Electric Vehicle Battery Thermal Protection and Health Monitoring during Charging and discharging

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Abstract

The research contribute towards better thermal management of lithium ion batteries due to harmful incidents occurred in the past decade. The effective radial thermal conductivity of the cell is a crucial factor in the thermal models of lithium-ion cells as per the recent investigations. The major goal is to illustrate how optimization techniques and certain thermal and structural design factors help LIBs achieve superior thermal performance, lower maintenance costs, a lower power to weight ratio, and longer life spans. Different BTMS heads, including as hybrid cooling, air cooling, liquid cooling, and PCM cooling, are taken into consideration while analyzing the optimization strategies utilized for LIBs. The majority of the researchers used various optimization methods, including GA, MODO, MMDO, MOGO, and NSGA-II; however, some of them also used iterative optimization techniques, such as the evaluation index method. HPPS method, enthalpy technique, and perturbation iterative approach. The researchers looked at a number of battery shapes, including prismatic, cylindrical, pouch-style, and flexible battery cells.

Keywords: *Thermal protection, Electric Vehicle, SoC Estimation*

1. Introduction

Recently, lithium-ion batteries have drawn increased attention, in part because they have occasionally caused harmful fires. Thermal runaway, also known as the rapid rise in temperature that results when a cell generates more energy than it can efficiently dissipate, is the root cause of these fire. Thermal runaway also has the issue of easily spreading from one cell to the other. Researchers have created analytical thermal models of individual lithium-ion cells and the batteries they make in order to better comprehend thermal runaway. The effective radial thermal conductivity of the cell is a crucial factor in these models.

Lithium-ion (Li-ion) battery stacks are used in a wide range of applications, including electric and hybrid vehicles, storage of renewable energy for later use, and energy storage on the grid for diverse functions such grid stability, peak shaving, and renewable energy time shifting.

Estimating a battery's state of health (SOH), which measures how well it can store and transmit electrical energy in comparison to a brand-new battery, is also crucial. Measurement of the cells' state of charge (SOC), which is the available capacity (in Ah) expressed as a percentage of their rated capacity, is crucial in these applications.

Since determining a battery's SOC is a difficult operation that depends on the battery type and the application in which it is used, there has been a lot of development and research done recently to increase the accuracy of SOC estimation. One of the key functions of battery management systems is accurate SOC estimation, which can help increase system performance and dependability as well as the battery's lifespan. In reality, accurate SOC assessment of the battery can prevent unexpected system interruptions and keep the batteries from being overcharged and over discharged, which could harm the internal structure of the batteries permanently. Battery discharge and charge, however, necessitate intricate chemical and physical processes, therefore accurate SOC estimation under varied operational circumstances is not simple. If the initial SOC is not known with sufficient accuracy, as well as other parameters like cell self-discharge and leakage effects, the accuracy of this approach may suffer.

The increased coulomb counting technique appears to be suitable for fitting the application requirements in terms of computational capabilities, necessary accuracy, real-time limitations, and system environment. In actuality, it is based on a straightforward real-time calculation and doesn't have any challenging hardware requirements. Clearly, it has a lower complexity than the other algorithms. Additionally, the improved coulomb counting technique has a modest estimation error, which enables it to provide precision that is acceptable. In addition, this algorithm only requires the information supplied by the manufacturer.

In order to regulate the thermal performance of Li-ion batteries in electric vehicles, a novel liquid cooling plate concept is presented in this study. The cooling plate that is being proposed has a phase change material inserted inside of it. Because it uses both active and passive cooling techniques, the cooling plate is known as a "hybrid liquid cooling plate." In comparison to conventional aluminium cooling plates, the cooling plate is lighter because to the usage of PCM. The hybrid cooling plate can prevent batteries from rapidly cooling in a cold climate by releasing the latent heat stored in PCMs in addition to its cooling capacity.

