



ASHESI UNIVERSITY

Maximum Power Point Tracking of Photovoltaic Systems for Rural Applications

Capstone Project

BSc. Electrical and Electronic Engineering

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ASHESI UNIVERSITY

Maximum Power Point Tracking of Photovoltaic Systems for Rural Applications

CAPSTONE PROJECT

Capstone Project submitted to the Department of Engineering, Ashesi University in partial fulfillment of the requirements for the award of Bachelor of Science degree in Electrical and Electronics Engineering.

LEONARD TWAGIRAYEZU

2019

DECLARATION

I hereby declare that this capstone is the result of my own original work and that no part of it has been presented for another degree in this university or elsewhere. Candidate's

Signature:

.....

Candidate's Name

.....Leonard Twagirayezu.....

Date:

.....23rd, April 2019

I hereby declare that preparation and presentation of this capstone were supervised in accordance with the guidelines on supervision of capstone laid down by Ashesi University.

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Date:

.....

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ABSTRACT

PV modules exhibit a point at which its power is maximum; this point is called Maximum Power Point (MPP). Due to changes in weather conditions, the MPP changes and the PV module efficiency. Specifically, temperature and irradiance are the parameters that affect the solar panel characteristic properties. This project describes and implements an MPPT algorithm that tracks the MPP at every point in time depending on the load. The algorithm was modeled using MATLAB Simulink and tested under different weather conditions. It was tested under standard test conditions which are the temperature of 25 °C and irradiance of 1000W/m² where the efficiency was 85.63%. The temperature and irradiance were changed, and the MPP was tracked under each circumstance.

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LIST OF ABBREVIATIONS

Abbreviation	Meaning
MPP	Maximum Power Point
MPPT	Maximum Power Point Tracking
PV	Photovoltaics
DC	Direct Current
EE	Electrical and Electronic

Chapter 1: Introduction

1.1 Background

Electrical energy generation is classified into nonrenewable and renewable energy [1]. Nonrenewable energy sources cannot be reused and produce electrical energy using fossil, fuel, and nuclear. Renewable energy sources are produced using water, wind, solar irradiance, and geothermal [2]. The world needs Renewable energy as its source of electrical energy because it is environmentally free. This project focuses on photovoltaic (PV) systems which highly depend on solar irradiation and temperature. Solar cells exhibit losses due to weather conditions from cloudy or rainy days, decreased irradiance levels and temperature changes [3]. The issue with Photovoltaic systems is their low efficiency when irradiance is low for example during winter or cold seasons [4]. PV systems exhibit a point on the current (I)- Voltage (V) characteristic curve where maximum power is reached [5]. Maximum Power Point Tracking (MPPT) is a way of getting the maximum power from PV modules [5].

This system uses different techniques to always track the Maximum Power Point (MPP) of the PV module. The goal is to extract the peak power of the solar panel at any time. Some of those techniques are perturbation and observation, incremental conductance, fractional open circuit voltage, fractional short-circuit current and fuzzy logic control and neural network [2]. MPPT microcontrollers have two main parts: the DC-DC converter and the part containing the algorithm [4]. The DC-DC converter is used to reduce power losses, normally also used to convert a higher input voltage from the solar panel to suit the desired application [6]. Mostly buck converters are used because they have a linear voltage transfer function when they operate in continuous conduction mode [7].

1.2 Problem Definition

PV systems are less efficient because of their dependency on weather [4]. During bad weather for example winter, irradiance becomes low which affects the efficiency of solar modules. Improving the efficiency of PV modules is necessary, and this is achieved through extracting the maximum power of a solar panel at any point. Every PV system exhibits a point at which its power is maximum on the IV curve characteristics. This point is called Maximum Power Point (MPP) [3] [4] [5] [6]. The MPP changes with weather conditions such as temperature and irradiance [3] [4] [6] as shown by Figure 1.1. Tracking this point is of interest in order to maximize the power output from PV systems. MPPT is a method used to track maximum power point from PV systems. MPPT is mainly composed of components such as PV modules or arrays, DC-DC converter, controller, battery and loads [4] [5] [6]. Developing an MPPT algorithm which is simple and fast-tracking maximum power point with less convergence speed is of paramount concern.

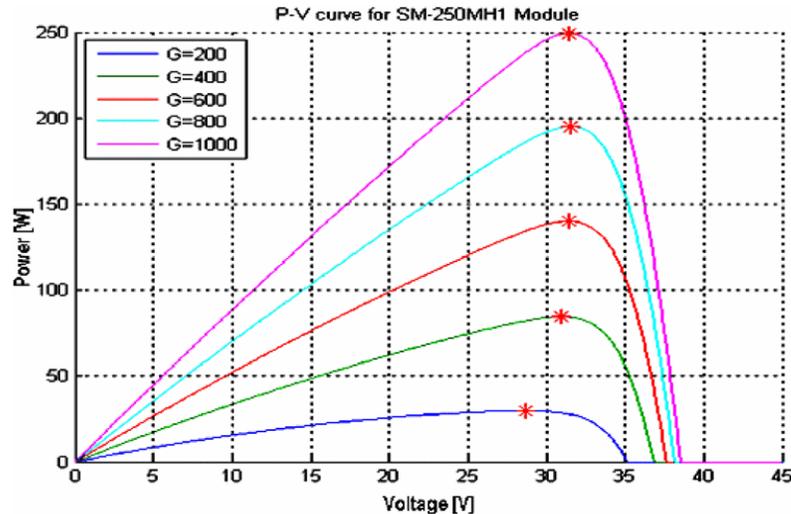


Figure 1. 1: Power against voltage for the PV module

1.3 Objectives of the Project Work

The objectives of the project work include:

1. Building a hardware prototype of MPPT for rural applications
2. Developing a model and simulating the developed MPPT technique
3. Develop a control algorithm for the maximum power point tracking

1.4 Expected Outcomes of the Project Work

The following are the expected outcomes of the project:

1. A built a prototype
2. The workable algorithm that can extract MPP from the PV system
3. A Working model
4. Report on the results of the improved algorithm

1.5 Justification of Project Topic

PV systems are being used widely in the past few years, but they depend on weather conditions. When irradiation becomes low, efficiency becomes low. From the literature, there are different MPPT algorithm that has been studied and approved. The challenge becomes how to improve the efficiency of PV systems through maintaining their maximum power point even during low solar irradiation.

1.6 Research Methods Used

The research methodologies used are:

1. Downloading and review of research journals conferences patents and books relating to the topic
2. Computer modeling and simulation
3. Designing a hardware prototype of the MPPT

4. Developing a software algorithm for the hardware
5. Implementation of the chosen algorithm using available resources.

1.7 Facilities Used for the Research

The facilities used for the project work include:

1. Computer, internet and library facilities at Ashesi
2. Ashesi Electrical and Electronics (EE) laboratory and Mechanical workshop
3. A PV system consisting of a solar panel, charge controller, batteries and DC-DC converter

1.8 Scope of Work

The project is limited to evaluating different MPPT algorithms and the use of computer modeling and simulation of PV systems for the chosen MPPT algorithm. The practical implementation of the best-chosen algorithm will also be considered.

1.9 Organization of the Project

The project is divided into different chapters. Chapter 1 talks about the introduction where the project is introduced and explained. Chapter 2 is about literature review where work done in the literature is reviewed. Chapter 3 is the material and methods. Chapter 4 talks about the results and analysis while chapter 5 contains the conclusion and recommendations.

Chapter 2: Literature Review

2.1 Introduction

Environmental conditions such as global warming led to the need for a cheap and environmentally friendly source of electrical energy with solar energy being preferred [8]. Photovoltaic (PV) systems depend on weather conditions including irradiation and temperature [3] [4] [5] [6] [8]. Weather conditions change, and this makes PV systems less efficient especially during rainy and cloudy days [4] [3].

