*ISSN(Online)* : *2456-8910*
International Journal of Innovative Research in Applied Sciences and Engineering (IJIRASE)
*Volume 2, Issue 9, DOI: 10.29027/IJIRASE.v2.i9.2019, 325-331 , March 2019*

# LITHIUM-ION BATTERY PACK AND BATTERY MANAGEMENT SYSTEM FOR AN ELECTRIC VEHICLE

Karthik D M
Department of Automation and Robotics
KLE Technological University
Hubballi, India
karthikdm1997@gmail.com

Kaviraj Doddamani
Department of Automation and Robotics
KLE Technological University
Hubballi, India
kaviadh08@gmail.com

Arun C Giriyapur
Head of Department
Department of Automation and Robotics
KLE Technological University
Hubballi, India
aroon@kletech.ac.in

***Abstract*— Environment pollution is increasing due to the very large number of gasoline-powered vehicles present today. To reduce environmental pollutions and Energy crisis electric and hybrid electric vehicles are very beneficial. Electric vehicles are powered by traction motor or electric motor (AC or DC) powered by the battery through the electric converter. Different types of batteries are available to power the electric vehicle like lead-acid, lithium-ion, lithium-polymer etc. Most suitable battery chemistry for electric vehicles is lithium-ion because of its discharge characteristics, high energy density, and low self-discharge etc. Despite its overall advantages lithium-ion batteries have some disadvantages. These batteries require a protection and monitoring system to operate battery in a "safe operation area". Proposed Battery management system [1] has functions such as charging and discharging control, cell balancing, SoC monitoring, and thermal management and control of the battery and BMS.**

***Keywords- Electric vehicles, Lithium-ion battery, Battery management system, Cell balancing.***

## I. INTRODUCTION

Lithium metal is the lightest metals with the highest electrochemical potential and the highest energy density. Despite its advantages, lithium-ion batteries [2] have some disadvantages. However, lithium-ion batteries are highly unstable while charging. So that lithium-ion batteries should operate only in "safe operation area (SOA)". The cell could be permanently damaged if it's operated outside the safe operating area.

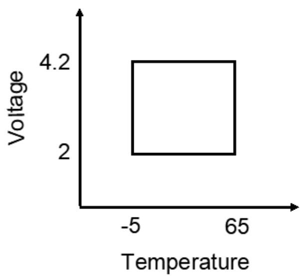


Figure1. Lithium-ion cell operation

In lithium-ion cells, lifecycles of the cell would be reduced if its operating temperature falls below 10℃ and above 40 ℃ . Furthermore, thermal runaway occurs when the temperature above 55℃. So thermal management system in the battery management system is must be designed to keep its cells should operate within its operating temperature range. Battery management system (BMS) is the intelligent control system behind the battery pack, it controls the battery from abuse damage, manage the output, charging and discharging system and provide the notification to the user. In this proposed intelligent battery management system discus about an implementation of some BMS functions such as charging and discharging control, bypass cell balancing, state of charge (SoC) identification using coulomb counting algorithm, adaptive cooling system for the thermal management and control, data acquisition system and protection system such as short circuit protection and reverse polarity protection system.

The fundamental importance of battery and battery management system [3] is to keep cells in a safety zone means safe operation area. This system could be achieved by protection circuits, cell balancing algorithm, and thermal management system.

## II. DEFINITION OF BATTERY MANAGEMENT SYSTEM

Definition of the battery management system could differ depending upon the application.
1. It should monitor and control the charging, discharging.
2. It should reduce the risk of damage to the battery pack
3. It should ensure that energy of the battery pack must be ready to power the product or vehicle.

## III. OBJECTIVE OF THE BATTERY AND BATTERY MANAGEMENT SYSTEM (BMS)

The BMS should follow these typical objectives
1. BMS should protect all the cells from any damages.
2. BMS should extend the life of the cells.
3. It should properly maintain charging, discharging, cell balancing and thermal management of the battery pack and make sure the battery always ready to use.

## III. DESIGNING OF THE BATTERY PACK

Designed and developed a 48Volt 44Ah lithium-ion battery to power all-terrain electric vehicle. Used SAMSUNG 18650 3.7Volt 2000mAh capacity lithium-ion cells. Total 286 cells are used to develop complete battery pack such as 13S22P pattern. That means 13 cells in series and 22 cells in parallel.

