A Review on Charge Controllers for PV Based System

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Abstract - This article presents an overview survey on the various components of PV system and the types of charge controllers that are available and developed for the purpose to be used with the PV based system. A charge controller is used with a PV system to uphold the proper charging voltage on the batteries. The primary function of the solar charge controller is to normalize the power departing from the solar panel to the batteries. As the input voltage from the PV system/solar rises, the charge controller regulates the charge to the batteries preventing any overcharging than the pre-defined or a set limit. In all aspects a charge controller must not allow any voltage flow into the battery unless it is higher than the minimum voltage permitted for the explicit controller.

Keywords: Charge Controller, Controller Set Points, MPPT, PWM, PV System

1. Introduction

Many individuals, professionals and groups have contributed to the solar energy harvesting, its development in efficiency and enhancement in PV technology. The key function of the controller is to charge the battery to its fullest level without allowing overcharge or reverse current flow that occurs mostly during the night time or during the adverse weather changes. The other function includes shielding the batteries from charge too much by the solar-cell array and also to protect the batteries from over discharging that occurs due to the load variations. The life of the battery will be badly affected if the PV array is connected to the battery without proper over charge protection or controllers. A charge controller for a PV system must be considered to manage the charging and discharging process.

2. PV system with Charge Controller

PV system with the charge controller, along with inverters and converters connected to the load is shown in the figure 1. The Inverter is responsible for converting the DC output from the charge controller to AC since it needs to cater the AC load that is connected at the load side. The power supplied from the Solar power is fed to the charge controller and then later to the battery for the charging purpose. The output from the battery is regulated by the way of DC-DC converter in order to provide supply to the DC load. These DC-DC converters may be Buck converter, Boost Converter, SEPIC, CUK or Hybrid converters depending on the load that it is connected to and other requirements.

3. Need for a charge controller

A charge controller will be installed or placed in between the PV/solar panel and the Batteries. This will help in maintaining the charge on the batteries. The essential purpose of the charge controllers is to obtain the regulated power from the PV arrays system and then move this power efficiently to the batteries without damaging the batteries when they are overcharged. Generally if you need a solar unit with more than 5 Watts it is required to have a charge controller. If your solar system produces less than 5 Watts of output then there is no need to have a charge controller in the system.

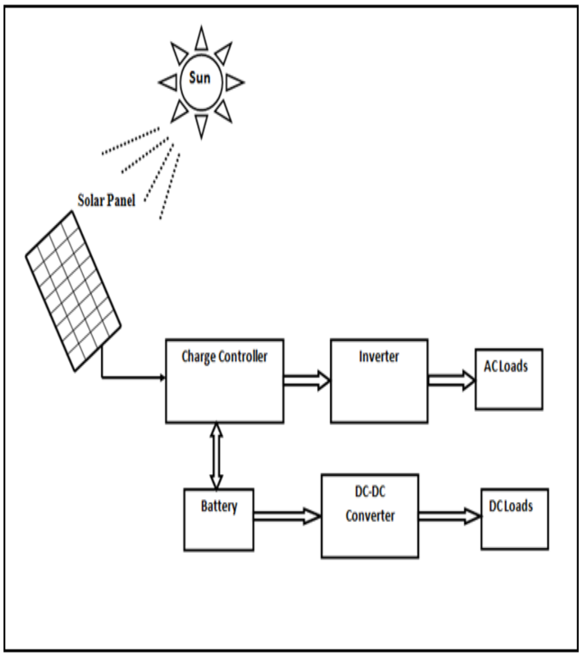

Figure1. A simple PV based system with loads connected.

4. Charge Controllers or Solar Regulators

Charge Controllers that are used along with PV systems are also called solar regulators. Solar charge controllers are the vital control unit regulating the overall energy flow within the system. Hence it is very important and essential activity to decide the charge controller components for a PV system. Various topologies and variants are available in the market these days. Still there is a room for further development and enhancement of the charge controllers that are used for the PV system.

4.1 Integrated Charge Controllers PV system

Integrated charge controller circuitry will be located in the battery powered device or power supply module or AC adaptor. Integrated charge controller circuitry might consist of few electrical components connected with wires or encapsulated in a single chip – IC generally called controller IC or charge control IC or charge controller IC. Majority of the charge control IC find its application in Mobile Phones, Lap/Palm Top, UPS, Audio/Video players etc.

