A Review on Technologies and Challenges of Electric Vehicle in India

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***Abstract*: Internal combustion engine vehicles are a major cause of global warming and environmental air pollution. Electric Vehicles are being launched as an innovative green product in the Indian market as an alternative to conventional vehicles. This effort not only planned to moderate the GHG emission but will also help in reducing oil imports of the country. The average fueling time for the internal combustion engine vehicle goes in minutes, whereas for an EV it can go up to an hour. The major impediments in the path of adoption of the EV are its high purchase cost and charging time. This paper provides an overview of the studies of Battery Electric vehicle, Hybrid electric vehicle, Plug-in Hybrid electric vehicle, advances of EVs regarding battery technology trends, charging methods and adoption of Electric vehicle in several countries.**

Keywords: Hybrid electric vehicle; Plug-in Hybrid electric vehicle; battery charging; batteries technology; charging modes

INTRODUCTION

The use of fossil fuels in industrial activities and automobiles contributes a larger volume of carbon dioxide (CO_2) emission in the air. Higher consumption of the fossil fuel results in the depletion of valuable resource and led to a dramatic increase in air pollution levels with higher concentration of pollutants such as Particulate matter (PM_{10} & $PM_{2.5}$), nitrogen oxides (NOx), Carbon monoxide (CO) and sulphur di oxide (SO_2). According to a report by the European Union, the transport sector is responsible for nearly 28% of the total carbon dioxide (CO_2) emissions, while the road transport is accountable for over 70% of the transport sector emissions [1]. In India, the transport sector is responsible for 13.5% of the country's energy-related CO_2 emissions, with road transport accounting for 90% of the sector's final energy consumption. Global transport emissions have continued to steadily increase, with transport emissions accounting for 24% of direct CO_2 emissions from fuel combustion [2]. Therefore there is an urgency to look at sustainable mobility solutions to reduce GHG emissions and mitigate adverse impacts of transportation. The CO_2 emission can be reduced by shifting of vehicles to cleaner modes of transportation.

India's commitment to limiting pollution and lowering its carbon footprint is growing. As the nation imports almost 80% of its total need for crude oil, or over $100 billion, the government wants carmakers to switch to electric vehicle production, so that it helps in reducing dependence on foreign fuel imports, protecting the country from currency swings. The minimal use of fossil fuel is a promising solution towards improving the air quality. The usage of Electric Vehicles (EVs) could be the alternative to decrease the CO_2 gas emission from the automobile sector [3]. The usage of EVs in India was started from the beginning in the mid-1990s. The adoption rate of EVs is very low in India due to high vehicle costs, battery performance issues, inadequate battery charging infrastructure, lack of awareness and limited driving range [4]. At present the majority of the electric vehicle segment (less than 1% of total vehicle sales) is dominated by electric 2 wheelers (62%) and electric 3 wheelers (37%). But there is very low or negligible adoption in case of four wheelers or personal cars. Now, the government of India realized that promoting the usage of EVs is the effective way towards promoting air quality, economic opportunity and various socio-economic advantages. In this paper, we present a comprehensive survey of the most significant aspects of EV technologies, batteries, charging modes, and the research carried out by different research teams on adoption of EVS.

SCHEME FOR PURCHASING EVS IN INDIA

In the Conference of the Parties (COP 21) or the Paris Agreement for the United Nations Framework Convention on Climate Change (UNFCCC), India has made a target to reducing the CO_2 emissions reduction by 45% by 2030 and net-zero by 2070. The National Mission for Electric Mobility (NMEM) Plan was launched in April 2015, and a Consumer Incentives Scheme" for Electric & Hybrid Electric Vehicles was published in the Gazette of India with an expectation to reach an annual sales 6-7 million vehicles by 2020, which may lead to savings of 9500 Million Liters of crude oil or Rs. 62000 Cr. The NEMM intends to allow hybrid and electric vehicles to become the first choice for the purchasers so that these vehicles can replace the conventional vehicles and thus reduce liquid fuel consumption in the country from the automobile sector. Under NEMMP 2020, Government has launched Faster Adoption and Manufacturing of (Hybrid &) Electric Vehicles in India (FAME India) scheme to promote manufacturing of electric and hybrid vehicle technology [5].

As a result, the Indian government's Department of Heavy Industry has provided a road map and guidance for the production of EVs in India. Various government policies which are intended to push electric vehicles are: The slash of Goods and Services Tax (GST) on cleaner vehicles from 12% to 5%, relaxation of permit for BEVs used for Taxis, Auto-rickshaws, exemption of registration fee for EVs, Tax exemption on purchase of EVs, Policy guideline issued for charging infrastructure at

Residential societies and offices and reduction of electricity charge to make it affordable and Customs duty reduction on all categories of EVs [6].

Electric vehicle overview

In India, the automobile Industries started their business using Internal Combustion Engines (ICEs) which have been around for over a century. The combustion process in the ICE releases energy to drive the vehicle. For the past few decades, they are undergoing changes due to the growing expense of fossil fuels and the environmental effect of their emissions. Hybrid Electric Vehicles (HEVs) and Battery Electric vehicles (BEVs) are progressively replacing internal combustion engines in the automobile industry. The most significant difference between ICE and BEV is found in the components called power train that generate power and deliver it to the wheels to move the car. HEVs and EVs have several advantages over conventional vehicles. The different types of electric vehicles found in India are listed below.

Electric Vehicles nomenclature

According to their engines technology, the EVs are sorted in five types namely Hybrid Electric Vehicle (HEVs), Plug-in Hybrid Electric Vehicle (PHEVs), Battery operated Electric Vehicle (BEVs), Fuel Cell Electric Vehicles (FCEVs) and Extended-range EVs (ER-EV) .

