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# Development and Simulation of 48V Li-ion Battery management system for Electric vehicles

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## Abstract.

Battery Management Systems (BMS) are being utilized in many commercial systems to use the battery efficiently and estimate battery state to enhance the life of battery and limit it entering destructive state. For this purpose, some very important monitoring techniques are employed to monitor the state of charge of battery, temperature and current. The proposed project, Battery management system for battery powered Electric Vehicles (EV) evaluates the battery performance like temperature, charging/discharging current, State of Charge (SOC) and other battery parameters. The system supports 16 Series cell battery pack of voltage up to 48V.

**Keywords**— Battery management system, Cell balancing, fault detection, state of charge, state of health, Analog Front End (AFE).

## 1. INTRODUCTION

Automobiles exhaust is one of the key contributors for air pollution in the atmosphere. The main agenda of the electric vehicles, concerns about air pollution caused by petroleum vehicles exhaust emissions. Electric vehicles are the future of transportation and are equipped with batteries and can be re-charged with electricity. The batteries supply the energy required for the electric motors to propel the vehicle forward using a series of propulsive electric motors. Plug-in Hybrid Electric Vehicles (PHEVs), Hybrid Electric Cars (HEVs), and Battery Electric Vehicles (BEVs) are the three primary types of electric vehicles (EVs) categorised by the degree to which electricity is used as a source of energy. The interest in EV batteries can be traced back to the mid-19th century when the first EV came into existence. The most prevalent electrical energy storage device for EVs is batteries.

The lithium ion batteries are very sensitive in nature as they should not be over charged, over discharged and should not be operated at high temperature. So, these batteries should be monitored to make it to operate in specified working environment. In electric vehicles, a battery management system (BMS) monitors the battery's operation and status, as well as to protect the battery. So, BMS can be used for smart battery management and maintenance. For electric vehicle batteries, BMS needs to monitor battery status to avoid over-charging and over-discharging of the battery, estimate SOC and SOH to prolong battery life.

## 2. LITERATURE SURVEY

The architecture of BMS has 3 main components i.e., the BMS IC and Microcontroller (8 bit/16bit) and battery pack [1]. BMS senses the cell parameters like, voltage and current measurement, cell balancing during charging and discharging, Over Voltage, Under Voltage, Over Current.

Type Energy	Efficiency (%)	Energy Density (Wh/kg)	Power Density (W/kg)	Cycle life (Cycles)	Self-discharge
Lead-acid	70 - 80	20 - 35	25	200 - 2000	Low
Ni-Cd	60 - 90	40 - 60	140 - 180	500 - 2000	Low
NI-MH	50 - 80	60 - 80	220	3000	High
Li-ion	70 - 85	100 - 200	360	More than 2000	Medium
Li-polymer	80-90	200	250 - 1000	More than 1200	Medium
LFP	90	325	260	More than 1200	Negligible
Fuel Cell	50 - 80	250 - 350	800 - 1200	More than 2000	Negligible
Super Capacitors	95	0.3 - 0.5	2500	More than 30 000	high

**Table 1:** Battery characteristics.

The table 1 shows the characteristics of various battery chemistries [6] and Li-ion batteries are widely utilized in applications such as electric automobiles and electric bicycles because of their high energy density, low discharge rate, high cell voltage, and lack of memory effect. Furthermore, the SOC and internal impedance of the battery cells constantly vary. This means that if the weak cell reaches the protection limit while the remaining cells in the series continue to power the system, the battery pack will no longer be usable. This will reduce the battery pack's capacity and efficiency.

Individual battery cells are combined to form a pack in this article, which presents a unique battery management method. As a result, each battery is individually monitored in order to increase the Li-ion battery pack's dependability and capacity. Due to their high energy density, high charging and discharging efficiency, and other qualities, lithium batteries are increasingly being preferred over lead acid batteries by electric bicycle manufacturers [6]. The battery management system can continuously monitor the voltage, current, temperature, energy storage, and Health of the battery pack, as well as communicate data to the Application end user.

