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COMPARATIVE ANALYSIS OF SIMULINK-BASED PWM AND MPPT CHARGE CONTROLLERS FOR VOLTAGE CONTROL IN SOLAR POWER SYSTEMS

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Abstract - Solar energy is stored electrically in battery systems for UPS implementations, and therefore, the battery is continuously being charged or discharged during the process. For overall performance of solar systems the charging and discharging of the batteries must be controlled by a charge controller. This work presents a comparative analysis of PWM and MPPT charge controllers in solar system, focusing on voltage control and system performance efficiency. The comparison was done using irradiance of $1000wm^{-2}$ and a temperature worst case scenario of an overcast weather of 18^{o}C, this is to measure the performance of PWM and MPPT charge controllers at that level. A 200ah 48V lead acid battery configured to an initial state of charge of 50% was used, and for stringent comparison, a DC-DC buck converter of the same circuit elements was implemented for both charge controllers. A Simulink result shows that the PWM controller model has a PV voltage of 49.11V, a PV current of 17.20A and a PV power of 844.70W. Its battery system has a voltage of 47.96V, a current of 17.20A, and a power of 826.40W, resulting in an efficiency of 97.65% for the PWM controller. On the other hand, the MPPT controller model has a PV voltage of 127.70V, a PV current of 16.20A and a PV power of 2058W. Its battery system has a voltage of 48.25V, a current of 39.77A, and a power of 1919W, registering an efficiency of 98.04% for the MPPT controller. From the results, MPPT controller produces higher battery voltage, higher system power, faster system stability and greater efficiency in performance than the PWM controller system.

Keywords: Solar Energy, Charge Controller, PWM, MPPT, Battery and Inverter.

1. Introduction

The most common type of energy received on our planet Earth is the sunlight which is termed solar energy and it radiates down in enormous quantities to heat up the Earth (Ashita et al., 2021). This energy generated by the sun reaches the Earth as electromagnetic radiant energy in the form of visible light and infrared radiation. The amount of solar energy absorbed is dependent on location and the magnitude of solar flux reaching a particular location on the Earth surface (Hakuba, 2015). This solar energy is a clean energy source, abundantly available from nature, pollution free and readily renewable (LokeshReddy et al., 2017). The solar energy can be harnesses and converted directly to electricity through an electrical device called Photovoltaic (PV) cell (Solar cell) (Bishwajit and Anupama, 2016). The electric energy generated by this source is not steady due to nature availability, and therefore while powering the DC load and AC load through an Inverter machine simultaneously, there is a need to charge the battery in process to create a power backup (Osaretin and Edeko, 2015). This arrangement will solve the problem of power supply fluctuation, with the battery acting as the system uninterruptable power supply (UPS) unit (Ogunrinde et al., 2017). The energy generated from the solar panel varies with the radiating sunlight, so that in the daytime the energy from the solar panel rises to its peak level and drops to zero from evening to morning period. This variation in voltage brings about variation in current flow, and consequently variation in power flow depending on the radiating sunlight. This variant in solar energy production affects the battery sustainability, hence requires a solar charge controller which controls the charging of the battery during the daytime sunlight as well as discharging of the battery during powering the system load (Acharya and Aithal, 2020). The solar charge controller functions to regulate and limit the amount of charges from the solar PV module into the battery system, this is to avoid the batteries from being overcharged. It also monitors and controls the amount of discharge flowing to the Inverter and the dc load to avoid battery from being over-discharged. In addition, it creates a multi-input port for connecting different dc loads (Tulika et al., 2018). There are different types of solar charge controllers available in the market but most charge controllers are variation of one of these four basic type, series charge controllers, shunt charge controllers, Pulse Width Modulation (PWM) charge controllers and Maximum Power Point Tracking (MPPT) charge controllers. However, the two main and practically used charge controllers are Pulse Width Modulation charge controllers and Maximum Power Point Tracking charge controllers (Ashita et al., 2021). Both controllers are great options for efficient functionality of a solar energy connected system. The major objective of the solar charge controllers is to control the flow of DC energy as per the need of the battery system, hence both controllers have primary function to monitor the battery voltage so as to control the flow of current in to the battery and out of the battery (Osaretin and Edeko, 2015). This is mainly to elongate the life span of the battery since it is fragile to excess voltage levels (over-charged and over-discharged). An analytical diagram of a wired charge controller is shown in Figure 1.

