LITHIUM-ION BATTERIES HEALTH MONITORING IN COMMERCIALIZED ELECTRIC VEHICLES

Mr.P.Jeyakumar,
Associate Professor and Head,
EEE Department
Rohini College of Engineering and Technology, India

Dr.D.Samharison,
Professor,
EEE Department, Rohini College of Engineering and Technology, India

Dr. T. Sreedhar,
Associate Professor EEE Department, Rohini College of Engineering and Technology, India

K. Sathiya Sivan
Student,
EEE Department, Rohini College of Engineering and Technology, India

Abstract: In electric vehicles (EVs), battery management systems (BMS) carry out various functions for effective utilization of stored energy in lithium-ion batteries (LIBs). Among numerous functions performed by the BMS, estimating the state of health (SOH) is an essential and challenging task to be accomplished at regular intervals. Accurate estimation of SOH ensures battery reliability by computing remaining lifetime and forecasting its failure conditions to avoid battery risk. Accurate estimation of SOH is challenging, due to uncertain operating conditions of EVs and complex non-linear electrochemical significance demonstrated by LIBs. In most of the existing studies, standard charge/discharge patterns with numerous assumptions are considered to accelerate the battery ageing process. However, such patterns and assumptions fail to reflect the real world operating condition of EV batteries, which is not appropriate for BMS of EVs.

This paper deals with the problem of state of health (SOH) estimation of lithium-ion battery. In order to validate the performance of lithium-ion battery, an accelerated aging experiment of the battery is designed. Based on the interval capacity corresponding to the voltage range from 3.95 V to 4.15 V, the least square method is introduced to estimate the battery SOH. Finally, a battery test bench is established, and the effectiveness of the proposed method is verified through experiment.

***Keywords**: Electric vehicle, Lithium Ion, Battery Management System, State of Health (SOH)*

I. INTRODUCTION

According to the research undergone previously vehicles with internal combustion engines are producing 18% of the suspended particulates, 27% of the volatile organic compounds, 28% of Pb, 32% of nitrogen oxides, and 62% of the CO of air-borne pollution in US. Along which the major cause of greenhouse effect of about 25% of energy-related CO2 are released from these existing vehicles. In recent times more number of people use public and personal transportation, due to which air pollution and noise pollution increases gradually. Simultaneously, the usage of electric vehicles are becoming popular. An electric vehicle contains the major components such as an electric motor, a motor controller, a traction battery, a battery management system, a plug-in charger that can be operated separately from the vehicle, a wiring system, a regenerative braking system, a vehicle body and a frame. Among which battery management system is one of the most important components for the researchers to overcome the challenges of existing electric vehicles, especially when using lithium-ion batteries. The three types of traction batteries that are available currently are the lead-acid, nickel-metal hydride and lithium-ion batteries. Lithium-ion batteries have a large number of advantages comparatively and they can perform well if an effective battery management system is installed.

II. SYSTEM DESCRIPTION

2.1 Lithium- Ion Battery

Lithium is the lightest metal with the greatest electrochemical potential and the largest energy density per weight of all metals found in nature. Using lithium as the anode, rechargeable batteries could provide high voltage, excellent capacity and a remarkably high-energy density. However, lithium is inherently unstable, especially during charging. Therefore, lithium ions have replaced lithium metals in many applications because they are safer than lithium metals with only slightly lower energy density. Nevertheless, certain precautions should be made during charging and discharging.The Sony Corporation was the first companyto commercialize the lithium-ion battery in 1991, which has since become popular and remains the best choice for rechargeable batteries. The lithium-ion battery requires almost no maintenance during its lifecycle, which is an advantage that other batteries do not have. No scheduled cycling is required, and there is no memory effect in the battery. Furthermore, the lithium-ion battery is well suited for electric vehicles because its self-discharge rate is less than half of the discharge rate of lead-acid and NiMH batteries. Despite the advantages of lithium-ion batteries, they also have certain drawbacks. Lithium ions are brittle. To maintain the safe operation of these batteries, they require a protective device to be built into each pack. This device, also referred to as the battery management system (BMS), limits the peak voltage of each cell during charging and prevents the cell voltage from dropping below a threshold during discharging. The BMS also controls the maximum charging and discharging currents and monitors the cell temperature.

