Advancements in Battery Technologies of Electric Vehicle

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Abstract. The Automotive Industry has undergone a huge revolution – Electric Vehicles! Electric cars are growing fast and the demand for them is increasing all around the world, thanks to the more and improved choice, reduced prices, and enhancing battery technology. Introduced more than 100 years ago, electric vehicles have gone through a tremendous amount of advancement. This paper reviews the current major challenges faced by the Electric Vehicle Industry along with possible solutions to overcome them. Although electric vehicles have come a long way, the battery used in the vehicles needs to be further explored to harness maximum energy with a compact design. Electric vehicles should soon be able to compete with combustion engine vehicles in every aspect. Also, this paper reviews alternative materials for electrodes and batteries to make charging faster and reliable than ever. This paper envisages few concepts that could revolutionize Automobile Industry further in the future.

1. Introduction

The global acceptance rate of electric vehicles has increased by 43% in 2020, accounting for a total of more than 3 million units sold. About 30% of all cars are expected to be electric by 2030 as stated by the IEA (International Energy Agency). Even though it sounds remarkable but only 1% to 3% of total passenger cars are electric today [1]. The sales numbers can only be achieved if electric vehicles are preferred over combustion engine vehicles by the customers. To make electric cars appealing to customers, the major challenges concerning electric vehicles must be resolved. To address the current issue of rocketing air pollution around the world, global warming, and depleting fuel reserves, electric vehicles are a possible alternative to the current fuel-driven vehicles as they do no harm to the environment and require a clean and renewable source of energy to power them up. The current global energy consumption by different sources of energy is shown in Figure 1.

Battery power is the most essential element for a vehicle that runs on electricity. Also, these vehicles have the advantage of recharging overnight due to the presence of an electric grid. Recently, due to environmental and security reasons, countries like U.S., India, China, and European Union are taking a keen interest in promoting electric vehicles through schemes, incentives, etc. In layman’s terms, the drive range is directly proportional to battery capacity. Due to the lack of charging stations everywhere, customers fear getting stuck somewhere causing delay, inconvenience, and anxiety in a journey. The term describing this is called “range anxiety”, fear of insufficient power in the vehicle to reach the destination or to any nearby charging infrastructure. OEMs are constantly working towards increasing the driving range by increasing battery capacity that impacts the size, chemistry, and battery management system. A customer willing to use an electric vehicle (EV) needs the vehicle to have shorter charging durations, lesser maintenance, and a cheaper cost of operation [2].
2. Challenges of Electric Vehicles

2.1 Battery Cost

Batteries of electric vehicles are highly priced which makes the overall cost of EVs more than Combustion engine vehicles. The cost of the battery is decided on the components which are used in the battery making like materials, electrodes (anode and cathode), and body shell etc. as shown in Figure 2. An EV uses the lithium-ion batteries which are on costlier side. A battery is composed of many cells which contain cathode electrode. The materials used for cathode are metals like cobalt, nickel, lithium etc., which yields more energy and are expensive. These materials are mined and processed to get highly efficient chemical compounds.

According to Bloomberg NEF reports, the prices of battery production have been decreasing gradually in past 10 years as shown in Figure 3 [4]. The battery cost was responsible for more than half (57%) of vehicle’s production cost in 2015. The average price for one kilowatt hour in 2010 is $1160. The price of kilowatt hour is now decreased by 87% which values $156 per kilowatt hour in 2019. It is expected that it will drop below $100 per kWh by 2024. Several new mines have been opened for the high demand of lithium-ion batteries. This will decrease the prices of battery and production cost as well [5].

![Figure 2. Composition of Battery and its costs (in $)](image-url)
2.2 Charging Time
Charging time for an EV is a big challenge as it is time consuming unlike refuelling a gasoline vehicle. A traditional gasoline vehicle can be entirely refuelled in 3-5 minutes whereas for an EV, even using fast charging technology it takes nearly an hour to charge the vehicle fully. For instance, an electric car with a 60kWh battery takes around 8 hours to charge from empty to full of a 7kW charging point.

The 5 main factors affecting the charge time of an electric vehicle are:

• Battery Size – Bigger the battery size, the longer will it take to charge.
• State of Battery – Topping up from 50% takes lesser time to charge than starting from empty.
• Charging Rate of Vehicle – A vehicle’s battery can only be charged at the maximum charge rate the vehicle can handle.
• Charging rate of Charge Point – It also depends on the charging rate of the charge point, if the charge point offers a lesser charging rate than what a vehicle can accept, then the rate of charging will be slow.
• Environmental Factors – Cold temperatures can increase the charge time of a vehicle[8].