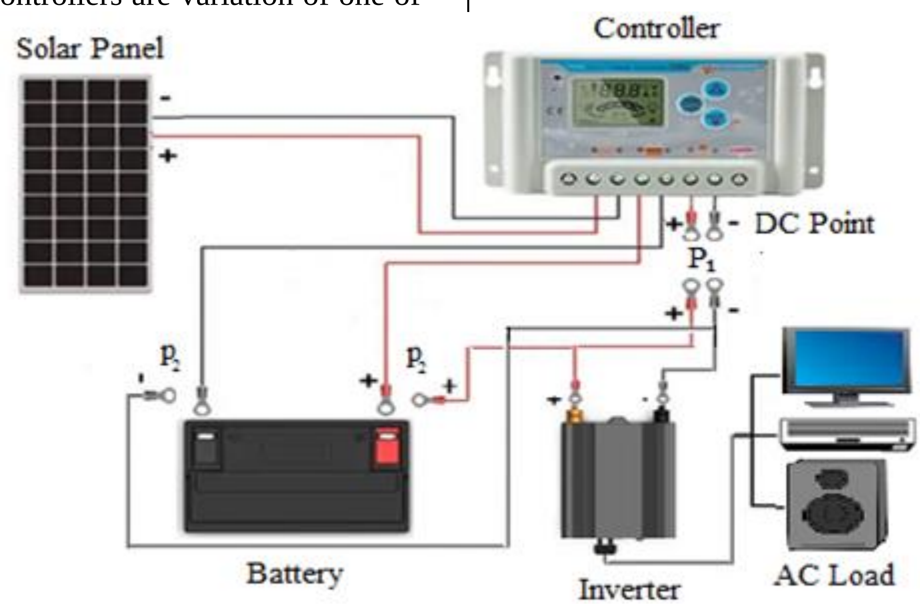


Figure 1. Solar Controller Wiring Diagram (Zhenghai, 2023)

2. Charge Controllers

The charge controller is a key component of a solar energy system, and it is also known as battery voltage regulator, whose main function is to regulate the current and voltage to prevent extreme state of battery voltage condition (Ikeh and Uzor, 2017). The solar controller can be connected in two ways as shown in Figure 1. Primarily the controller controls the charging of the batteries from the solar panel arrays to avoid the batteries from being overcharged. If the load is connected to the controller through point P_1, the controller will monitor and control the amount of battery discharge to avoid being over-discharged. But if the load is connected to the controller through point P_2, then an internal controlling unit in the Inverter will be energized to monitor and control the amount of battery discharge. The controller also functions to maintain the energy flow by attempting to extract maximum energy from sunlight when the battery voltage is low, then limiting the incoming energy as the battery approaches full charge, and finally stopping the charging process when the battery is fully charged. At this point, the charge controller decouples the PV arrays from the battery (Acharya and Aithal, 2020). This decoupling functionality of the controller is a very important aspect that prevent battery current from destroying the solar panel, since the battery is at a higher potential at night time. Most modern controllers have advanced features to ensure that the battery is charged precisely and efficiently (Manoj and Biranchi, 2021). Both PWM and MPPT charge controllers have their own advantages and disadvantages, so that selecting any one will depend on site conditions, system components, size of solar panel, size of load, and cost for a particular solar power installation (Tulika et al., 2018).

2.1 Pulse Width Modulation (PWM) Charge Controller

Pulse width modulation (PWM) charge controller function like a switch which connects the solar panel to the battery. When the switch contact is made, the solar panel array and the battery will be approximately at the same voltage. The battery voltage increases with an increasing solar panel voltage, which allows steady battery charging. The charging is slowed down when the batteries are getting fully charged. This allows the battery to be completely charged without stress. The steady and slow delivery of voltage to the battery reduces the battery heating and gassing, hence lengthen the battery life (Mollik et al., 2019). The working principle of a PWM charge controller depends on the battery voltage, as there is need to match the normal voltage of the solar array with the voltage of the battery (i.e. 12V Solar Panel to 12V battery) (Ikeh and Uzor, 2017). The PWM charge controller has an oscillating circuit whose pulse width depend on the battery voltage. If the battery voltage is less, the pulse width will be high and this initiates storage of solar energy into the battery. As the stored battery voltage increases, the pulse width of the PWM controller reduces, consequently the solar energy storage reduces. At the point when the battery is completely full, the pulse width of the PWM controller will reduce to a minimum (Arun and Pavan, 2020).

