Battery Management System (BMS): PART 2

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Prevention of Battery Failures by design of Battery Management System (BMS)

EV Bus Failure

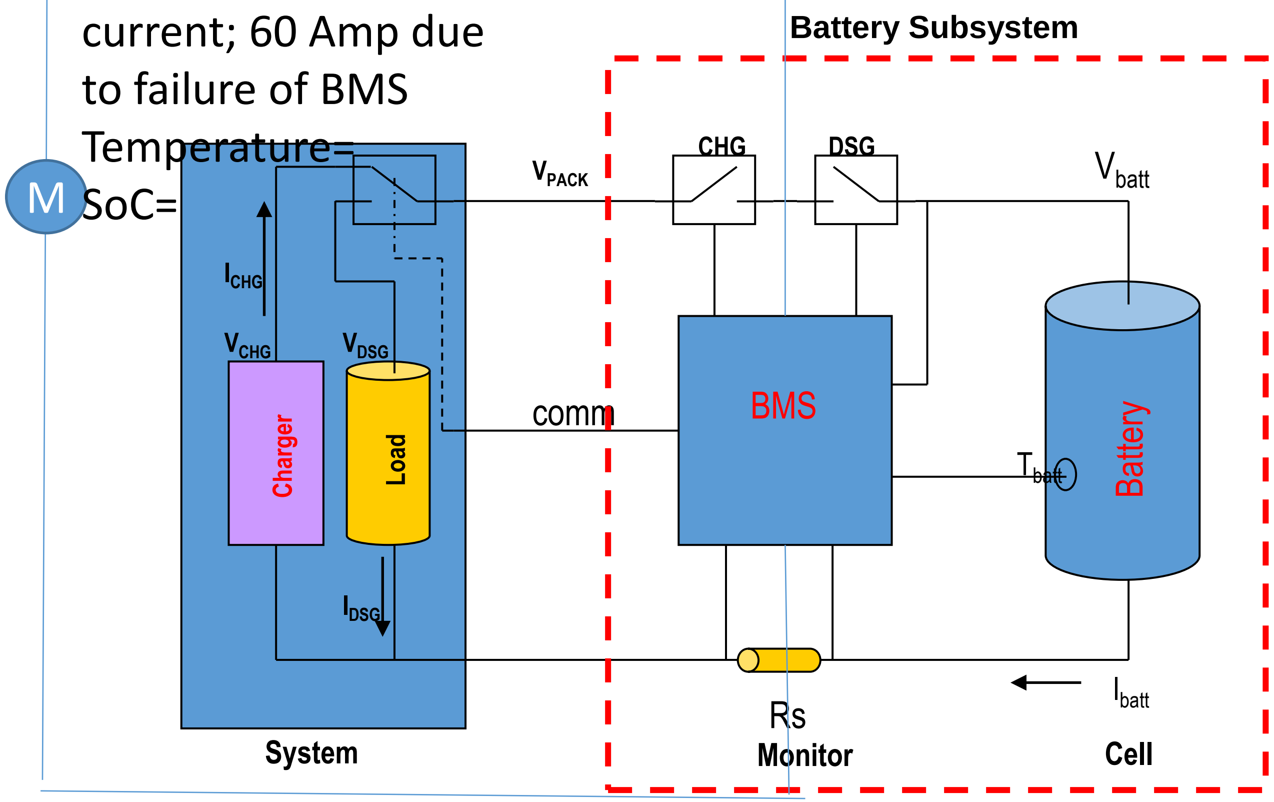
- EV electric bus caught fire during charging (Excessive Charging current will lead to higher heat generation (Heat generation: i^2*R))

- BMS Failure (Over current sensing failure; Over Temperature)

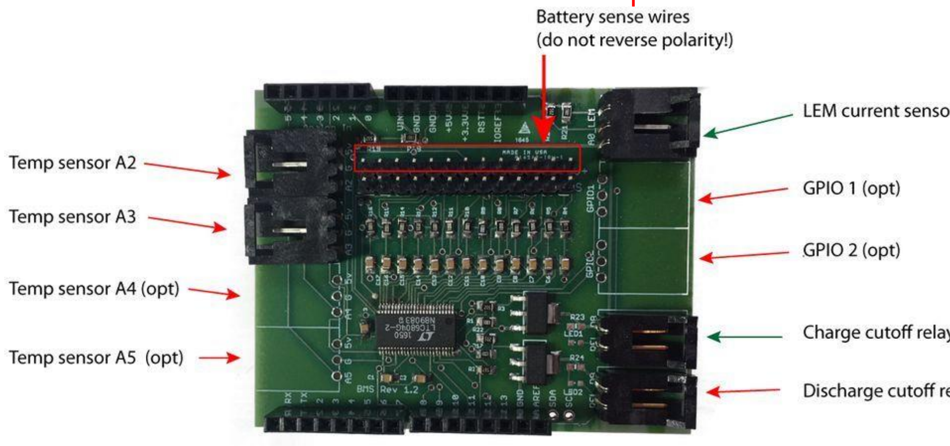
- Without a BMS, there is no safe lithium ion battery

What does a battery monitor do?

