An Overview of Electric Vehicle Battery Management System (BMS)

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ABSTARCT

Battery management systems (BMS) are electronic control circuits that monitor and regulate the charging and discharge of batteries. The characteristics of the battery to be monitored include the detection of battery type, voltages, temperature, capacity, State of Charge (SOC), power consumption, remaining operating time, charging cycles, and some more characteristics. The job of the Battery Management System (BMS) is to protect the batteries from deep discharge, from over-voltage, which is the result of extreme fast charge and extremely high discharge current. In the case of multi-cell batteries, the battery management system also provides for cell balancing function, to manage that different battery cells have the same charging and discharging requirements.

Keywords: *State of Charge (SOC), Cell balancing, Communication, State of Health (SOH), Battery Management System (BMS) Topology*.

1. INTRODUCTION:

A pack of batteries is made up of a tiny group of cells connected in series or parallel [1]. These cells are highly unstable. The voltage across the cells needs to be precisely monitored or balanced [2]. While a battery is charging, we must apply Voltage and Current to it. If Voltage is more than the specified limit then it is charging in overvoltage, which increases the temperature of the battery. Every battery has a specific temperature range if the temperature increases above its operating range which ends up reducing the State of Charge (SOC) this condition also increases the internal resistance of the battery eventually the power loss across the battery increases [3]. If the Voltage across to the battery is lower, then it will also lead to over temperature. So, overvoltage and low voltage lead to temperature increase which leads to a reduction in battery life. If we use the battery in less than the specified temperature limit, then its capacity decreases. In the over-temperature time, the battery may catch fire as well [4]. There is always a slight difference in the State of Charge (SOC), discharge capacity, the impedance between two cells even if the cells are from the same manufacturer and produced in the same batch. While charging or discharging some of these cells altogether, will experience a lot of stress in the battery pack and it led to degradation. To avoid all this overvoltage and low voltage state of the battery we need to closely watch battery temperature and ensure the level of charge of the battery stays within recommended State of Charge (SOC) by balancing every cell. To ensure all these things a fast and smart Battery Management System (BMS) should be used [5].

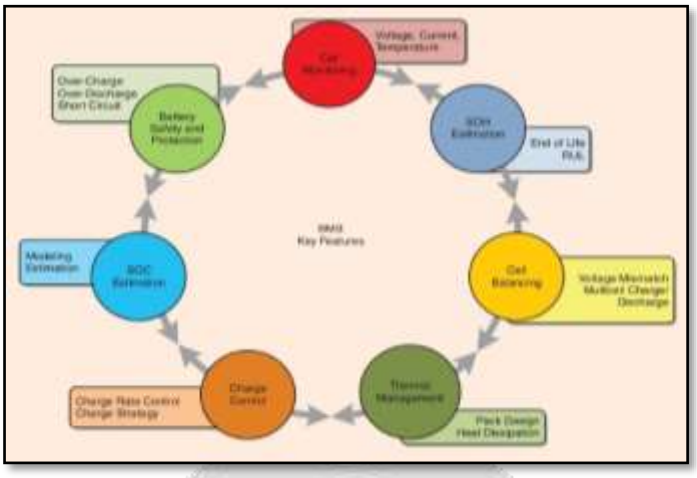

Fig 1. Battery Management System (BMS) features [6].

2. DISCHARGE CONTROL:

The primary goal of the Battery Management System (BMS) is to keep the battery away from its out of safety zone. Battery Management System (BMS) needs to protect the cell during discharging [7].

3. STATE OF CHARGE (SOC) DETERMINATION:

One of the features of the Battery Management System (BMS) is to track the State of Charge (SOC) of the battery [8]. The State of Charge (SOC) indicates to the user about the current capacity of the battery [9], [10]. The State of Charge (SOC) can be determined by several methods,

- Direct Voltage Measurement
- Coulomb Counting
- Combination of Coulomb Counting and Voltage Measurement

3.1. DIRECT VOLTAGE MEASUREMENT:

To measure the State of Charge (SOC) directly we can use Voltmeter because the Voltage decreases more or less linearly during the discharge cycle of the battery so if the Voltage decreases the State of Charge (SOC) of the battery also decreases [11].

