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COMPARATIVE PERFORMANCE ANALYSIS OF PWM AND MPPT CHARGE CONTROLLERS UNDER NO-LOAD AND ON-LOAD CONDITIONS

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ABSTRACT

Charge controllers are implemented in several electronic systems to protect and control the charge and discharge rates of a battery. For off-grid Photovoltaic (PV) systems, there are two most popular types of technologies: Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT). In this paper, the performance of PWM and MPPT charge controllers are compared in PV systems with the same technical specifications to determine the behaviour of each under no-load and loading conditions through experimental set-up under similar environmental conditions. The two charger controllers were connected to a 12V, 150W solar panel, and a 100Ah Deep cycle battery each while the panel voltage, battery charging voltage, and current were measured in an interval of 10mins through a Multimeter to validate the comparative performance of MPPT and PWM using 5W direct current (DC) bulb as load. The results show that the MPPT controller has a charging current of 8.5A and 7A while the PWM controller produces 7.5A and 6A current to the battery under no-load and load conditions respectively. In terms of charging rate, the MPPT has higher efficiency than PWM but with higher cost.

KEYWORDS: Charge controller; Solar system; Battery; MPPT; PWM; Analysis; Performance

INTRODUCTION

Recently, most developing countries in the world are facing energy shortages due to the increase in population and daily energy demand. This has led to a shortage in natural resources like oil and gas which are the major primary sources of power generation but are not eco-friendly. To meet this high power demand, renewable energy sources are introduced. The most popular renewable energy system today is the solar energy system. The reason is that solar energy can be implemented at an individual house or industry level fulfilling the small energy requirements and also at a large scale fulfilling the commercial requirements in megawatts (Acharya & Aithal, 2020). There are various standards for energy storage from solar panels, and this stored energy is provided to the load as supplemental energy with the aid of an inverter. From a single, small house with a few watts to industrial requirements satisfying several megawatts, solar energy can be implemented (Acharya & Aithal, 2015). Solar energy is typically used for domestic or small-scale industrial purposes as a renewable energy source to supplement the conventional public power utility. The energy provided by the backups such as inverters is of different storage voltage levels and the acceptable ranges are 12V, 24V, 48V, 110V, or 240V DC as a result, one, two, four, ten, or twenty 12V batteries are connected in series to form the backup system. The solar panel rated 12V can produce between 16-20V under high sun intensity and below 12V under very low sun intensity. The amount of sunlight incident also affects the current rating and due to this variation, a charge controller is required, which regulates the incoming solar energy according to the demands of the battery backup. When the battery backup is very low, the controller is expected to allow charging when there is intensity from the sun and equally restrict the incoming *energy from the solar panel* to the battery when it is fully charged.

The two major types of solar charge controllers that are commonly used are those based on PWM (Pulse Width Modulation) and MPPT (Maximum Power Point Tracking) (Acharya & Aithal, 2021). Controlling the flow of DC energy according to the demands of the battery backup is the main goal of solar charge controllers. In this study, the focus is to analyze the performance of each charge controller using the same brand of battery and solar panel under no-load and loading conditions of the controllers using a 5W D.C. bulb as the load.

LITERATURE REVIEW

The energy coming from the solar array into the battery bank is managed and *controlled* by a solar charge controller. It prevents the deep cycle batteries from being overcharged during the day and prevents the batteries from being drained at night by electricity flowing backward to the solar panels. Although some charge controllers include extra features like lighting and load management, their main function is to manage electricity. The electric cell draws the charging current coming from the solar panels due to the potential difference between the solar panel and the battery terminals. Typically, 12V-rated panels produce between 16 and 20V, from which only 14 – 14.5V is required for charging, so if there is no regulation, the electric cells will be overcharged and suffer damage. Charge controllers come in different types based on their mode of operations and current ratings which determines their sizes and prices. Two different types based on mode operations are PWM and MPPT which are the focus of this study (Serrano et al., 2019; Nisa et al., 2021).