2. Literature Review

In BTMS with hybrid cooling, the combination of PCM/PSG and forced air cooling shows to be a better option for optimising battery pack temperature and ensuring temperature uniformity across the pack, which improves the overall thermal performance of LIBs at various discharge rates[1].It's important to ascertain the best structural design modifications to be made to the battery system, including the positioning of the inlet and outlet plenums for fluid flow or the collecting tabs for electric current, the desired optimal cell spacing, the arrangement of the cells in the battery module, and the type of cell geometry. These ideal conditions more effectively regulate a battery system's thermal performance, preventing the LIBs from overheating[2].Controlling the maximum temperature distribution on the battery cell surface, heat dissipation from the battery pack, better temperature uniformity, and reduced power consumption can be accomplished with the help of an appropriate numerical optimization algorithm or experimental iterative optimising scheme[3].While increasing the total cost and weight of the BTMS, the use of PCM with the proper optimization technique aids in maintaining the thermal stability of LIBs. According to studies on PCM cooling, the thermal efficiency of LIBs can be significantly increased by utilising PCM particles with the ideal mass fraction, thickness, position, and form [4].

Numerous small channel kinds, including straight, serpentine, leaf, tree, and bifurcated double layered network types, were investigated while using glycol and water as a coolant. The major factors that can increase the energy density of a battery, control the maximum temperature difference between the cells placed in a battery module or pack, and ultimately help to reduce the pressure drop in the channel part are the location of the mini channel in a battery pack, the inlet temperature of coolant, the angle of branch channels, the number of channels, the area of the mini channel, and the number of splitters used in a cooling plate[5].Almost all cell layouts are suitable for low-cost BTMS air cooling. It has been shown that, despite the naturally cooled air BTMS's excellent simplicity, ease of installation, and low cost, it is practically difficult for the systems to provide adequate cooling conditions for the high energy density LIBs used in EVs [6].The number of works on the themes discovered during this study period indicates a shift in direction from a naturally air-cooled system to a pressurised air-cooled system. Additionally, pressurised air based BTMS offer a high heat transfer coefficient, a straightforward design, and a low cost in comparison to alternative cooling systems [7].To ensure effective cooling at low energy consumption, it's critical to find the least expensive, lightest, and most energy-efficient system possible. As a result, research must be bolstered at the pack level to fully comprehend the effects of heat accumulation from various cycle performance. Numerous experimental and computational analyses have been done to determine the BTMS's thermal performance in this aspect [8].

