What is a Charge Controller?

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A charge controller is an essential part of nearly all power systems that charge batteries, whether the power source is PV, wind, hydro, fuel, or utility grid. Its purpose is to keep your batteries properly fed and safe for the long term.

The basic functions of a controller are quite simple. Charge controllers block reverse current and prevent battery overcharge. Some controllers also prevent battery overdischarge, protect from electrical overload, and display battery status and the flow of power. Let's examine each function individually.

Blocking Reverse Current

Photovoltaic (PV) panels work by pumping current through your battery in one direction. At night, the panels may pass a bit of current in the reverse direction, causing a slight discharge from the battery. (Our term "battery" represents either a single battery or bank of batteries.) The potential loss is minor, but it is easy to prevent. Some types of wind and hydro generators also draw reverse current when they stop, but most do not, except under fault conditions.

In most controllers, charge current passes through a semiconductor (a transistor) which acts like a valve to control the current. It is called a semiconductor because it passes current in only one direction. It prevents reverse current without any extra effort or cost.

In some controllers, an electromagnetic coil opens and closes a mechanical switch. This is called a relay. It switches off at night, to block reverse current. As it turns on and off, there is an audible clicking sound.

If you are using a very small array relative to the size of the battery, then you may not need a charge controller. This is a rare application. An example is a tiny maintenance PV module that trickle-charges a battery and compensates for battery discharge in a parked vehicle but will not support significant loads. In this situation, you can install a simple diode to block reverse current. A diode used for this purpose is called a blocking diode.

Preventing Overcharge

When a battery reaches full charge, it can no longer store incoming energy. If energy continues to be applied at the full rate, the battery voltage gets too high. Water separates into hydrogen and oxygen and bubbles out rapidly. It looks like it's boiling so we sometimes call it that, although it's not actually hot. There is an excessive loss of water, and a chance that the gasses can ignite and cause a small explosion. The battery will also degrade rapidly and may possibly overheat. Excessive voltage can also stress your loads (lights, appliances, etc.) or cause your inverter to shut off.

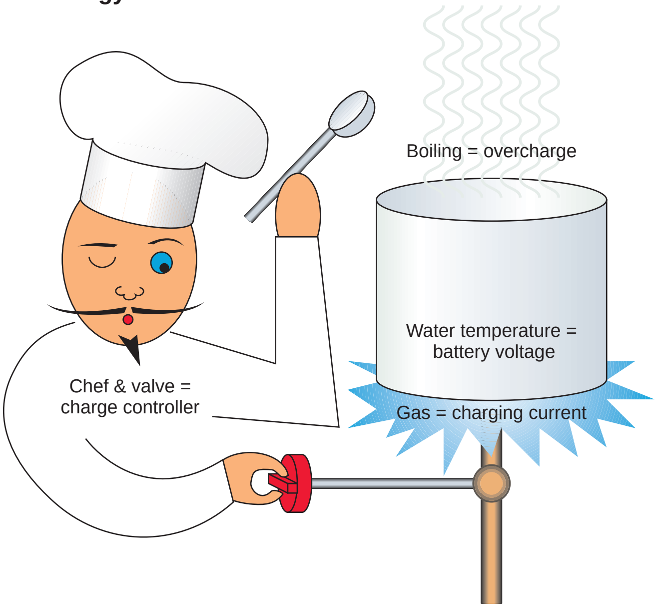
Preventing overcharge is simply a matter of reducing the flow of energy to the battery when the battery reaches a specific voltage. When the voltage drops due to lower sun intensity or an increase in electrical usage, the controller again allows the maximum possible charge. This is called voltage regulating. It is the most essential function of all charge controllers. The controller "looks at" the voltage, and regulates the battery charging in response. This can be illustrated by an analogy:

The Energy Chef is watching a pot of water on a gas burner, which is fed by a tube coming from the sun. He has one hand on the gas valve. He's thinking, "I need to get this water as close to a boil as possible before the sun goes down, but I must never boil the water."

