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An Assessment of Batteries form Battery Electric Vehicle Perspectives

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***Abstract*—A battery is the key component in Battery Electric Vehicles. Main challenge for the Battery Electric Vehicle is low range and need frequent charging. Another issue is the longer charging time required by the batteries. In this review paper different types of batteries and their development is discussed. Lithium Ion, Zebra and Lead acid battery are discussed from Battery Electric Vehicle point of view. Electric motors another key component in electric vehicles is discussed with application of batteries point. The technological development in the batteries to overcome barriers for the electrical vehicle can be a solution, but use of super capacitor or small internal combustion engines as range extender in conjunction with the batteries sounds to be an smart alternative for the market penetration of electric vehicles. This paper will provide current trends in this field.**

Keywords-Battery Electric Vehicles, Lithium Ion Battery, Super Capacitor, Range Extender.

I. INTRODUCTION

One of the major reasons for the rapidly growing air pollution and fossil fuel consumption is road transportation. Increasing price of energy global warming and health problems are combine indicator of that an acceptable solution is required to replace conventional internal combustion engine vehicles. It is vital to develop low carbon and oil independent transport solution. This issue can be tackled by improving efficiency of current vehicles, biofuels and electric power trains. With the increase of population and development of society more and more vehicles are coming on the road. Total independence on oil and zero tail pipe emission technology is the need in the long term due to increment in the passengers [1].

Battery Electric Vehicles (BEVs) satisfy these two conditions. BEVs operate on the simple principle: electric motor is powered by a battery and eliminate the need of Internal Combustion Engine Vehicle (ICEV) and fuel tank. BEVs can be plugged in for charging when not in use. Advantages of BEVS are: High efficiency, zero emission, good acceleration and can be charged any time with low cost electrical energy. If electrical energy is produced by renewable energy sources BEVs can operate with clean energy and good for local air quality. Challenges for BEVs are: Long battery charging, expansive storage of electricity and limited range of vehicles. Adequate charging spot infrastructure must be in place before market penetration. Impact of BEVs on power system grid is damaging. Another confront for BEVs is social acceptance. The high cost of BEVs is a barrier and could not be overcome by the low operating cost. The range of BEVs is lower than conventional vehicle and creates anxiety in users that they will not be able to complete their journey. Government road map plan with technological improvement, new policy development and probable new business models may compensate some of the disadvantages of BEVs [2].

II. BATTERIES

A. Battery Glossary and Related Definitions [3]

The important terms and ideas are presented to clarify the concepts involved with battery in this section.

State of Charge (SOC)

The remaining battery capacity that is available for discharge as a percentage of the maximum battery capacity

State of Health (SOH)

SOH describes the state of the battery compared to its new state, measured as a percentage. SOH depends on internal resistance, impedance/conductance, capacity voltage, charge acceptance, and number of charge discharge cycle.

Depth of Discharge (DOD)

DOD is the discharged percentage of battery, consequently counter part of SOC.

Charge/Discharge Rate

The charge and discharge current of a battery is evaluated in C- rate. As an example for a 40Ah battery rates are, C/2 is 20A, 1C is 40A and 2C is 80A.

Cycle Life

The charge/discharge cycle number that the battery can experience before its normal capacity falls before predetermined threshold of its rated value. It varies with different charging discharging conditions. C rate and DOD are the main parameters that influence Cycle life. Higher DOD lower will be the Cycle life.

Calendar Life

The time period before the battery becomes unusable. Calendar life depends on SOC, time and temperature

Specific Energy (Wh/kg)

The nominal energy per mass (Wh/kg) is defined as Specific energy. Battery chemistry and packaging are deciding factors.

Specific Power (W/kg)

The maximum available power per mass (W/kg) is defined as the specific power. Battery chemistry and packaging are deciding factors.

Energy Density (Wh/L)

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The nominal energy per unit (Wh/L) is defined as the energy density. Energy density mainly depends on battery chemistry and packaging.

Power Density (W/L)

The nominal power per unit volume (W/L) is defined as the energy density. Power density mainly depends on battery chemistry and packaging.

Capacity Fade

The amount of battery capacity reduction during battery life.

Power Fade

The increment of battery resistance over the battery period. It reduces the power capability of battery.

Energy Efficiency

It refers to the percentage maximum rate of conversion of energy by a battery. Higher energy efficiency refers to low losses in battery.

B. Key Requirement of Batteries [1,3]

The power density, the energy density, the cycle life, the calendar life and the cost per KWh are the key parameters for a comparison of batteries. Energy efficiency and discharge safety and volume are also to be considered for the selection of battery. One needs to deal with the energy and power density while designing the battery.

With the increase of battery capacity, additional weight of battery will also increase as a result reduces efficiency on the road. So battery capacity and car range are not having linear relationship.

Another important parameter is the price of battery as it increases the overall cost of BEVs. Technical improvements and breakthrough may bring down this cost in future. However present price of battery make it difficult for BEVs to penetrate in the market.

Cycle and calendar lives are also important in deciding battery lives. Frequent replacement of batteries due to cycle and calendar lives results in increment of BEVs ownership cost. Rate of discharge, charge and temperature of operation decides cycle and calendar lives.

