



Design, Construction, and Testing of Maximum Power Point Tracking (MPPT) Charge Controller for Photovoltaic (PV) Power Generation

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Authors' contributions

This work was carried out in collaboration among all authors. Author BIM designed the work, draft the manuscript, performed the calculations, statistical analysis and computation of result. Author JPCM carried out the result analysis and discussion and author DOI proof read and managed the literature searches. All authors read, reviewed and approved the final manuscript.

Article Information

DOI: 10.9734/JERR/2020/v17i117180

Editor(s):

(1) Dr. Guang Yih Sheu, Chang-Jung Christian University, Taiwan.

Reviewers:

(1) J. Barsana Banu, Mahath Amma Institute of Engineering and Technology, India.

(2) Navdeep Singh, Madan Mohan Malaviya University of Technology, India.

(3) Tarana Afrin Chandel, Integral University, India.

Complete Peer review History: <http://www.sdiarticle4.com/review-history/61184>

Original Research Article

Received 10 July 2020

Accepted 17 September 2020

Published 25 September 2020

ABSTRACT

Maximum Power Point Tracking (MPPT) charge controller is designed for using an easy and effective way to charge a 12v battery and a laptop charger of 19v simultaneously through the principle of the bulk-boost converter. This research work is suitable for 150W solar panels, as the Maximum Power Point (MPP) of Photovoltaic (PV) power generation systems changes with variation in atmospheric conduction, an important consideration in the research work is the efficiency of PV systems to track the Maximum Power Point (MPP) correctly. It enhances battery life by providing higher efficiency to it. The efficiency of the research work was calculated from the power dissipated, and also calculated the point at which the battery extracts maximum power from the PV module. As the work was tested, the voltage and current were obtained which was used to

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plot the voltage-current and voltage-power characteristics curve. Though a lot of works have been published on this topic, but none has researched on MPPT that can charge both 12v battery and 19v laptop charger simultaneously. Hence, this work is aimed at researching on Maximum Power Point Tracker (MPPT) that will be able to perform the above mentioned features. Also, it is the objective of this work to compare the theoretical and experimental relationship between MPPT and PWM charge controller which the efficiency of the MPPT was calculated theoretically to be 97% while, experimentally we obtained it as 91.1% while for PWM the efficiency was calculated theoretically as 75% and experimentally as 70.4% which shows that MPPT charge controller is approximately 30% efficient more than the PWM charge controller.

Keywords: Maximum power point; battery; photovoltaic; pulse width modulation; solar panel.

1. INTRODUCTION

Maximum Power Point Tracking (MPPT) of a photovoltaic array is a very important stage of a PV system. Hence, a lot of MPPT methods have been introduced and numerous variants of each method have been proposed to overcome specific disadvantages. Avalanche of methods proposed can make it tedious to determine the best technique to adopt when implementing a PV system [1-2]. However, all the methods vary in complexity, a number of sensors required; digital or analog implementation, convergence speed, tracking ability, and cost-effectiveness. Furthermore, the type of application can have a significant impact on the selection of the MPPT algorithm [3]. Maximum Power Point Tracking (MPPT) and Pulse Width Modulation (PWM) charge controllers are both mostly used to charge batteries with solar power. The MPPT controller is more refined and more expensive; it will adjust its input voltage to harvest the maximum power from the solar array and transform this power to supply the varying voltage requirement of the battery plus load. Thus, it essentially unlinks the array and battery voltages so that there can be, for example, a 12volt battery on one side of the MPPT charge controller and panels wired in series to produce 36volts on the other. It is generally accepted that MPPT will outperform PWM in a cold temperate climate. The PWM controller is a switch that connects a solar array to the battery. The result is that the voltage of the array will be pulled down to near that of the battery. Global warming and energy policies have become a hot topic on the international agenda in the last years. Developed countries are trying to reduce their greenhouse gas emissions. For example, the European Union (EU) has committed to reduce the emissions of greenhouse gas to at least 20% below 1990 levels and to produce no less than 20% of its energy consumption from renewable sources by 2020 [4]. The demand for photovoltaic (PV) power generation in power

systems and the distribution sector is growing significantly. Research shows that the contribution of PV systems to energy generation was approximately 14,000MW in 2010 and is expected to be 70,000MW in 2020 [5]. Generating power from photovoltaic cell has been one of the leading sources of power due to the combination of these following factors such as low maintenance, minimal wear and tear of components, absence of moving parts, lack of audible noise, absence of fuel cost, and pollution-free operation after installation [6]. Small-scale PV installations are very popular as lighting and water pumping solutions in developing countries, remote villages, and small rural and urban communities. These systems are also commonly used in developed countries that have a considerable amount of solar irradiation, modern photovoltaic technology transforms buildings from energy users to energy producers [7]. Hence, this work is aimed at researching on Maximum Power Point Tracker (MPPT) that will be able to work on principle of buck-boost converter, where the MPPT charge controller will be able to charge a 12v battery by buck converter method and 19v laptop battery by method of boost converter. Also, it is the objective of this work to compare the theoretical and experimental relationship between MPPT and PWM charge controller which the output power and efficiency of the MPPT and PWM will be calculated and analyzed both theoretically and experimentally. However, in this work the best approach will be adopted in order to design and construct an MPPT charge controller that will be able to charge both 12v battery and 19v laptop charger simultaneously with high efficiency.