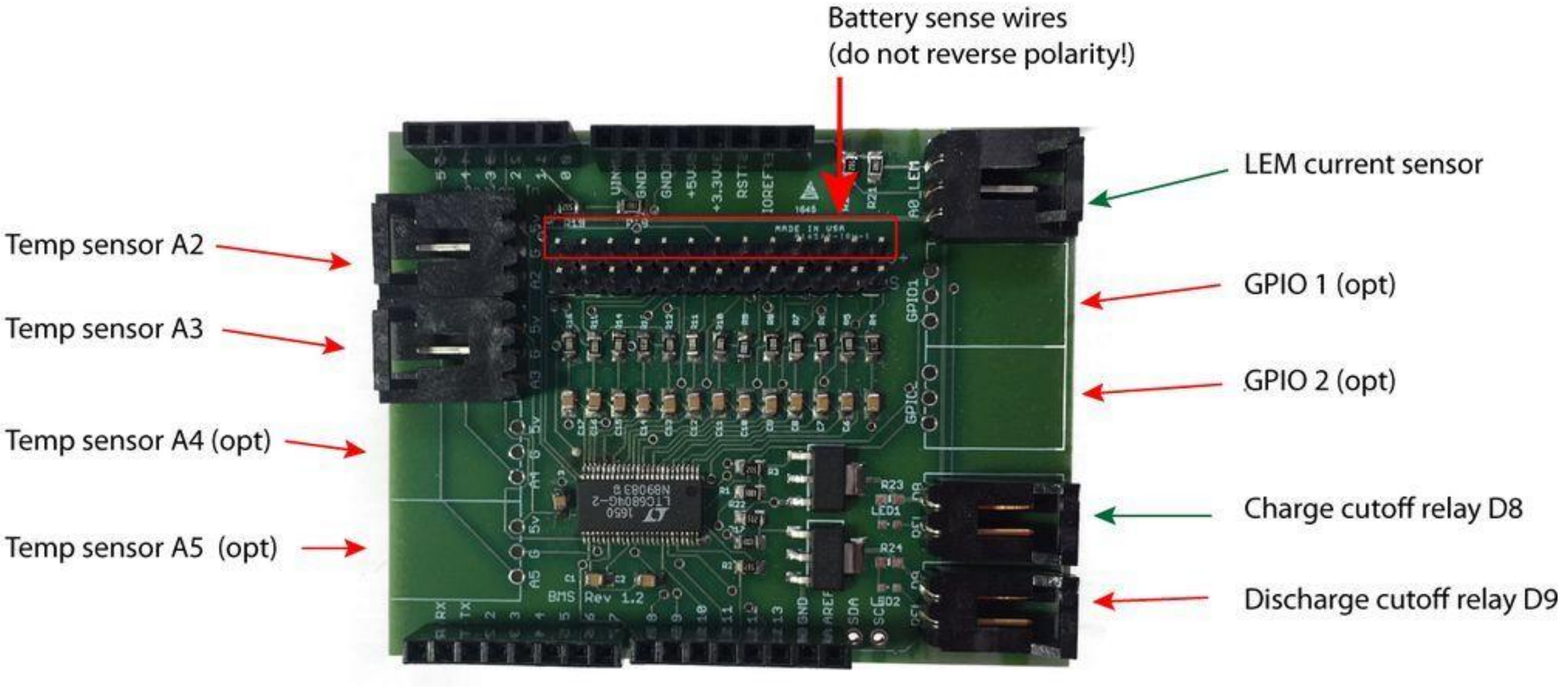
I = 40 Amp/50 discharge Amp current; 60 Amp due to failure of BMS
Temperature=
SoC=



- Capacity estimation
- Safety/protection
- Charging support
- Communication and Display
- Logging
- Authentication