## 3. BATTERY MANAGEMENT SYSTEM

Battery management system is an efficacious electronic system that monitors the single cell and whole pack, connected in series and parallel combination and loaded with algorithms to protect the cells and battery pack from being operated outside its safe operating region and monitoring its state, cell balancing, reporting that data, calculating data, controlling its operation depending on real-time parameters.

Parameters calculated are:

- **SOC (State of Charge):** The ratio of remaining charge in the battery to the total charge/ maximum charge of the battery is defined as the **State of Charge**. This algorithm is used to estimate the percentage of the battery charge available for the usage. This can be calculated by monitoring the cell voltage, coulomb counting, by estimating depth of

discharge (DOD) and Kalman filter method. SOC estimation depends on types of electrolytes used in battery, operating condition, internal resistance (increases with aging), Battery aging, temperature change. SOC can be estimated by equation mentioned below.

$$\text{SOC} = \frac{\text{capacity remaining}}{\text{total capacity}} = \text{SOC}(t_0) - \left( \int \frac{I(t)}{\text{Capacity}} dt \right)$$

▪ **SOH (State of Health):** The ratio of present battery capacity to the total charge/ battery capacity at beginning is defined as the **State of Health**. The health of the battery depends on the environment which pack being used and its aging. The conditions that are affecting the battery health should be monitored and rectified to enhance the battery life. SOH can be estimated by equation mentioned below.

$$\text{SOH} = \frac{\text{present total capacity}}{\text{capacity at beginning}}$$

▪ **SOE (State of Envelope):** It is the operating area with respect to voltage, current and temperature boundary. This helps detecting fault, which helps to increase the battery life and hence the health of the battery maintained well.

• **Safety and fault management:** It is related to SOE, which defines the algorithms like SOA (Safe operating area), operating area within voltage, current and temperature limits.

Other operations of the battery management system are to provide Cell balancing, estimating the DOD, limiting C-rate, preventing thermal run away, as these may affect the performance.

#### 4. PROPOSED METHOD

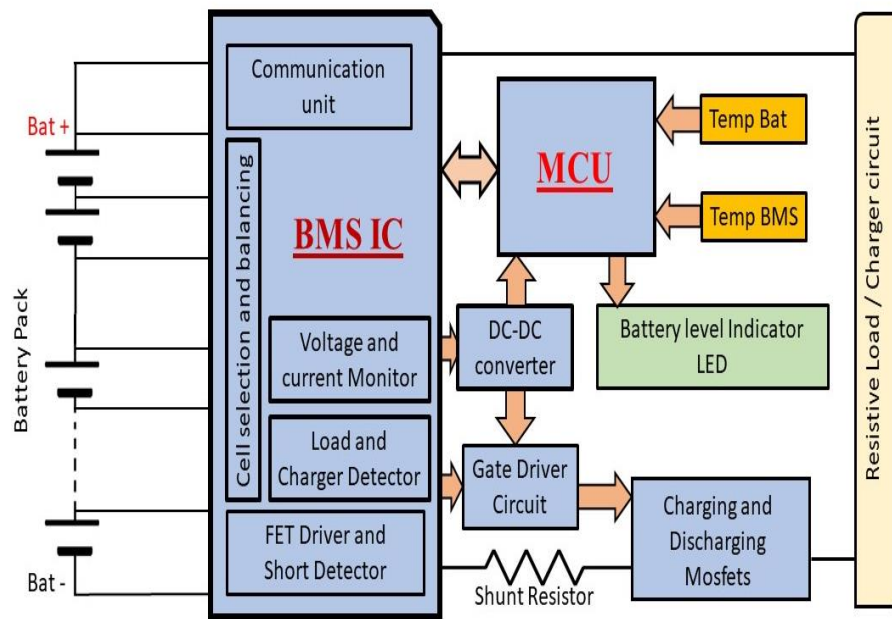
Usually a BMS consists of Battery pack, BMS IC, MCU and switches connected to load <sup>[2][3][6]</sup>. Fig 1 shows the block diagram of the Battery management system and it consists of the battery pack connected to the battery management IC (ML5238 by LAPIS) through discharging resistors. On the low side of pack, FETs for the charging and discharging are connected.

