum power point. Now if the operating voltage of the PV module is perturbed by a minute amount the resulting power P is then observed. If it is seen that the P is positive, then in that case it is supposed that it has moved the operating point closer to the MPP. Hence further voltage perturbations in the same direction will continue moving the operating point toward the MPP. If the P is negative, in that case the operating point will be moving away from the MPP and the path of perturbation should be inverted to move back toward the MPP [7].

Benefits of using the P&O method include;

- I. The simplicity of its algorithm
- II. Ease of implementation
- III. It has comparatively less implementation cost
- IV. It is comparatively a more accurate method

Limitations of the P&O method include;

- I. It cannot determine when it has actually reached the MPP. Under steady state operation the output power oscillates around the MPP.
- II. This method is quite slow to find the MPP if the voltage is far away from MPP.
- III. In any case if there is any shadow on any of the panels (as they are in series of parallel) then the power-voltage curve of the PV will have several peaks and the P&O will not be able to distinguish them and find the genuine peak.

2.6.4 Incremental conductance method:

This algorithm works by searching for the voltage operating point at which the conductance is equal to the incremental conductance. At this point, the system stops perturbing the operating point. The advantage of this algorithm is that it has the ability to ascertain the relative “distance” to the maximum power point (MPP), therefore it can determine when the MPP has been reached. Also, it is capable of tracking the MPP more precisely in highly variable weather conditions, and exhibits less oscillatory behavior around the MPP [8].

In incremental conductance method the array terminal voltage is always adjusted according to the MPP voltage it is based on the incremental and instantaneous conductance of the PV module. The MPP can be calculated with the help of the relation between dI/dV

and $-I/V$. The incremental conductance method is based on the fact that, the slope of the PV array of the power curve is zero at the MPP, positive on the left of the MPP and negative on the right on the MPP. This can be given by,

$$\frac{dP}{dV} = \frac{d(V.I)}{dV} = I \frac{dV}{dV} + V \frac{dI}{dV} \quad \dots (2.5)$$

$$\frac{dP}{dV} = I + V \frac{dI}{dV} \quad \dots (2.6)$$

MPP is reached when $dP/dV = 0$. Thus from the equation above,

$$I + V \frac{dI}{dV} = 0 \quad \dots (2.7)$$

Therefore,

$$\frac{dI}{dV} = -\frac{I}{V} \quad \dots (2.8)$$

The basic idea of the incremental conductance method can be illustrated using the chart below;

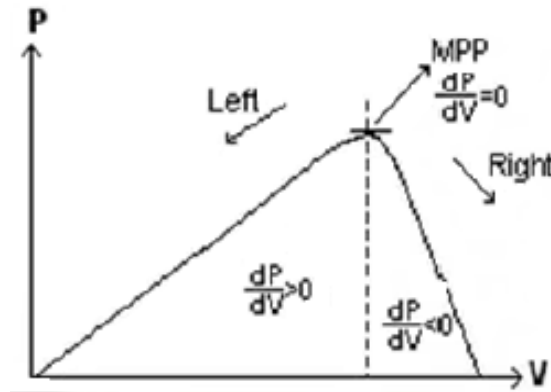


Fig 2.3 PV curve of a PV-panel

If

$$\frac{dP}{dV} > 0 \text{ then } V_p < V_{mpp} \quad \dots (2.9)$$

$$\frac{dP}{dV} = 0 \text{ then } V_p = V_{mpp} \quad \dots (2.10)$$

$$\frac{dP}{dV} < 0 \text{ then } V_p > V_{mpp} \quad \dots (2.11)$$

Also from fig. 2.3, it shows that the slope of the P-V array power curve is zero at The MPP, increasing on the left of the MPP and decreasing on the Right hand side of the MPP. The basic equations of this method are as follows.

$$\frac{dI}{dV} = -\frac{I}{V} \text{ At MPP} \quad \dots (2.12)$$

$$\frac{dI}{dV} > -\frac{I}{V} \text{ Left of MPP} \quad \dots (2.13)$$

$$\frac{dI}{dV} < -\frac{I}{V} \text{ Right of MPP} \quad \dots (2.14)$$

Where I and V are P-V array output current and output voltage respectively. The left hand side of equations represents incremental conductance of P-V module and the right hand side represents the instantaneous conductance. When the ratio of change in output conductance is equal to the negative output conductance, the solar array will operate at the maximum power point i.e. the MPPT regulates the PWM control signal of the dc – to – dc buck-boost converter until the condition: $(\partial I/\partial V) + (I/V) = 0$ is satisfied [7].

Benefits of the incremental conductance method include;

- i. It is able to successfully detect any changes in the irradiation and shift its MPP value by adjusting the duty cycle.

- II. It has a good tracking efficiency.
- III. This method reduces oscillation around the MPP point.
- IV. It is able to reduce power loss and system cost as well.

Drawbacks of the incremental conductance method include;

- I. The computational time is increased due to slowing down of the sampling frequency resulting from the higher complexity of the algorithm compared to the P&O method.

2.7 DC-DC Converter

An electronic circuit which converts a source direct current (DC) from one voltage level to another is known as a DC-DC converter. These DC-DC converters are commonly used in controlled switch-mode dc power supplies and in dc motor drives applications [2]. The inputs of these converters are often not any regulated DC voltage. This is obtained by rectifying the line voltage hence it will fluctuate because of the changes in the line voltage magnitude. Switch-mode DC-DC converters are used to convert the unregulated dc input into a controlled/ monitored DC output at a desired voltage level. The heart of MPPT hardware is a switch-mode DC-DC converter. MPPT uses the converter for a different purpose: regulating the input voltage at the PV MPP and providing load matching for the maximum power transfer. The different topologies of DC-DC converter are; boost converter, buck converter and the buck-boost converter. Of interest in this research is the boost converter which is being discussed in the section below.

2.7.1 Boost converter

Generally, a boost converter is a DC to DC converter that produces an output voltage greater than the source voltage. It is sometimes called a step-up converter since it “steps up” the source voltage [13]. For example, applications for boost converter operations in DC motor's rebounding breaking circuit and regulated DC power supply. In this type of converter, the output voltage is always greater than the input voltage. Therefore, the step-up converter can be applied to the MPPT system where the output voltage should exceed the input voltage such as in the systems connected to the grid, where the boost converter holds a high output voltage, even if the PV array voltage falls at lower prices.

