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Experimental and Simulated Analysis of Lithium-Ion Battery Parameters for Electric Vehicles

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Abstract: *Electric mobility contributing to greater extent to balance the energy and power demands, energy storage units as well as environment safety for current automobile sector. Electric vehicle has major efficient features of zero combustion, longer charging and discharging cycle which plays a vital role to replace the ongoing increase in price of petroleum fuels and its harmful effect son environment with their degrading store. Many non-conventional energy sources like solar, tidal, wind etc. Can be used to generate energy and store it in suitable types of batteries to run these vehicles. The Different types of batteries like lead acid, lithium ion, nickel bromide is used as an energy storage device for these electric vehicles. But with many advantages these batteries have some structural and thermal issues if not designed or connected properly. These issues are capacity loss, cell balancing, thermal runaway, reduction in battery life etc. therefore much focus need to give on proper battery connections considering its working parameters. Possible types of connections for batteries are active, passive and semi active as per their connections in series and parallel type. These connections depend on increasing the voltage and capacity of the battery. For series combinations apposite terminals of batteries are connected to each other, in which current remains constant and battery voltage is summed up to increase for maintaining the same capacity or ampere hour (Ah) rating of batteries. Whereas in parallel connections same terminals of the batteries are connected to each other in which voltage remained constant and battery current is summed up to rise. This is needed when we need to double the battery capacity or ampere hours (Ah) rating according to your system needs while maintain the same level of voltages. Each connections have its significance for battery performance. The present work focused on various design parameters of electric vehicle i.e., Comparative analysis of both series and parallel connection of batteries through its circuit connection, active and passive cell balancing of battery cells. This analysis will be carried out in Experimental with simulation study using by analyzing the behavior of it on battery performance characteristics such as state of charge, voltage and current variation as per load cycle.*

Keywords: E-mobility, Types of Batteries, Series and Parallel Connections, State of Charge, Cell Balancing, etc.

I. INTRODUCTION

Electric vehicle (EV), which is powered by lithium-ion battery (Li-ion), is an eco-friendly option in today's global warming scenario due to its zero-emission rate. Lithium-ion battery is the most suitable option for an EV owing to its long cycle life, high specific energy, power density, nominal cell voltage, and low self-discharge rate, charging time as compared to other batteries.But, the charge capacity and the charging time of the cell vary with the intensity of the charging current. The charge and discharge characteristics of the battery vary from one manufacturer to another and also between different cells of the same manufacturer. This variation is studied by running tests with constant current and constant voltage in a charge– discharge testing apparatus. Battery or accumulator is a general electrical energy storage media. The main disadvantage of the battery is the long duration during charging process, short lifetime and less environment friendly.

This is one of the obstacles in the development of electric vehicles. Due to the limited voltage and capacity of the single battery cell, the series and parallel connection is needed in the actual use to obtain higher voltage and capacity, so as to meet the actual power demand of the equipment. When Lithium batteries needs to be connected in series add the voltage of batteries, capacity remains the same, and internal resistance increases. The proposed work is focused on simulation and experimental analysis of using two batteries as an energy source and analyzing the various problems of battery cell balancing, charging and discharging issues w.r.to changes in battery working parameters. The basic application considered here is headlights of four wheelers in order to efficient use of battery pack.

Problem Statement:

Electric vehicles are equipped with lithium-ion battery pack, which is a series or parallel combination of many nos of single battery cells. The combination of this series and parallel needs to analyze in order to get efficient voltage and current capacity for specific applications. Further while charging the battery pack individual cells can differ in charging capacity in terms of voltage and current, therefore it's balancing via active and passive needs to understand. Finally, as the increasing growth of electric vehicle relying only on one battery pack won't be feasible solution.

Objectives:

1. To understood the earlier work done on different types of combinations of lithium-ion batteries for electric vehicle through literature surveys and to know the further scope of work.
2. To study the various basics related to batteries like steps of battery pack calculations, precautionary measures etc.
3. To evaluate lithium-ion battery and its pack parameters like voltage, current, and state of charge during charging and discharging for applied load.
4. To study the comparative analysis of series and parallel combination as well as active and passive cell balancing issues for electric vehicle with simulated study using MATLAB / Simulink.
5. Experimental and simulation analysis of implementing two battery pack as two energy storage devices for given application of four-wheeler headlights.

Methodology:

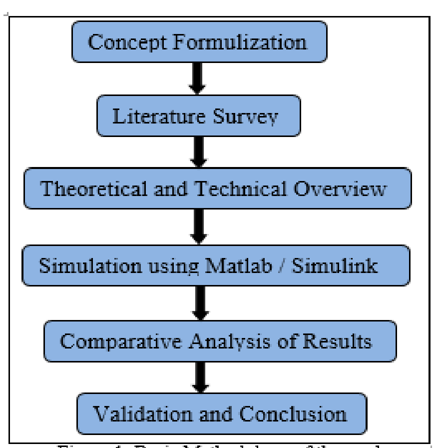

Figure 1: Basic Methodology of the work

Scope of the Project:

The main idea behind working on this project is to simply the dependency on only one energy storage system. This project can be suitable for head lights of four wheelers, two wheelers and other types of automobiles we well. The scope is limited to electric vehicle of load approximately 200 watts but not limited to the application. It can be further enhanced to boost the performance by structural optimization.