3. Battery Model Overview

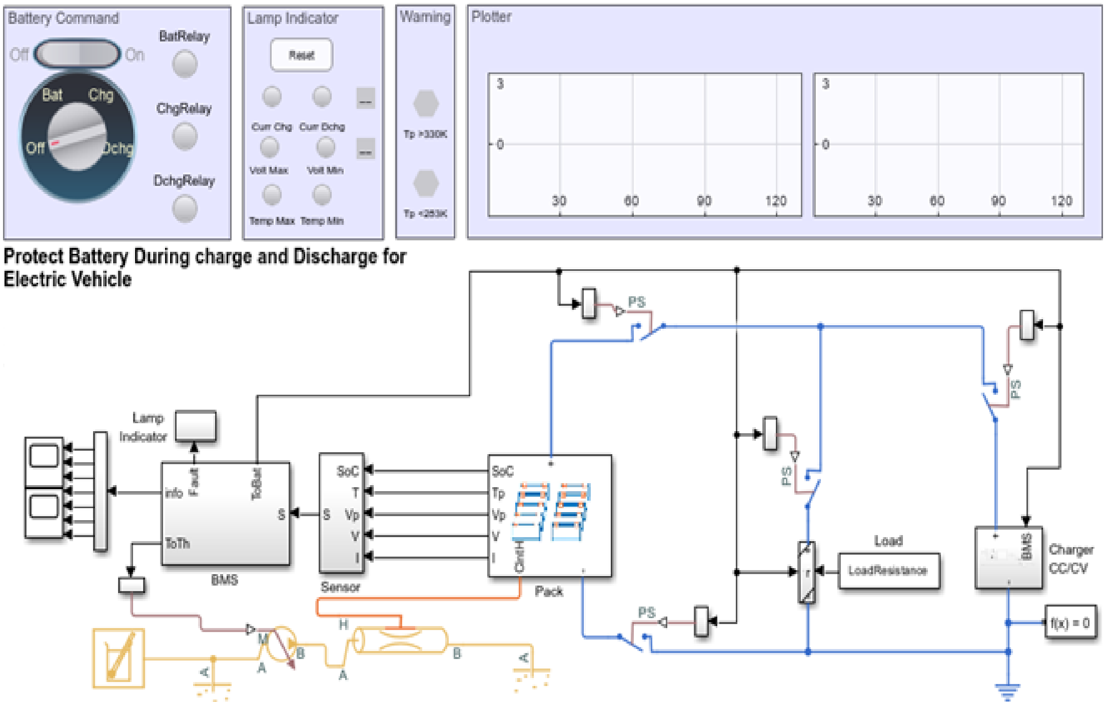

Fig. 1. Battery plant model

3.1 Battery Module

The battery comprises a battery pack of 400V, generally used in electric vehicles. Since a single cell cannot provide such voltage or power levels, multiple cells are connected in series and parallel to create the desired battery pack. The battery pack in this example comprises 10 modules, each with 11 series-connected parallel sets (p-sets). Each p-set comprises three cells in series. All modules are connected in series to form a pack of 330 cells.

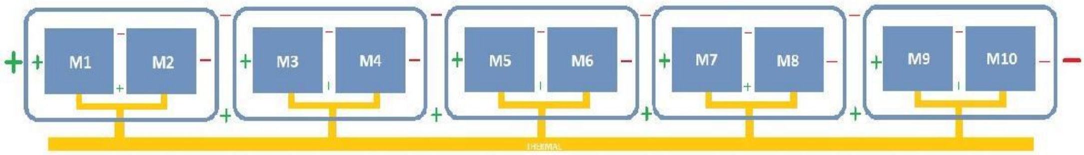

Fig.2: Battery Module with Thermal Effects

3.2 Mode Control Dashboard

In an electric vehicle, you can control the charging and discharging operations of the battery. To start the car, the key is turned which connects the battery circuit breakers and connects the battery to the system of the car. While driving, the battery is in discharge mode. When you connect the car to a charger, the battery is in charging mode. In a car, the discharging and charging modes are mutually exclusive. This study emulates this scenario by implementing a charging control dashboard in the model, called Battery Command. This dashboard comprises a rotary switch for manual operations, an on-off switch for automatic operations, and indication lamps.

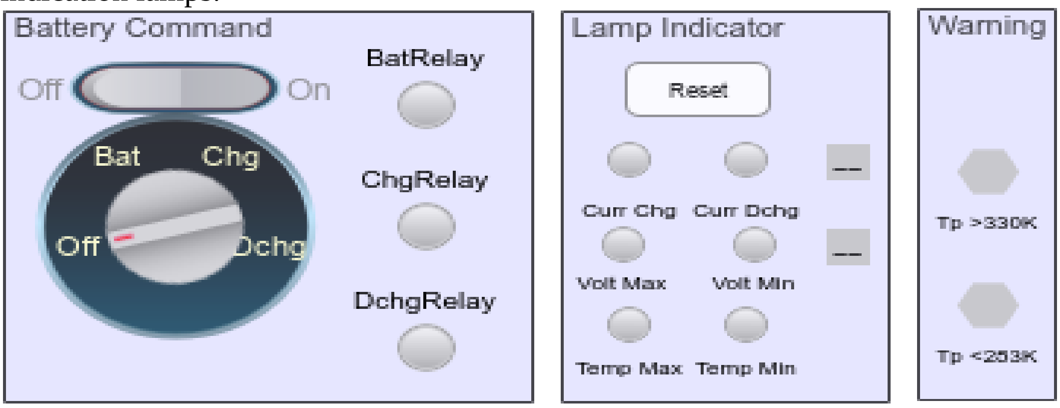

Fig. 3: Control Dashboard

The rotary switch is chosen manually between the charging and discharging modes. The position of the rotary switch affects the battery mode:

Off — The battery is disconnected.
Bat — The battery is connected.
Chg — The battery is charging.
Dchg — The battery is discharging.

The on-off switch is used to switch between modes automatically by setting the switch to on and by specifying the battery command (BatCmd) variable. When the BatCmd variable is equal to:

0 — The battery is disconnected.
1 — The battery is connected.
2 — The battery is charging.
3 — The battery is discharging.