Pulse width modulation (PWM) solar charge controller

A PWM (Pulse Width Modulation) solar charge controller *regulates* the amount of current flowing into the battery using a series of ON and OFF pulses. PWM controllers operate under the theory that voltage produced by solar cells is displayed via a voltage indicator. Following this measurement, a voltage controller controls the voltage, and solar panel batteries are charged using this voltage (Shariful et al., 2015). The PWM charge controller comprises an oscillating circuit whose pulse width depends on the battery voltage. For a lower battery voltage, the pulse width is more and the entire output from the solar energy is used to store in the battery. When the battery storage voltage increases the pulse width of the PWM decreases. Similarly, solar energy storage is reduced. Once the battery backup is full then the pulse width of a PWM just reduces to a spike. During this stage, the controller will only sense the battery voltage without charging as summarized in Figure 1 (Rezoug et al., 2019).

Maximum Power Point Tracking (MPPT) Solar Charge Controller

Using a microprocessor, the MPPT (Maximum Power Point Tracking) solar charge controller tracks the solar array's peak output. The purpose of this type of charge controller is to maximize the power output from the cell and guarantee that batteries are charged to their fullest potential. By utilizing MPPT, the system will start functioning at Maximum Power Point (MPPT) and produce its maximum power production by sensing the maximum radiation from the sun that falls into the PV modules (Bhattacharjee et al., 2018). Here the solar panel output is taken at its maximum power either by increasing the voltage and decreasing the current or by increasing the current by decreasing the voltage. Normally the solar panel output voltage varies from 0 to 18V (typically 12V Solar Panel). The required voltage for the battery backup (typically 12V) is 12V- 14V. Any solar output voltage outside this range will be wasted. The MPPT technology will convert the solar output voltage to the range required for charging the battery backup. Thus, any voltage from 0V to 18V will be reconverted to 14V by adjusting the current so that the battery backup can get the charging during all conditions wherein the solar voltage varies depending on the sunlight. The conceptual model of the MPPT charger is shown in Figure 2.

Other components used in solar charge charging systems

Solar charging system involves two other components connected with a solar charge controller as input and output devices which are batteries and solar panels.

Solar panels

A solar panel, or solar module, is one component constructed out of a series of photovoltaic cells arranged into a panel. Solar panels collect energy in the form of sunlight and convert it into electricity that can be used to power appliances. These panels can be used to supplement a building's electricity or provide power at remote locations. In addition to residential and commercial use, there is large-scale industrial or utility use of solar. In this case, thousands or even millions of solar panels are arranged into a vast solar array, or solar farm, which provides electricity to large urban populations (Swarnakar & Datta, 2013). Monocrystalline and polycrystalline are the two major types of solar panels. When sunlight falls on the mono-crystalline solar modules, the cells absorb the energy and create an electric field through a complicated process. Hence it comprises voltage and current which is directly used to run DC while polycrystalline solar panels are solar modules that consist of several crystals of silicon in a single PV cell as shown in Figure 3.

Battery

A battery is a device for energy storage. The two main battery types that can be utilized to store solar energy are lithium-ion and lead-acid battery which comes from tubular plates and flat plate types as shown in Figure 4. The size of tubular batteries is significantly greater than that of flat plate batteries. In UPS and inverter systems, tubular batteries are used. The positive plate of the tubular batteries is enclosed in a cloth-wrapped tube that stores the electrodes' electrical potential. Tubular plate batteries have benefits such *as* higher efficiency, longer operational life, and minimal maintenance cost. There are many ways in which the types of batteries can be classified (for example, according to the materials manufactured or the application used), and here we will adopt the classification of batteries commonly used in solar energy in terms of the materials manufactured from them, which are divided into three main types (Benanti & Venkataraman, 2006). When the battery is used after charging, its positive pole must be connected to the positive pole of the load, as well as its negative pole to the negative pole of the load. If the load needs 12 volts for two batteries, in this case, the two batteries must be connected in parallel by connecting the similar poles in the batteries to each other. If the load needs 24 volts, in this case, two batteries must be connected in series by connecting a positive one to the negative of the second (Serrano et al., 2019)., Types of batteries used in solar energy are:

i. Lead Acid Batteries: It is available in several types, the most important of which are: Open Lead Acid, Sealed Lead Acid, AGM, Gel, and Deep Cycle Batteries.
ii. Lead Carbon Battery: Recently, carbon was added to the negative pole of the battery to reduce sulfurization and in return increase the ability to draw/fast charge, which reaches 60% of its capacity without damaging the poles, and withstands a high temperature of up to 60 degrees Celsius.
iii. Lithium Ion Battery: It is similar to LED-carbon batteries, where iron-lithium phosphate has been replaced, and it has a long life at a 75% discharge rate, unlike its predecessors with its lightweight, and its drawback is that it needs integrated charging regulators that regulate the charging and discharging process.

