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MODELLING OF LITHIUM-ION BATTERY PACK USING SIMULINK

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ABSTRACT

Lithium-ion batteries gain its popularity with the increase in technological demands of the world. Lithium-ion batteries are extensively used in mobile phones and laptops due to its high energy density, stability and charging rate. Lithium-ion batteries are further improved to give better performance. Lithium-ion batteries offer great opportunity for development of hybrid and electric vehicle, and it has huge contribution in making electrical vehicle available for commercial use. In this review, the focus is on identifying the different battery parameters associated with the batteries of electric vehicle, and building a simulation model using Simulink which might give initial idea to the designer regarding the battery pack design and might be helpful in selecting the type of battery with given constrained space.

Keywords: Battery, Lithium-Ion Battery, Rechargeable, Simulation, Anode, Cathode, Electric Vehicle.

I. INTRODUCTION

Electrochemical storage system, also known as batteries, are gaining popularity due to limited reserves of conventional resources for energy generation. Varying nature of renewable sources like wind and solar energy has led challenge for storing the energy until consumers needs it.[1] In 2017, more than 1 GW of batteries are manufactured around the globe. Most popular type of batteries are Lithium-ion batteries due to their high energy density, relatively low self-discharge and low maintenance.[5] Performance revolution of lithium-ion batteries has led the development of Plug-in Hybrids Electric Vehicle (PHEV) and Electric Vehicle (HEV). One of the areas in which electrification is gaining popularity is in the field of electric vehicles. Increased level of electrification gives features like frequent start-stop with fuel saving, regenerative braking, motor assistance, etc..[1] The performance of EV is mainly depending on design of battery pack which must be capable to deliver enough current for the motor for an extended period of time.[6] Since, one battery provides quite low voltage and capacity, in an EV, Hundreds of batteries are connected in series and parallel to make battery pack which provides the required voltage and amp hours (Ah). For example, Tesla Model S has 7104 cells.[7]

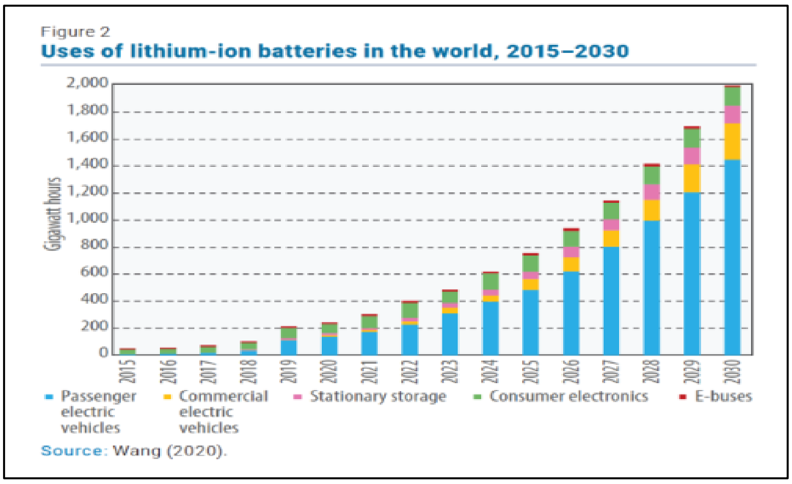

Figure 1: Lithium-ion batteries use worldwide

II. LITHIUM-ION BATTERIES

2.1 Construction

Lithium-ion batteries mainly consists of anode, cathode, separator between two electrodes and electrolyte which fills the space of the battery. Since, lithium is unstable in element form, so the combination of lithium and oxygen called lithium oxide is used for cathode.[4] Lithium oxide is used as an active material and is coated with conductive additive and binder coating. Aluminum substrate of thin aluminum film is used to hold the frame of cathode. Cathode determines characteristics of battery. Higher the amount of lithium, higher is the capacity of the battery with higher potential difference between anode and cathode.[3] When battery is charged, lithium ions are stored in anode not inn cathode. Graphite is use for anode due to its structural stability, low electrochemical reactivity and low cost. Electrolyte is a medium for the movement of only lithium ions between cathode to anode. High ionic conductivity material is use for electrolyte. Electrolyte is composed of salts, solvents and additives. Separator ensures the safety of battery by acting as a physical barrier between cathode and anode.[5]