The microcontroller (ML62Q1367) monitors the battery parameters continuously and makes sure that battery is operating in safe operating area. The load and charger are connected at same terminal but the BMS IC decides whether it has to charge/discharge the battery.

ML5238 (BMS IC) is an Analog Front End IC for 16 series Lithium Ion battery pack protection system <sup>[8]</sup>. ML5238 has built-in SPI communication feature and provides functionalities like of cell voltage monitoring, cell balancing, charge/discharge current monitoring function, and it can detect over charge, over current and over discharge. This also provides built-in short current detecting function which can turn off the external charge/discharge MOS-FET without external MCU.

ML62Q1367 (MCU) is 16-bit RISC CPU microcontroller [7], which can operate at 16 MHz clock frequency, supports SPI communication and is chosen as the controller for the system.

MCU monitors the BMS IC continuously to monitor the battery parameters [9].



**Fig 1:** Block Diagram of BMS.

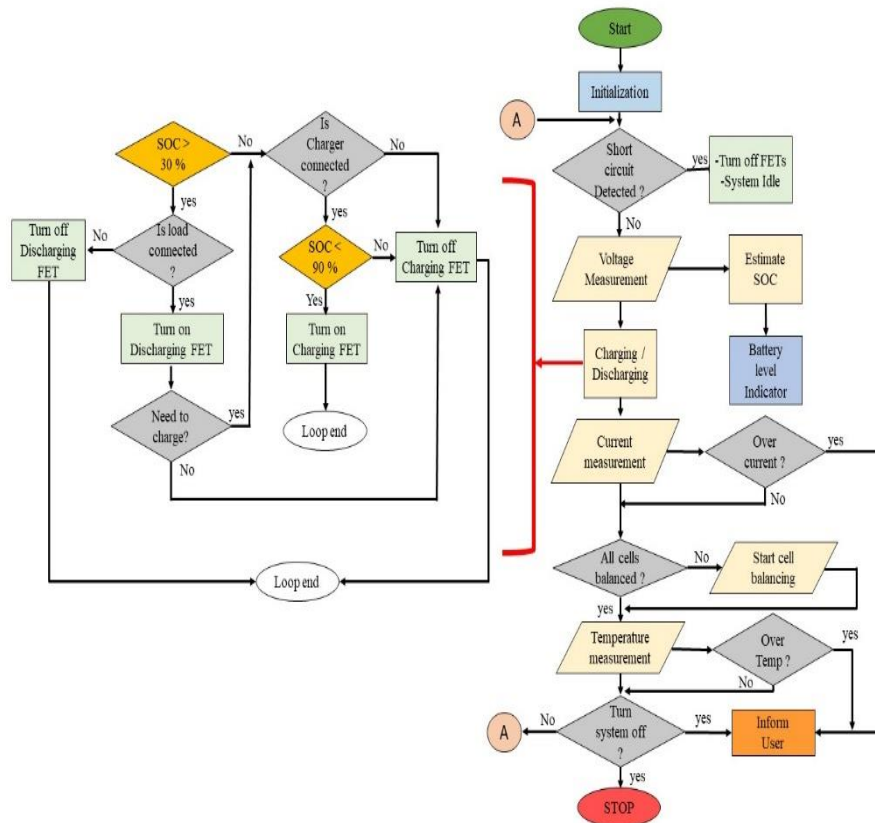
BMS IC monitors the voltage of each cell in the battery pack and estimates the battery pack voltage and current flowing in and out of the battery pack and outputs to the MCU. The MCU retrieves the voltage and current parameters from the BMS IC and estimates the lowest cell voltage in the battery pack. The MCU writes into the BMS IC to perform the cell balancing for high voltage cell, to make charge equal throughout the pack. MCU reads the voltage of cells from the BMS IC and estimates the SOC of the battery pack. Communication between the MCU and BMS IC happens by SPI protocol.