The relationship between the output voltage (V_O) and the input voltage (V_{IN}) is given by the relationship;

$$V_O = (1-D) \times V_{IN} \quad \dots (2.15)$$

Where D = duty cycle

Circuit topology of step-up converter as shown in Fig. 2.4 below

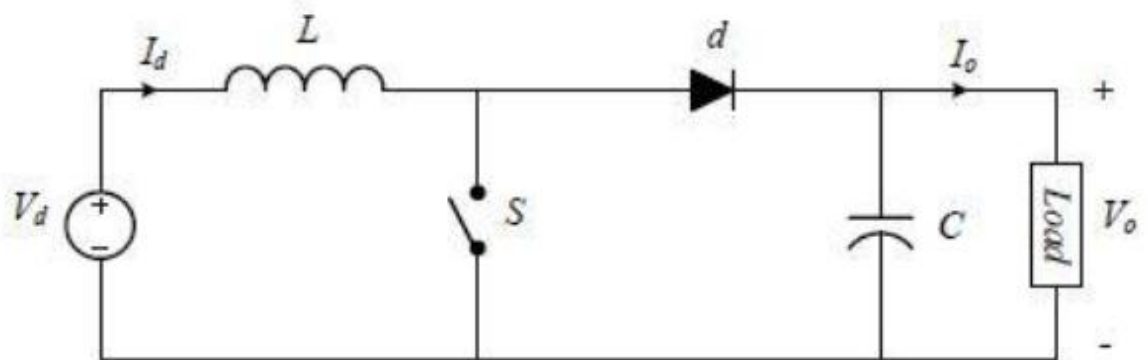


Fig. 2.4 circuit topology of a boost converter

2.7.2 Buck converter

A buck converter is a DC to DC converter that produces an output voltage lesser than the source voltage. It is sometimes called a step-down converter since it “steps down” the source voltage. The buck converter has the capability of stepping-up the current while stepping down the source voltage, therefore the buck converter can be utilized in an MPPT system where high current is needed to charge the load [1].

The relationship between the output voltage (V_O) and the input voltage (V_{IN}) is given by the relationship;

$$V_O = D \times V_{IN} \quad \dots (2.16)$$

Where D = duty cycle

The circuit diagram for the buck converter is shown below;

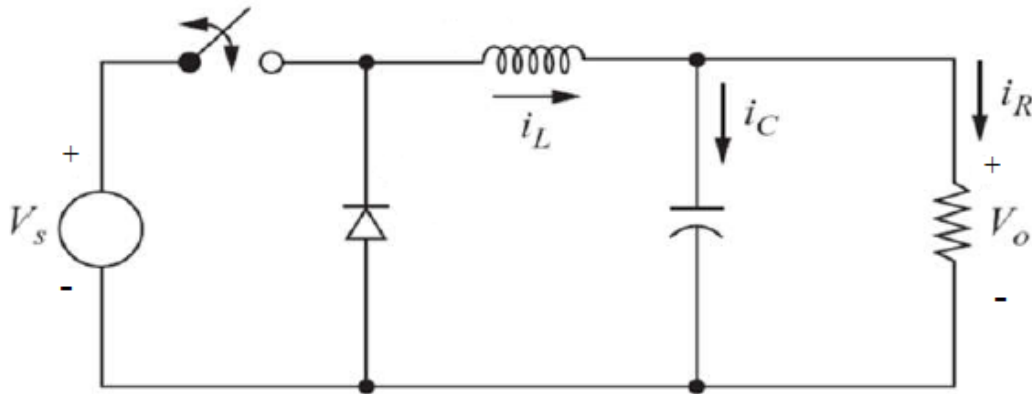


Fig 2.5 Circuit topology for a buck converter

2.7.3 Buck-boost converter

The buck-boost DC-DC converter offers a greater level of capability than the buck converter or the boost converter individually, i.e. it can perform the function of a buck

converter (to step down source voltage) and a boost converter (to step up source voltage) [2].

The relationship between the output voltage (V_O) and the input voltage (V_{IN}) is given by the relationship;

$$V_O = \frac{D}{(D-1)} \times V_{IN} \quad \dots (2.17)$$

Where D = duty cycle

The circuit diagram for a buck-boost converter is shown below;

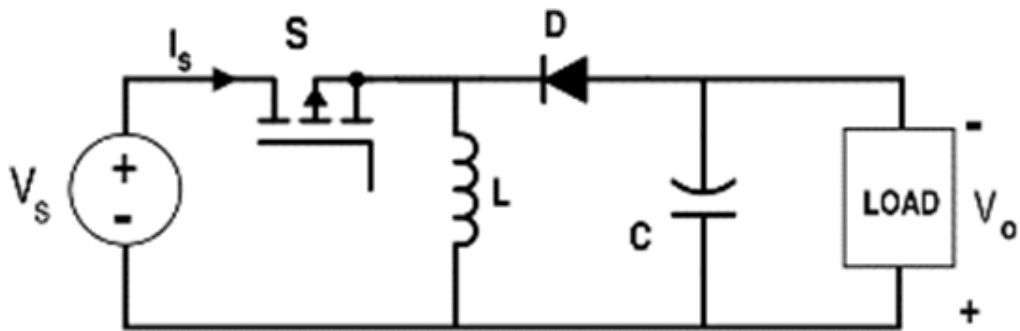


Fig 2.6 Circuit topology for a buck-boost converter

The equivalent circuit diagram for the buck-boost converter in ON mode (i.e. when the MOSFET is switched ON) and in OFF mode (i.e. when the MOSFET is switched OFF) are shown in figure 2.8 and 2.9 respectively;