2.2 Photovoltaic Systems

PV systems are systems that directly generate electric power from solar power. Complete PV systems consist of solar panels, charging and loads controllers, batteries, inverters, circuit breakers and wires [9]. Different type of technologies for PV systems are under research but the most used today is crystalline silicon which produces the efficiency between 13% and 18% [9].

2.3 Maximum Power Point Tracking Techniques

Different MPPT techniques are used when tracking the maximum power point. The most used are perturb & observe method, incremental conductance, Fuzzy logic and neural network, parasitic capacitance method, Constant Voltage method, fractional short circuit current, fractional open circuit voltage, temperature method, and neural networks. [4] [2] [3] [4] [5] [6] [3] [8] [10].

The most used algorithm is perturb and observe method mainly because of its simplicity in implementation. It finds the maximum power point by incrementing or decrementing the output power from the PV array as sensed by voltage and current sensors [10]. The incrementation and decrementation are done by adding or subtracting a constant value of power

depending on whether the change in power is positive or negative. DC-DC CONVERTER is used as a controller [10].

2.3.1 Perturb and Observe Method

This is a hill climbing and iterative algorithm. The panel operating voltage is sensed periodically and then compared to the previous voltage. If the change in voltage is positive, the perturbation increases in the same direction as before. When the change is negative, perturbation increases in the opposite direction. The process continues until the change in voltages is zero where the maximum power is reached [11]. The flowchart for this algorithm is shown below in Figure 2.1 [11]:

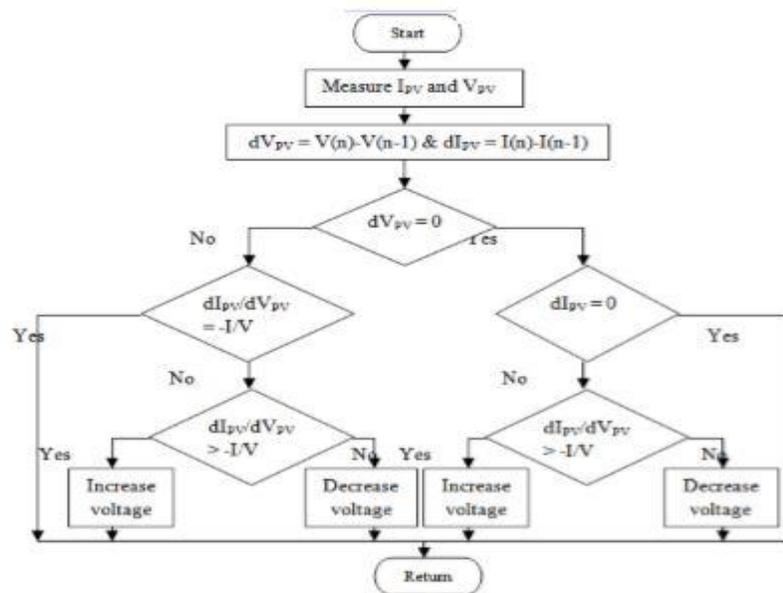


Figure 2. 1: Perturb and observe method algorithm

Power is calculated from sensed voltage and current and then compared to the previous power to find the sign of the change in power. Then the maximum power point is tracked respectively [11]. This method is easy and simple to implement but it may track wrongly under rapidly changing irradiance and temperature, and it oscillates around the MPP [5] [11].

2.3.2 Incremental Conductance

This is another hill climbing method where the oscillation around the MPP that occurs in perturb and observe method is removed through comparing the instantaneous conductance of the panel and the previous conductance of the panel. The change in conductance keeps changing until it goes to zero as shown in Equation 2.1 [11]. The flowchart of incremental conductance is shown in Figure 2.2 [11]. Incremental conductance is more efficient than perturb and observe method, but it requires a complex control circuit [11].

$$\frac{dI}{dP} = 0 \quad (2.1)$$

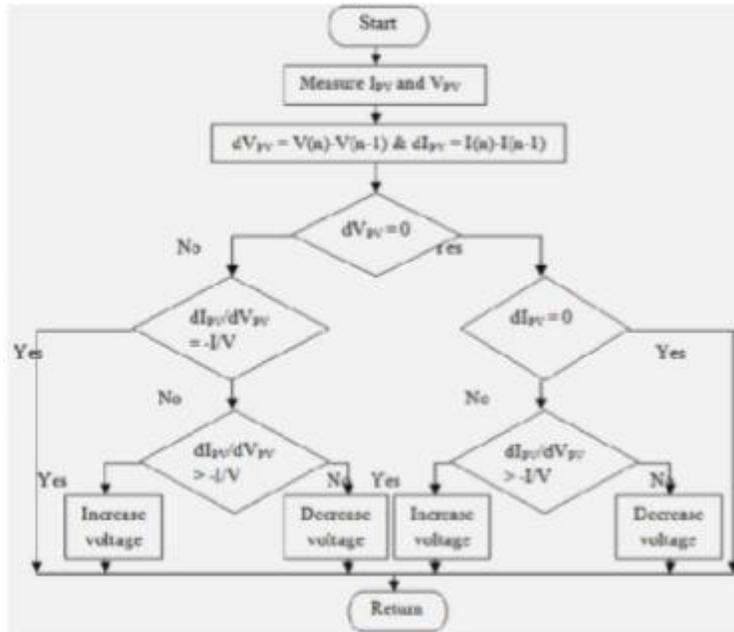


Figure 2. 2: Incremental conductance flowchart [11]

3.2.3 Fractional Open Circuit Voltage Method

This method operates on the basis that Voltage at maximum power point (V_{mpp}) and the open circuit Voltage (V_{oc}) are constant [5].

$$V_{mpp} = kV_{oc} \quad (2.2)$$

Where k is the fraction constant between 0.7 and 0.8 [5]

This method is simple, but it exhibits power loss because PV arrays get disconnected from the load after regular sampling period of the array voltage. The period between two successive array voltages also takes too long [12].

2.3.4 Fractional Short Circuit Method

This method also operates under the condition that optimum operating current I_{mpp} has a linear dependence with short circuit current I_{sc} [11].

$$I_{mpp} = k_i * I_{sc} \quad (2.3)$$

Where k_i is the constant of proportionality or current factor with values between 0.71 and 0.90 [13].

The main issue with this method is measuring the short current while PV systems are in operation. This is solved by connecting a parallel circuit to the system for the I_{sc} measurement purposes [5] [13].

2.3.5 Fuzzy Logic Method

This is an MPPT algorithm which can handle linearity and nonlinearity inputs. It has four stages of operation: fuzzification, rule base, inference engine and De-fuzzification [14]. Fuzzification deals with changing input data into linguistic variables based on membership function, then form a set of rules-based table for easy determination of direction and change of duty cycle. Finally, the linguistic variable is converted into a numerical variable by a membership function, and then the analog signal is sent to the microcontroller for MPPT [13]. The advantage of this method is its good performance under varying weather conditions but the right choice of rule-based table and error computation is highly required [13] [14].

2.3.6 Neural Networks Method

Neural networks method draws its functionality from how the brain functions. This method draws its functionality from brains capability to process different information through millions of neurons [13]. Different input to solar PV modules such Voc, Isc, irradiation, temperature or a combination of these factors can input to the neural network. Three layers are used in the neural network: input, hidden and output layer. Duty cycle is used to control the power converter so that PV operates at its MPP. The better training and algorithm used in the hidden layer, the better the performance in tracking MPP [13]. Figure 2.3 shows the layers in the neural network method.