2. MATERIALS AND METHODS

2.1 Materials

In the design and construction of the maximum power point tracking system, the major materials used are as follows:

Led: 1 red LED display
 Jumper Wire (s): Twenty pieces of jumper wires
 Vero Board (s): Two Vero boards
 Socket: One Eight pin dip socket
 Fuse (s): Two 5amps Fuses
 USB Port: One USB port
 Solar Panel: One 150W/ 21V Solar panel
 Battery: One 12v battery
 Switch: Two push switch
 Screws/Nu and Bolts, Soldering Iron, Hobby knife, wire cutter, ruler and pencil, multi-meter, 12 Volt Cooling Fan.

150W solar panel for source, 12V lead-acid type rechargeable battery as load, and a charge controller for control both portion. The voltage sensor senses the voltage and output are given to the microcontroller in MPPT. It demonstrates maximum power point tracking capability, using the calculation below;

The solar panel power (P_s) = 150W
 The maximum voltage (V_m) of the panel =18.5V
 Therefore; the maximum Current (I_m) of the panel is given by;

$$I_m = \frac{P_m}{V_m} = \frac{150W}{18.5V}$$

$$I_m = 8.11A \tag{1}$$

The following Specifications of components were used in the construction of the project

2.2 Experimental Design and Method

The approach used in experimental design and method is to design an effective MPPT controller from few components.

The power output from the buck converter is given by the formula

$$P_{bc} = V_{out} \times I_m \tag{2}$$

2.3 Experimental Setup

Fig 1. shows the block diagram of the charge controller. This block diagram is divided into three portions namely source, control, and load.

Where $V= 13.8V$ (Output voltage that will charge the battery)

$$I_m = 8.11A$$

$$P_{bc} = 13.8 \times 8.11 = 111.9W$$

Table 1. Specifications and Quantities of the Proposed Components

| Components | Specifications/ Rating | Quantities |
|--------------------|---|------------|
| Capacitors | 1 x 2200µF16v, 2 x 2200µF/ 32v | 3 |
| Resistor | 1 x 22kΩ, 3 x 10kΩ, 1 x 1000kΩ, 1 x 100kΩ | 6 |
| Variable Resistor | 1 x 10kΩ, 1 x 100kΩ | 2 |
| Integrated Circuit | 1 x LM358, 2 x NE555, | 3 |
| Diode | 2 x IN4148 | 2 |
| Zener diode | 1 x IN5817, 1 x IN5359B | 2 |
| Transistor | 1 x MOSFET IRF1407 | 1 |
| Inductor | 1 x 1351µH | 1 |
| Voltage Regulator | 1 x 78L05 | 1 |

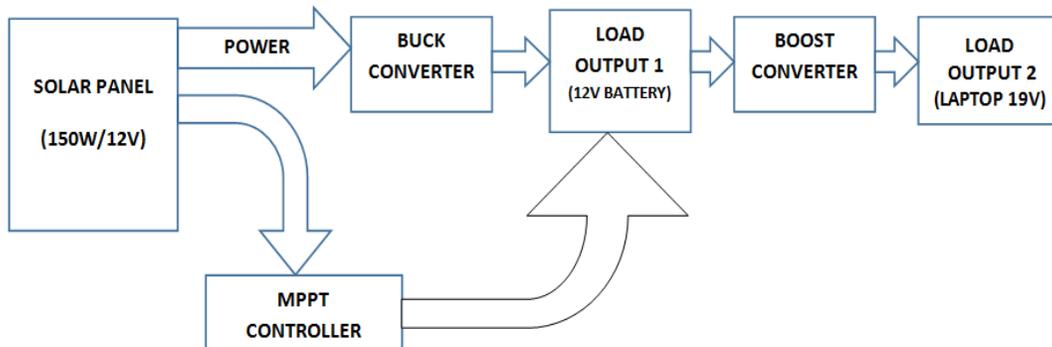


Fig. 1. Block diagram of the MPPT Controller

Thus the bulk converter (PWM) utilizes only 111.9W of the power from a 150W solar panel. And the remaining 38W power was dissipated as heat or wasted.