Cell specifications:
Nominal Voltage: 3.7V
Max. Voltage: 4.2V
Nominal capacity: 2000mAh
Ambient temperature: -100C to 550C
Charging voltage: 4.2V
Life cycle: 1500 cycles @ 230C.

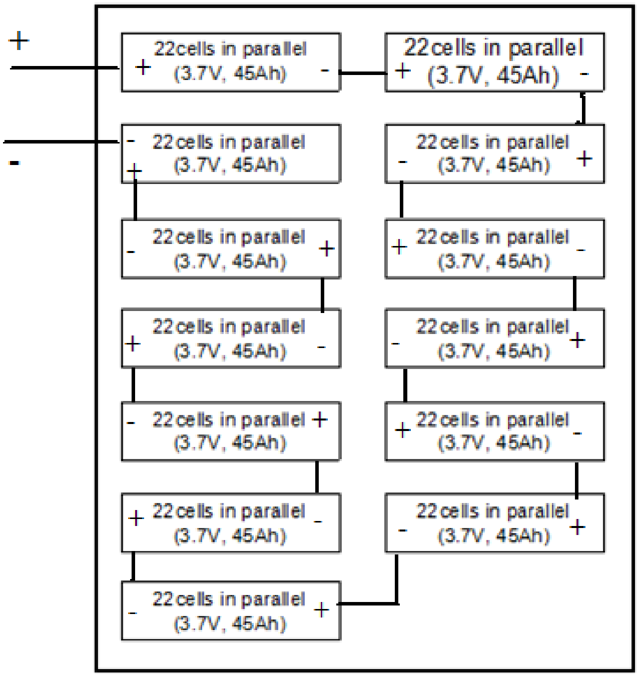


Figure2. Cells series and parallel arrangement

### *A.* Battery pack designing:

Designed and developed a battery pack with proper way for coolant (air) flow. And develop a battery case with aluminum material because aluminum has good heat dissipation capacity and lighter in weight. Copper material is used to connect cells in battery pack because copper has good electrical conductivity compared to other conductive materials like nickel and aluminum.

The total size of the battery is 353.5mm length, 321.5mm width, and 173mm height. And the total weight of the battery pack is 36Kg.

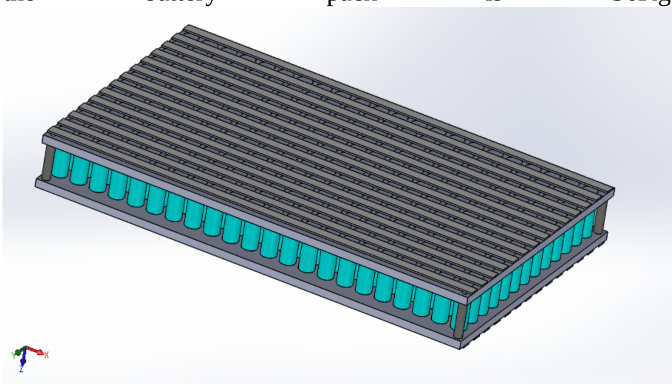

Figure3. Cells structure in the battery pack

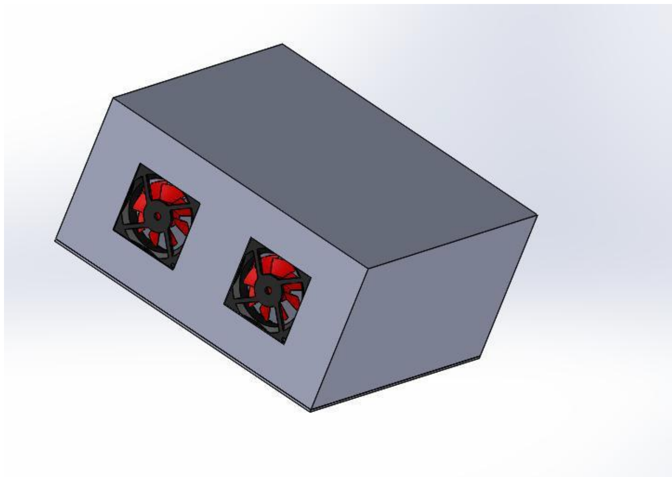

Figure4. Design of complete battery pack with casing

### B. Analysis and simulation of the battery pack.

The thermal and static structural analysis had been done for the cells and battery pack using ANSYS 16.0 workbench, according to the simulation output battery pack can able to handle 10g force on vertical direction and 3g force on horizontal directions.