3.2. COULOMB COUNTING:

In the Coulomb counting method, the current coming in and out of the battery is measured for some time to calculate the relative amount of charge. It is like pouring water into the water tank and fetching it out. Imagine the battery as a tank and water is like electrical energy as charge [12]. The Battery Management System (BMS) measures the current going inside the battery and calculates the charge deposited inside the battery over time. When the calculated charge is near to the rated capacity of the battery then the Battery Management System (BMS) informs that the battery is fully charged. And while discharging it follows the same procedure.

3.3. COMBINATION OF COULOMB COUNTING AND VOLTAGE MEASUREMENT:

In this method, both the Coulomb counting, and voltage measurement methods are used to determine the State of Charge (SOC) of the battery. Here the voltmeter is used to monitor the battery Voltage and calibrate the State of Charge (SOC) when the actual charge approaches at the end [13].

4. STATE OF HEALTH (SOH) DETERMINATION:

The battery can store charge and deliver electrical energy when compared with the new battery. Any physical parameter of the battery such as internal resistance or conductance changes significantly with age can be used to indicate the State of Health (SOH) of the cell [14]. In practice, the State of Health (SOH) could be estimated from the internal resistance or by the cell conductance, where the internal resistance of the battery increases [15] as the battery gets older.

5. CELL BALANCING:

It is the method of compensating the weaker cells by equalizing the charge on all cells in the chain to extend the overall battery pack life [16]. In the whole battery pack, small differences between the cells due to tolerance or operating conditions cause a rise to uncertainties. During charging weaker cells may get over stress and became even weaker until they eventually fail. Which causes the whole pack to fail prematurely. So, to avoid this the Battery Management System (BMS) must provide the cell balancing [17]. There are two cell balancing techniques. They are,

- Active Cell Balancing
- Passive Cell Balancing

6. LOGBOOK:

The Battery Management System (BMS) should work on logbooks because the State of Health (SOH) of a battery is a relative term as it compares the new battery and old battery and the values from this measurement should be saved for later use. Then the Battery Management System (BMS) will use these values to compare the initial condition of the cell and with the same cell as it gets older [18]. So, the logbook function of the MEMS (micro-electromechanical system) should record such important data into the memory [19].

7. COMMUNICATION:

The Battery Management System (BMS) provides information about the health, State of Charge (SOC) along with much more details for service and maintenance [20]. In general, the user who is driving the vehicle may not be technically well known about the battery. So, the information should be simple and interpretable. On the other hand, the battery service technicians or engineers demand very precise technical information for research or fault detection. So, the Battery Management System (BMS) should capable enough to provide the necessary data to both. So, these all things the Battery Management System (BMS) should do for the safety of the battery [21].

8. BATTERY MANAGEMENT SYSTEM (BMS) TOPOLOGY:

The Battery Management System (BMS) topologies fall into 3 categories [22]. It shows how we can connect the cell with the Battery Management System (BMS). The types are.

- Distributed Topologies
- Modular Structure
- Centralized Topology

8.1. DISTRIBUTED TOPOLOGY:

In this topology, there are small voltage and discharge monitor circuits which communicate with the master controller of the Battery Management System (BMS) [23]. The advantage of this design is that it is simple to implement and has high reliability. The disadvantage of this system is it requires many small Printed Circuit boards (PCB), and it becomes difficult to mount on every type of cell [24].

8.2. MODULAR STRUCTURE:

In this topology, multiple slaves like Battery Management System (BMS) controllers are used to fetch the data and forward it to the master controller. So, no special Printed Circuit boards (PCBs) are necessary to connect the individual cell. However, isolated master-slave communication is quite difficult.

8.3. CENTRALIZED TOPOLOGY:

A centralized Battery management System (BMS) control unit is directly connected to each cell of the battery. The controller unit protects and balances all the cells [25]. Using this topology will decrease the hardware but excess heat could be generated because the controller is the only source for cell balancing [26]. In addition, the cells are distributed within the various location of the vehicle which requires a lot of wiring.

9. BATTERY MANAGEMENT SYSTEM (BMS) WORKING:

It Is made up of many hardware and software functional blocks which have cut off MOSFET (Metal Oxide Semiconductor Field Effect Transistor), fuel gauge monitor, cell gauge monitor or cell balancing circuit, real-time clock, and temperature monitor system [27], [28].

