A Review of Major Battery Technologies for Electric Vehicles

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Abstract - *Given the growing concern of environmental pollution and global warming, the major contributors being the automotive industry is due to the growing use of petroleum fuels. Over the years, drastic measures and rigorous research has led to development of Electric Vehicles and battery technologies. This paper reviews battery technologies for EVs from the traditional low cost Lead acid battery to the latest Metal Air battery which is much greener and a sustainable solution, including the current market dominant lithium ion battery. This paper gives an insight of four major battery technologies for EVs, their evolution, advantages and technical advancement and also the possible battery technology that can take over the future of the wide spread and growing Electric Vehicle market.*

Key Words*: *Electric Vehicle (EVs), Hybrid Electric Vehicle (HEV), Internal Combustion Engine (ICE), Lead Acid Battery (LAB), Nickel Metal Hydride Battery (NiMH Battery), Lithium ion battery (Li-ion battery) and Aluminium air battery (Al air battery).

1.INTRODUCTION

The increase in demand of fossil fuels in the international markets and the raising environmental impact caused by this usage amount, such as global warming and environmental pollution has be of utmost concern to the researchers. The internal combustion engine based factories, industries and vehicles have been major contributors to environmental pollution due to their enormous emission of carbon gases. The International Energy Agency (IEA, 2009b) shows an average annual increase in global transport energy demand of 1.6% between 2007 and 2030[3]. The raising need of an eco-friendly, sustainable and reliable solution to meet the global transportation needs while reducing the intake of fossil fuels has caught the attention of many researchers.

Electric motive power was started in year 1827, when a Hungarian priest built the first electric motor, comprising stator, rotor and commutator. Yet the first battery-operated vehicle was built in 1881 in Paris, an electrified horse cart powered by the Faure-type pasted plate lead-acid variety patented that same year. Over the years with development in technology led to, Hybrid Electric Vehicles (HEV), which uses both electrical as well as the conventional internal combustion energy to run the motors and Electric Vehicles (EVs), which uses chemical energy stored in rechargeable batteries with no secondary source of propulsion, these were developed to meet transportation needs and also reduce the emission of greenhouse gases drastically.

The battery technology for EVs should meet various performance requirements for it to be incorporated such as, high energy density, power density, maintenance free operation, longer life cycle and low cost per cycle. With the technological advancements, the battery technology has reached new heights showing better energy and power density, which is discussed in the later sections. Even though petroleum based fuels and biofuels show much better energy and power densities compared to the current battery technology, which makes it a long shot, but it is a complete solution to all current problems of environmental risks, increase in oil price and the dependency on the limited fossil fuel deposits.
The increase in demand for EVs is not only for its environmental benefits but also its economical and technical benefits. These benefits of EVs over traditional ICE vehicles are:
 Environmental benefits: The reduced emissions, which is brought down to zero, thus being eco-friendly. EVs being extremely quiet during the drive have shown no contribution to noise pollution.

 Management benefit: Reduced cost in maintenance unlike traditional vehicles which include liquid replacement. Being a non-pollutant vehicle, EVs are not subjected to echo pass or limited-traffic areas movement restrictions. [2]

These benefits have been the source of interest for all the development and investment in EVs and Battery technologies.

2. COMPARISON OF DIFFERENT BATTERY TECHNOLOGIES FOR EVs

Power density, energy density, volume, weight, life cycle and cost are the important parameters considered for selecting a battery for an EV. Operating temperature safety, range, material recycling, and maintenance can be seen as other parameters. The acceleration ability is known as power density while the potential range is known as electrical density. The battery lifetime is dependent on cycle life which gives an indication of when the battery needs to be charged. Weight and volume play factors that can affect the range and efficiency of the EV [3].

2.1 Lead Acid Batteries (LABs):

Due to its low cost, easy availability and mature technology, LABs have been used in EVs for a very long time. They have an energy density of about 30-40Wh/Kg which is lower than any petroleum fuels or biofuels like all batteries. They contribute a significant 45-50% of the final vehicle mass of EVs. The operations of these batteries emit Hydrogen. Oxygen and Sulfur which are harmless when properly released as they are naturally occurring.

Unfortunately, due to overcharging, undercharging and degradation these batteries face performance failure. The quick discharge of these LABs significantly decrease their operating performance. Permanence, safety as well as battery operations are extremely dependent on the charging and discharging, if they are met, leads to a highly efficient battery for an EV. Similarly, the charging and discharging battery operations related performance degradation is also a significant problem in HEVs [11].

This performance degradation can be overcome without tampering with the chemistry of the LAB. The optimization can be done by developing an algorithm presenting a control technique for its battery management. This is used to enhance the battery's storage capabilities, lifespan as well as its efficiency. This electronic design approach and algorithm developed can be used to control the charging and discharging currents as well as the operational temperature [10].

2.2 Nickel Metal Hydride batteries (NiMH battery):

Nickel-metal hydride batteries compared to LAB are less efficient in charging and discharging. NiMH batteries also have a much better energy density of 30–80 Wh/kg. NiMH batteries tend to provide exceptionally long life based on maintenance which is a great benefit of this battery for EVs and HEVs. Its poor efficiency, high self-discharge and poor performance in cold weather tend to project as demerits of this battery.
Efforts over the years have shown considerable progress being made in NiMH systems with reference to performance. Showing 1000W/Kg of specific power signifies an increasing degree of competition for capacitor systems since, in addition to comparable power levels, they also are energy storage mediums which also is around twenty times higher, making it an option where batteries of small size, highly powerful and quick charge are required. The calendar service life under various temperature conditions has been a factor for its poor performance in the automobile industry [12].