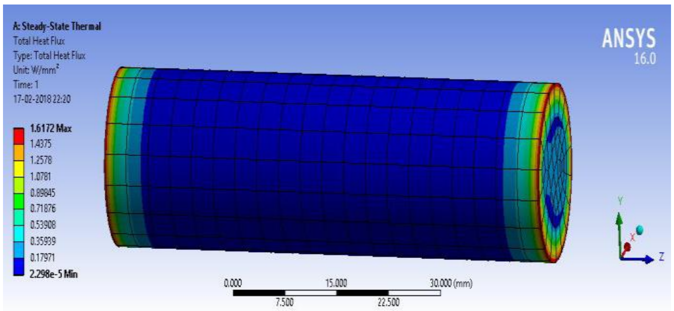


Figure5. Steady state thermal analysis (Total heat flux) of the cell

According to this simulation maximum heat flux is 1.6172W/mm$^2$.

ISSN(Online) : 2456-8910
International Journal of Innovative Research in Applied Sciences and Engineering (IJIRASE)
Volume 2, Issue 9, DOI: 10.29027/IJIRASE.v2.i9.2019, 325-331 , March 2019

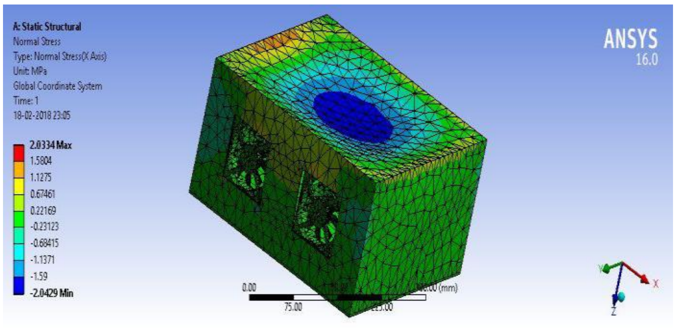


Figure6. Static structural analysis (Normal Stress) of the battery pack

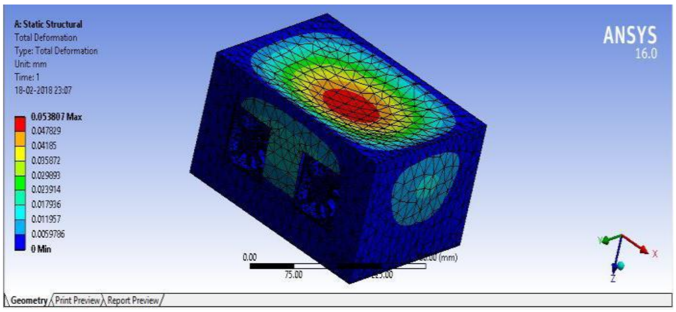


Figure7. Total deformation of battery pack

## IV. FUNCTIONS OF BATTERY MANAGEMENT SYSTEM

A. *Discharging control*:

The principal function of the battery management system is to keep the battery in the safe operation area. The battery management system (BMS) should protect the battery pack or cell from any eventuality during the discharging time. Otherwise, the cell could operate outside the safe operating area. Lithium-ion cells have a cut-off limit for the both charging and discharging, in this particular 18650 lithium-ion cells the maximum discharging limit is up to 3.6Volt, if we discharge under this range there is a chance to damage of cells and this will lead to reducing the cell life cycle. A 48volt battery pack nominal voltage is 48Volt and the maximum voltage is 54.6Volt. In this particular battery pack, we need to cut the discharging system at 47Volt or 48Volt. The discharge control system will continuously be monitoring the battery voltage and cut down the discharging process with the proper voltage level using a relay or solid state switching devices.

B. *Charging control*:

Lithium-ion cells are mainly damaged due to inappropriate way of charging than any other case. Therefore, charging control of the battery pack is a very important process and feature of the BMS. In these particular type 18650 cells, the maximum voltage of the cell is 4.2Volt charging system shouldn't charge the cell more than that limit. In the 48volt battery pack, 54.6Volt is the maximum voltage range. Charging system should cut off the charging process at 54.6volt.

For lithium-ion battery mainly two stages of charging methods are used that is constant current (CC) - constant voltage (CV) method. During the first stage (constant current stage), the charger should provide the constant current and gradually increasing voltage. This process will increase the battery voltage.