In this analogy, the temperature of the water represents battery voltage; the flow of gas represents charging current; boiling represents overcharge; and the energy chef manipulating the valve is like the charge controller.

Some controllers regulate the flow of energy to the battery by switching the current fully on or fully off. This is called on/off control. Others reduce the current gradually, called pulse width modulation (PWM). Both methods work well when the voltage set points are properly selected for your type of battery.

The Energy Chef



A PWM controller holds the voltage more constant. If it has two-stage regulation, it will first hold the voltage to a safe maximum for the battery to reach full charge. Then it will drop the voltage lower to sustain a "finish" or "trickle" charge. Two-stage regulating is important for a system that may experience many days or weeks of excess energy (or little use of energy). It maintains a full charge but minimizes water loss and stress.

The voltages at which the controller changes the charge rate are called set points. When determining the ideal set points, there is some compromise between charging quickly before the sun goes down, and mildly overcharging the battery. The determination of set points depends on the anticipated pattern of use, the type of battery, and to some extent, the experience and philosophy of the system designer or operator. Some controllers have adjustable set points, while others do not.

Control Set Points vs Temperature

The ideal set points for charge control vary with battery temperature. Some controllers have a feature called temperature compensation. When the controller senses a low battery temperature, it will raise the set points. Otherwise when the battery is cold, it reduces the charge too soon. If your batteries are exposed to temperature swings greater than about 30°F (17°C), compensation is essential.

Some controllers have a temperature sensor built in. This type of controller must be mounted in a place where the temperature is close to that of the batteries. Better controllers have a remote temperature sensor on a small cable. The probe should be attached directly to a battery in order to report its temperature to the controller.

An alternative to automatic temperature compensation is to manually adjust the set points (if possible) according to the seasons. It may be sufficient to do this only twice a year, in spring and fall.

Control Set Points vs Battery Type

The ideal set points for charge controlling depend on the battery design. The vast majority of RE systems use deep cycle lead-acid batteries of either the flooded type or the sealed type. Flooded batteries are filled with liquid. These are the standard, economical deep cycle batteries.

Sealed batteries use saturated pads between the plates. They are also called "valve-regulated," "absorbed glass mat," or simply "maintenance-free." They need to be regulated to a slightly lower voltage than flooded batteries or they will dry out and be ruined. Some controllers have a means to select the type of battery. Never use a controller that is not intended for your type of battery.

Low Voltage Disconnect

The deep cycle batteries used in renewable energy systems are designed to be discharged a maximum of 80 percent (20% state of charge). If they are discharged 100 percent, they are immediately damaged. Imagine a pot of water boiling on your kitchen stove. The moment it runs dry, the pot overheats. If you wait until the steaming stops, it is already too late!

Typical Set Points for 12 V L-A Batteries at 77°F (25°C)

Set Point	*Voltage*
High limit (flooded battery)	14.4 V
High limit (sealed battery)	14.0 V
Resume full charge	13.0 V
Low voltage disconnect	10.8 V
Reconnect	12.5 V
Typical temperature compensation per 1°C deviation from 25°C	-0.03 V

These are typical set points, presented here only for example.

Similarly, if you wait until your lights look dim, some battery damage will have already occurred. Every time this happens, both the capacity and the life of the battery will be reduced by a small amount. If the battery sits in this overdischarged state for days or weeks at a time, it can be ruined quickly.

The only way to prevent overdischarge when all else fails is to disconnect loads (appliances, lights, etc.), and then reconnect them only when the voltage has recovered due to some substantial charging. When overdischarge is approaching, a 12 volt battery will drop below 11 volts (a 24 V battery will drop below 22 V).

A low voltage disconnect (LVD) circuit will disconnect loads at that set point. It will reconnect the loads only when the battery voltage has substantially recovered due to the accumulation of some charge. A typical LVD reset point is 13 volts (26 V on a 24 V system).