C. Types of Batteries for BEVs

The various types of batteries are discussed here:

Batteries used for BEVs should be reliable, high power, high capacity, safe, durable lightweight and inexpensive. The most popular batteries in market which are used in BEVs are lead acid, NIMH, Li-ion and ZEBRA.

The first type of battery considered is lead acid battery. It was invented in 1859 by French physicist Gaston Plante and it is the oldest type of rechargeable battery available at present. In 1880 Camilie Faure has finalized a technique that made it easy to manufacture lead acid batteries. This battery uses plates made of pure lead or lead oxide for the electrodes. Sulfuric acid for the electrolyte is cheap and widely used in various applications. Lead acid batteries are commonly used in energy systems. These batteries are having short life span and create pollutants during the production process and having low specific energy between 20-40KWh/kg. For a range of 200km more than 500kg of lead acid cells will be needed [4].

A nickel metal hybrid (NiMH) battery is made of several components. It is a rechargeable battery which is having similar chemical reactions as Nickel Cadmium (NaCd) battery. This battery has a thin design and good battery life. It is very light weight and safe to use. The main concern about this battery is its cost. It is found to be more costly than the most accepted Lithium Ion (Li-Ion) battery.

In early 1970s first non rechargeable Li-ion became commercially available. Like other battery cell Li-ion has four main components anode, cathode, electrolyte and separator. During discharging lithium in the anode is ionized and transfers via the electrolyte through plastic porous separator in to the cathode material. As a result electrons liberated from the anode and electric current travelling in the reverse direction in the external circuit. During charging electrons leave anode to travel in the external circuit. Lithium ion moves from cathode to anode. Charging and discharging of Li-ion cell is shown in Fig.1[5,2].

Lithium being the lightest of the metal elements, it's also the greatest electrochemical potential and thus provides the largest specific energy per weight. Li-ion batteries are considered to have the greatest power battery system and potential for development. A lithium ion battery has a high energy density, can store energy for long periods of time and does not produce pollution. The concerns about Li-ion batteries are it always has application in small electronics and with the increase of capacity it poses a considerable safety hazards.

ZEBRA or molten salt batteries are also found application BEVs. These batteries are cheap and having high safety. The main issue with ZEBRA batteries is its operating temperature 270-350^{o}C and low power density which makes it unsuitable for application to BEVs. Battery characteristics described in this section is summarized in Fig. 2 and Table 1 [1,4].

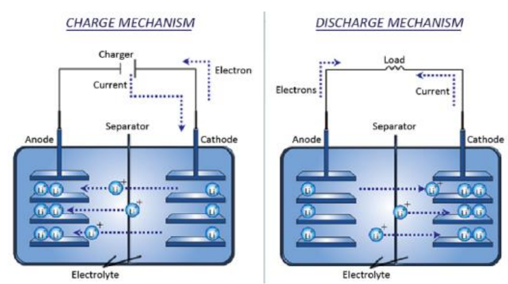

Figure 1. Charging and discharging of Li-Ion cell [5,2]

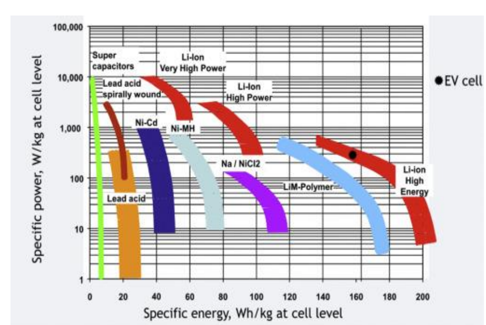

Figure 2. Specific Energy and Specific Power of Different type of Batteries [1,4]

TABLE I.THE CHARACTERISTICS OF BATTERY TYPES USED IN BEVS [1,4].

Characteristics	Lead Acid	NiMH	ZEBRA	Li-ion
Nominal cell voltage (V)	2	1.2	2.58	2.5/ 3.3/ 3.6–3.7
Specific energy (Wh/kg)	30–45	30–80	90–100	90–220
Energy density (Wh/L)	60–75	140–300	160	280–400
Specific power (Wh/kg)	180	250–1000	150	600–3400
Cycle life	500–800	500–1000	1000	1000–8000
Self-discharge (%/month)	2–4	20–30	0	2–5
Temperature range (°C)	−20–60	−20–60	270–350	−20–60
Relative costs ($/kWh)	150	500	270	700
Efficiency (%)	85	80	75–85	93

III. COMPONENTS OF ELECTRIC VEHICLES

Electric Motors

Electric motors have many advantages over internal combustion engines: electric motor offers high torque and power density. Electric motors have better torque characteristic and offer high torque at starting. Efficiency of electric motors is 75%-95% which is higher than internal combustion engines. Electric motors can be used as generators during breaking. Motors produce less noise during their operation; speed control is simple, robust, reliable and environment friendly [6].