2.2 Maximum Power Point Tracking (MPPT) Charge Controller

The major role of an MPPT charge controller is to extract the maximum power from the PV module at any given irradiance and temperature. It measures the voltage of the PV module and adjusts it to match the battery voltage, ensuring optimal performance and efficient power transfer between the solar panel and the battery bank. Thus, the MPPT charge controller steps down high voltage from the solar panel arrays to low voltage needed to charge a battery bank (Tarang, 2016). Since the maximum power varies with solar radiation, it therefore regulates its input voltage to produce maximum power from the solar panel and then deliver this power to the batteries and loads in accordance with controller connections (Mayur et al., 2021)(Isaac et al., 2017). So practically the MPPT charge controller is a DC-to-DC transformer that transforms power from a higher voltage to a lower voltage. Its inbuilt microprocessor and sophisticated software (such as the perturb and observe algorithm) detect the maximum power point of the solar module, set the output voltage of the solar module to its maximum, and hence draw the maximum current at that point. The amount of power transfer does not change, except for small power lose in transformation process. This means that if the output voltage of the module falls below the input voltage of the controller, then the output current will increase beyond the input current, ensuring that the product P = V × I remains constant to maintain power (Ikeh and Uzor, 2017).

3. Methodology

3.1 Comparative Controller Simulation Approach

The simulation investigation was done in two phases, the first phase involve solar module, PWM charge controller and battery, while the second phase involve solar module, MPPT charge controller and battery. This is to create ample chances of comparing PWM and MPPT charge controller's behaviors in moderating the voltage from solar panel to the battery and load.

3.2 Solar Module Charging the Battery through PWM Charge Controller.

The model for solar panel charging the battery through PWM charge controller is shown in Figure 2 and PWM charge controller configuration is shown in Figure 3.