II. LITERATURE SURVEY

Author, Year of publication and Publisher	Title of the Paper	Methodology /Findings
Federico Baronti, Roberto Di Rienzo et.al. In IEEE transactions 2014,	Investigation of series-parallel connections of multi-module batteries for electrified vehicles.	Simulation tool for battery pack with Gaussian density and different variance.
Xianzhi Gong and Rui Xiong, et.al. In IEEE Transactions on Industry Applications, Vol. 51, No. 2, 2015	The Characteristics of Battery Packs in Electric Vehicles with Parallel-Connected Lithium-Ion Battery Cells.	Battery packs with different degradation levels by experimental and simulation for parallel pack of lithium-ion batteries.
Thomas Bruen, James Marco in ELSEVIER journal of power sources 2015	Modelling & experimental evaluation of parallel connected lithium- i o n cells for an EV battery system.	Impact of connecting cells, with varied properties, in parallel and the issues of energy imbalance and BMS to reduce temperature effects.
Mohammad Haris Shamsi, MSc ET Examensarbete 30 hp Juni 2016.	Analysis of an electric ECM of a Li-Ion battery to develop algorithms for battery states estimation.	Design of a BMS for high energy and high-power applications to analyses battery parameters with equivalent circuit model in MATLAB.
Chuanxue Song and Yulong Shao et. Al. (2016) in MDPI energy article.	Energy Management of Parallel-Connected Cells in Electric Vehicles Based on Fuzzy Logic Control.	Construction of parallel-connected cell pack model that considers thermal effects to reduce loop current and the resulting battery inconsistency, and a novel Simscape model that is based on PCCP.
C. S. Westenhover, D. A. Wetz in IEEE transactions 2017,	Current Sharing in Parallel Cell Batteries Cycled at High C Rates.	Single battery management system (BMS) and its use for Any impedance mismatches among a parallel array of cells is introduces to check the possibility for current imbalances.
Shouguang Yao, Wei Liu et.al. Journal of Renewable and Sustainable Energy 10, 034105, 2018.	Series-parallel grouping modelling simulation and experimental analysis of zinc-nickel single flow batteries.	Battery system with a zinc-nickel single flow battery (ZNB) stack by a series-parallel-connected system based on a two-order Thevenin equivalent circuit model for single-cell stack and parameter identification of the experimental model.
Andrea Pozzi, Massimo Zambelli et.al. In IEEE transactions Feb 2019	Balancing-Aware Charging Strategy for Series-Connected Lithium-Ion Cells: A Nonlinear Model Predictive Control Approach	Electrochemical model, tailored to control model-based optimization strategies for Charge unbalance in series connected Lithium-ion cells. Proposed a general nonlinear model predictive control (MPC) for balancing-aware optimal charging.
Premananda Pany, in IJRTE ISSN: 2277-3878, Volume-8 Issue-4, November 2019	A Novel Battery Management System for Series Parallel Connected Li-Ion Battery Pack for Electric Vehicle Application.	A novel battery management system for lithium-ion battery to monitor and control the battery current, voltage, state of charge and the cell temperature. The validation is done of its performance with a driving cycle of electric car.
Tanvir R Tanim, Eric J Dufek et.al. INL/JOU-19-55581- Revision-0, 2020.	Advanced Diagnostics to Evaluate Heterogeneity in Lithium-ion Battery Modules.	Innovative diagnostic tools and algorithms like the impedance-based diagnostic and DQ/DV method.

Hemavathi S Energy Storage. 2020; e203. wileyonlinelibrary.com/journ al/est2,	Overview of cell balancing methods for Li-ion battery technology	The passive cell balancing technique equalizing the SOC of the cells by the dissipation of energy from higher SOC cells and formulates all the cells with similar SOC equivalent to the lowest level cell SOC. The active cell balancing transferring the energy from higher SOC cell to lower SOC cell, hence the SOC of the cells will be equal.
Yanhui Zhang and Shili Lin et.al. In WILEY Hindavi 2021.	A Novel Pigeon-Inspired Optimized RBF Model for Parallel Battery Branch Forecasting.	Radial basis function neural network model based on the pigeon-inspired optimization method and successfully applies the algorithm to predict the parallel branch current of the battery pack.
Dipanwita Bhattacharjee, Pankaj Kalita, et.al., Springer Nature Singapore Pte Ltd. 2021	Investigation of Charging and Discharging Characteristics of Lithium-Ion Batteries for Application in Electric Vehicles.	Comparative analysis of the charge and discharge characteristics of two cylindrical cells by subjecting it to a voltage less than its maximum voltage and suggests approaches to reduce undercharging of battery for EV applications. Results shows SOC is directly proportional to the charging time and inversely proportional to charging current.
Claude Ziad El-Bayeh, Khaled Alzaareer et.al. MDPI world electric vehicle journal 2021.	Charging and Discharging Strategies of Electric Vehicles: A Survey.	Worked on various literature related to battery charging and discharging characteristics. Covering Plug-in Electric Vehicles (EVs) contains many charging/discharging strategies.
Zhai Haizhou, International Journal of Online and Biomedical Engineering (IJOE) 2021.	Modelling of Lithium-ion Battery for Charging/ Discharging Characteristics Based on Circuit Model.	Mathematical and Simulated modelling of the principle and charging/discharging characteristics of lithium-ion battery.
Yin Jin, Wenchun Zhao et.al. In Journal of Physics Conference Series EMIE 2021	Modelling and Simulation of Lithium-ion Battery Considering the Effect of Charge-Discharge State	The battery model parameters in charging and discharging state with the influence of SOC model parameters through battery performance test experiments. The ECM of li-ion battery with variable parameters are established by Simscape language, and simulation analysis is carried out.
Neetu Meena, Vishakha Baharwani et.al. IEEE transactions on Power and Energy Systems: Towards Sustainable Energy PESTSE 2014	Charging and discharging characteristics of Lead acid and Li-ion batteries	Worked on the charging and discharging characteristics of Lead acid and Li-ion batteries Experiment aiming to introduce the reader to the concept of end of charge and discharge of battery.
S.S. Zhang, K. Xu et. al. in ELSEVIER Journal of Power Sources 160, 2006	Charge and discharge characteristics of a commercial LiCoO2-based 18650 Li-ion battery.	The charge and discharge characteristics of commercial LiCoO2-based 18650 cells by using various electrochemical methods, including discharging at constant power, ac impedance spectroscopy, and dc-voltage pulse.