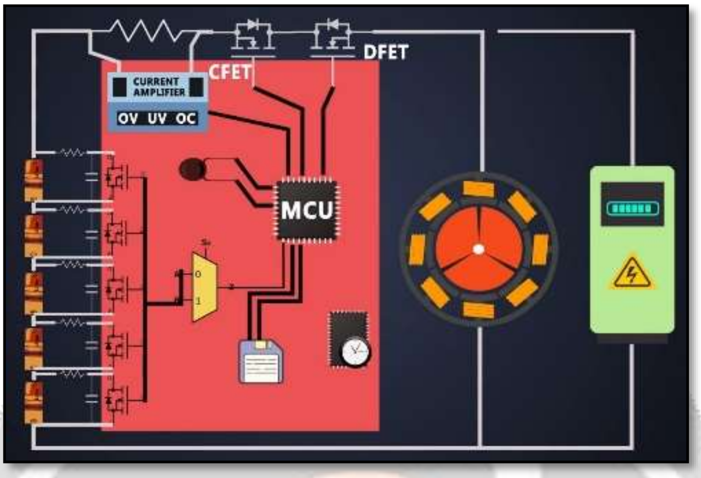

Fig - 2. Battery Management System (BMS) diagram.

9.1. CUT OFF MOSFET:

MOSFET is nothing but control switches. They are used for connection and isolation of battery pack between load and charger [29]. The microcontroller unit (MCU) measures the Voltage and Current in real-time and based on that it switches the MOSFET [30]. These can be configured in two ways.

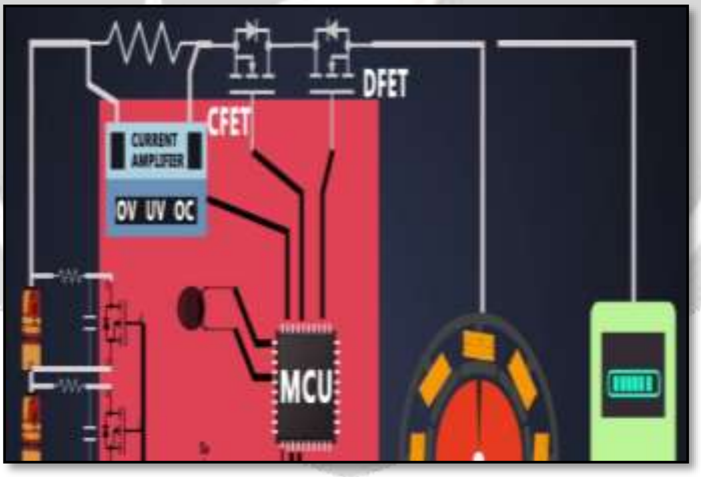

Fig - 3. Single connection for charger and load.

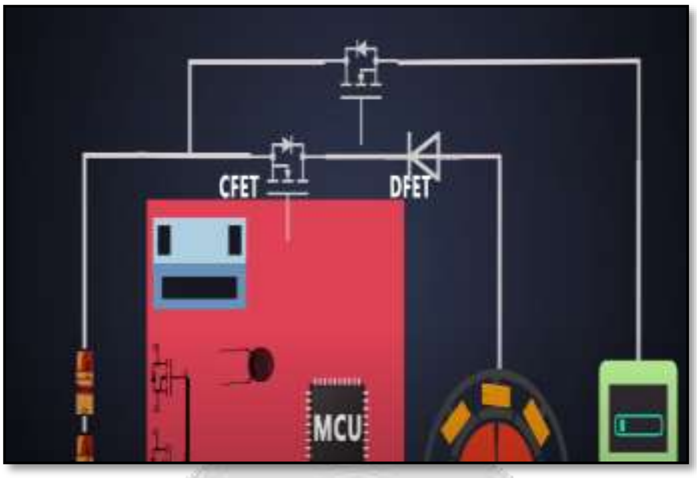

Fig - 4. Two different connections for charger and load.

- Single Connection for Charger and Load: It has a single connection to the charger and load.
- Two Different Connection for Charger and Load: In an electric vehicle it has a motor controller or motor, so it has two different connections.

Generally, the first configuration is used in Battery Management System (BMS) because it reduces the hardware, and only one bus will control the charging and discharging [31]. Initially, the two MOSFET switches are turned off so, when the charger is connected, the current will not flow through it [32]. Then Battery Management System (BMS) senses the voltage at the input, and it turns on the CFET (Charge Control Field Effect Transistor) which lets the battery get charge [33]. If the voltage at the input is not present, then the Battery Management System (BMS) determines that the motor is connected, and it turns on DFET (Discharge Field Effect Transistor) [34] which lets the battery gets discharged.