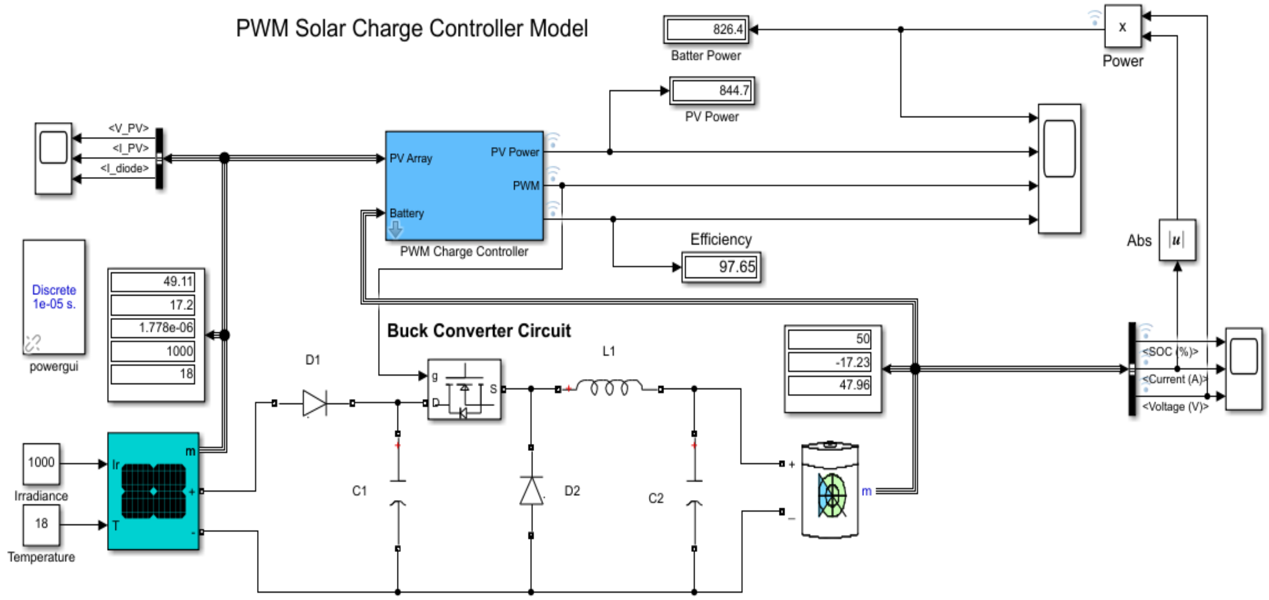


Figure 2. PWM Solar Battery Charging System

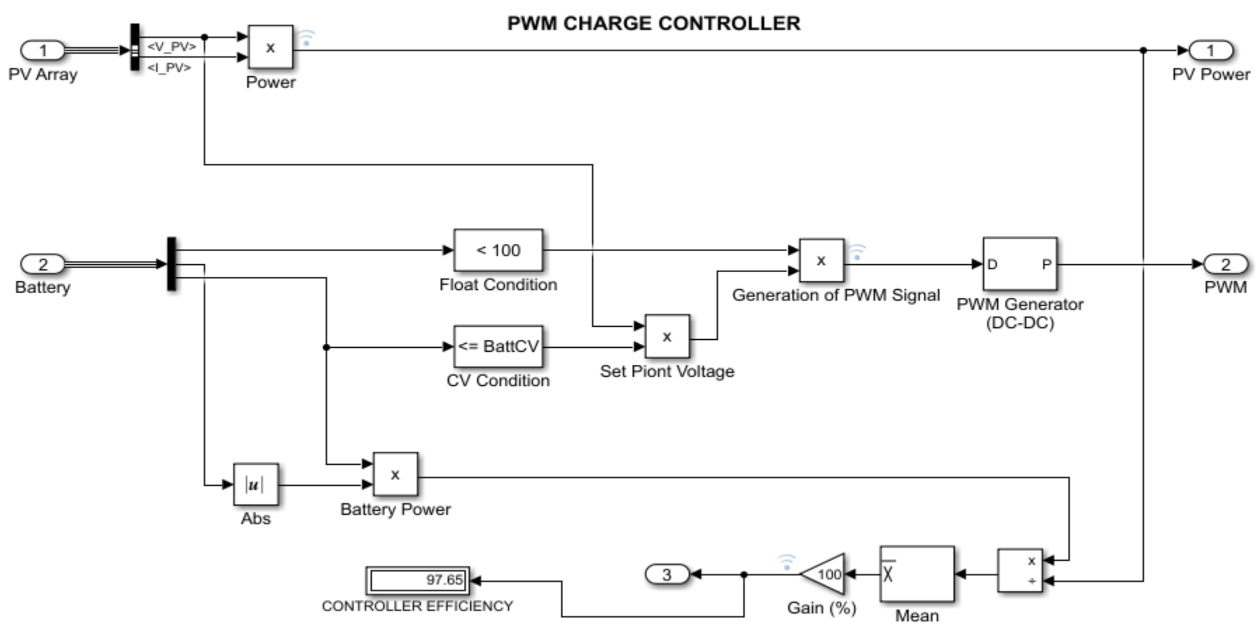


Figure 3. PWM Charge Controller Model

3.3 Solar Module Charging the Battery through MPPT Charge Controller.

The model for solar panel charging the battery through MPPT charge controller is shown in Figure 4 and the MPPT charge controller configuration is shown in Figure 5.