MCU retrieves the status of load and charger connection from the BMS IC. Depending on our requirement and the battery voltage level, MCU makes the BMS IC to generate gate signal for the FET's by considering whether it has to charge or discharge. Also, the MCU performs the temperature monitoring of the entire system including the battery pack.

Buck regulator IC, BD9G341AEFJ, brings down the battery pack voltage to the level required for the operation of Gate driver IC - BD2310G, which generates the gate pulses for

Charging and Discharging MOSFETs. The output from the buck converter is also used for generating 5V using Low Dropout Regulator (LDO - BD433M2FP3).

Fig 2 represents the flowchart of the Battery management system for method proposed, which also shows the firmware <sup>[5]</sup> operation sequence.



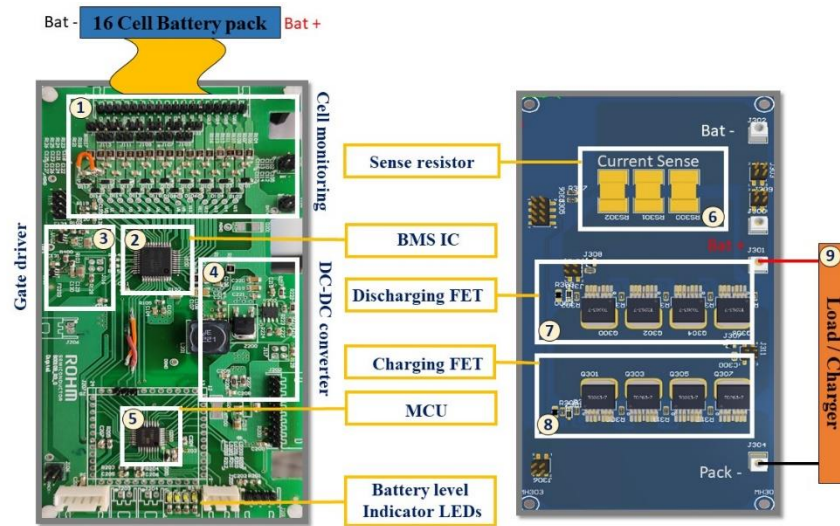
**Fig 2:** Flowchart of firmware for BMS

## 5. HARDWARE

The hardware circuitry consists of two boards: A Digital board (low voltage board) and a power board (high current board). In fig 3, The digital board (left side board) includes cell monitoring, discharging resistors, AFE BMS IC, DC-DC converter, the microcontroller and the gate driver circuit. The power board (right side board) includes the charging and discharging Mosfets and current sensing resistors.

In fig 3, Section 1 shows the cell monitoring section and the discharging resistors for the cell balancing. Battery pack of 16 series cells is connected for battery monitoring through the discharging resistors to consume 130mA (200 mA - max) current while cell

balancing. Section 2 shows the BMS IC, where cells to be monitored are connected. Section 3 shows the gate driver for driving the charging and discharging FETs. Section 4 shows the DC-DC step down converter to drop battery pack voltage to the voltage level for the gate driver and for the MCU power up and Section 5 shows the MCU used for controlling the BMS IC with the set of algorithms written into it.



**Fig 3:** Hardware rig-up of BMS using ML5238.

Metal clad copper PCB board of  $115\mu$  thickness is used for the power application section of the BMS, which has high current carrying capability up to 200 A. Section 6, shows the current sensing resistors connected in parallel. Here,  $5\Omega$  is used as current sensing resistor, as testing is carried out to sense the low current<sup>[4]</sup>. Section 7 and 8, shows the MOSFET used for the charging and discharging. The Mosfets used can handle up to 100V voltage and 200A current. section 9, shows the load/charger connected to the power board.