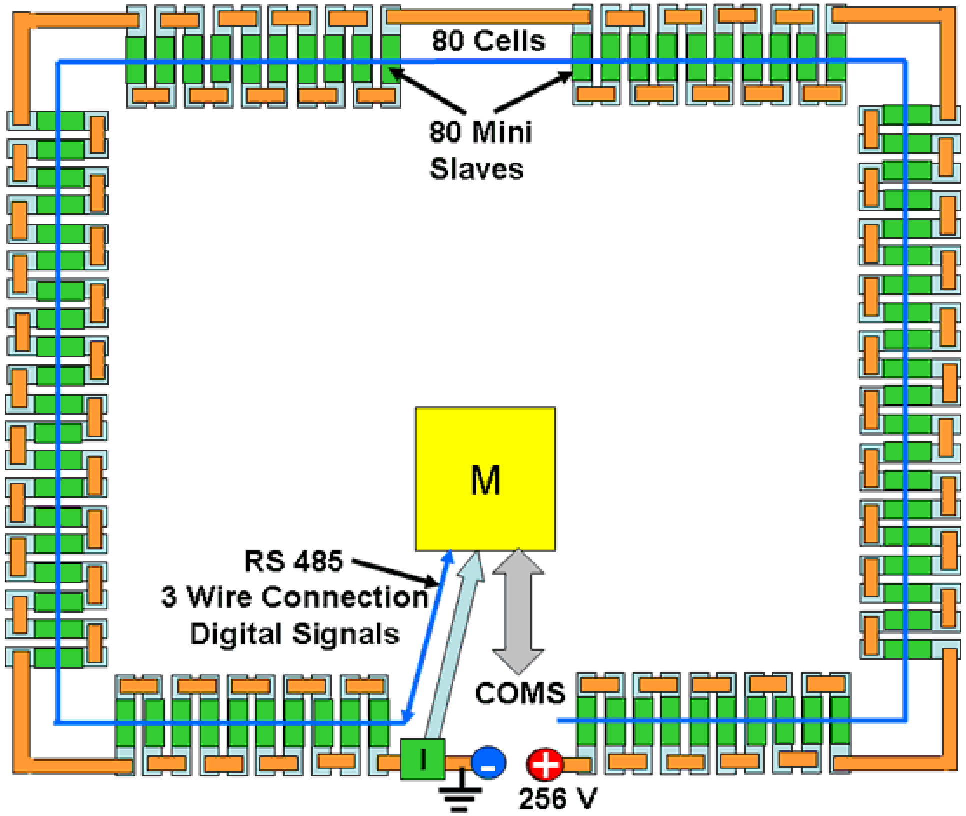


Arduino LTC6804 BMS - Part 1: Main Board



BMS Topology: Distributed

- Put voltage monitor and discharge balancer on each cell, with digital communications for charger cutoff and status.

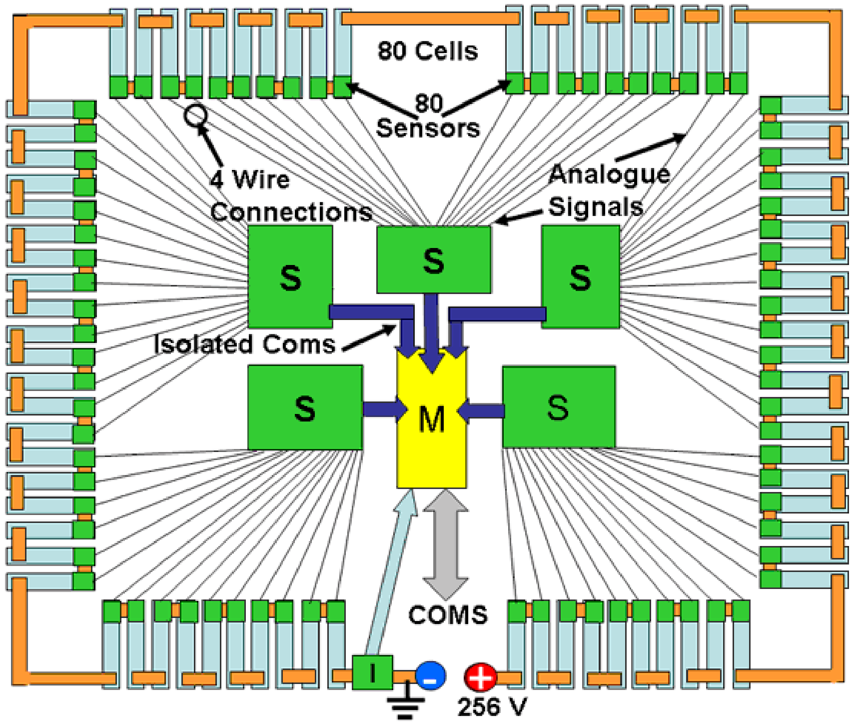


Advantages: Simpler design and construction and its potential for higher reliability in an automotive environment.

Disadvantages: Large number of mini-slave printed circuit boards which are needed and the difficulty of mounting them on some cell types.