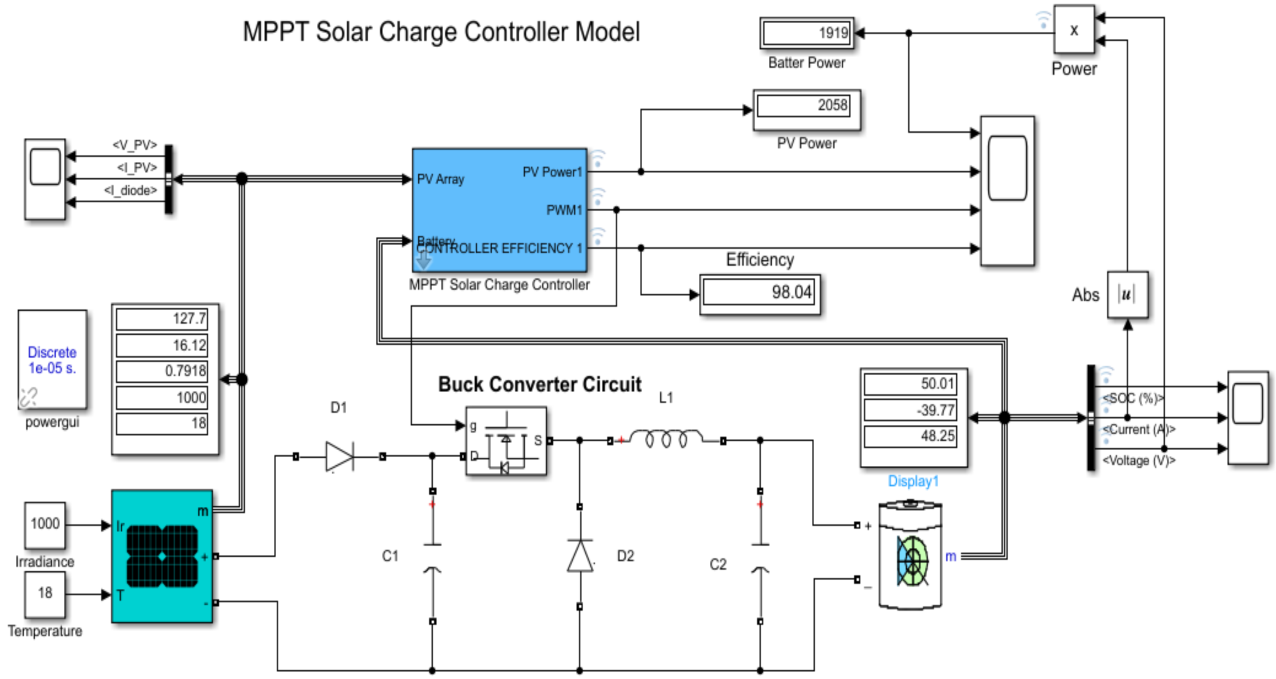


Figure 4. MPPT Solar Battery Charging System

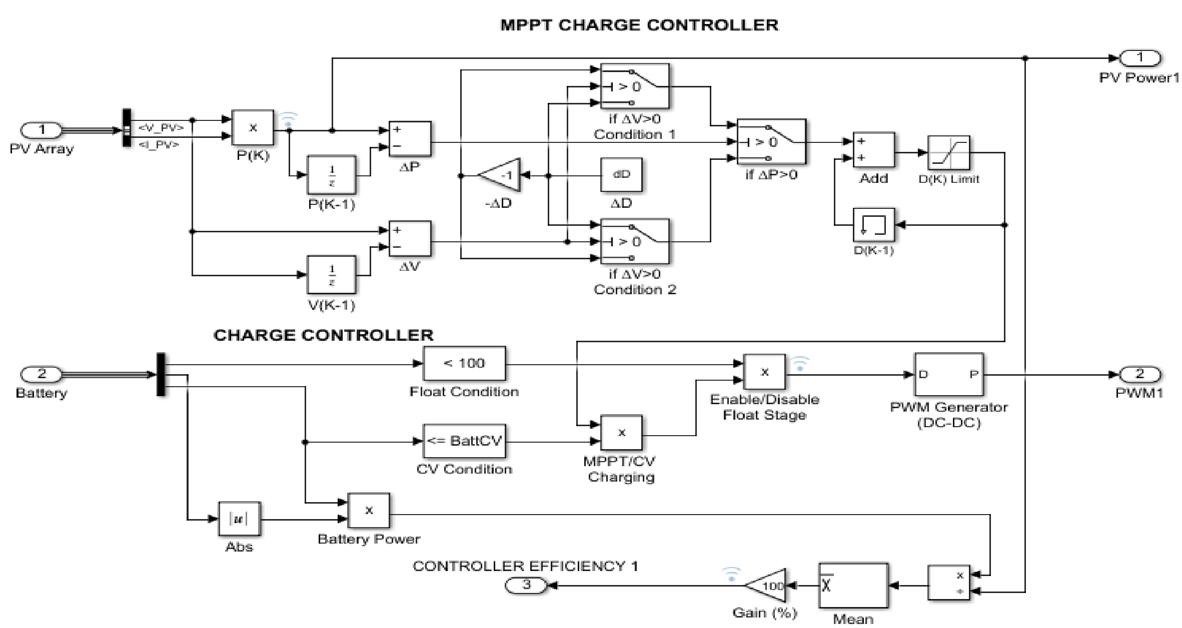


Figure 5. PWM Controller Model

4.0 Result and Discussions

Ths section presents the graphical results of the simulink analysis on the performance efficiency of Pulse Width Modulation (PWM) and Maximum Power Point Tracking (MPPT) methods. In the graphs, the red line represents the PWM data, while the blue line represents the MPPT data for comparison.