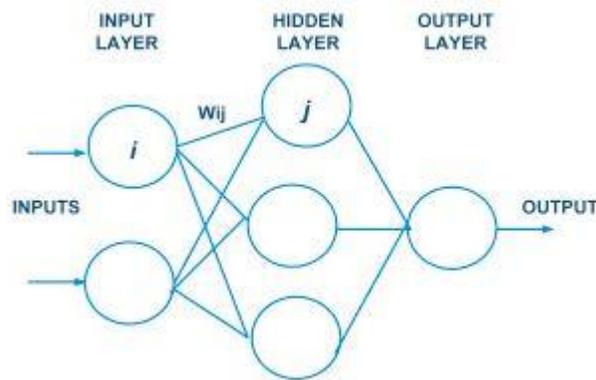


Figure 2. 3: Neural network method layer [13]

2.4 Review of Related Works on MPPT

According to Blue Sky Energy (2009), MPPT is defined as a system that allows PV modules to always produce their maximum power. The study pointed out that MPPT can be used together with a mechanical solar tracking system even though they are completely different systems of maximizing PV output power. When PV modules are directly connected to the battery, they are forced to operate at the battery voltage. According to the paper, MPPT helps in enabling the PV modules to operate at their maximum power which increases their efficiency [9].

Armstrong, et al (2014) evaluated different MPPT techniques through different criteria such as effectiveness, convergence speed, complexity, and cost. The sated techniques were perturbation and observation, incremental conductance, constant voltage, temperature, feedback voltage (current), open voltage, Fuzzy logic control, and neural network methods. From the study, the choice of techniques to use is application dependent due to the different advantages and disadvantages attached to each technique. For example, if fast convergence is highly important like in solar cars, fuzzy logic and neural network are required. For residential areas, payback time is of interest which requires to constantly and continually track MPPT. Then, perturb and observe method and incremental conductance are required [10].

Ahmed, et al (2013) talked about how it is necessary to increase the efficiency of PV systems through MPPT techniques. The proposed MPPT algorithm in the paper was perturb and observe method due to its convergence speed, easy complexity, and low cost. Using MATLAB/Simulink, perturb and observe method were simulated and implemented using a microcontroller [12].

Ktchaou, et al (2016) talked about six different techniques such as perturb and observe, incremental conductance, sliding mode control, Robust Unified control algorithm, fractional open circuit voltage and fractional short-circuit current methods. The paper provided mathematical model of PV module and talked about DC to DC converter in addition to comparing and simulating using MATLAB/Simulink the mentioned techniques. In order to satisfy required loads' power, PV systems require a techniques that maximize its power [5].

Kamala, et al proposed a microcontroller based buck converter to implement MPPT. The paper stated that the maximum power point of a solar module varies according to weather condition; MATLAB/Simulink was used to model and simulate the Controlled fuzzy logic

MPPT techniques. Fuzzy logic method is efficient in tracking MPP but expensive and complex [6].

According to Atallah, et al (2014), PV systems are advantageous because of low maintenance required, being environmentally friendly and fuel free but they have disadvantages of low energy conversion efficiency and high initial cost. Three MPPT algorithms were explained including Perturb and observe, incremental conductance and constant voltage method. Perturb and observe method were implemented using MATLAB Simulink and the testing was done with two DC to DC converter types which buck and buck-boost converters. Perturb and observe was tested due to its low complexity in implementation and fast-tracking capability [13].

Hamid, et al (2016) focused on implementing the MPPT algorithms, specifically, perturb and observe algorithm using Arduino Nano. The paper talked about how Photo-Voltaic systems without MPPT wastes power and less efficient because of the changing atmospheric conditions such as temperature and sun irradiation. This makes keeping the operation of the power at its maximum point a very important concept. The paper explained the working principle of MPPT and it was implemented using Arduino Nano. Simulations were done using Proteus and a buck converter was used a way to step down the power [7].

This project seeks to find the best MPPT techniques in terms of improving efficiency and conversion speed. In addition to modeling and simulation of the chosen MPPT technique, implementation will also be considered.

Chapter 3: Materials and Methods

3.1 Design Concept and Criteria

Figure 3.1 shows a block diagram of the MPPT system. MPPT system consists of PV module, maximum power point tracker and the loads. PV module produces power from solar irradiance. Maximum power point tracker consists of DC to DC converter (Buck-boost converter), a control unit. The Buck-boost converter is to boost and decrease the voltage obtained from the PV module. Control unit consists of an MPPT algorithm which is implemented using a microcontroller. The power obtained from the PV module is tracked by the control unit in order to always operate the load at the maximum point of the PV module.

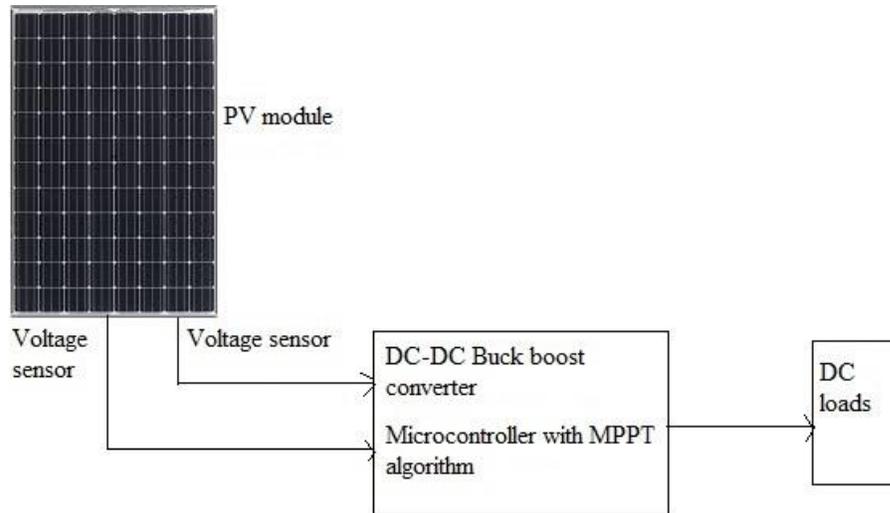


Figure 3. 1: Block diagram of MPPT system

It is important to note that the power from PV modules depends on different factors that affect their performances and efficiencies. Among those factors include variation in solar radiation, shading, temperature, parasitic resistances and soiling [15]. The MPPT is tracking the maximum power at every point in time in order to increase the efficiency of the PV system.

In evaluating components and the system, the following criteria are to be examined:
Efficiency, complexity in implementation, conversion rate and tracking capability

3.2 Model of PV Module

A solar cell is the smallest block of solar generation [16] The model of any solar cell depends on the behavior of the diode under which the exponential behavior is found [17]. The solar cell can be modeled using a Resistor R in series with a current source connected in parallel with two diodes as shown by the circuit diagram in figure 3.2 [16]. Where I_{ph} is the photo-generated current.

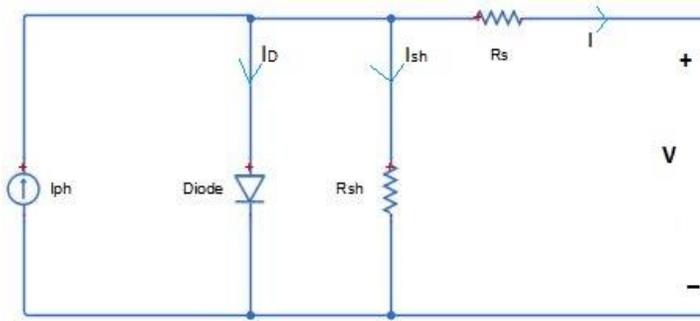


Figure 3. 2: circuit diagram of a solar cell model

Equations (3.1) to (3.5) are used to model the solar cell:

$$I = I_{ph} - I_0 \left[\exp\left(q * \frac{V+I.R_s}{n.K.N_s.T}\right) - 1 \right] - I_{sh} \quad (3.1)$$

$$\text{Where } I_{ph} = [I_{sc} + k_i.(T - 298)]. \frac{G}{1000} \quad (3.2)$$

$$I_0 = I_{rs} . \left(\frac{T}{T_n}\right)^3 . \exp\left[q . E_{g0} . \left(\frac{1}{T_n} - \frac{1}{T}\right)\right] \quad (3.3)$$

$$I_{rs} = \frac{I_{sc}}{\left[e^{q \cdot n N_s K T} - 1 \right]} \quad (3.4)$$

$$I_{sh} = \left(\frac{V+I.R_s}{R_{sh}} \right) \quad (3.5)$$

Where I_{ph} -photo-current,

I_0 -Saturation current,

I_{rs} -reverse saturation current,

I_{sh} -current through the shunt resistor. I and V are current and voltage of the photovoltaic module

respectively. T and T_n are temperatures,

K is the Boltzmann constant,

q is the proton number, and

V_{oc} is the open circuit voltage.

