Fundamentals of Electric Vehicle Conversion

Session #8
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This presentation is complementary to Chapter 8 Batteries and Chapter 9 The Charger and Electrical System in the course manual "Build Your Own Electric Vehicle" by Seth Leitman and Bob Brant second edition illustrated. The book is published by McGraw-Hill Professional, 2008 (MHPROFESSIONAL.COM, ISBN 978- 0-07-154373-6, MHID 0-07-154373-2, 329 pages)

Before we start with the electronics stuff, I will reiterate on some terms and definitions already mentioned during the course.
Matching cells or matched cells means that all cells in a series circuits behave identically.
Cell balancing is a method to guarantee the matched cells have the same charge.
Equalizing is a term used for lead acid batteries only. It is a process where overcharging cleans the cells from unwanted sulfur buildup. This is not balancing.
Capacity is the amount of energy a cell can store and deliver in a single cycle. Capacity of a cell changes with history, time and temperature. Matched cells capacity should track each other when all other conditions are identical.

What is a BMS?

A Battery Management System (BMS) is an electronic device that measures voltage(s), current(s) and temperature. The BMS provides control signals to the vehicle and alarms to the user.
Based on this definition a voltmeter, an ammeter and a thermometer in the dashboard should do. We will see that this is a subset of the type of monitoring required to extend battery life.

A proper BMS should calculate from the measurements usable information about the battery for the user's benefit. Here are some terms that better defines a battery in quantitative terms. State of Charge (SoC) tells the user how much energy remains in the battery. That is your fuel gauge. State of Health (SoH) tells the user how much capacity remains in the battery. Coefficient of Performance (CoP) shall reflect the expected usefulness of the battery in the application.

A BMS may also take action on behalf of the user to prevent damage or premature degradation of the battery. The BMS will indicate to the user the state of the battery and will alarm the user in case of a fault condition or a pending catastrophic failure.

Some BMS will record the charge-discharge cycles of a battery to map a history of the battery usage. Ultimately a BMS should provide assistance for the serviceability of a battery to provide a long usable life of the vehicle and improve regular maintenance schedule.

Why is a BMS required?

With the present electric car conversions the user is part of the feedback loop. The user is the brain of the BMS. You should devise a battery management strategy prior to the conversion.