During the second stage (Constant voltage stage), the battery will reach a constant voltage. In this time charger will provide the constant voltage and charging current will decrease exponentially up to 0.25C rate.

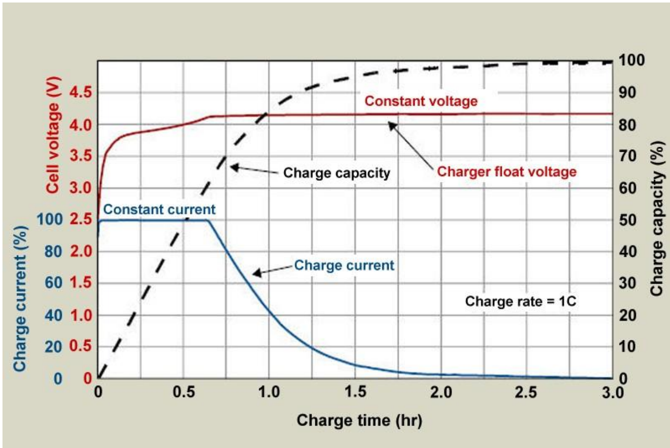


Figure8. Charging stage graph of lithium-ion cell

C. *State of charge identification(SoC) using coulomb counting algorithm:*

One main feature of the battery management system is to keep track of the state of charge of the battery pack. The SoC could signal for the user to get know about how much percent of charge remaining in the battery pack and controls the charging and discharging process. There are three major methods to determining the state of charge (SoC) of the battery those are the direct method [4] or voltage method (voltage SoC), coulomb counting method (current SoC) and the combination of voltage and coulomb counting method. In the voltage method (vSoC) method, simply need to connect the voltmeter or voltage sensor to the battery terminals. According to the battery voltage, the control system should turn on and turn off the charging and discharging process. In the case of Lithium-ion cell, voltage SoC method is not a good practice because lithium-ion cells SoC vs Time curve is more straight line curve.

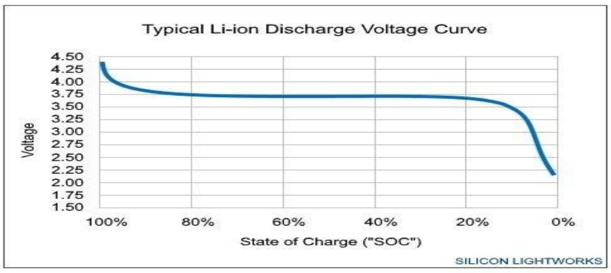


Figure9. Lithium-ion battery discharge curve.

So in this case controller, ADC properly can't read the battery voltage with good accuracy. For this reason, determination of the state of charge using coulomb counting method is used to overcome from his kind of problem.

In this coulomb counting method, the current going into or coming out of the battery is integrated to produce the state of charge of the battery pack. It's a similar counting to the amount of water coming into the water tank and amount of water going out of the water tank to determine the relative amount of the water in the water tank. Remaining state of charge (SoC) = Initial SoC - consumed SoC
This formula during the time of discharge,
Remaining SoC = current SoC + added SoC
This formula is used in charging time
SoC (t) = Initial SoC (100%) - DoD (t)
SoC (t) = Present SoC (x %) + Charged SoC (t)

To determine the state of charge of the battery pack LEM HTFS 200P non-invasive current sensor is used. HTFS 200P is a noninvasive type current sensor it has the capacity to measure the maximum 200Amps DC current.

Figure10. LEM HTFS 200P current sensor

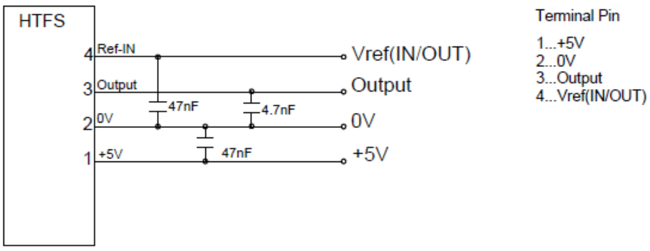


Figure11. Circuit diagram of current sensor

D. *Cell balancing:*

Cell balancing is the process of compensating weaker cells by equalizing charge on all the cells in the battery pack to extend the overall battery life. Lithium-ion cells need cell balancing or battery balancing circuitry when more than one cells are connected in series in the battery pack. This process is important to get maximum life, reliability, and safety of the battery pack. The main cell balancing algorithms are passive and active cell balancing. In the case of active cell balancing [5] charge from the stronger cell is removed and provided to the weaker cell. It's basically energy transfer system and this method is more efficient than passive and consumes less charging time.