III. STRUCTURAL ANALYSIS

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

Single battery with 3.7 V and 2500mAh capacity.

Using formulae (assuming 80% efficiency of the battery)

$$\text{time(t)} = \frac{\text{Efficiency} \times \text{Battery voltage} \times \text{Battery capacity}}{\text{Total required power}} = \frac{0.8 \times 11.1 \times 20}{100} = 1.776 \cong 2\text{Hours}$$

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.

Hybridization Ratio:
It is the ratio of electric power to the total powertrain power. E.g. if the motor rated at 50 kw and engine rated at 75 kw then,

$$\text{Hybridization Ratio} = \frac{50}{(50+75)} \times 100 = 40\%$$

In case of proposed hybridization of li-ion battery and auxiliary battery hybridization ratio will be 100%.

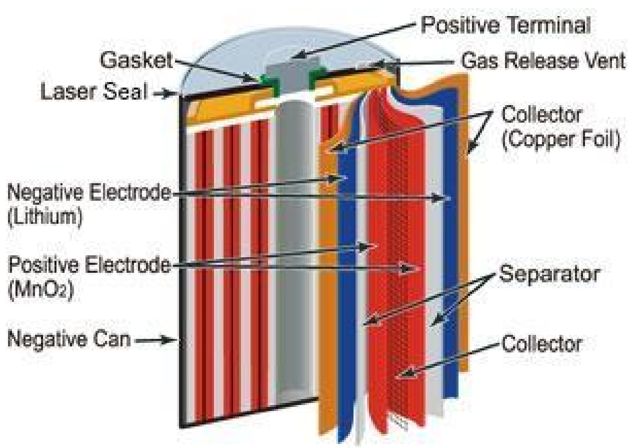

Figure 2: Lithium-ion battery structure

Cell Capacity Grading

Voltage Internal Impedance Sorting and Matching

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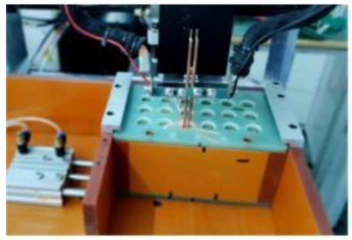
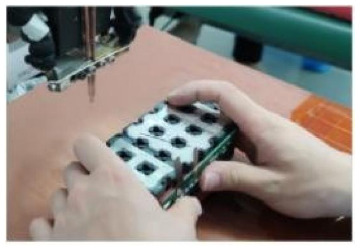
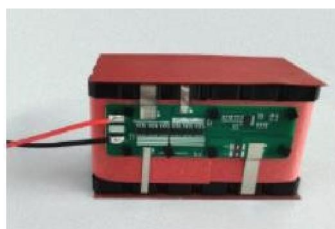


