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# TECHNIQUES OF BATTERY SELECTION FOR USAGE IN ELECTRIC VEHICLES

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***Abstract:*** Battery chemistries plays a pivotal role for range enhancement and performance of electric vehicles. In the present research different battery chemistry used in Electric Vehicles (EVs) were analyzed. In the present work analysis is done on sodium ion, lithium ion, and metal air batteries chemistries for usage in EVs. Technical parameters and process for selection of battery for EV application is presented. Based on the review a comparative chart is prepared that help in selection of a battery chemistry for application in EV as per the requirement. Battery Management System (BMS) which is responsible for cell balancing, temperature monitoring at cell level, providing data on state of health (SoH) and State of Charge (SoC) of a battery is also studied.

***Index Terms* - Battery, Lithium-ion battery, Metal air battery, Battery selection, Battery Management System.**

## I. INTRODUCTION

Emissions from conventional vehicles degrade the environment [Vashist D & Mukthar F. et al, 2021] [Bindra M. et al, 2019] and thus has enhanced the adaptation of electric vehicles (EVs) [11] but the challenging part in the completely adaption of an electric vehicle is its range which is dependent on the type of battery used in the electric vehicle. The different battery chemistries that can be used in EVs include sodium-ion, lithium-ion, lead-acid, nickel-cadmium (Ni-Cd) and metal air batteries [Vashist D. et al, 2021]. The battery technology which fulfills the desired parameters EV commercialization are the lithium-ion batteries. They (Lithium-ion batteries) have been successfully used to power the EVs in India. The battery performance characteristics can be specified by several parameters, but energy efficiency and power density are being utilized by designers for designing lighter and smaller size batteries, respectively. [Vashist D. et al, 2021]

Batteries used in Electric vehicle (EV) are the rechargeable batteries with different energy density which means they can hold different amount of charge. Like sodium-ion battery uses sodium ions as the charge carriers, in lithium-ion battery lithium-ion moves from the negative electrode and vise versa, lead acid battery has a negative electrode made of porous lead which facilitate the formation and dissolution of lead, while in metal-air electrochemical cell, anode is made up of pure metal, ambient air acts as cathode, with an aqueous or aprotic electrolyte. Table 1 provides a comparison details of different battery chemistry parameters.[Vashist D. et al, 2021]

Table 1: Comparative sheet for different battery chemistry parameters [Vashist D. et al, 2021]

| **Battery type** | **Lead-acid** | **Ni-Cd** | **Ni-MH** | **Lithium-ion** |
|---|---|---|---|---|
| **Energy density (W/kg)** | 30-50 | 45-80 | 60-120 | 110-160 |
| **Power density** | 180 | 150 | 250 – 1000 | 1800 |
| **Nominal voltage** | 2V | 125V | L25V | 3.6V |
| **Over charge tolerance** | High | Moderate | Low | Very low |
| **Self-discharge** | Low | Moderate | High | Very low |
| **Operating temperature** | -20-60•C | -40-60•C | -20-60•C | -20-60°C |
| **Cycle life** | 200-300 | 1500 | 300-500 | 500-1000 |

In the present study a work on battery selection for an EV is done. Further an analysis related to two battery chemistries that is Li ion and Metal air batteries is made.

## II. BATTERY SELECTION:

Selecting battery for an electric vehicle (EV) is one of the important step in the EV design process [Vashist D. 2019]. If the battery pack does not match the drivetrain, the desired performance and range cannot be achieved and there may be risk of damaging the drivetrain components or misbehavior batteries instances. Important parameter in selecting the battery are the required power and range for EVs. The required power, range & size (Space available) determine the design of the battery pack.

***Required driving range***

The range for EV determines the final size of the battery pack. Therefore, a designer has to decide on the theoretical range in order to convert this to the capacity in kWh. This is a key requirement to while designing a battery pack. The range designer wants between charging, determines the battery capacity. i.e a car uses 0.2 kWh per km for simple calculations. So, EV designer can estimate the capacity for desired range by multiplying the amount of km by a factor 0.2. That will provide him a simple estimate of the minimum capacity of battery pack.