9.2. FUEL GAUGE OR CURRENT MONITOR:

This block keeps track of the charge coming in and going out of the battery pack. The charge is the product of current and time (Q = i.t). For measuring the current, the current sensing amplifier and Microcontroller Unit (MCU) will use the analog to digital converter [35]. A low-value current sense resistor is connected in series with the battery. The voltage drop across this resistor is measured by the amplifier and amplifies the signal and delivers it to the analog to digital converter in Micro Controller Unit (MCU) [36]. The Micro Controller Unit (MCU) measures the unit and calculates the charge according to the time [37]. The discharge and charging current get sensed by the direction of the current. If the current is going after the battery, it is discharging and if the is coming outside the battery it is charging [38]. Using a fuel gauge IC (Integrated Circuit) adds additional cell cost to the Battery Management System (BMS) design. Then in the case of the electric vehicle, the load current is changing continuously so, using a shunt resistor is always the best option [39]. This configuration always helps us to prevent overcurrent. When the current rises above the safety level, the fuel gauge circuit senses and it gives the signal to turn off DFET (Discharge Field Effect Transistor) or CFET (Charge Field Effect Transistor).

9.3. CELL BALANCING / CELL VOLTAGE MONITOR / CELL VOLTAGE BALANCING CIRCUIT:

Generally, Li-ion batteries are used in the electric vehicle because the voltage of Li-ion batteries ranges from 2.5V to 4.2V and it depends on Chemistry [40]. As we saw operating a battery outside the voltage range significantly reduces the lifetime, even if the cells are manufactured from the same manufacturer the internal resistance, nominal voltage, and temperature imbalance will slightly differ from each other [41] so, not every cell behaves the same while charging and discharging. While charging if the battery pack has a weaker cell, then it will reach its full limit first, while the rest of the cells are still charging [42]. So, this weaker cell heats up and its lifespan decays on the other hand. The weaker cell discharges faster than the rest of the cells as well. The weaker cell trips the discharge limit first leaving the rest of some charge remains inside them. This can be overcome by cell balancing and this cell balancing is divided into two types. They are,

- Passive Cell Balancing
- Active Cell Balancing

9.3.1. PASSIVE CELL BALANCING:

Passive cell balancing is the simplest and cost-effective method. In passive cell balancing method, a dummy load like a resistor is used to discharge the excess voltage and equalize it with other cells [43]. These resistors are known as Bypass resistors. Each cell connected in series in a pack will have its bypass resistor connected [44]. While charging the weaker cell charges very fast so the MOSFET connected across the weaker cell is turned on. So, the charge of this cell is removed and dissipated through its resistor [45]. This process minimizes the charge rate of the weaker cell. Whenever the charge level of the weaker cell tends to go near its full capacity the MOSFET is turned on. So, all the cells along with the weaker cells charge at the same time. But this is not useful while discharging. The weaker cell may reach its minimum cut-off voltage earlier than other cells [46]. This balancing technique is inexpensive and technically easy to implement. But it is not very efficient because electrical energy is dissipated as heat in the resistor and FET's. Another drawback is that the entire discharge current flows through the MOSFET which is mostly built into the controller IC (Integrated Circuit). Hence the discharge current must be limited to a lower value up to the IC's (Integrated Circuit) limit which increases the discharge time. So, this configuration of the built-in resistor and MOSFET minimize the charge and discharge rate by slowing the charging and discharging of the cell.

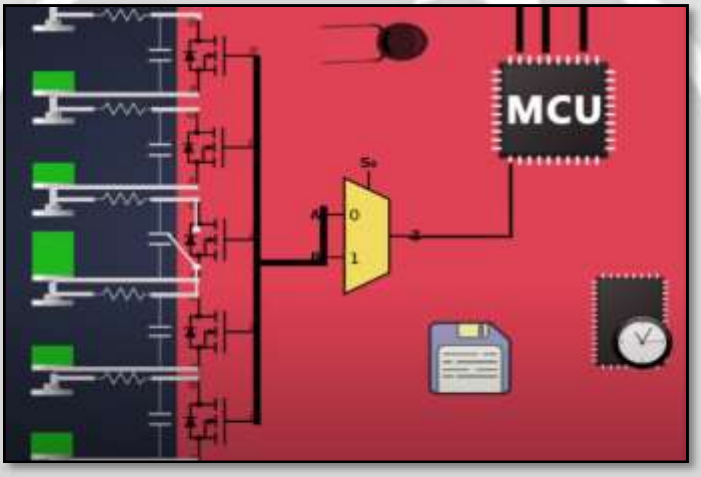

Fig – 5 (a). Passive cell balancing.

