

New Sensor Technology for Total Battery Management

Whenever a battery is used as a critical source of energy such as with uninterruptible power supplies (UPS), electric vehicles (EV), hybrid electric vehicles (HEV) and mobile life support equipment, it is essential that the user has complete confidence in the battery's ability to deliver its expected amount of energy. It is also important that the user can have faith in the battery status display. Raztec recognised this gap in current sensing technology some years back, and have recently developed a device specifically tailored for measuring battery current for battery management purposes. **Warren Pettigrew, CTO Raztec Sensors, Christchurch, New Zealand**

In practice it has been remarkably difficult to accurately determine the state of health (SOH) and the true state of charge (SOC) of a battery. There is just such a big stack-up of variables. However, with good and appropriate sensing technology and the use of refined algorithms appropriate for the chemistry, it is now possible to compute reliably the SOH and SOC of a battery.

With most battery applications, the fundamental issue is simply the minimisation of the cost of operation. So much the better if battery life can be extended by predictive maintenance and the charging programme monitored to assure correctness (very commonly batteries are destroyed through incorrect charging techniques). Cost of operation is very much linked to the cost of failure – failure for the battery to deliver its power when vitally needed. It is much better to replace or repair the battery before it fails when the SOH monitor predicts the need.

Additionally, the battery management system may be required to protect the battery or its load from overload, as well as to generate alarms if parameters fall outside prescribed safety windows.

Variables for SOC determination

Monitoring the cell/battery voltage is a common, simple, but inaccurate method. Many variables overlay the voltage/capacity relationship:

- If it is to be measured during discharge, then battery resistance must be considered - but resistance is capacity, time and temperature dependant.
- Cell voltage is temperature dependant.
- There is a memory/hysteresis effect after charge/discharge with a logarithmic approach to a settling voltage.
- Newer high performance batteries such

as Lithium Ion have a very flat charge discharge characteristic such that temperature effects dominate cell voltage changes.

- Battery voltage changes as a battery ages and its cycle count increases.
- Generally, there is inequality of individual cell performance.

Net coulomb count: One may believe that a battery will give up the ampere-hours (Ah) that are put into it. But this is far from the case. Many batteries will give up less than half their capacity under fast discharge - with some chemistries and structures behaving worse or better than others. This effect also applies for charging. You never get out the Ah that are put in. Again, temperature is a dominate variable with many batteries performing very poorly indeed at low temperature.

Battery impedance: There is a reasonably consistent relationship between SOC and battery impedance. The impedance measurement may be a steady-state DC impedance or an impedance measured under AC conditions. The algorithm has to be calibrated for a particular chemistry, structure, capacity and manufacturer and is still affected by the usual gambit of variables.

Specific gravity measurement: This is only applicable for batteries that have a free electrolyte. This method can give reasonable results provided the system is pre-calibrated and temperature is considered. It is also important that the electrolyte is stirred, with stratification being a common problem.

Variables for SOH determination

Capacity: Rarely possible to measure this during normal usage.

Cycle count: When used according to

specification, batteries have a design discharge/charge cycle count with the depth of discharge thrown in as a modifier. For a battery subjected to cyclic usage this method may be appropriate but it does not accommodate abuse or faulty cells.

Impedance measurement/ripple voltage: As a battery ages, its DC and AC impedance rises in a fairly predictable manner so a number of SOH measurement products are based on this means. The product has to be calibrated for a particular battery and indications are diluted if only one cell of a long string begins to fail.

Float/leakage current: The float current for a particular voltage and temperature is a good indicator of SOH. This parameter increases as the battery ages and also increases as the result of a number of failure mechanisms. The challenge is its actual measurement.

Individual cell temperature: A battery which has all its cells at equal temperature during charge and discharge is probably in good health. Again this technique is more appropriate for cyclic usage.

Individual cell voltage: A battery without a cell equalisation strategy which has good equality of voltage down the string is likely to be in good health. Effectively though, this is a measure of leakage or float current for each cell.