2.3 Driving Range
The distance a fully charged battery electric vehicle can run before the battery is out of electricity is defined as the driving range. Combustion engine vehicles have an average range of 400-600km whereas electric vehicles only have an average range of 350km as shown in Figure 4. This difference in range makes a customer pick gasoline vehicle over EV. The driving range can be increased by increasing the battery capacity and improving battery management. There are two ways to increase range – install a bigger battery or reduce the energy consumption of the vehicle. The latter is more beneficial as installing bigger batteries increases cost and weight, ultimately increasing energy consumption [9].

![Figure 3. Cost of Batteries in past decade [7].](image-url)
2.4 Lack of Charging Infrastructure

Due to the lack of charging infrastructure for electric vehicles, drivers can face “range anxiety” speculating how far they can go before the next charge and find a charging station before the car dies. Charging infrastructure should be developed covering most parts of the country just like a gas station. The government should divert its attention to building more charging points for accommodating the traffic waiting for their vehicle to be charged[11]. A simple solution to establish a wide network of charging points is by installing charging points on all the street lamps as there will be a constant supply of current to these lamps. Adding more charging points will decrease the overcrowding of people waiting for their vehicles to be charged. These charging points can be digitally monitored, pay, and use kind [12].

2.5 Safety

Safety is the most dominant aspect in vehicles. EV manufacturers must follow the design regulations and enhance the safety of the drivers and passengers. The usage of electric batteries is prone to explode and breakage of cells. Lithium-ion batteries are made up of power cells which can cause short-circuiting if it has any defect.

**Temperature Range.** The batteries of EVs are stable at 15°C to 45°C and has a good range at these temperatures. As the temperature of the battery increases or decreases, it affects the health of the battery which reduces the range of the vehicle. A cooling management system must be installed for the safety of the battery, electric components, and vehicle.

**Thermal Runaway.** Many cells are packed into the battery to increase their capacity. In lithium-ion batteries, the liquid used as the electrolyte is highly flammable. Thermal energy will be transferred to its neighbouring cells which is difficult to stop once started. It undergoes combustion when the cells of the battery are short-circuited which causes fire at 60°C and above temperatures. It can be caused if the EV is exposed to higher temperatures, charging incorrectly, and left in direct sunlight for a longer time. Engineers and manufacturers are working on this issue to prevent and reduce the chance of thermal runaway [13].

2.6 Thermal Effects

Batteries being the most important component in electric vehicles, Lithium-ion batteries are widely applied across the automotive section because of their high energy and operation stability. The thermal effects of the batteries influence their temperature and electrochemical properties like charging and discharging performance, vehicle performance and responses, internal resistance etc. This affects battery health and safety. The heat can be classified into two categories-

- **Reversible heat**- This heat comes from the entropy change of the electrochemical reaction.
Irreversible heat- This is mainly caused by the internal resistance of the battery and occasionally causes uncontrolled heat release. The accumulation of heat for a longer time at the rising temperature inside the batteries may lead to breakages and explode or burn the connections. The mechanisms of the batteries cause battery temperature changes, which is influenced by the battery size, material of battery, packaging material, load connections and temperature. The battery energy powers both, the vehicle and the support system like air conditioning of the vehicle and maintaining the temperature of the battery in an optimal range[14]. It is observed that most EVs follow a similar range curve, regardless of model and production. Both cold and hot temperatures impact the health of the battery in terms of range, charging and discharging time. The most notorious battery killer is cold weather which has a larger impact on batteries. Therefore, analysing the thermal effects of battery and predicting the temperature changes of batteries is important for their practical application and improvisation of battery health[15].

3. Advancements In Battery Technology

3.1 Aluminium-ion Batteries
Lithium-ion batteries are being used in EVs for a long time. Drawbacks of li-ion batteries made alternative research on chemicals to maximize the efficiency of batteries. Aluminium-ion batteries are good for energy storage, which is for their gravimetric and volumetric capacities. Aluminium is more abundant than lithium. Al-ion batteries provide four times more energy than Li-ion batteries at a low cost. In Al-ion batteries, Aluminium is used as a negative electrode and graphite as a positive electrode when graphitic materials are used. AlCl3 and 1-ethyl-3-methylimidazolium chloride is taken as ionic liquid. This ionic liquid has half-reversible reaction for both the electrodes:

Negative electrode: $\text{Al} + 7 \text{AlCl}_4^- \rightarrow 4 \text{Al}_2\text{Cl}_7^- + 3\text{e}^-$

Positive electrode: $\text{C}_n [\text{AlCl}_4] + \text{e}^- \rightarrow \text{C}_n + \text{AlCl}_4^-$

Therefore, Aluminium-ion batteries can be used in future for energy storage systems [16][17].