2.3 Lithium Ion Battery (Li-ion battery):

Initially, Li-ion batteries, were developed and commercialized for use in consumer electronics. They have now become dominant in EVs because of their high energy density and long cycle life compared to the older technologies of LAB and NiMH batteries. Minimum size, quick charge, high energy density, no memory effect, longer cycle life, high load handling capability are some of the major merits of Li-ion batteries explaining their take over the EV markets.

Despite the benefits of Li-ion batteries the safety, environmental impact and recycling, memory effect for partially numerous successive charge-discharge cycles, cost [1] show a downside of these traditional batteries. These factors lead to performance degradation of Li-ion battery with age. The fire safety risk due to the thermal instability of anode still is a concern. These batteries also exhibit significant sensitivity to temperature and poor performance at low temperatures.

The variation in Li-ion chemistry to develop variants such as Li[NiCoMn]O2 and LiFePO4 batteries has be utilized to resolve most of the earlier mentioned problems[5]. These are addressed by focusing on dynamic energy recuperation ability as well as charge acceptance of lithium-ion cells of different formats and varying chemistries [6]. Also, for enhancing the life cycle, development of battery management as well as charge equalization systems is done to have a controlled operation [1].Regarding the environmental impacts of its production and disposal, by undertaking sophisticated and proper measures, it can be minimized to a greater extent.

2.4 Aluminium Air Battery (Al air battery):

Having the largest energy density compared to all other batteries, Aluminium air batteries are a certain choice for EVs. As they have the potential of eight times the range of Li-ion batteries. These batteries work on the chemistry between aluminium and oxygen present in the air. These batteries are non- rechargeable as they are primary cells, instead the aluminium is replaced once it's completely used. This replacement of aluminium can be met by recycling the by-product after the complete reaction to obtain aluminium which can be reused to feed the battery for further reactions to obtain electricity.

Aluminum air battery is capable of generating power and energy densities comparable with gasoline powered vehicles for long driving ranges. It gives a cost benefit because of the recycling of aluminium in the technology. Al air batteries having long life cycle, give a travel range comparable to ICEs unlike LAB or NiMH batteries. Al air based EVs are a better and more reliable solution due to the travel range, safety, life cycle and fuel cost benefits [7]. Better solutions are to be yet developed for certain problems like aluminium corrosion which are currently handled by using an alloy. Also the electrolyte is stored in a tank outside the battery and transferred to it as and when required to increase the shelf life of the battery.

3. COMPARATIVE ANALYSIS

Table -1: Comparison of battery technologies for EV

Comparison of battery technologies for EV			
Battery type	**Energy density(Wh/Kg)**	**Nominal cell voltage(V)**	**Advantages**
Lead Acid Battery	20-100	2.1	Low cost, mature technology.
Nickel Metal Hydride Battery	50-80	1.2	High specific power, safety, large temperature range, long service life.
Lithium ion Battery	90-200	3.6	High voltage operation, Higher specific energy
Aluminium air Battery	300-500	1.2	High energy density, cost efficient, safety

The table 1 shows the comparison of parameters of the battery technologies discussed earlier for EVs [3] [7]. The lead acid batteries do continue to be used in various EVs due to its mature technology and recent advancements which has led to an increase in its energy density over the years. NiMH batteries show the least of energy densities compared to other technologies despite its safe operation and long service life benefit. Lithium ion batteries show high voltage operation and have good energy density, they also are light weight batteries which can improve overall system efficiency in EVs. Aluminium air batteries have large energy density, but practically, the energy density range is comparable to Li-ion batteries. The availability of aluminium and its production rate compared to all the reserves of lithium is far more. This gives aluminium air batteries the larger market place in the future while lithium ion batters fall short and show escalating prices. NiMH has most expensive life-cycle costs compared to aluminium air batteries which share almost the same as LAB.

3. CONCLUSION

The review shows the development in battery technology for electric vehicles, the recent advancements in this field shows its significance in the current world. The raising needs for better technology to completely omit the current ICE based vehicles because of the raising environmental risks have attracted many researchers resulting in great growth of battery technologies for EVs.

The comparison made between the battery technologies discussed also show the evolution of battery technologies over the years from lead acid batteries to metal air (aluminium air) batteries. The matured technology of LABs are continued to be used despite the lower energy density compared to the later battery technologies of Li-ion and Al air due to its minimal cost which is because of mass production plants. The aluminium air batteries show the highest energy density theoretically, making them the closest to ICE based vehicles. Currently, in practice they show a similar range as Li-ion batteries. But aluminium air batteries are a much safer and greener technology compared to lithium ion batteries which require proper disposal and hold fire safety risks. The future of EVs can be based on the advancements in aluminium air batteries compared to lithium ion batteries due to its raw material (aluminium) abundance making them a reliable and sustainable solution over all for the automobile industry. The aluminium air batteries can take over the wide spread market till now being dominated by lithium ion batteries by addressing its demerits like corrosion of the anode, size of the battery and also by making technological advancements to increase its practical energy density for better performance.

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