Electrolyte monitoring: Where a battery has free electrolyte, specific gravity and electrolyte level trends can be monitored to give an indication of battery and cell SOH. This technology being more appropriate for larger battery sets and where cost of failure is high such as in nuclear power stations.

How do battery monitors operate?

Because of the seemingly impossible number of variables, the best approach is

to build a mathematical model of the battery based on parameter measurement and real life experience. The model then operates by sensing as a very minimum:

- Battery voltage including ripple voltage
- Battery current including ripple current
- Battery temperature
- Real time.

Additionally, it could also sense:

- Cell voltage
- Cell temperature
- Ambient temperature
- Cycle count
- Specific gravity and electrolyte level
- Connection resistance
- Ground fault current.

The model must accommodate:

- Battery chemistry and structure
- Capacity
- Cell count
- Temperature dependencies
- Affect on capacity of charge/discharge current
- Self-discharge parameters
- Charge/float voltages.

This all adds up to a very complex machine, highly dependant on software algorithms rather than hardware, but there are some measurement issues particularly of current.

Measurement issues

In order to assure reliability of a battery which has more than about 10 cells in series, it is desirable to monitor cell voltage and also force cell equalisation. This adds significantly to hardware costs but can greatly improve battery reliability and life.

Cell equalisation can be via cell current extraction or addition. Subtraction being the easier to manage. This is effectively forcing equal cell self discharge.

Individual cell temperature monitoring is also worthwhile, as one hot cell indicates conclusively a problem. Again, all this is hardware intensive.

Finally, we have battery current sensing. With reliable current sensing it is possible to

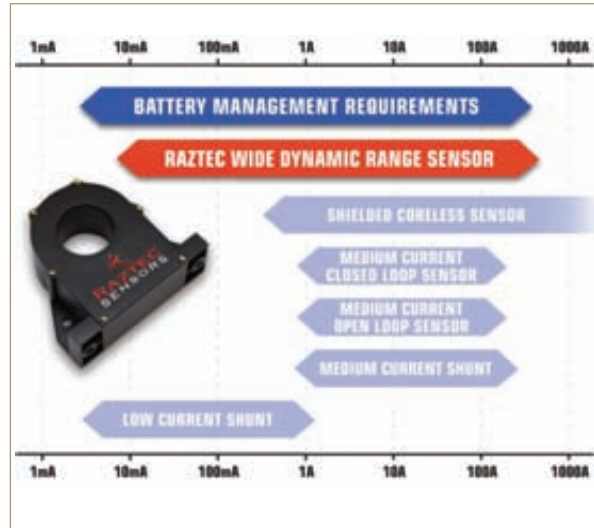


Figure 1: Current range and appropriate sensors for battery management

measure the following parameters:

- Coulomb count
- Ripple current
- Float current
- Charging current
- Discharge current
- Earth leakage current
- Ohmic resistance
- Connection resistance.

Current measurement techniques

Figure 1 outlines the current range and appropriate sensors for battery management. The simplest way to measure current is by using a shunt, however, shunts have a number of

shortcomings: A shunt that is required to measure both high and low currents will generate considerable heat at high current levels. A shunt has to break the battery circuit. In other words, an intrusive connection which is often not desirable. Shunt output voltage often has a very poor signal to noise ratio. Shunts are incapable of measuring the dynamic range of float currents and discharge currents.

Another method is to use Hall-effect current sensors – either open or closed-loop. These sensors are non-intrusive, so don't have the noise issues of shunts, but traditionally don't give the dynamic range as they can't accurately measure currents much less

