Journal of Research Administration
Society of Research Administrators International

ELECTRICAL AND THERMAL INVESTIGATIONS OF A HYBRID ENERGY STORAGE SYSTEM

Ravikant K. Nanwatkar[1], Deepak S. Watvisave[2]
[1] Department of Mechanical Engineering, STES's Sinhgad College of Engineering, SPPU, Pune, India.
Email: ravikant.nanwatkar@sinhgad.edu
[2] Department of Mechanical Engineering, MKSSS's Cummins College of Engineering for Women, SPPU, Pune, India.
Email: deepak.watvisave@cumminscollege.in

ABSTRACT

This paper presents a variation of electrical and thermal parameters of a hybrid electric vehicle that utilizes both a lithium-ion battery and a supercapacitor for energy storage. The structural analysis evaluates electrical characteristics for planning and enhancing the hybrid compartments to ensure its structural integrity and safety during operation. The thermal analysis investigates the heat generation and dissipation of the battery and supercapacitor systems, which can affect their performance and lifespan. A computational fluid dynamics model is emerge to simulate the thermal effects of the compartments and their surrounding airflows. The effects of different cooling strategies on the temperature distribution and thermal management of the HEV were also examined. The results of the structural and thermal analysis provide insight into the performance and safety of the hybrid energy storage system in the HEV. The optimized design of the battery and supercapacitor compartments can ensure their structural integrity and minimize the risk of damage during operation. The thermal analysis can guide the development of effective cooling strategies to maintain the optimal temperature range for the energy storage systems, thus improving their performance and longevity. Overall, this study provides valuable information for the design and development of efficient and reliable HEVs with hybrid energy storage systems.

KEYWORDS: hybrid electric vehicle, lithium-ion battery, a supercapacitor, structural and thermal analysis, computational fluid dynamics.

1. INTRODUCTION

Lithium-ion batteries and supercapacitors are both commonly used in hybrid electric vehicles (HEVs) due to their high energy and power density, respectively. A hybrid electric vehicle system that combines both technologies can benefit from the advantages of both and overcome some of their individual drawbacks. Here is a basic structural analysis of the Lithium-Ion Battery and Supercapacitor based hybrid electric vehicle:

Lithium-Ion Battery:

The lithium-ion battery is the primary energy storage system in a hybrid electric vehicle. It is made up of numerous battery cells that are linked in either series or parallel or both arrangements to make a battery pack. Every battery cell comprises an anode, cathode and an electrolyte solution.

The electrodes are made up of a thin layer of active material made of oxides such as lithium cobalt lithium manganese oxide, or lithium iron phosphate coated on a conductive substrate such as copper or aluminum. The electrolyte is typically a lithium salt dissolved in an organic solvent.

Supercapacitor:

The supercapacitor, alias an Ultracapacitor or a multilayer capacitor, is a device that stores energy electrostatically. It is made up of two electrodes that are separated by an electrolyte, which acts as a charge separator. The electrodes are made of a high-surface-area material such as activated carbon, which allows for a large amount of charge to be stored in a small volume. The supercapacitor can be connected in parallel with the battery to provide additional power during acceleration or regenerative braking.

Hybrid System:

In a Lithium-Ion Battery and Supercapacitor based hybrid electric vehicle, the lithium-ion battery and supercapacitor are connected in parallel with a power electronics module. The power electronics module manages the flow of power between the battery, the supercapacitor, and the electric motor. During acceleration, the supercapacitor can discharge quickly to provide an additional burst of power, while the battery can provide sustained power. During regenerative braking, the supercapacitor can quickly absorb the energy from the motor and store it for later use, while the battery can absorb the remaining energy at a slower rate. The power electronics module can also control the charging of the battery and the supercapacitor to ensure optimal performance and longevity. Overall, the hybrid system can provide the high energy density of the lithium-ion battery and the high power density of the supercapacitor, resulting in a more efficient and responsive hybrid electric vehicle. Thermal analysis is an important aspect of designing Lithium-Ion Battery and Supercapacitor based Hybrid Electric Vehicles. HEVs require a thermal management system to maintain the battery temperature within a safe operating range to prolong the battery life and improve the vehicle performance. The thermal behaviour of LIB and SC is different due to their different physical and chemical properties. LIBs generate heat during charging and discharging due to the electrochemical reactions inside the cell. This heat can cause thermal runaway if not controlled, which can result in a catastrophic failure of the battery. SCs, on the other hand, generate less heat during operation and have a higher power density, but they have a lower energy density compared to LIBs. To analyze the thermal behaviour of LIB and SC based HEVs, various techniques can be used, including numerical simulations and experimental measurements.

The following are some of the commonly used techniques:

- **Thermal modeling:** A numerical simulation can be helpful to predict the temperature dissemination inside the battery and supercapacitor pack. This can help in designing an efficient thermal management system to maintain the temperature within a safe range.

- **Thermal imaging:** Thermal imaging can be used to measure the surface temperature of the battery pack and SCs. This can help in identifying the hotspots and improving the thermal management system.
- **Calorimetry:** Calorimetry can be used to measure the heat generated by the battery pack and SCs during operation. This can help in predicting the temperature rise and designing an effective thermal management system.
- **Thermal cycling:** Thermal cycling can be used to simulate the real-world operating conditions of the battery pack and SCs. This can help in evaluating the performance and reliability of the thermal management system.

Finally, thermal analysis of li-ion battery and supercapacitor based Hybrid electric vehicle is important to ensure the safety and performance of the vehicle. A combination of numerical simulations and experimental measurements can be used to design an efficient thermal management system which maintain the temperature within a safe operating limit. Identification and analysis of cooling system of a hybrid energy storage system for electrically driven vehicles and creating an ideal cooling control scheme to maintain the temperature at an acceptable range of 15°C to 35°C is important to improve safety, lengthen the service life of cell pack, and decreasing costs. When selecting a cooling and emerging approaches, adjustments is essential to be made amongst expenses, complication, heft, refrigeration properties, temperature consistency, and scrounging power.

Figure 1: Ragone plot of different energy storage system.