The indication lamps show which mode the battery is currently operating in. When the lamps are red, the specific mode is off. When the lamps are green, the specific mode is on. The model also contains indication lamps that track fault appearances and a Reset button to reset all the faults to zero for testing purposes. A red lamp indicates the presence of a fault.

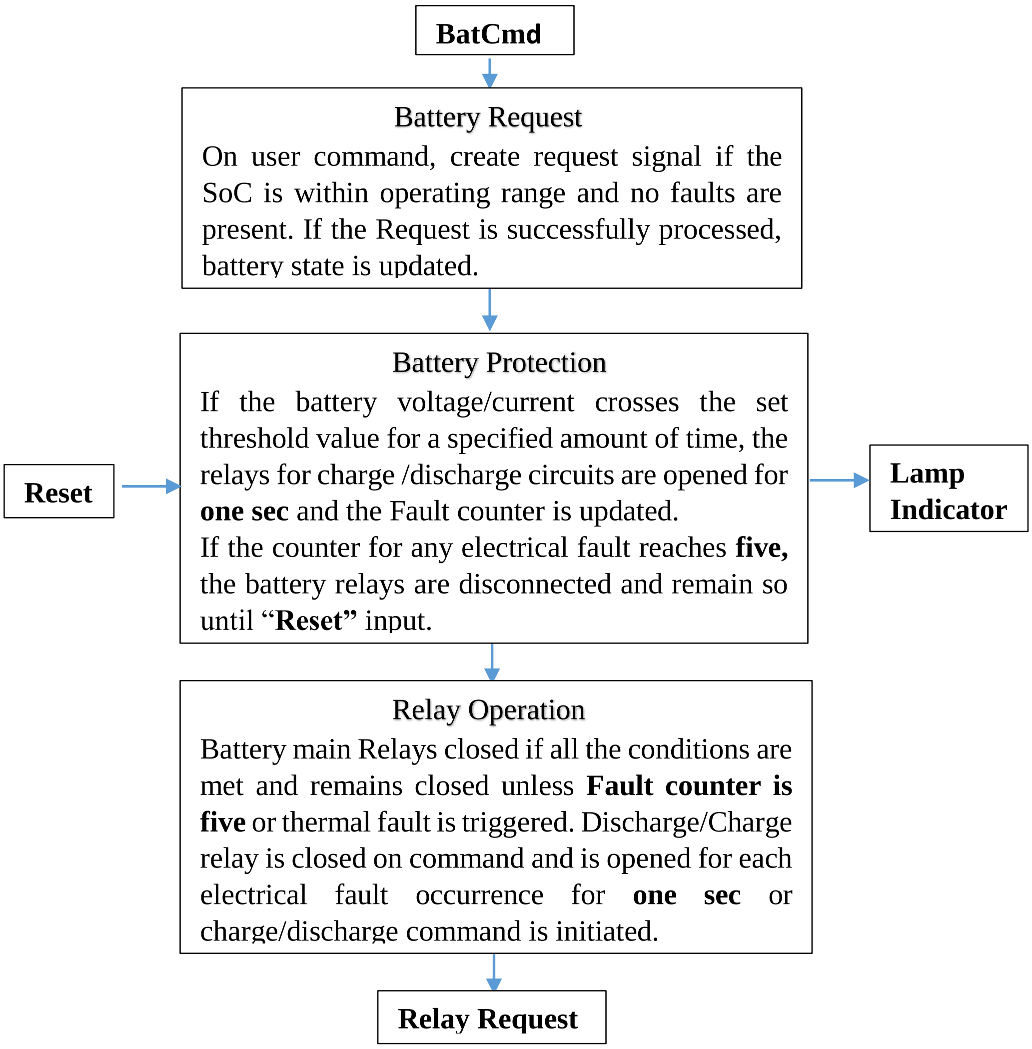

Fig. 4: Coordinated Operation of Relay

Table-3 Electrical Parameters of Cell

Temperature vector T [K]	T_vec= [278 293 313]
Cell capacity AH	AH=27
Cell capacity vector AH(T) [Ahr]	AH_vec= [28.0081 27.6250 27.6392]
Cell state of charge vector SOC [-]	SOC_vec= [0, .1, .25, .5, .75, .9, 1]