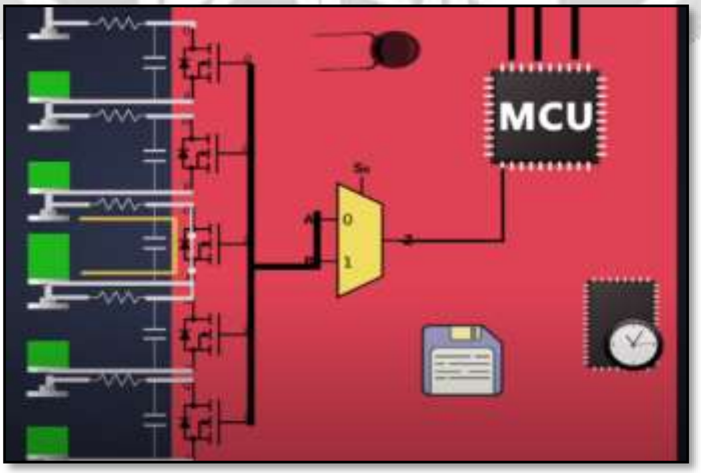

Fig 5 (b). Passive cell balancing.

9.3.2. ACTIVE CELL BALANCING:

Unlike the passive balancing inactive balancing, the excess charge from one cell is transferred to another cell that has a low charge to equalize them [47]. So, this can be done by charge storing components like capacitors and inductors [48]. There are many methods to perform active cell balancing and the most used method is Charge Shuttles / Flying Capacitors [49]. In this, the capacitors are used to transfer the charge from high voltage cell to lower voltage cell [50]. The capacitors are connected through SPDT (Single Pole Double Throw) switches. Initially the switches connect the capacitor to the cell which has high voltage and once the capacitor is charged then the switch connects to the cell which has low voltage and the charge from the capacitor flows into the cell [51]. These capacitors are called Flying Capacitors. The problem with the method is that the charge can be transferred only between adjacent cells. But it is still better than passive balancing.

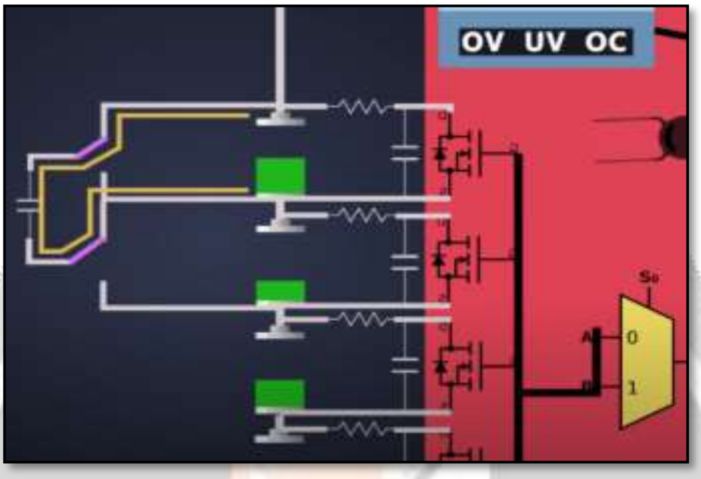

Fig 6 (a). Active cell balancing.

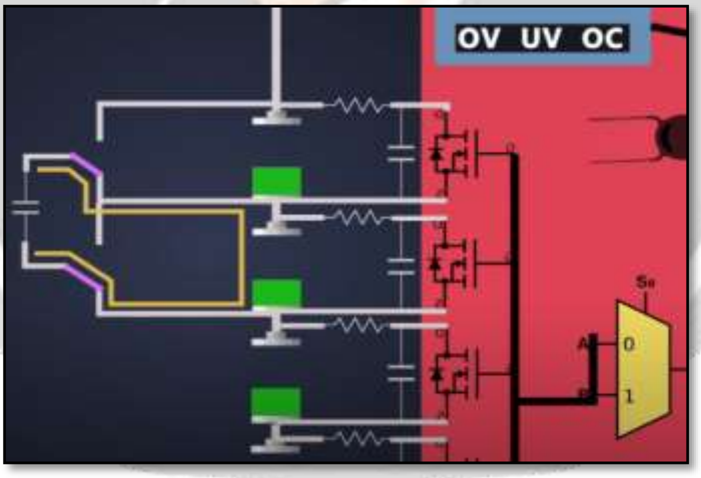

Fig 6 (b). Active cell balancing.