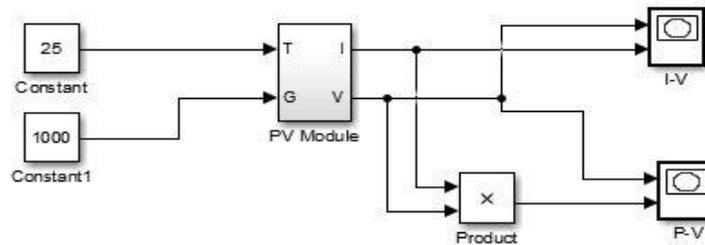


Figure 3. 3: Masked model of PV module

The following is the detailed MATLAB/Simulink of the mathematical model:

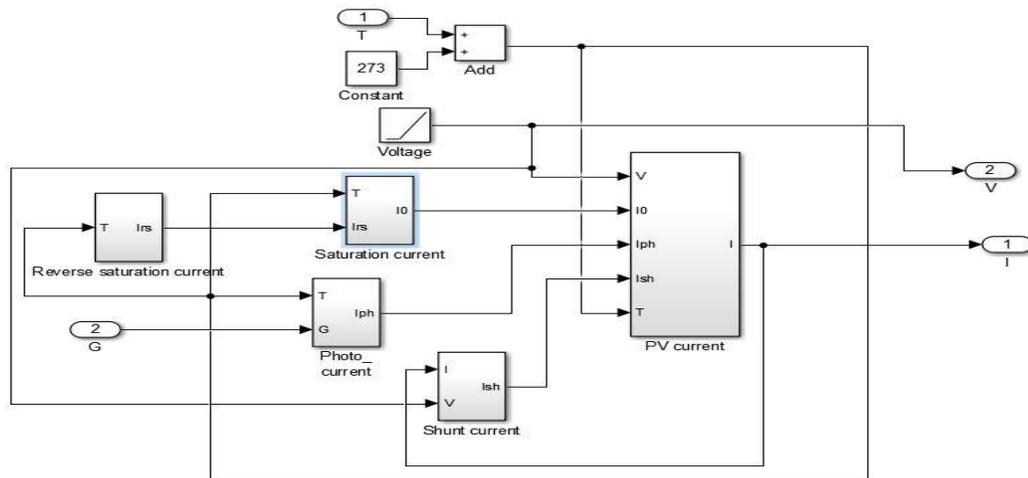


Figure 3. 4: Mathematical model of the PV model.

With the input of 25 °C and irradiance of 1000 Wb/m² as shown by figure 4, PV and I-V characteristics curves of the PV module were found as in Figure 3.5 and Figure 3.6.

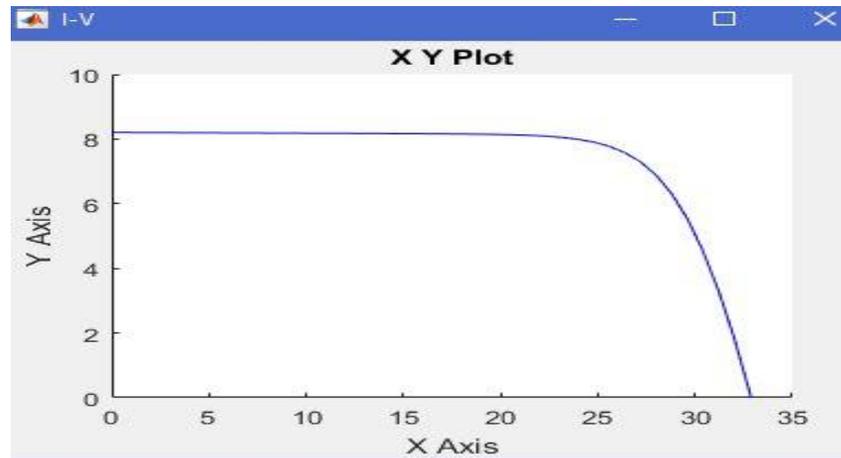


Figure 3. 5: I-V characteristic curve of the model

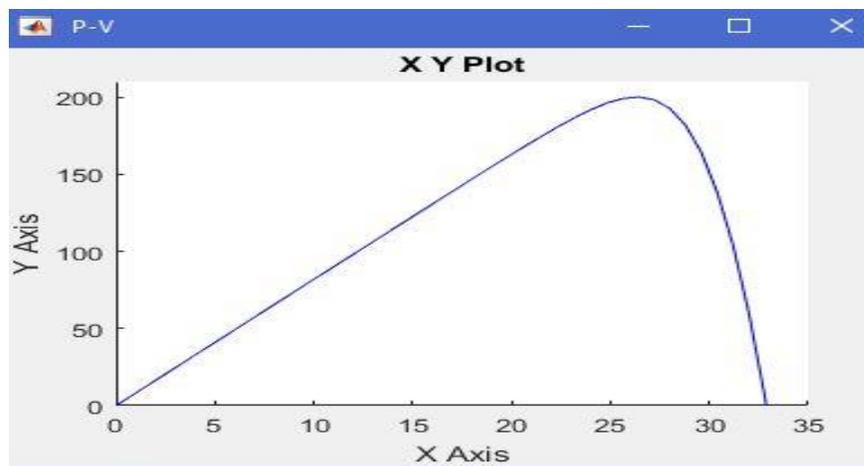


Figure 3. 6: P-V characteristic curve of the model

3.3 Current and Voltage Sensor

Current sensor and Arduino voltage sensor modules are used to measure PV output current and voltage. Photovoltaic measurement accuracy is dependent on sensor circuit, and programming code used [20]. Measurement is done continuously in order to keep updating the current and voltage measured previously. In this project, a comparator was built and used as a

voltage sensor. Op-Amp comparator compares two voltages or current and then produces an output voltage or current based on the comparison.

3.4 Buck-Boost Converter

A buck-boost converter is a DC-DC converter. It can operate in two modes: buck and boost mode. Through changing the duty cycle, the output voltage from the buck-boost converter can be either be less or greater than the input voltage [18]. The specifications of the buck-boost converter are given in Table 3.2.

Table 3. 1: specifications for the buck-boost converter

Components	Symbol	Value
Input Voltage	Vs	0 – 22 V
Input Current	Is	0 – 2A
Output Voltage	Vo	12 – 24 V
Output Current	Io	1A
Output Power	Po	20 W
Switching frequency	fs	10 kHz
Duty cycle	d	$0.1 \leq d \leq 0.9$

Figure 3.7 represents the designed buck-boost converter. The mosfet IRFZ44N/IR2104 serves as a switch. When the switch is closed, the inductor gets charged and then goes to the loads. When the switch is opened, inductors get discharged and give the supply to the load.