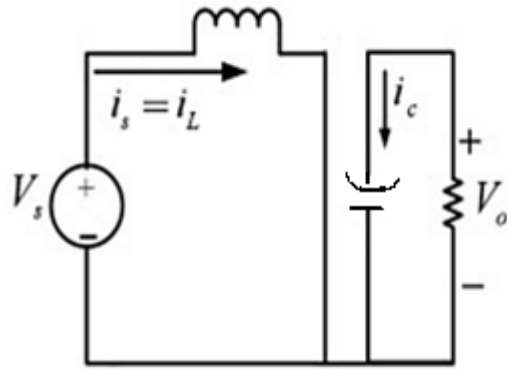


Fig 2.7 Equivalent circuit diagram for buck-boost in ON mode

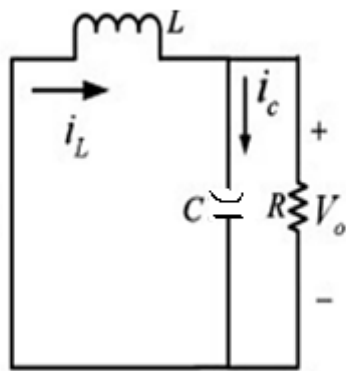


Fig 2.8 Equivalent circuit diagram in OFF mode

CHAPTER THREE: DESIGN AND CONSTRUCTION PROCEDURE

3.1 System Description

This chapter deals with the detailed aspect and neat presentation of the design and construction of the system as a whole, which includes the use of block diagrams, circuit diagrams and flowcharts where necessary in describing the various stages that are involved in the design procedure of the maximum power point tracking system.

The system is made up of multiple components that is being accessed by the microcontroller. Herein will be made an analysis of the individual components and parts that constitute this project, taking into account their values and the reason why the choice was made where there is an option.

3.2 Block Diagram:

The block diagram representation for the MPPT charge controller including the various units involved in the setup is shown in the figure below;

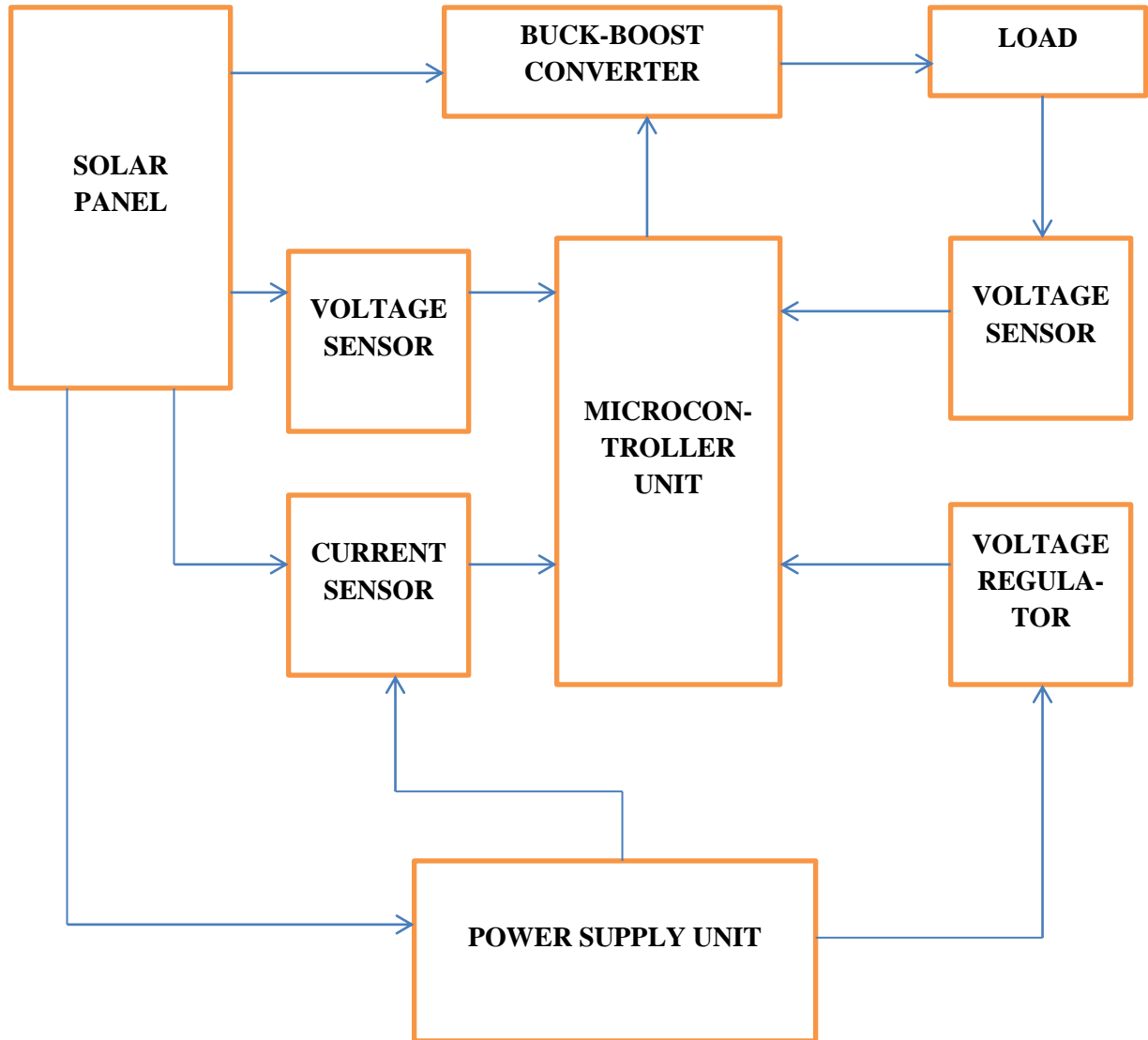


Fig. 3.1 Block diagram representation of MPPT

3.2.1 Solar panel:

The PV module that was used is based on polycrystalline silicon diode. Usually, this type of PV module is used in home usage. Two panels were used each with a 12V rating and power of 100W. Connecting the panels in series will give a voltage of 24V and an open circuit voltage of 34V.

