

Reserve Power Cell LLC

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Battery Monitoring and Management
A Reserve Power Cell, LLC White Paper

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Contents

Introduction	Page 3
Requirements for Battery Management Systems (BMS)	Page 4
Measuring Battery Variables	Page 5-7
Current Industry Concepts	Page 8
Overcoming the Challenges	Page 9-10
Summary	Page 11

Introduction

Technology in vehicle electrical systems is advancing at an alarming rate, placing ever-increasing demands on batteries that have remained largely unchanged in the past decade. Today's automotive engineers are introducing new safety systems; drive-by-wire, idle stop start as well as a host of comfort, convenience and telematics systems.

These advances in technology are contributing to the ever-increasing demands of vehicle requirements on current battery capabilities. Battery manufacturers are working on new battery technology like lithium polymer and nickel metal hydrate and others, but these technologies have not reached a level where they can be cost effectively introduced into the current automotive market. The only solution to this situation is to better manage the health and performance of the current available battery power.

In order to ensure optimum performance and reliability of today's battery systems in vehicles, an in-depth knowledge of the battery status is necessary. In the past 5 years a variety of companies have invested large sums of money and resources in the development of technologies that will monitor and analyze the status of automotive battery systems.

A number of markets including Automotive, Heavy Trucks & Buses, and Military depend on the use of Battery Management Systems (BMS) to ensure fail safe operation of their vehicles. This paper addresses some of the available technologies as well as the current difficulties in developing a cost effective solution to monitoring the state of health (SOH) and state of charge (SOC) in batteries. This paper also introduces some of the latest developments in warranty tracking, end user early warning systems and multiple battery string management.

Requirements for Battery Management Systems (BMS)

- The BMS must ensure that the battery is capable of fulfilling its application requirements.
- The BMS needs to accurately determine State of Charge (SOC).
- The BMS must accurately determine the State of Health (SOH), assuring an appropriate replacement of the battery including prognosis of the time to failure of the battery.
- Continuous information on the available Charge Acceptance (CA) and Discharge Rate (DR) from the battery. More batteries fail due to incorrect charging than any other cause.
- The BMS must be able to accurately determine the internal temperature of the battery chemistry as this will affect the results of all other measurements taken.
- The BMS must identify the battery technology and adapt to the parameters of that technology.
- The BMS must have hardware that is capable of operating with a high level of accuracy in extreme environmental conditions.
- The BMS must be able to actively adapt to continuous changes in the parameters being monitored.
- As BMS are required to make predictions on pending failure, it is necessary for them to record historic data for periodic evaluation.
- The BMS must deal with and identify issues such as battery exchange remote charging (battery chargers) or external cranking support (jump start).
- The BMS must have a communications interface, allowing the captured data to be transferred to the vehicles Electronic Control Unit (ECU) or other external logging devices that will in turn make the required changes to support a good SOH of the battery.
- The BMS should be active during the manufacture of the vehicles to ensure that the battery has 100% SOC and SOH.
- The BMS must be in a compact format and require no extra effort from the end user or owner of the vehicle.
- The BMS must provide alarm functions indicating pending failure or fault conditions to both the technician as well as the end user.
- Cost is one of the most important factors in battery management in order to make it commercially viable.

Measuring Battery Variables.

In order to calculate the SOH, SOC and pending failure conditions, the BMS needs to accurately measure and record conditions and trends relating to the voltage, temperature, internal resistance or impedances and load currents as well as charging currents. Some of the current systems do not cover all of these measurements. Because each of these variables has an effect on the other, all of them need to be monitored to ensure accuracy. However, development of BMS thus far has been a compromise between accuracy and cost.

Voltage

Battery voltage is most accurately measured directly from the battery poles. Some systems measure the voltage at a point further down the harness and need to estimate the effect of the resistive drop introduced by the length and gauge of the wire. Voltage is an important variable that is used to determine single cell failure as well as charge rate. This will also be a reference for accurately measuring the current drawn from the battery. Voltage is measured using an ADC (analog to digital converter). ADCs come in a variety of precision levels, i.e. 10-bit, 12-bit, 16-bit and others.