3.2 Foldable Batteries
The foldable battery is Jenax’s innovation [18]. It is a lithium-ion battery that can be folded over 200,000 times without compromising performance. These batteries support fast charging and can be used to power up small components in EVs. It is stable even with bending fatigue and has a high energy density. Foldable batteries have an operating temperature from -20°C to 60°C which makes them suitable for any climatic condition. The battery capacity is 30mAh and has passed the safety test along with being waterproof [19].

3.3 Lithium-Air Battery
The lithium-air battery (LiO2B) is yet another lithium battery that needs to be explored more due to its high capability in producing energy. In the cell, the anode is lithium metal, the cathode is porous carbon and the electrolyte used is non-aqueous[20]. It can theoretically produce a high specific density of 3505 Wh/kg. The cell reaction is as follows:

$2 \text{Li} + \text{O}_2 \rightarrow \text{Li}_2\text{O}_2$

The theoretical energy density of non-aqueous lithium-air batteries is higher than that of the conventional gasoline engine. The reaction justifying the theoretical energy density of an aqueous lithium-air battery is:

$4 \text{Li} + \text{O}_2 + 6\text{H}_2\text{O} \rightarrow 4(\text{LiOH.H}_2\text{O})$

The energy density of aqueous lithium-air batteries is lower than that of non-aqueous lithium-air batteries but higher than that of the traditional gasoline engine [21].

3.4 Lithium-Sulfur Battery
Sulfur is an element that is abundantly present in nature and inexpensive. It is environmentally friendly so lithium-sulfur batteries are not toxic to the environment. Lithium metal is used as the anode and sulfur composite as cathode while the electrode being an organic liquid. Sulfur has a theoretical capacity of 1675 mAh/g while lithium metal has a theoretical capacity of 3860 mAh/g. Lithium-sulfur battery has a specific energy of 2567 Wh/kg.

The discharge of this battery occurs in 2 stages:
\[
S_8 + 2e^- + 2Li^+ \rightarrow Li_2S_8 \\
Li_2Sn \rightarrow Li_2S_n + (8-n)S
\]

3.5 Material selection of electrodes for Fast charging
The efficiency of the battery is determined by the material used for electrodes. Li-ion batteries are capable of fully charging in less time. In a Li-ion battery, graphite is used as one electrode. Materials should be selected in such a way that it decreases the time of charging. Red phosphorus can be used for its high-energy-density fast charging of Li-ion batteries. Lithium bis(fluorosulfonyl)imide is mixed with the solvents of intrinsically flame-retardant triethyl phosphate and fluoroethylene carbonate as a solid electrolyte interface. This enhances the electrochemical performance of P anode.

3.6 Solar Panel
Usage of solar panels for producing power for EVs has been proposed by researchers. Solar panel module can be used to energize the battery packs automatically which reduces the driver’s anxiety, unnecessary stops and increases the range of the EV. Production of batteries using renewable energy sources will reduce the toxic wastes caused by vehicles. This concept is perfectly environmentally friendly. The solar panel modules are installed on the roof of the EVs. The output from the battery depends on the solar light it absorbs. The solar panels yield maximum output at 25°C. Electrical energy is generated when the sun’s rays are captured by panels. Engineers are working to improve the current solar panel technology and to maximize its efficiency.

3.7 Solid-State Battery Interfaces
A solid-State battery (SSB) is made up of solid components which is fundamental in electron transfer and ion transport. A solid-state battery has higher energy when compared to the Li-ion battery which uses liquid as the electrolyte solution. SSB are safer than current battery systems. Since it is made up of solids, it is less risky, non-flammable, and there is no worry of electrolyte leaks. The flame-resistant electrolyte is used in SSBs. Solid states batteries are also used in improving other types of batteries. These batteries increase energy density per unit area since few batteries are used. A solid-State battery is perfect to make an EV battery system. Car manufacturers are working on Solid-State batteries to improve vehicle’s efficiency.

3.8 Supercapacitors
Supercapacitors are an innovation built to store chemical energy but follow a completely different principle than that of a battery. Supercapacitors, also called electric double-layer capacitor (EDLC), has gained more importance lately due to its applications in the EV industry. They have more than half a million life cycles by storing their energy in an electrostatic field. The batteries have a shorter life cycle as compared to supercapacitors. EDLCs also have the potential to work under a wider temperature range of -40°C to 70°C while batteries tend to cause problems in colder temperatures. The internal resistance is also lower than that of batteries contributing to lesser heat loss and higher energy efficiency. With supercapacitors, it is possible to achieve a high-power delivery (10kW/kg) within few seconds.

4. Conclusion
This paper summarises the major challenges faced by electric vehicles such as lack of charging infrastructure, drive range and thermal management of batteries. Possible solutions to overcome these
issues are also discussed in the paper. The advancements in battery technology to improve the quality of electric vehicles are put forward. It also discusses a few concepts that may not be possible currently but will aid with future technology improving electric vehicles.

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