

# Lead-Acid Battery State of Charge vs. Voltage

Richard Perez

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**A** battery voltmeter is the most basic system instrument. Battery voltmeters are inexpensive, easy to install, and can provide a wealth of system information to renewable energy users, RVers, or anyone who depends on a battery.

## Why a Voltmeter?

Ten years ago, voltmeters were all we had for information about our systems. Ampere-hour meters that calculated battery efficiency were a pipe dream. Even now, small systems cannot justify the additional expense and complexity of the new sophisticated battery state of charge (SOC) instruments. I still use a homebrew battery voltmeter in addition to our hi-tech instruments like the Cruising Amp-hour meter, the SPM 2000, and the Power Monitor 15. The voltmeter is always there, consumes virtually no power, and tells me at a glance what's happening with our system.

Reading a battery voltmeter and turning that information into a reliable assessment of the battery's state of charge is like tracking an animal by its footprints. Tracking requires noticing small details and extrapolating information from these details. A tracker uses his knowledge of the animal's habits. A tracker considers the weather and season. A tracker's knowledge of his subject and its environment allows him to predict the actions of his subject.

After watching the voltmeter for a few of the battery's charge/discharge cycles, the user gets a idea of his battery's voltage profiles. After watching the voltmeter for a season or two, the user learns how to relate the

effects of temperature and current on his battery's voltage. Just like the behavior of animals vary with type and location, the behavior of batteries differ with type and operating environment.

## What Kind of Voltmeter?

It really doesn't matter what type of voltmeter you use to measure your battery's voltage. Better instruments yield more accurate measurements with higher resolution. Differences in battery voltage of 0.1 VDC are significant, so the instrument should have a basic accuracy at least 0.5% or better. Accurate analog battery voltmeters can be purchased for under \$40. Digital multimeters cost from \$40 to \$300 and perform highly accurate voltage measurements and much more besides. Or you can homebrew an expanded scale analog battery voltmeter, see HP #35, Page 92. You can homebrew an LED Bat-O-Meter, see HP #10, Page 26. Any of these instruments will give you the voltage measurement you need.

Installation of a battery voltmeter is easy. Just connect it to the battery's main positive and negative buss or terminals. Be sure to get the polarity right because analog meters can be damaged by reverse polarity. Since the battery voltmeter consumes very little power, the wires feeding it can be small (18 gauge copper or smaller).

## Reading the Curves

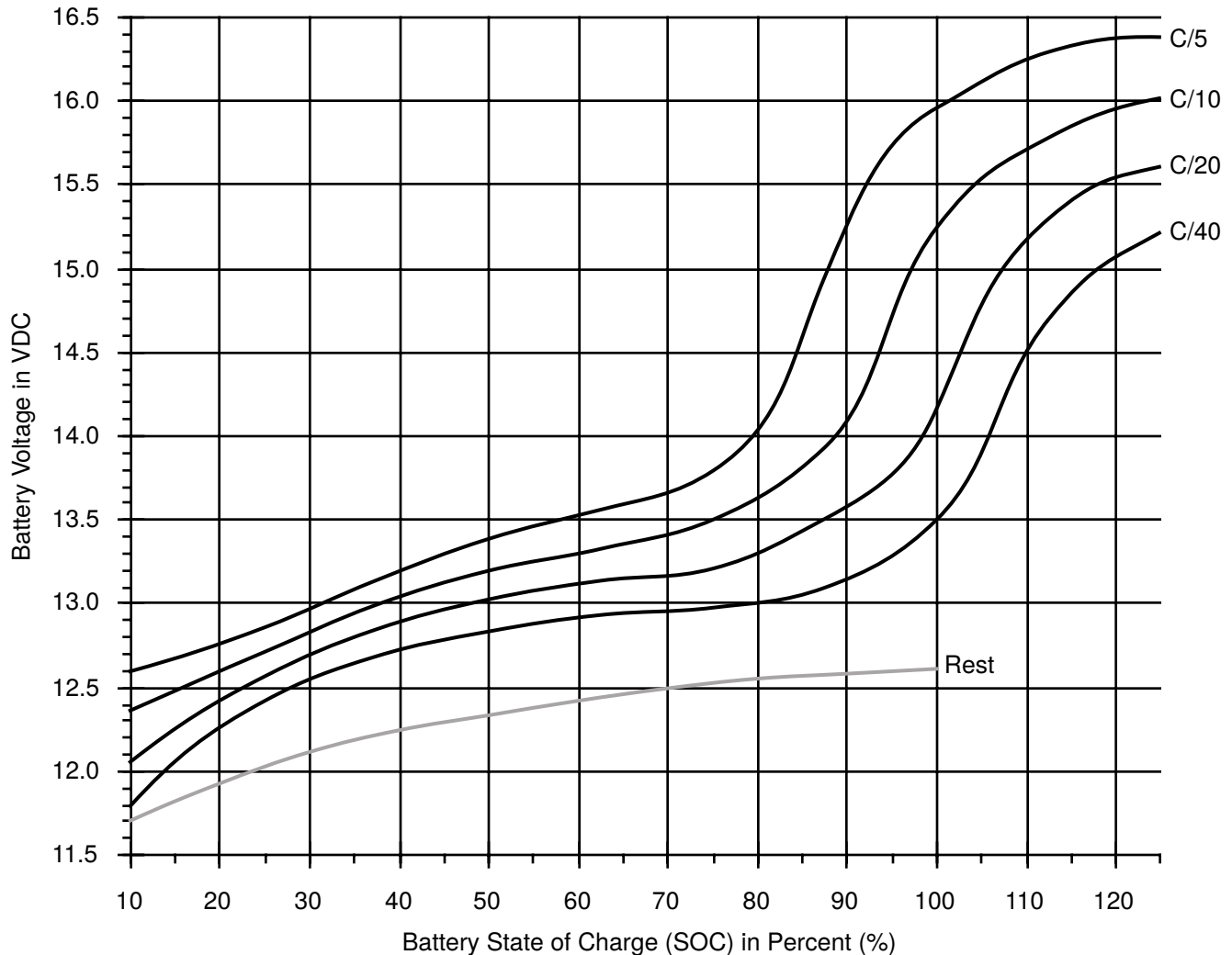
The data presented here on the graphs was generated from our set of Trojan L-16W deep cycle lead-acid batteries. Each Trojan L-16 battery is composed of three series connected, 350 Ampere-hour, lead-acid cells. The graphs and the data here relates to six of these lead-acid cells in series forming a 12 Volt battery. Those of you using a 24 Volt system with twelve lead-acid cells in series must multiply the voltage in the text and on the charts by two. The voltage versus state of charge (SOC) profiles will match those of similarly constructed cells. Other types of lead acid cells, like car batteries, lead-calcium cells, and "RV deep cycle" batteries will have different charge/discharge curves. I offer these graphs as examples of what to look for with your battery. While specific voltage vs. SOC points will vary from battery type to battery type, the shape and relationship of the curves is similar for all deep cycle lead-acid technologies.