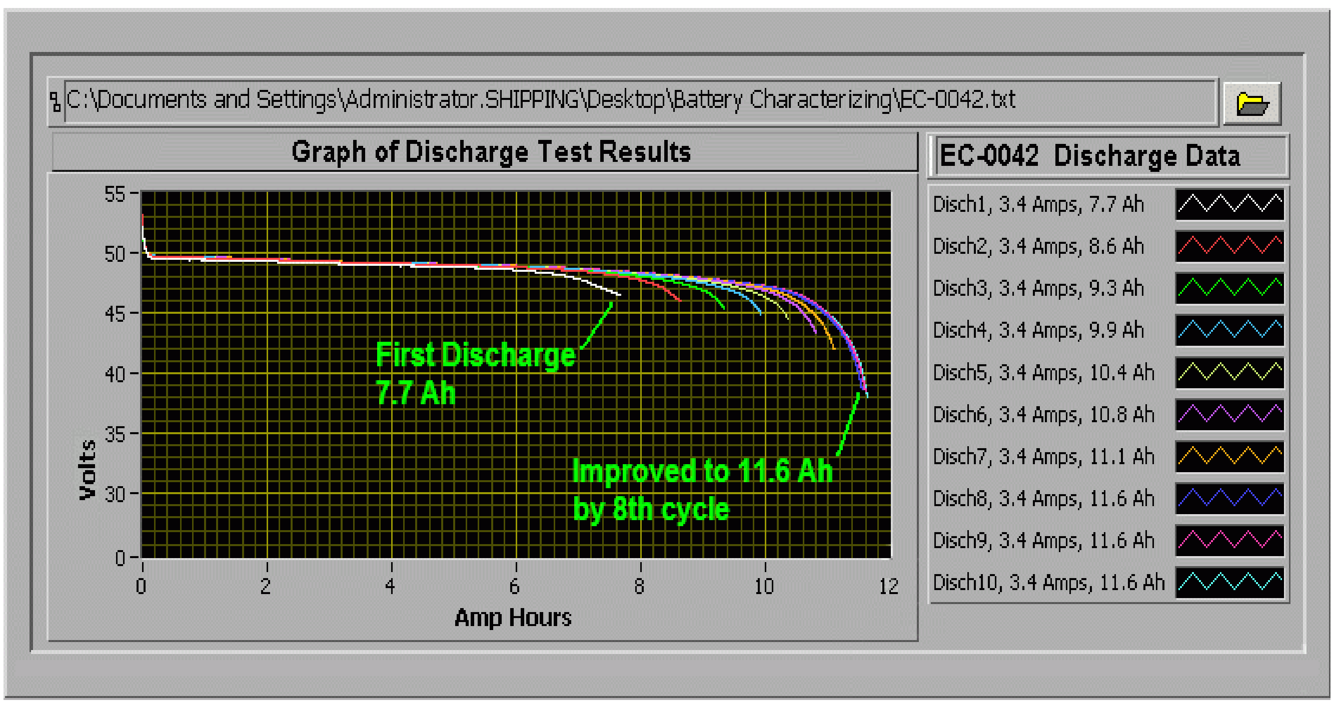
A battery is a chemical reaction where limits should be imposed to ensure proper long term use. In some cases abuse shortens the useful life of a battery drastically. Neglect also impacts the batteries greatly. A BMS can quantify, analyze and act on the information to prolong a battery's usefulness.
It only takes one event to damage a battery. To get the previous performance the battery must be serviced or replaced.

Having a BMS will ensure that the battery complies with the manufacturer specifications.
Looking at the economics of an electric vehicle we can see that a 20 kilowatt*hour charge costs about $2.00. Assume an SLA deep cycle battery can be cycled 800 times. The total cost of the energy over the life of the battery is $1600. The battery cost is about $3000 dollars. So the cost of the stored energy over the life of the battery is about half to the cost of the battery. The point is you should take good care of the battery.

The Difference a BMS Circuit Can Make

From: http://www.ebikes.ca/

The switched capacitor balancing BMS circuits had arrived and were testing out well. The graph below shows a case in point. This battery pack started off delivering only 7.7 Amp-hours at the time that we inserted the new BMS. After each charge and discharge cycle after that, the capacity improved from one discharge to the next until finally leveling off at a full 11.6 A-h.