$$\text{Hence; the theoretical Efficiency of PWM} = \frac{\text{Power output of B.C}}{\text{Solar panel power}} \times 100 \quad (3)$$

$$\text{Efficiency of PWM} = \frac{111.9W}{150W} \times 100 = 75\% \quad (4)$$

For the MPPT, solar charge controller boosts the current output from the panel to 30%

$$\text{Therefore; } I_{mpp} = \frac{30}{100} \times I_{BC} + I_{BC} \quad (5)$$

$$I_{mpp} = 0.3 \times 8.11 + 8.11$$

$$I_{mpp} = 10.54A$$

$$\text{From the formula; } P_{mpp} = V_{out} \times I_{mpp} \quad (6)$$

$$P_{mpp} = 13.8V \times 10.54A$$

$$P_{mpp} = 145.45W$$

$$\text{Theoretical Efficiency of the MPPT Controller} = \frac{\text{Power output of MPPT}}{\text{Solar panel power}} \times 100$$

$$\text{The Efficiency of MPPT} = \frac{145.45W}{150W} = 97\% \quad (7)$$

When the MOSFET is ON, the current would flow through the inductor, delivered to the output capacitor. Since the diode is forward biased thus current flows, and magnetic energy is stored in the inductor and electrical energy in the capacitor. When this MOSFET is off the stored energy in the inductor is released and the current completes its path through the diode and at the same time the charge stored energy in the capacitor supplies current to the load. IRF1407 MOSFET is used for better and quick switching. Since it has a very low amount of voltage drop it increases the total efficiency of the system. Liquid crystal display (LCD) is used to display panel and battery voltages and load conditions of the maximum power point tracker.

$$\text{Output current, } I_{out} = \frac{\text{bulk power}}{\text{Output voltage, } V_{out}} \quad (8)$$

$$I_{out} = \frac{98.6W}{13.8V}$$

$$I_{out} = 7.15A$$

$$\text{Switching frequency, } F_s = 2KHz$$

$$\text{DUTY CYCLE, } D = \frac{V_{out}}{V_{in}} \quad (9)$$

$$D = \frac{13.8V}{21V}$$

$$D = 0.657 = 66\%$$

$$\text{Now, Inductor, } L = \frac{(V_{in} - V_{out})D}{\Delta F_s} \quad (10)$$

2.4 Converter

For this research, we used a product that converts and regulates a certain DC (V_{dc} of 21V for our case) voltage level to different DC (V_{dc} of 13.8V for our case) voltage level.

2.5 Design Consideration and Calculation

2.5.1 Inductor selection

The inductor used in this project was arrived by doing the following calculations;

The output voltage, $V_{out} = 13.8V$

The input voltage, $V_{in} = 21V$

Where Δ = Inductor ripples current.

A good estimation for the inductor ripple current is 20% to 40% of the output current. Let,

$\Delta = 40\%$ of the rated current

$\Delta = 40\%$ of 7.15A

$\Delta = 2.86A$

Now, from equation (1)

$$L = \frac{(V_{in} - V_{out})D}{\Delta F_s} \quad (11)$$

$$L = \frac{(21 - 13.8) 0.66}{2000 \times 2.86} = 831\mu H$$

$$I_p = I_{out} + \frac{\Delta}{2} \quad (12)$$

$$I_p = 7.15 + \frac{2.86}{2}$$

$$I_p = 8.58A$$

2.5.2 Capacitor selection

The output of the buck converter and the charge controller has a certain amount of ripple. A capacitor is used to minimize the voltage overshoot and ripple and also store charges.

$$C_{out} = \frac{\Delta}{8 \times F_s \times \Delta V_{out}} \quad (13)$$

Where, Inductor ripple current, $\Delta = 2.86A$
 Switching frequency, $F_s = 2 \text{ KHz}$
 Output voltage ripple, $\Delta V_{out} = 125mV$ (assumed)
 Now, from equation (13) we have,

$$C_{out} = \frac{\Delta}{8 \times F_s \times \Delta V_{out}}$$

where $\Delta = 2.86$

$$C_{out} = \frac{2.86}{8 \times 20000 \times 0.125}$$

$$C_{out} = 1430\mu F$$

2.5.3 Mosfet selection

The IRF1407 MOSFET is used, in this project has a voltage rating of 20% more than the required voltage, with minimum heat conduction loss.

2.6 Simulated Circuit Diagram of a Buck Converter of Mppt

The buck converter circuit used in this work in order to step down the voltage that will charge a 12v battery was designed and simulated with Proteus 8.7 professional software.

2.7 Simulated Circuit Diagram of the Boost Converter

The boost converter circuit used in this work in other to step up the voltage that will charge a 19v laptop charger was designed and simulated with Proteus 8.7 professional software.

2.8 Experimental Procedures

The circuit was designed according to the diagram shown in Fig. 4.

The step by step process taken in the construction of the bulk converter maximum power point tracking solar charge controller.