Table-4 parameters of Coolant, Module and Charger

Cell Thermal	Cell thermal mass (mass times specific heat=100 [J/K]) Cell level coolant thermal path resistance=1.2 K/W Temperature to switch on coolant flow=320 K Temperature to switch of coolant flow=303 K
Module Electrical	Number of series connected strings Ns=110 Number of parallel cells per string Np=3
Battery CC-CV charger parameters	Maximum voltage for charger=4.2 V Charger controller proportional gain=1 Charger controller integral gain=1

Table-5 Battery Fault Parameters

Voltage Fault parameters	Min Cell Voltage limit=3 (V) Max Cell Voltage limit=4.2 (V) Voltage offset for immediate fault=0.2 (V)
Current fault parameters	Max Charging Current =100 (A) Max Discharging Current=120 (A) Charger constant current value=50 (A) Constant voltage charger value=62 (V) Current offset for immediate fault =20 (A)
Thermal Fault parameters (Kelvin)	Min Cell temp for fault in K - 5 deg Celcius Max Cell temp for fault in K - 60 deg Celcius

4. Results of Fault Simulations

The Battery faults occur when the battery is subjected to in extreme scenarios.

4.1 Fault during Battery Charging

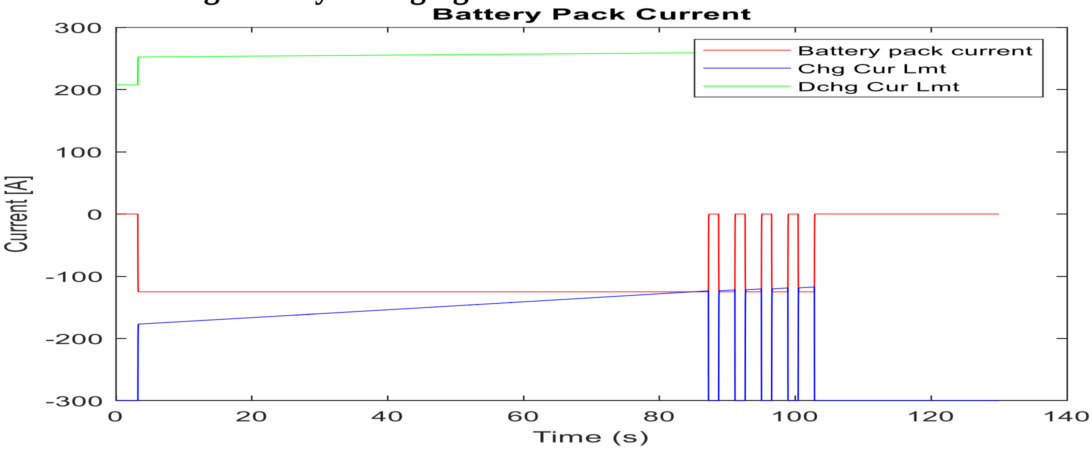

Fig. 5: Battery pack current at overvoltage fault during charging

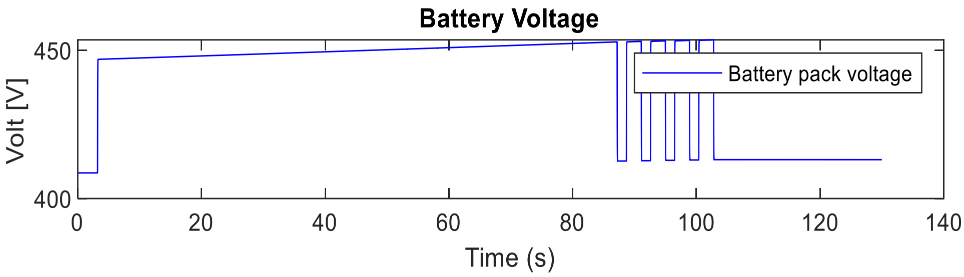

Fig. 6: Battery voltage at overvoltage fault during charging

A battery can experience two type of faults during charging are given below:

Overvoltage fault — An incompatible device charges the battery beyond its rated voltage.

Overcurrent fault — A current higher than the allowed limit charges the battery.