4.2 Stand-alone PV system

The charge controller in a stand-alone PV system is used to regulate the current from PV array in order to guard the battery from being overcharged. The charge controller is also known as energy manager in a stand-alone PV system. The battery voltage decides the system voltage in a stand-alone system. This is the reason that the battery's State of Charge (SOC) utters the operating point of the PV element. In a classic stand-alone PV system the PV array will be designed to supply adequate power during the most awful case of the weather conditions. Due to this reason in a stand-alone PV system there will always be excess power than which is actually required to charge the battery. Few converters have the capacity to route these excess power to a nonessential load (secondary load) or if the provision is not available then this excess power will be dissipated as heat.

4.3 Modern Charge Controllers

Charge controllers come with additional features these days based on the load, applications and requirement. Currently smart charge controllers are being developed that employ the fuzzy logic technique. Preventing reverse current flow is one of the added features of the modern charge controllers. Several features that are available with modern controllers are 3-stage charge control, equalization charging mode, DC load control, Night-Light mode, digital display, Temperature or heat protection and Temperature Sensing characteristics, remote display, dump control and light control etc.

4.4 Pulse Width Modulation

A PWM (Pulse Width Modulated) solar charge controller is the conventional style. Figure 2 shows a conventional PWM circuit that is built using a comparator. In this traditional type modulating signal Vc(t) is given as one input and the Triangular or Saw tooth waveform C(t) is given as the another input to the comparator - COM. The resulting output is the PWM output. In general the PWM solar controllers are robust, inexpensive and widely used in solar panel applications.

In PWM as the name infers the process of adjusting the pulses (duty cycle) of the switches as the input changes to produce the constant output voltage. PWM control can be done by two modes such as i) Current Mode ii) Voltage Mode. In voltage mode of operation the output voltage increases or decreases with the increase or decrease in the duty ratio. This type of strategy leads to the extended battery life since the PWM allows to fully charging the battery with less stress on them.

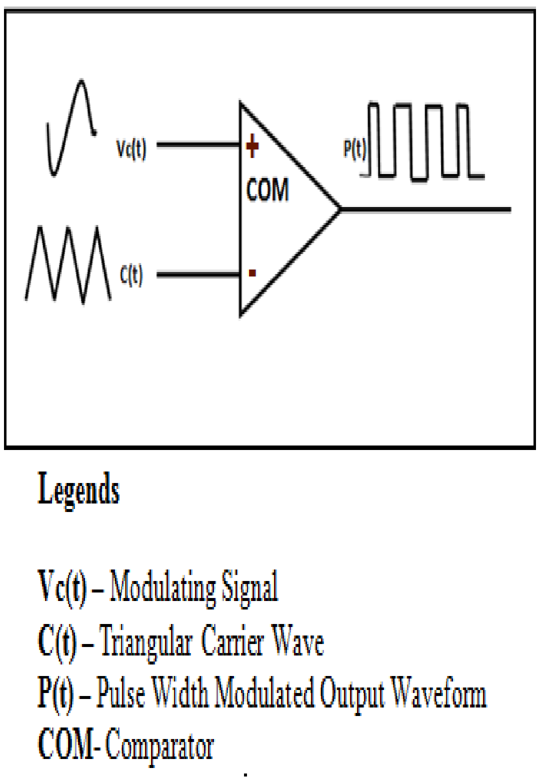

Figure 2. A conventional PWM circuit

Based on the PWM regulation and control the current from the solar panel decrease off in concurrence with the battery's condition and recharging requirement. Figure 3 shows a simple PWM circuit schematic that is controlled using PWM concept. The control signals are generated as pulse depending on the variations.