BMS Topology: Modular

- Several Slave controllers consolidate data to a master

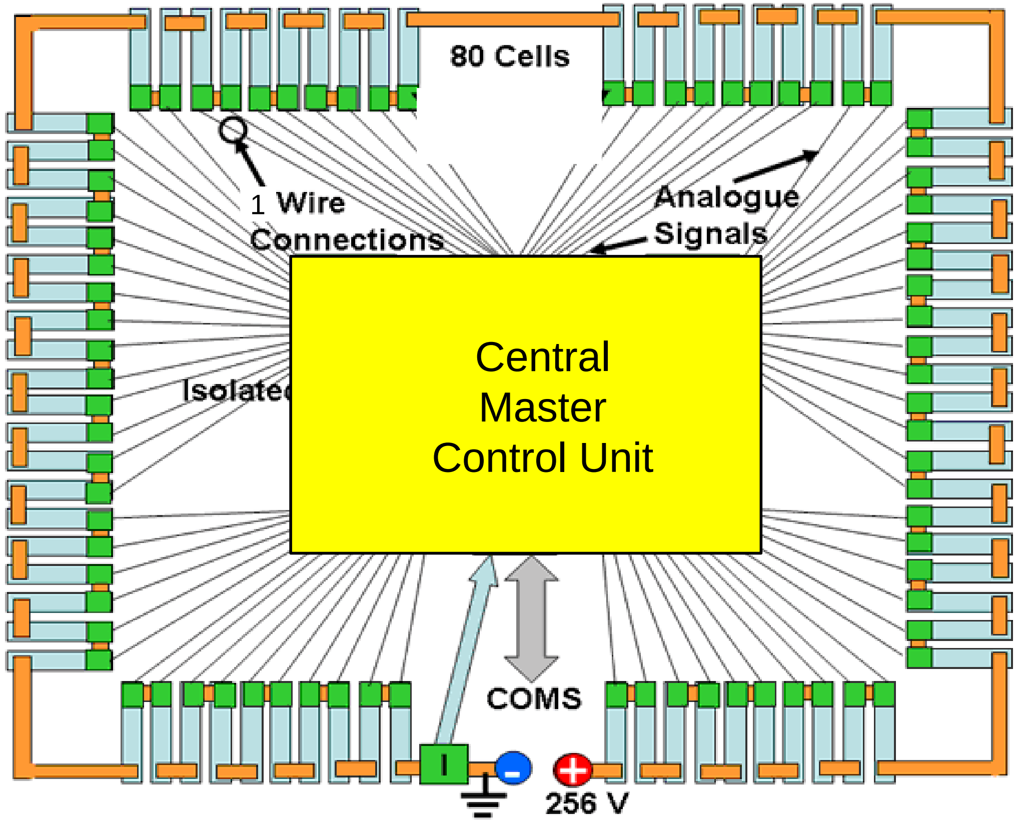


Advantages: Does not need printed circuit boards connected to individual cells.

Disadvantages: Master-Slave isolated communications can be challenging in an EV.

BMS Topology: Centralized

- Centralized Master Control Unit



Advantages: Single installation point. No complex inter-vehicle communications

Disadvantages: Typical EV batteries are distributed in the vehicle, requiring wiring to a central location.
Single source for balancer heat generation.

ENTER THE LITHIUM BMS

- Many thoughts and discussions on what constitutes a Battery Management System (BMS):
  - Monitor and Detect Cell Over-Charge, and cut off charger
  - Monitor and Detect Cell Over-discharge and alert operator, or cut off system power.
  - Cell Balance for string charging
  - Temperature Monitoring
  - Remaining State of Charge determination

Battery Modeling I

1. Need of Battery Modelling for BMS
2. State of Charge (SOC) and State of Health (SOH) measurement and estimation of Batteries
3. Classification of Battery Models

1. Need of Battery Modelling for BMS

1. Why there is Need of Battery Modelling

The battery packs when integrated with vehicle makes a complex system and encounter ***many safety problems such as the vibration, overcharging, self-discharging, capacity fading, impedance increase, thermal runway, shocks, aging (calendar and cyclic), etc.*** Majority of these problems are at micro-level which requires the deeper understanding of fundamentals (physical and chemical) of the mechanisms occurring at the cell level. While some other problems such as the vibration, shocks and insulation are at macro-level, however can also influence the problems at the micro-level directly or indirectly.

To counter these problems, ***researchers attempted to design an efficient battery management system (BMS)*** that ***incorporates the numerical modelling methods and the new mechanical designs***.

BMS is found in Electric cars or other large electrically driven equipment's.

1.1 Battery Management System (BMS)

BMS means different things to different people. To some it is simply ***Battery Monitoring, keeping a check on the key operational parameters during charging and discharging such as voltages and currents and the battery internal and ambient temperature. The monitoring circuits would normally provide inputs to protection devices which would generate alarms or disconnect the battery from the load or charger should any of the parameters become out of limits.***

Battery Management System (BMS)

One of the main functions of the BMS is to keep the cells operating within their designed operating window (the green box above). This is not too difficult to achieve ***using safety devices and thermal management systems***. As an additional safety factor some manufacturers set their operating limits to more restricted levels indicated by the dotted lines.

There is however very little the BMS can do to protect against an internal short circuit. The only prevention action that can be taken is strict process control of all the cell manufacturing operations.

Lithium Charged but Not Guilty?