While charging, as the voltage and temperature of the battery increase, the charging current limit decreases. If the current limit goes below the charging current, a charging fault triggers and the charging circuit is disconnected from the battery for protection. After five fault occurrences, the battery circuit breakers disconnect for the rest of the simulation.

The setting of the simulation parameters are as follows.

Simulation parameters: Charger max charging current (Ah)= Charger CC_A = 125, Initial SoC of the pack set to low= Initial Pack SOC = 0.5

The model is simulated for comparison of current and voltage during over voltage fault.

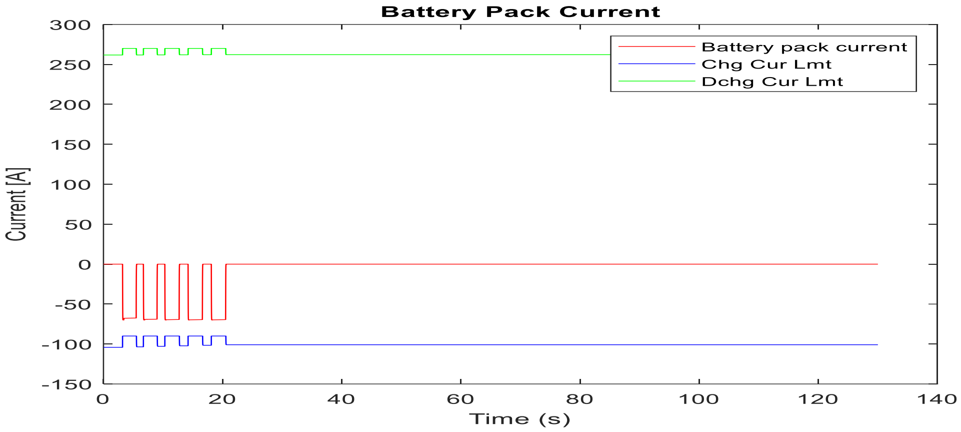

Fig. 7: Battery pack current at Overcurrent fault during charging

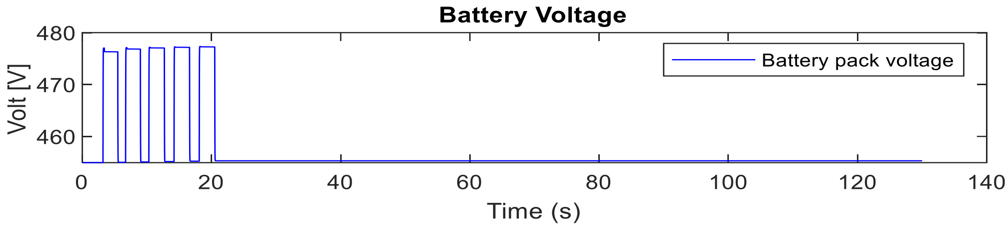

Fig. 8: Battery voltage at overcurrent fault during charging

For higher values of SOC, the cell voltage is closer to the full charge voltage. A high charging current can overcharge the battery or increase the battery voltage too much, which triggers an overvoltage fault. After five fault occurrences, the battery circuit breakers disconnect for rest of the simulation.

Voltage comparison

Overvoltage fault — An incompatible device charges the battery beyond its rated voltage.

Simulation parameters are as follows:

Cell max voltage limit=4.2 , Charger max charging current =70 A, Initial SoC of the pack set to high=0.95, Battery input for vehicle in charge at three sec