MATERIALS AND METHOD

In this study, an experimental method was used to obtain the data. This was carried out in the power systems laboratory of the electrical & electronic engineering department of the Federal Polytechnic, Ado Ekiti. The block diagrams for the experimental connections for No-load and On-load conditions are shown in Figures 5 and 6 respectively while the actual experimental set-ups showing the arrangements of the devices are shown in Figure 7.

The connections of the solar charge controllers were made here under no-load and on-load conditions using a 150W solar panel, 12V, 100Ah battery for each charge controller while a 5W, 12V DC bulb was connected to the load terminal of the charge controllers for load assessment.

The solar panels were placed under the same sun intensity and angular displacement as shown in Figure 8 while the panel voltage, charging voltage, and charging current of the battery were recorded using a digital Multimeter at an interval of 10mins. Each of the experimental setups involved the use of three sets of Multimeter in which two were set in 200Vdc range and connected across the solar panel and battery to determine the solar panel and battery voltage respectively while the third meter was set in 20A dc range and connected in series with the battery to determine the charging current of the battery.

RESULTS AND DISCUSSION

Case 1: No-load condition

The Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) solar charge controllers were subjected to the same test during the experiment under no-load conditions while the panel voltage, battery voltage, and charging current were recorded with the aid of a Multimeter set. The panel voltage under the two charge controllers shows variations based on the changes in the sun intensity as shown in Figures 9 and 10 for PWM and MPPT respectively. It also validates the need for charge controllers to regulate the voltage that gets to the battery to prevent overcharging or discharging.

Figures 11 and 12 show the respective comparison of the battery charging voltage and charging current between PWM and MPPT charge controllers under no-load conditions. It can be seen that the maximum voltage of PWM was 13.40V while that of the MPPT was 13.20V which implies the PWM controller has quicker charging than MPPT but the charging current that determines the rate at which the battery stores energy is higher using MPPT than PWM.

Case 2: On - load condition

Under this condition, the connections of the PWM and MPPT charge controllers were done as shown in Figure 13 where 5W and 12V DC bulbs were connected to the load terminals of the controllers to examine their behaviour under load conditions.

The parameters recorded for the no-load condition were repeated under this condition for comparative analysis. The variation of the sun intensities also influences the panel output voltage under this condition as shown in Figures 14 and 15 for PWM and MPPT respectively with a maximum voltage of 20V.

Figures 16 and 17 show the respective comparison of the battery charging voltage and charging current between PWM and MPPT charge controllers under no-load conditions. It can be seen that the maximum voltage of PWM was 13.10V while that of the MPPT was 13.70V which implies the MPPT controller has a higher charging voltage than PWM. The charging current recorded for MPPT ranges between 2.1-7A while that of PWM ranges between 1- 6.7A which implies that the MPPT still maintains its higher charging capability over PWM.

CONCLUSIONS AND RECOMMENDATIONS

In the course of this work, the comparison and analysis made between Pulse Width Modulation(PWM) and Maximum Power Point Tracking(MPPT) solar charge controllers show that the MPPT charge controllers have more charging efficiency compared to pulse width modulation solar charge controllers under no-load and on-load conditions. The time that the MPPT solar charge controller takes to charge the battery is less compared to that of the PWM charge controller which takes more time to charge the battery and also validates its efficiency. The results show that the MPPT controller has a charging current of 8.5A and 7A while the PWM controller produces 7.5A and 6A current to the battery under no-load and load conditions respectively. In terms of charging rate, the MPPT has higher efficiency than PWM but with higher cost.