3.2.2 Voltage sensor:

A voltage divider was used to form the voltage sensing unit. The voltage divider is being connected to the microcontroller for further control operations. The maximum voltage received by the voltage sensor is 34V while the maximum power point voltage given to the microcontroller is 5V. A voltage sensor is connected at the input and output terminals to sense the input and output voltage respectively. A diagram of a voltage divider circuit is shown in the figure below;

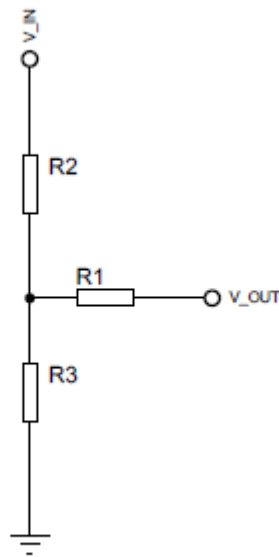


Fig. 3.2 Voltage divider circuit

3.2.3 Current sensor:

The current sensor used is the ACS-712 which was manufactured for the purpose of sensing AC, DC current in research, industrial and communication systems [6].

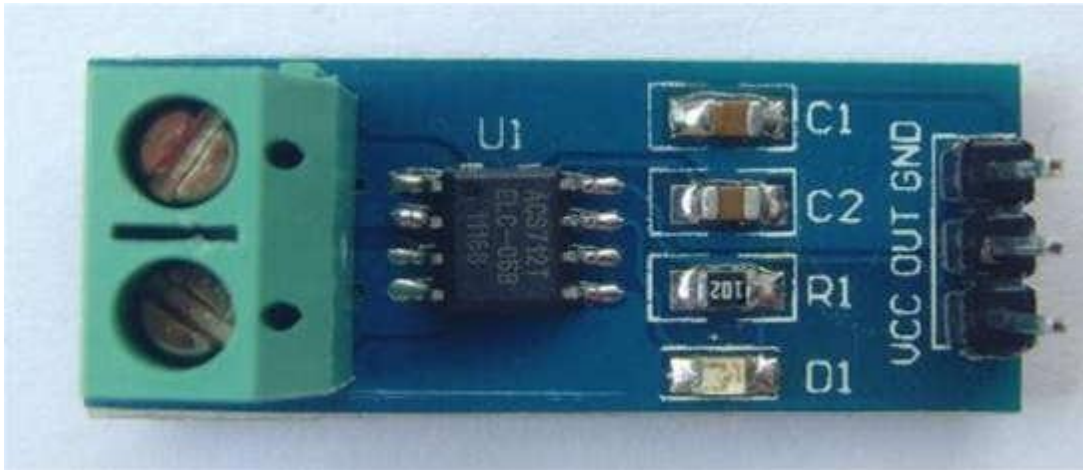


Fig. 3.3 diagram of current sensor ACS-712

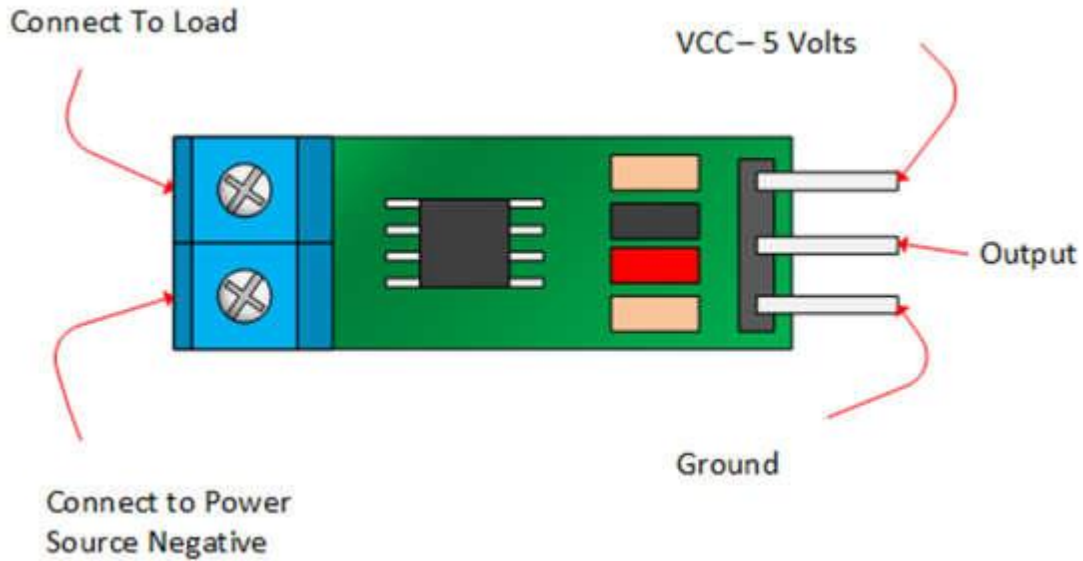


Fig. 3.4 Pin configuration of the ACS-712

The current sensor which is being powered by the power supply senses the current from the solar panel and then delivers this sensed current to the microcontroller through the output pin.

3.2.4 Microcontroller:

The microcontroller used is the 18F4550. The microcontroller was programmed such that with the information it receives from the voltage and current sensor it increases or decreases the duty cycle in order for the buck-boost converter to produce a controlled output. The PIC18F4550 device offers the advantages of all PIC18 microcontrollers – namely, high computational performance at an economical price – with the addition of high-endurance, Enhanced Flash program memory. In addition to these features, the PIC18F2455/2550/4455/4550 family introduces design enhancements that make these microcontrollers a logical choice for much high performance and power sensitive applications [14].

3.2.5 Buck – boost converter:

The buck-boost converter was connected in such a way as to provide a stepped-up or stepped-down voltage at the output depending on the value of the duty cycle provided by the microcontroller. The components that makes up the buck - boost converter includes; inductor, MOSFET, diode and capacitor.

3.2.6 Power supply:

This gives the necessary electrical power requirement for all the components in the system. The microcontroller unit and the voltage regulator operate on 5V whereas the MOSFET driver and current sensor operates on 12V as such there is

need for a power supply. In this project a switched mode power supply with a switching frequency of 100 kHz.

3.3 Hardware Design

Electric hardware design is the analysis and synthesis of electronic circuit components. It deals with physical components and their interrelationships. The circuit diagram used in this project is shown in Figure 3.1. The hardware design involves the design of the circuitry in each of the functional blocks.

