Chapter 7

Charge Controllers

Types and Characteristics ● Functions and Features ● Specifications and Ratings ● Sizing
Overview

- Explaining the purpose for battery charge control in PV systems.
- Describing the primary functions and features of charge controllers.
- Classifying the different types of controller switching designs and charging algorithms.
- Selecting appropriate charge control set points based on the types of batteries and controllers used.
- Identifying the key specifications and ratings for charge controllers and their application in circuit design.
A charge controller is required in most PV systems that use battery storage to regulate battery state-of-charge, optimize battery and system performance, and help prevent damage to the batteries or hazardous conditions resulting from the charging process [690.72(A)].

- Charge controller protects battery from overcharge by PV array
Typical Charge Controllers

- Morningstar ProStar controller
- Morningstar TriStar controller
- Outback MPPT controller
- Xantrex C-series controller
- Morningstar lighting controller
Functions of charge controllers include:
- Battery overcharge and/or overdischarge protection
- Control of loads or other energy sources

Features of charge controllers include:
- Type of switching and control algorithm
- Temperature compensation
- Equalization charging
- Meters and indicators for system status and operating information
Overcharge Protection

Charge controller protects battery from overcharge by PV array

PV Array → Charge Controller → Battery

Battery is not protected from overdischarge by load.

DC Load
Overdischarge Protection

This controller protects battery from overcharge

This controller protects battery from overdischarge

PV Array → Charge Controller → Load Controller → DC Load

Battery
Charge Controller Designs

- **Array switching:**
  - Shunt type
  - Series type

- **Regulation algorithm:**
  - On-off (interrupting)
  - Single- or multi-stage
  - Linear or constant-voltage
  - Pulse-width-modulated (PWM)
  - Array maximum power point tracking (MPPT)
  - Diversionary control
Shunt Charge Controller

- **PV Array**
- **Blocking Diode**
- **Regulation Control**
- **Shunt Element**
- **Battery**
- **LVD Control**
- **Load Switching Element**
- **DC Load**
Shunt Charge Controller Using Zener Diode

Diagram:
- PV (solar panel) connected to R1
- D1 (diode) connected to Battery
- D2 (diode) connected to Load
- R1 is a series resistor
Series Type Controller

PV Array → Series Element → Battery → Load Switching Element → DC Load

- Series Element
- Load Switching Element
- PV Array
- Battery
- DC Load

Regulation Control
LVD Control
Increasing battery state-of-charge >>

Battery current >

Time >
Maximum Power Point Tracking Charge Controllers

- MPPT charge controllers operate the PV array at maximum power, independent of the battery voltage.

- Can improve array energy utilization, and permit the use of more efficient higher-voltage arrays with lower battery system voltages.
This controller protects the battery when the diversion load is unavailable.

Diversionary controller protects the battery from overcharge by diverting power to a diversionary load.
PV systems with using diversionary charge control and DC diversion loads must meet the following requirements [690.72(B)(2)]:

- The DC diversion load current must be no greater than the controller maximum current rating.
- The DC diversion load must have a voltage rating greater than the maximum battery voltage.
- The DC diversion load power rating must be rated at least 150 percent of the maximum PV array power output.
- The conductors and overcurrent protection for DC diversion load circuits must be sized for at least 150 percent of controller maximum current rating.
PV systems with using interactive inverters as diversionary loads to control battery charging must have a second independent charge control means to protect the battery if the inverter fails or the grid becomes unavailable to divert power [690.72(B)(3)].

This controller protects the battery when the grid is unavailable.

The inverter normally protects the battery from overcharge by diverting power to the grid.

Power may flow in reverse directions if inverter also includes a battery charger.
Set points are the battery voltage levels at which a charge controller performs regulation or control functions, and are critical parameters affecting battery life and system performance.

Charge regulation set points protect a battery from overcharge and optimize charging.
- Voltage regulation (VR)
- Array reconnect voltage (ARV) – only applies to interrupting controllers

Load control set points limit allowable battery depth-of-discharge by disconnecting system loads.
- Low voltage disconnection (LVD)
- Load reconnect voltage (LVR)
Charge Controller Set Points

- Voltage Regulation (VR)
- Voltage Regulation Hysteresis (VRH)
- Array Reconnect Voltage (ARV)
- Load Reconnect Voltage (LRV)
- Low Voltage Disconnect Hysteresis (LVDH)
- Low Voltage Load Disconnect (LVD)
# Charge Regulation Setpoints