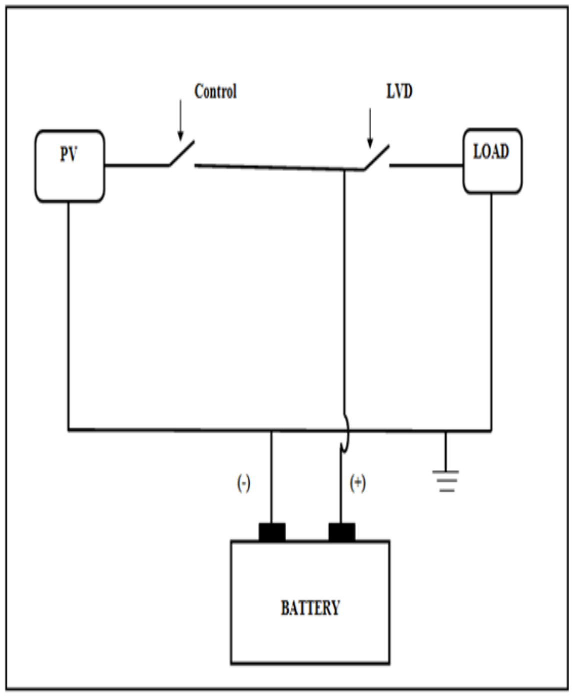

Figure 3. A simple PV system with PWM control schematic

4.5 Maximum Power Point Tracking - MPPT

MPPT controllers are best suited for PV systems for its two fold reasons i) it is able to convert the excess voltage in to amperage ii) Enhanced MPPT charge controller significantly reduces the power loss in wires used in the PV based system.

MPPT in charge controllers gives improved efficiency. The MPPT charge controllers in reality detect the best possible operating voltage and amperage of the solar panel array and equal that with the battery bank. The effect is additional 15-30% more power out of your solar array versus a PWM solar controller.

MPPT solar charge controllers are in general worth the deal for any solar electric system with more than 200 watts rating. The MPPT charge controllers have the capability to boost the amount of charging by converting the additional or excess input voltage to amperage. With the improvement in MPPT technology the system is able to track the changing Voltage and hence maximize the energy harvesting at even worst weather and environmental conditions. Table 1 summarizes the pros and cons of PWM and MPPT based charge controllers.

Table 1. MPPT versus PWM controllers

MPPT charge controllers	**PWM charge controllers**
MPPT's comes with higher frequency charge control and are suitable for systems more than 200 watts and cold weather conditions.	PWM controllers are best suited for systems with less than 200 watts.
MPPT controllers are expensive.	Cost wise the PWM controllers are inexpensive.
MPPT controllers present enormous flexibility for the system growth.	PWM controllers have very limited capacity for the system growth.
MPPT circuitry is complex and is generally larger in physical size.	The PWM controller circuitry is compact and smaller in size.
With MPPT controllers additional energy harvesting can be done by operating the controllers at PV peak power point fairly than battery voltage.	PV Array and Battery voltages must match. PWM based controllers operates at battery voltage.
With MPPT controllers the PV array is sized in watts i.e., based on total power.	With PWM charge controllers the PV array is sized in Amps.
MPPT controllers have the capability of converting the excess input voltage into amperage.	Standard PWM controllers are not able to convert the excess input voltage into amperage.

4.6 Charge controller features

Charge controllers may vary in their complexity depending on the requirement and the application for which it is required to cater for. But the core choice for selection of the charge controller depends on the system voltage need and the maximum charge current.

Here the maximum charge current means the highest current produced by the solar panel.

To size the charge controller, it is advised to have or design the charge controllers with at atleast 25% larger than what it is actually required. This increase in size allows the charge controller to operate in cool and also it helps in enhanced lifetime of the component. For an instance if the controller is rated with a cut in 14 Volts, then it means that it (charge controller) won't charge the battery unless and until it receives at least 14 Volts of input from the solar panel.

Factors to be considered to select or find a suitable controller and the PV system might vary due to the influence of various parameters. To enhance the performance of the system and make it more end user responsive the below are few key parameters or features to be included in your charge controller system.

1. To maximise the charging efficiency the system must come with a Built-In PV charge control.
2. Auto reconnection feature – To reconnect after recovering from the under voltage Protection.
3. Protection circuits or safeguard units for over discharge or over charge. Short circuit Protection.
4. Using PWM technique for the charging control.
5. Protection circuit or logic for over temperature protection.
6. A jamming system to guard against the reverse polarity connection of PV panel and block current from battery to the PV panel.
7. Charge controllers with the display unit to display the system data and also provision to transmit data to the remote display.
8. Data logging feature to track the electric flow over a period of time.

4.7 Charge Controller Set Points

Controller set points refer to the battery voltage levels at which a charge controller carry out control or switching functions. In common for majority of the charge controllers there are four controller set points are defined such as High Voltage Array disconnect - HVD, High Voltage Reconnect - HVR, Low voltage load disconnect – LVD and Load Reconnect voltage – LRV. Figure 4 shows the battery voltage versus time graph with the set points.

LVD - Low voltage load disconnect consign to the voltage set points on which the load is cut off from the battery to prevent over discharge. The controller disconnects the load at this voltage avoiding any further discharge of battery.