4.2 Fault During Battery Discharging

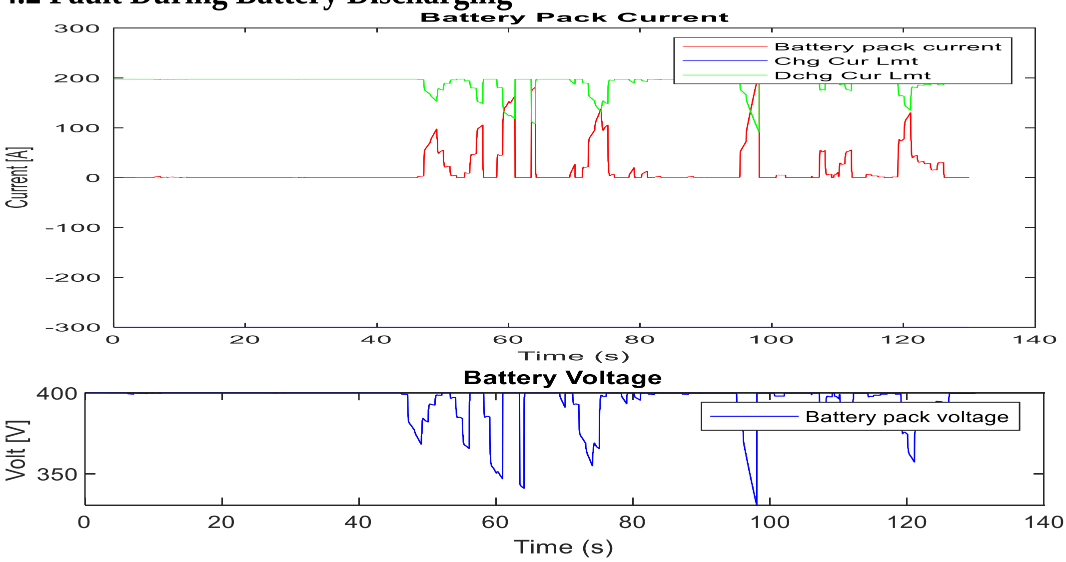

Fig. 9: Variation of Battery Pack current during discharge

Initial SoC of the pack set to low= initialPackSOC = 0.25
Battery input for vehicle in discharge at three sec
In discharge mode, a battery can experience these faults:
Under voltage fault — The battery discharges beyond its minimum rated voltage.
Overcurrent fault — A current higher than the allowed limit discharges the battery.
While discharging, as the battery voltage decreases and the battery temperature increases, the discharging current limit decreases. If the current limit goes below the discharging current, a discharging fault triggers. If the cell voltage goes below the minimum voltage limit, a voltage fault triggers. For any of these faults the discharging circuit is disconnected from the battery for protection. After five fault occurrences, the battery circuit breakers disconnect for the rest of the simulation.
Simulation parameters are as follows:
Battery minimum voltage limit= MinVoltLmt=3.2