The precision level will determine the granularity that can be measured over the required range. For example, a 10-bit system will allow for 1024 steps in the required range. If the required range is 0 volt to 10 volt, the granularity will be $10/1024 = 9.7\text{mV}$.

Another critical issue when measuring all of the variables is the voltage references used. Due to the inherent noise level in the vehicle close attention needs to be placed on filtering the reference voltages used for the ADC.

Current

Current measurement is one of the most important variables in calculating SOC as well as the rate of draw that the loads place on the battery. Current needs to be measured as it is delivered by the battery, but more importantly as the battery is drawing current from the vehicles charging system.

There are presently two widely accepted sensors for measuring current, the “shunt type” and the “hall effect” sensor. Both sensors have advantages and disadvantages. While the shunt type (a series resistor) provides a high level of accuracy, the hall sensor allows for potential free measurement as the component does not have to be in line. Hall sensors measure the magnetic affect that a current passing through them will have; they then convert this signal to a voltage. The shunt sensor is a series resistor; by measuring the voltage drop over the resistor the current is calculated.

Currently manufacturers are finding it difficult to find a cost effective solution to sensors that are able to measure large ranges of current with the required precision. 12V automotive batteries have to supply currents during parking conditions in the order of 10mA as well as a cranking current of 1000A. This full range needs to be measured to differentiate between low-level parasitic loads and high level starting currents. The ability to measure this complete range of current will ensure accuracy when determining Remaining Capacity (RC). Shunt type sensors also require temperature compensation as they heat while current is passing through them. This heating effect will change the value of the resistor causing inaccurate measurements.

Temperature

When referring to battery temperature we are referring to the temperature of the electro chemistry within the battery case. In some instances the temperature is measured at the battery post and a calculated offset is used to estimate the actual value. It is best to measure the actual temperature within the battery as factors like thermal soak can adversely affect the outcome of the offset calculation. It is imperative to have this variable as the temperature of the battery is one of the most significant contributors to battery failure. The temperature of the battery will affect the ability to deliver current as well as the ability to accept charge. Finally the battery temperature will have an effect on the sensors used to measure voltage, current and internal resistance.

Internal Resistance/Impedance

Internal resistance is the sum of the ionic and electronic resistances of the cell components. At different levels of charge the battery will display different internal resistance. As the battery's SOH changes, the internal resistance will change.

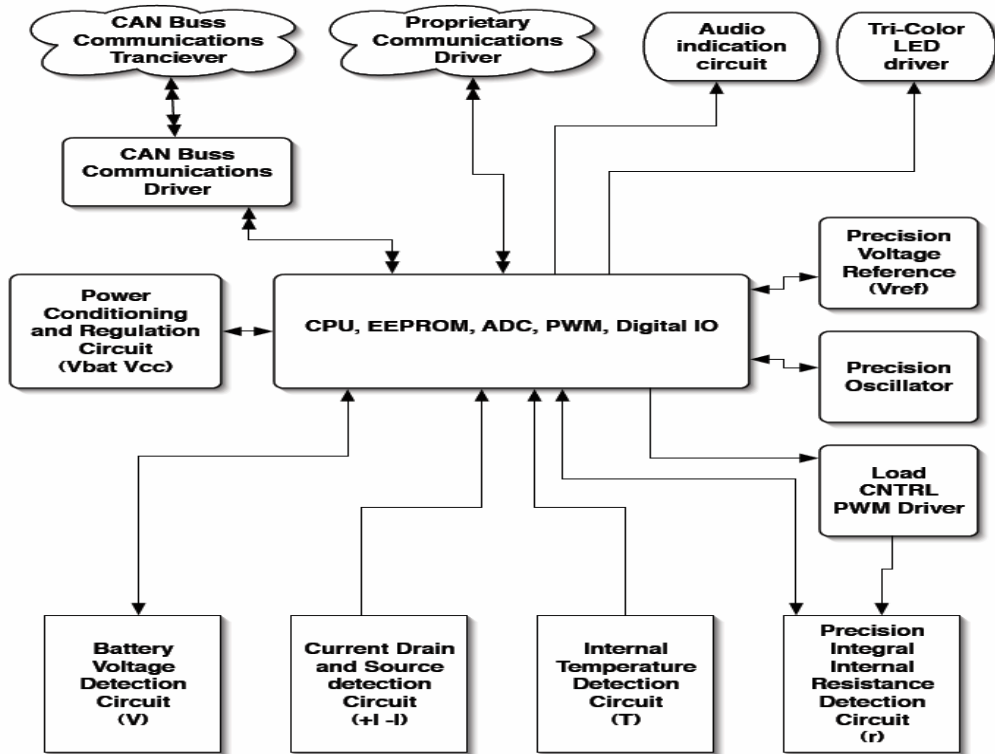
By monitoring this change we will have another variable to use when determining the battery's SOH. Connecting the battery to a pre-determined load and measuring the current flow at a specific voltage measurement less the resistance of the load will determine the internal resistance.