Simulation of the circuit using Proteus software was made to verify if the circuit diagram is correct before mounting it in the Vero board, after that the components stated in the circuit diagram were mounted in the prototype circuit board (Vero board) as illustrated in the circuit diagram

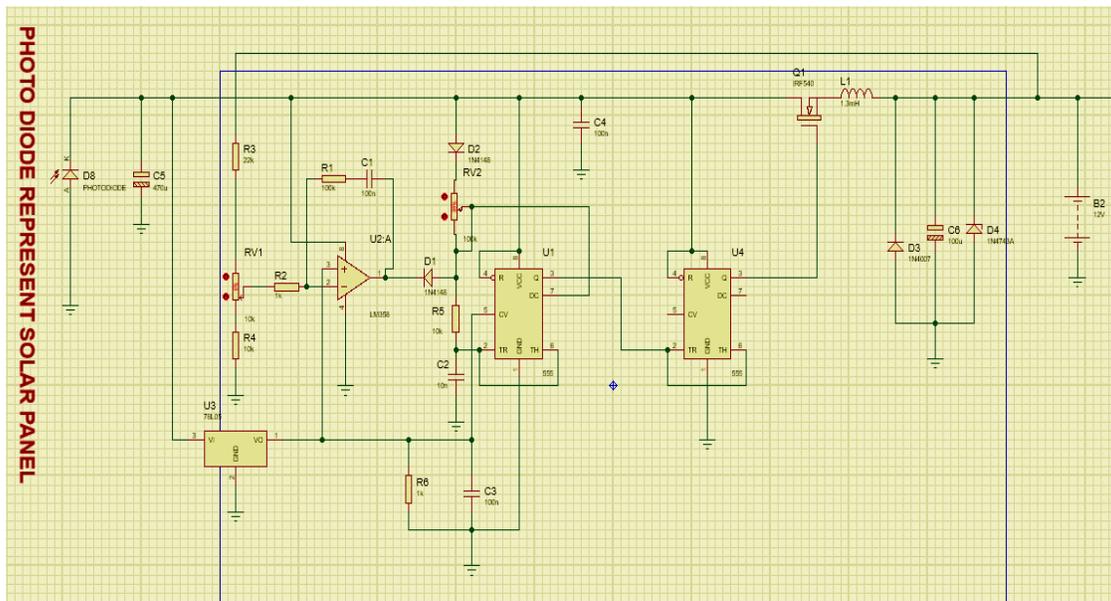


Fig. 2. Simulated circuit diagram of the Buck converter maximum power point tracking solar charge control designed with Proteus 8.7 professional software

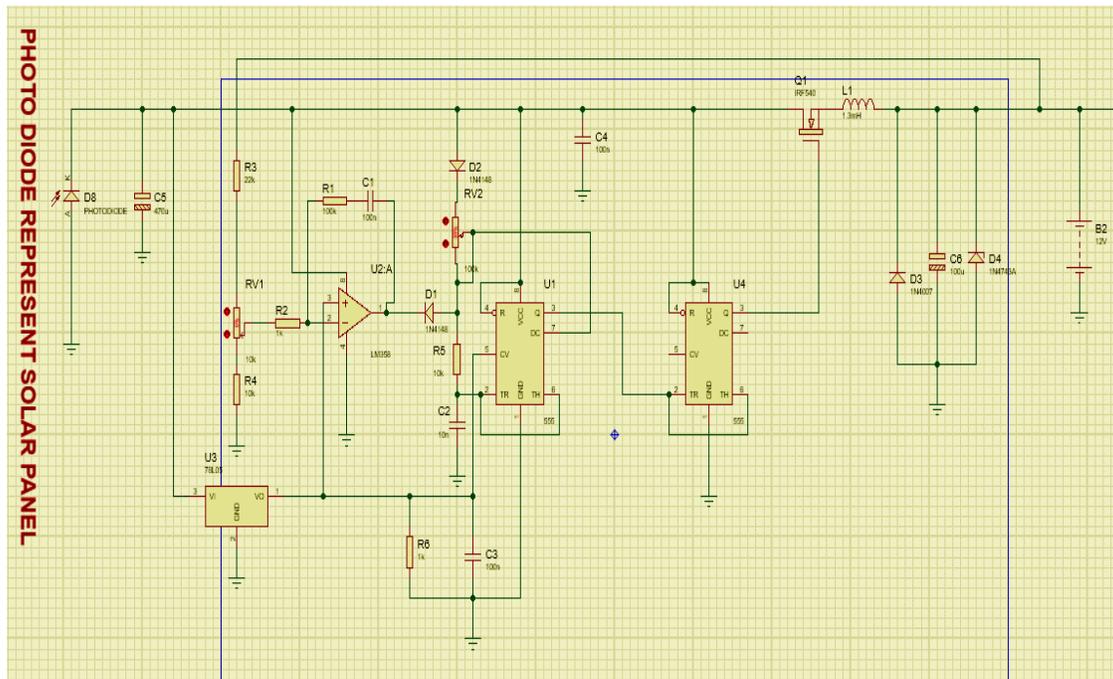


Fig. 3. Simulated circuit diagram of the Boost converter to charge a laptop using a 12V battery designed with Proteus 8.7 professional software