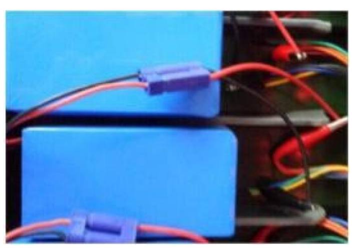
Cell Spot Welding



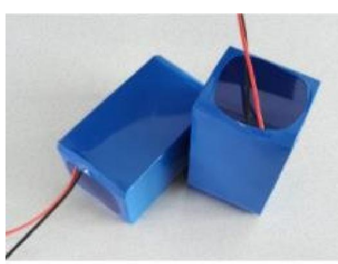
Welded PCM



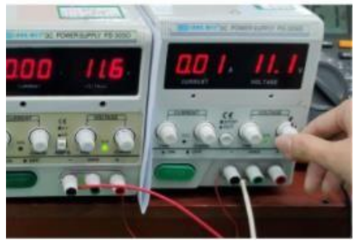
Battery Insulation



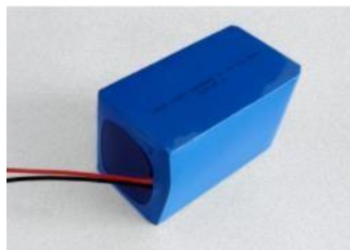
Battery Pack Aging



PVC Shrink Film



Finished Product Performance Test



Battery Code-spurting

Figure 3: Steps involved in lithium-ion battery pack manufacturing

LIST OF COMPONENTS REQUIRED FOR EXPERIMENTAL ANALYSIS

Particulars	Specifications	Quantity
A switched-mode power supply	12V, 10A	01
Li-ion Battery Pack	11.1V, 20A	02
Voltage display unit	0-200 V	01
Current display unit	0-75A	01
Shunt resistor	75Mv	02
Switches	10A X 1 Way, 220-240V	03
Load (Head lights)	120 watts	02
Other Accessories	Nickel wire, solder gun, cables, cutter, etc.	As per requirement

Figure 4: Shunt resistor

Figure 5: A switched-mode power supply (SMPS) for controlling power supply to HESS

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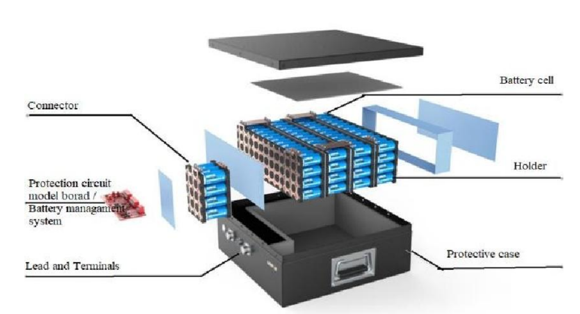

Figure 6: Components of lithium-ion battery pack

Figure 7: Lithium-Ion Battery Pack

IV. SIMULATION AND EXPERIMENTAL ANALYSIS

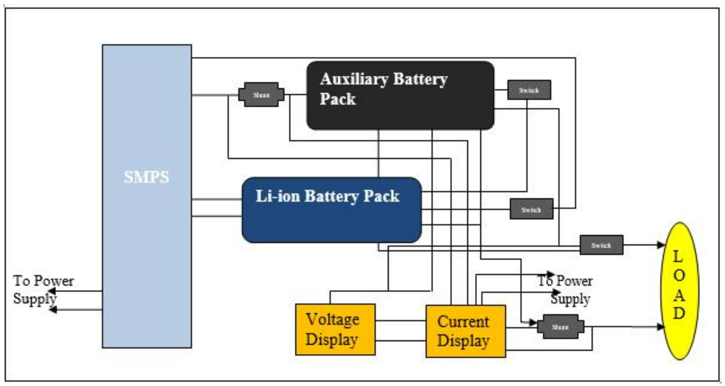

Figure 8: Proposed set up for experimentation

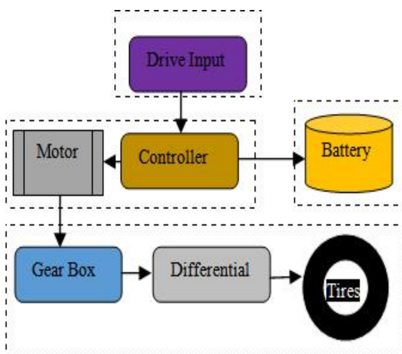

Figure 9: Proposed set up for simulation in MATLAB/Simulink

Input Parameters for simulation

<table>
<tr><td colspan="2">Software used: MATLAB / Simulink version 2020a.</td></tr>
<tr><td colspan="2">Time of simulation 2500 seconds.</td></tr>
<tr><td>Battery used: Lithium-ion battery Specifications:
• Nominal voltage 3.7 V
• Rated capacity 2.5 Ah
• Initial state of charge 100%
• Battery response time 30seconds</td><td>IGBT / Diode
• Internal resistance (Ron) 1e-3 Ohms
• Snubber resistance (Rs) 1e5 Ohms
• Series Resistance 1 Ohms</td></tr>
</table>

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[A] Simulations for Battery connections