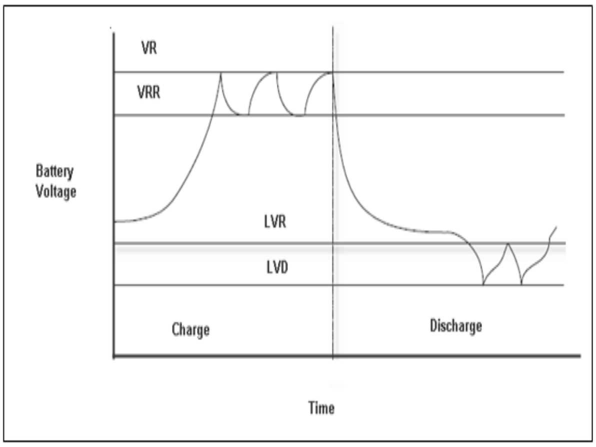

Figure 4. A classic charging and discharging graph for ON/OFF charging

LVR- Low voltage reconnect refers to the activity that occurs after LVD that is after the battery is disconnected. LVR is the threshold voltage that the battery must reach before the load is reconnected to the battery.

HVD - The High Voltage array disconnect and High voltage array reconnect demote to the voltage set points at which the PV is connected with the battery or disconnected from the battery. The High Voltage array disconnect is also known popularly as Voltage Regulation – VR.

5. Charge controllers Types

Charge controllers are available in all variants, many sizes, features and a range of cost. But basically any controller might be built upon two broad categories of configuration such as series type or shunt type configuration. The most frequently used controls used to charge battery based system are in the range of 4 amps to 60 amps. Figure 5 illustrates the broad categories of charge controllers.

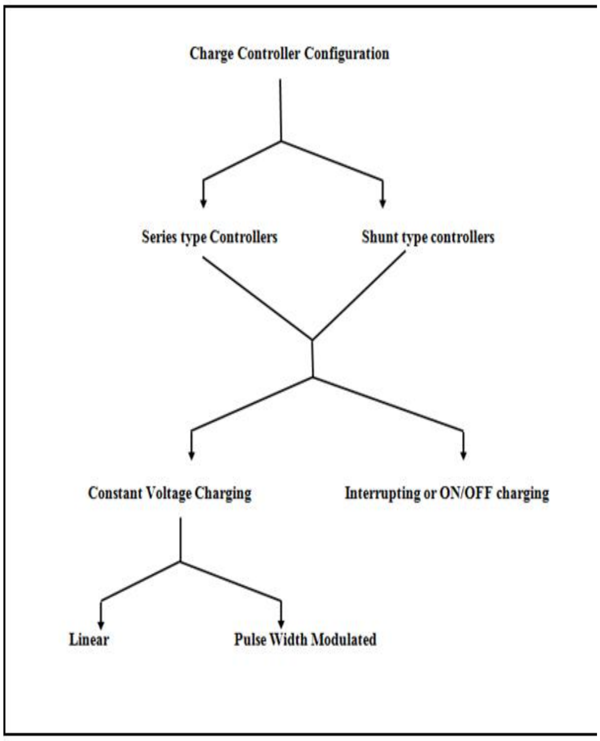

Figure 5. Type of charge controller categories

There is noteworthy difference between the first make charge controller and the one what we see today and this is because of the reason simply called maximum possible power. These days solar charge controllers finds it place as a core control unit for regulating the overall energy flow within system and finds its best place in home based applications, inverters, industrial application, AC and DC based loads, PV hybrid systems etc. Some other charge controllers that are widely used are shunt type, series type charge controller, Relay type, PWM type, MPPT type etc.

5.1 Series Controllers

A series charge controller is also known as series regulator in fact stops the further current flow going in to the batteries when the batteries are fully charged. In simple words a series controller functions in such a way that as a battery draw near its maximum charge, the controller must open circuit the PV array and hence reducing the charging current that is supplied to the battery. Figure 6 shows a simple series controller arrangement fashion.