## 6. SIMULATION

Simulation circuit is designed for the 48V BMS in MATLAB Simulink. The circuit can perform real-time monitoring of battery cell voltage, cell balancing and charging and discharging as per our requirement. Bi-directional converter is used between the battery and the charger/load for efficient charging and discharging process<sup>[3]</sup>. The simulation circuit is shown in fig 4 below. Two 24 V battery packs are chosen and set to operate as lithium-ion battery chemistry. Every pack is connected to the discharging resistors through the Mosfets for cell balancing.

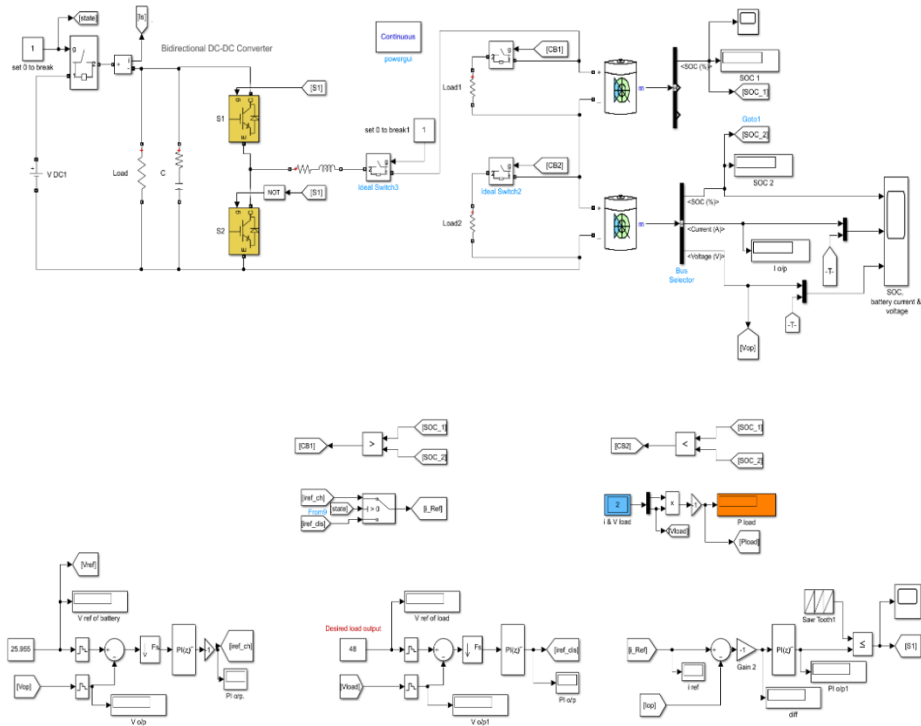


Fig 4: Simulink model for BMS.

## 7. RESULTS AND DISCUSSIONS

### 8.1.1 Hardware

The system designed for the battery management can perform the real-time monitoring of the Battery pack and each cell of pack for its voltage measurement, cell balancing, current and temperature monitoring. The BMS limits the battery pack from being over charged and discharged and make it to operate in the safe operating area. Fig 5 shows the voltage monitoring of each cell and current of the pack. The BMS system also indicates the remaining charge (SOC) of the battery by LED indicators.

0.5 mA  
-Current  
measured  
by the sense  
resistor in mA.

**Note:** A battery  
pack of 8 cells, 27V  
voltage is used for  
testing purpose.

Expression	Type	Value	Address
(x)- I_sense	float	5.06520092e-01	0xef84
(x)- V8	float	3.35074210e+00	0xefd8
(x)- V9	float	3.43617177e+00	0xefdc
(x)- V10	float	3.42667961e+00	0xefe0
(x)- V11	float	3.44566417e+00	0xefe4
(x)- V12	float	3.24632812e+00	0xefe8
(x)- V13	float	3.44566417e+00	0xefec
(x)- V14	float	3.44566417e+00	0xeff0
(x)- V15	float	3.42667961e+00	0xeff4
(x)- Vtotal	float	2.72235947e+01	0xef8c