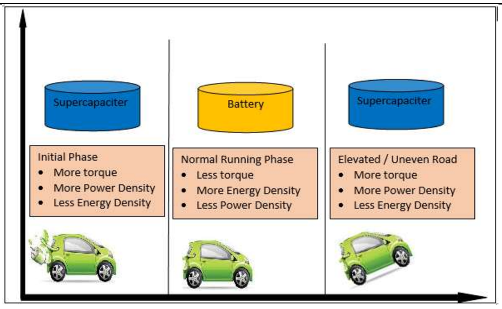


Figure 2: Energy and power requirements of proposed hybrid energy storage system for electric vehicle.

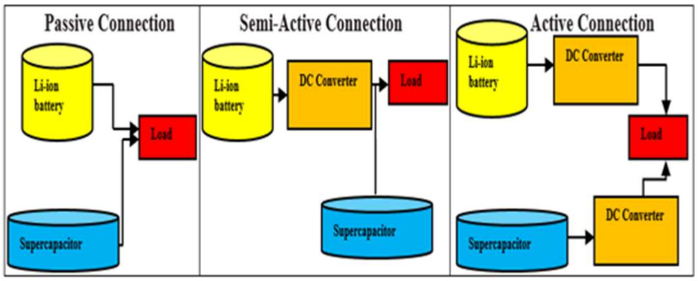


Figure 3: Connections for HESS

2. LITERATURE SURVEY

Marek Michalczuk et.al. [1] In 2012 has worked on Energy recovery through regenerative braking and the results are simulated using Matlab / Simulink PLECS toolbox. Jian Cao et.al. [2] In 2012 experimented on HESS with PSAT (The Power System Analysis Toolbox) with a compact dc/dc converter that acts as a restrained energy pump for maintaining an inflated amount of supercapacitor compared to the battery at driving conditions. Rebecca Carter et.al. [3] Worked on novel HESS of lead acid battery and supercapacitor using regenerative braking. It worked on supercapacitor characteristics and energy recovery through regenerative braking. Modifications can be done by increasing the supercapacitor operating voltages to enable energy content to be maintained while reducing equivalent series resistance. A. Ostadi et.al. [4] 2013 worked on various literatures related to HESS of batteries and supercapacitor by connecting them to DC sources to meet energy and power demands of the vehicle including energy management issues. Experimentation showed that the dissociate arrangement with the supercapacitor cell connected to the DC bus and battery cell connected via a bidirectional DC-DC converter is an efficient associating organized in EV/HEV applications. C. J. Mi et al. (2014): This paper reviewed the thermal management of lithium-ion batteries in electric and hybrid vehicles. The authors discuss various thermal management strategies and their impact on the performance and safety of the battery. Seyed Hamidi et.al. [5] In 2015 worked on Lithium-ion batteries and Supercapacitors for network applications with variant materials for cathode, anode, and a lithium-ion battery that result in a variety of output performance characteristics along with equivalent electrical circuits. Their work relates Lithium-ion and supercapacitor for high power density with extensive discharge demand application to improve issues encountered in Lithium-ion batteries like high production cost, and high sensitivity for thermal runaway. C. Cao et al. (2016): This paper reviewed of supercapacitor modeling, estimation, and control for use in hybrid electric vehicles. The authors discuss various modeling techniques and control strategies for improving the performance and efficiency of the hybrid system. A study performed by Wu et al. (2016) investigated the mechanical behaviour of a LIB pack in a HEV under different loading conditions. The study concluded that the shear stress and von Mises stress were the two main factors that affected the mechanical behaviour of the LIB pack. The study recommended the use of low modulus and high-strength materials for the ESS housing to minimize stress concentration. Clemente Capasso et.al. [6] 2016 worked on HESS with Na-Cl batteries & EDLC using a Controlled DC/DC bi-directional power Converter. Further work is proposed on Simulation & experimental study with HESS of lithium-ion and supercapacitor. Similarly, a study conducted by Liu et al. (2017) investigated the structural behaviour of a SC pack in a HEV. The study concluded that the SC pack was prone to deformation and failure under severe mechanical loading. The study recommended the use of a protective casing around the SC pack to minimize deformation. A. Bhatt et al. (2017): This paper presents a design and thermal analysis of a lithium-ion battery module for use in hybrid electric vehicles. The authors develop a numerical model of the module and investigate the thermal behaviour of the battery under different operating conditions. A study conducted by HE et al. (2017) worked on the thermal behaviour of a LIB pack in a HEV under different operating conditions. The study concluded that the temperature of the LIB pack increased rapidly during charging and discharging. The study recommended the use of an efficient cooling system to maintain the temperature of the LIB pack within a safe operating range. Similarly, a study conducted by Wu et al. (2018) investigated the thermal behaviour of a SC pack in a HEV. The study concluded that the SC pack was less prone to thermal runaway compared to the LIB pack. The study recommended the use of an enhanced cooling system to prolong the temperature of the SC pack within a safe operating range. Wenhua Zuo et.al. [7] 2017 worked on various combinations of HESS with a high capacitive battery and rated capacitive electrode. Further works remained on BSH with fluent high voltage window and integrated 3D electrodes set up. Anuradha Herath et. al. [8] 2018 worked on the charging and discharging algorithm of batteries and supercapacitor as per their acceleration and deceleration conditions. The work focused on reducing the strain on the batteries while extending the range of the vehicle compared to the traditional pure battery-based electric vehicle. Mahdi Soltani et.al. [9] 2018 worked on Lithium-ion capacitors that are used as a high-power storage unit for MLTB driving cycle. Further work remained to optimize the li-ion battery and capacitor unit for optimized cost, and size with a higher energy and power density. Lip Sawa et.al. [10] 2018 worked on HESS with Lithium-ion batteries and a supercapacitor model to evaluate the thermal and electrical performance parameters for different driving cycles. The simulation results in improved dynamic stress, better thermal performance for peak power demand better life span of the battery, and reliability of HESS. The remained work is set up formation for an electric propulsion system test bench to validate the simulation results and to incorporate the intelligent energy management system in the model. Md. Arman Arefin et.al. [11] 2018 worked on Simulations of HESS with battery and supercapacitor new and partially used battery cells. The results showed inverse proportionality between the temperature and the hybrid system efficiency. This Hybridization with increases the battery life span, and the efficiency of the energy storage system and power train. This HESS gives advantages of reduction in battery aging, peak battery current, and more number of executed cycles with an increase in power conserving size of the scheme that rises the battery preservation interlude. Lia Kouchachvili et.al. [12] 2018 worked on battery and supercapacitor HESS by coupling the battery with a supercapacitor, which is basically an electrochemical cell with a similar architecture, but with a better capability rate and cyclability. The Basic principle was a supply of excess energy by the supercapacitor when the battery won't be able to do so. Configurations, design, and performance of HESS had been discussed with active, semi-active, and passive types of HESS. Various applications area of HESS like mobile charging stations, and racing cars, have been discussed with different batteries and supercapacitor combinations, related issues, and future aspects. M. Palma et al. (2018): This paper presents a structural analysis of lithium-ion battery modules for use in electric vehicles. The authors develop a finite element model of the module and investigate the mechanical behavior of the battery under different loading conditions. S. K. Lee et al. (2019): This paper presents a structural and thermal analysis of a lithium-ion battery pack for use in an electric vehicle. The authors develop a finite element model of the pack and investigate the thermal behaviour of the battery under different operating conditions. Immanuel N. et.al. [13] 2019 proposed a well-organized hybridization of battery, supercapacitor, and hybrid capacitor for efficient energy consumption in electric vehicles. The work remits the issue of deficiency in autonomy between two recharge points for the supercapacitor. Experimentation involved analysis of multiple inputs for DC-DC convertor and obtaining electric vehicle profiles for proposed HESS. This work can be further extended for various load profiles with peak crest factors. S Devi Vidhya et.al. [14] 2019 worked on the simulation, design, and power arrangement of the hybrid energy storage system of li-ion battery and supercapacitor which combined a bi-directional convertor for a light electric vehicle under Indian driving conditions to get optimized working parameters to enhance the life of both energy storage systems. Simulation and experimental analyses were carried out to maintain the potency of the proposed system with modelled prototype system components of a light electric vehicle. A.Bharati Sankar et.al. [15] 2019 worked on a smart power converter for an electric bicycle, powered by hybridization of lead acid battery and supercapacitor. The supercapacitor was connected in parallel to the battery pack via Arduino controller-based power converter that adjudges power between both energy storage systems. Experimental results showed an enhancement in the ascending speed w.r.to time of the bicycle as an undeviating result of the power converter delicate to reaping the remaining current from the high power adjustable supercapacitor neglecting extensive discharges from the battery to improve its life without a change in maximum speed. The main battery pack was protected from high discharge currents to improve its life cycle. Walvekar, A. et.al. [16] 2020 worked on the hybridization of Li-ion batteries and supercapacitor for lightweight electric vehicles. In this paper, the result of various combinations of hybrid energy storage systems and the effect of hybridization is analysed w.r.t. current, voltage, and State of Charge (SOC). Results showed that the use of HESS for pure battery-based Electric two-wheelers decreases the higher value of the Current of the battery with the corresponding improvement in battery life.