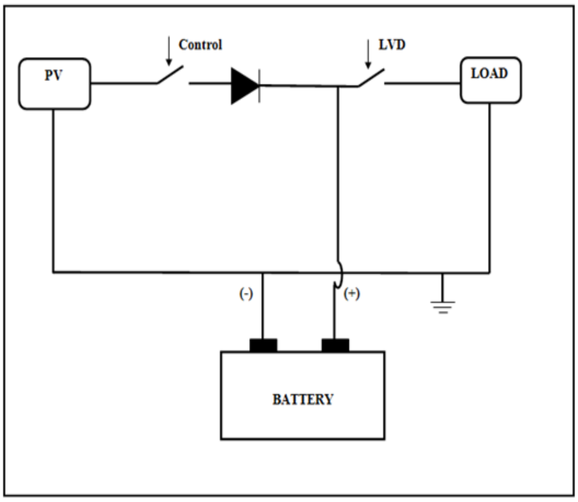

Figure 6. A simple series controller schematic

5.2 Series Linear Control Type

In series linear type of charge controllers a constant voltage is applied to the battery till it reaches the full charge – VR set point. The series controller utilises a control element that acts like a variable resistor. The control element dissipates the balance of the power that is available to the battery which is unused charge.

5.3 Series - Interrupting or On/Off Type

Series On/Off type charge controller utilises the in-series element that will be responsible for the termination of charging at the VR setpoint and this is also responsible for temporary break up or open circuit of the PV array with battery. The charging will restart once the battery voltage descends below the VRR - Voltage Regulation Reconnect set point.

5.4 Shunt Controllers

Shunt type charge controllers are most primal type and have been in use since its inception of solar energy harvesting. These are specifically used only as solar charge controllers. The operation of shunt type charge controllers is that they shunt i.e. short circuit the energy from the solar panel when the battery is completely charged. Shunt type controllers have a preset ON and OFF voltage with hysteresis connect. A shunt charge controller is also known some times as shunt regulator that in fact diverts the surplus electricity to a supplementary or a shunt load when the batteries are fully charged. Figure 7 depicts a simple shunt controller schematic diagram.

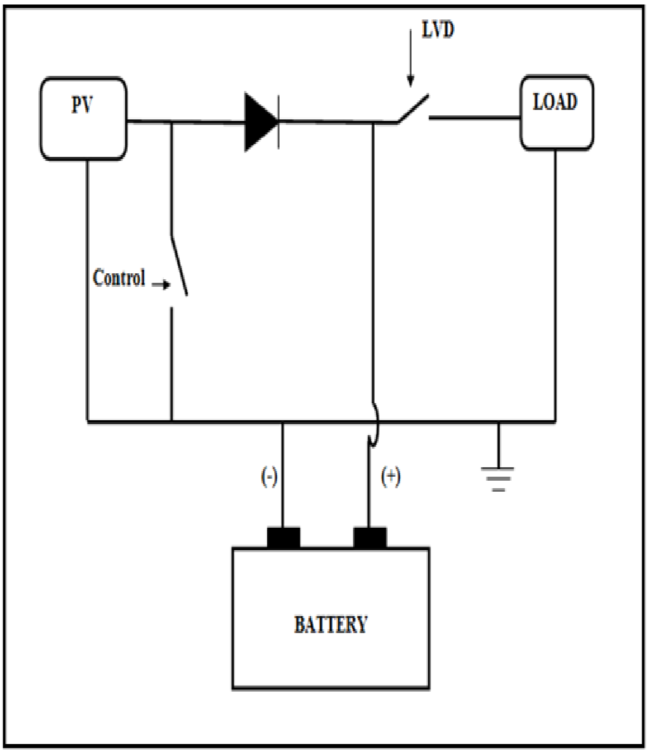

Figure 7. A simple shunt controller schematic

5.5 Shunt Linear Control Type

Shunt linear type utilises a control element to maintain the battery at the VR set point as and when the battery attains the full charge. Shunt linear type controller provides a constant voltage charge to the battery by shunting the power away from the battery in a linear fashion. A Zener diode will be mounted in parallel with the battery; the Zener diode must be set in such a way that its reverse voltage rating is equal to the VR set point. Table 2 illustrates the summary of various charging methods, merits and demerits of various charge controllers.

5.6 Shunt Interrupting or On/Off Type

The shunt interrupting type charge controller diverts the excess energy from the array to a parallel or shunt path when the charge of the battery reaches to its maximum level as per set conditions which is called VR – Voltage Regulation. The charging of the battery will be start again once the battery voltage descends below the set poi called VRR – Voltage Regulation Reconnect.