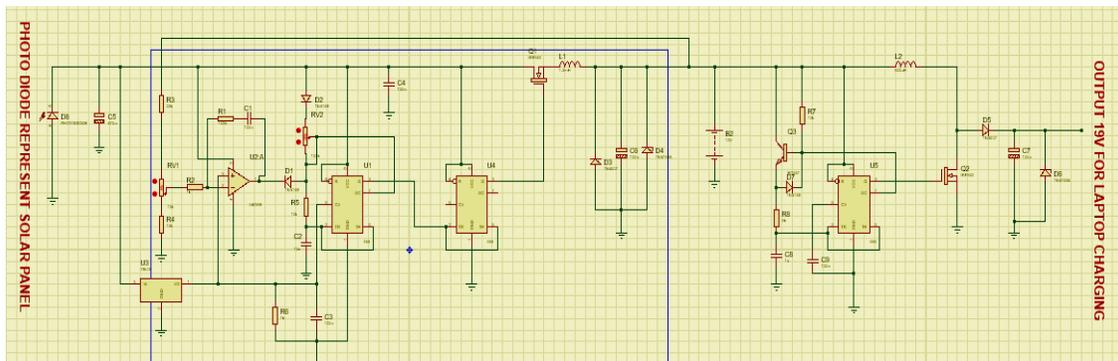


Fig. 4. The complete simulated circuit of the research

in Fig. 4 and the components were connected with jumper wires were necessary. Then the components and the jumper wires were soldered using soldering iron and soldering lead after which the designed circuit was tested with a 12V battery and 150W solar panel.

3. RESULTS AND DISCUSSION

The outcome of this research work gave rise to a constructed maximum power point tracker system equipment with a robust search and discovery capabilities in terms of a photovoltaic was tested with a 150 W maximum output power

solar panel. Fig. 5. Shows the picture of the device. The output of the simulated, and the tested circuit is discussed, and also the comparison is done between the output powers extracted with the MPPT circuit and without the MPPT circuit when the same insolation is provided. The output waveforms are also shown to verify the results. A table of comparison is formed to show directly the usefulness of the MPPT circuit. The efficiency is also calculated with and without the presence of an MPPT circuit and a table of comparison is formed to show the direct comparison. Also, the results are compared with the results of

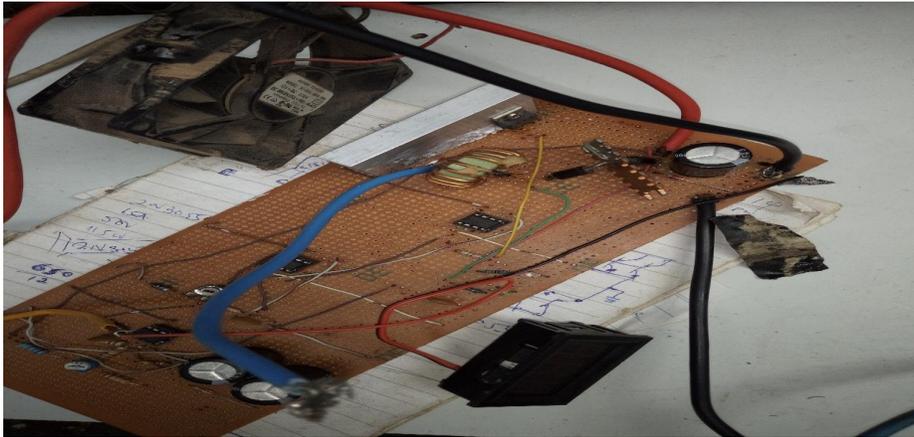


Fig. 5. The designed image of a buck converter of MPPT controller

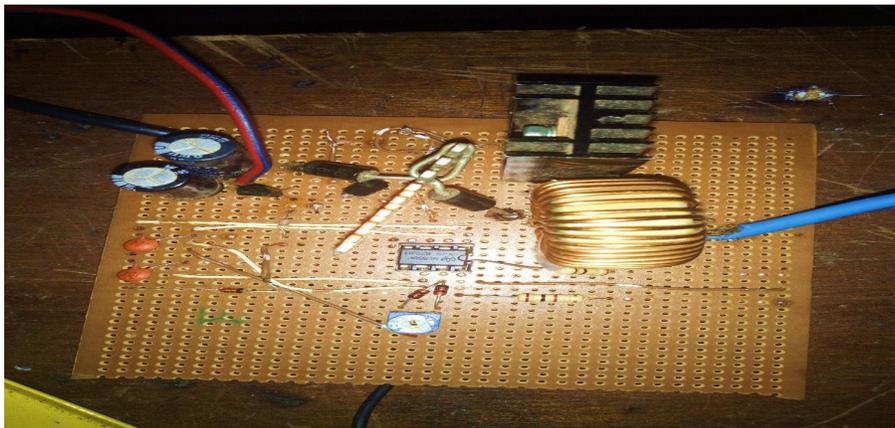


Fig. 6. The designed image of a boost converter for charging of laptops



Fig. 7. The complete image of the Designed and Constructed Maximum Power Point Tracker (MPPT) couple with plastic material in under to serve as an insulator to avoid overheating of the components

similar work done with different types of Converters. In Table 1 the output power at load and the maximum power that can be delivered by the solar panel is shown. A comparison is done between the output power with the MPPT circuit and without the MPPT circuit.