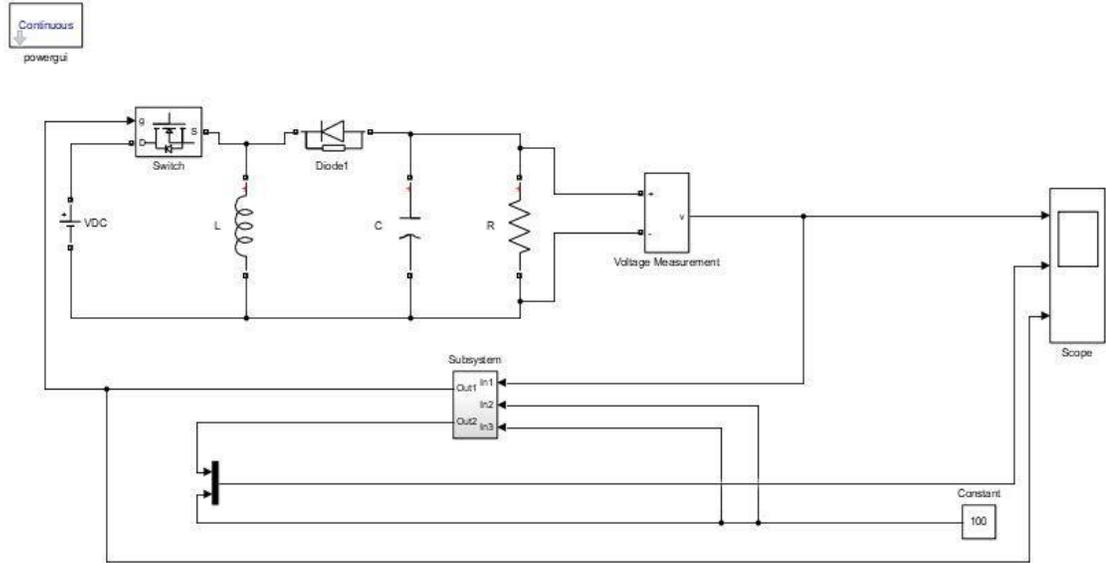


Figure 3. 7: Designed buck-boost converter

Inductor value and capacitor values are calculated using Equation (3.6) to Equation (3.8).

$$L = V_{in} * \frac{\delta}{f * dI} \quad (3.6)$$

$$C = I_{out} * \frac{\delta}{f * dV} \quad (3.7)$$

$$N d_I = 0.8 + I \quad (3.8)$$

Where

L – inductance inductor, C – capacitance of the capacitor I_{out} – output current, δ – duty cycle, I – input current, f – frequency, dV – change in Voltage and d_I – change in current

Using parameters specified in Table 1 and the duty cycle of 0.6, the capacitor values were found

to: $L = 14\text{mH}$ and $C = 1\mu\text{H}$

The following is the design of buck-boost converter in MATLAB Simulink

3.5 The Microcontroller

This project used is Arduino Nano. This is a small compact Arduino similar to Arduino Uno. The Arduino Nano is a small, complete, and breadboard-friendly board based on the ATmega328 (Arduino Nano 3.x). It functions more or less the same as Arduino Duemilanove but lacks DC power jack. It has digital and analog inputs pins, power supply, small USB and reset button [20]. The Arduino is used for this project because it is an open source, easy to use for hardware and software and its availability.

3.6. Control Algorithm Flow Chart

As shown in Figure 3.8 below, voltage and current are sensed from the PV module. In this project, the comparator is used to compare the reference voltage and current, and the voltage from the PV module to get the output which the voltage and current from the PV. Power is then calculated from the measured current and voltage. The voltage and current are continuously sensed, and then the power is compared to the previous power to decide whether to change the voltage in order to find the maximum power. The MPP is found through doing different iterations until the change in voltage is zero. It is important to note after developing the algorithm from scratch; it came out to be the same as perturb and observe method. The resemblance was because the algorithm was developed based on hill climbing method.

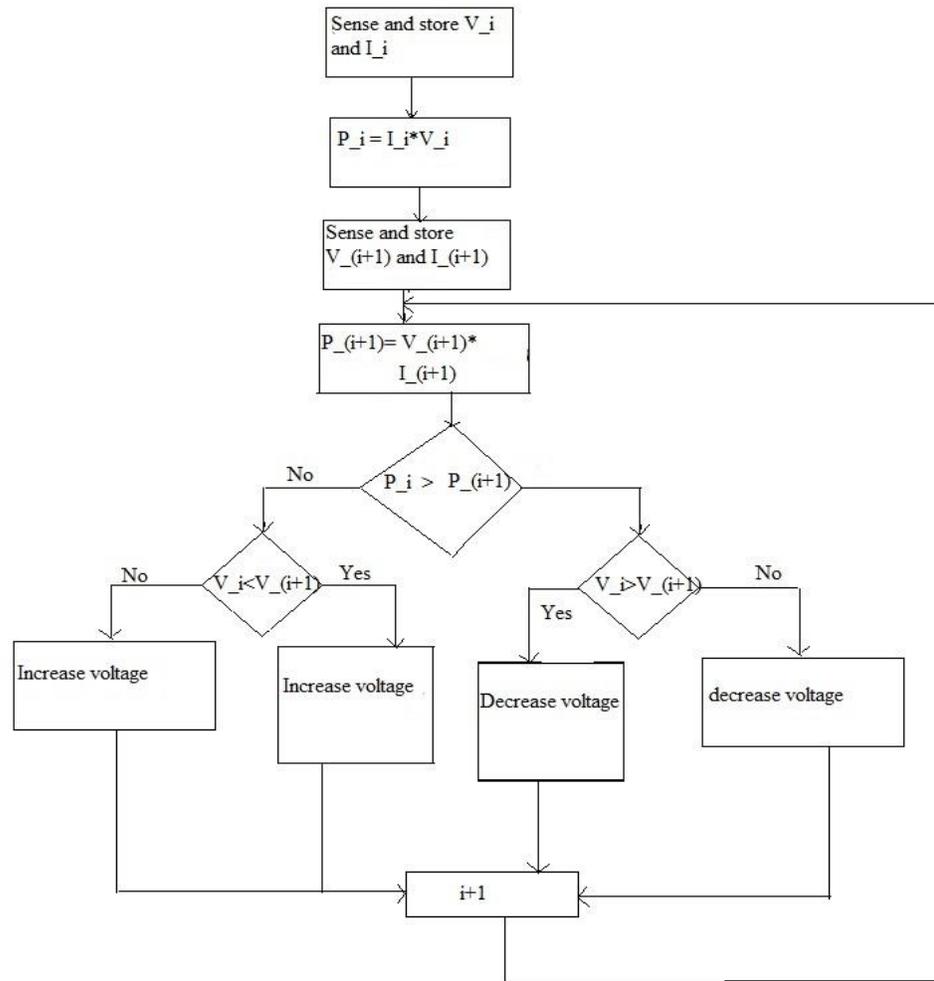


Figure 3. 8: flowchart of the control algorithm of the MPPT

3.7 DC Loads

Loads are electrical devices that need a power supply to work. DC loads are loads that use DC power supply. DC loads are directly connected to the DC battery where DC appliances such as LED lights, small radios, and small dc powered TVs are connected [21]. These DC loads are used in rural applications to which this project is concerned.