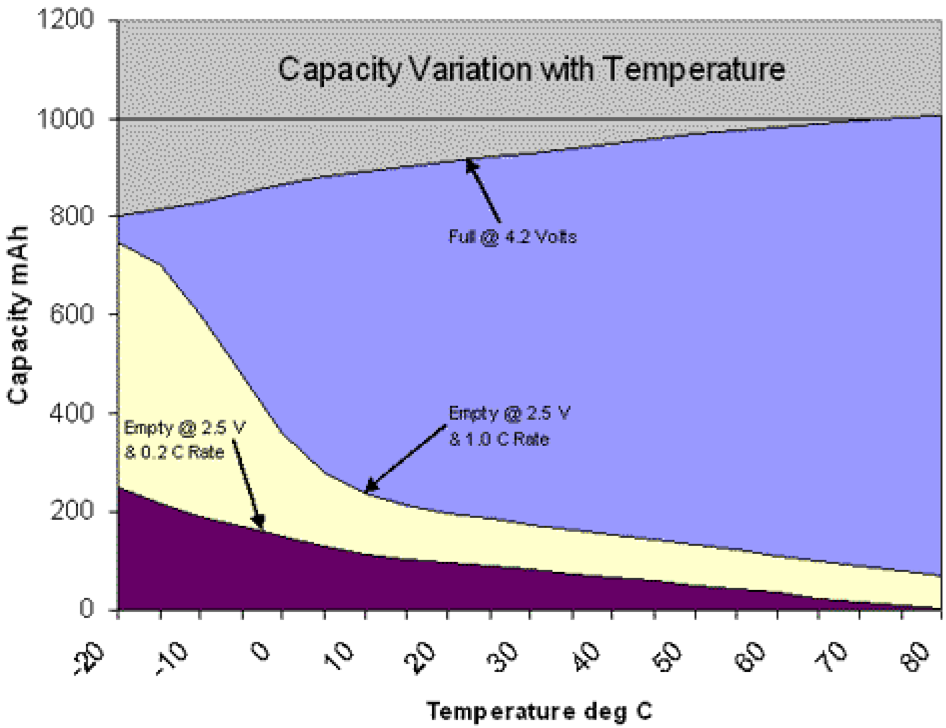


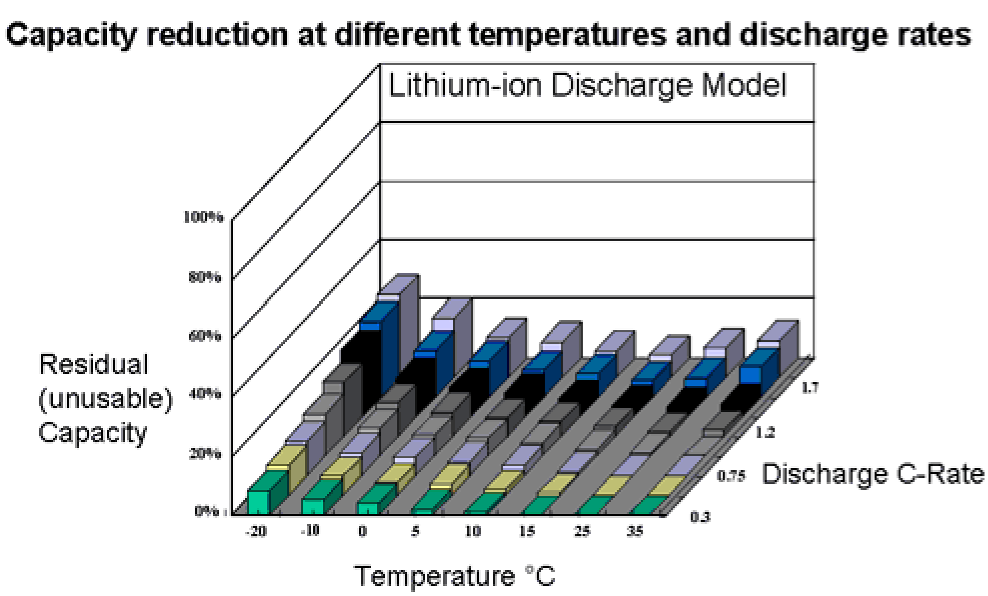
For those with LiFePO4 battery packs and have replacement BMS circuits, we have produced a brief instruction guide on how to go about opening the pack and wiring in the replacement.

What are the parameters required for BMS?

A BMS will monitor battery voltage at the very least. Some BMS can measure battery current (rate of discharge). Still other BMS can monitor individual cell voltage and temperature.

The most useful result calculated from the parameters is the State of Charge (SoC). With the proper measurements the BMS can calculate and report a precise SoC. With the SoC the usable amount of energy can be calculated from rate of consumption and temperature. For a vehicle this translates into range of autonomy. So how can the driver know how far the car can go? Temperature and rate of discharge has great impact on capacity. See the diagram in the book on page 187 figure 8.2 middle left. A BMS needs temperature measurements to report proper SoC.