***Calculations for battery power.***

The amount of power designer needs for his designed EV determines the kind of batteries that will be required in the battery pack. The peak power that the motor demands (from the battery pack) determine the maximum discharge current of the batteries. The continuous power the motor uses during EV movement decides the continuous discharge current of the batteries. The answers about the peak power output of the motor and the peak current the motor will use lies in maximum discharge output of the battery pack. The amount of power EV will be using continuously will determine the continuous current of the batteries. If the designer plans to connect all the batteries as one serial string with one battery parallel, the values received will be the maximum discharge values for each battery (module). If it is planned to connect two or more batteries parallel to each other, the discharge currents need to be multiplied by the number of batteries connected parallel, to know the maximum discharge current of the battery pack. If in a one experimental problem 5 batteries are arranged in parallel and peak discharge is 30A per battery with Continuous discharge as 15A per battery, maximum discharge power of the battery pack will be 5 x 30A = 150A while continuous discharge power of the battery pack will be 5 x 15A = 75A. Some results on selection of the battery pack with input data in table 2 is provided in table 3

Table 2 Input data for selection of battery pack.

| input | unit | range | Info |
|---|---|---|---|
| **600** | V nom | 12 - 800 | The nominal voltage the application requires |
| **100** | kW | < 1000 | The maximum power needed |
| **60.0** | kWh | <500 | The amount of energy required |

Table 3 Results for selection of LiFePo4 pack with input data

| | | **extreme** | **endurance** | **extreme** | **endurance** | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Item** | **unit** | **21700-12P** | **21700-12P** | **21700-8P** | **21700-8P** | **LiFePo4 50Ah** | **LiFePo4 110Ah** | **LiFePo4 400Ah** | **LiFePo4 1000Ah** |
| **amount of modules in series** | #S | 168 | 168 | 168 | 168 | 188 | 188 | 188 | 188 |
| **amount of modules parallel** | #P | 2 | 2 | 3 | 3 | 2 | 1 | 1 | 1 |
| **Total amount of modules** | # | 336 | 336 | 504 | 504 | 376 | 188 | 188 | 188 |
| **volume** | L | 181.4 | 181.4 | 191.5 | 191.5 | 289.5 | 270.7 | 1665.7 | 4211.2 |
| **weight** | Kg | 332.0 | 327.9 | 366.4 | 362.4 | 515.1 | 524.5 | 2538.0 | 7708.0 |
| **minimum voltage** | V | 420.0 | 420.0 | 420.0 | 420.0 | 470.0 | 470.0 | 470.0 | 470.0 |
| **nominal voltage** | V | 604.8 | 604.8 | 604.8 | 604.8 | 601.6 | 601.6 | 601.6 | 601.6 |
| **maximum voltage** | V | 705.6 | 705.6 | 705.6 | 705.6 | 676.8 | 676.8 | 676.8 | 676.8 |
| **capacity** | Ah | 100.8 | 117.6 | 100.8 | 117.6 | 100 | 110 | 400 | 1000 |
| **Energy** | kWh | 61.0 | 71.1 | 61.0 | 71.1 | 60.16 | 66.176 | 240.64 | 601.6 |
| **Continuous discharge current*** | A | 600 | 230 | 600 | 225 | 200 | 110 | 1200 | 3000 |
| **Maximum discharge current 50%duty cycle*** | A | 840 | 350 | 840 | 345 | 540 | 275 | 1600 | 4000 |
| **Peak discharge current*** | A | 1080 | 350 | 1080 | 345 | 540 | 275 | 1600 | 4000 |
| **Continuous discharge power*** | kW | 362.9 | 139.1 | 362.9 | 136.1 | 120.3 | 66.2 | 721.9 | 1804.8 |
| **Maximum discharge power*** | kW | 508.0 | 211.7 | 508.0 | 208.7 | 324.9 | 165.4 | 962.6 | 2406.4 |