3.3.1 Power supply design:

Devices like microcontroller, MOSFET driver, current sensor and voltage regulator have their various power requirement as such there is need for the design of a switch mode power supply to meet the requirement.

3.3.1.1 **Design specifications:** The specifications for the SMPS are given below;

- i. Input Voltage (V_I): 12 – 34V_{DC}
- ii. Output Voltage (V_O): 12V (± 50 mV)
- iii. Maximum Output Current (I_O): 1A
- iv. Minimum Output Current ($I_{O\text{MIN}}$): 0.1A
- v. Switching Frequency (F_S): 100KHz
- vi. Efficiency (η): 0.8

3.3.1.2 **Pre-design calculation:** calculations for the various component values are shown below;

- i. Output power (P_O): The output power for the SMPS is given by;

$$P_O = V_O I_O \quad \dots (3.1)$$

Where P_O = output power

V_O = output voltage = 12V and

I_O = maximum output current = 1A

Thus,

$$P_O = 12 \times 1 = 12W$$

ii. Input power (P_I): The input power of the SMPS can be obtained using;

$$P_i = \frac{P_o}{\eta} \quad \dots (3.2)$$

Where P_I = input power

P_O = output power = 12W and

η = efficiency = 0.8

Thus,

$$P_i = \frac{12}{0.8} = 15W$$

iii. Maximum input current: The maximum input current is given by;

$$I_{IN(MAX)} = \frac{P_{in}}{V_{(L)}} \quad \dots (3.3)$$

Where $I_{IN(MAX)}$ = maximum input current

P_I = input power = 15W and

$V_{(L)}$ = lowest input voltage = 12V

Thus,

$$I_{IN(MAX)} = \frac{15}{12} = 1.25A$$

- iv. Minimum input current: The minimum input current of the SMPS can be obtained using;

$$I_{IN(MIN)} = \frac{P_{in}}{V_{(H)}} \quad \dots (3.4)$$

Where $I_{IN(MIN)}$ = minimum input current

$P_{(IN)}$ = input power = 15W and

$V_{(H)}$ = highest input voltage = 34V

Thus,

$$I_{IN(MIN)} = \frac{15}{34} = 0.441A$$

- v. Peak current (I_{PK}): The input power of the SMPS can be obtained using;

$$I_{PK} = \frac{5.5P_O}{V_L} \quad \dots (3.5)$$

Where I_{PK} = peak input current

P_O = output power = 12W and

$V_{(L)}$ = lowest input voltage = 12V

Thus,

$$I_{PK} = \frac{5.5 \times 12}{12} = 5.5A$$

- vi. Maximum output resistance Value: The maximum output resistance of the SMPS can be obtained using;

$$R_{O(max)} = \frac{V_o}{I_{O(min)}} \quad \dots (3.6)$$

Where $R_{O(MAX)}$ = maximum output resistance

V_o = output voltage = 12V

$I_{O(MIN)}$ = minimum output current = 0.1A

Thus,

$$R_{O(max)} = \frac{12}{0.1} = 120\Omega$$

- vii. Minimum resistance value: The minimum output resistance of the SMPS can be obtained using;

$$R_{O(min)} = \frac{V_o}{I_{O(max)}} \quad \dots (3.7)$$

Where $R_{O(MIN)}$ = minimum output resistance

V_o = output voltage = 12V

$I_{O(MAX)}$ = maximum output current = 1A

Thus,

$$R_{O(min)} = \frac{12}{1} = 12\Omega$$

- viii. Inductance value (L_P): The inductance value for the SMPS can be obtained using;

$$L_P = \frac{V_L \times d_{max}}{I_{PK} \times f_s} \quad \dots (3.8)$$

Where L_P = inductance value

V_L = lowest input voltage = 12V

d_{max} = maximum duty cycle = 0.49

I_{PK} = peak current = 5.5A

F_s = switching frequency = 100kHz

Thus,

$$L_P = \frac{12 \times 0.49}{5.5 \times 10^5} = 10.69\mu H$$

- ix. Turns ratio: The turns ratio of the SMPS can be obtained using;

$$n = \left[\frac{V_L}{V_O + V_D} \right] \times \left[\frac{d_{max}}{1 - d_{max}} \right] \quad \dots (3.9)$$

Where n = turns ratio

V_L = lowest input voltage = 12V

$V_D = \text{voltage difference} = 1\text{V}$

$V_O = \text{output voltage} = 12\text{V}$ and

$d_{\max} = \text{maximum duty cycle} = 0.49$

Thus,

$$n = \frac{12 \times 0.49}{(12 + 1) \times 0.51} = 0.887 \cong 1.0$$

- x. Maximum duty cycle: The maximum duty cycle of the SMPS can be obtained using;

$$d_{\max} = \frac{(V_O + V_D) \times n}{V_L + (V_O + V_D) \times n} \quad \dots (3.10)$$

Where $n = \text{turns ratio} = 1$

$V_L = \text{lowest input voltage} = 12\text{V}$

$V_D = \text{voltage difference} = 1\text{V}$

$V_O = \text{output voltage} = 12\text{V}$ and

$d_{\max} = \text{maximum duty cycle}$

Thus,

$$d_{\max} = \frac{13 \times 1}{12 + 13} = 0.52$$

- xi. Maximum inductance (L_{PMAX}): The maximum inductance of the SMPS can be obtained using;

$$L_{Pmax} = \frac{V_L \times d_{max}}{I_{PK} \times f_s} \quad \dots (3.11)$$

Where L_{Pmax} = maximum inductance value

V_L = lowest input voltage = 12V

d_{max} = maximum duty cycle

I_{PK} = peak current = 5.5A and

F_s = switching frequency = 100kHz

Thus,

$$L_{Pmax} = \frac{12 \times 0.52}{5.5 \times 10^5} = 11.35\mu H$$

xii. Output capacitance: The output capacitance of the SMPS can be obtained using;

$$C_O = \frac{I_{O(max)}}{V_{ripple} \times f_s} \quad \dots (3.12)$$

Where C_O = output capacitance

$I_{O(max)}$ = maximum output current = 1A

V_{ripple} = voltage ripple = 50mV and

F_s = switching frequency = 100 kHz

Thus,

$$C_O = \frac{1}{50 \times 10^{-3} \times 10^5} = 200\mu F$$

- xiii. Number of primary turns (minimum): The minimum number of primary turns of the SMPS can be obtained using;

$$N_{P(min)} = \frac{V_L \times d_{max}}{B_{max} \times A_e \times f_s} \quad \dots (3.13)$$