2.2 Challenges of Lithium Battery

The operating temperature and voltage are the most important parameters that determine the performance of lithium-ion cells.

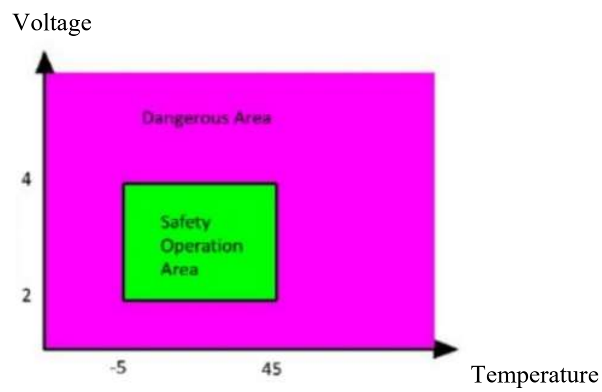

Figure 2.1 Lithium-ion cell operation window (Voltage)

Figure 2.1 and 2.2 shows that the cell operating voltage, current and temperature must be maintained within the area indicated by the green box labeled "Safe Operation Area" (SOA) at all times. The cell could be permanently damaged if it is operated outside the safety zone. The batteries could be charged above its rated voltage or be discharged under the recommended voltage. If the recommended upper limit of 4.2 V was exceeded during charging, excessive current would flow and result in lithium plating and overheating. On the other hand, overly discharging the cells or storing the cells for extended periods of time would cause the cell voltage to fall below its lower limit, typically 2.5 V. This could breakdown the electrode.

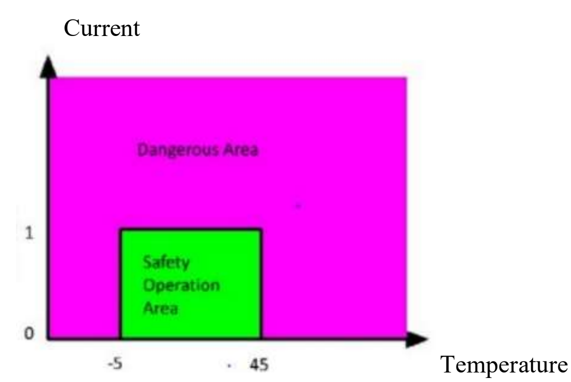

Figure 2.2 Lithium-ion cell operation window (Current)

The operating temperature of lithium-ion cells should be carefully controlled because excessively high or low temperatures could damage the cell. Temperature-related damages could be grouped into three types: low-temperature operational impact, hightemperature operational impact and thermal runaway. While the effects of voltage and temperature on cell failures are immediately apparent, their effects on the lifecycle of the cells are not as obvious. However, the cumulative effects of these digressions may affect the lifetime of the cells. Figure 2.3 shows that the lifecycles of the cell would be reduced if its operating temperature falls below approximately 10 °C. Similarly, their lifecycles would be reduced if the cells were operated above 40 °C. Furthermore, thermal runaway would occur when the temperature reached 60 °C. The thermal management system, which is part of the BMS, must be designed to keep the cells operating within its limitation at all times.

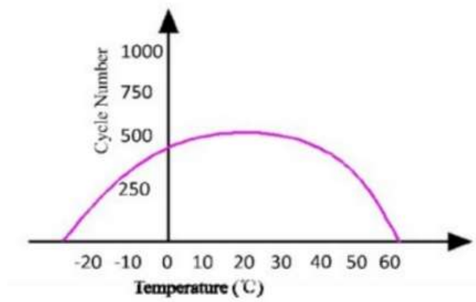

Figure 2.3 Lifecycle versus operating temperature of Li-ion cells

It is clear from the discussion above that the goal of the BMS is to keep the cells operating within their safety zone; this could be achieved using safety devices such as protection circuits and thermal management systems.