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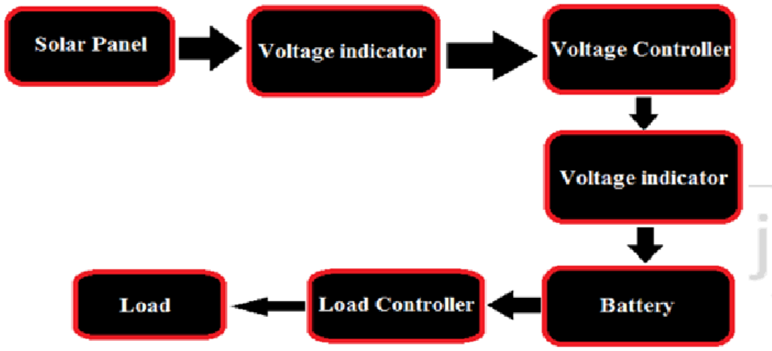

Figure 1. Mode of operation of PWM solar charge controller

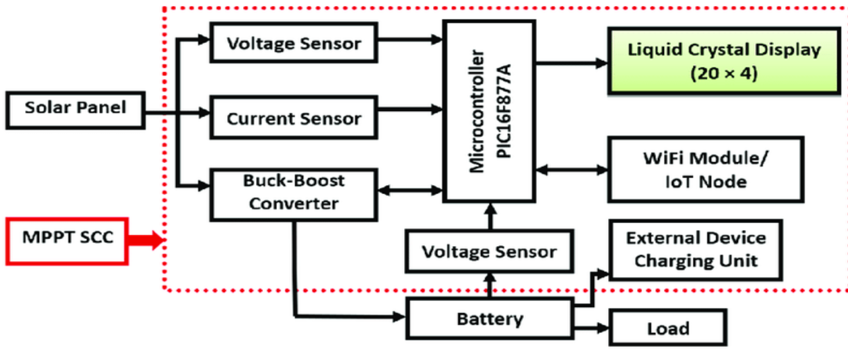

Figure 2. Mode of operation of MPPT solar charge controller(Bhattacharjee et al., 2018).