<table>
<thead>
<tr>
<th>Regulator Design Type</th>
<th>Battery Type</th>
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<tbody>
<tr>
<td></td>
<td>Flooded Lead-Antimony</td>
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<tr>
<td></td>
<td>Flooded Lead-Calcium</td>
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<td></td>
<td>Sealed, Valve Regulated Lead-Acid</td>
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<tr>
<td></td>
<td>Flooded Pocket Plate Nickel-Cadmium</td>
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<tr>
<td>Charge Regulation Voltage at 25°C</td>
<td>Per nominal 12 volt battery</td>
</tr>
<tr>
<td></td>
<td>Per Cell</td>
</tr>
<tr>
<td>On-Off, Interrupting</td>
<td>14.6 - 14.8</td>
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<tr>
<td></td>
<td>14.2 - 14.4</td>
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<tr>
<td></td>
<td>14.2 - 14.4</td>
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<tr>
<td></td>
<td>14.5 - 15.0</td>
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<td></td>
<td>2.44 - 2.47</td>
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<td>2.37 - 2.40</td>
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<td></td>
<td>2.37 - 2.40</td>
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<tr>
<td></td>
<td>1.45 - 1.50</td>
</tr>
<tr>
<td>Constant-Voltage, PWM, Linear</td>
<td>14.4 - 14.6</td>
</tr>
<tr>
<td></td>
<td>14.0 - 14.2</td>
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<td></td>
<td>14.0 - 14.2</td>
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<tr>
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<td>2.40 - 2.44</td>
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<tr>
<td></td>
<td>1.45 - 1.50</td>
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</tbody>
</table>
Low-voltage disconnect (LVD) set points are selected based on the desired battery depth-of-discharge and discharge rates.

High discharge rates (current) will lower battery voltage by a greater amount than lower discharge rates at the same battery state-of-charge.

For a typical lead-acid cell, a LVD set point of 1.85 to 1.91 VPC corresponds to a depth-of-discharge of 70 to 80% at discharge rates C/20 and lower.
Some charge controllers can provide manual or automatic equalizing charge functions.

Charge regulation voltage is periodically increased for a certain period of time to equalize battery cells.

Equalizing charge is typically performed on flooded, vented batteries, and some types of AGM batteries.
Set Point Adjustments

- Means for charge controller adjustment must only be accessible to qualified persons [690.72(A)].
Temperature Compensation

- Temperature compensation adjusts charge regulation voltage based on battery temperature.
  - Increases regulation voltage when battery is cold, improving ability to charge battery.
  - Decreases regulation voltage when battery is warm, decreasing electrolyte loss and battery overcharge.

- The standard temperature compensation coefficient for lead-acid cells is -5 mV/°C.
Temperature Compensation Sensors
A charge controller for a nominal 24-volt VRLA battery has a regulation voltage of 28.2 volts at 25°C. What should the charge regulation voltage be if the battery operates at 0°C?

\[ V_{\text{comp}} = V_{\text{set}} - (C_{\text{cell}} \times [25 - T_{\text{bat}}] \times n_s) \]

\[ V_{\text{comp}} = 28.2 - (-0.005 \times [25 - T_{\text{bat}}] \times 12) \]

\[ V_{\text{comp}} = 28.2 + 1.5 = 29.7 \text{ V} \]

Conversely, if the battery temperature is 40°C, the charge regulation voltage will be reduced to 27.3 volts.
Three-Stage Charging

- **Bulk Stage**
  - Increasing Voltage
  - Maximum Charge Current

- **Absorption Stage**
  - Bulk Charge - Constant Voltage
  - Reducing Absorption Current

- **Float Stage**
  - Float Voltage
  - Float Current

**Battery Voltage**

**Battery Current**

**Time**

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Multiple Charge Controllers

PV Subarray #1 -> Charge Controller #1
PV Subarray #2 -> Charge Controller #2
PV Subarray #3 -> Charge Controller #3
PV Subarray #4

One subarray may be directly connected to battery without charge control if charge current x 1 hr is less than 3% of battery capacity.

Battery

DC Load

Note: No overdischarge protection shown.
Battery voltage sense leads are available on some charge controllers to counter the effects of voltage drop on charge regulation set points.
Self-regulating PV systems operate without charge battery charge control. Certain design requirements help ensure that the battery is neither overcharged nor overdischarged.

- PV maximum charge current x 1 hour must be less than 3% of the battery capacity. Lower voltage modules are typically used for self-regulating effect.
- Battery must be oversized in relation to PV array charge rates and load energy.
- Load must be well-defined, operate daily and not subject to user control.
Self-regulating PV systems use lower-voltage PV modules to naturally limit the array current as battery voltage increases.

**Diagram:**
- **High-Voltage Module:**
  - Current remains high over battery voltage range
- **Low-Voltage Module:**
  - Current limits as battery voltage increases

**Legend:**
- $I_{sc}$: Short-circuit current
- $I_{mp}$: Maximum power point current
- $V_{mp}$: Maximum power point voltage
- $V_{oc}$: Open-circuit voltage
- Battery voltage range
Electrical ratings for charge controller are used to properly specify equipment and size circuits and include:

- Nominal and maximum PV array and battery voltages.
- Maximum and continuous PV array and load currents.

Charge controllers used in PV system must be listed to UL 1741.
Conductors, overcurrent protection devices and other equipment must normally be sized for at least 125% of the maximum PV output circuit current, or 156% of the short-circuit current for the PV output circuit [690.8].

For example, a PV array with rated short-circuit current of 16 A requires a charge controller with at least a 24 A continuous rating (16 A x 156%). The conductors in the PV output circuit must be sized for at least 24 A after deratings for conditions of use have been applied.
Charge controllers are used to protect batteries from overcharge and may perform other system functions.

There are a variety of charge controller designs and regulation methods.

Charge controller set points trigger functions such as charge regulation or load control, and are key to maximizing battery health and system performance.

Listed charge controllers are rated for certain electrical parameters that are used to properly size the controller for specific system applications.
Questions and Discussion