Where B_{MAX} = flux density = 0.2

$$A_e = \text{area of the core} = (6.35 \times 6.35) \times 10^{-6} \text{ m}^2$$

d_{max} = maximum duty cycle = 0.52 and

F_s = switching frequency = 100 KHz

Therefore,

$$N_{P(min)} = \frac{12 \times 0.52}{0.2 \times 6.35^2 \times 10^{-6} \times 10^5} = 7.74 \cong 8 \text{ turns}$$

- xiv. Minimum number of secondary turns: The minimum number of secondary turns of the SMPS can be obtained using;

$$N_{S(min)} = \frac{N_{P(min)}}{n} \quad \dots (3.14)$$

Where $N_{S(min)}$ = minimum number of secondary turns

$N_{P(min)}$ = minimum number of primary turns = 8 turns and

n = turns ratio = 1

Thus,

$$N_{S(min)} = \frac{8}{1} = 8 \text{ turns}$$

3.3.2 Buck-boost design:

The buck–boost design includes the calculation of values used for components like the switching MOSFET, diode, inductor, capacitor and resistor. The specifications of the buck–boost are discussed in the sub-section that follows.

3.3.2.1 Buck-boost specifications: The specifications for the buck-boost are shown below;

- i. Input Voltage (V_I): 12 – 34V_{DC}
- ii. Output Voltage (V_O): 12V
- iii. Maximum Output Current (I_O): 10A
- iv. Minimum Output Current (I_{OMIN}): 0.5A
- v. Switching Frequency (F_S): 100KHz

3.3.2.2 Predesign Calculations: The calculations for the various components are shown below;

- i. Maximum duty cycle: The equation for maximum duty cycle is given by;

$$d_{max} = \frac{V_O}{V_O + V_L} \quad \dots (3.15)$$

Where d_{max} = maximum duty cycle

V_O = output voltage = 12V

V_L = lowest input voltage = 12V

Thus,

$$d_{max} = \frac{12}{12 + 12} = 0.5 \text{ or } 50\%$$

ii. Minimum duty cycle: The equation for minimum duty cycle is given by;

$$d_{min} = \frac{V_O}{V_O + V_H} \quad \dots (3.16)$$

Where d_{min} = minimum duty cycle

V_O = output voltage = 12V

V_H = highest input voltage = 34V

Thus,

$$d_{min} = \frac{12}{12 + 34} = 0.26 \text{ or } 26\%$$

iii. Maximum resistance value: This can be obtained as shown below;

$$R_{O(max)} = \frac{V_O}{I_{O(min)}} \quad \dots (3.17)$$

Where $R_{O(max)}$ = maximum output resistance

V_O = output voltage = 12V

$I_{O(min)}$ = minimum output current = 0.5A

Thus,

$$R_{O(max)} = \frac{12}{0.5} = 24\Omega$$

iv. Minimum resistance value: The minimum output resistance can be obtained using;

$$R_{O(min)} = \frac{V_O}{I_{O(max)}} \quad \dots (3.18)$$

Where $R_{O(min)}$ = minimum output resistance

V_O = output voltage = 12V

$I_{O(max)}$ = maximum output current = 10A

Thus,

$$R_{O(min)} = \frac{12}{10} = 1.2\Omega$$

- v. Inductor value: The inductor value can be gotten using the equation below;

$$L = \frac{1.25(1-d_{min})^2 R_{max}}{2F_S} \quad \dots (3.19)$$

Where L = inductance

R_{max} = maximum output resistance = 24 Ω

F_S = switching frequency = 100 kHz

d_{min} = minimum duty cycle = 0.26

Thus,

$$L = \frac{1.25(1 - 0.26)^2 \times 24}{2 \times 10^5} = \frac{1.25 \times 0.74^2 \times 24}{2 \times 10^5} = 82.14\mu H$$

- vi. Capacitance value: This can be obtained as follows;

$$C = \frac{1.25d_{max}}{2R_{min}F_S} \quad \dots (3.20)$$

Where C = capacitance

R_{\min} = minimum output resistance = 1.2Ω

F_S = switching frequency = 100 kHz

d_{\max} = maximum duty cycle = 0.5

Thus,

$$C = \frac{1.25 \times 0.5}{2 \times 1.2 \times 10^5} = 2.6\mu F$$

- vii. Maximum inductor current ($I_{L\max}$): The maximum inductor current can be obtained using;

$$I_{L\max} = \frac{V_L \times d_{\max}}{(1-d_{\max})^2 \times R_{\min}} \quad \dots (3.21)$$

Where $L_{P\max}$ = maximum inductance value

V_L = lowest input voltage = 12V

d_{\max} = maximum duty cycle = 0.5

R_{\min} = minimum output resistance = 1.2Ω

Thus,

$$I_{L\max} = \frac{12 \times 0.5}{(1 - 0.5)^2 \times 1.2} = 20A$$

- viii. Minimum inductor current ($I_{L\min}$): The minimum inductor current can be obtained using;

$$I_{Lmin} = \frac{V_H \times d_{min}}{(1-d_{min})^2 \times R_{min}} \quad \dots (3.22)$$