The cause of many fires has been attributed to Lithium batteries and there is a fear of Lithium because of its well known vigorous reaction with water. Under normal circumstances, most (but not all) batteries do not contain any free Lithium. The Lithium content is combined into other compounds which do not react with water. The amount of Lithium deposited during the Lithium plating when cells are damaged as described above is very small and not usually responsible for the fires which have occurred.

Furthermore, many of the reported fires are due to burning electrolyte rather than the Lithium compounds.

1.2 Battery Management System (BMS) (Contd.)

Designing a BMS

In order to control battery performance and safety it is necessary to understand **what needs to be controlled and why it needs controlling.** This requires an in depth understanding of the fundamental cell chemistries, performance characteristics and battery failure modes particularly Lithium battery failures. The battery can not simply be treated as a black box.

BMS Building Blocks (objectives)

There are three main objectives common to all Battery Management Systems

1. Protect the cells or the battery from damage
2. Prolong the life of the battery
3. Maintain the battery in a state in which it can fulfil the functional requirements of the application for which it was specified.

1.3 Battery Management System (BMS) (Contd.)

To achieve these objectives the BMS may incorporate one or more of the following functions. (Follow the links to see how these functions are implemented.)

Cell Protection Protecting the battery from out of tolerance operating conditions is fundamental to all BMS applications. In practice the BMS must provide full cell protection to cover almost any eventuality.

Charge control This is an essential feature of BMS. More batteries are damaged by inappropriate charging than by any other cause.

Demand Management While not directly related to the operation of the battery itself, demand management refers to the application in which the battery is used. Its objective is to minimise the current drain on the battery by designing power saving techniques into the applications circuitry and thus prolong the time between battery charges.

SOC Determination *Many applications require a knowledge of the State of Charge (SOC) of the battery or of the individual cells in the battery chain. This may simply be for providing the user with an indication of the capacity left in the battery, or it could be needed in a control circuit to ensure optimum control of the charging process.*
SOH Determination *The State of Health (SOH) is a measure of a battery's capability to deliver its specified output. This is vital for assessing the readiness of emergency power equipment and is an indicator of whether maintenance actions are needed.*

Cell Balancing In multi-cell battery chains small differences between cells due to production tolerances or operating conditions tend to be magnified with each charge / discharge cycle. Weaker cells become overstressed during charging causing them to become even weaker, until they eventually fail causing premature failure of the battery. Cell balancing is a way of compensating for weaker cells by equalising the charge on all the cells in the chain and thus extending battery life.

History - (Log Book Function) Monitoring and storing the battery's history is another possible function of the BMS. This is needed in order to estimate the State of Health of the battery, but also to determine whether it has been subject to abuse. Parameters such as number of cycles, maximum and minimum voltages and temperatures and maximum charging and discharging currents can be

1.4 Battery Management System (BMS) (Contd.)

The **numerical modelling (battery modelling)** methods are mainly used for control purposes to estimate the battery states such as the state of charge (SOC), state of health (SOH), state of function (SOF), temperature distribution, voltage, etc. for fault diagnosis and prognostics to mitigate the safety risk.

On the other hand, the **mechanical designs** of the battery packs include an incorporation of cooling/heating systems by air/liquid to operate in cold temperatures and prevent self-discharging and thermal runway, providing insulation to absorb vibration and shocks, addressing the suitable location of battery pack to minimize the danger of explosion on sudden impact/collision, the suitable materials for battery pack box, etc.

Among these functions, SOC and SOH estimation is most important ones of BMS for solving problems inside the battery pack. Therefore, we shall study about SOC, SOH of batteries and how are these measured and/or estimated.

2. State of Charge (SOC) and State of Health (SOH) measurement and estimation of Batteries

2.1 State of Charge (SOC)

Knowing the amount of energy left in a battery compared with the energy it had when it was full gives the user an indication of how much longer a battery will continue to perform before it needs recharging.

It is a measure of the short term capability of the battery. Using the analogy of a fuel tank in a car, State of Charge (SOC) estimation is often called the "Gas Gauge" or "Fuel Gauge" function.

The preferred SOC reference should be the **rated capacity of a new cell rather than the current capacity of the cell**. This is because the cell capacity gradually reduces as the cell ages. For example, towards the end of the cell's life its actual capacity will be approaching only 80% of its rated capacity and in this case, even if the cell were fully charged, its SOC would only be 80% of its rated capacity

2.1 State of Charge (SOC, contd.)

Methods of Determining the State of Charge

Several methods of estimating the state of charge of a battery have been used. Some are specific to particular cell chemistries. Most depend on measuring some convenient parameter which varies with the state of charge.

1. Direct Measurement

This would be easy if the battery could be discharged at a constant rate. The charge in a battery is equal to the current multiplied by the time for which it flowed. Unfortunately there are two problems with this. In all practical batteries, the discharge current is not constant but diminishes as the battery becomes discharged, usually in a non-linear way. Any measurement device must therefore be able to integrate current over time. Secondly, this method depends on discharging the battery to know how much charge it contained. In most applications except perhaps in qualification testing, the user (or the system) needs to know how much charge is in the cell without discharging it.