3. METHOD AND MATERIAL

Experimental set up consists, hybrid connections of Lithium ion battery pack of 11.1V and 20A, and supercapaciter pack 13.5V and 100 faraday. HESS is supplied and electric power through Switched Mode Power Supply of 12V & 10 A. two shunt resistors are connected to control the current and voltage supply and to get correct input and output reading on display devices. Three Separate switches are connected to battery pack; supercapacitor pack and HESS of both to operate it individually and in HESS mode during experimental analysis. Here experimentation is performed taking two four wheeler headlights of 100 watt each for different drive cycle for individual load as well as combine load. Figure 4 shows the block diagram of connections done for experimental investigation. Table 2 shows the Component Specifications for the experimental set up. Conduction is the transfer of heat by direct contact between bodies or through the same body. In conduction, there is no transfer of matter, only energy. Molecules vibrate or move with greater speed in a region at a higher temperature. And heat flows from higher to lower temperature. Comparative analysis is performed for four types of cooling systems: air, liquid, fin cooling and phase change method. In this project, we will use a non-direct cooling method with a shell and tube structure. Copper coil is placed in between the lithium ion battery and acrylic sheets are placed on both sides of the battery pack. The coolant used in the project is propylene glycol. One end of the coil is connected to the pump, and the pump is placed in the sump. The other end is also placed in the sump or cooling tower. When the battery pack temperature increases above the optimal range of the battery pack, the circulation of the coolant starts in the copper tubes. This causes heat transfer. Due to this decrease in the temperature of the battery pack happens, we compared this non-direct liquid flow cooling with the force airflow cooling. After applying the same load to the both battery packs, a change in temperature happens. Both the battery packs reach a temperature well above their optimal range. Then we apply both cooling methods, air flow and liquid flow, for 55 minutes, read through the observations, and calculates the effectiveness of the non-direct liquid cooling system over the airflow system. In this working model, we used two 14.8 V and 10 A battery packs, with each cell rated at 3.7V and 2.5A. Each battery pack contains 16 cells. Then a load bulb of 100W is applied to the both battery packs. The temperatures of both battery packs reached 39°C after 55 minutes, while the initial room temperature was 27°C. This change in temperature causes less effectiveness of the battery and may reduce battery life. A cooling effect should be used to regulate the battery temperature within the optimal range of 15°C -35 °C.

Particulars	**Specifications**
A switched-mode power supply (SMPS)	12 V, 10 A
Li-ion Battery Pack	11.1 V, 20 A
Supercapacitor Pack	13.5 V, 500 F
Voltage display unit	0-200 V
Current display unit	0-75 A
Resistor for supercapacitor connections	470 KΩ, 2 W
Shunt resistor (2nos)	75 mV
Switches	3
Load	200 W
Other Accessories i.e. solder gun, wire, pump, Speed controller, Cooling fan, Propylene glycol, Copper coil with U bent, Insulating sheet, Thermocouple.	As per requirement

4. ELECTRICAL ANALYSIS

Calculations of the battery pack for generating approx.100-watt energy for approx. 2 hours.

- Single battery with 3.7 V and 2500mAh capacity.
- Assuming 80% efficiency of the battery.

- Therefore 24 cells of batteries with a pack of three (3.7 x 3 = 11.1) pairs in parallel and eight (2500mAh x 8 = 20Ah) in series combination.
- Total Energy generated: VA/100 = (11.1 x 20) / 1000 = 0.222 Kwh = 222 w/h
- Total Power generated: VA = 11.1 x 20 = 222 watt.