3.1 Analysis of the Experimental Results

Experimental data of the solar charge controller in Tables 1 and 2 represents the experimented data of voltage, current, and powers for both the PWM and MPPT, from this tested value, the overall efficiency of these charge controllers was determined. The average Efficiency of the PWM is 70.4% while the average Efficiency of the MPPT is 91.1%. The graph shows the efficiency of the controllers as time varies. At the beginning

of the testing, at 1.00 PM, PWM and MPPT power was 106.4W and 131.9W respectively. It was also observed that at the same time PWM and MPPT voltage are 13.3V and 13.6V and the current was 8.0A and 9.7A respectively, at that time experimented efficiency was 70.9% and 91.1%. The highest efficiency for PWM which is 74.0% was obtained at 2.30 PM while at 1.30 PM, the highest efficiency for MPPT was recorded as 96.6%, while the lowest efficiency was 67.9% at 3.30 PM. For PWM and 88.0% at 3.30 PM as well.

Fig. 6, and Fig. 7 Show the relationship between the PWM and MPPT power as they vary with time due to the sun intensity, it was observed that the MPPT Controller has more power at every time interval than the load power.

Table 2. Showing the result of Current, Voltage, and Efficiency when Maximum Power Point Tracker (MPPT) is not connected i.e. (PWM)

| Time (PM) | Voltage (V) | Current(A) | Power(W) | EFF(%) |
|-----------|-------------|------------|----------|--------|
| 1:00 | 13.3 | 8.0 | 106.4 | 70.9 |
| 1:30 | 13.6 | 7.9 | 107.4 | 71.6 |
| 2:00 | 13.8 | 7.8 | 107.6 | 71.7 |
| 2:30 | 13.7 | 8.1 | 111.0 | 74.0 |
| 3:00 | 13.6 | 7.5 | 102.0 | 68.0 |
| 3:30 | 13.4 | 7.6 | 101.8 | 67.9 |
| 4:00 | 13.5 | 7.9 | 106.7 | 71.1 |
| 4:30 | 13.2 | 8.0 | 105.6 | 70.4 |
| 5:00 | 13.8 | 7.4 | 102.1 | 68.1 |
| 5:30 | 13.6 | 7.7 | 104.7 | 69.8 |

Solar Panel Power = 150W

$$\text{The efficiency of the PWM} = \frac{\text{Power output of PWM}}{\text{Solar panel power}} \times 100 \tag{14}$$

The Experimental Average Efficiency of the PWM = 70.4%

Table 3. Result showing the Current, Voltage and Efficiency when MPPT is connected

| Time (PM) | Voltage (V) | Current (A) | Power (W) | EFF (%) |
|-----------|-------------|-------------|-----------|---------|
| 1:00 | 13.6 | 9.7 | 131.9 | 87.9 |
| 1:30 | 13.8 | 10.5 | 144.9 | 96.6 |
| 2:00 | 13.7 | 9.8 | 134.3 | 89.5 |
| 2:30 | 13.4 | 10.4 | 139.4 | 92.9 |
| 3:00 | 13.8 | 10.0 | 138.0 | 92.0 |
| 3:30 | 13.6 | 9.8 | 133.3 | 88.9 |
| 4:00 | 13.8 | 10.1 | 139.4 | 88.0 |
| 4:30 | 13.5 | 10.3 | 139.1 | 92.9 |
| 5:00 | 13.7 | 9.9 | 135.6 | 90.4 |
| 5:30 | 13.5 | 10.2 | 137.7 | 91.8 |

Solar Panel Power = 150W

$$\text{Efficiency of the MPPT} = \frac{\text{Power output of MPPT}}{\text{Solar panel power}} \times 100 \quad (15)$$