2.3 Battery Management system

There are different types of BMSs that are used to avoid battery failures. The most common type is a battery monitoring system that records the key operational parameters such as voltage, current and the internal temperature of the battery along with the ambient temperature during charging and discharging. The system provides inputs to the protection devices so that the monitoring circuits could generate alarms and even disconnect the battery from the load or charger if any of the parameters exceed the values set by the safety zone. The battery is the only power source in pure electric vehicles. Therefore, the BMS in this type of application should include battery monitoring and protection systems, a system that keeps the battery ready to deliver full power when necessary and a system that can extend the life of the battery. The BMS should include systems that control the charging regime and those that manage thermal issues. In a vehicle, the BMS is part of a complex and fast-acting power management system. In addition, it must interface with other on-board systems such as the motor controller, the climate controller, the communications bus, the safety system and the vehicle controller.

- LV-BMS architecture

The proposed system is designed to combine the functions of cell balancing, charger, discharger, cell monitor, and protection. These functions are carried out autonomously and the energy is provided from the internal battery. Furthermore, the proposed system is flexible, modular and extensible. It can be used with Li-Ion and Li-Po type batteries due to their similar usage limits. To accomplish the aim of the study, extruded batteries should be charged with active batteries. However, batteries must be connected in series to charge in general BMS. To overcome this problem, the battery charging line is connected in parallel and charging is carried out with low voltage by using parallel charging lines. The system consists of 4 units: the control unit, battery switching unit, measurement unit and charging unit. The control unit processes the data it collects from the measurement unit and determines the condition of the battery switching unit and charging unit. The measurement unit monitors the battery voltage and the instantaneous current of the battery. The battery switching unit ensures that the battery is isolated from the power line. The charging unit implements charging algorithms for different battery packs and battery types.

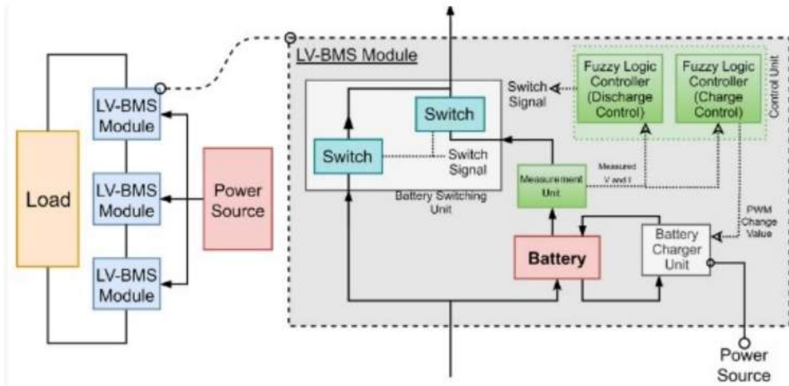

Figure 2.4 Low voltage battery management system (LV-BMS) block diagram

In order to achieve low power consumption, transistors with low drain-source resistance (Rds) were selected. MOSFETs can be switched via logic levels to avoid the usage of an external gate driver. The microcontroller is selected to have low power consumption and operate directly with the battery voltage range. Foregoing the voltage regulator also decreases the total power consumption. The energy that needs to be supplied from the batteries is reduced because the energy required for the charging structure is provided by the charging line contains the list of components used in the LV-BMS architecture.

- Battery switching unit

The battery switching structure consists of five MOSFETs and a schottky diode. NPN MOSFET is used as the auxiliary element for the control of PMOS transistors. The switching unit is located in each module. The energy for the unit is provided by the battery. The gate signal of the auxiliary MOSFET is provided directly by the microcontroller. Due to the low Rds resistance of the MOSFETs used in the switching unit, an external gate driver and voltage converters are not used. A schematic of the battery switching unit is shown in Figure 2.5. The charging of the batteries can also be performed while the batteries are discharged. As a result, the complexity of the structure is simplified and the number of components used in the structure is reduced.

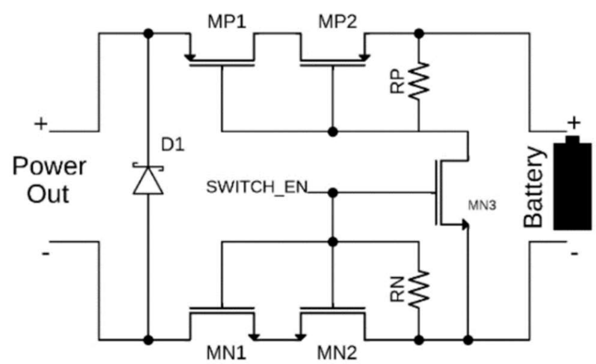

Figure 2.5 Schematic of the battery switching unit.