All modern inverters have LVD built in, even cheap pocket-sized ones. The inverter will turn off to protect itself, your loads, and your battery. Normally, an inverter is connected directly to the batteries, not through the charge controller, because its current draw can be very high, and because it does not require external LVD.

If you have any DC loads, you should have an LVD. Some charge controllers have one built in. You can also obtain a separate LVD device. Some LVD systems have a "mercy switch" to let you draw a minimal amount of energy, at least long enough to find the candles and matches! DC refrigerators have LVD built in.

If you purchase a charge controller with built-in LVD, make sure that it has enough capacity to handle your DC loads. For example, let's say you need a charge controller to handle less than 10 amps of charge current, but you have a DC water pressurizing pump that draws 20 amps (for short periods) plus a 6 amp DC lighting load. A charge controller with a 30 amp LVD would be appropriate. Don't buy a 10 amp charge controller that has only a 10 or 15 amp load capacity!

Overload Protection

A circuit is overloaded when the current flowing in it is higher than it can safely handle. This can cause overheating and can even be a fire hazard. Overload can be caused by a fault (short circuit) in the wiring, or by a faulty appliance (like a frozen water pump). Some charge controllers have overload protection built in, usually with a push-button reset.

Maximum Power Point Tracking

A new feature is showing up in charge controllers. It's called maximum power point tracking (MPPT). It extracts additional power from your PV array under certain conditions.

The function of MPPT is analogous to the function of a transmission in a car. When the transmission is in the wrong gear, the wheels do not receive maximum power. That's because the engine is running either slower or faster than its ideal speed range. The purpose of the transmission is to couple the engine to the wheels in a way that lets the engine run in a favorable speed range in spite of varying acceleration and terrain.

Let's compare a PV module to a car engine, with voltage analogous to engine speed. At the ideal voltage, the PV can deliver maximum power. This is the maximum power point, also called peak power voltage (Vpp). Vpp varies with sunlight intensity and with solar cell temperature. The voltage of the battery is analogous to the speed of the car's wheels. It varies with battery state of charge, and with the loads on the system (any appliances and lights that may be on). For a 12 V system, it ranges from about 11 to 14.5 volts.

In order to charge a battery (increase its voltage), the PV module must apply a voltage that is higher than that of the battery. If the PV module's Vpp is just slightly below the battery voltage, then the current drops nearly to zero (like an engine turning slower than the wheels). To play it safe, typical PV modules are designed with a Vpp of around 17 volts when measured at a cell temperature of 77°F (25°C) on a cool day. They do that because it will drop to around 15 volts on a very hot day. However, on a very cold day, it can rise to 18 volts!

What happens when the Vpp is much higher than the voltage of the battery? The module voltage is dragged down to a lower-than-ideal voltage. Traditional charge controllers transfer the PV current directly to the battery without giving you the benefit of this added potential.

Now let's make one more analogy. The car's transmission varies the ratio between speed and torque. At low gear, the speed of the wheels is reduced and the torque is increased. Likewise, MPPT varies the ratio between the voltage and current delivered to the battery in order to deliver maximum power. If there is excess voltage available from the PV array, it is converted to additional charging current for the battery. It's like an automatic transmission. As the Vpp of the PV array varies with temperature and other conditions, it "tracks" this variance and adjusts the ratio accordingly. That's why it's called a maximum power point tracker.

What advantage does MPPT give in the real world? That depends on your array, climate, and seasonal load pattern. It gives you an effective current boost only when the Vpp is more than about 1 volt higher than the battery voltage. In hot weather, this may not be the case unless the batteries are at a low state of charge (SOC). In cold weather however, the Vpp can rise as high as 18 volts. If your energy use is greatest in the winter (typical in most homes) and you have cold winter weather, then you can gain a substantial boost in energy when you need it the most!