Calculations for Supercapacitor pack,

- We have taken 5 nos of Green cap EDLC (DB) supercapacitor with 2.7 V and 500 faradays, having size 35 mm x 60mm and connected in series for experimental analysis.
- Input current limit –1mΩ, Discharge limit – 470kΩ,
- Total voltage 2.7 x 5 = 13.5 V

$$\frac{1}{C_T}=\frac{1}{C_1}+\frac{1}{C_2}+\frac{1}{C_3}+\frac{1}{C_4}+\frac{1}{C_5}=\frac{1}{500}+\frac{1}{500}+\frac{1}{500}+\frac{1}{500}+\frac{1}{500}=\frac{5}{500}$$

- Total capacitance (CT) = $C_T = 500/5 = 100\text{Faraday}$
- Energy calculation (E) = $\frac{1}{2}C_T V^2 = \frac{1}{2}\times 100\times 13.5^2 = 9112.5\text{joules} = 2.53125\text{w/h}$
- Power generated = E/(t_2-t_1) = (2.53125 / 3) = 843.75 watt.

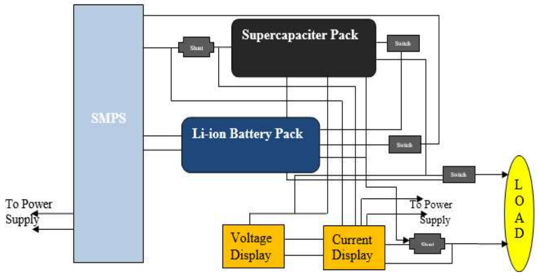


Figure 4: Block diagram of set up

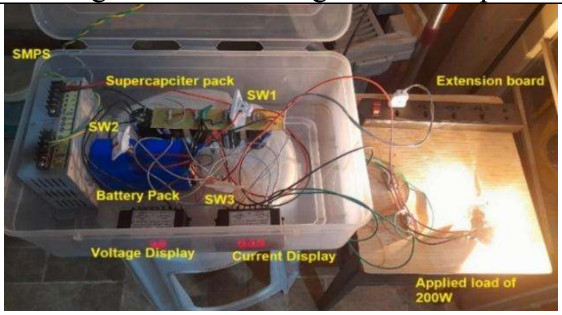


Figure 5: Experimental set up

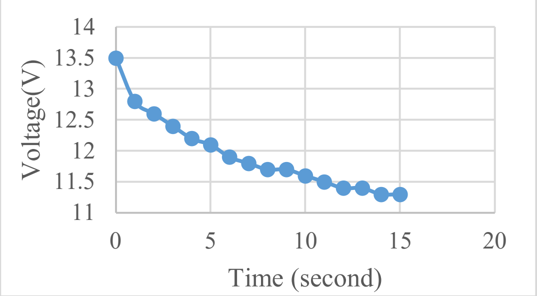


Figure 6: HESS voltage variation w.r.to time at no load condition

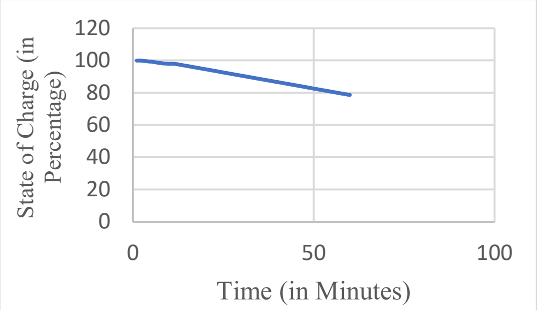


Figure 7: HESS SOC variation w.r.to time at load of 220 W

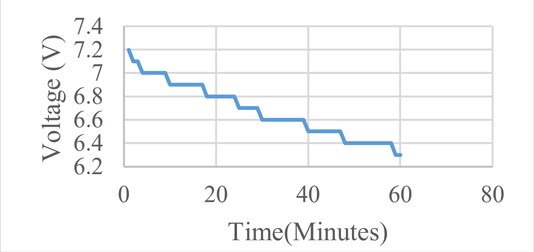


Figure 8: HESS voltage variation w.r.to time at load of 220 W

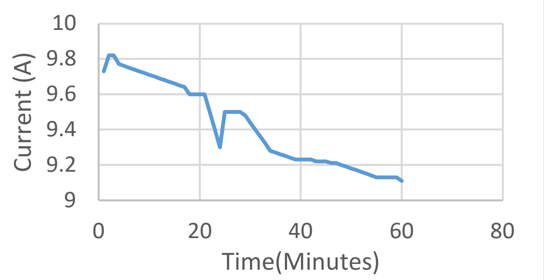


Figure 9: HESS voltage variation w.r.to time at a load of 200 W

5. THERMAL ANALYSIS

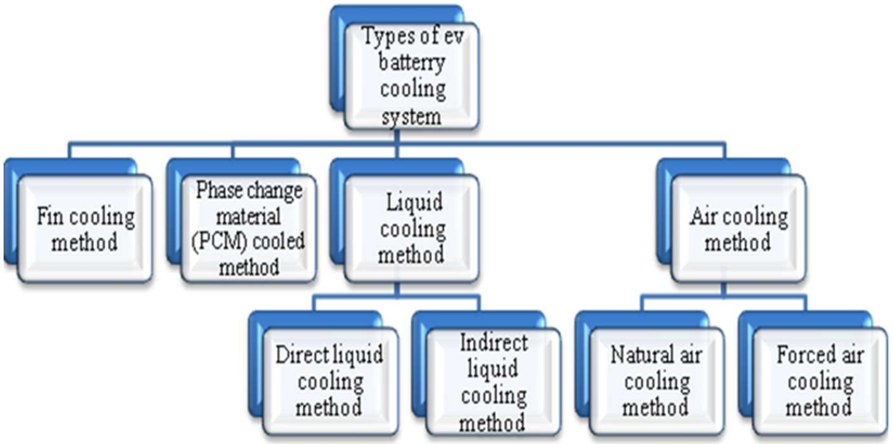
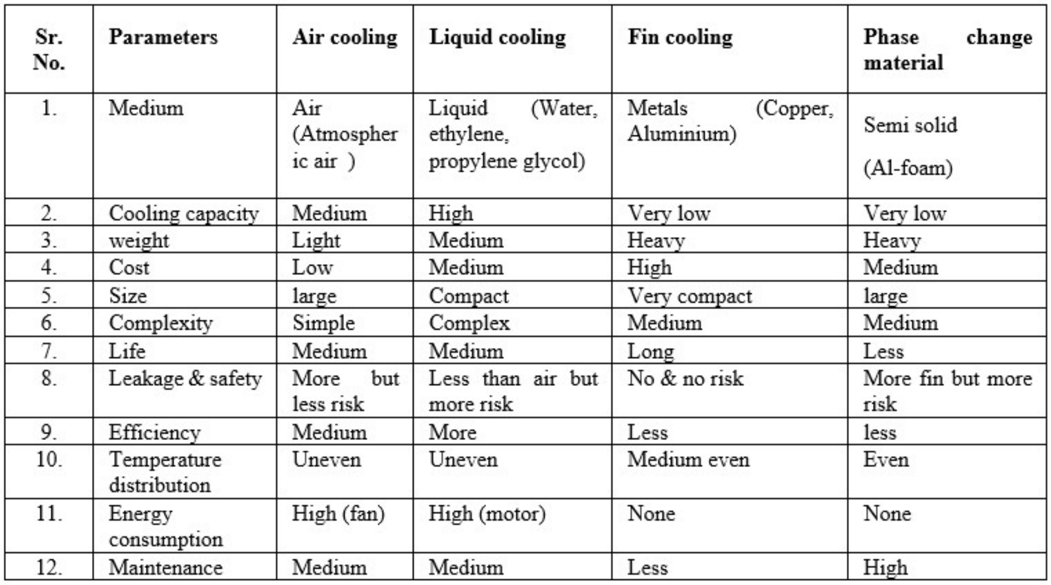