The other method is to measure internal impedance, the battery's opposition to change in frequency. In some instances this is the preferred method as it does not require placing the battery under load, which in turn decreases the batteries charge level. As measuring the internal impedance is more accurate when using multiple frequencies, this method also becomes more complex. Thus far, internal impedance is infrequently monitored due to the complexity of accurate measurement models.

In the diagram below, each of the above mentioned sensors are fed into an Application Specific Integrated Circuit (ASIC) that contains the Central Processing Unit (CPU), Electrically Erasable Programmable Memory (EEPROM), Analog to Digital Converters

(ADC), Pulse Width Modulators (PWM) and Digital Input, Output circuits (Digital IO). This ASIC is a programmable device that reads the sensors and processes the data through the algorithms required to calculate the SOC and SOH. The ASIC is also connected to a range of peripherals that will manage communication as well as audible and visual indicators.

Reserve Power Cell Internal Battery Monitoring Circuit Description



Current Industry Concepts

There are three major approaches to battery monitoring systems as presented by Dirk Uwe Sauer at the AABC, 05.

- **External Battery monitoring system with current measurement.** Here the BMS is part of the vehicle and needs to be included with the battery sensor somewhere in the battery cable, preferably directly at the poles. This type of BMS remains in the car over the vehicle's lifetime. Hence, it must be able to detect the type and major performance parameters of the battery, which could differ e.g. after replacement of the battery. The major disadvantage of this system is the inability to monitor any external activities such as jumpstarts or remote charging. The algorithms for determining SOH and SOC are more complex and inaccurate due to the lack of in-depth knowledge of the battery that is currently installed into the vehicle.
- **External BMS, without current sensor.** The intention is to decrease the overall cost of the system. However, as previously indicated, removing the current sensor prevents reliable analysis of the SOH and SOC of the battery. These systems can perform active impedance measurements if they supply a current pulse, which they must measure, but the accuracy is reduced due to the inability to account for the noise on the power net.
- **Battery integrated management.** This approach has the BMS internal to the battery. The BMS communicates information on the battery to the vehicle or other external devices via a communications port. It is commonly referred to as the "Intelligent Battery". The advantage is that the system has precise knowledge of the battery model that it is working on; it is capable of more accurate measurements and does not require calculated offsets.

Overcoming the Challenges

Consumer Applications

Club Assist (AAA) reports that nearly two-thirds of their roadside assistance calls are due to battery failure, i.e. “Jump Starts” and or battery replacement. Battery Management Systems can enable active energy management and user warning strategies to improve battery state of charge & performance, and eliminate surprises and risks associated with unexpected discharge or failure.

