1.0 Lithium-ion Battery Management System for Electric Vehicles

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1.1 : Introduction

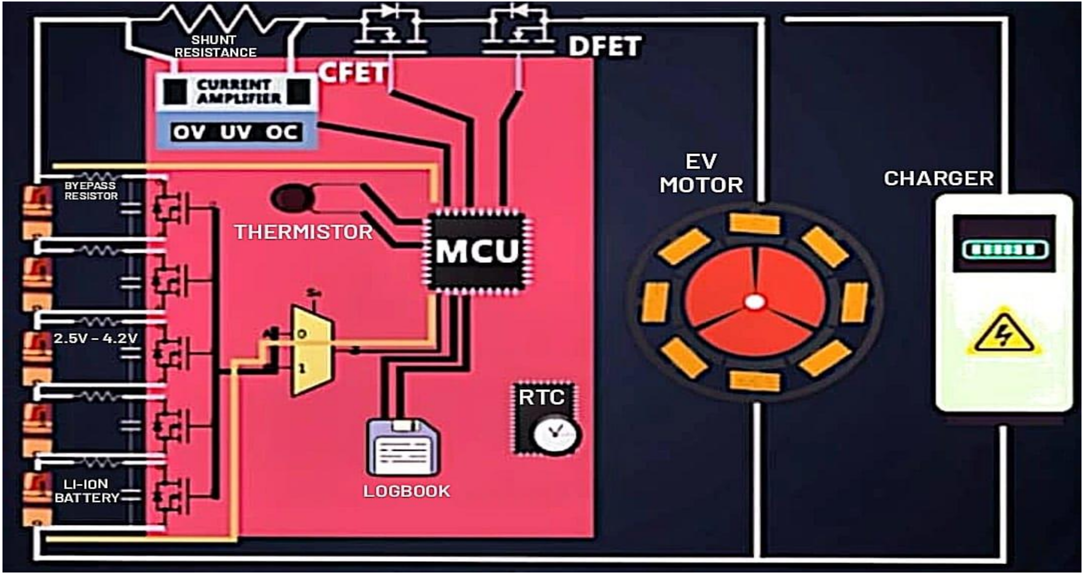
- The *BMS (Battery Management System)* is required to monitor the charge rate across the whole pack up to cell level to ensure peak performance and prolong battery life.
- The main aim of Li-ion BMS in an EV is to keep the battery within the *safety operation region* in terms of voltage, current and temperature during charging and discharging and in certain cases at open circuit.
- A Li-ion BMS for EVs (Electric Vehicles) is made up of many hardware and software *functional blocks* which has cut-off *MOSFETs* (metal-oxide-semiconductor field effect transistor), fuel gauge/current monitor, Cell voltage monitor/cell voltage balancing circuit, real time clock and temperature monitoring system.

1.2 : Cut-off FETs

- Generally, *MOSFETs* are used as cut-off FETs and they act as control switches because it is used in both depletion mode and enhancement mode unlike JEFT (junction field effect transistor) which is operated only in depletion mode. These are used for connection and isolation of the battery pack between load and charger.
- *MCU (microcontroller unit)* of the BMS measures cell voltage and current in real time and based on that it switches the FETs. It can have a *CFET (charge control FET)* and a *DFET (discharge control FET).*
- Here in the figure on the next slide, it has single connection to the charger and load *(In the case of EVs, the load is motor)*. Initially both MOSFETs are turned off. When a charger is connected, the current is not flowing because FETs are off. BMS senses the voltage at the input and then it turns on the CFET which lets the battery get charged. If the voltage at the input pin is not present then the BMS determine that the EV Motor is connected and it turns on the DFET.