It is not possible either to measure directly the effective charge in a battery by monitoring the actual charge put into it during charging. This is because of the Coulombic efficiency of the battery. Losses in the battery during the charge - discharge cycle mean that the battery will deliver less charge during discharge than was put into it during charging.

2. Voltage Based SOC Estimation

This uses the voltage of the battery cell as the basis for calculating SOC or the remaining capacity. Results can vary widely depending on actual voltage level, temperature, discharge rate and the age of the cell and compensation for these factors must be provided to achieve a reasonable accuracy.

2.1 State of Charge (SOC, contd.)

3. Current Based SOC Estimation - (Coulomb Counting)

The energy contained in an electric charge is measured in Coulombs and is equal to the integral over time of the current which delivered the charge. The remaining capacity in a cell can be calculated by measuring the current entering (charging) or leaving (discharging) the cells and integrating (accumulating) this over time . In other words the charge transferred in or out of the cell is obtained by accumulating the current drain over time. The calibration reference point is a fully charged cell, not an empty cell, and the SOC is obtained by subracting the net charge flow from the charge in a fully charged cell. This method, known as Coulomb counting, provides higher accuracy than most other SOC measurements since it measures the charge flow directly.

4. Charge Estimation Algorithms

Several different methods such as ***Fuzzy Logic, Kalman Filtering, Neural Networks*** and recursive, self-learning methods have been employed to improve the accuracy of the SOC estimation as well as the estimation of state of health (SOH).

2.1 Factors influencing State of Charge (SOC, contd.)

1. Charge-discharge rate
2. Temperature
3. Cell ageing
4. Self discharge

2.2 State of Health (SOH)

The **State of Health is a "measurement" that reflects the general condition of a battery and its ability to deliver the specified performance compared with a fresh battery**. It takes into account such factors as charge acceptance, internal resistance, voltage and self-discharge. It is a measure of the long term capability of the battery and gives an "indication" not an absolute measurement, of how much of the available "lifetime energy throughput" of the battery has been consumed, and how much is left.

Unlike the SOC which can be determined by measuring the actual charge in the battery there is no absolute definition of the SOH. ***It is a subjective measure in that different people derive it from a variety of different measurable battery performance parameters which they interpret according to their own set of rules. It is an estimation rather than a measurement***. This is fine so long as the estimate is based on a consistent set of rules but it makes comparisons between estimates made with different test equipment and methods unreliable.

2.2 State of Health (SOH, contd.)

What is the SOH used for?

Its purpose is to provide an indication of the performance which can be expected from the battery in its current condition or to provide an indication of the how much of the useful lifetime of the battery has been consumed and how much remains before it must be replaced. In critical applications such as standby and emergency power plant the SOC gives an indication of whether a battery will be able to support the load when called upon to do so. **Knowledge of the SOH will also help the plant engineer to anticipate problems to make fault diagnosis or to plan replacement.** This is essentially a monitoring function tracking the long term changes in the battery.

SOH for Electric Vehicle (EV) applications

For EV applications, the ability to achieve the range when called upon to do so is most important, **hence the SOH is based on a comparison of current capacity with capacity when new.**

SOH for Hybrid Electric Vehicle (HEV) applications

For HEV applications the ability to deliver the specified power is mos important and so SOH is based on a comparison of the DC resistance (or 1 kHz impedance)

2.2 State of Health (SOH, contd.)

How is the SOH determined?

Any parameter which changes **significantly with age, such as cell impedance or conductance**, can be used as a basis for providing an indication of the SOH of the cell. Changes to these parameters will normally signify that other changes have occurred which may be of more importance to the user. **These could be changes to the external battery performance such as the loss of rated capacity or increased temperature rise during operation or internal changes such as corrosion.**