## Current and Batteries and Ohm's Law

Battery voltage can be affected by three factors — state of charge, current, and temperature. State of charge is what we are trying to find out, so that leaves current and temperature as factors to reckon with.

Current means the rate of electron flow through the battery caused by either charge or discharge. Every

### 12 Volt Lead Acid Battery State of Charge (SOC) vs. Voltage while battery is under charge



electrochemical cell has internal resistance. As current moves through the cell, the cell's voltage changes because of this internal cell resistance. When the cell is being recharged, current flow causes the cell's voltage to rise. The higher the recharging current the higher the voltage rise. As the cell is discharged, the discharging current causes the cell's voltage to drop. The higher the discharging current, the greater the battery's battery depression. This holds true for all electrochemical cells regardless of type, size, or environment. While absolute values vary widely between different acid and alkaline technologies, the relationship between current flow and cell voltage remains constant.

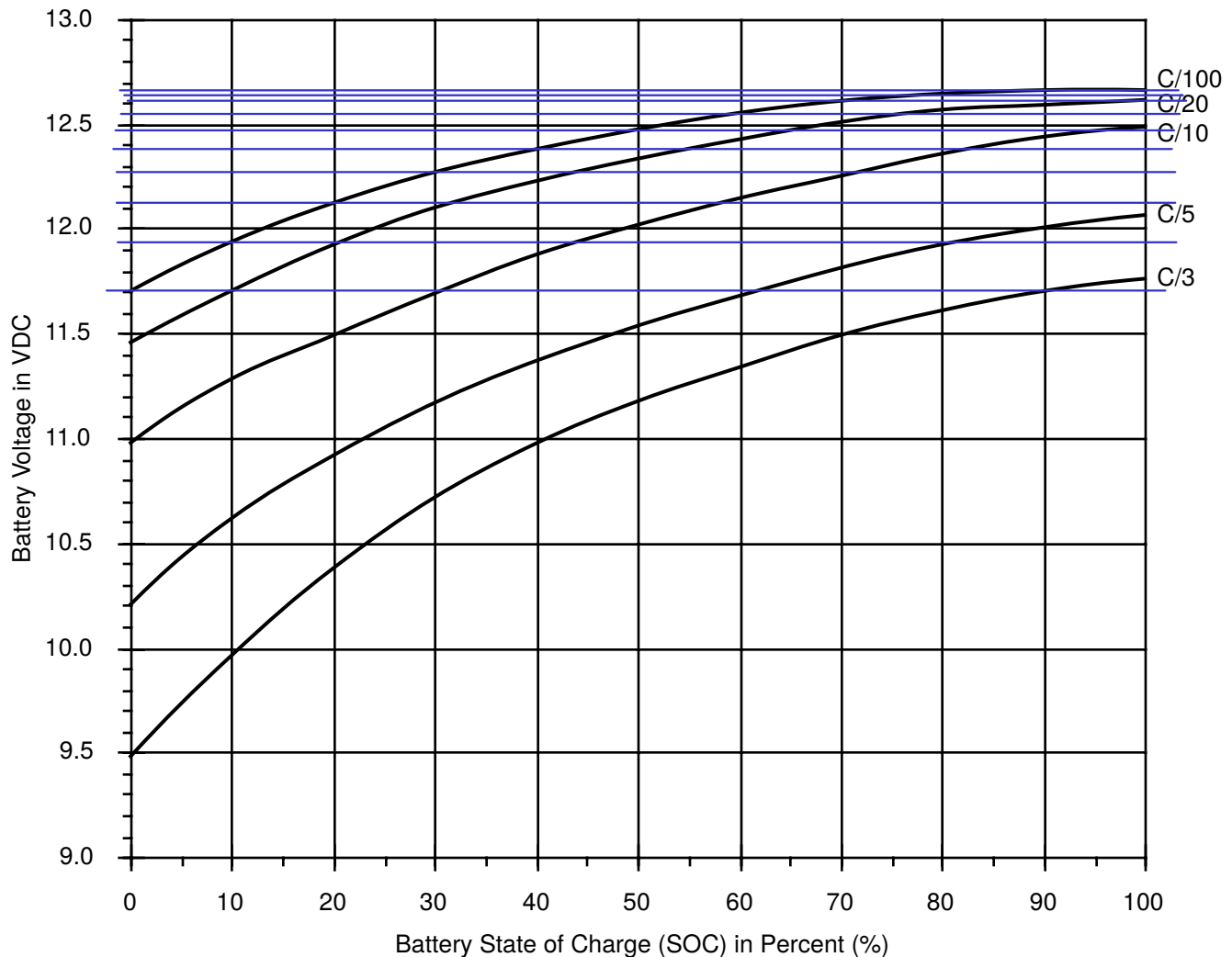
The graphs show a variety of recharge and discharge rates from C/5 to C/100. This C/XX number is actually a rate of charge or discharge in Amperes proportioned to the capacity of the battery. For example, consider a battery of 100 Ampere-hours. If you divide this Ampere-