4.1 Solar Panel Graphical Results

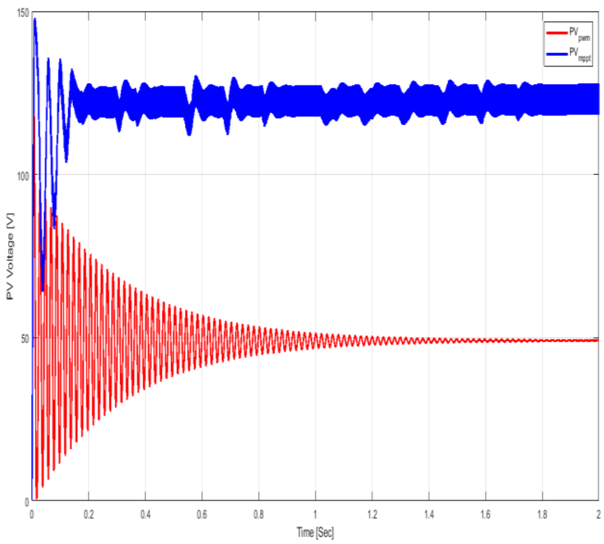


Figure 6. PV Voltages for PWM and MPPT Charge Controller Graphical Results.

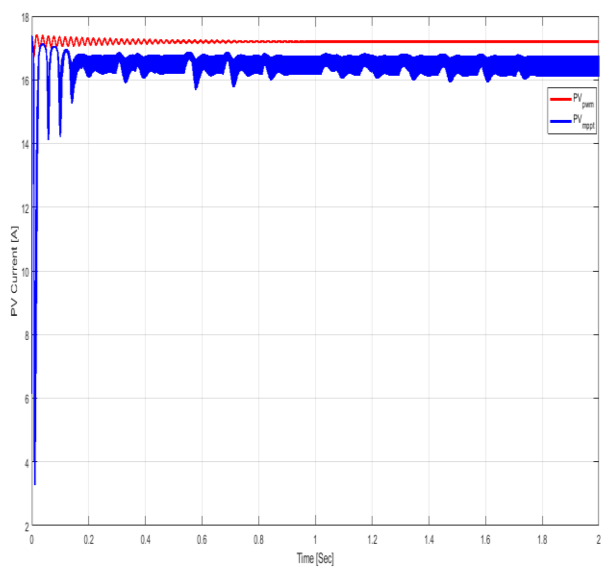


Figure 7. PV Currents for PWM and MPPT Charge Controller Graphical Results.

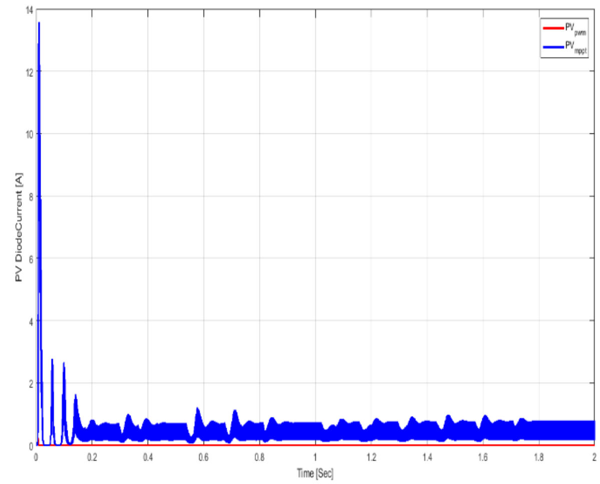


Figure 8. PV Diode Currents for PWM and MPPT Charge Controller Graphical Results.

From Figure 6 it is seen that the PV voltage for PWM system is 49.11V, while the PV voltage for MPPT system is 127.7V. And from Figure 7 the PV current for PWM system is 17.20A, while the PV current for MPPT system is 16.12A. Also from Figure 8, the PV Diode current for PWM system is 1.78 x 10^{-6}A, while the PV diode current for MPPT system is 0.79A. It is noticed from the gaphs that MPPT signals get stabilized faster than PWM signals.