The Experimental Average Efficiency of the MPPT = 91.1%

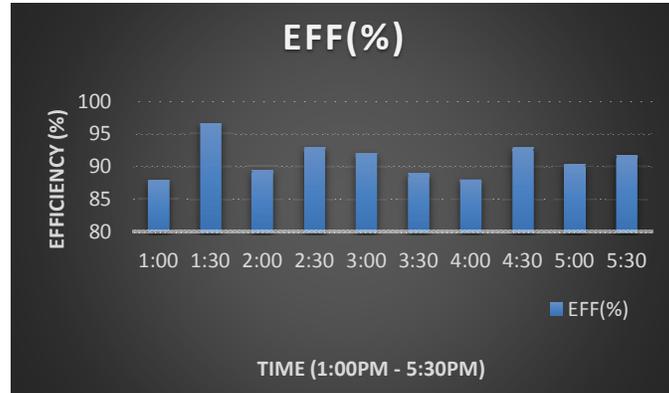


Fig. 8. The Graph Showing the Efficiency of the Controller PWM

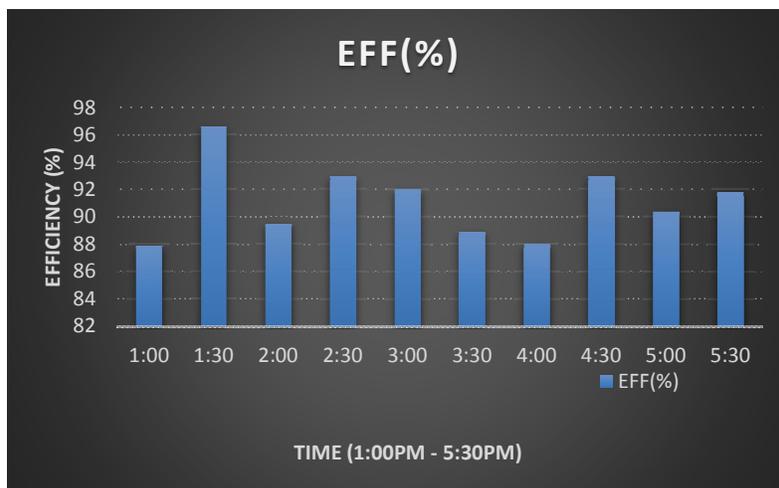


Fig. 9. The Graph Showing the Efficiency of the MPPT Controller

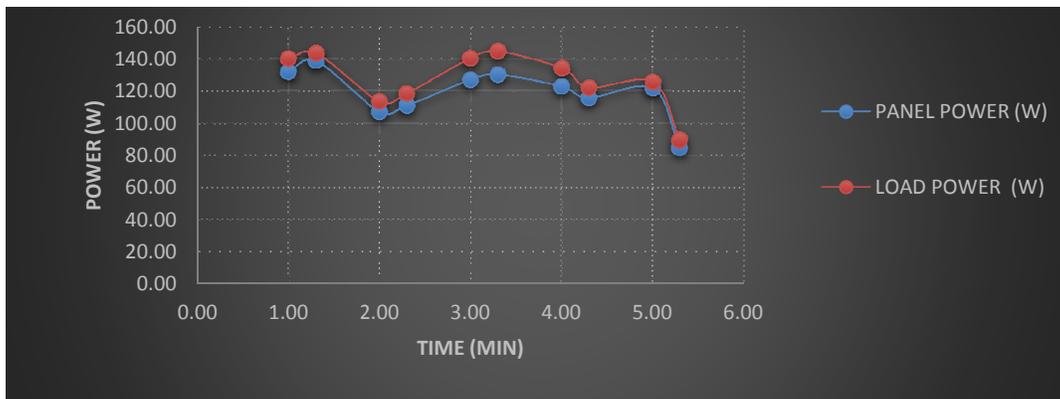


Fig. 10. The Graph Showing the Power of the Panel and Power of the Load of MPPT Controller

Table 4. Shows the Voltage and Current Reading obtain from the MPPT Controller

| Voltage (V) | Current (A) | Power (W) |
|-------------|--------------|------------|
| 3.74 | 10.52 | 39.34 |
| 5.62 | 10.48 | 58.89 |
| 7.49 | 10.44 | 78.20 |
| 9.36 | 10.26 | 96.03 |
| 11.24 | 10.08 | 113.30 |
| 13.11 | 9.90 | 129.79 |
| 14.10 | 9.27 | 130.71 |
| 14.80 | 9.00 | 133.20 |
| 15.50 | 8.19 | 126.95 |
| 16.01 | 7.65 | 122.48 |
| 16.70 | 7.02 | 117.23 |
| 17.78 | 5.13 | 91.21 |
| 18.21 | 4.05 | 73.75 |
| 18.26 | 3.33 | 60.81 |
| 18.29 | 3.06 | 55.96 |
| 18.32 | 2.25 | 41.22 |
| 18.35 | 1.80 | 33.03 |
| 18.38 | 0.36 | 6.62 |
| 18.41 | 0.18 | 3.31 |
| 18.44 | 0.10 | 1.84 |