Passive cell balancing is a dissipative type of balancing method. In this method, the system will monitor the cell voltage and make the least cell SoC is a reference and dissipate the energy of the higher SoC cells in the form of heat through the passive resister. Passive cell balancing is not an efficient method as compared to active or bypass cell balancing method and this method has some power loss in the circuitry.

Bypass cell balancing method is quite similar to the passive cell balancing algorithm. In passive cell balancing, dissipating cell energy through the external resistor but in bypass cell balancing system bypass cell charging current to other cell using MOSFET switch or relay. If cell_A has more SoC than Cell_B, we need to first give higher charging current to cell_B to equalize charge of both the cells, so first close MOSFET_A and current start bypassing and charge cell_B with higher charging current. Bypass cell balancing method is more efficient than the passive cell balancing because in this type there is no dissipation occurs. Either MOSFET or relay can be used as a switch in the circuitry in any type of cell balancing circuitry. IRF540N N-MOSFET is used in this BMS for cell balancing system.

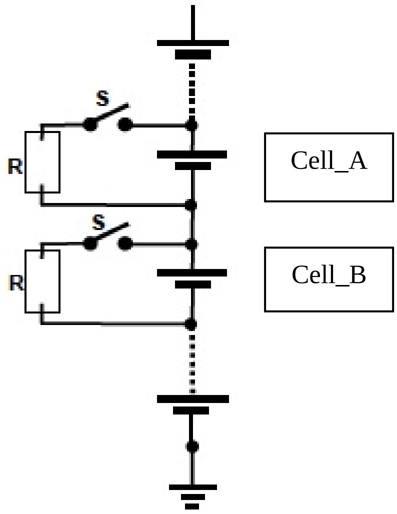


Figure12. Bypass cell balancing

E. *Thermal management of the battery pack.*

Thermal management of the battery pack is a very important function in the battery management system. Ambient temperature range of the lithium-ion cell is $-10^{0}$C to $55^{0}$C. BMS should keep battery to operate within this temperature range. Designed an adaptive cooling system for monitoring and control the temperature of the battery pack. In this control system, a temperature range is set as a reference point if the battery temperature increases more than that set point the cooling fans start at reducing the temperature of the battery. And once battery voltage reaches the set point limit cooling system fans will stop.

ISSN(Online) : 2456-8910
International Journal of Innovative Research in Applied Sciences and Engineering (IJIRASE)
Volume 2, Issue 9, DOI: 10.29027/IJIRASE.v2.i9.2019, 325-331 , March 2019

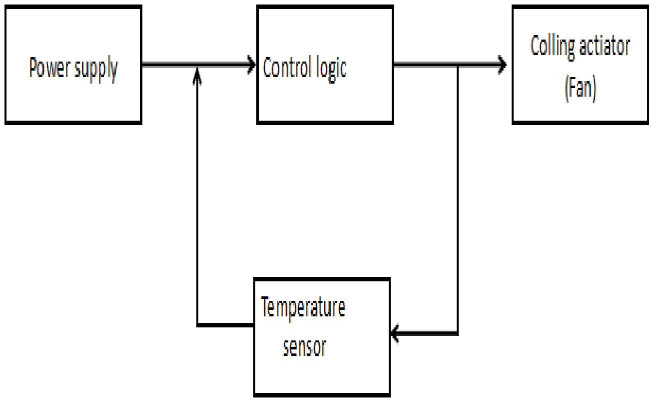


Figure13. Temperature control system.

