A Rule-of-Thumb for Estimating Battery Charge from Measurement of Open-Circuit Voltage

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With traditional lead-acid batteries, measuring the specific gravity (density) of the electrolyte using a hydrometer provided a good indication of battery charge. With modern “sealed” batteries, no such measurement is possible. This paper describes a method for quickly estimating battery charge from a measurement of open-circuit voltage. The method was derived from published tables relating charge, voltage and temperature. The resulting rule can be summarized as:

"For every .01 volt drop in temperature-corrected, open-circuit, rest-state voltage, a lead-acid battery has lost about 1.2% of its original charge."

The problem: no easy way to measure charge in sealed batteries

With traditional automotive batteries, the easiest way to measure state-of-charge (SOC) — the remaining percentage of a battery’s original amp-hour capacity — is to test the electrolyte’s specific gravity. This is a fairly accurate method, especially when corrected for temperature.

Today’s sealed "no maintenance" batteries (flooded cell, Gel or AGM) offer no way to test specific gravity. This drawback can be pretty significant, especially going into a winter. There are published graphs and tables that relate SOC to battery voltage and to temperature, but using these can be very inconvenient. A “carry around in your head” substitute for the graphs and tables is developed below.

Relationship of battery voltage to state-of-charge

As with electrolyte density, a lead-acid battery’s open-circuit voltage depends on SOC. An established method to determine SOC from open-circuit voltage and from tabulated data uses these steps:

1) Measure the battery's rest-state, open-circuit voltage (see ”Measurement Practices” below),
2) Correct for temperature (using tabulated data),
3) Subtract this temperature-corrected voltage from the battery's full-charge voltage (from tabulated data or a manufacturer spec.),
4) Convert the voltage decrease, if any, to a loss-of-charge percentage (from tabulated data).

The battery's SOC equals 100% minus this loss-of-charge percentage.

Our objective here is to create a rule-of-thumb to replace all the tabulated data: To find such a rule, published data for full-charge voltages, voltage-v.-charge relationships, and voltage-v.-temperature relationships were examined. The primary data source used was www.batteryfaq.org. Note: The data presented at batteryfaq.org seemed to me the best supported among many websites. But values reported for each data item vary somewhat from site to site. Use of data from other websites would produce a slightly different rule than that developed here.

The following values and relationships were found in the data:
Full-charge, open-circuit voltages for batteries at 80 deg. F. are:
- **12.80** volts for sealed batteries, including AGM (absorbed glass mat) batteries.
- **12.65** volts for non-sealed (traditional or low-maintenance) batteries.

(Manufacturer-specified values for a specific battery, if known, should be used instead.)

At constant temperature, open-circuit voltage decreases by about **0.01 volt for every 1.2% loss of charge** (most accurate in the range 50%-100% of original charge).

Temperature effects on voltage are well approximated by:

<table>
<thead>
<tr>
<th>Temperature (deg. F)</th>
<th>Voltage Correction (volts)</th>
</tr>
</thead>
<tbody>
<tr>
<td>90</td>
<td>subtract .01 volts from measured voltage</td>
</tr>
<tr>
<td>70</td>
<td>none</td>
</tr>
<tr>
<td>50</td>
<td>add .03 V</td>
</tr>
<tr>
<td>30</td>
<td>add .06 V</td>
</tr>
<tr>
<td>0</td>
<td>add .13 V</td>
</tr>
</tbody>
</table>

Instead of referring to all the tabulated data, we can use these relationships to estimate SOC from measured voltage, as detailed in the following.

**Practices: measurements and SOC estimates**

Estimating SOC does not require reference to tabulated data; it requires remembering only:
- the battery's full-charge **voltage** (known or estimated),
- the relationship: voltage decreases by **0.01 volt for each 1.2% loss of charge**.
- a rule for **temperature** correction (need not be precise),

Just as when using tabulated data, the four steps for making an SOC estimate are … **measure** voltage, **correct** for temperature, **subtract** from full-charge voltage, **relate** voltage decrease to loss of charge. Practices for these steps are as follows:

1) **Measure** the battery's voltage, under open-circuit conditions, after a "rest" period of **at least 4 hours and preferably 8 hours** without charging or discharging the battery. **Without a rest period, voltage is a misleading indicator of charge.** To get a reliable charge estimate, voltage must be measured to the nearest .01 volt using a digital voltmeter. This is so because large changes in SOC produce only small changes in voltage. (The small current drain occurring with the battery installed in most modern cars can be considered an open-circuit condition for our purposes.) Typical measurement: 12.25 to 12.80 volts.

2) **Correct** the measured voltage for temperature using some approximation to the table shown above. Because temperature effects are relatively small, in most cases only a small error is introduced by using some easy-to-remember rule. Example: hot or warm day, no correction; 50 deg, add .03 V; around freezing; add .06 V.

3) **Subtract** this temperature-corrected voltage from the full-charge value for the battery being tested (12.80 V, 12.65 V, or manufacturer spec’). Typical values after this step range from 0.00 to 0.40 volts.

4) Using the relationship of 1.2% loss of charge per .01 volt, calculate …

\[
SOC = 100\% - [1.2\% \times \text{adjusted voltage decrease in units of .01 volt}].
\]

Typical results are in the range of 50% to 100%.
This result can be stated as …

For every .01 volt drop in temperature-corrected, open-circuit, rest-state voltage, a lead-acid battery has lost about 1.2% of its original charge.

With careful measurement this method can be accurate to ~5 % for batteries holding at least 50% of their original charge … if the battery’s original, full-charge voltage is known. (This is the weakest link in estimating absolute SOC from voltage. Unless we test a battery when new, or have a manufacturer’s spec, we must rely on estimates for full-charge voltage. Perhaps of more value, this method makes it possible to monitor SOC over time, and to detect changes as small as a few percent.)

*Note*: the result doesn’t say whether the battery under test is or is not capable of holding additional charge (e.g. if put through a charging routine). It just tells us the current SOC.

### Example of an SOC Estimate

A measurement of the 4 1/2 year-old maintenance-free battery in my XK8 on a cold morning:

- battery’s (assumed) full-charge voltage = 12.80 V
- measured voltage = 12.37 V
- temperature ~ 30 deg. F
- temperature-corrected voltage (add .06 volts) = 12.43 V
- voltage decrease from full-charge value = 12.80 - 12.43 = 0.37 V
- estimated SOC = 100% - (1.2% x 37) = 56%

The measurement says that this battery, in its current state, no longer contains its original charge of 100 amp-hours, but only about 56 amp-hours. If charging does not improve the SOC of such a battery, then it may be nearing the end of its useful life.

### Comparison to Load Testing

The best of devices called “load testers” will produce the most accurate measurement of battery charge. But not all devices identified as load testers are so accurate, and some can actually be misleading. A load test providing only a pass/fail result is of little value. (An internet search provides lots of information about this.) The voltage-based method described here is about as accurate as the traditional hydrometer-based method of determining battery charge, which was widely used with non-sealed batteries.

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