Where I_{Lmin} = minimum inductor current

V_L = highest input voltage = 34V

d_{min} = minimum duty cycle = 0.26

R_{min} = minimum output resistance = 1.2Ω

Thus,

$$I_{Lmin} = \frac{34 \times 0.26}{(1 - 0.26)^2 \times 1.2} = 13.6A$$

ix. Maximum switching current: This can be obtained as follows;

$$I_{S(MAX)} = d_{max} I_{L(MAX)} \quad \dots (3.23)$$

$I_{S(MAX)}$ = maximum switching current

$I_{L(MAX)}$ = maximum inductor current = 20 A

d_{max} = maximum duty cycle = 0.5

Thus,

$$I_{S(MAX)} = 0.5 \times 20 = 10A$$

x. Minimum switching current: This can be obtained as follows;

$$I_{S(MIN)} = d_{MIN} I_{L(MAX)} \quad \dots (3.24)$$

$I_{S(MIN)}$ = minimum switching current

$I_{L(MAX)} = \text{maximum inductor current} = 20A$

$d_{min} = \text{minimum duty cycle} = 0.26$

Thus,

$$I_{S(MIN)} = 0.26 \times 20 = 5.2A$$

xi. Maximum diode current: This can be obtained as follows;

$$I_{D(MAX)} = (1 - d_{MIN}) \times I_{L(MAX)} \quad \dots (3.25)$$

$I_{D(MAX)} = \text{maximum diode current}$

$I_{L(MAX)} = \text{maximum inductor current} = 20A$

$d_{min} = \text{minimum duty cycle} = 0.26$

Thus,

$$I_{D(MAX)} = (1 - 0.5) \times 20 = 14.8A$$

xii. Minimum diode current: This can be obtained as follows;

$$I_{D(MIN)} = (1 - d_{max}) \times I_{L(MAX)} \quad \dots (3.26)$$

$I_{D(MIN)} = \text{minimum diode current}$

$I_{L(MAX)} = \text{maximum inductor current} = 20A$

$d_{max} = \text{maximum duty cycle} = 0.5$

Thus,

$$I_{D(MIN)} = (1 - 0.5) \times 20 = 10A$$

3.3.3 Circuit diagram:

The circuit diagram for the various blocks and their components including the values for each component are shown in the figure below;

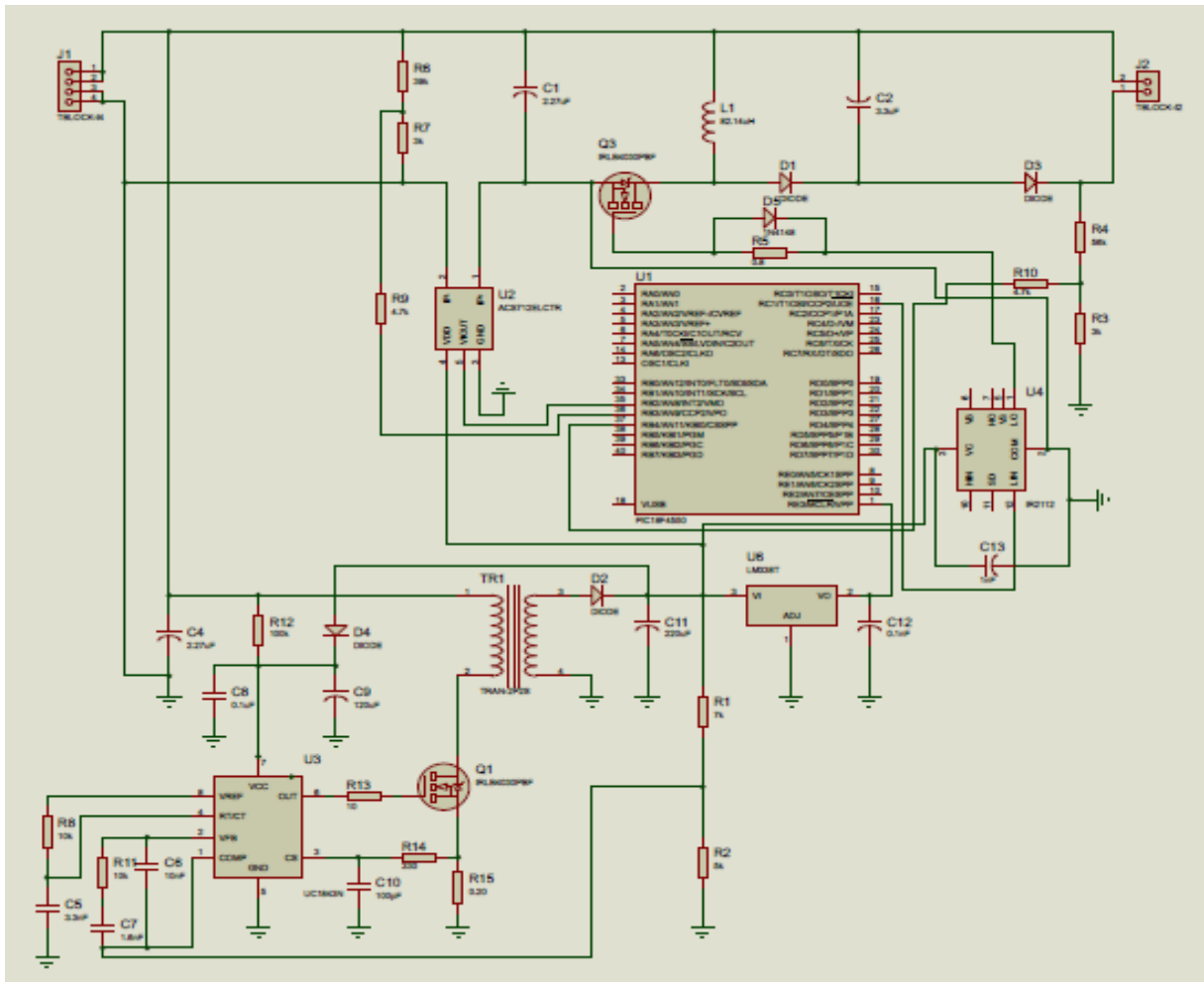


Fig. 3.5 circuit diagram representation

3.3.4 PCB layout:

The diagram describes the circuit diagram using the bottom silk of the board. The corresponding PCB layout for the above circuit diagram is shown below;