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **Peak discharge power*** | kW | 653.2 | 211.7 | 653.2 | 208.7 | 324.9 | 165.4 | 962.6 | 2406.4 |
| **nominal charge capability*** | A | 100.8 | 58.8 | 100.8 | 58.8 | 100.0 | 110.0 | 400.0 | 1000.0 |
| **nominal charge capability*** | kW | 61.0 | 35.6 | 61.0 | 35.6 | 60.2 | 66.2 | 240.6 | 601.6 |
| **fast charge capability*** | A | 201.6 | 117.6 | 201.6 | 117.6 | 150 | 165 | 400 | 1000 |
| **fast charge capability*** | kW | 121.9 | 71.1 | 121.9 | 71.1 | 90.2 | 99.3 | 240.6 | 601.6 |

### *Operating temperature and battery chemistry*

Operating temperature of battery pack play a major role in determining the life span or number of cycles a battery can perform during its lifespan. If it is working below zero degrees Celsius, chemistry of the batteries will be affected. Two battery chemistries suitable for EV's are the lithium-ion (Li-Ion) batteries and the lithium-iron-phosphate (LiFePO) batteries. The Li-Ion batteries have an operating range between 10 to 60 degrees Celsius. The LiFePO batteries have an operating range between -10 to 60 degrees Celsius. Hence it can be observed that for applications where operating temperatures are below zero degrees and there is no room for heating element, LiFePO batteries are the most suitable, for applications where temperature is not an issue or low power is discharged from the battery pack (causes raise of temperature), Li-ion batteries are the most suitable.

## III. LITHIUM ION BATTERY FEATURES

As can be inferred from table 1 Lithium-ion battery has the highest energy density among its peers. Even when external systems are added to keep the batteries within their temperature range, the energy density, including the weight and volume of these systems, is still lower as compared to LiFePO batteries. Thus Li-ion battery provides added benefit for usage.[Vashist D. et al, 2021]

For both chemistries it is desirable to keep the batteries within their operating temperature range. If the range is crossed, it will affect the lifespan and capacity of the battery pack. It's hazardous if the temperature of the batteries rises above the $60^0$C because may lead to fires and further explosions..

## IV. LITHIUM-ION BATTERIES TYPES

Lithium-ion batteries have advantages that include wider working temperature width for operation, fast charging capability, no memory effects, more cycle life and less self-discharge rate. Majority of lithium-ion batteries uses graphitic carbon as anodes (negative electrode materials), and good material combinations are available for selection of cathodes (positive electrode materials) thus making them a fit case of selection for EV application.

Based on cathode materials of lithium ion batteries an analysis is provided for

a. $LiCoO_2$ known as LCO (Lithium Cobalt Oxide)
b. $LiMn_2O_4$, known as LMO (Lithium Manganese Oxide)
c. LiFePO4, known as LFP (Lithium Iron Phosphate)
d. LiNi1-y-zMnyCOzO2, known as NMC (Lithium Mixed Nickel-Manganese-Cobalt Oxide)

The below figure 1 shows the relationship between battery capacity and voltage, which represents the amount of charge contained in four different types of lithium-ion batteries. From the plot it is observed that higher capacity and higher voltage provides energy in all four lithium combinations. LCO-based lithium-ion batteries has shown better results in terms of specific energy and power but durability and safety are the issues associated with it. Because LCO based Li-ion batteries are unstable, battery industry is moving towards other available alternatives where in the battery chemistries can bear abuse conditions such as overheated or overcharged faced by the batteries while in use on EVs. Table 4 provide details about the commercial application of these batteries by the industry.

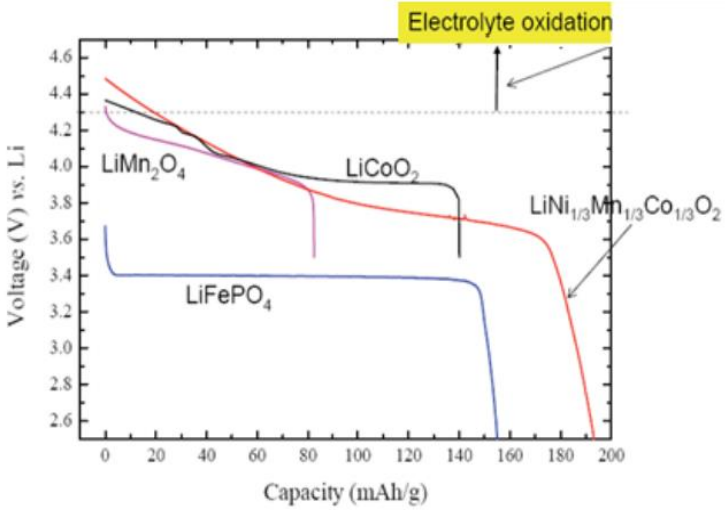

Figure 1: Relationship between battery capacity and voltage [Gabbar H. A etal 2021]

