State of charge

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State of charge (**SOC**) is the equivalent of a fuel gauge for the battery pack in a battery electric vehicle (BEV), hybrid vehicle (HV), or plug-in hybrid electric vehicle (PHEV). The units of SOC are percentage points (0% = empty; 100% = full). An alternate form of the same measure is the **depth of discharge** (**DoD**), the inverse of SOC (100% = empty; 0% = full). SOC is normally used when discussing the current state of a battery in use, while DoD is most often seen when discussing the lifetime of the battery after repeated use.

Contents

Determining SOC

Usually, SoC cannot be measured directly but it can be estimated from direct measurement variables in two ways: offline and online. In offline techniques, the battery desires to be charged and discharged in constant rate such as Coulomb-counting. This method gives precise estimation of battery SoC, but they are protracted, costly, and interrupt main battery performance. Therefore, researchers are looking for some online techniques.[1] In general there are five methods to determine SOC indirectly:[2] [3]

- chemical
- voltage
- current integration
- Kalman filtering
- pressure

Chemical method

This method works only with batteries that offer access to their liquid electrolyte, such as non-sealed lead acid batteries. The specific gravity or pH of the electrolyte can be used to indicate the SOC of the battery.

Hydrometers are used to calculate the specific gravity of a battery. To find specific gravity, it is necessary to measure out volume of the electrolyte and to weigh it. Then specific gravity is given by (mass of electrolyte [g]/ volume of electrolyte [ml])/ (Density of Water, i.e. 1g/1ml). To find SOC from specific gravity, a look-up table of SG vs SOC is needed.

Voltage method

This method converts a reading of the battery voltage to SOC, using the known discharge curve (voltage vs. SOC) of the battery. However, the voltage is more significantly affected by the battery current (due to the battery's electrochemical kinetics) and temperature. This method can be made more accurate by compensating the voltage reading by a correction term proportional to the battery current, and by using a look-up table of battery's open circuit voltage vs. temperature.

In fact, it is a stated goal of battery design to provide a voltage as constant as possible no matter the SOC, which makes this method difficult to apply.

Current integration method

This method, also known as "coulomb counting", calculates the SOC by measuring the battery current and integrating it in time. Since no measurement can be perfect, this method suffers from long-term drift and lack of a reference point: therefore, the SOC must be re-calibrated on a regular basis, such as by resetting the SOC to 100% when a charger determines that the battery is fully charged (using one of the other methods described here).

Combined approaches

Maxim Integrated touts a combined voltage and charge approach that is claimed superior to either method alone; it is implemented in their ModelGauge m3 series of chips, such as MAX17050,[4][5] which is used in the Nexus 6 and Nexus 9 Android devices, for example.[6]

Kalman Filtering

To overcome the shortcomings of the Voltage method and the Current integration method, a Kalman filter can be used. The battery can be modeled with an electrical model which the Kalman filter will use to predict the over-voltage, due to the current. In combination with coulomb counting, it can make an accurate estimation of the state of charge. The strength of a Kalman filter is that it is able to adjust its trust of the battery voltage and coulomb counting in real time.[7][8]

Pressure method

This method can be used with certain NiMH batteries, whose internal pressure increases rapidly when the battery is charged. More commonly, a pressure switch indicates if the battery is fully charged. This method may be improved by taking into account Peukert's law which is a function of charge/discharge rate or ampere.

See also

- Battery balancing
- Battery balancer
- Battery charger
- Battery management system (BMS)
- Battery monitoring
- Depth of discharge (DOD)
- State Of Health (SOH)

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