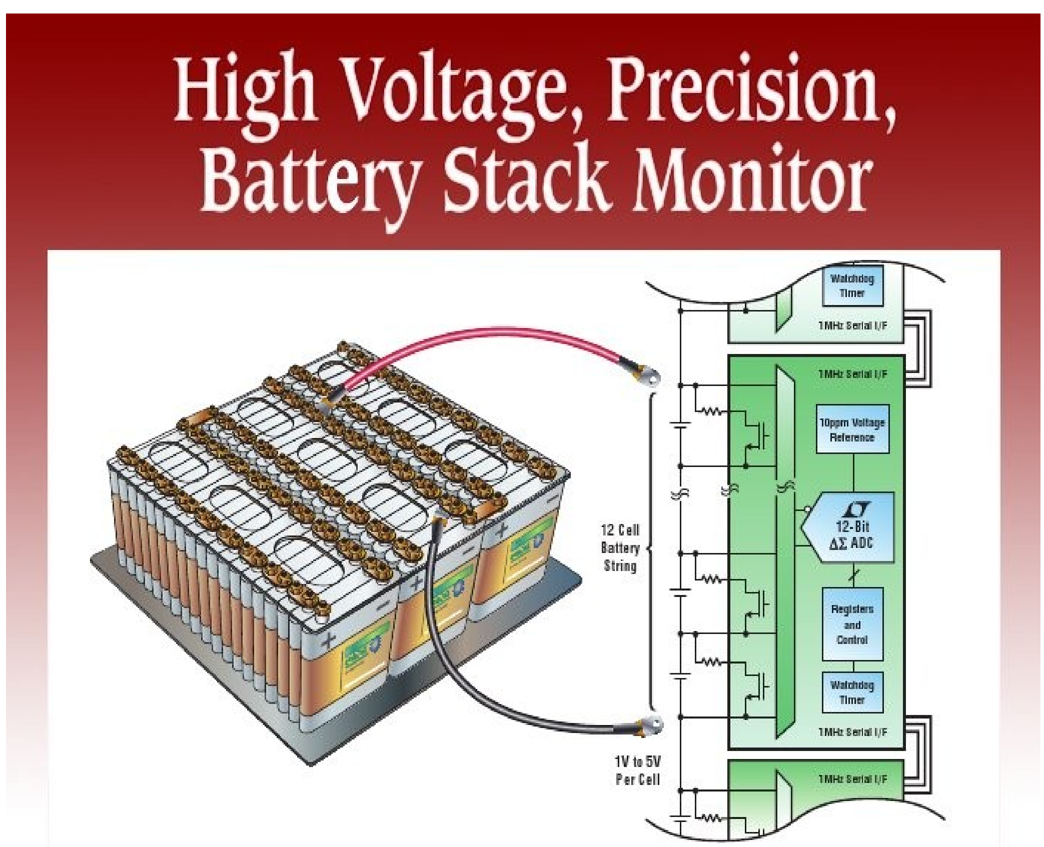


Diagrams from http://www.mpoweruk.com/soc.htm

Parts used for BMS implementation.