Fig : Li-ion Battery Management system for Electric Vehicle

(Figure taken from BMS for EVs, ijert.org)



1.3 : Fuel gauge/Current monitor

- This block keeps the track of the charge coming in and going out of the battery pack. Total Capacity of a battery pack is measured in *Ah i.e. (I x t).* For measuring the current, a Current sense amplifier and a MCU which has an *ADC (Analogue to digital converter)* is used. A very low value current sensing resistor is connected in series with the battery line, voltage drop across this resistor is measured by the amplifier and then it amplifies the signal and delivers it to the ADC of the microcontroller. The MCU measures that voltage and calculates the charge according to time. The charging and discharging current are sensed by the *direction of the current*.
- Also, there are certain fuel gauge ICs (integrated circuits) which takes care of the *SoC (state of charge)* and *SoH (state of health)* estimation of the battery. When current rises above safety level, fuel gauge IC senses and give the signal to turn off the DFET and CFET.

1.4 : Cell voltage monitoring/ Cell balancing

- Generally, Li-ion batteries are used in EVs. The voltage of Li-ion cells ranges from *2.5v to 4.2v* and it depends on the cell chemistry. Operating the battery outside the voltage range significantly reduces the lifetime of cell. Even if the cells are created by the same manufacturer and in the same lot, the properties like internal resistance, nominal voltage and temperature imbalance will slightly differ from each other.
- While charging, if the battery pack has a weaker cell than an average cell, this would result in the weakest cell to reach out its limit first and the rest of the cells are still charging, so this weaker cell heats up and its life span decays. On the other hand, the weaker cell discharges faster than the rest of the cells and it trip the discharge limit first, leaving the rest of the cells with some charge remaining inside them. So, this can be *overcome by cell balancing*, the cell balancing is derived into two parts –

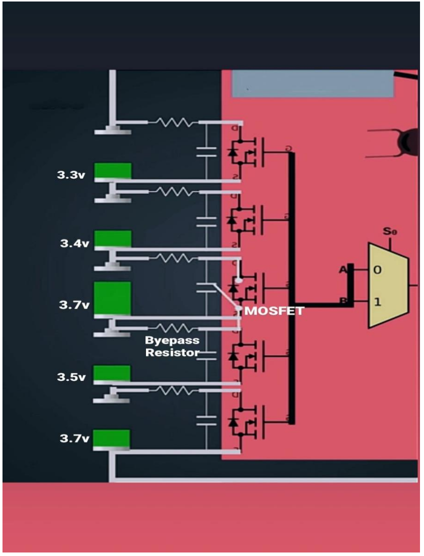
1.4.A : Passive cell balancing

A dummy load like resistor is used to discharge the excess voltage and equalize it with other cells, these resistors are known as *bypass resistors*. Each cell connected in series in a pack will have its own bypass resistor connected through a switch. While charging, the weaker cell charges very fast and the MOSFET connected across the weaker cell is turned on, the charge of this cell is removed and dissipated through bypass resistor. This process minimizes the charging rate of the weaker cell. Whenever charge level of the weaker cell tends to go near to its full capacity, the MOSFET is turned on. So, all cells along with weaker cell charge at the same time but this method is *not useful while discharging*, as the weaker cell reaches to its minimum cut off voltage earlier than the other cells.

However, this balancing technique is cheap and technically easy to implement but is *inefficient* because electrical energy is dissipated as heat in the resistors and FETs have switching losses. Also the entire discharge current flows through the MOSFET which is mostly built into the controller IC and hence the discharge current has to be limited to the lower value up to the ICs limit.

Fig : Passive cell balancing

(Figure taken from BMS for EVs, ijert.org)