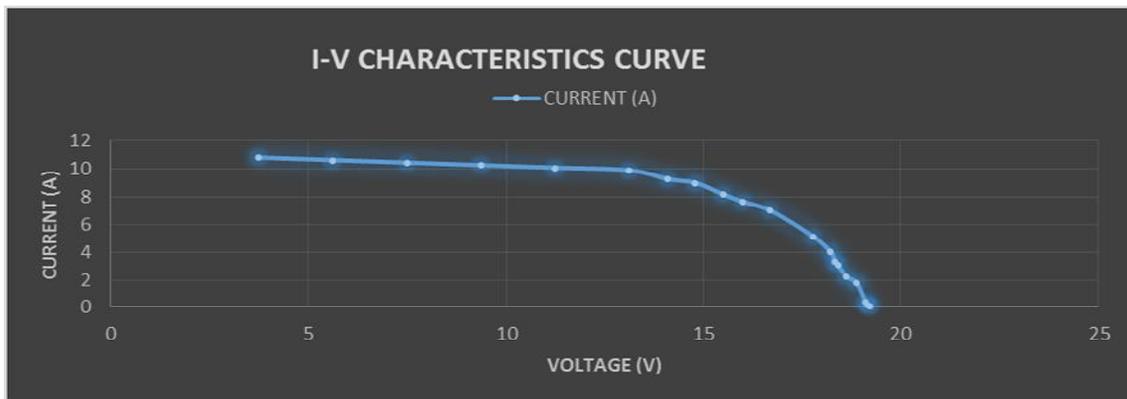


Fig. 11. I-V Characteristic Curve of the MPPT Controller

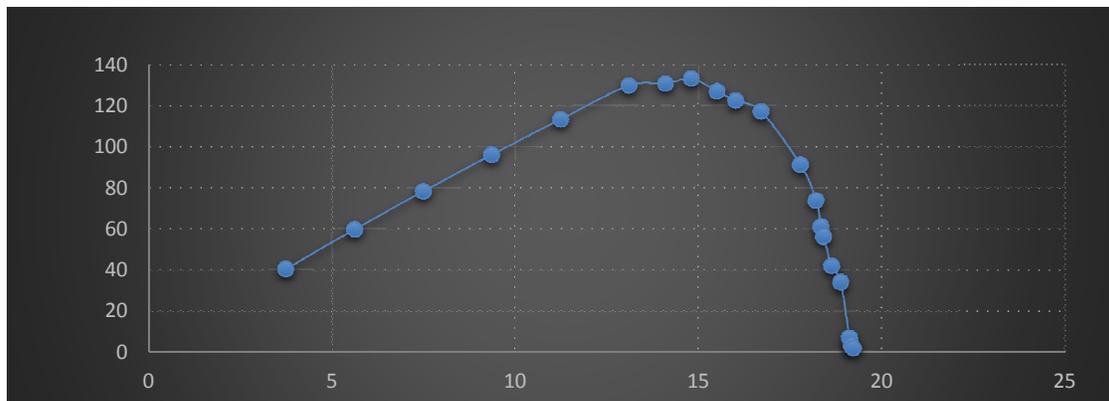


Fig. 12. P-V Characteristic Curve of the MPPT Controller

3.2 Analysis of the Curves in Fig. 10, and Fig. 11

The graphs which we obtained are the expected ones though, it has a little variation due to some factors that affect the operation of the MPPT. From the I-V curve, we can find that the maximum voltage the panel can attain is 18.44V, and the maximum current of the panel is 10.52A. It shows that depending on the level of isolation a PV array has a point where power derived from the array is maximum, this point is the maximum power point (MPP).

Also in Fig. 12. we can see from the P-V curve that the maximum energy of our solar panel is almost 133W attainable at a load of approximately 2-ohms load.

From this formula:

$$P = IV \quad (16)$$

$$133 = 15 \times I$$

$$I = \frac{133}{15} = 8.87A$$

$$\text{Using } V = IR \quad (17)$$

$$15 = R \times 8.87$$

$$R = \frac{15}{8.87}$$

R = 2 ohms (approx.)

So for this specific panel, we need to use a load closer to two (2) ohms to get the maximum power output from the panel. But as the sun condition changes, the "maximum power resistance" must also change.

4. CONCLUSION

In the light of this research work which provides results showing that the photovoltaic module output power using a Maximum power point tracker (MPPT) is much better than a Pulse width modulation (PWM) under variable weather conditions. Though this resistance was considered to fit in the PV module performed at the maximum power point, the result implies that on cloudy days, the PV power output amplified with the use of the MPPT charge controller as compared to the case where the PV module is connected directly to a fixed resistance i.e. (PWM). The PV array output power delivered to the load is maximized by up to 30% using the MPPT control method.

One unique feature of this research work is that it uses a buck-boost converter to charger a 12V

lead-acid type rechargeable battery at the voltage of 13.8V by using buck converter and at the same time charge a laptop battery with a different voltage 19V, by using a boost converter. The theoretical result from our calculation shows that MPPT efficiency was 97%, as compared to 75% of the PWM charge controller. In The experimental result on the other hand, due to some losses, we obtained the efficiency of the constructed MPPT as 91.1% as compared to PWM, which is 70.4%. Converter and overall system are calculated at different irradiances. Using the MPPT charge controller with solar panel installations has a clear advantage because the PWM charge controller gives low power output.

Generally, the application of PV array normally faces the shading problem of solar light which lead to inconsistent power generation and low efficiency of the MPPT charge controller. Hence, future research can investigate to solve the partial shaded problems in photovoltaic power generation employing Z-source inverter. More improved MPPT methods or other intelligent MPPT methods can be applied so that it can run both in standalone and in grid connected mode.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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