Out of different type of electric motors the most suitable technology for BEVs is found to be DC motors. As they can work with DC, battery output can be used directly and do not require any power electronics converter. These motors are less expensive and less complicated. However these motors offer high maintenance due to commutators and brush assembly. This makes the technology unsuitable from BEVs' perspective.

AC motors offer higher efficiency and power density, light in weight and smaller in size which make it suitable for the automobile application. AC motors are less expensive but they need inverter to convert dc output of battery to ac output which increases cost [6].

Induction, switched reluctance and permanent magnet motors found their application with BEVs. Induction motor is cheaper, having better efficiency and smaller in size compared to DC motors. Switch reluctance motors offers simple construction, low manufacturing cost and suitable torque speed characteristic for BEV application. However they suffer from problems such as found noisy in operation and control for this motor is difficult. These motor has been suitable for low range BEVs [7].

All these motors found applications since long, but when applied to the BEVs they found some constraints with the size and weight of the motors and robustness etc.

IV. RANGE EXTENSION OF BEVS

A. Battery Management System

Although battery technology is growing day by day but still there is a need of effective battery system for the smart reliable and efficient operation of BEVs and smart grid. Along with controlling the operational conditions of battery management system (BMS) will estimate SOC and SOH accurately. BEVs one major concern is safety- battery and vehicle components should be protected against fire and shock hazards. As being the only available energy source in BEVs, it is essential to determine accurately, the driving distance, supported by battery. Long distance application of BEVs, uses battery to the minimum permissible charge level, protection of battery during deep charging and discharges is crucial need. BEVs battery pack are made from series-parallel arrangement of cells to achieve required energy and power densities. Proper thermal management of battery pack through BMS is required to maintain operating temperature of battery pack to 30-40^{o} C, which will result in higher efficiency of battery. BMS is aggregation of electronics based control units which monitor high and low voltage and act as a battery protection for the battery. Accurate BMS can determine SOC, SOH and remaining useful life (RUL) as a result efficiency and life of battery will increase [1].

B. Range Extender

Batteries when applied for the automobile application mainly suffer from the low range problem. a range extender a smalll internal combustion engine or fuel cell can be a solution for this problem. range exttender can produce electricity to charge the battery when it is required by the battery this make a series hybrid vehicle. when the battery is in postion to supply power to the vehicle generator or fuel cell will remain turned off. However when range provided by the battey is insufficient, generator or fuel cell connected witht the power train of vehicle will generate electricity and either charge the battery or feed vehicle directly. With inclusion of small engine with the battery the total range of vehicle is very high[1].

C. Super Capacitors

Super capacitors also known as ultra capacitors have been developed since 1990.They are high power density and low energy density device. When used in conjunction with DC/ DC converter its offer high power density and can be used for regenration and smoothing the battery power output. With application of supercapacitors it smooth out current, reduce temperature and improves the life of battery[8].

Apllication of super capapcitror with ZEBRA battery gives promising results. ZEBRA batteries are 3 times cheaper then Li-Ion battery but can not be used with its lower power density. With supercapapcitor it offers excellent performance and simplicity and safety too. However super capacitor can store energy for a short period of time[8,1].

D. Battery Sswapping Stations

Battery swapping station is the quickest charging solution. Instead of waiting for the battery charging it is being replaced by the another fully charged battery. It has some problem such as high tension section of the BEV is open and every time there will be a safety hazard. Stations should be equiped with the sufficient infrasturcture to charge batteries and should have number of batteries available. It introduce some modification in BEVs for the switchable batteries which are not at present commercially available. Lastly a high level of standardization is required [9].

V. CONCLUSION

Climate and energy security concern makes the infusion of electric propulsion inevitable for the road transport sector. Among the possible technologies BEVs have high potential. Illustrated by their important role despite the fact that there are some challenges which have to be overcome. It is clear that the future landscape of the road transport mix will be composed of various propulsion technologies, each one being a compromise between emissions and range. BEVs will probably the most suitable for the urban small to medium size vehicles, while hybrid vehicles and fuel cell vehicles appear to be more applicable for the longer ranged and larger vehicles.

However, challenges must be overcome to obtain important market penetration from the current very low update. The social acceptance of BEVs must be earned. Technology and particularly that of the battery must improve to meet the cost and range extension of consumers. Infrastructures must be developed, and they require important standardization efforts. Education and information are also crucial so that consumers can base their choices on sound perceptions of the total cost of ownership and performance of electric vehicles.

Research for BEVs is very active. For instance new battery material and designs are developed. Range extenders can overcome the 'range anxiety' issue. Alternatives such as range extender, swapping stations, battery management system and super capacitor can be a smart alternative to overcome the drawbacks of batteries.

Literature on BEV is very rich on this field and continuously and rapidly changing. Few years ago BEVs were considered as market with unclear future but this opinion has changed. Currently the potential of the technology is recognized and the efforts are made for faster market penetration. However the future of the technology in terms of uptake and in term of long term vehicle power mix is still uncertain as the cost of battery will probably remain prohibitively high in the next 20 years also competition from other low carbon technologies with smaller battery capacities. It is hoped that this paper will be a useful resource for the scholars, to improve the design of battery and make energy efficient batteries applicable for BEVs.

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