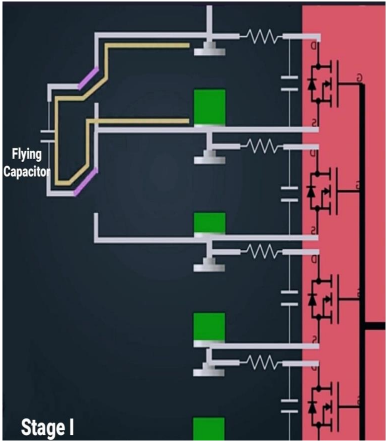


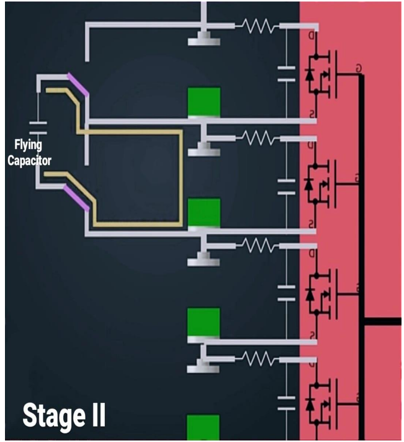
1.4.B : Active cell balancing

- Unlike passive balancing, in active balancing the charge from one cell is transferred to another cell which has low charge to equalize them. So, this can be done by charge storing components like capacitors and inductors. The Flying capacitor/ charge shuttle is the most commonly used method in active balancing. In this, the capacitors are used to transfer the charge from high voltage cell to low voltage cell.
- The capacitor is connected through SPDT (single pole double throw) switches, initially the switch connects the capacitor to the cell which has higher voltage and once the capacitor is charged then the switch connects it to the cell which has lower voltage and the charge from the capacitor flows into the cell. These capacitors are called as flying capacitors. The problem with this method is that the charge can be transferred only between adjacent cells but still this is better than passive cell balancing.

Fig : Active cell balancing

(Figure taken from BMS for EVs, ijert.org)





1.5 : Temperature Monitoring System

- Li-ion batteries provide a lot of current while maintaining constant voltage which can lead to *thermal run-away* condition that causes the battery to catch fire. The construction of a battery is highly volatile and this temperature measurement is not just for safety, it can also suggest if the temperature of the battery is suitable for charging or not.
- Generally, the *thermistors* are used as temperature sensor. The thermistor is basically a temperature dependent resistor, whenever there is a change in temperature, the resistance of the thermistor changes and the BMS calculates the temperature rise accordingly.
- The BMS also *senses the electrical insulation* and checks that the vehicle chassis is completely isolated from the high voltage battery pack at all times to prevent the user from getting an electric shock.

1.6 : Logbook & real time clock (RTC)

- The BMS acts as a *log book* to calculate the *SoH, SoC and other parameters* of the battery. So, for this purpose the BMS has to take the data according to time, so it should be working even if the vehicle is not on, but it might consume the excessive power from the battery pack itself. So, to avoid this a *RTC (real time clock)* is integrated with the BMS which needs very small power and it does our job.
- So that's a brief about the Lithium-ion Battery Management System for an Electric Vehicle.

1.7 : Conclusion

- The *MCU is the brain inside the BMS*. The MCU captures all data from the sensors through its peripherals and processes the data based on the configuration file of the battery pack to make appropriate decisions.
- The MCU having the ADC measures the voltage and calculates the charge according to time.
- Temperature monitoring ensures safety from thermal run-away and suggests suitable temperature to charge the battery.
- BMS is integrated with RTC to save power and to take data according to time.

1.8 : Recommendations

- In order to achieve charge – discharge function, *two MOSFETs in series* should be used. If only one MOSFET is used and is turned off, reverse current will flow through the body diode on discharge of Li-ion battery.
- As the load current is erratic in case of EVs, using the *Shunt resistor over a fuel gauge IC* for current monitoring and SoC estimation is always a better option. Also, using a Fuel gauge adds additional cost to the BMS design.
- Active cell balancing method using Flying capacitors is recommended for high power applications (as in the case of EVs) as it is economical and have low voltage stress, preferred during both charge and discharging.
- We should setup the BMS for energy recovery mechanism to restore the maximum applied power while the vehicle is slowing down. This method is called as *Regenerative braking*.
- In the present scenario, we can regenerate around *10-20 % of the total traction force applied*. By the time this percentage is supposed to reach *up to 80 % of the total traction force applied*. This would increase the efficiency of the Electric Vehicle multiple times and will also bring down the EVs cost, increase the EVs range and thereby making it environment friendly.