A Comparative Study of MPPT and PWM Solar Charge Controllers and their Integrated System

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Abstract. The most popular renewable energy system today which is getting implemented 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 large scale fulfilling the commercial requirements in megawatts. In most cases, solar energy is used to store the energy in battery backup along with the energy utilization to the load. The energy storage needs a variation in the flow of current as required and a constant potential difference between the two terminals. But the solar panel generates a current flow as well as the potential difference purely depending on the sunlight. To convert the solar energy generation to the required format different types of charge controllers used. There are various methods of charge controllers which will convert the solar energy into the format that is required to the storage devices. Among them, the most popular charge controllers are PWM based as well as MPPT technology based. This paper highlights the benefits of PWM and MPPT technology. The paper also highlights the differences between the two types and gives a conceptual model of integration of both MPPT as well as the PWM solar charge controllers. The conceptual model shows how to balance the storage backup as well as the load so as to utilize the complete solar energy thus produced. The merits and demerits of the integrated system are also discussed.

Keywords: Solar energy, MPPT, PWM, Integrated model, Battery, Energy backup

1. Introduction
Among the different renewable energy resources solar energy is in the lead [1]. This is due to the wide range of the energy supply from solar energy from a few watts to several megawatts. The solar energy implementation can be done from a single simple house with a few watts to industrial requirements fulfilling several megawatts [2]. In most of the cases the solar energy is used for domestic or small-scale industries as a supplement renewable energy along with the traditional commercial energy system.[3] This supplement energy is taken from the solar panel and it is stored in a battery backup. This stored energy with the help of an inverter is given to the load as supplement energy [4]. There are different standards for energy storage from the solar panel. This is decided by the energy that is supplied by the backup. The standards include 12V, 24V, 48V, 110V or 240V DC. Accordingly, the backup is arranged with one, two, four, ten or twenty batteries connected in series. Similarly, the solar panels must be connected in series to store the energy in the battery [5].

The energy produced from the solar panel varies with the incident sunlight. During day time, the energy from the solar panel increases to the peak level and decreases to zero from morning till
evening. During noon the energy from the solar panel is at its peak [6]. The solar panel having 12V rating increases the potential difference from 0V to 18V max and then back to 0V from the sunrise to sunset. The current rating also varies depending on the incident of sunlight. This variation in solar energy depending on the sunlight requires a controller which controls the charging of the battery backup.

The battery backup also needs the charging voltage and current depending on the energy stored inside it. The required voltage for the battery ranges from 12V to 14V and the current ranges from maximum input current to zero amps depending on the energy stored in it [7]. The incoming solar energy and battery needs are totally different. This difference needs a charge controller which controls the incoming solar energy as per the need of the battery backup [8]. The main role of the solar charge controller is to convert the input solar energy as per the need of the battery backup. The controller tries to extract the maximum energy from the sunlight when the battery backup is very less. As and when the battery backup is getting full the controller has to limit the incoming energy towards the battery. Once the battery is full then the controller should not charge the battery instead of sense the battery voltage.

There are different types of solar charge controllers available in the market. Depending on various concepts the charge controllers store the energy from the solar panel to the battery backup. The most frequently used solar charge controllers are PWM based charge controller and MPPT based solar charge controller [9]. The major objective of the solar charge controllers is to control the flow of the DC energy as per the need of the battery backup. The durability of the battery will increase with the charge controller which regulates the solar energy as per the need of the battery [10]. The working of PWM solar charge controller depends on the current battery voltage. The PWM charge controller has an oscillating circuit whose pulse width depends on the current battery voltage. If the battery voltage is less then the pulse width is more and the entire input solar energy is used to store in the battery. As the battery storage voltage increases the pulse width of the PWM reduces. Similarly, solar energy storage reduces. 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 [11]. The major advantage of this charge controller is to improve battery life. Another popular type of solar charge controller is the MPPT type wherein the charger will boost the input voltage during the initial stage reducing the input current and reduce the input voltage during the peak hour increasing the input current. In this case, the maximum energy is utilized for the storage of the battery backup system [12].

2. Objective
With the intention of improving the performance of currently available solar chargers the objective of this study are:
(1) To study the performance of the currently available PWM and MPPT charge controllers and to identify their limitations.
(2) To propose a model by integrating the above two systems and to study the performance of the combined solar charging system.

3. Methodology
The performance of the existing charge controllers is studied using solar charging method. The disadvantages of each charge controller are determined through experimental technique. The new proposed model is designed and its charging characteristics are studied using conventional charging-discharging method. Based on the performance analysis of the newly developed model the merits and demerits are discussed.

4. PWM Charge Controller
One of the most adopted charge controllers for storing the energy from the solar panel to the battery backup is the Pulse Width Modulation (PWM) charge controller. Here the input solar energy has to pass through a switching circuit to store in the battery backup. This switching circuit is controlled by
an oscillator whose pulse width is varying with the amount of energy stored in the battery backup. The block diagram of the solar PWM charge controller is as shown in figure 1.

![Block Diagram of Solar PWM Charge Controller](image1.png)

**Figure 1.** Conceptual model of solar PWM charge controller.

If the energy in the battery backup is less than the pulse width high state will be large enough and the pulse width of low state will be a single spike. The nature of pulses during the heavy charging mode is as shown in the figure 2.