3.8 Complete Hardware Design

The following is the complete hardware design from the Eagle software:

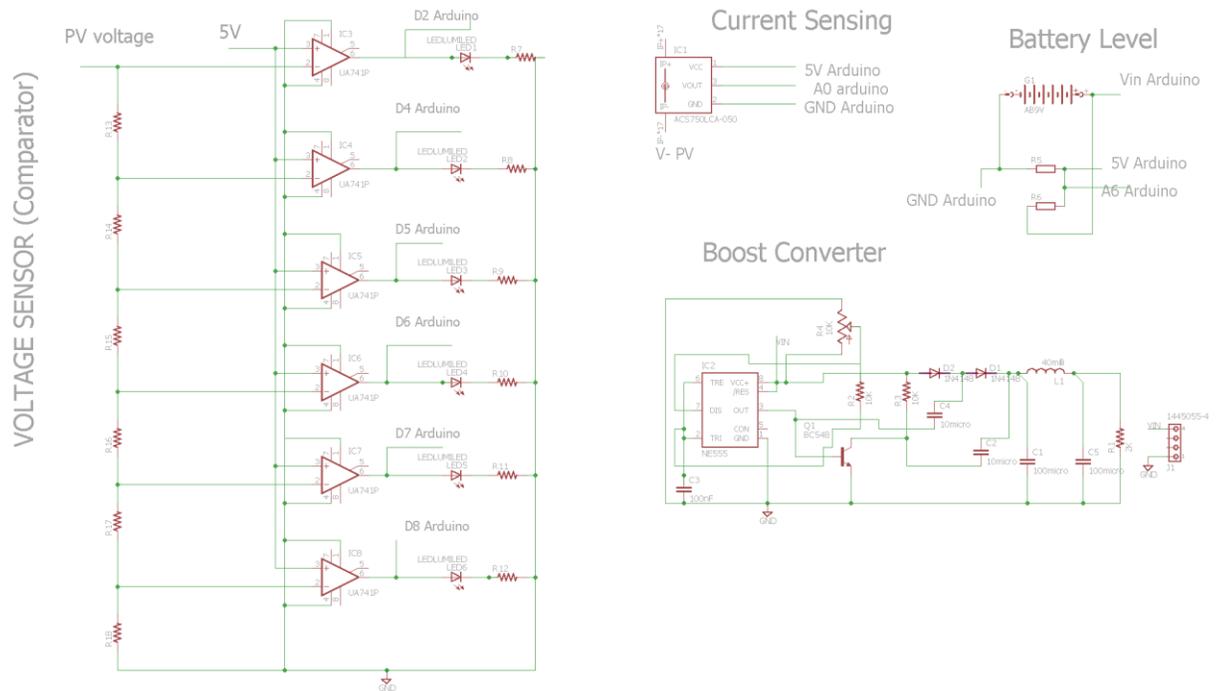


Figure 3. 9: complete design of the system in Eagle software

Chapter 4: Results and Discussions

4.1 Introduction

This chapter presents the results from MATLAB Simulink simulation and the implemented circuits. Analysis of the results will also be discussed in this chapter. The presented algorithm was used under different temperature and irradiance to search for the maximum operating power.

4.2 Results of Computer Simulation and Discussion

4.2.1 Simulation at 25 °C and Irradiance of 1000W/m²

Typically, most photovoltaic module data that are provided on the datasheets were tested under the standard test conditions. Those conditions are the temperature of 25 °C and irradiance of 1000 W/m² [22]. The MATLAB/Simulink of the proposed algorithm was tested under the same conditions to track the maximum voltage. The following graph of output voltage with the MPPT algorithm was found as shown in figure 4.1:

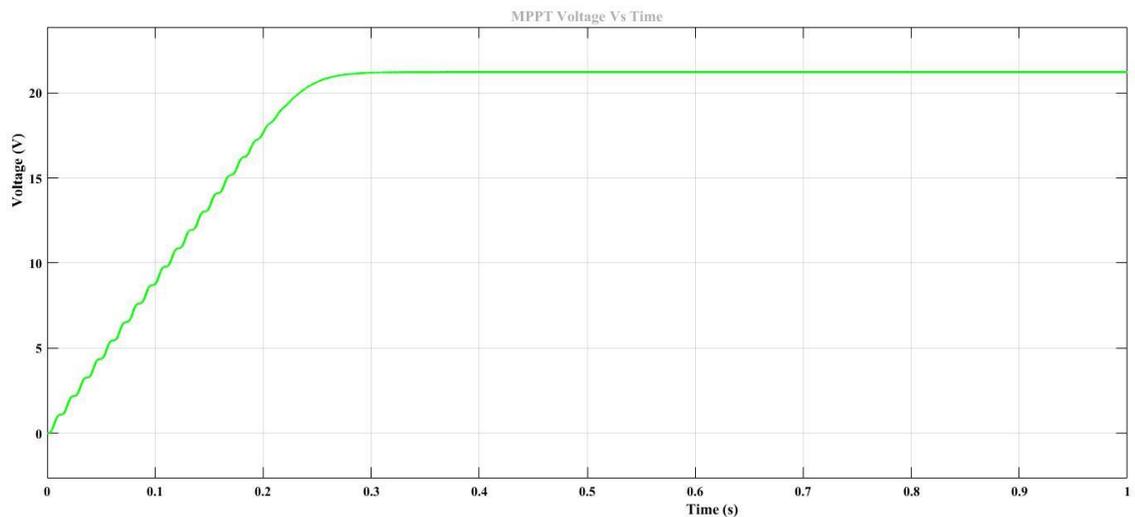


Figure 4. 1: Graph of tracking Voltage output with MPPT algorithm at Standard Test Conditions of 25 °C and 1000 W/m²

From Figure 4.1, It is seen that the voltage increased as time increased and reached it maximum point after 0.25 seconds. The graph is a result of PV module characteristic under the standard test conditions which are temperature of 25⁰C and irradiance of 1000 W/m². The maximum voltage that was reached is 21.22V. The maximum power is found to be 19.18W and the current was found to be 1.27A. The rated Power of the PV Panel is Prated = 22.4W

This shows that the MPP was reached at a voltage which to 21.22V despite the maximum voltage provided to be 22.05V. The efficiency of the developed MPPT algorithm can be calculated using Equation (4.1) is found as follows:

$$Efficiency = \left(\frac{P_{out}}{P_{rated}} \right) * 100 \quad (4.1)$$

$$Efficiency = \left(\frac{19.18W}{22.4W} \right) * 100 = 85.63\%$$

4.2.2 Simulation at 40⁰C and Irradiance of 1000 W/m²

To find out the effect of increased temperature on the characteristics of the PV model, the MPPT algorithm was tested under standard test irradiance of 1000 W/m² and increased temperature to 40⁰C. Figure 4.2 represents the output voltage from the MPPT algorithm

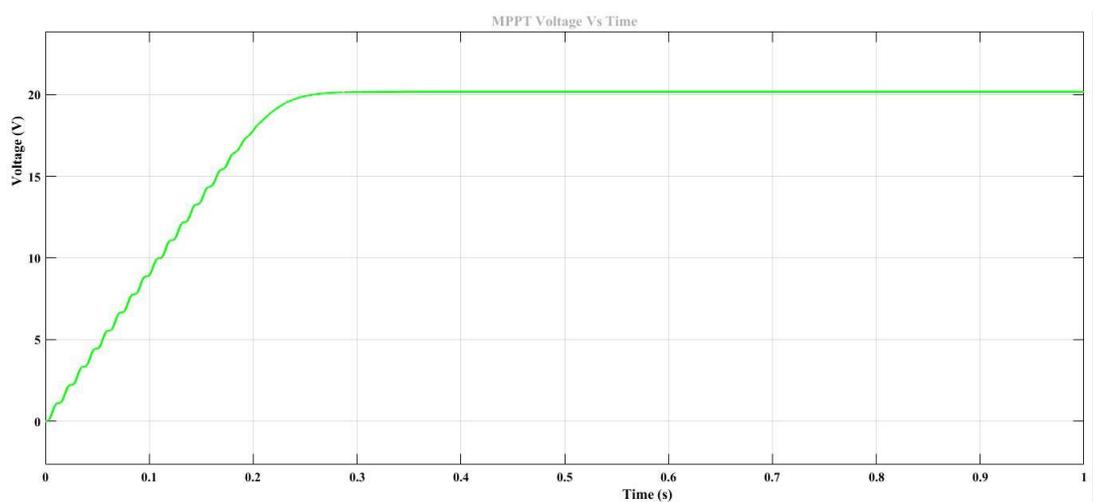


Figure 4. 2: Graph of tracking Voltage output with MPPT algorithm at a temperature of 40⁰C and irradiance of 1000 W/m²

As shown by Figure 4.2, when temperature increased to 40 °C and irradiance of 1000 W/m², the maximum voltage obtained was 20.18V, and it was tracked after 0.25 seconds. The Maximum power was found to be 20.81W with the current being 1.31A. With an increase in temperature, the maximum voltage obtained decreased compared to when temperature and irradiance were at standard test conditions. This shows the fact that temperature affects the output characteristics of PV modules when increased. As the maximum voltage decreased, the MPP tracked by the MPPT algorithm also decreased.