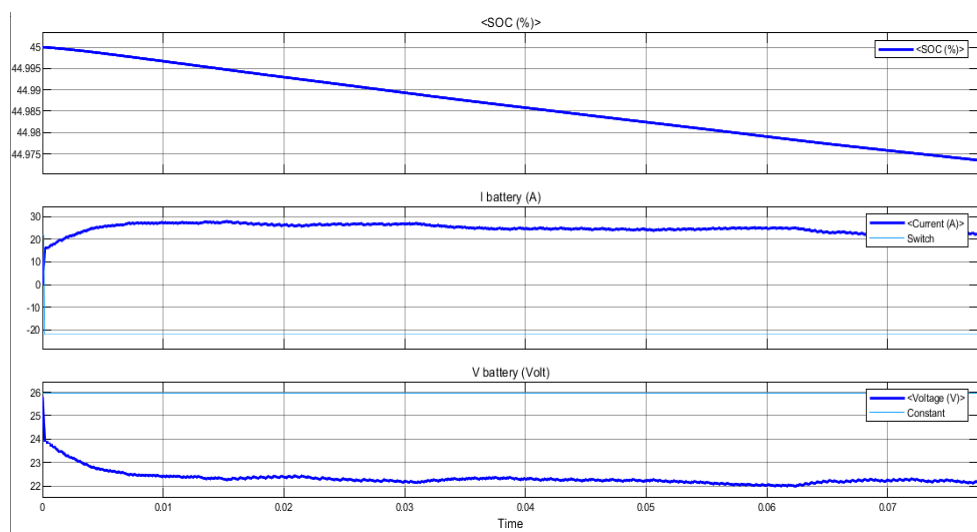
Represents the voltage  
of each cell and Vtotal  
represents the Total  
pack voltage

**Fig 5:** ADC voltage reading of cells

How proposed method is different from the existing? – The BMS IC used in this work supports 16 series Li-ion cells and consume less power in its normal state and power down state when compared to other IC's. The IC provides the separate bits for increasing the gain of the parameters measured, so, the small values can be measured very accurately and increase the protection of the battery. It has built-in function to detect the short circuit and if short circuit is noticed, BMS IC will turn off the charging and discharging Mosfets without instruction from the MCU. This has become the independent operation for protection.

### 8.1.2 Simulation

Circuit designed in the MATLAB can perform cell Voltage monitoring, cell balancing function and current measurement function. Fig 6 shows the plot of the SOC decreasing and current consumed by the load.



**Fig 6:** SOC, current and voltage of the battery.

The simulation is carried out with operational logic of BMS IC and the microcontroller and the hardware is carried out with large resistive load (compared with simulation) to limit the current drawn from the battery pack. The above figure shows the discharge waveform of the battery pack with current drawn up to 30A with slight sag in the voltage and when discharging is stopped, voltage comes to normal (voltage will be decreased over time, as it is in discharging state). The voltage sag of 2V is observed, as every source has current limitation, if current drawn exceeds that limit, supply voltage decreases to match the power delivery and when load is disconnected, voltage comes back to actual terminal voltage of the pack at that time after discharging.

It is observed that the hardware and simulation designed for 48 V battery management system performs the on demand basic operations of BMS efficiently and the parameters estimated in the hardware are also obtained from the simulation accurately.



## 8. CONCLUSION

In this work, Battery Management system used in EV applications is simulated and tested the hardware topology for functionalities like, operation and safety. In this research, our primary focus was to develop hardware to implement all the basic functionalities for a battery management system. The desired area of application is automotive sector and all the algorithms and designs were considered for the same. Ample literature survey was conducted initially to understand the requirements of a battery management system for EV's and based on the that information a basic BMS hardware was developed. The hardware and firmware prioritize better battery usage and thereby maintaining good battery health.

In the hardware section, the Analog Front End IC was integrated with various sections like a microcontroller, DC-DC converter, Charging and discharging FET's, Fuel gauge, temperature sensor and a SPI interface. Features like cell voltage and current monitoring, Cell balancing, Temperature monitoring and charging/discharging were controlled by firmware. The designed system can be configured for a 48V battery EV by considering the operating environment.

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