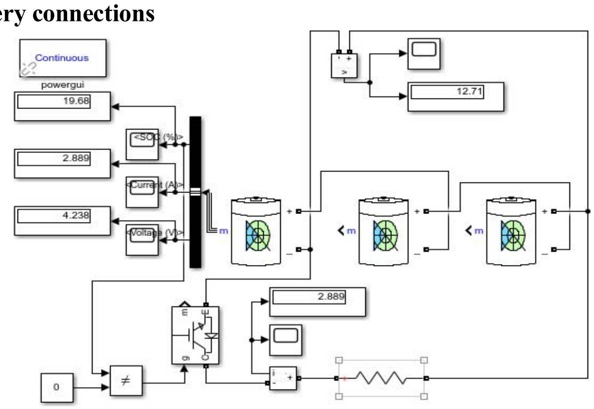

Figure 10: Simulation model Lithium- I o n batteries connected in series

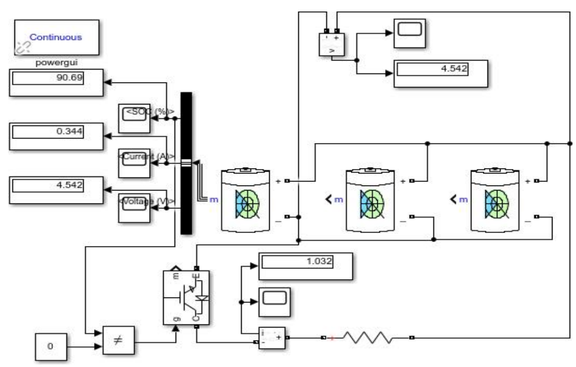

Figure 11: Simulation model Lithium- I o n batteries connected in parallel

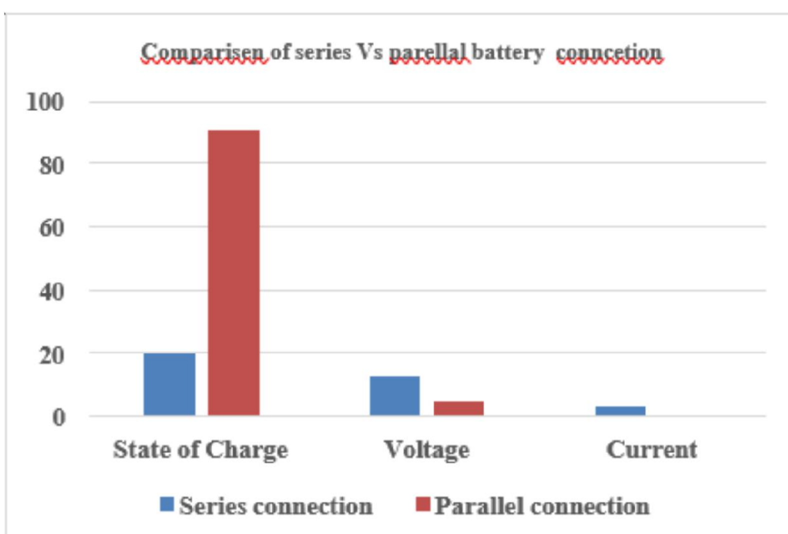

Figure 12: Comparative analysis of observation results in battery connection

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[B] Charging and Discharging Circuit of Battery

DC Voltage 12V, Nominal Voltage 11.1V, Rated Capacity 20Ah, Initial SOC 0, Time of Simulation 30 Minutes (1800 seconds).