Figure 10: Classification of cooling systems for automobiles



Sr. No.	Parameters	Air cooling	Liquid cooling	Fin cooling	Phase change material
1.	Medium	Air (Atmospheric air)	Liquid (Water, ethylene, propylene glycol)	Metals (Copper, Aluminium)	Semi solid (Al-foam)
2.	Cooling capacity	Medium	High	Very low	Very low
3.	weight	Light	Medium	Heavy	Heavy
4.	Cost	Low	Medium	High	Medium
5.	Size	large	Compact	Very compact	large
6.	Complexity	Simple	Complex	Medium	Medium
7.	Life	Medium	Medium	Long	Less
8.	Leakage & safety	More but less risk	Less than air but more risk	No & no risk	More fin but more risk
9.	Efficiency	Medium	More	Less	less
10.	Temperature distribution	Uneven	Uneven	Medium even	Even
11.	Energy consumption	High (fan)	High (motor)	None	None
12.	Maintenance	Medium	Medium	Less	High

Table 2: comparative analysis of cooling methods

Here we have taken 18650 battery cells to form a battery pack. Considering above the diameter of hollow copper wire is taken as 7 mm.

- Copper coil is fitted in the gap of battery to get proper thermal insulation and more contact area.
- Temperature increases coolant will flow through a coil.
- The battery comes to normal temperature.
- Temperature at an optimal range of 150C to 350C
- Here two battery packs with lithium ion battery cell were inspected i.e. first without coolant and second with air and water coolant to evaluate the results.
- The CFD analysis was performed to validate the experimental results.

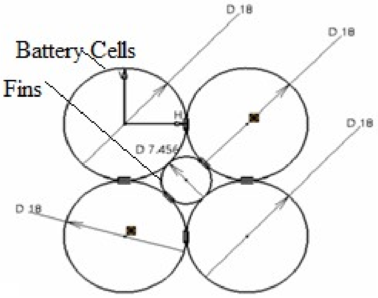


Figure 11: Conceptual design for battery pack

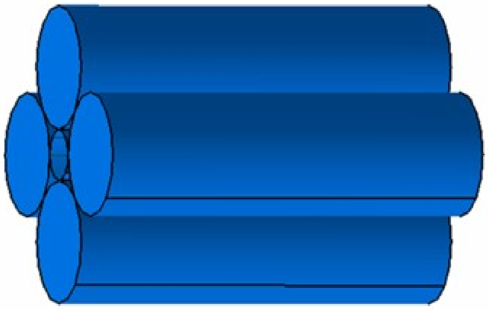


Figure 12: Model design for battery pack

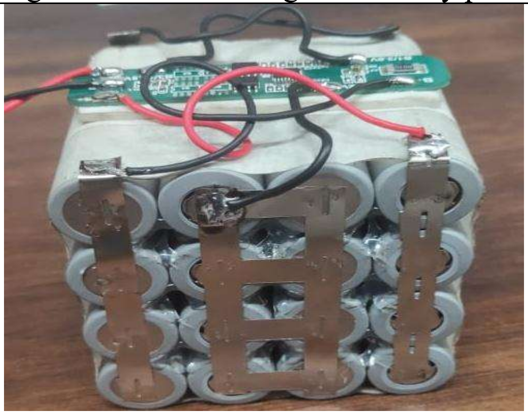


Figure 13: Li-ion cell battery pack

Figure 14: Li-ion cell battery pack with fins

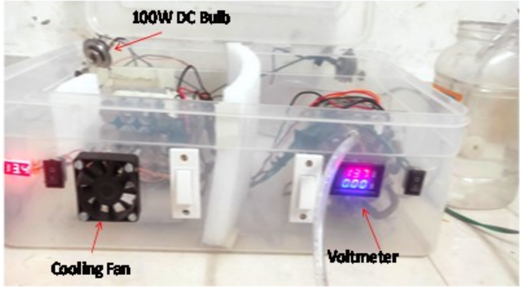


Figure 15: Li-ion cell battery pack with fan cooling

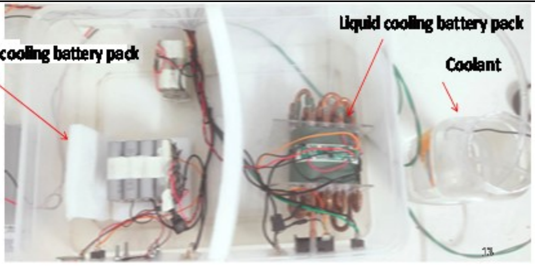


Figure 16: Li-ion cell battery pack with liquid cooling

Here, thermal analyse results evaluated based on experimentation to check the effects on electrical parameters like voltage, current and state of charge.

