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# Enhancing the design of battery charging controllers for photovoltaic systems

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ABSTRACT

Batteries are the power tank of solar power systems. They play the role of power supply when the sun does not shine. This paper provides a review of battery charging control techniques for photovoltaic systems. In addition, it presents a new battery charge controller that keeps on the good features and resolves the drawbacks and limitations of the traditional controllers. The new controller is based on a newly developed maximum power point tracking (MPPT) technique enabling very fast maximum power point (MPP) capture. Moreover, it utilizes the constant current, constant voltage (CCCV) charging scheme to reduce the battery charging time. In addition, it enables accessing all system parameters remotely for monitoring and administration purposes. In order to determine the performance parameters of the proposed controller, a prototype was implemented together with microcontroller based DC–DC converter. The experimental results show that, the new controller tracks the MPP faster than the conventional controllers do. Moreover, the charging period is significantly reduced. Moreover, the proposed controller has high accuracy and minimizes the steady state oscillation errors around the target MPP.


**Contents**



## 1. Introduction

Photovoltaic (PV) systems have high fabrication cost and low energy conversion efficiency due to their nonlinear and atmosphere dependent current to voltage (*I–V*) and power to voltage

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(*P*–*V*) characteristic [1]. Therefore, the maximum output power changes with the incident solar radiation and weather conditions especially the temperature. Moreover, the location of the MPP on the *I*–*V* curve could not be easily located. Therefore, it must be determined either through calculation models or by search algorithms. In addition, the process of tracking the maximum power point should be very fast to deal with the fast changes in temperature and or irradiance. The partial shading is not our addressed points. But, it is one of the cases that need fast tracking response. In partial shading, objects like planes, trees, clouds, or buildings cover the sun partially or wholly. Consequently, the MPP may change suddenly and rapidly. In order to maximize the power transfer from the photovoltaic array to the battery bank, a battery charger with charge controller should be utilized. It performs two main functions. The first one is tracking accurately the maximum power point (MPP) so fast in order to keep the operating point of the PV panels at the MPP for the most of the time. The other function is minimizing the battery charging time to back up the PV arrays as fast as possible. In addition, it should protect the battery from overcharging and under discharging.

The algorithm of a battery charge controller determines the effectiveness of battery charging as well as the PV array utilization, and ultimately the ability of the system to meet the electrical load demands. The most common approaches for charge controllers are the shunt, series, pulse width modulation (PWM) and MPPT charge controllers. The shunt regulator controls the charging of a battery from the PV array by short-circuiting the array internal to the controller. The series controller utilizes some type of control element connected in series between the array and the battery. While this type of controller is commonly used in small PV systems, it is also the practical choice for larger systems due to the current limitations of shunt controllers. The MPPT battery charge controller incorporates a DC-to-DC converter such that the PV array can operate at the maximum power point at the prevailing solar irradiance [2].

The battery charging control methods are classified into two classes: single stage, and multi-stage method. The constant current charging is a good example for single stage method, while the constant current, constant voltage technique is a good example for multistage charging method. Studies show that, the multi-stage charging is the most efficient for battery charging regardless of the battery type [3].

The structure of battery charge controllers depends on the type of the controller. In the series and shunt controllers, it simply consists of a switching element, such as a relay that is switched on/off based on the value of a predefined set point. In a PWM and MPPT controllers, the circuits are more sophisticated. In PWM generator circuits or microcontrollers are needed in order to drive the switches of a DC–DC converter. However, the MPPT controller consists of a controller that manages the maximum power point tracking process and DC–DC converter [2].

This paper provides a review of the conventional battery charging control techniques pointing out their good features, drawbacks and limitations, as well. Then it is augmented by the design and practical implementation of a new charge controller that keeps on the good features and resolves the drawbacks and limitations of the traditional controllers. The new controller utilizes a new MPPT algorithm based on genetic neural algorithm (GA). The simulation results of this controller show that, it tracks the maximum power point much faster than the conventional ones [4]. On the other hand, the proposed battery charge controller uses the constant current–constant voltage as a charging scheme in order to reduce the charging time. Moreover, the proposed controller overcomes the other limitations such as depending on battery types, charging voltage levels, and size of PV modules. In addition, the proposed controller has high accuracy and minimizes the steady state error with zero oscillation around the target MPP.

## 2. Materials and methods

There are intensive and continuous research efforts on the design and implementation of the solar charger regulators to improve their performance parameters. The targets are: improving their efficiency, increasing their speed of maximum power point tracking and reducing the period of charging. In this section, the recent publications on the design and implementation of charger controllers will be reviewed to show their main features, drawbacks, and limitations. This would assist us to achieve advancements in the solar charger controller.

A new MPPT technique was introduced in [4]. It has significant improvements in tracking the maximum power point thanks to employing the binary search instead of using linear search technique in the traditional MPPT methods. In addition, a review of different strategies, algorithms, and methods to implement a smart charging control system was presented in [5]. Furthermore, Ref. [6] analyzed the life cycle of three types of batteries, flow-assisted nickel zinc-, manganese dioxide-, and valve-regulated lead-acid batteries. It introduced a comprehensive review and a full process-based life cycle analysis of batteries. This study provided good information for sizing and selecting the appropriate battery type.

An optimized model of hybrid battery and energy storage system based on cooperative game model was proposed in [7]. This study is helpful in planning and designing of battery and energy storage station with the most economical types of batteries and optimal capacity configuration of energy storage station. In [8] the design considerations and evaluation of the performance of PV chargers used to charge major batteries including nickel–cadmium (Ni–Cd), nickel–metal-hydride (Ni–MH), lithium-ion (Li-ion) and sealed lead-acid batteries at real operating conditions are presented. Furthermore, in [9], a socio-technical approach was taken to understand the reasons for failure. A strategy was subsequently developed to influence user behavior and increase the PV array size to reduce capacity shortage through the year and improve the lifetime of the lead acid batteries found on these systems.

Ref. [10] presented the potential of lithium ion (Li-ion) batteries to be the major energy storage in off-grid renewable energy. It introduced the electric vehicle sector as the driving force of Li-ion batteries in renewable energies. In addition, it presented the incomparable advantages of Li-ion batteries over other technologies even if some challenges are still to overcome for a wider usage in stationary energy storage. In addition, the impact of the charging methodology on the battery lifetime was investigated in [11]. Three charging techniques was used in this work: constant current (CC), constant current–constant voltage (CC–CV) and Constant Current–Constant Voltage with Negative Pulse (CC–CVNP). A comparative study between these techniques was presented in this research.

In addition, the State of Health (SOH) determination for lithium ion batteries was discussed in [12]. In this study, the equivalent DC resistances of Lithium ion battery cells of various health conditions during charging under different temperatures were collected and the relationships between equivalent DC resistance, health condition, and working temperature were identified. Furthermore, Ref. [13] proposed a control strategy based on DC link voltage sensing for PV powered smart charging station. This system designed to charge the plug in hybrids electric vehicles (PHEVs) from grid-connected photovoltaic generation or the utility or both. Furthermore, Ref. [14] introduced an approach for estimating the open circuit voltage as a function of parameters of the electrical