Table 4 Details about the commercial application of these batteries by the industry.

| **Types of Cathode Material** | **Manufacturers of** | **EVs Developers and EV** | **Usable Capacity (kWh) of battery pack** | **Approx. Range (miles)** |
|---|---|---|---|---|
| Lithium Cobalt Oxide (LCO) | Panasonic,<br>Tesla | Tesla-Roadster<br>Daimler BENZ-Smart EV | 56<br>16.5 | 245<br>84 |
| Lithium Manganese Oxide (LMO) | AESC, EnerDel,<br>GS Yuasa, Hitachi, | Think-Think EV<br>Nissan-Leaf EV | 23<br>24 | 99.4 |
| Lithium Iron Phosphate (LFP) | Al23, BYD,GS Yuasa, Lishen, Valence | BYD-E6<br>Mitsubishi-iMiEV | 57<br>16 | 249<br>99.4 |
| Lithium (Nickel-Manganese-Cobalt) Oxide (NMC) | Hitachi, LG Chem, Samsung | BMW-Mini E | 35 | 150 |

## V. METAL–AIR BATTERIES

These chemistries are in the initial stages of development and are considered to have high capabilities of storing green fuel for the modern automotive industry. Metal air systems prevalent today are Al–air, Li–air, Mg–air, Fe–air, and Zn–air., among these Li-air systems is found to give better results as compared to other combinations.

One of the research projects predicts specific energy of the Li–air battery in the range of 12 kWh/kg, excluding the oxygen mass. This is comparable with the energy density of gasoline, which is 13 kWh/kg. According to one of the studies Li–air battery could supply an energy in the order of 1.8 kWh/kg after losses from over potentials to run a vehicle approximately 300 miles on a single charge. A comparative chart is shown in figure 2

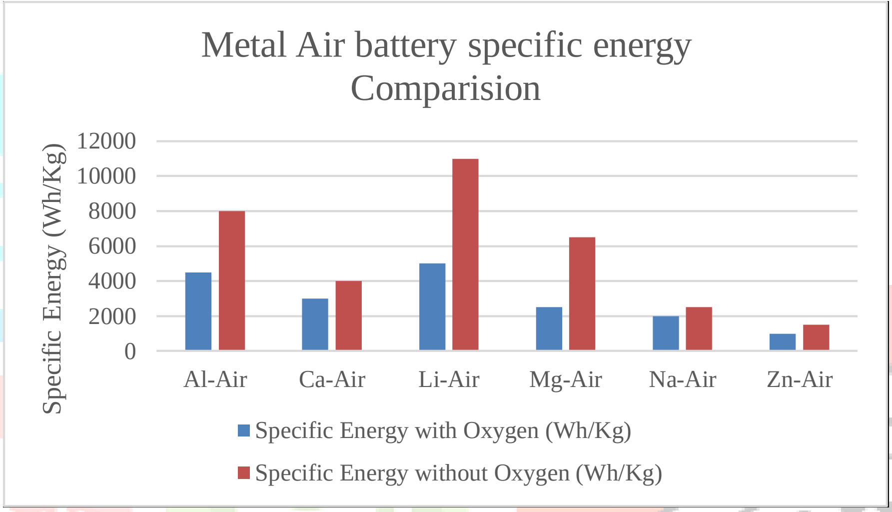

Figure 2 Comparison of Specific energy for different metal air battery systems

The air-electrode plays a pivotal role and is most important part of the Li–air battery that faces technical issues which includes partial discharge, contaminants removal from incoming air, and waste product removal. New works in this field suggest usage of oxygen selective membranes for purifying incoming air.