4.2 Battery System Graphical Results

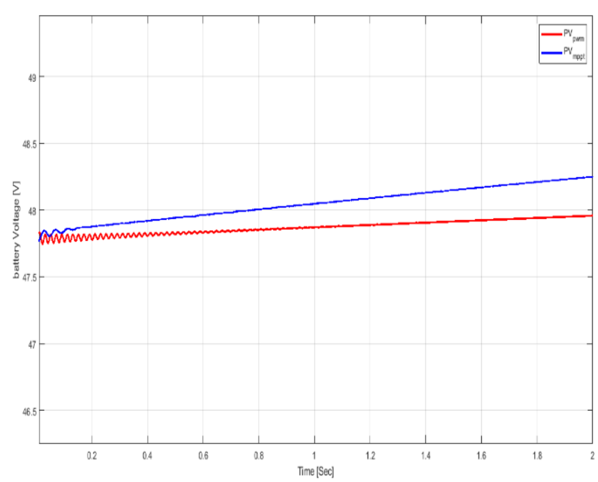


Figure 9. Battery Voltages for PWM and MPPT Charge Controller Graphical Results.

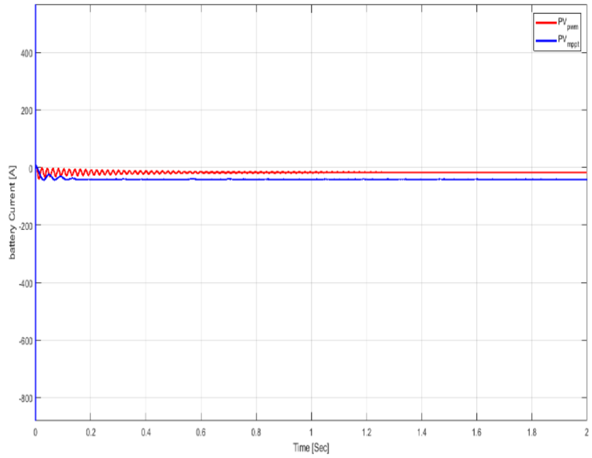


Figure 10. Battery Current for PWM and MPPT Charge Controller Graphical results.

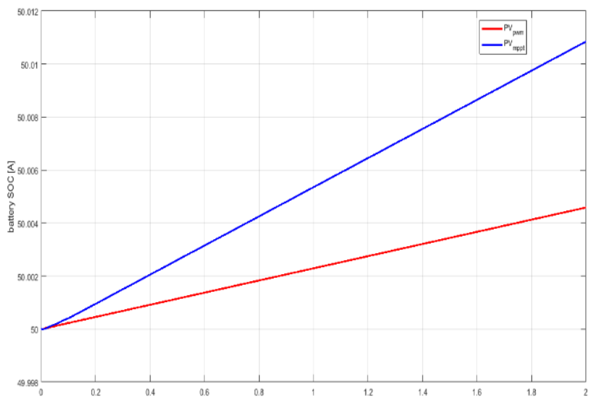


Figure 11. Battery SOC for PWM and MPPT Charge Controller Graphical Results.

From Figure 9 it is seen that the battery voltage for PWM system is 47.96V, while the battery voltage for MPPT system is 48.25V. And from Figure 10 the battery current for PWM system is 17.23A, while the battery current for MPPT system is 39.77A. Then from Figure 11 the battery SOC for PWM system raised from 50% to about 50.005%, while the battery SOC for MPPT system raised from 50% to about 50.011%. Also it is noticed that MPPT signals get stabilized faster than PWM signals.

4.3 Charge Controller Graphical Results

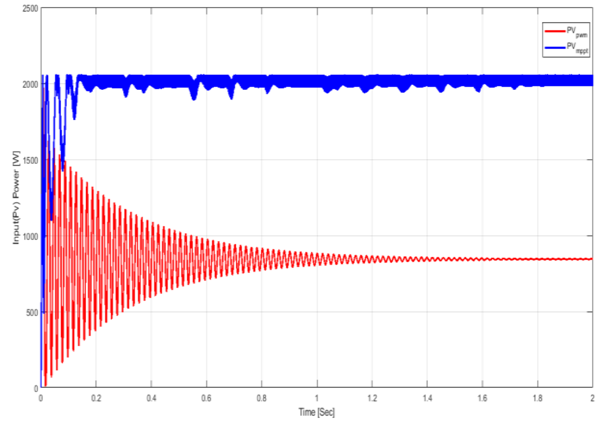


Figure 12. Input Power for PWM and MPPT Charge Controller Graphical Results.