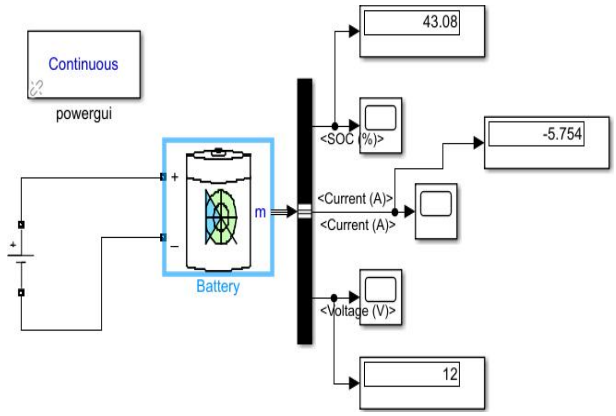

Figure 13: Charging Circuit for Lithium-ion Battery in MATLAB / Simulink

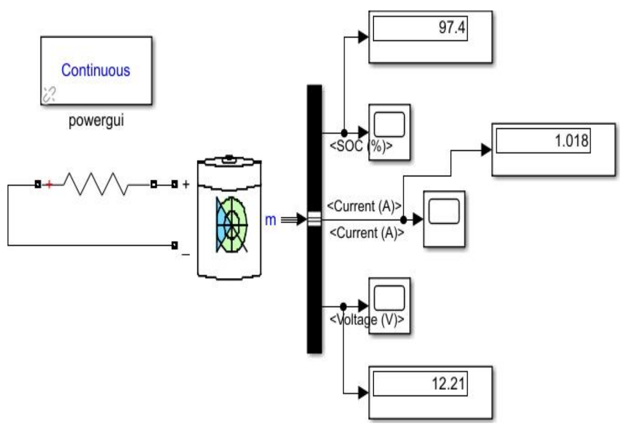

Figure 14: Discharging Circuit for Lithium-ion Battery in MATLAB / Simulink

[C] Balancing circuit of the battery

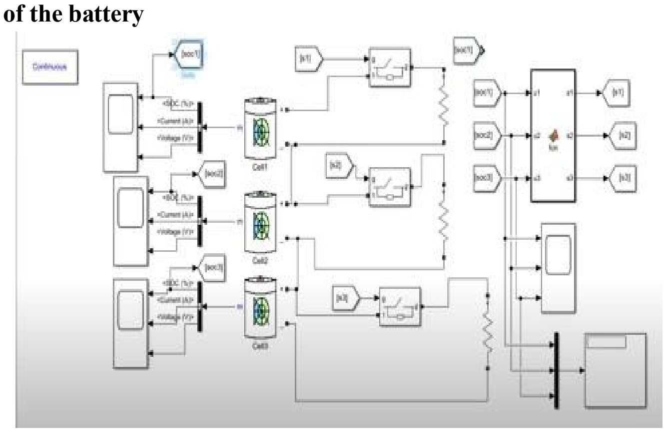

Figure 15: Simulink circuit for passive cell balancing

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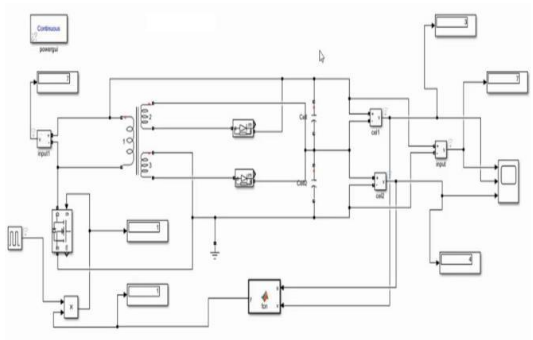


Figure 16: Simulink circuit for active cell balancing

Application based simulation (time of simulation 10 s with step size of 4s)

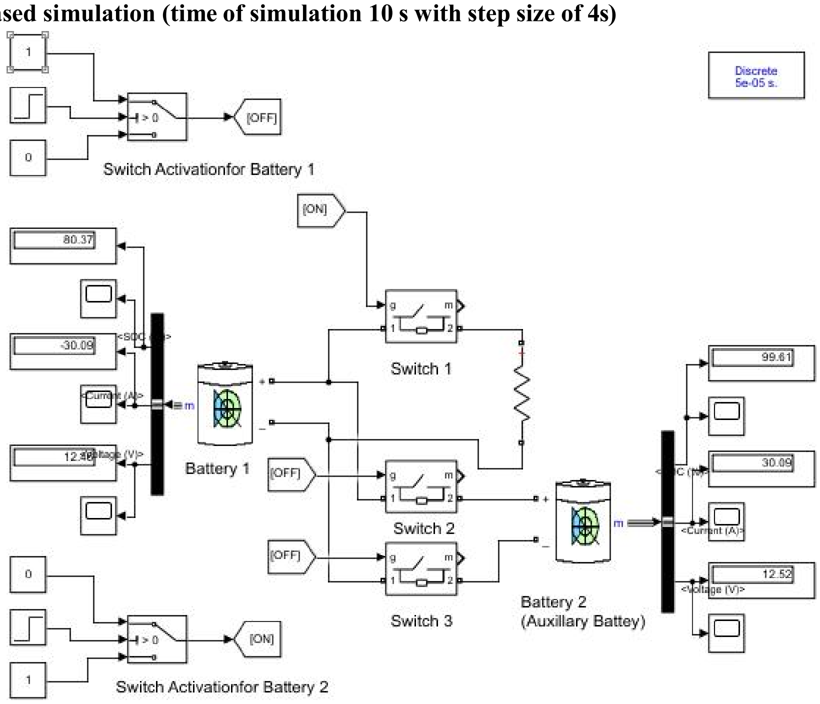
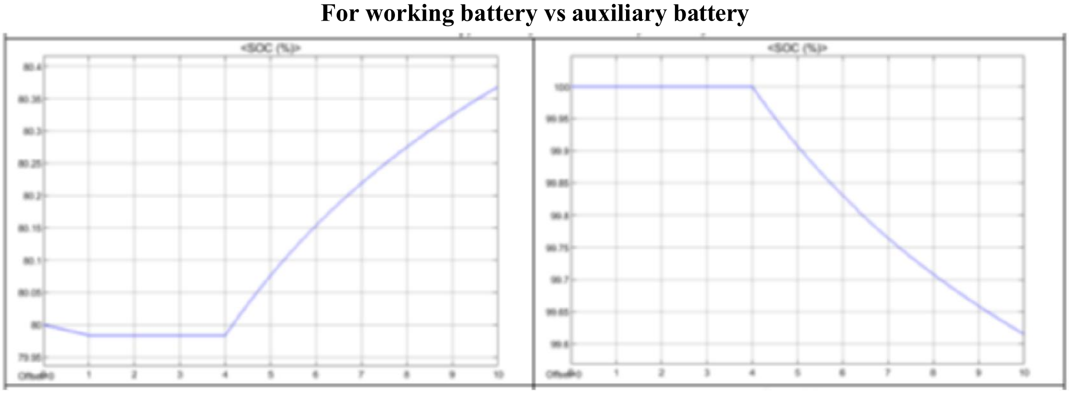