A major concern for Li–metal anode is high reactivity with water as per new researches in this field . The main source of water contents in the cell are electrolyte, atmospheric air, side reactions, and their by-products.

## VI. BATTERY MANAGEMENT SYSTEM

Battery management system (BMS) is management scheme that monitors, controls and optimizes an individual's battery performance. It is used to improve battery performance with proper safety measures within a system. In Electric Vehicles BMS is used for energy management in different system interfaces and ensure the systems safety from various hazards [Gabbar H. A et al 2021]. BMS consist different functional blocks. These functional blocks are connected with batteries and perform their respective task. BMS cannot be used alone as a single device It is integrated with other system modules to accomplish the system objectives.[ Xing Y et al 2011] In electric vehicle energy management system consists of battery management module (BMM), battery interface module (BIM), battery units. The system secure and protect the battery pack, extend the health of battery, control the power demand. The common function of BMS are

- Data acquisition
- Safety protection
- Cell balancing
- Thermal management
- Ability to control battery charging and discharging
- Determine State of charge of the battery
- Determine state of health of battery
- Helps In communications with all battery components
- Delivery of battery status and authentication to user interface

BMS performs important task such as cell balancing, temperature monitoring , obtaining data on state of battery which includes state of charge (SoC), state of health (SoH).

SOC indicates the present available charge stored in the battery compared to the full capacity charge of the battery.[Xiong R et al 2017] It does similar work of the fuel gauge in fueled driven vehicle which indicates how much power is left inside the battery to power the EVs .Accurate analysis of SoC of battery helps to obtain real-time energy availability data of the battery that includes capacity and energy that provide assurance of a reliable and safe vehicular operation.[Xiong R et al 2017] range anxiety of the driver is removed through availability of SOC values that indicates the remaining capacity in the battery [Yang R et al 2017]. This prediction also helps in prediction of battery's peak power capability and thus improve the battery's safety by preventing it from possible over-charging or over-discharging. SoH is another important parameter of battery that can be observed at the cell level or pack level. SoH indicates total number of times the battery can be charged and discharge before battery gets expired [How DNT et al 2019]. In other words, it is a parameter which reflects present condition of the battery cell described in percentage, being the 100% a fresh cell [Rahimi-Eichi H et al 2013]. If it became less than 80% the battery cannot be used more and removed from the electric vehicles. To determine the SoH of the battery there are two main methods which include experiment techniques and adaptive battery models. Experimental techniques consist direct measurements and model based on measurements. Adaptive battery models consist of some methods such as Kalman Filters, Neural Networks, Fuzzy logic etc. [Berecibar M 2016],[ Johnson N M. 2014].
As we above discussed that BMS consist different types of functional blocks. There are several types of blocks [Cheng KWE et al 2011]

a. Battery Algorithm Block
b. Measurement Block
c. Capability Estimation Block
d. Cell Equalization Block
e. Thermal Management Block

The measurement block is used to capture individual cell voltages, battery current and battery temperature at different points of the battery bank. All of these data are used to estimate battery status. Battery algorithm block is used to obtain SoC and SoH of the battery. Voltage ,current , and temperature is used as input to this model and these inputs can easily obtain by respective sensors. The sensors provide analog signals which are digitalized using ADC (9). Another block which are useful for cell balancing is Cell equalization block this model compares the cell voltages and find the difference between the highest voltage cells and the lowest voltage cells .If the difference is larger than predefined threshold voltage then charging is terminated and the highest voltage cell is discharged through the discharge resistor. This approach is called dissipative cell balancing. Another cell balancing technique is active balancing which transfers the charge from the highest voltage cell to the lowest voltage cell. BMS is used for temperature monitoring the thermal management block is responsible for this monitoring. Thermal management refers to monitoring and controlling the battery temperature so that the battery is not harmed by very high or very low temperature. This block operates heater and cooler as per the environmental conditions.

## VII. CONCLUSION

Battery selection for EVs depend of parameters of the designed vehicle. The process selection of battery is explained with the help of data that will be helpful to designers and researchers. Characteristics of the Li ion ion and Metal ion air batteries are discussed which will be helpful for researchers for have features in single document

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