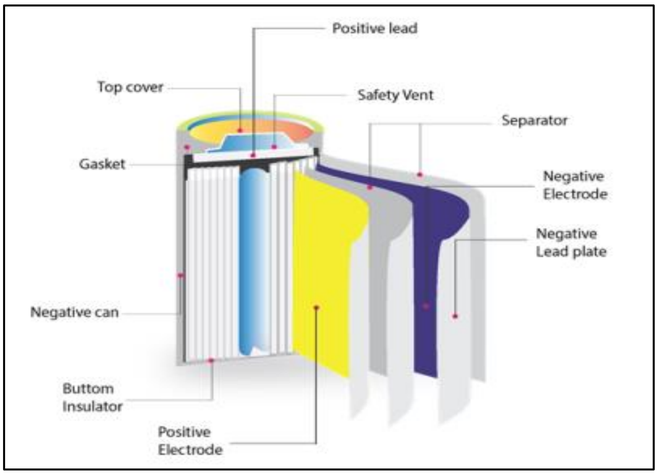

Figure 2: Construction details of Lithium-ion battery.

2.2 Working of Lithium-ion batteries

Anode and cathode are capable to store the lithium-ions. Cathode is the source of lithium-ions and it determines the capacity and average voltage of the battery. Anode stores and release lithium-ion form cathode, allowing the pass of current through external circuit.[1] Electrolyte carries positively charged lithium ions from the anode to the cathode and vice vera through separator. Movement of ions creates free electrons in anode, ultimately creating the charge at positive current collector. Separator blocks the flow of current inside the battery. While the battery is discharging and providing electric current, anode releases lithium ions to cathode, generating flow of electrons from one side to another. While charging the battery is charging lithium ions are released by cathode and receives by anode.[6] Energy density and Power density are two most important terms associated with batteries. Energy density is the amount of energy a battery can store relative to its mass and is expressed in Watt-hour/Kilogram (Wh/Kg). While, Power density is the amount of power a battery can store relative to its mass and is expressed in Watts per kilogram (W/kg).[2]

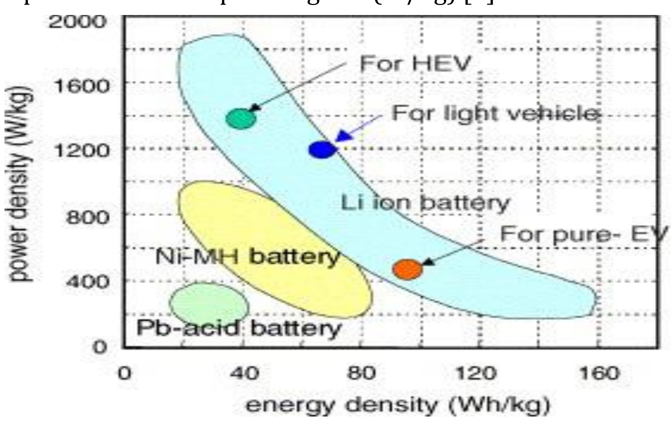

Figure 3: Power Density (W/kg) vs Energy Density (Wh/kg)

2.3. Types of lithium-ion batteries

Based on constituents' lithium-ion batteries can be divided into following types

- Lithium Iron Phosphate (LFP)

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- Lithium Nickel Manganese Cobalt Oxide (NMC)
- Lithium Manganese Oxide (LMO)
- Lithium Cobalt Oxide (LCO)
- Lithium Nickel Cobalt Aluminum oxide (NCA)
- Lithium Titanate (LTO)

Comparison between different types of Lithium-ion batteries is graphically shown in figure.[5]