4.3 Battery Thermal Fault

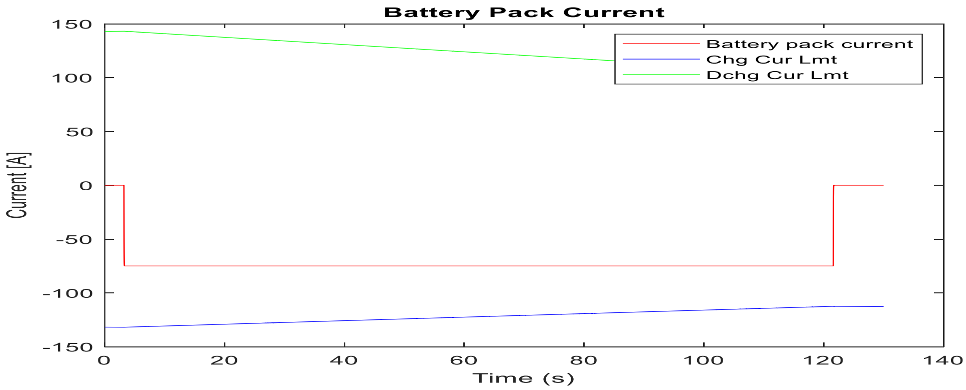

Fig .10: Variation of Battery pack current during thermal fault

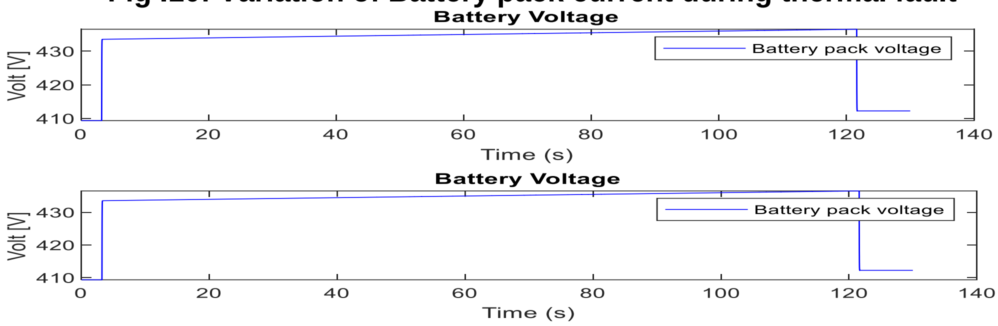

Fig. 11: Variation of Battery Voltage during thermal fault

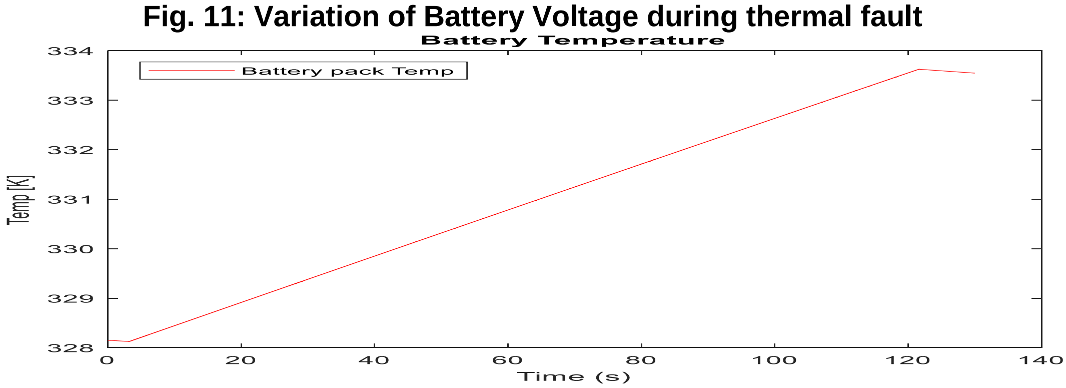

Fig 12: Variation of Battery pack Temperature during thermal fault

Thermal faults trigger if the battery temperature goes beyond the safe operating range. A simple on-off strategy controls the flow of coolant in the thermal circuit to manage the battery temperature.
To simulate a thermal fault, this study first turns off the coolant control so that the temperature in the battery is unregulated. The initial temperature of the battery is high. A high current charges the battery and brings its temperature to values beyond the safe operating range. This triggers the thermal fault and the battery circuit breakers disconnect for the rest of the simulation.
Simulation parameters:
Temperature parameter to "switch on" flow for thermal control
CoolantSwitchOnTp = MaxThLmt +5;
switch on temp set to 338.15 K (65 deg C)
Temperature switch is on for coolant flow which set five degrees more than the max allowed temperature for battery.
Initial temperature set to high(K) - 55 deg Celcius = initial_Batt_Temp=328.15;
charger max charging current = Charger_CC_A = 75;
Initial SoC of the pack set to low= initial_Pack_SOC = 0.5;
Battery input for vehicle in charge at 3 second.

5. Conclusion:

The most work in relation to LIBs, wherein only two forms of heat transport are more carefully considered, i.e. by completely ignoring the radiation effects, conduction, and convection. Radiation can therefore be regarded as a significant mode of heat transport in a wide range of contexts. While passive methods of heat transfer enhancement have a much wider application with iterative types of optimization techniques, active methods of heat transfer enhancement are widely reported by most studies. It is uncommon to find analyses of cylindrical battery cells, which have varying discharge rates and structural design characteristics including varying width ratios, cell spacing, and the kind and placement of cooling plates. To examine the thermal (temperature behaviour) and electric (charging and discharging rate) performance of the LIBs, Nano fluids and PCM in cooling plates may be used. Due to its higher heat transfer coefficient than air BTMS, liquid BTMS is regarded as a superior choice. Additionally, PCM is advised since it minimises the need of the active cooling and heating systems for the majority of operation; but, poor thermal conductivity is problematic when it comes to chilling or pre-heating the battery. Therefore, more study should be done to produce PCM with high thermal conductivity. Since heat pipes are being used for BTMS for the first time, more research is needed to understand the potential for combining heat pipes with air or liquid cooling.

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