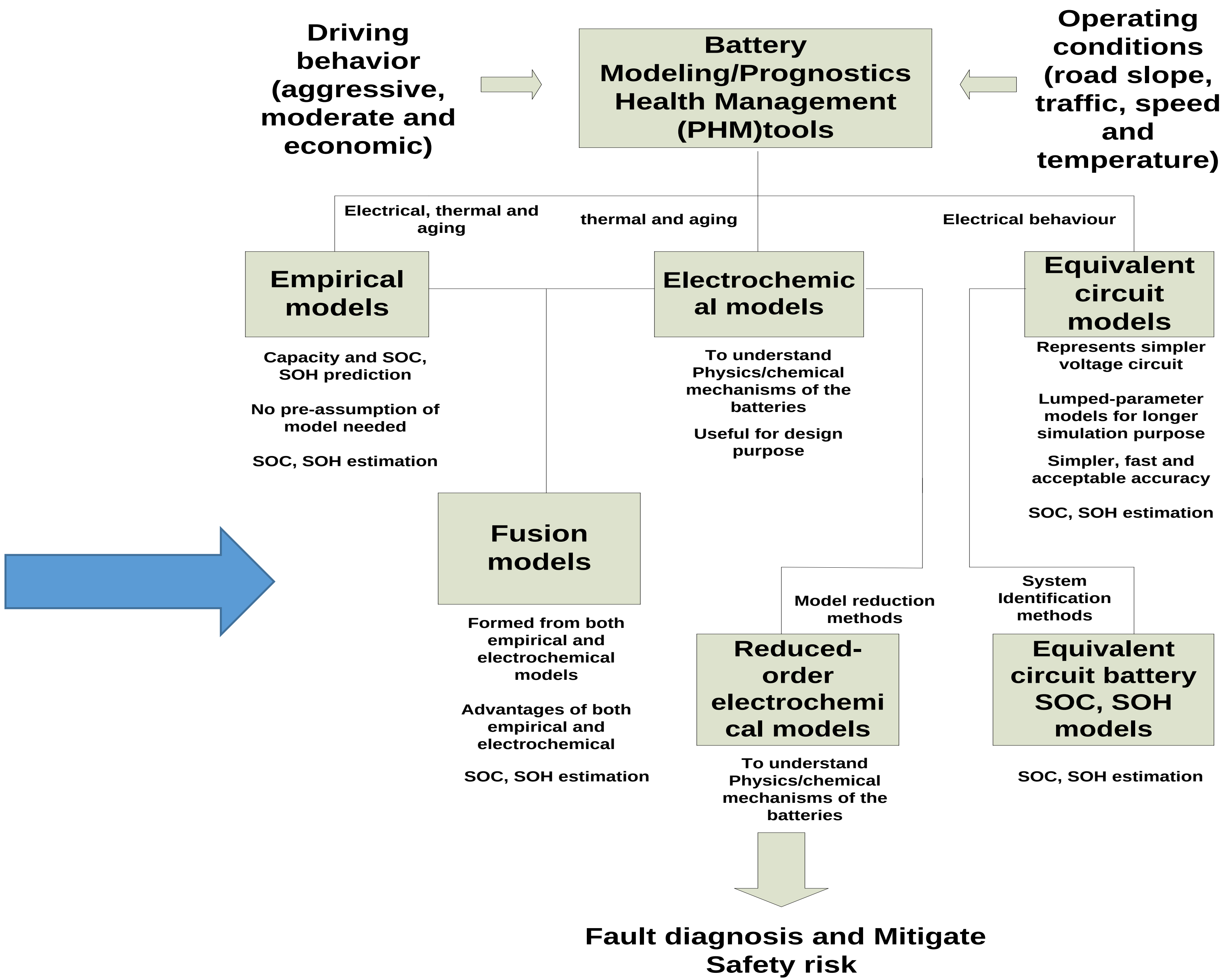
In practice some people estimate the SOH from a single measurement of either the cell impedance or the cell conductance.

3. Classification of battery models

Battery Modeling Methods

The **control of the battery management system is achieved by battery modelling**. The battery modelling is a broad term and primarily deals with ***the numerical methods for the estimation of temperature distributions, voltage measurement, battery states (SOH and SOC) and the critical current limits for charging/discharging so as to monitor the battery performance for fault diagnosis***, to mitigate safety risks and prolong the battery life span and reliability. An extensive research on applications and also development of the new numerical methods has been done to estimate the battery states.

Battery Models Classification



Empirical model

The models formulated based on only the data obtained from the experiments on batteries. One does not know inside of batteries much and so used some methods to formulate these empirical models.

Data comprises of

Discharge rate (X): Temperature (Y)

2 Ahr: 50

3 Ahr: 55

….   :   …

Empirical model (y) = f(X)

***Methods** include Genetic programming (gp), Fuzzy Logic, Kalman Filtering, Neural Networks to build empirical model*

Electrochemical model

The electrochemical models are based on the chemical processes that take place in the battery. The models describe these battery processes in great detail. This makes these models the most accurate battery models. However, the highly detailed description makes the models complex and difficult to configure.