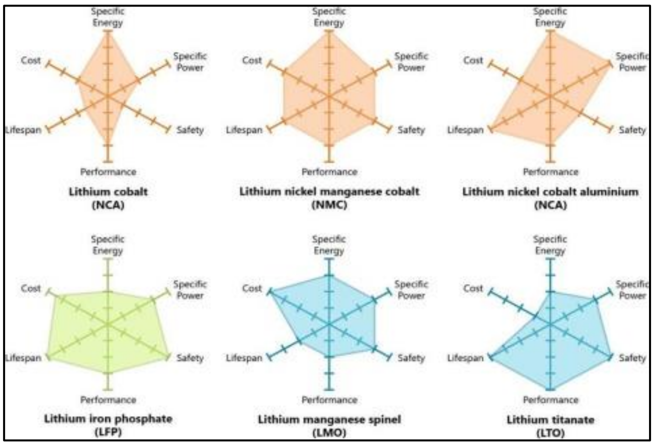

Figure 4: Comparison of Different types of Lithium-ion batteries.

Cells of Lithium-ions can be made in different shape and forms to suit for desired application and space constraints. General forms of battery are shown in following figure.[8]

Table 1: Comparison of different type of Li-ion batteries based on shape.

	Cylindrical	Prismatic	Pouch
Electrode Arrangement	Wound	Wound	Stacked
Mechanical Strength	++	+	-
Specific Energy	+	+	++
Energy Density	+	++	+
Heat Management	-	+	+

III. BATTERY PACKS

Electric Vehicle Battery pack need to meet vehicle's electrical power and energy demand. Assembly of cells into module and ultimately makes the battery pack.[1] Battery packs need to manage the electronic control interface with remaining vehicle control modules and to maintain their cells within predetermined operating parameters for life and safety of battery.[2]

Individual cell voltage is insufficient to provide required power since practical considerations with electrical motor, cabling and power electronics limit the current flow to <500A. [1] So, a single series or series-parallel combination of cells is use to electrically and mechanically form a battery module. Battery modules typically contain cell arrangement such that voltage is < 50 V and weight < 22 kg for ease of handling and safety. [5]

Battery modules are electrically combined to provide full power and energy need for electric vehicles. Depending upon the vehicle type and design, electrochemical cells may account for about 50-75 % of pack cost, weight and volume.[4] Specific performance of battery pack system is always less than that of modules and the modules less than that of cells.[1]

Battery pack must be placed in vehicle by ensuring the safety during normal condition, crash events and vibration. So, placing a battery pack outside the passenger zone of the car is possible, but it will require structural reinforcement to be added to ensure crash integrity. It will also increase the cost, weight and volume for such reinforcement.[3] Mechanical Packaging influences the robustness against water and dust intrusion.

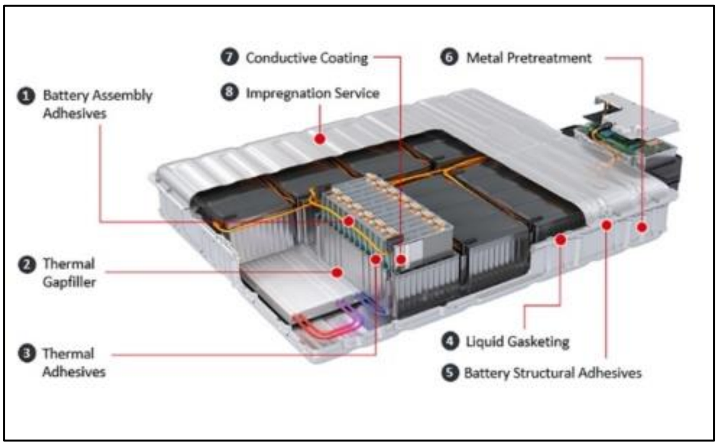

Figure 5: Electric Vehicle Battery Pack.

Low voltage (< 50 V) battery pack are typically grounded to vehicle chassis, whereas high voltage (> 50 V) systems are required to be electrically isolated.[1] Voltage and current of pack, battery and module are measured and controlled by Battery Management System (BMS).[5]