5.7 Simple 1 or 2 stage control

1 - Stage controllers are the traditional type controllers that basically depend on the relay type or shunt transistors to control the voltage in single stage. 1-stage or 2-stage charge controllers will either make or break type i.e., short or disconnect type. These controllers have a convey that opens the charging circuit when a fixed or defined high voltage tip is reached and the relay closes (shorts) the circuit again when preset or defined low voltage limit is attained and allows the charging to continue. These single stage controller devices are reliable and inexpensive.

5.8 Three - Stage control

The 3-stage PV charge controller uses the PWM and Processor control to provide best possible and secure charging to the batteries that are connected to the panel. Figure 13 shows the three stages in PWM graphically.

Controller Type	Series Linear Controller	Series Interrupting Controller	Series/Shunt-PWM Controller	Shunt Interrupting Controller	Shunt Linear Controller
Method used for Charging	Constant Voltage Charging	ON/OFF Charging	Constant Voltage Charging	ON/OFF Charging	Constant Voltage Charging
Pros	Narrowed current charging	Does not require power dissipation, simple circuitry ,reliable and inexpensive	Low Power Dissipation & narrowed current charging	Lower voltage drop across controller, Simple circuitry, reliable and inexpensive	Narrowed current charging, low voltage drop across controller
Cons	Requires power dissipation & Voltage drop across controller	Charging fully the battery at higher levels is not easy	Voltage Drop, Complex Circuitry, Interference in nearby equipments	Requires Blocking diode, hotspots in high voltage arrays, power dissipation in bulky systems	Requires Blocking diode, power dissipation in bulky systems

Table 2. Summary of charging methods, Pros and Cons of controllers

Stage 1 – Bulk Charge Phase: In this stage of the charge cycle, the voltage steadily mounts to the Bulk Level i.e., to the maximum rated value for an instance 14.4 or 14.6 volts and the batteries draws maximum current.

Stage 2 – Absorption Charge Phase: In this stage the voltage is maintained at the same level as the first stage of Bulk Voltage Level for a reasonable particular time for an instance one hour or more. During this stage the batteries charge up and hence the current progressively diminish off.

Stage 3 – Float Charge Phase: The float phase occurs after the absorption phase ends. In this phase the voltage is decreased to float level for an instance from 14.4 to 13.4 Volts. A small amount is current is drawn by the batteries in this phase that will be utilised for the maintenance.

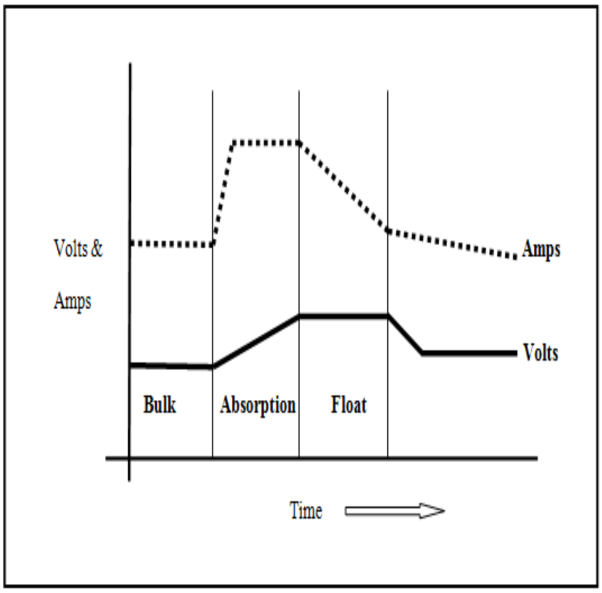

Figure 8. Graphical representation of 3 - stages in PWM

5.9 Charge Controllers for smaller Loads

Usually there is no need for a charge controller with little maintenance or dribble solar panels with the rating of up to 5 watts. Some of the examples of smaller load applications are standard golf car battery with 12 volts (series pair). In this case the 5 watt panels are needed to provide 4.2 watts of power to the golf car.

Conclusion

This paper has addressed the overview of the quite a few technical literatures on controllers for the PV based system. Eventually as the end users we require a PV system that must provide us a higher charging efficiency, rapid recharging and a healthy battery life at full capacity. Modern solar powered applications claim high performance, greater efficiency and adaptable charge controllers. The advancement in solar power systems is due to the advantage from the enhancement in the technology of charge controllers design. Today's charge controller capitalizes on system prospective and boosts the yield of abundant renewable energy and therefore reducing the overall system cost.

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