## V. FUNCTION STRUCTURE DIAGRAM OF BMS

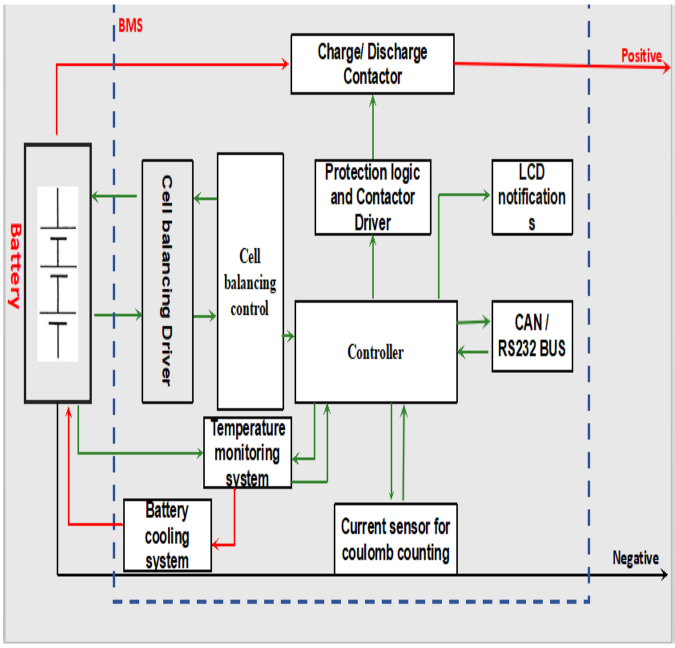


Figure14. Function structure diagram of BMS.

The proposed BMS consists of Centralized BMS topology (Architecture), the master controller monitoring and controls the charging, discharging, SoC identification and cell balancing functions. This BMS consist of CAN and RS-232 communication system to the user (Instrumentation Cluster). When charger connected to the BMS at that time BMS will turn off discharging relay and when charger disconnected BMS will turn off charging relay and turn on discharging relay.

Function structure diagram of BMS will explain the working structure of the battery management system [6]. And Functions structure diagram will elaborate the software working of the battery management system. If Charger is connected, and if the charging process is on, the system will check SoC of the battery and turn on charging relay and cell balancing circuitry [7]. During the discharging process, the system will check the SoC and state of health (SoH) of the battery pack if SoC and SoH are in the proper level system will allow to discharging process or else discharging relay will be turned off.

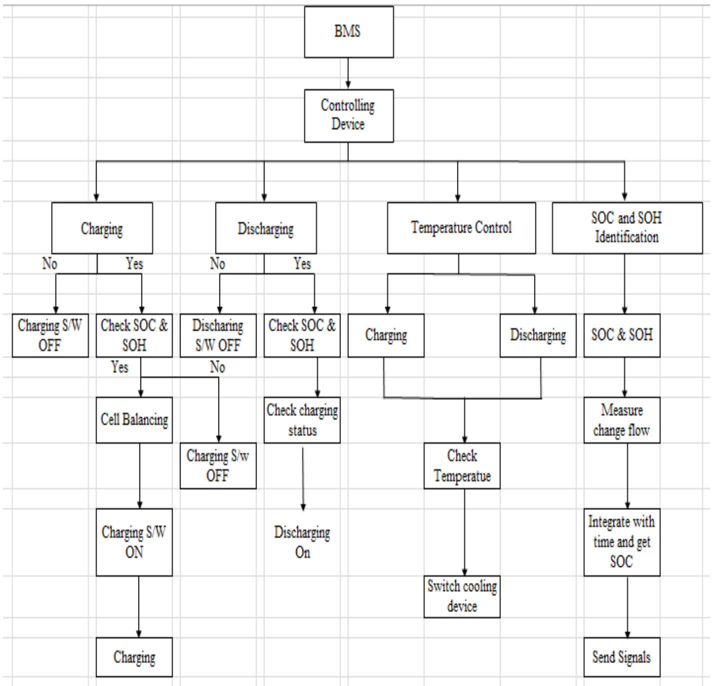


Figure15. Function structure diagram.