Electric vehicle battery packs commonly employ thermal management system to maintain cell temperature within normal operating range. Most lithium-ion batteries are capable of achieving desired balance of available energy and power in the range of 10-40°C. [9] Cooling system can vary in design and complexity but typically fall into three categories: passive air, active air, or liquid temperature control. A passive air approach receives air from passenger cabin and relies on vehicle operator to determine conditioning strategy. This arrangement was used in Toyota Prius. In active air approach, conditioned air from vehicle air conditioning system to battery pack. Such arrangement was used in First-Generation Ford Escape Hybrid, US Model 2004-06. Due to additional air channel involved, weight and cost associated will be more.[1] So, use of active air approach is less common. Liquid cooling allows greater degree of thermal control as compare to air cooling. Liquid is cooling is volumetrically efficient due to high specific heat capacity. But it does increase the weight and cost. As a result, this type of cooling is for large EV and PHEV batteries like in Ford Focus and Chevrolet Volt.[1]

IV. BATTERY PARAMETER

Some important battery parameters are as follows [5]:

1. **Rated Voltage** – It is the nominal voltage value at which battery is supposed to operate.
2. **Cut-off voltage** – It is the voltage value below which, if voltage drops it will damage the battery.
3. **Capacity** – It is the amount of charge that battery can deliver at rated voltage. Battery capacity is measured in Ampere-hour or amp-hour. Capacity of battery is also expressed as energy capacity of battery which is the product of capacity of battery and rated voltage.
4. **C-rate** – C-rate is the discharging rate of battery relative to its capacity. C-rate is basically the discharging current, at which battery is being discharged, over nominal battery capacity. This discharging rate is sometimes referred as number of hours it takes to fully discharge the battery. In general, C-rate depends on charging and discharging currents.
5. **Battery Efficiency** – It is the ratio of total storage system input to total storage system output.
6. **State of Charge (SOC)** – It is the percentage of battery capacity available for discharge.
7. **Depth of Discharge (DOD)** – It is the percentage of battery capacity that has been discharged.
8. **Cycle Lifetime** – It is number of charging and discharging cycles after which battery capacity drops below 80% of nominal value.

V. BATTERY MODELLING USING SIMULINK

Battery with required value of parameters can be modelled in Simulink for design of the battery pack. Voltage and current requirement of vehicle determines the number of cells need to be connect in series or parallel in order to achieve required power and energy demands.[1]

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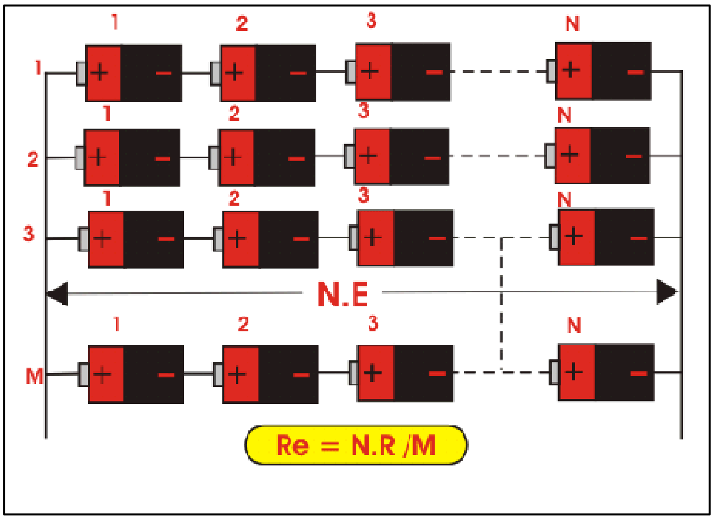

Figure 6: Combination of series and parallel connection of batteries.

Volume required for battery pack can also be estimated by considering the volume occupied by individual cell. Range of the electric vehicle can be estimated by considering battery pack capacity and energy consumption of battery per unit distance.[2]

Building a Simulink model starts with taking into account individual cell parameters like cut-off voltage, nominal voltage, maximum cell voltage, ampere-hour rating, size of cell.[3] Then, the energy and power requirements of the vehicle is considered which the battery pack need to fulfill. Simulink model allows graphical visualization of battery pack and give idea for type of Lithium-ion battery need to be use to meet target demands in given space constraints, or gives idea regarding the size of battery pack and how much space designed battery pack will occupy.[4]

For the Simulink model, we have used the battery parameters of Tesla Model S electric vehicle for building the Simulink model of battery pack which is used in Tesla Model S.

Figure 7: Tesla Model S.