Figure 17: Simulink circuit for battery charging using auxiliary source

For working battery vs auxiliary battery



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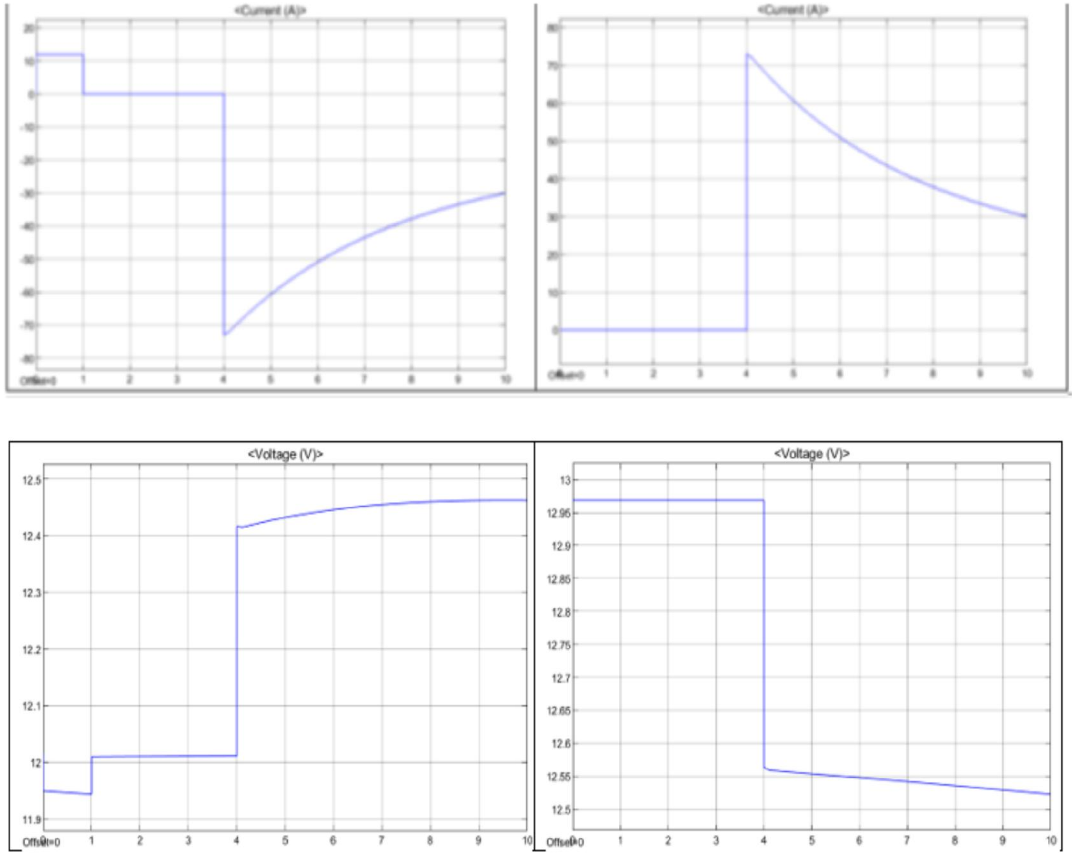

Figure 18: Simulink circuit Results for battery charging using auxiliary source

V. EXPERIMENTAL ANALYSIS

Motor Specification

- Type: Brushless DC Motor 12watt.
- 12 V, 5000 Rpm Capacity

[A] Battery Pack Experimentation for charring and discharging of battery pack

Calculations of battery pack for generating approx. 100-watt energy for approx. 2 hours.
Single battery with 3.7 V and 2500mAh capacity.
Using formulae (assuming 80% efficiency of the battery)

$$\text{time(t)} = \frac{\text{Efficiency} \times \text{Battery voltage} \times \text{Battery capacity}}{\text{Total required power}} = \frac{0.8 \times 11.1 \times 20}{100} = 1.776 \cong 2\text{Hours}$$

Therefore, we need 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.

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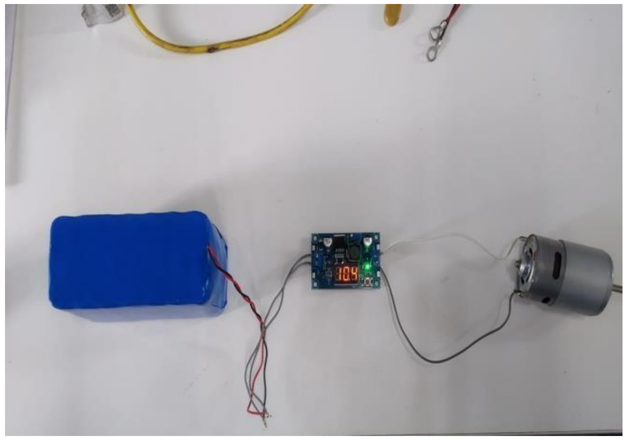