The efficiency found is the following:

$$Efficiency = \left(\frac{20.81W}{22.4W} \right) * 100 = 92.90\%$$

The efficiency decreased due to the decrease in maximum power. The increase in temperature caused a decrease in MPP.

4.2.3 Simulation at 20 °C and Irradiance of 800 W/m²

To verify the effect of reduced temperature and irradiance to the output characteristics of PV modules, the MPPT algorithm was tested under the temperature of 20 °C and irradiance of 700 W/m².

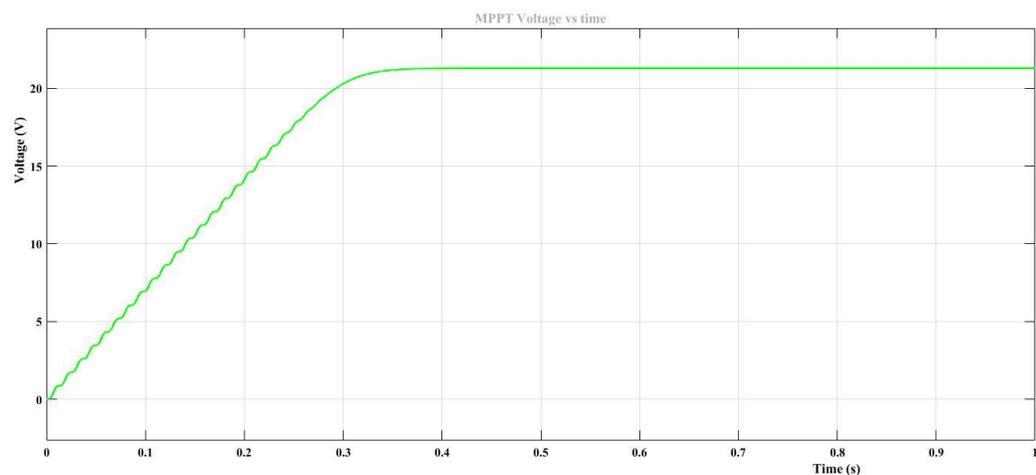


Figure 4. 3: Voltage output with MPPT algorithm at 20 °C and 800 W/m²

When the weather condition changes, the maximum voltage changes even though the changes are not high compared to when the temperature increases. As shown in Figure 4.3, the maximum voltage obtained with the temperature of 20⁰C and irradiance of 800 W/m² is 21.14V, and a maximum power of 15.29W and the maximum current was found to be 0.89A. The voltage decreased, and this shows the effect of decreased temperature and irradiance. The MPP was found at 15.29W, and the PV module is rated at 20W. then the efficiency is found to be the following:

$$Efficiency = \frac{P_{out}}{P_{rated}} * 100 = \frac{15.29W}{20W} * 100 = 76.45\%$$

A decrease in weather conditions, temperature and irradiance, caused a big decrease in efficiency of the PV module characteristics. This shows how influential weather conditions are on the solar panel.

4.2.4 Simulation at 25 ⁰C and Time-Varying Irradiance

Changing temperature and irradiance changes the MPP. The MPPT algorithm was tested under the standard temperature of 25 ⁰C and time-varying irradiance. The irradiance changes between 600 W/m² and 800 W/m². Figure 4.4 shows the output voltage of the PV module with the MPPT algorithm.

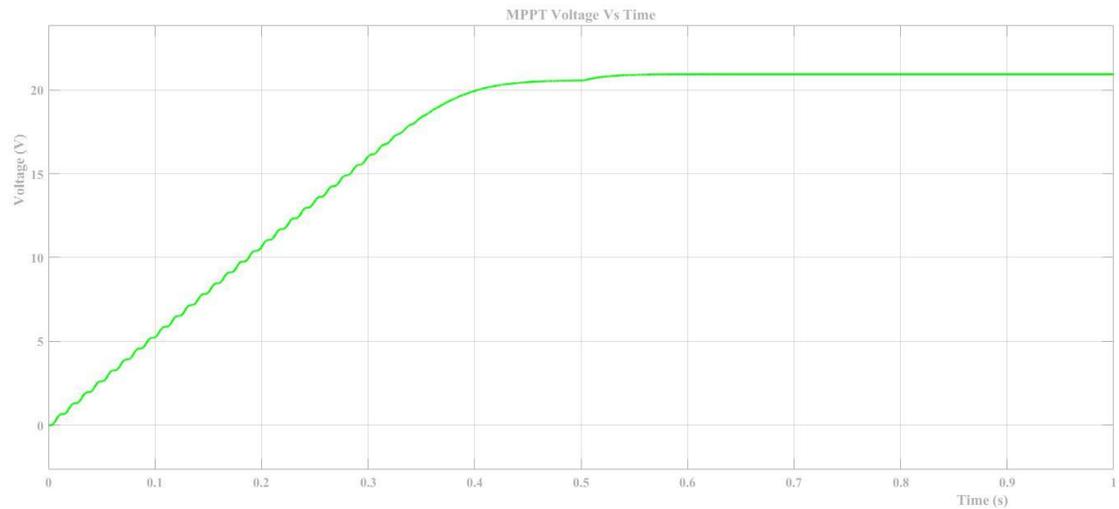


Figure 4. 4: Graph of tracking Voltage output with MPPT algorithm at Standard Test Condition of 25 °C and time-varying irradiance

With a standard temperature of 25 °C and time-varying irradiance, the maximum voltage output obtained is found to be 20.95V, and the maximum power 12.56W is with a maximum current of 0.77A. This MPP was tracked after 0.5 seconds, and it decreased due to the continuous changes in irradiance. The time-varying irradiance makes it hard for the system to track the MPP using the implemented algorithm.

The efficiency of the MPPT algorithm at 25 °C and time-varying irradiance was found to be the following:

$$Efficiency = \left(\frac{12.56}{22.4} \right) * 100 = 56.07\%$$

4.2.5 Simulation at 20 °C and Time-Varying Irradiance

The MPPT algorithm was tested under reduced temperature and time-varying irradiance to investigate the effect of those two changes. Irradiance changes between 600 W/m² and 800 W/m². Figure 4.5 shows the voltage output with MPPT when Temperature is reduced to 20 °C and time-varying irradiance.

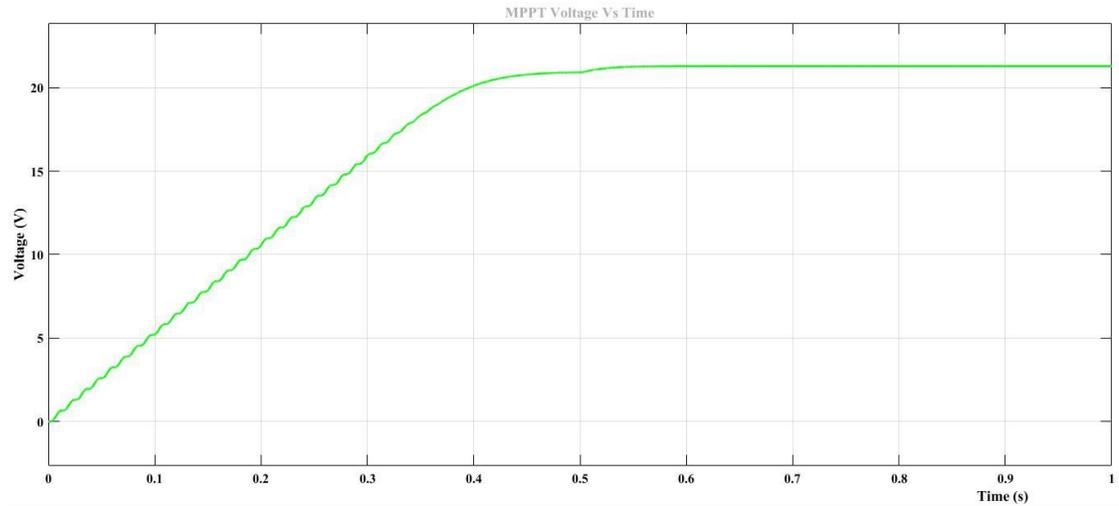


Figure 4. 5: Graph of tracking Voltage output with MPPT algorithm at a reduced temperature of 15 ⁰C and time-varying irradiance

With a decrease in temperature and time-varying irradiance, the maximum voltage obtained using the MPPT algorithm is 21.3V and it was attained after 0.51 sec. The maximum power that was tracked by the implemented algorithm is 12.99W, and the maximum current is 0.76A.