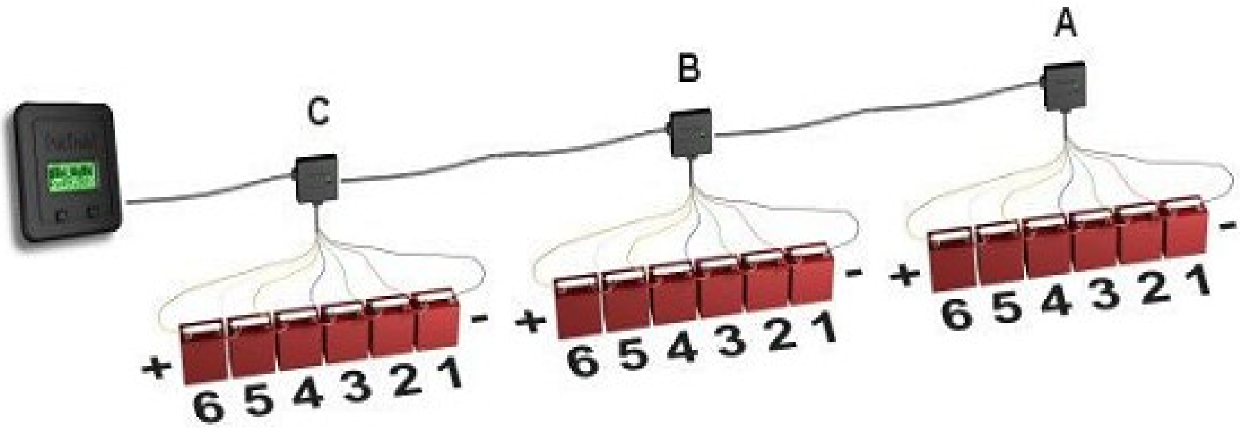
Now that we have viewed some key definitions, lets get down to some nuts and bolts or rather connectors and ICs since most of the BMS is electronics.
When measuring voltages caution should be taken to not touch metallic surfaces with your body. Every part should be well identified. You should be familiar with the car. Read the manuals. Know the voltages to expect and the condition of the battery.

Because a battery is operated in harsh environment there can be conductive liquids, dust and salts in the battery compartment. Batteries may leak thus very reactive acids (or base) maybe present. Another danger on a battery is burn risk. If you short a wire it can become white hot almost instantly (if it is not properly fused). When a wire shorts a voltage source it is possible that the wire welds to the metal. It will not be possible to remove the wire by hand. Also the event may generate a blinding flash called a plasma. Do a visual inspection of all the cabling insulation. Be weary of condensing environment (fog and dew) in and near any electrical appliance. Wear gloves and appropriate clothing.



We will look at voltage measurement. A galvanic contact is needed on the battery terminals to a voltmeter. Voltmeters have a positive red probe and a negative black probe. A typical voltmeter has an insulation rating of about 2000Vdc. This is the most basic measurement on a battery.

The BMS has the equivalent of a voltmeter integrated in it although it is not rated for voltages higher then normal battery voltage. The probes are replaced by fused wires. The insulation on these wires is just as important as on the power cables. Because the wires going to the BMS are small it may be easier to break, damage or pinch. In many BMS a wire harness going to each cell is terminated to a connector or a module. The voltage on this connector will be Vcell times the number of cells. For example a SLA battery has 6 cells of 2.25Vdc will make 13.5Vdc on the posts for each battery. Each sensing wire may be fused or the wire itself can act as a fuse.



Here is an example of a good monitoring system called the **Paktrakr**. Some BMS may provide isolation for each cell being monitored. A common method is to provide isolation between modules such as the Paktrakr. The purpose is to reduce the risk to the driver since the indicator placed in the dashboard is never connected directly to cells.

The voltage will, to a chemist, determine the state of the chemical reaction. To a user the voltage can indicate a coarse state of charge. I say coarse because this measurement by itself cannot provide the data required to determine fine state of charge. A history of the current measurement is required to determine precise state of charge. A current sensor can be located anywhere on a battery with cells connected in series. That is to say the current will be identical on all cells in the chain.

At this point we will add a term in the presentation. The positive (red) terminal of the battery can be referred to as the high side (anode or hot terminal) and the negative (black) terminal can be referred to as the low side (cathode, the neutral or ground).

The current sensing circuit may be of a non-isolated type that is to say it maybe at the battery voltage. There are two main types of current sensing. The first uses a sense resistor of a few milliohms buffered by an amplifier. A hall effect sensor has the advantage of providing electrical isolation from the high current loop thus can be connected at any point in the series loop.

Temperature will affect the overall energy transfer from a battery during a charge and discharge cycle. To determine the state of charge, temperature is monitored in the battery compartment or on each cell. Some BMS provide for such functionality. Thermocouples are sometimes used although thermistors are more common. The BMS manufacturer will recommend a device.