The drain nodes of the PMOS transistors are connected to each other and the source nodes of the NMOS transistors are connected to each other. According to the connection of the transistors, the battery is separated from the power line. The gate voltages of PMOS and NMOS transistors are connected to the positive and negative terminals of the battery using pull-up and pull-down resistors, respectively, so it is ensured that transistors are turned off. When the gate signal of MN3 is increased by the microcontroller, the MOSFETs (MN1, MN2, MP1, MP2) are turned on and connect the batteries to the power line. Battery pack configuration examples are provided in Figure 2.6 all three cells are active and the total voltage of the cells is 10.3 V. In two cells are active and the second battery is out of use, and the energy stored by the batteries that are available for use is transferred to the power line through transistors. After the second battery is excluded from the system, the current flows through the diode element in the transmission mode.

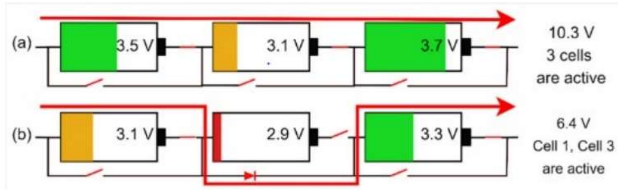

Figure 2.6 Battery pack configuration examples (a) 3 cells active (b) 2 cells active

- Battery Charging Unit

One of the purposes of this study was to charge the serial connected cells with a low voltage such as 5 V. In this regard, the batteries should be charged in parallel. Thanks to the proposed structure, solar panel and power supplies with different voltage levels can be used for charging.

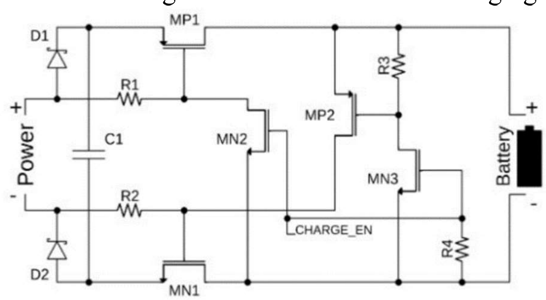

Figure 2.7 Schematic of the battery charging unit

The charging unit supports up to 2 A charging current and for a 5–8 V input voltage range; but the charging current is software-limited to 1.2 A in order to avoid problems during use with different battery models. Figure 2.7 shows the schematic of the charging unit. Gate voltages of MP1 and MN1 are not directly connected to the battery cells. When the charging source is connected, the gate voltages are provided by the charge line via diodes D1 and D2. When the charging adapter is not connected, the C1 capacitor is charged from the battery cell via MOSFET body diodes and MOSFET gate voltages are supplied by this stored energy. In this way, the gate voltages of the transistors are provided continuously and the MP1-MN1 transistors remain off.

III. SYSTEM MODELLING

3.1Implementation of an Intelligent Digital Battery Management System

This design is a lithium battery management control system designed with STM32F103C8T6 microcontroller as the core. In addition to the conventional voltage and power collection circuit, the system also has a discharge current collection circuit and a temperature collection circuit.

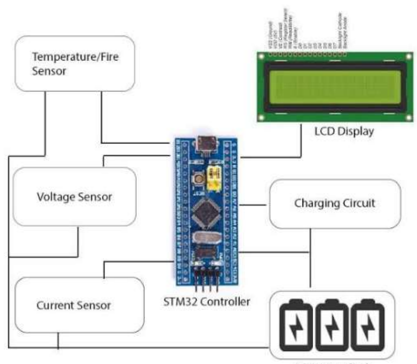

Figure3.1 Implementation of an Intelligent Digital Battery Management System

The voltage is collected through the A/D digital-to-analog conversion of the microcontroller; the discharge current is collected through the ACS712 current collection sensor, the DS18B20 temperature sensor detects the ambient temperature, and the key circuit can set the lower limit of SOC, thus realizing the monitoring of the voltage and SOC of the lithium battery, and alarming when the SOC is lower than the set value. The Li ion battery management system has a reasonable and scientific design, good feasibility, low cost, simple operation, stable performance and easy to use for daily monitoring.