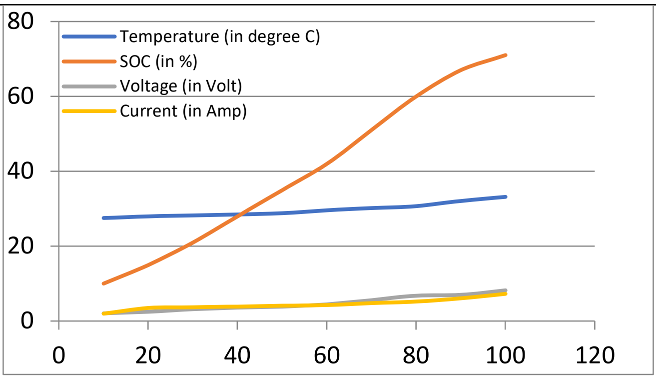


Figure 17: Battery parameter variation w.r.to time without cooling system

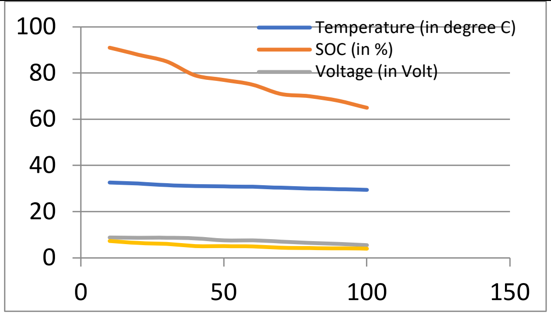


Figure 18: Battery parameter variation w.r.to time with cooling system

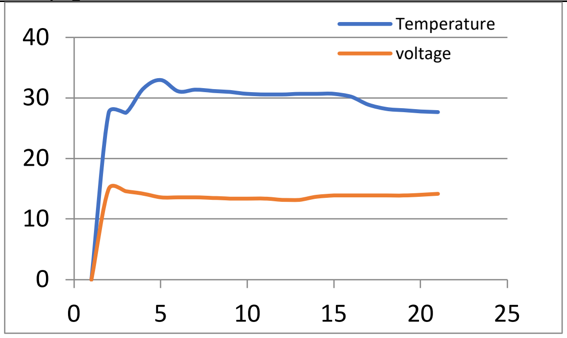


Figure 19: Battery parameter variation w.r.to time without cooling system

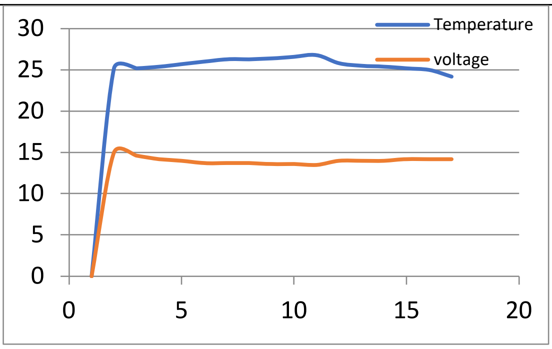


Figure 20: Battery parameter variation w.r.to time with cooling system

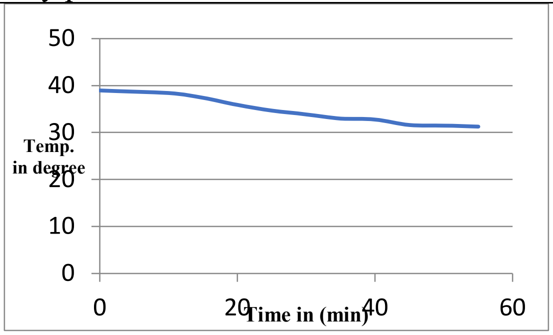


Figure 21: Battery parameter variation w.r.to time with air cooling system

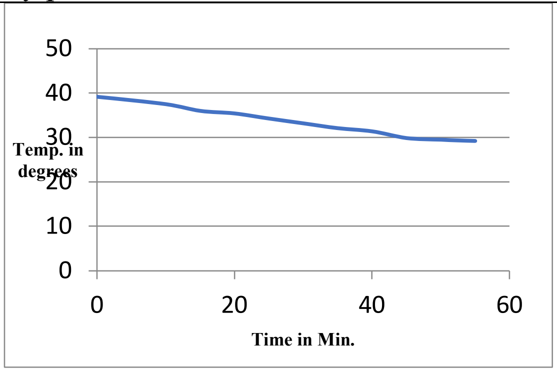


Figure 22: Variation of temperature vs time of battery pack

Volumetric flow rate

$Q = v\,A$

Q=volumetric flow rate (m^3/s)

v=flow velocity (m/s)

A=cross-sectional vector area (m^2)

Efficiency formula=

$$\eta\% = \frac{\text{Difference between final temperature of air flow and liquid flow cooling}}{\text{Final temperature of air flow *100}}$$

6. CFD ANALYSIS

Here, Analysis is performed using ANSYS Fluent software.

For water flow rate was 100 watt

Convectional rate 10 w/mm2

Ambient temperature 22 degree
Material aluminium box, pipe copper.

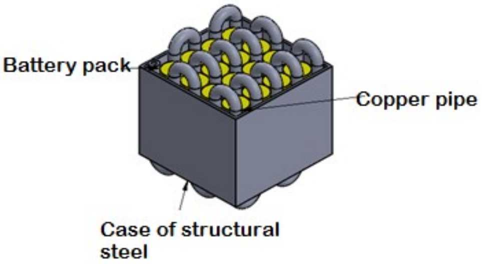


Figure 23: CFD model for battery simulation with internal fins

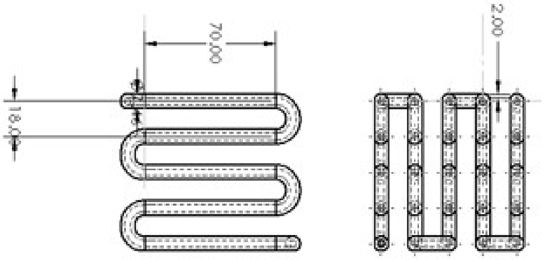


Figure 24: Copper fin shape model for analysis

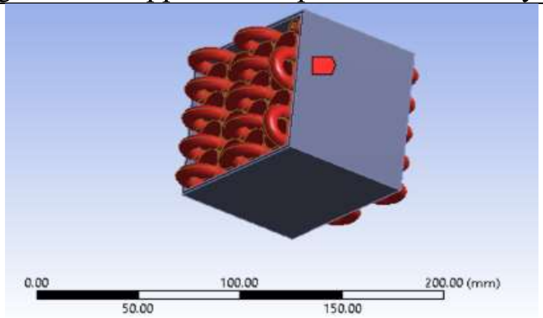


Figure 25: CFD model for battery simulation with internal fins with boundary conditions