A BMS itself does not increase the capacity of the battery but provides the information to drive battery power management. The BMS can inform the Energy Management System (EMS) of the battery condition, which in turn can manage loads on the battery to reduce the overall power consumption, as well as trigger advanced charging strategies to prevent overcharge failures and virtually eliminate discharge related no-starts.

Information is also vital. If the user can be warned of an imminent battery failure, precautions can be taken to have the battery replaced or serviced. Information is also a vital tool for service technicians to verify the functionality of the battery, thus ensuring that batteries can be checked during regular vehicle maintenance. The BMS can also facilitate introduction of a warranty tracking system to enable retailers and battery manufacturers to reduce warranty costs.

Integration of the BMS into the battery ensures that all essential measurements to accurately determine SOH and SOC can be taken directly without calculated interpretation, and results in more reliable indication of battery charge state and condition.

Battery Monitoring Systems will become a standard in automobiles, light trucks and marine applications in the near future. Reserve Power Cell (RPC) has developed technologies that allow the BMS to integrate into the battery itself. With that each battery has its own BMS; therefore the battery model parameters are specific to the BMS.

Military Applications

Some of the current battery systems within today’s military vehicles lack the ability to determine SOH or SOC. The fact that these vehicles operate on multiple batteries has led to replacement of complete sets of batteries rather than replacing the single battery experiencing a failure condition. Due to this replacement practice the U.S Military has reported that vehicle battery failure is occurring in significant numbers and as such, batteries taken out of service are being stockpiled in holding lots. A majority of these batteries are simply discharged.

With RPC's technologies this problem can be avoided. Each battery is monitored independently of the others in the string. With the data on a central display, the operator of the vehicle or maintenance tech can determine which battery needs to be replaced.

Today's military vehicles are suffering from the same technology overloads as the consumer vehicles. In a silent watch mode some of these vehicles can consume upward of 100 Amps, thereby placing tremendous strain on the batteries. Currently the vehicles' operators have no way of knowing the remaining capacity of the batteries. This often results in the vehicle requiring a jumpstart which could jeopardize a mission and put our soldiers at greater risk.

Using RPC's technologies, the operator of the vehicle will have a constant display of the remaining capacity of the batteries. The system can also have a pre-determined warning set-point that will tell the operator when the batteries are about to drop below the level required to start the vehicle, affording the time to take precautionary steps.

Summary

RPC, a technology provider, together with a major battery manufacturer, is developing BMS systems that are internal to the battery. The result of this unique partnership is an “Intelligent Battery” that overcomes many of the difficulties currently experienced by other BMS systems:

- the BMS is internal,
- being internal, all relevant parameters are accurately measured
- with accurate measurements, the SOC and SOH can be determined precisely
- the BMS communicates directly to the user or external monitor
- efficient battery management can be achieved in a cost effective manner.

RPC is developing a range of BMS solutions for automotive and military applications. This provides the vehicle’s user increased safety and our military personnel a better opportunity to accomplish their mission.

Some of our technologies currently under development:

- A handheld radio frequency device to verify the SOC and SOH of batteries without having to remove cover panels or physically connect to the batteries. The service technician will simply walk down a row of vehicles and capture the vehicle’s battery data with this handheld device.
- An electronic multiple battery switching system that will allow battery sets to be switched into or out of the vehicle’s electrical system as required. The BMS ensures that the vehicle will always have the battery power required to complete its mission.
- An array of battery SOC and SOH displays that will keep the driver informed of the individual battery’s condition. As a result, batteries can be managed more efficiently.

Intelligent battery management is critical for safety and mission accomplishment. It can also have significant economical benefits. By incorporating the BMS into the battery itself, RPC and its partner can provide a complete solution for military use.

The material in this paper is covered by following patents (pending) 10/604,703 – 10/708,739 – 10/913,334 – 11/392,620 – 11/486,101 PCT/US04/25842 and others yet to be published.