Tesla have used cylindrical type of cells in their battery pack. Tesla installed the battery pack on the floor of the vehicle, thus resulting in more space in passenger space. Batteries are connected in series and parallel to make battery modules and ultimately the battery pack for required energy and traction power.[7] Cell specifications used by Tesla model S is shown in Table below.

Table 2: Specification of Cell used in Tesla Model S.

Brand	Panasonic
Model	NCR18650 B
Rated Voltage	3.6 – 4.2 V
Discharge Cut-off voltage	3.3 V
Battery Capacity	3400 mAh
Charging time	4 hours / 100 mA
Quick Charge	2 hours / 100 mA
Discharge Rate	1C

Output Voltage (VDC)	3.7
Length	65 mm
Width	18 mm (Body diameter)
Weight	45 gm

Figure 8: Panasonic NCR18650 B cell.

Battery pack requirement of Tesla Model S is given in following table.

Table 3: Battery pack requirement of Tesla Model S.

Nominal Battery Pack Voltage	350 V
Peak Battery efficiency	94 %
Energy Consumption	170 Wh/km
Battery Pack Rating	230 Ah

From this requirements, constant blocks of battery parameters are created on Simulink. These parameters include nominal voltage, cut off voltage, maximum voltage, size of cells. Also, ampere hour rating, voltage requirement of battery pack and energy consumption of battery are given as input block and value is assigned to constant blocks.[3] These blocks are connected to obtain required number of cells to be connected in series and parallel in order to achieve desired output from the battery pack.

Figure 9: Tesla Model S Battery Pack.

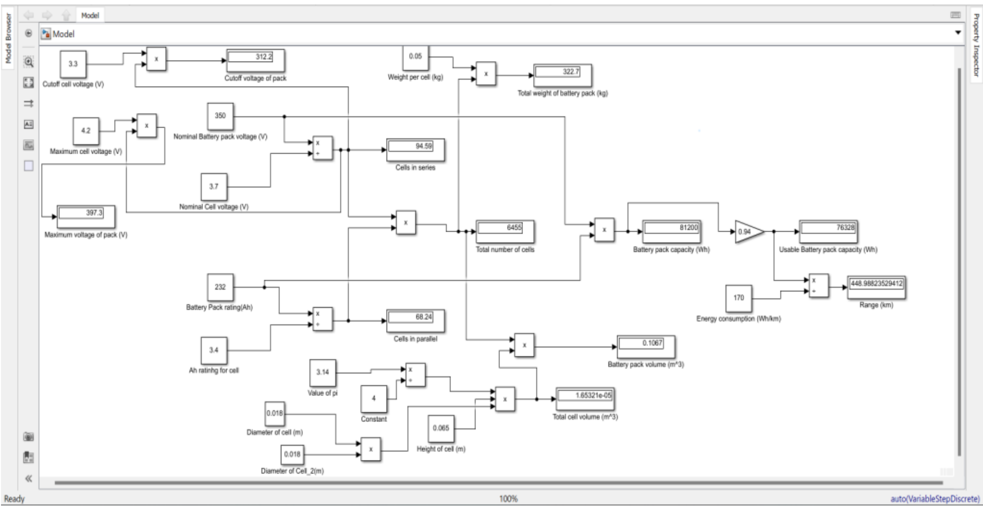

Figure 10: Battery Pack model on Simulink.

VI. RESULT

After running the Simulink model, different results are obtained. Results obtain through Simulink model is compared with the actual battery pack data of Tesla Model S and is given in Table.

Table 4: Comparison between actual battery pack data and model battery pack data

Battery Parameter	Actual Battery Pack Data	Model Battery Pack Data
Total number of cells	7104	6455
Battery Pack Volume	0.1583 m3	0.1067 m3
Total weight	500 kg	322.7 kg
Usable Battery Pack Capacity	75000 Wh	76328 Wh
Range	560 Km	448.98 Km

VII. CONCLUSION

By checking the results and comparing with actual battery parameter of Tesla Model S, there is great similarity in the result of battery model with the actual battery parameters. Battery model of Simulink can give idea to the designer regarding the battery pack design, shape and helpful while selecting the type of battery need to select for required vehicle performance.

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