The efficiency of the PV module with the MPPT algorithm is found to the following:

$$Efficiency = \left(\frac{12.99W}{22.4W} \right) * 100 = 57.99\%$$

As found with a standard temperature of 25 ⁰C and time-varying irradiance, the algorithm decreases even when the temperature is decreased, and irradiance varies with time.

Table 4.1 represents the maximum values of the PV characteristics tracked by the MPPT algorithm

Table 5. 1: Summary of Results

Item	Weather conditions		Maximum Values			Efficiency
	Temperature	Irradiance	voltage	current	Power	
1	25 ⁰ C	1000W/m ²	21.22V	1.27A	19.81W	85.63%
2	40 ⁰ C	1000W/m ²	20.18V	1.31A	20.81W	92.90%
3	20 ⁰ C	800W/m ²	21.14V	0.89A	15.29	76.45%
4	25 ⁰ C	600-1000W/m ²	20.95V	0.77A	12.56W	56.07%
5	20 ⁰ C	600-1000W/m ²	21.3V	0.76A	12.99W	57.99%

4.3 Results of Hardware Implementation

The hardware implementation was focused on the DC to DC converter. It was first designed in Proteus as shown in Figure 4.6.

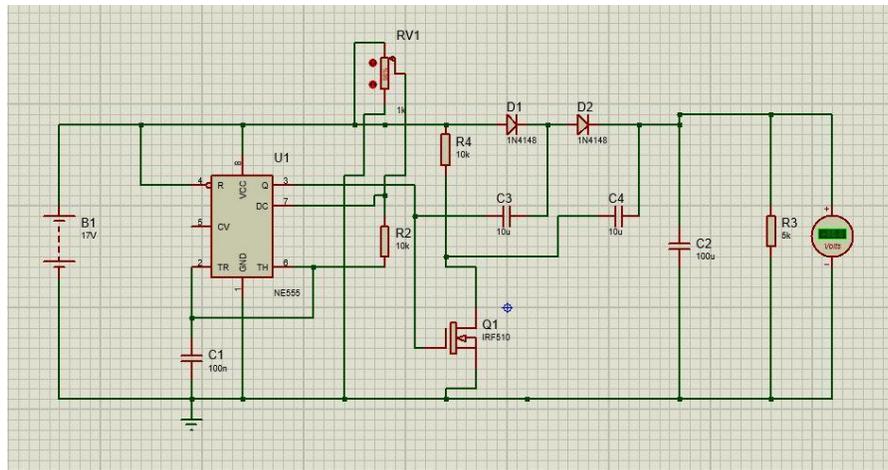


Figure 4. 6. Boost converter for the MPPT

The DC voltage from the battery was boosted from 17V to 27V. Since PV module provides DC voltage, It is expected that if a PV module is connected, the same effect will happen. This will be able to provide the MPP of the solar panel.

When the boost converter was connected to the solar using the breadboard as shown in Figure 4.7, the voltage did not reach the expected 24V when PV supplied 15.7V. Output decreased to 14.6 instead. This may be due to electrical losses and components which were not exact gotten as requested.

The following is the complete picture of the prototype on the breadboard:

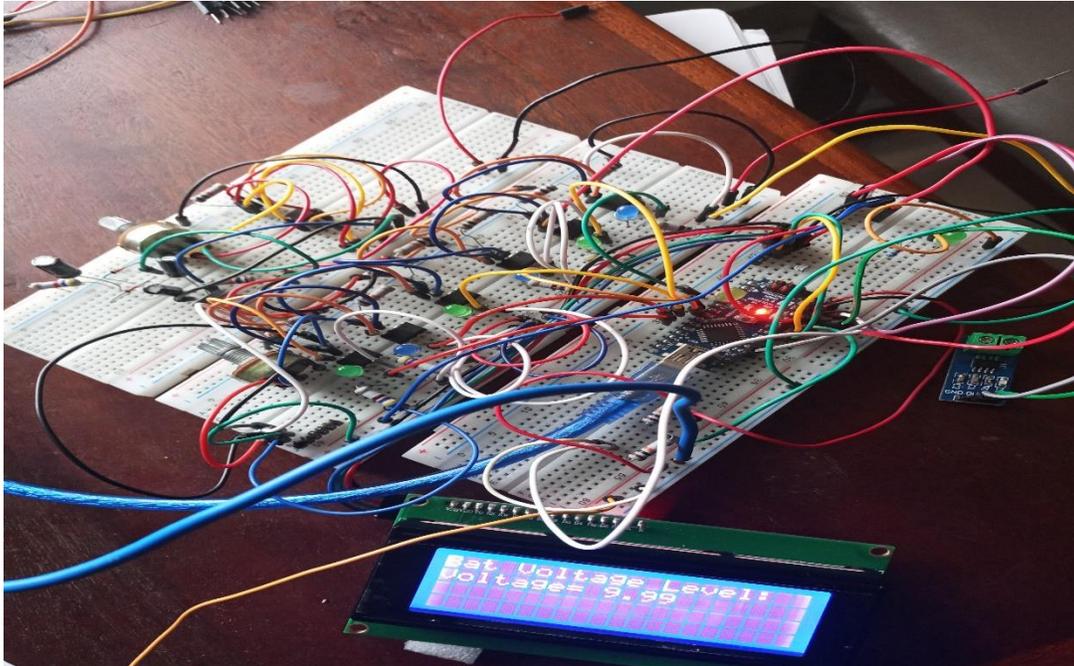


Figure 4.7: picture of the complete system

Chapter 5: Conclusion and Recommendations

5.1 Introduction

This chapter presents the conclusion and recommendations about the project as a whole.

5.2 Conclusion

PV module power delivered to the load can be maximized through the MPPT algorithm. This is tracking and extracting the MPP of the PV module so that it continuously deliver it maximum power. In this project, an MPPT algorithm was implemented and tested under different conditions. The power efficiency of the PV module was found to be changing under different weather condition. Under standard test conditions, the efficiency was 85.56%. When the temperature increased the efficiency was found to be 92.90% while power efficiency decreased to 76.45% when the irradiance and temperature decreased at the same. The efficiency also decreased to 56.07% and 57.99% when irradiance changed with time with a temperature of 25⁰C and 20⁰C respectively. Considering the efficiencies found in different test conditions, the Algorithm tracked the MPP efficiently.

5.3 Recommendations

Based on the project work following recommendations are made:

1. Implementing the MATLAB/Simulink for many PV modules to power many applications
2. Designing and constructing the battery management system to reduce maintenance cost and avoid damaging the battery.
3. Expand this project to wind power and solar powered vehicles

5.4 Limitations and Future Works

As the project progressed, there were some limitations to the project such as:

1. Limited knowledge about the implementation of the MPPT was a challenge to the completion of the project
2. Getting appropriate materials was a challenge again; some of the components had to be fabricated manually.

For future works, the following would have to be included for the implementation of this project:

1. Include system protection in the different circuit to avoid overvoltage and overcurrent
2. Work on automatically changing the duty cycle of the converter as weather conditions changes.

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