All the measuring devices for voltage, current and temperature interface to a microcontroller. The microcontroller will validate the data, calculate useful parameters and possibly save the data. The BMS should be able to send information to a display in real time to provide the driver with an energy gauge. The BMS should be able to interface to a PC to download data to a custom application to analyze the data. The functionality should be context sensitive to provide information to a service technician. The purpose is to expedite repair and service of a battery.

What is out there?

http://www.paktrakr.com/ is a monitoring system.
http://www.micro-power.com/ (battery solution provider for portable mainly)
http://revolectrix.com/ (more of the distributor for hobbyist)
http://www.schulze-elektronik-gmbh.de/index_uk.htm (for hobbyist primarily)
Here is a some list of BMS, http://carrott.org/cgi-bin/twiki/view/BMS/AvailableBMSs and
http://liionbms.com/php/bms_options.php
Also available are battery analyzer, see http://www.cadex.com/

For electrical engineers who are familiar with electronic components, there is a new type of IC dedicated for cell monitoring and cell balancing. Analogue Device makes the AD7208 and Linear Technology makes the LTC6802-1. These ICs do not require isolation devices thus can reduce the cost of implementation. Note that the ICs by themselves do not have full BMS capability but offer basic monitoring functionality. These ICs must be interfaced to a microcontroller.
Here is a link to these ICs.
http://www.linear.com/ad/6802.jsp and
http://www.analog.com/en/power-management/battery-management/ad7280/products/product.html

To take full advantage of the more advanced BMS some parameters must be entered in the BMS by the user or the manufacturer. Cell voltage and capacity for example should be required. State of charge will not be known to the BMS on the first cycle until it is measured and verified. The BMS may have a learning time as well.

Manuals, Manuals, More Manuals and Practical Considerations.

If you buy a completed conversion or a kit for do-it-yourself the manuals should be included. You should get familiar with them and should verify which parameters are measured. These parameters are probably accessible on a display however the important information for a driver is SoC.

The battery placement was allocated on space availability in the chassis and weight balance of the car. You should also consider the BMS module format. Some modules need a minimum amount of cells to work. The last module on the high side or positive terminal of the battery is usually the only module allowed to have partial cell population. Get familiar with these restrictions and get confirmation of your installation plan with the manufacturer of the BMS if necessary.

Once you have learned and evaluated all this and have selected a BMS you can put all the theory aside and concentrate on the specifics of installation. Instrumentation display installation needs to go in while the dash board is out (unless its a stick on). You need to put wires in with the harness. Modular BMS provide electrical isolation. Keep high voltage and high power wire separate from low voltage signal wires in there own hard insulation guides. Another reason to do this is electromagnetic interference (EMI) mitigation. Do a layout of the wiring diagram and label your wires and modules. If you make a change in the wiring, annotate your diagrams. You will be doing service on your car or someone else will. Knowing what to look for is half the work.

The wiring of the BMS to the cells should be done at the same time or just after installation of the power cables. Note some BMS have very specific sequence for the hook up to the batteries.
Once the BMS is installed the manual should provide a check list of verifications to validate system installation.

Conclusion

Planning your EV means taking into consideration the life cycle of your batteries. A BMS should be part of this approach. It is only in the past decade that electronics equipment have become available and affordable to the EV enthusiast. The BMS will provide quantitative measurement thus adding to the qualitative feel that the user will have about the batteries. These automated systems should not replace the knowledge of the user but should complement it to provide a safe reliable vehicle.

Each BMS provider will offer different features. Some will be adapted to specific chemistries. Others will provide generic solutions that can be configured. There will always be many solutions available just has there are many types of batteries. The best implementation is the one that will fulfill your requirements.

For fully automated systems without user intervention a BMS must be integrated into a service schedule to the dealership.