Figure 3. Polycrystalline and Monocrystalline solar panels

Figure 4. Tubular and Flat Plates Batteries

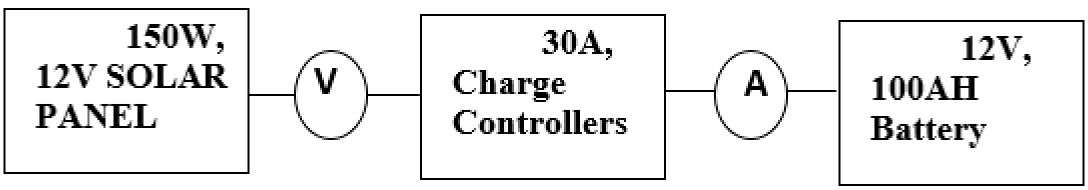

Figure 5. Block Diagram for the Experimental Set-up for No-Load Condition

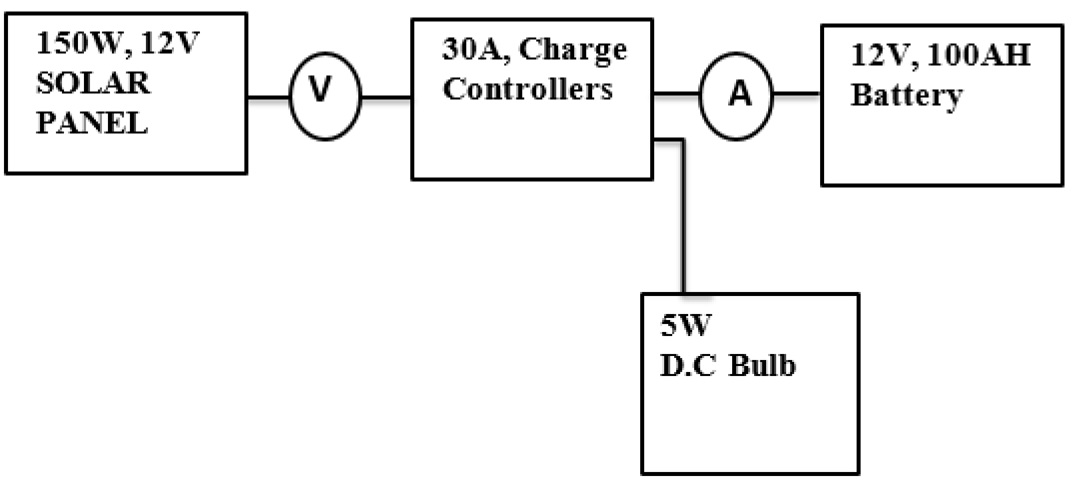

Figure 6. Block Diagram for the Experimental Setup for loading condition

Figure 7. Experimental Setup for the devices and measuring instruments

Figure 8. The solar panels with similar specifications used for the experiment

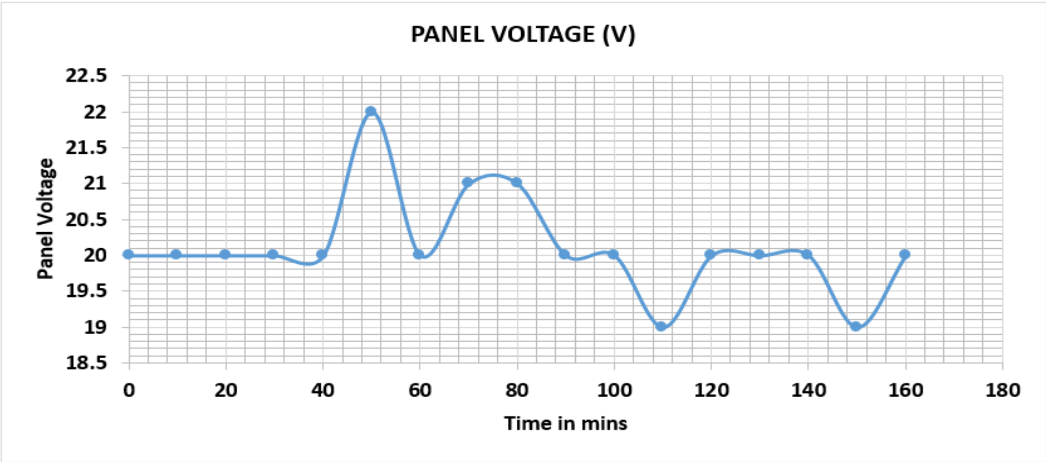

Figure 9. Panel voltage variation against time for PWM charge controller at no-load condition

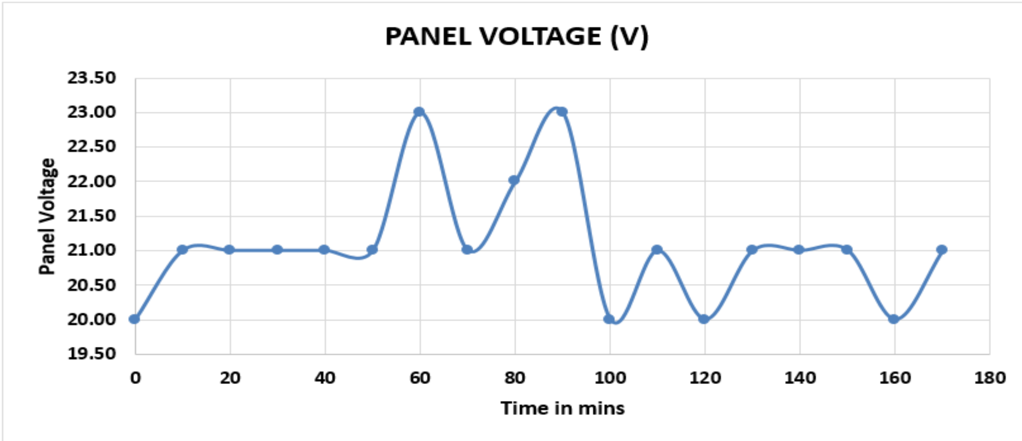

Figure 10. Panel voltage variation against time for MPPT charge controller at no-load condition