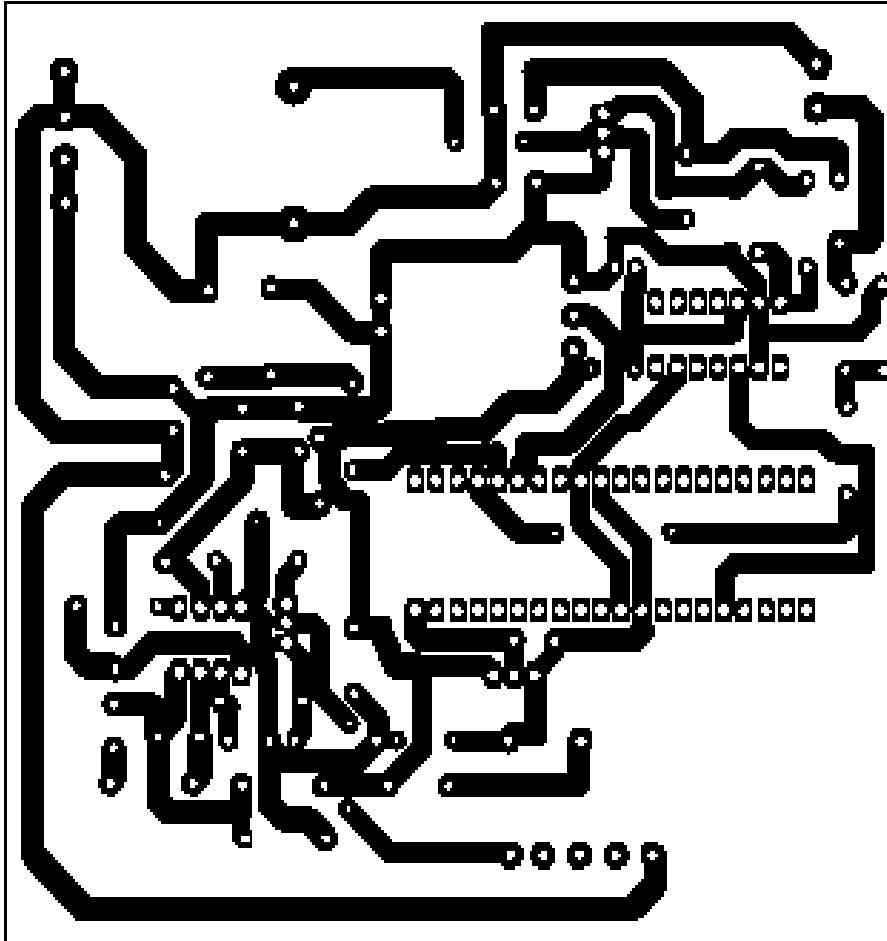


Fig. 3.6 diagram of the PCB layout.

CHAPTER FOUR: PERFORMANCE AND COST EVALUATION

4.1 Performance Evaluation

The aim of this project is to design and construct an MPPT charge controller that transfers maximum power at different cases of irradiance and temperature. At a lower temperature and high irradiance, the voltage supplied by the panels is high, therefore at this instance, the microcontroller reduces the duty cycle thereby stepping-down the voltage and then increasing the current also at high or low temperature with low irradiance, the voltage from the panel is low and as such, the microcontroller increases the duty cycle thereby increasing the voltage and reducing the current so that the input power and output power will be the same.

4.2 Cost Evaluation

The cost estimate of this project is summarized in the Table 4.0 below. The analysis mainly considers the physical cost of implementing this project, such as components/materials costs and transportation cost. The cost estimate here assumes a unit production cost of this system. However, producing the same system at large scale may reduce the cost of production, as transport cost per unit item, design cost, construction cost etc., might have reduced for each unit. This will provide a cost-effective production, thus, making the system affordable. It will also offer a reduced cost for institutions that may intend to implement this system for various research purposes.

Table 4-1 COST EVALUATION

S/N	COMPONENT	COMPONENT DESCRIPTION	QUANTITY	UNIT PRICE (N)	AMOUNT (N)
1	Microcontroller	PIC18F4550	1	2500	2500
2	Inductor		1	200	200
3	Capacitor	Ceramic (3.3 and 10nF)	3	50	150
		Electrolytic (220 and 4700uF)	8	50	400
		Electrolytic (120uF)	1	150	150
4	Diode	N5408	2	50	100
		N400	2	50	100
		1N4148	1	50	50
5	Resistor	Color resistor	14	10	140
		Chalk resistor	1	50	50
6	MOSFET	IRLB 4030	1	100	100
		IRF 3205	1	100	100
7	MOSFET driver	IR 2112	1	200	200

8	Control IC	UC3843	1	100	100
9	Voltage regulator	LM7805	1	100	100
10	Connector	TBLOCK I4	1	40	40
		TBLOCK 12	1	30	30
11	Current sensor	ACS 712	1	1000	1000
12	Chemicals	HCL, H ₂ O ₂	1	200	200
13	Transport fees			2000	2000
	TOTAL				7710

CHAPTER FIVE: CONCLUSIONS

5.0 Summary

The problem that led to the development of the maximum power point tracking system has been properly discussed and relevant literature reviewed. The system was designed and constructed using PIC 18F4550 microprocessor. Performance evaluation was carried and it was found that the system reliability is considerable good, and the efficiency is around 80 %. This revealed that the system is capable of performing the required task and satisfactory results were obtained as anticipated, with avoidable errors, during the test period.

5.1 Conclusions

Generally, the maximum power point tracker can be used to generate electrical energy which on the long run can become cheaper the consumer. This project is a perfect replacement of the popular PWM charge controller which is just concerned with monitoring the charge that goes to the load. Additionally, the system can be employed for both off-grid and on-grid applications. Having tested for and obtained all the expected result; it can be concluded that the aim and objectives of the project have been fully achieved.

5.2 Recommendations

The system presented in this work achieves maximum power supplied from the panel to the load for a given irradiance and temperature. Future research works can focus on improving/extending the work in the following areas.

1. Design and construction of maximum power point tracking system for higher voltage ratings e.g. 24V, 48V, 72V and so forth.
2. Addition of a Bluetooth module so as to be able to communicate (i.e. to know the supplied voltage, temperature and irradiance at a given instance of time) with the device remotely from another device.
3. An LCD display can be incorporated into the system for a better professional look.

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