Example of **electrochemical model consist of six coupled, non-linear differential equations**. Solving these equations gives the voltage and current as functions of time, and the potentials in the electrolyte and electrode phases, salt concentration, reaction rate and current density in the electrolyte as functions of time and position in the cell

Equivalent Circuit model

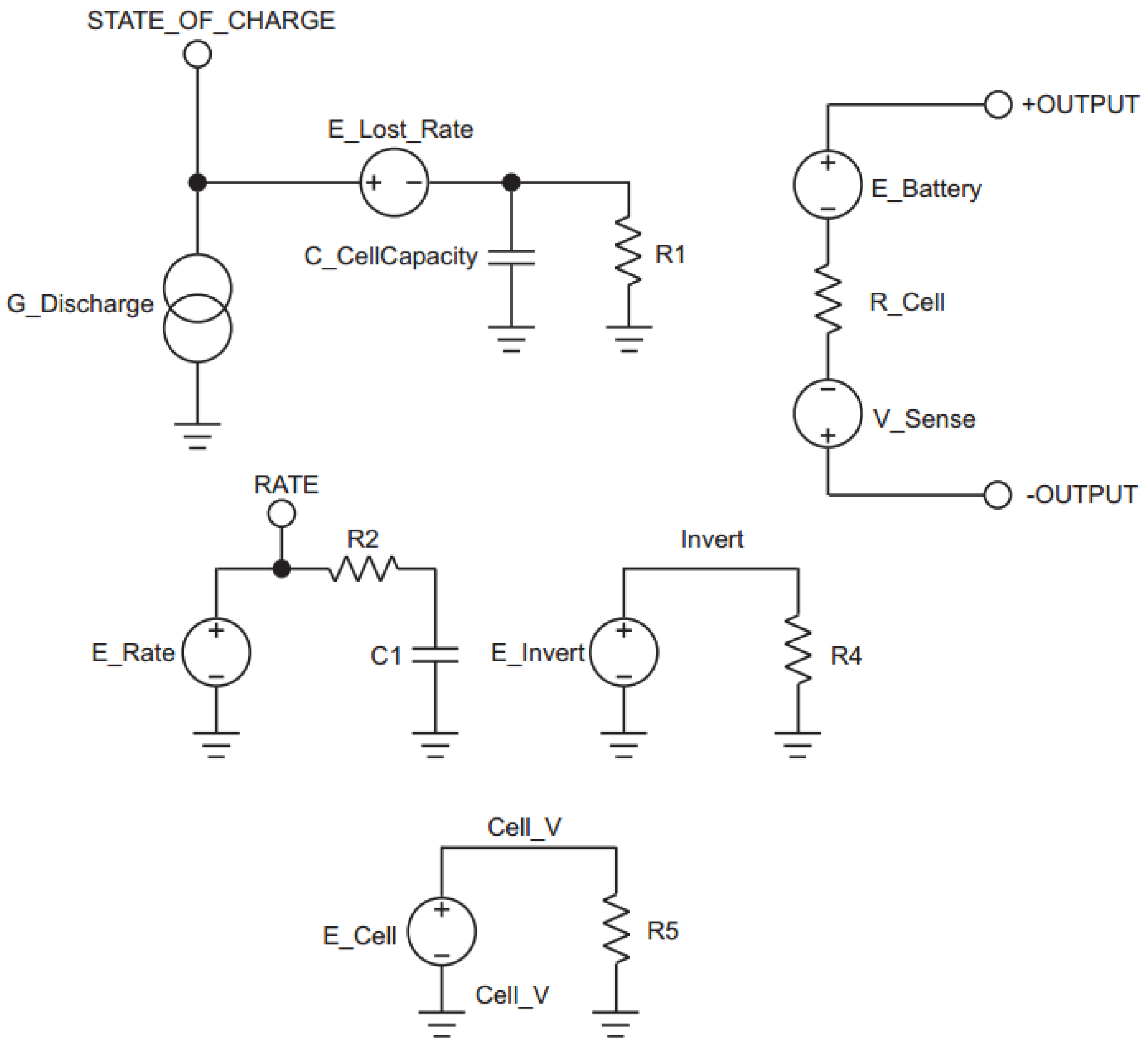


Figure shows the basic ci
for a specific cell type. Al
computationally less expensive, it still takes some effort to configure the electrical-circuit models. Especially the lookup tables used in the model require much experimental data on the battery’s behavior. Furthermore, the models are less accurate, having an error of approximately 10%.

Fusion model

The models are based on combination of **empirical and electrochemical models**. ***Data is obtained from the finite element simulation (electrochemical models) of the battery phenomenon. The quantification of data is then obtained by building empirical models using methods such as Fuzzy Logic, Kalman Filtering, Neural Networks.***

Reduced-order model

The electrochemical models based on differential equations solved in finite element softwares can be computationally expensive and time taking. Therefore, the order of differential equations can be reduced further to simplify and fasten the computation process. Thus, these are known as Reduced-order Electrochemical models.

These models are used to understand the physical/chemical mechanisms in the batteries.

4. Problems in the Models

Existing problems and Challenges

1. Uncertainties and realistic conditions based on bumpy road, crash, outside impact is not taken into while estimating state of charge and state of health.

2. Models work accurately when used offline. But, the models do not work accurately when used in real-time and online.

3. Very difficult to model the state of charge and state of health for entire battery pack when compared to a single battery/cell.

Thank you
If you have any doubts, kindly contact me!!

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