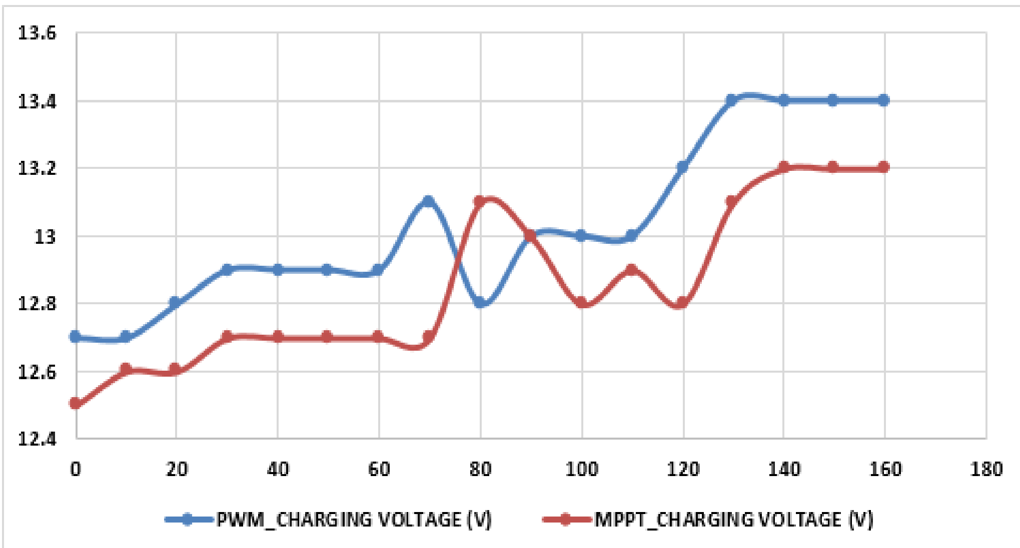

Figure 11. Battery charging voltage for PWM & MPPT at no-load condition

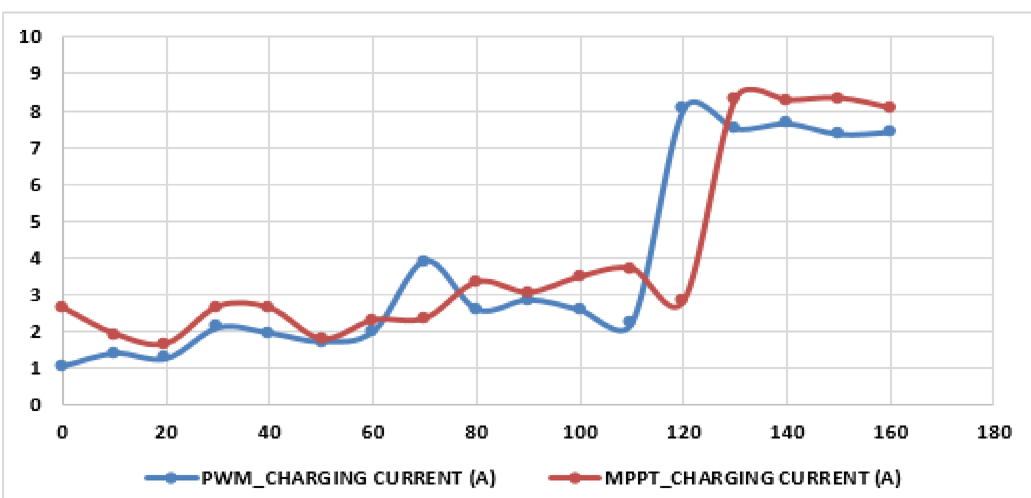

Figure 12. Battery charging current for PWM & MPPT at no-load condition

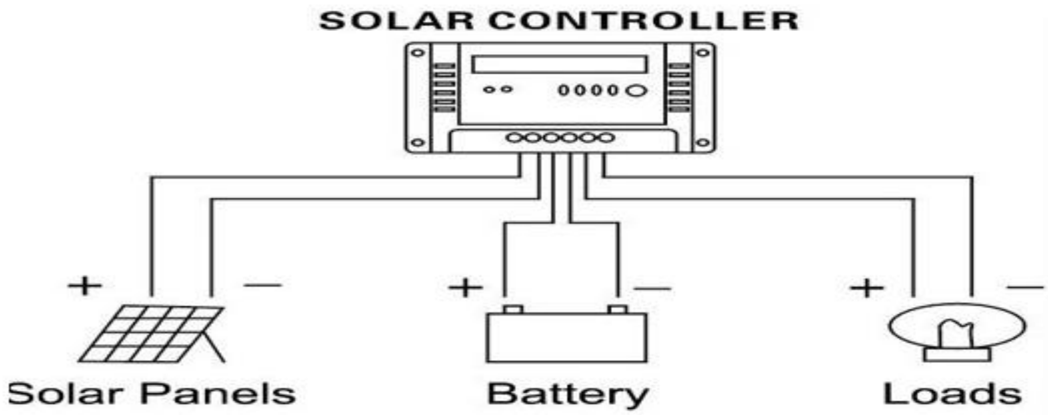