IV. RESULT & DISCUSSION

The circuit was designed experimentally with LCD for displaying the result.

Figure4.1 Relay RCC L90CSDC12V

The continuous monitoring system shows the change in values of voltage, current and temperature by which the automatic tripping relay will trip the circuit for system reliability.

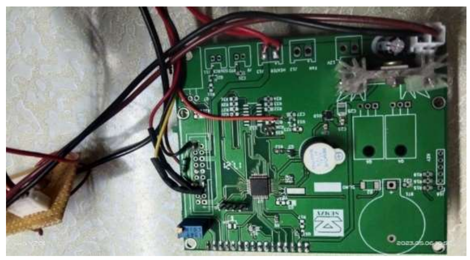

Figure 4.1 Hardware circuit design of the electric vehicle with digital battery management system.

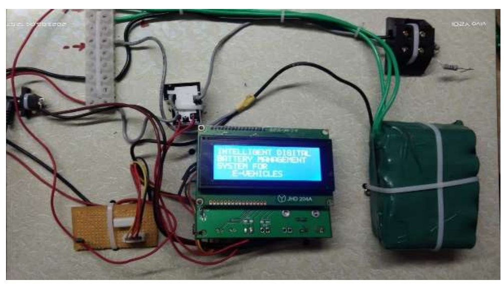

Figure 4.2 Display of Digital Battery Management System

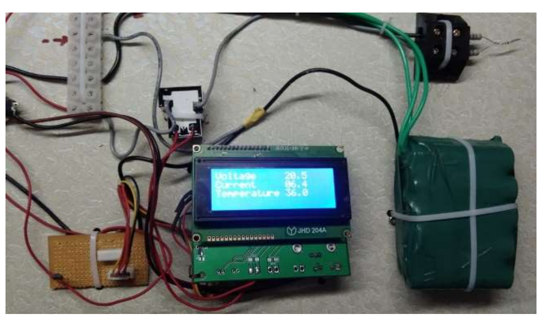

Figure 4.3 Voltage, Current and Temperature of Li- ion battery of electric vehicle

The voltage, current and temperature are being monitored, if any changes in voltage, current or temperature beyond the reset limits the relay in the circuit will get tripped automatically so that the battery can be saved and can last long.

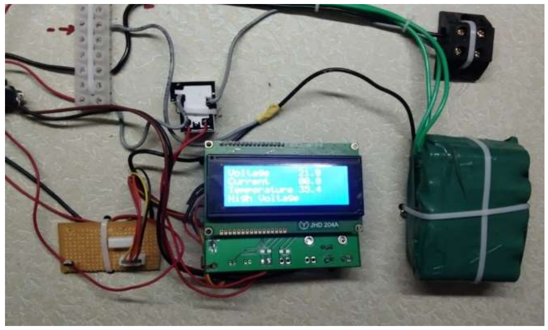

Figure 4.4 Voltage, Current and Temperature of Li- ion battery of electric vehicle (HV)

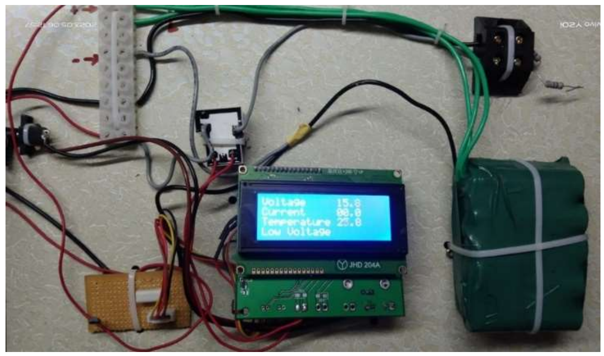

Figure 4.5Voltage, Current and Temperature of Li- ion battery of electric vehicle (LV)

Here in figure 4.4 and 4.5 the battery management system has managed to display the voltage,current and temperature during High Voltage and Low Voltage respectively.

V. CONCLUSION

For an even more pollution free environment by which our future generation can also enjoy the eco-friendly nature, this invention of electric vehicle gathered everyone's attention. But the drawbacks in it like voltage, current and temperature fluctuations can be comparatively reduced using this digital battery management system by means of continuous monitoring of their limits and auto- tripping system will make the vehicle more reliable.

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