Figure 19: Battery charging

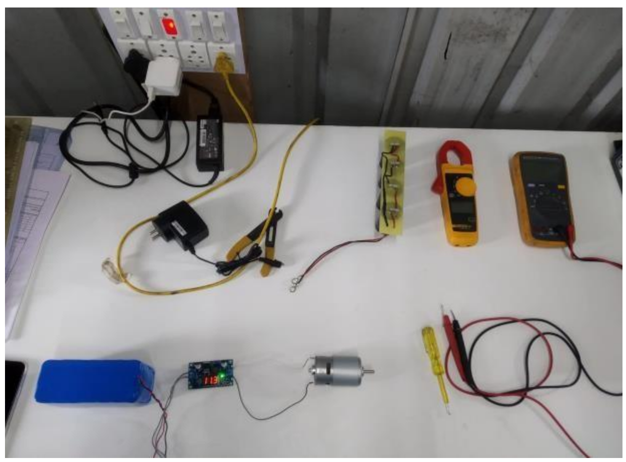

Figure 20: Battery discharging

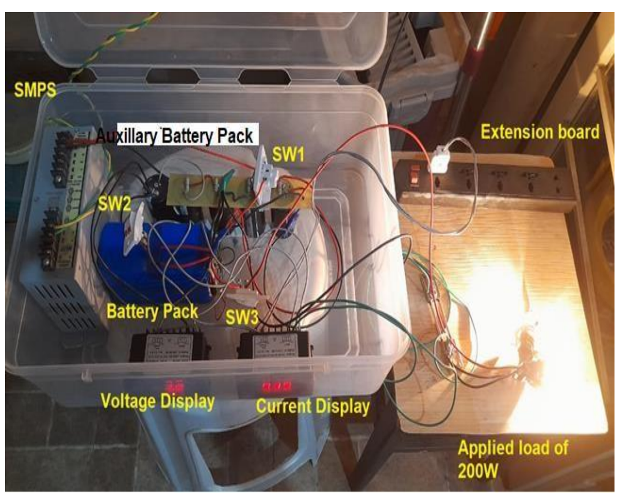

Figure 21: Battery charging and discharging for two battery pack

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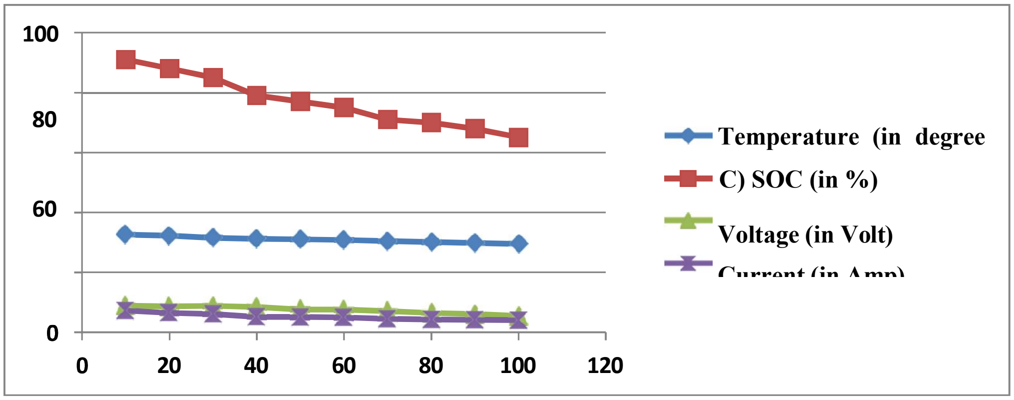

Figure 22: Battery discharging characteristics for battery pack

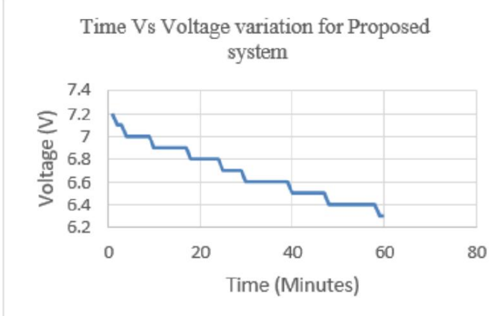

Figure 23: Experimental results for Time Vs Voltage variation for proposed system

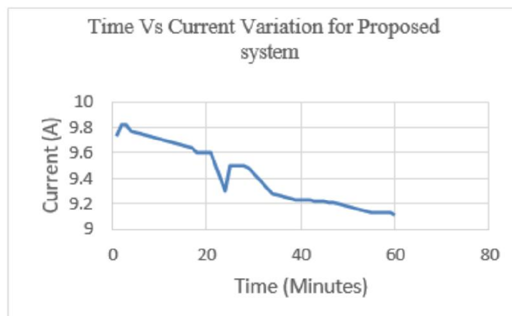

Figure 24: Experimental results for Time Vs Current variation for proposed system

VI. CONCLUSION AND FUTURE SCOPE

Conclusions:

- Battery connections is most crucial point in battery pack design for efficient use as per the need of applications. Some of it need only series/parallel or combination of both. Proper Battery management system and battery pack making steps need to follow to overcome drawbacks of thermal runaway, battery overcharging etc.
- Simulation results shows that,
  1. Series and parallel both connections in with proper calculations are needed for efficient battery pack for EV applications.
  2. Analysis and Simulation of active and passive cell balancing of lithium-ion battery pack with simulated results found satisfactory results.
  3. Charging and discharging characteristics are within acceptable limits for voltage, current and state of charge.
  4. Battery pack with simulation with one axillary source simulation sows that as working battery discharges for prescribed time step second auxiliary battery starts charging to earlier one which is the most exciting results of the proposed idea.
- Experiential and simulated results are matched up to acceptable accuracy level as per the comparative graphical analysis. Battery pack charging and discharging time were in hours i.e., approximately 3 to 4 hours.
- A light weight structural design of two-wheeler / three-wheeler is proposed for further application using the lithium-ion battery.

Future Scope:

- Mathematical modeling and comparative analysis for CFD analysis using ANSYS fluent or other related software like LS Dyna.
- Similar experiment can be performed on different lithium batteries like lithium polymer as well as other batteries like lead acid, nickel bromide etc. to getting more efficient solution for electric Vehicles.

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