Figure 13. A typical connection of the charge controllers on-load condition

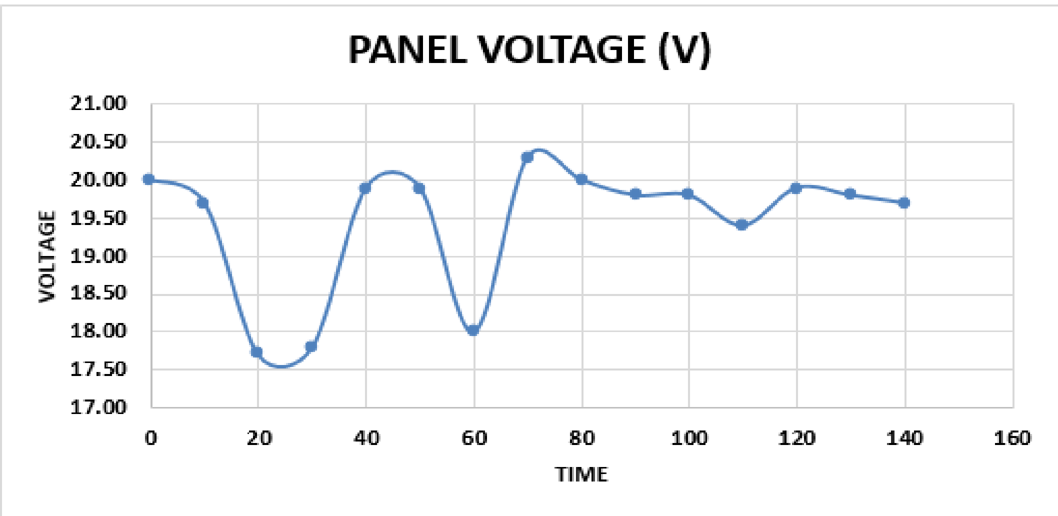

Figure 14. Panel voltage used for PWM on-load condition

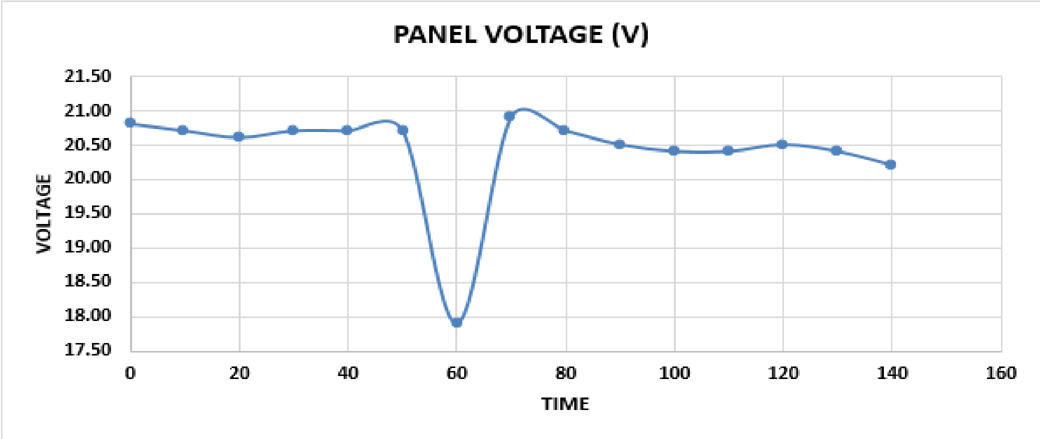

Figure 15. Panel voltage for MPPT on-load condition