## VI. BMS ARCHITECTURE

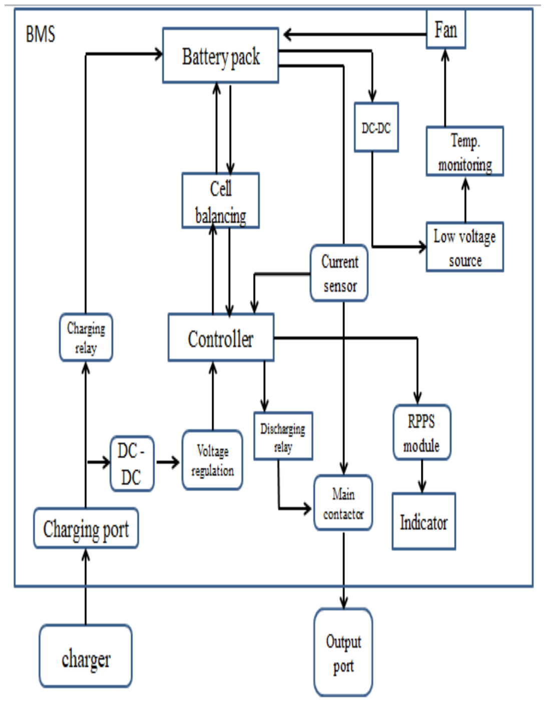


Figure16. Architecture of the battery management system

## VII. System Integration

Final integration of battery and battery management system is tested with 2kw BLDC motor. The power of the battery pack is 2.16kwh and the battery pack is efficient to power the BLDC motor. Electric vehicle powertrain [8] consists of a battery, motor controller, motor, gearbox, and wheel assembly.

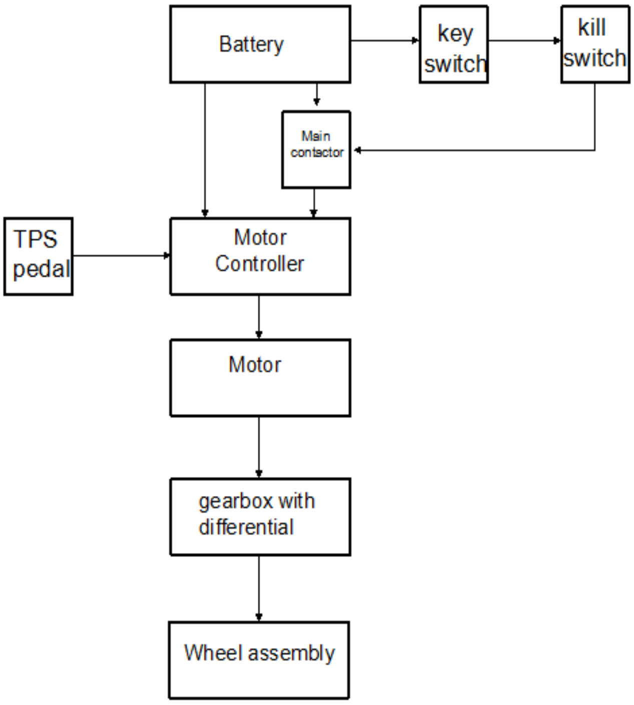


Figure17. Powertrain system of an electric vehicle

Figure18. Integration of battery and BMS with BLDC motor controller and motor

The battery pack is connected to the motor controller and motor (Load) is connected to the motor controller. The motor throttle is controlled by using the TPS (Throttle potentiometer) pedal. This BMS consist of the DAQ system (instrumentation cluster) battery data like SoC, voltage, charging or discharging indication and load current is displayed.

## VIII. Conclusion

In this paper, designing of battery pack and battery management system (BMS) is presented. Using these algorithms and techniques, BMS can be designed with less power loss and with the proper safety. Cell balancing methods are used to reduce power loss in the system and decrease the charging time also. The proposed control system architecture has proven its efficiency both in simulation and hardware implementation. The BMS consist of several functions like charging; discharging, thermal management and State of charge estimation and these functions are properly monitored and controlled by the BMS circuitry.

## References

[1] R. Hu, Battery Management System for Electric Vehicle Applications. Ottawa: Library and Archives Canada = Bibliothèque et Archives Canada, 2012.

[2] Sandeep Dhameja, Electric Vehicle Battery Systems, 2002, ISBN 0-7506-9916-7

[3] Elithion website, http://liionbms.com/php/index.php

[4] R. Xiong, Q. Yu, and L. Y. Wang, "Open circuit voltage and state of charge online estimation for lithium ion batteries," Energy Procedia, vol. 142, pp. 1902–1907, Dec. 2017

[5] G.-H. Min and J.-I. Ha, "Active cell balancing algorithm for serially connected li-ion batteries based on power to energy ratio," in 2017 IEEE Energy Conversion Congress and Exposition (ECCE), Cincinnati, OH, 2017, pp. 2748–2753.

[6] B. van W. Horn, "The Development of a 48V, 10kWh LiFePO4 Battery Management System for Low Voltage Battery Storage Applications.," p. 120.
[7] Y. Barsukov, "Battery Cell Balancing: What to Balance and How," p. 8.
[8] https://bajatutor.net/topic/power-train/