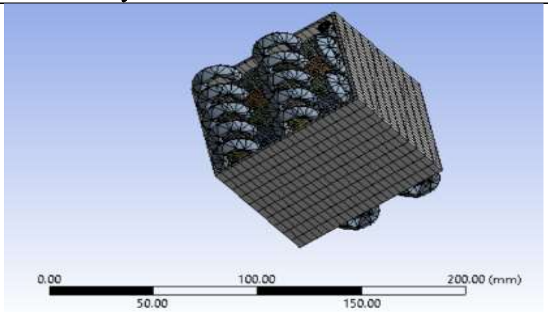


Figure 26: Mesh CFD model for battery simulation with internal fins with boundary conditions

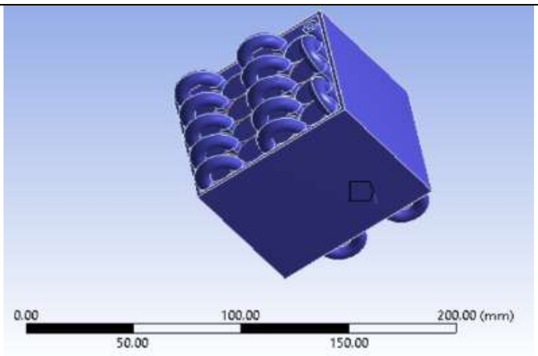


Figure 27: CFD model for battery simulation with internal fins boundary conditions for air cooling

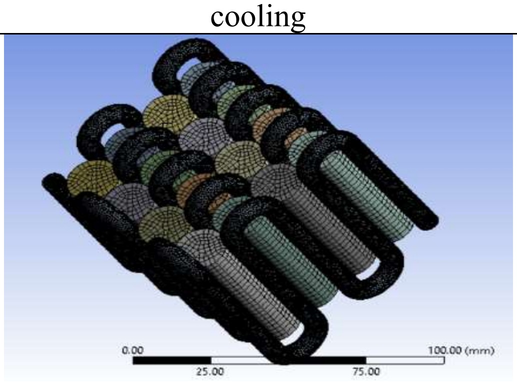


Figure 28: Mesh CFD model for battery simulation with fins boundary conditions for air cooling

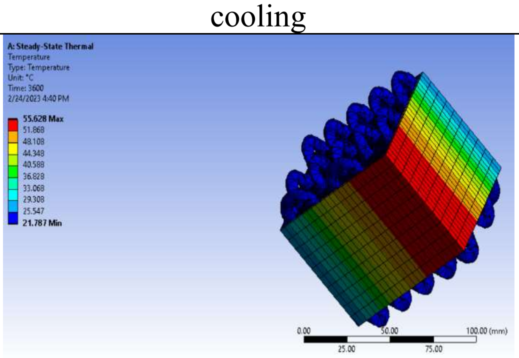


Figure 29: CFD model for battery simulation for deformation

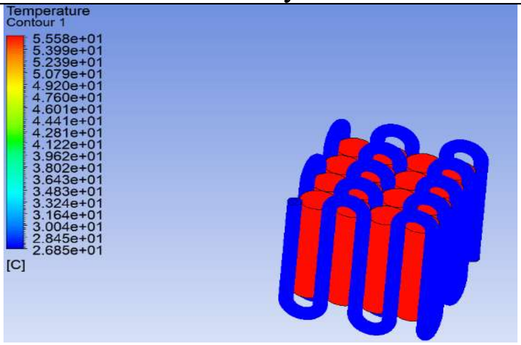


Figure 30: CFD model for battery simulation for temperature stresses

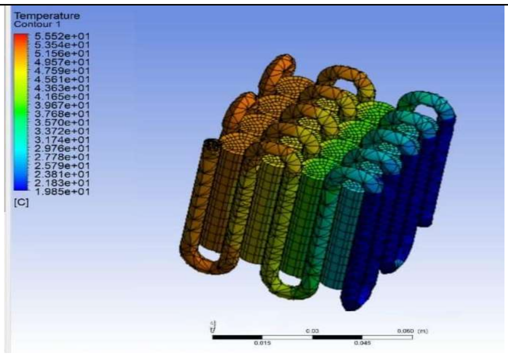


Figure 31: CFD Analysis of battery pack by air cooling

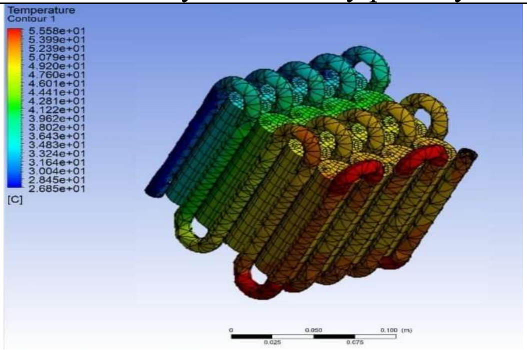


Figure 32: CFD Analysis of battery pack by liquid cooling

7. RESULTS AND DISCUSSION

A. Structural Analysis:

1) Initially, the HESS is tested without any load to check the effects on the supercapacitor, it observed that a very negligible effect was observed on the lithium-ion battery pack but considerable change has been observed on the supercapacitor pack with a change in voltage capacity at constant as shown in figure 19.
2) Further the HESS is tested for a load of 200 watts (four-wheeler headlights) for approximately 1 hour,
3) At loading conditions voltage of HESS decreased stepwise with the initial jerk for the first 2 minutes.
4) The current variation is discrete with an initial jerk for the first 2 minutes with linear variation till 18 minutes, later it is constant for the next 2 minutes. For the next 2 to 3 minutes it decreases drastically to 9 amperes. The current increases suddenly to 9.6 amperes to decrease in further operation. This is the point where the supercapacitor comes into working as shown in figure 21.
5) HESS state of charge varies linearly w.r.to time as shown in figure 20.
6) It is observed that the supercapacitor charge and discharge time is approximately 3 minutes for the given setup and that for the battery it is approximately 2.5 hrs.