9.4. TEMPERATURE MONITORING:

The Li-ion batteries provide a lot of currents while maintaining constant voltage which can lead to thermal runaway condition that causes the battery to catch fire [52]. The construction of a battery is highly volatile so, temperature measurement is not just for safety but also suggests that the battery is suitable for charging or not [53]. To measure the temperature of these batteries a temperature measuring sensor is used. Generally, the thermistor is used as a temperature sensor [54]. The thermistor is a temperature-dependent resistor. When there is a change in temperature the resistance of the thermistor changes and the Battery Management System (BMS) calculates the temperature rise accordingly [55]. The Battery Management System (BMS) acts as a logbook to calculate the SOH (State of Health) and other parameters of the battery. So, the purpose of the Battery Management System (BMS) is to take the data accordingly to time [56]. So, it should be working even if the vehicle is not on, but it might consume excessive power from its battery pack so, to avoid this a real-time clock is integrated with Battery Management System (BMS) which needs very small power to do its work.

10. INNOVATION:

In the above reference, we came up with an idea for improving the efficiency of the Battery Management System (BMS). The centralized topology is efficient, but it generates a large amount of heat when compared with the other two topologies. Our idea is about reducing the heat and make it an efficient one. We are placing a cooling system to dissipate the heat which is generated in the Battery Management System (BMS) controller as shown in the figure.

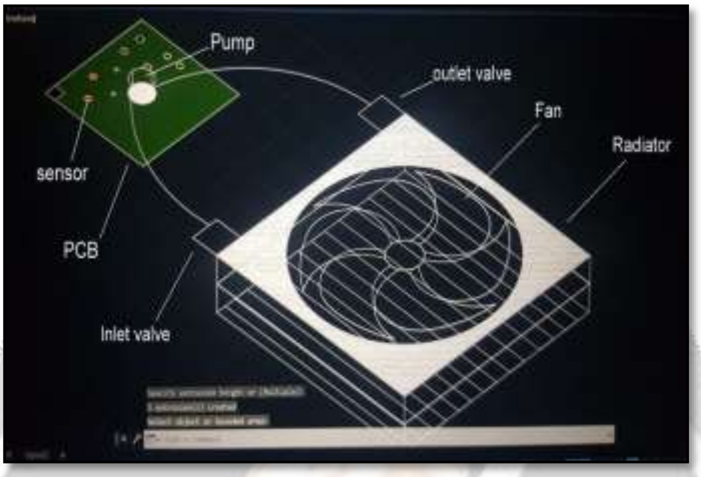

Fig 7. Cooling system.

There is an infrared (IR) sensor that monitors the temperature of the Battery Management System (BMS) controller. when the Battery Management System (BMS) controller reaches a certain temperature the cooling system is get activated. There are two valves in the cooling system, one is the inlet valve and another one is the outlet valve. The inlet valve of the radiator will collect the coolant which has a high temperature from the pump which circulates the coolant. A pipe is used to connect the pump and inlet valve and then the coolant will flow through the fins of the radiator. The fan in the radiator, which is placed in front of the radiator, sucks atmospheric air, and lets the atmospheric air pass through the fins by this process the temperature of the coolant gets lowered. Then the low-temperature coolant flows through the outlet valve and reaches the pump through another pipe that connects the outlet valve and the pump mounted above the Battery Management System (BMS) controller. The pump is the main device that is used to circulate the coolant through the entire system and this process goes on continuously. In this process, the heat generated by the Battery Management System (BMS) controller is absorbed by the coolant and it passes to the inlet valve of the radiator then the coolant gets cooled and again passes through the Battery Management System (BMS) controller and this process goes on continuously. By this process, we can dissipate the heat produced in the Battery Management System (BMS) controller and can achieve higher efficiency.

11.CONCLUSION:

Battery Management System (BMS) is a technology that collects the information of the battery like it is State of Health (SOH), State of Charge (SOC), temperature, voltage, current in and out, etc. Its main objective is to maintain the battery in the safety zone. Without this Battery Management System (BMS) the battery of the electric vehicle cannot operate in the safe zone. We explained our idea in the centralized topology in Battery Management System. With the help of the below reference, we collect more information about Battery Management System (BMS) that leads us to frame a new idea on this topic.

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