Battery lifetime

Predicting the aging effects of individual battery cells, and therefore battery lifetime, is a complex task, but crucial if the reliability and usability of EV's is to be improved. According to Troltsch et al.[1], the main aging mechanism is the growth of a surface film, also known as the solid electrolyte interface (SEI), on the negative electrode. Other physical effects occur over time, which affect the conductivity of the electrolyte and hence increase the internal resistance. The net effect is a decrease in battery capacity over time. The lifetime of the battery is the time whereby the battery capacity is above a minimum accepted capacity. As described in *Handbook of Batteries*[2], this lifetime depends on the depth of discharge (DOD), the number of cycles and the age.

Specific energy limitation

The state of health (SOH) of a battery system is a term used to describe the energy content of the battery after consideration of aging effects. In terms of EV performance, relating the State of Charge (SOC) to the SOH provides a more accurate indication of the energy remaining in the battery and thus a more accurate fuel gauge to the driver. This concept is explained with reference to the Table below. Assuming an energy usage of 0.2kWh/km and a battery with a capacity of 30kWh, a range of 150km is achieved. However as the battery ages and the capacity decreases, the range decreases. If the battery energy indicator does not consider this aging effects, the EV will have a shorter range than predicted.

Table: Effect of Battery Age on SOH

Age	SOH (% of capacity)	Range (km
Beginning of life (BOL)	100	150
Middle of life (MOL)	90	135
End of life (EOL)	80	120

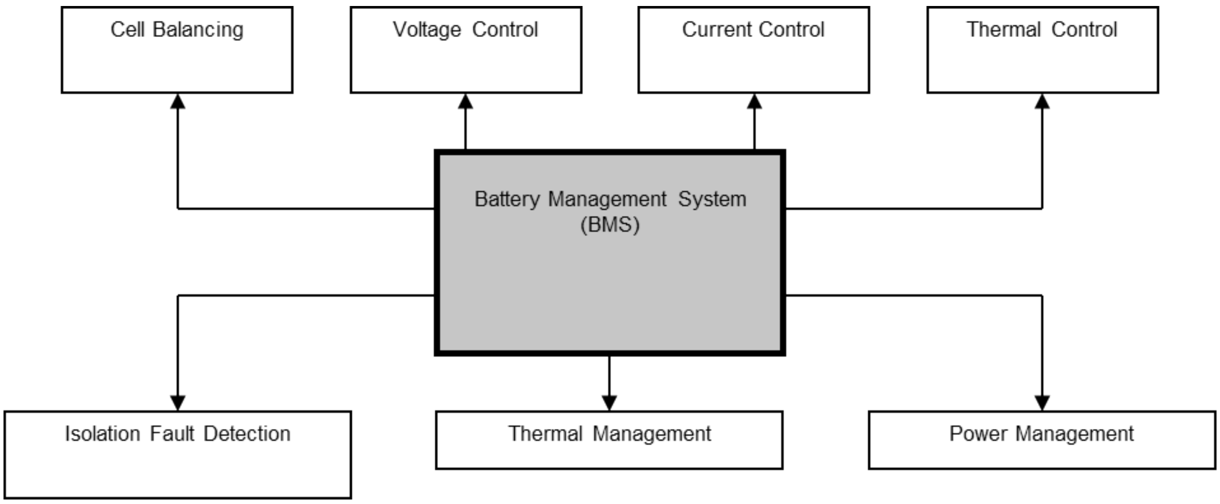
Battery Management system

Batteries for electric vehicles consist of many interconnected cells in combination forming a battery pack. Individual battery cells a show a reduction in capacity with increasing charge and discharge cycles, as well as variations in temperature. When cells are connected in a series or parallel configuration as in a battery pack, management and control of the charge and discharge conditions becomes crucial to extend the lifetime and limit ageing effects of individual cells. A battery management system (BMS) is used to monitor, control and balance the pack. The main functions of a BMS are outlined in the figure below. Without balancing the battery pack, the battery is not only risking unnecessary damage, it is also operating sub-optimally. Because the worst cell is limiting the performance of all cells in the battery pack, it is very important to prevent big differences in cell's state of charge.

The cost and complexity of a BMS depends on the functionality and intelligence built into the management system. State-of-charge (SOC) estimation is an important parameter to measure accurately, especially if EV's are integrated with a smart electrical grid.

Different methods of estimating SOC are detailed in *Battery Management Systems: Accurate State-of-Charge Indication for Battery-Powered Applications*[3].