B. Thermal Analysis:

1) On basis of comparative analysis of different cooling system we found that Air & Water is available in ample amount in nature but there are certain chances of Corrosion due to Air & Water. So for long term it is not a suitable solution but if we provide a good refrigerant area in that cooling region so refrigerant cooling system can found out to be desirable solution.
2) The consequences indicated that an air-cooling scheme expended two to three additional dynamism to preserve the identical normal temperature. A direct liquefied cooling scheme has the lowermost extreme temperature upsurge; and a fin cooling structure enhances around 40% spare burden of cell, that considers furthermost, when types of cooling methods have the identical capacity. Indirect liquid cooling is more useful than direct liquid cooling with drawback of lower cooling performance.
3) Percentage efficiency of liquid cooling over air cooling, Percentage efficiency = 6.70%
4) Efficiency of the cooling system is increased by 6.70%. According to study of non-direct liquid cooling system, comparing with air cooling system, liquid cooling system is more efficient due to the higher specific heat capacity, density and thermal conductivity of water.

8. CONCLUSION

- After structural analysis of the proposed hybridization of lithium-ion battery and supercapacitor, we can find that when the HESS is worked for given load considerable results show that The Supercapacitor acts only when there is more power requirement else is ideal.
- As soon as the supercapacitor is discharged it gets charged from the battery when the battery is not working for heavy loads. Further, as the load decrease battery acts for the next working and keeps the supercapacitor ideal. This effectively decreases the load on the battery for high power requirements. This shows a significant solution for automobiles for effective hybridization to meet current demands of energy and power in the energy and automobile sector.
- Comparative analysis of simulated and experimental results showed acceptable deflections in current, voltage, and state of charge w.r.to time.

CONFLICTS OF INTEREST

"The authors declare no conflict of interest."

STATEMENT OF ETHICAL APPROVAL

a) Statement of human rights

“For this type of study, statement of human rights is not required.”

b) Statement on the welfare of animals

“For this type of study, statement on the welfare of animals is not required.”

STATEMENT OF INFORMED CONSENT

“For this type of study, informed consent is not required.”

REFERENCES

1. Mahdi Soltani, Joris Jaguemont, Peter Van den Bossche, Joeri van Mierlo and Noshin Omar, “Hybrid Battery/Lithium-Ion Capacitor Energy Storage System for a Pure Electric Bus for an Urban Transportation Application” in applied science article, 2012, pp.1-19.
2. Jian Cao and Ali Emadi, IEEE Transactions on Power Electronics, “A New Battery/Supercapacitors Hybrid Energy Storage System for Electric, Hybrid, and Plug-In Hybrid Electric Vehicles”, Volume 27, No. 1, January 2012, pp.122-132.
3. Rebecca Carter, Andrew Cruden, IEEE transactions on vehicular technology, “Optimizing for Efficiency or Battery Life in a Battery/Supercapacitor Electric Vehicle”, May 2012, 61(4):1526-1533.
4. Ostadi, M. Kazerani et.all. In IEEE transactions IEEE Transportation Electrification Conference and Expo (ITEC), “Hybrid Energy Storage System (HESS) in vehicular applications: A review on interfacing battery and ultra-capacitor units” 2013, pp.275-281.
5. Seyed Ahmad Hamidi, EmadManla, and Adel Nasiri, “Li-Ion Batteries and Li-Ion Ultra capacitors: Characteristics, Modelling and Grid Applications” in IEEE transactions, 2015, pp.4973-4979.
6. Clemente Capasso, OttorinoVeneri, “Integration between supercapacitor and ZEBRA batteries as the high-performance hybrid storage system for electric vehicles” in Science directory ELSEVIER publication, 2017, pp. 2539-2544.
7. Wenhua Zuo, Ruizhi Li, Cheng Zhou, Yuanyuan Li, Jianlong Xia, and Jinping Liu “Battery-Supercapacitor Hybrid Devices: Recent Progress and Future Prospects” in Advanced Science News publication, 2017, pp.1-21.
8. Herath, Pasan Gunawardena, “Conversion of a Conventional Vehicle into a Battery-Supercapacitor Hybrid Vehicle” in American Journal of Engineering and Applied Sciences, a science publication article 2018, pp.1178-1187.
9. Mahdi Soltani, Jan Ronsmans et.al. , July 2018 Applied Sciences 8(7):1176, “Hybrid Battery/Lithium-Ion Capacitor Energy Storage System for a Pure Electric Bus for an Urban Transportation Application”2018, pp.1-19.
10. Lip Sawa, Hiew Poona, in ELSEVIER science direct journal ICAE 2018, “Numerical modelling of hybrid supercapacitor battery energy storage system for electric vehicles”, 2018, pp.2751-2755.
11. Md. Arman Arefin, Avijit Mal, Journal of Mechanical and Energy Engineering, Vol. 2(42), No. 1, “Hybridization of battery and supercapacitor for low weight electric vehicle”, 2018, pp. 43-50.
12. Lia Kouchachvili, Wahiba Yaïci in ELSEVIER journal of power sources 374, “Hybrid battery/supercapaciter energy storage system for the electric vehicles”, 2018, pp. 237-248.
13. Immanuel N. Jiya, Nicoloy Gurusingheet.all., Indonesian Journal of Electrical Engineering and Computer Science Vol. 16, No. 2, November 2019, “Hybridization of battery,

supercapacitor and hybrid capacitor for load applications with high crest factors: a case study of electric vehicles",2019, pp. 614~622

14. S Devi Vidhya and M Balaji, in Measurement and Control 2019, Vol. 52(9-10), "Modelling, design and control of a light electric vehicle with hybrid energy storage system for Indian driving cycle", 2019,pp. 1420–1433.
15. A.Bharathi Sankar, R.Seyezhai, in WSEAS TRANSACTIONS on POWER SYSTEMS E-ISSN: 2224-350X, Volume 14, 2019, "Super capacitor/Battery based Hybrid Powered Electric Bicycle", 2019, pp.156-162.
16. Walvekar, A., Bhateshvar, Y et.all. In SAE international US, ISSN 0148-7191 in 2020, "Active hybrid energy storage system for electric Two wheeler",2020,. pp.1-6.
17. Vittore Cossalter, "Motorcycle dynamics", Second English edition 2006.
18. Thomas Reddy, Handbook of batteries. McGraw-Hill Professional; 4th edition, 2010.
19. Scott J. Moura, Jason B. Siegel, Donald J. Siegel, Hosam K. Fathy, and Anna G. Stefanopoulou, "Education on vehicle electrification: Battery Systems, Fuel Cells, and Hydrogen," in IEEE Vehicle Power and Propulsion Conference, 2010.