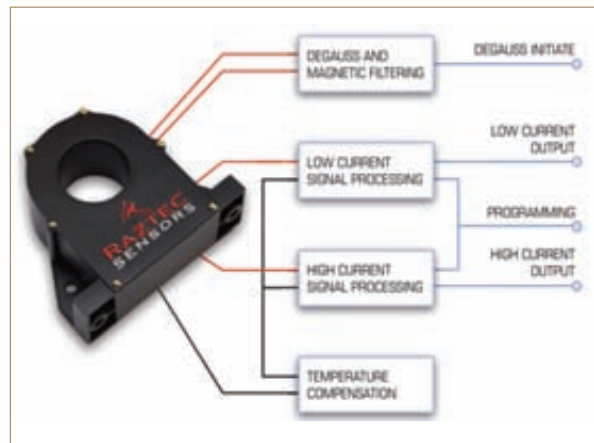


Figure 2: Wide dynamic range current sensor basis structure

PRELIMINARY SPECIFICATION	DIGITAL SENSOR	ANALOGUE SENSOR
Current range ¹	<10mA – 400A+	<10mA – 600A+
Resolution	1mA	N/A
Frequency Response	DC – 400Hz	DC – 25kHz
Accuracy	<+/-2% +/-5mA over 0-+80C	<+/-2% +/-5mA over 0-+80C
Interface	Serial/Digital Data Stream	Dual Channel Analogue
Power Supply Requirement	5V+/-0.1VDC @ 200mA	5V+/-0.1VDC @ 50mA
Aperture Diameter	32mm	32mm
Overload Rating	Limited only by conductor	Limited only by conductor
NOTE – Excellent immunity to stray magnetic fields and conductor position within aperture		
¹Higher current ratings available in subsequent production releases		

Table 1: Raztec Wide Range digital and analogue current sensor properties

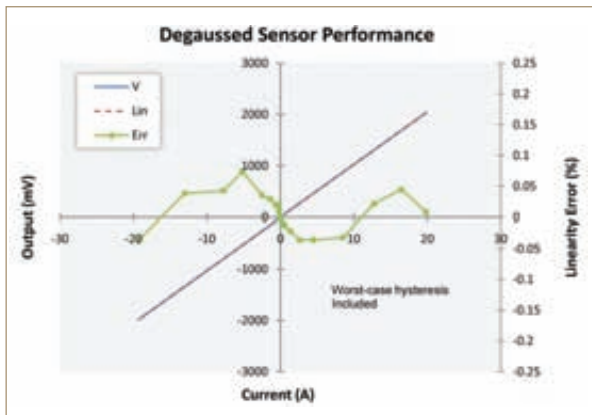


Figure 3: Automated degaussing eliminates hysteresis issues

filtering techniques.

Hysteresis cancelling (Figure 3):

- Automated degaussing eliminates hysteresis issues.

Thermal drifts often associated with hall magnetic field sensors:

- Minimised by the use of very high performance sensors which exhibit minimal drift
- Performance further enhanced by drift cancelling techniques which use thermal mapping.

Environmental immunity:

- Comprehensive shielding protects against stray electric and magnetic fields.

Cost management:

- The power of modern microcomputers allows extensive circuit integration thereby reducing cost and improving reliability.

Literature

Current Sensing Solutions for Hybrid Electric Vehicles, Power Electronics Europe 3/2008

Current Sensor Selection for Demanding Applications, Power Electronics Europe 2/2008

Selecting the Most Effective Current Sensing Technology, Power Electronics Europe 8/2007

Guide for Selection and Use of Battery Monitoring Equipment in Stationary Applications, Standard IEEE1491

than 0.5 of an ampere.

Sophisticated sensors based on flux-gate technology may work, but they are expensive and there are practical issues with the dynamic range of the output signal. There are presently two offerings:

- An analogue sensor with separate low and high current outputs. The low current output being heavily filtered to allow the extraction of float current in the presence of a high ripple current as is typical in double conversion UPS systems.
- A sensor with a very high bit count digital output to give 1mA resolution which also exhibits good precision and stability in the mA float current region. This sensor avoids the noise issues typical associated with measuring sub-millivolt DC signals.

Raztec offers a choice of current sensors to address the measuring challenges outlined above.

Non-intrusive:

- Assures no common mode voltage and noise issues
- No extra heat generated from the primary conductor
- Complete flexibility with the mounting position
- Excellent signal to noise ratio.

Wide dynamic range of current measurement (Figure 2 and Table 1):

- Achieved from dual range analogue circuits
- Or from a very high bit count A/D with floating point and sophisticated noise

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