![Output Waveform of PWM Oscillator (Low Battery Power)](image2.png)

**Figure 2.** The output of PWM oscillator during low battery storage.

The output of the PWM oscillator is then connected to a switching circuit to control the battery charging. Here most of the time of an entire pulse cycle the switch remains on and the solar energy will be getting stored in the battery backup. When the battery backup is getting filled the on stage of the pulse width will reduce and the off stage of the pulse width will increase. The nature of the pulse during the 50% charged battery stage is as shown in the figure 3.

![Output Waveform of PWM Oscillator (50% Battery Charged)](image3.png)

**Figure 3.** The output of PWM oscillator during 50% battery storage.
Similarly, the pulse width of the PWM oscillator changes in such a way that most of the time the pulse will be in a low state only and there will be a spike in high state during battery storage backup is full. This state is just to sense the battery backup level. The pulse width of the PWM oscillator during the charged state battery is as shown in the figure 4.

![Figure 4. The output of the PWM oscillator during fully charged battery.](image)

5. MPPT Charge Controller

Recently another type of charge controller which is working with more efficiency than of the predecessors is the MPPT charge controller. The MPPT stands for Maximum power point tracking system. 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 is varying depending on the sunlight. The conceptual model of MPPT charger is as shown in figure 5.

![Figure 5. Conceptual model of MPPT charge controller](image)

In this model, the solar energy is boosted to 14V with the help of a boost converter until the solar voltage reaches 14V. During this period the input current reduces substantially. Once the solar energy reaches more than 14 V the buck converter reduces the voltage to 14V by increasing the current. Thus, the energy from the solar panel is utilized throughout the day for charging the battery backup instead of solar voltage from 14V to 18V.

6. The proposed new Model
The proposed model is the conceptual theoretical model by integrating the idea of both PWM and MPPT based charge controllers. The model uses Buck and Boot converters to use the entire range of solar energy from 0V to 18V. The PWM controller will regulate the charging of the battery backup. The model also supplies the energy to the load along with the battery backup. The proposed diagram of the model is as shown in figure 6. Here the study is a purely theoretical study mentioning the theoretical aspects of the different charge controller and then the theoretical integration of the available models to arrive at the new model. The working of the model is also the theoretical model.

![Proposed model of the charge controller.](image)

7. **Working of the New Model**

The model initially converts the panel voltage to the high voltage AC signal and sends it to the ground station for the charge controller. The reason is to avoid the thick cables to carry the large current and a small voltage solar energy to the charge controller. These thick cables waste solar energy while carrying the energy towards the ground station into heat.

The converter will increase the input voltage and decrease the input current. This high voltage undergoes the MPPT converter after reconversion to the DC signal. The MPPT converter regulates the input DC and sends the energy to PWM controller. The PWM charges the battery backup using a variable pulse width. This works like a trickle charging where the pulse width will be more when the energy stored in the battery is less. Whereas when the battery voltage is reaching its peak point the pulse width reduces. When the battery is full the PWM charge controller simply senses the battery voltage and does not charge the battery.

The functionality of the PWM charge controller is not only restricted to the charging of the battery instead of a supplement energy resource to the load. Here the idea is to utilize the solar energy which is not getting stored in the negative cycle of the PWM pulse. Here for every negative cycle, solar energy will be used as a supplement resource to the load. The PWM charge controller will supply the incoming solar energy directly to the load when the battery backup is full. This model utilizes the input solar energy to the maximum extent supplying the energy to battery backup as well as to the load.

8. **Performance Analysis**

The performance of the above model is compared with the PWM and MPPT charge controller. The comparative study is as shown in the following table 1.
Table 1. Comparative study of the performance of the newly proposed model.

| Sl. No | Parameter                              | PWM Charge Controller | MPPT Charge Controller | New Proposed Model |
|--------|----------------------------------------|-----------------------|------------------------|--------------------|
| 1      | Charge is controlled by the width of a pulse | Yes                   | No                     | Yes                |
| 2      | Solar energy is utilised from 0V to 18V | No                    | Yes                    | Yes                |
| 3      | Buck and Boost Conversion              | No                    | Yes                    | Yes                |
| 4      | Use of DC-AC-DC conversion             | No                    | No                     | Yes                |
| 5      | Simultaneous supply of energy to both battery backup and Load | No                   | No                     | Yes                |
| 6      | Battery Life                           | Long Life             | Long Life              | Long life          |
| 7      | Trickle Charging                       | Yes                   | No                     | Yes                |

9. Merits & Demerits of Integrated Controller

9.1. Merits

- The charger utilizes all the energy generated from the solar panel to charge the battery as well as to the load through the inverter.
- The controller uses PWM pulses for charging the battery which will increase the life span of the battery as the battery charging becomes smooth and steady.
- The charge controller uses Maximum Power Point all the time resulting in usage of solar energy for the charging from morning till evening.
- When the battery is full the entire solar energy will be utilized for the load through the inverter system.

9.2. Demerits

- Integration of the solar energy along with the battery stored energy to the inverter system causes impedance matching problem.
- There will be chances of reverse current to either the battery or the controller system.
- Inverter may find it difficult to balance the solar energy as well as the battery backup energy.

10. Conclusion

The proposed model is designed for the maximum utilization of solar energy in the day time. The entire energy from the solar panel from morning till evening is utilized. Solar energy is not only used for charging the battery backup but also the energy is used as a supplement to the load along with the energy from the battery backup. The battery life will be improved due to the trickle charging.

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