hour capacity by 10 hours, then you get a charge (or discharge) rate of 10 Amperes. Ten Amperes is a C/10 charge (or discharge) rate for a 100 Ampere-hour battery. Consider another battery of 500 Ampere-hours capacity. Here a C/10 rate would be 50 Amperes. While the absolute values of the charge (or discharge) currents is different between the two batteries of different capacity, their effect on the battery's voltage is the same. The currents are in the same proportion to the batteries capacity.

If voltage is to be related to battery state of charge, then we must compensate for voltage variation due to current movement through the battery. Hence there are a variety of curves on both the charge and discharge graphs.

Included on the charge graph is a gray curve entitled "Rest". This rest curve is a generic representation of six

### 12 Volt Lead Acid Battery State of Charge (SOC) vs. Voltage while under discharge



lead-acid cells in series *and* at Rest. "At Rest" means that *no* current is moving through the cells, i.e., that they are neither being charged or discharged. Determining a battery's state of charge from voltage measurement is vague enough if current is moving through the battery. The vagaries increase exponentially if *no* current is moving through the battery. This is why this curve is gray.

#### Temperature and Batteries

The lead acid reaction is temperature sensitive. Cooling the cell changes its voltage vs. SOC profile. As the lead-acid battery cools, its internal resistance increases. This means that voltage elevation under recharging is increased in cold cells. The same internal resistance increase produces increased voltage depression in cold cells when discharged.

At 32°F (0°C), the effect of temperature becomes

pronounced enough to distinctly change not only the battery voltage vs. SOC profile, but also its useful Ampere-hour capacity. The discharge voltage curves may be depressed by as much as 0.5 VDC from those shown on the graph. Charge voltages will be elevated by as much as 0.5 VDC for a cold 12 Volt lead-acid battery.

#### Lead-acid Internal Resistance and SOC

In lead-acid cells, the electrolyte (sulfuric acid) participates in the cell's normal charge/discharge reactions. As the cells are discharged, the sulfate ions are bonded to the plates — sulfuric acid leaves the electrolyte. The process is reversed when the cell is recharged.

A fully charged lead-acid cell has an electrolyte that is a 25% solution of sulfuric acid in water (specific gravity about 1.26). A fully discharged lead-acid cell has

virtually no sulfuric acid in its almost pure water electrolyte (specific gravity about 1.00). As the sulfuric acid concentration in the electrolyte changes so does the electrical resistance of the electrolyte, which in turn changes the internal resistance of the entire cell.

The bottom line is that the internal resistance of all lead-acid cells changes with the cell's state of charge. This characteristic gives the lead-acid reaction its particular shape or signature on the voltage vs. SOC graphs. This signature is unique — very different from alkaline cells whose electrolyte resistance remains constant regardless of SOC. The shape of the lead-acid curves makes it possible to use a voltmeter to determine a battery's state of charge.

#### Reading the Tracks

The more you understand the relationship between battery voltage and real life events like current movement and temperature, the more information transferred by a simple voltage measurement. Your battery savvy here is worth more than a \$400 voltmeter.

#### Access

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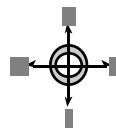
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**12 Volt Lead-Acid Battery Chart- 78°F.**