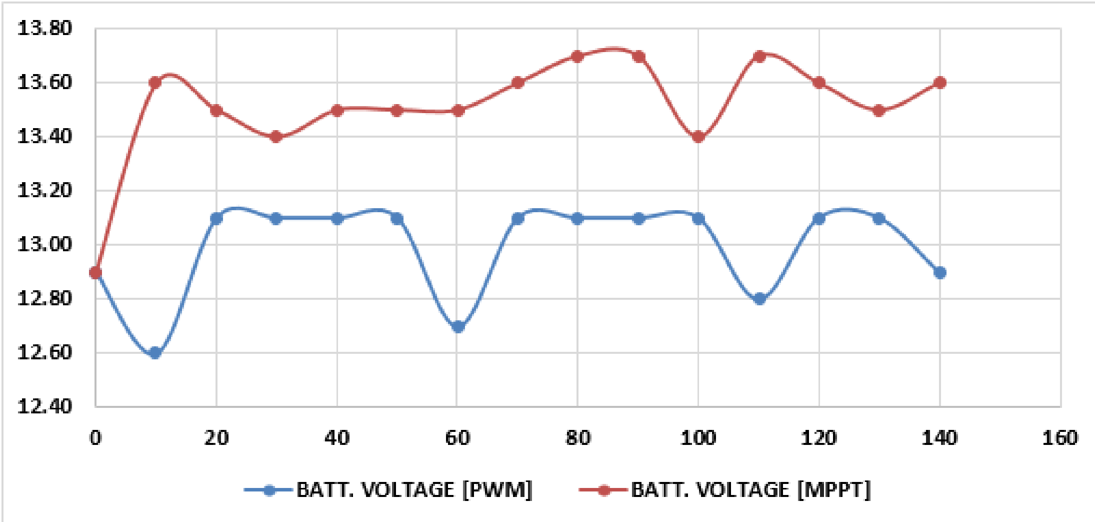

Figure 16. Charging voltage for the batteries using PWM & MPPT on-load condition

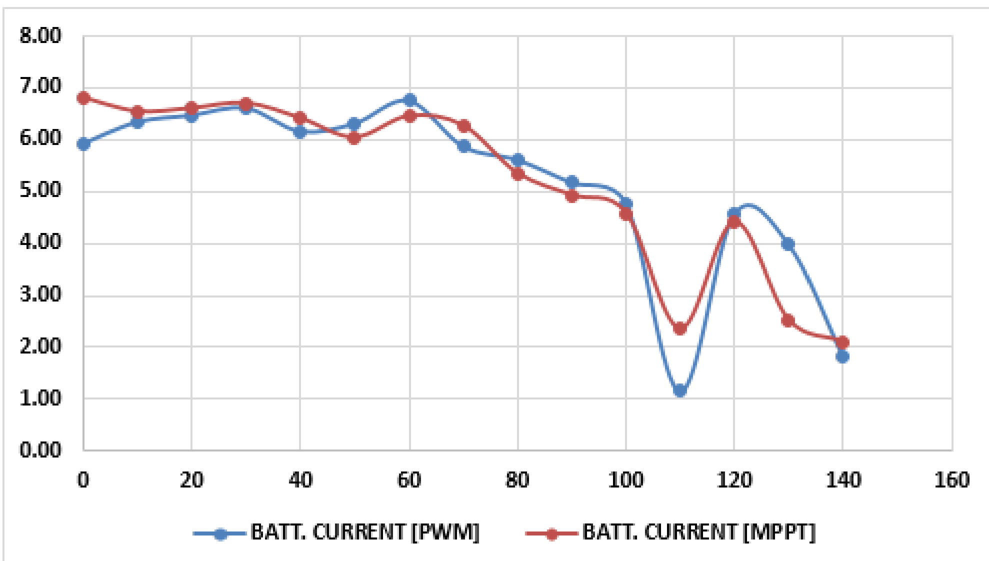

Figure 17. Charging current of the batteries under PWM & MPPT on-load condition