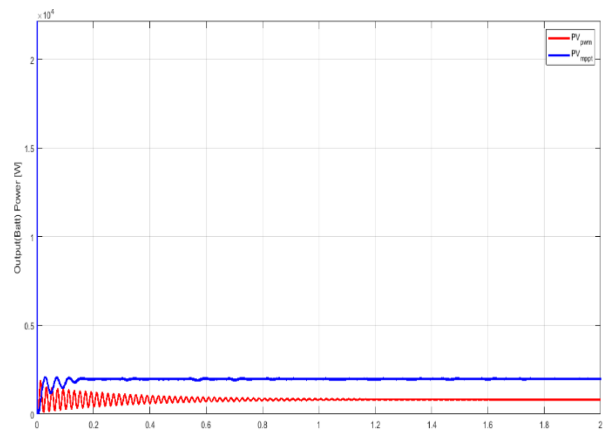
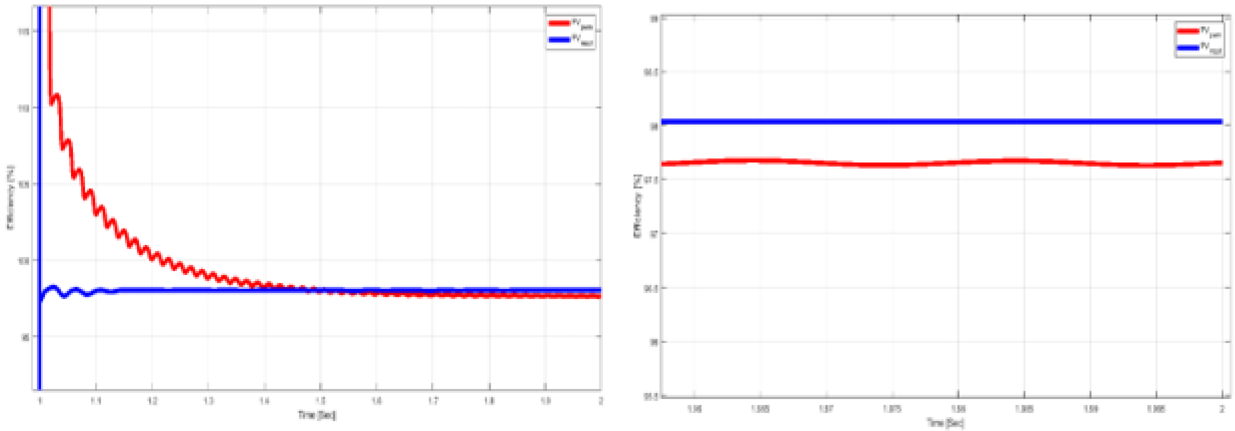


Figure 13. Output Power for PWM and MPPT Charge Controller Graphical Results.



(a) (b)

Figure 14. Efficiency PWM and MPPT Charge Controller Graphical Results.

From Figure 12 it is seen that the input power which is the PV power for PWM system is 844.7W, while the PV power for MPPT system is 1919W. And from Figure 13 the output power which is the battery power for PWM system is 826.4W, while the output power for MPPT system is 2058W. This brings the PWM efficiency to 97.65% and MPPT efficiency to 98.04% as shown in Figure 14a and 14b. However it is noticed that the efficiency of PWM was higher but dropped with time and falls below that of MPPT at 1.5sec from the starting point. Also notable signal stability was registered with MPPT system than PWM system.

Conclusion

The simulations for PWM and MPPT charge controllers were conducted using the same DC-DC buck converter parameters, and under a worst-case weather condition scenario. Based on the simulation results, the PWM charge controller exhibited a PV voltage of 49.11V and a PV current of 17.20A, resulting in an input power of 844.70W. Its battery voltage and battery current were 47.96V and 17.20A respectively, yielding an output power of 826.40W. This corresponds to an efficiency of 97.65% for the PWM charge controller. In contrast, the MPPT controller system showed a PV voltage of 127.70V and a PV current of 16.20A, with an input power of 2058W. The battery system has a voltage of 48.25V and a current of 39.77A, resulting in an output power of 1919W. This yielded an MPPT charge controller efficiency of 98.04%.. From the results, MPPT charge controller produces higher battery voltage, higher system power, faster system stability and greater efficiency in performance than the PWM charge controller system.

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