Here is an example of MPPT action on a cold winter day:

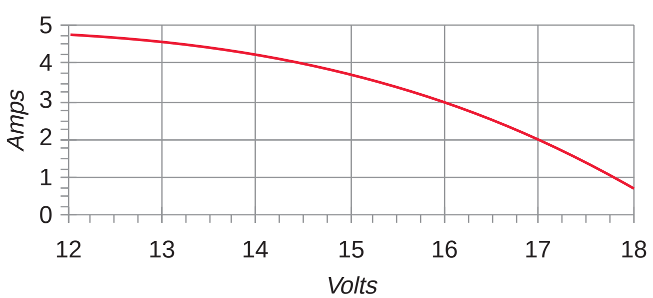
The outside temperature is 20°F (-6.6°C). The wind is blowing a bit, so the PV cell temperature rises to only around 30°F (-1.1°C). Vpp = 18.0 V. The batteries are a bit low, and loads are high, so battery voltage = 12.0 V.

Ratio of Vpp to battery voltage is 18:12 = 1.5:1

Under these conditions, a perfect MPPT (with no voltage drop in the array circuit) would deliver a 50 percent increase in charge current! In reality, there are losses in the conversion just as there is friction in a car's transmission. Reports from the field indicate that increases of 20 to 30 percent are typically observed.

MPPT controllers are a new technology that is just starting to become available. This sidebar is a simplified introduction to a complex topic. Watch for more information in future issues of *Home Power.*

Typical PV IV Curve



Built-in overload protection can be useful, but most systems require additional protection in the form of fuses or circuit breakers. If you have a circuit with a wire size for which the safe carrying capacity (ampacity) is less than the overload limit of the controller, then you must protect that circuit with a fuse or breaker of a suitably lower amp rating. In any case, follow the manufacturer's requirements and the *National Electrical Code* for any external fuse or circuit breaker requirements.

Displays and Metering

Charge controllers include a variety of possible displays, ranging from a single red light to digital displays of voltage and current. These indicators are important and useful. Imagine driving across the country with no instrument panel in your car! A display system can indicate the flow of power into and out of the system, the approximate state of charge of your battery, and when various limits are reached.

If you want complete and accurate monitoring however, spend about US$200 for a separate digital device that includes an amp-hour meter. It acts like an electronic accountant that keeps track of the energy available in your battery. If you have a separate system monitor, then it is not important to have digital displays in the charge controller itself. Even the cheapest system should include a voltmeter as a bare minimum indicator of system function and status.

Have It All with a Power Center

If you are installing a system to power a modern home, then you will need safety shutoffs and interconnections to handle high current. The electrical hardware can be bulky, expensive, and laborious to install. To make things economical and compact, obtain a ready-built power center. It can include a charge controller with LVD and digital monitoring as options. This makes it easy for an electrician to tie in the major system components, and to meet the safety requirements of the *National Electrical Code* or your local authorities.

Charge Controllers for Wind and Hydro

A charge controller for a wind-electric or hydro-electric charging system must protect the batteries from overcharge, just like a PV controller. However, a load must be kept on the generator at all times to prevent overspeed of the turbine. Instead of disconnecting the generator from the battery (like most PV controllers) it diverts excess energy to a special load that absorbs most of the power from the generator. That load is usually a heating element, which “burns off” excess energy as heat. If you can put the heat to good use, fine!

Is It Working?

How do you know if a controller is malfunctioning? Watch your voltmeter as the batteries reach full charge. Is the voltage reaching (but not exceeding) the appropriate set points for your type of battery? Use your ears and eyes—are the batteries bubbling severely? Is there a lot of moisture accumulation on the battery tops? These are signs of possible overcharge. Are you getting the capacity that you expect from your battery bank? If not, there may be a problem with your controller, and it may be damaging your batteries.

Control Your Charge!

The control of battery charging is so important that most manufacturers of high quality batteries (with warranties of five years or longer) specify the requirements for voltage regulation, low voltage disconnect, and temperature compensation. When these limits are not respected, it is common for batteries to fail after less than one quarter of their normal life expectancy, regardless of their quality or cost.

A good charge controller is not expensive in relation to the total cost of a power system, nor is it very mysterious. I hope this article has given you the background that you need to make a good choice of controls for your power system.

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