Because the performance of battery cells varies with temperature, it is therefore crucial to include a thermal management system in the battery pack. This ensures all cells are both electrically and thermally balanced and the lifetime will be extended. Thermal management systems can either use air or liquid as the transfer medium. For integrating into the vehicle, the power consumption must be low and it must not add much additional mass. The thermal management system can realize its performance requirements using either passive or active means. A passive system using only the ambient environment may provide sufficient thermal control for some battery packs whereas active control may be required for others.



To understand the importance of the battery management system, we take a closer look inside. The BMS has the possibility to monitor and control (directly or indirectly) several different parameters of the battery:

1. Voltage
2. Current
3. State of charge
4. Temperature
5. State of health

First of all, the **voltage** of the total battery pack and of the individual cells are monitored by the BMS. The BMS can keep track of the difference between the minimum and the maximum cell voltages, and estimate if there is a dangerous imbalance in the battery pack. The charging and discharging **current** of the battery pack is essential to control, as too high current can overheat a battery and lead to a failure. Further, improper control of the charging and discharging current can lead to overvoltage and undervoltage of the battery, respectively that can harm the battery on the long run.

The **state of charge** function is extremely important to keep track on, because many batteries must not be discharged below a certain percentage. This is because, if the depth of the discharge becomes too high, some batteries can start to break down or lose their capacity. The state of charge can be determined from the measured values of the voltages and currents.

Another function is the **temperature** of the battery pack and the individual cells. Temperature is directly related to the battery lifetime, as high temperatures can degrade the battery faster. The individual cell temperature is important to know as well, to see if there are local hot spots, indicating a possible failure. Using the BMS together with the battery thermal management system can cool the battery and keep it within a nominal range. When there is a coolant available, the temperature of the intake and output coolant temperature is an important indicator of the temperature of the battery pack.

The **state of health** is a measurement to estimate the overall condition of the battery with respect to lifetime. Battery cell balancing is key feature of the BMS to help increase battery lifetime. Naturally after a while, the different cells in a battery pack will start to show differences in the state of charge and thus show localized under or overcharging. This can have multiple causes. For example: manufacturing inconsistencies, different charging/discharging currents, heat exposure and more. This is detrimental to the lifetime of the battery pack, because most cells in the battery pack are connected in series (adding voltages). This means that if 1 battery cell breaks down, the whole battery pack will seem to be broken (zero current). The BMS can perform balancing in an passive or active way. In case of passive cell balancing, passive elements such as resistors are used. This is simple but inefficient as it leads to power losses in the resistors. On the other hand, in case of active balancing, DC-DC power electronic converters are used to equalize the cells and reduce the differences between the operational state of individual cells.

Battery lifetime

Almost all electric vehicle battery systems are made with the lithium-ion battery chemistry. Lithium-ion rechargeable batteries are more sensitive to imbalance than other battery chemistries. This is because lithium battery chemistries are more susceptible to chemical damage, like cathode fouling, molecular breakdown and unwanted chemicals from side reactions. The chemical damages will occur quickly in lithium-ion batteries when slight overvoltages or overcurrents are applied. Heat accumulation inside the battery pack can accelerate these unwanted chemical reactions.

Lithium battery chemistries often permit flexible membrane structures, which makes it possible to use lightweight sealed bags , improving the energy density and specific energy of the battery. Some unwanted chemical reactions that occur when the battery is mistreated, will result in gaseous byproducts. This leads the batteries to become 'puffy' or 'balloon-like', which is a strong indicator of a failed battery. The big danger in lithium-ion batteries is the accumulation of pressure, which can lead to an explosion. The organic electrolyte contains hydrocarbon chemicals which are flammable, leading to a dangerous cocktail upon battery failure. This illustrates why a proper battery management system is crucial for lithium-ion batteries.

Techniques to improve battery life

It is clear that the BMS, through balancing, thermal management and control of voltage and current helps in improving the battery life. Another important factor that can improve battery life is to reduce the number of charge-discharge cycles and the maximum depth of discharge. The battery should not be completely charged and discharged, because this is detrimental to battery life. Furthermore, some EV manufacturers let their customers set the maximum percentage until which the battery should be filled for every-day use, and they recommend a rather low setting of around 80%, which can be increased for longer trips.

Another setting in EVs which is sometimes available is the option to limit the power output of the car. This has the downside of having lower acceleration, but it limits the discharge rate of the battery, and therefore is less detrimental to the battery.

References

1. Troltzsch, U., et al., *Characterizing Aging Effects of Lithium-Ion Batteries by Impedance Spectroscopy,* Electrochimica Acta 51, 1667-1672, 2006
2. Linden, D. and T.B. Reddy, *Handbook of Batteries.* 3rd ed. 2001: McGraw Hill
3. Pop, V., et al., *Battery Management Systems: Accurate State-of-Charge Indication for Battery-Powered Applications.* 2008: Springer Science and Business Media