Hybrid Electric Vehicle is also known as a dual-power-source vehicle. It consists of an internal combustion engine and an electric motor. Here the battery gets charged by the engine. The onboard computer system determines the fuel to be used to operate the vehicle through a process known as “regenerative braking”. The HEV can be connected in various arrangements depending upon the type of hybrid system like series hybrid, parallel hybrid and power spilt hybrid [7].

Plug-in Hybrid Electric Vehicles have both ICE and electric motor with a rechargeable battery which is charged up with electricity. One big difference from HEVs is that a PHEV can travel a decent distance on electric power alone about 20 to 30 milesfor miles without routing to gas. The advantage of PHEV is the flexibility as it will act like a conventional hybrid electric vehicle if the battery is not charged up. Moreover, the choice of selection is more as there are 32 PHEVs available in the U.S as of September 2021. At the same time there are19 battery-electric vehicle models available in the U.S. and 26 total including model variants as of January 2021. The cost of maintaining its ICE, non-electric parts and the cost of gas brings the costs of a PHEV up over its lifetime [8].

Battery operated Electric Vehicle consists of high capacity rechargeable battery packs that must be charged through an external source. It has no internal combustion engine, no fuel tank, and no exhaust pipe. One of its biggest advantages of the BEV is easy charging, which means that the vehicle can be simply plug in and go after recharging. It does not require engine oil resulting in significant savings over the life time of the vehicle and therefore it requires very little maintenance. It draws their electricity from the grid, reduces carbon emission, and thus contributing to a cleaner environment [9].

Fuel Cell Electric Vehicles are powered by hydrogen. It consists of an electric engine wherein a mix of compressed hydrogen and oxygen obtained from the air are used. They are more efficient than conventional internal combustion engine vehicle and produce no tail pipe emission and have some advantages over Electric vehicles. The refueling of hydrogen is a matter of few minutes, delivers a long driving range, and the driving range does not depend upon the atmospheric temperature [10]. The draw backs are the cabin space that becomes small due to the hydrogen fuel tank, and hydrogen cost is more than electricity. Based on the power train configuration, the FCEV is categorized into two types, namely Fuel Cell Electric Vehicle (FCEV) and Fuel Cell Hybrid Electric Vehicle (FCHEV).

Extended-range EVs run primarily on electricity, but they also include an auxiliary power unit called a ‘Range Extender”. It is very similar to those ones in the BEV category but provided with a supplementary combustion engine, which charges the batteries of the vehicle if needed [11]. This type of engine, unlike those provided by PHEVs and HEVs, is only used for charging, so that it is not connected to the wheels of the vehicle.

Types of batteries in EVs

The key components of a Battery Electric Vehicle are Electric motor, Inverter, Battery, Battery charger, Controller and Charging cable. The major components of batteries used in automotive engine are container, Cathode, Separators, Anode, Electrolyte and Collector. The electric vehicles don’t charge the auxiliary batteries like the conventional internal combustion engines that use the alternator to boost their batteries while running. The EVs use a DC-to-DC converter to controls the voltage to the required float-charge voltage. Although (Li-ion) batteries are increasingly used in EVs, there exists a great variety of batteries [12] and the working principles of the batteries are as follows:

- **Lead – acid (Pb-PbO_2) batteries**: These batteries are the oldest kind of rechargeable batteries which were invented in 1859 and are very common in conventional vehicles now a day. Earlier, it has also been used in EVs. The battery consists of

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sulfuric acid and a group of lead plates. In the discharged state both the positive and negative plates become lead (II) sulfate ($PbSO_4$), and the electrolyte loses much of its dissolved sulfuric acid and becomes primarily water [13].

- **The nickel–cadmium (Ni–Cd) batteries**: These batteries were used in the 1990s. This type of rechargeable batteries using nickel oxide hydroxide and metallic cadmium as electrodes. The Cadmium used in these batteries is hazardous and very expensive. Due to low lifespan, these batteries are currently being substituted by nickel-metal-hydride (NiMH) batteries [14].
- **Nickel-metal-hydride (NiMH) batteries**: In these batteries Cadmium (Cd) is replaced with an alloy that stores hydrogen and these batteries are used in many hybrid vehicles [15].
- **Zinc – bromine (Zn-Br_2) batteries**: These batteries are rechargeable battery system that uses the reaction between zinc metal and bromine to produce electric current, with an electrolyte composed of an aqueous solution of zinc bromide [16].
- **Sodium chloride and nickel (NA-NiCL) batteries**: A sodium nickel battery (Na-$NiCl_2$) is a high-temperature energy storage system that uses sodium as the anode and nickel and sodium chloride as the cathode. The battery works on the basis of electrochemical reactions that involve the transfer of sodium ions between the positive and negative electrodes. They are very similar to sodium sulphur batteries. Their advantage is that they can offer up to 30% more energy in low temperatures. These are ideal for its use in electric vehicles [17].
- **Sodium sulphur (Na-S) batteries:** NaS battery consists of molten sulfur at the positive electrode and molten sodium at the negative electrode with the active materials separated by a solid beta alumina ceramic electrolyte. These batteries have a high energy density, high loading and unloading efficiency (89-92%) and long life cycle and its materials have a very low cost [18].
- **Lithium – ion (Li-ion) batteries:** A lithium-ion or Li-ion battery is a type of rechargeable battery which uses the reversible reduction of lithium ions to store energy. These batteries have the advantages of the lightness of their components, high loading capacity, internal resistance, high loading and unloading cycles and reduced memory effect [19].

CHALLENGES AND ADVANCEMENT IN BATTERIES FOR EVS

Amid the growing interest in battery electric vehicles, the industry still faces various challenges to gain wider adoption in the market. Among the often-cited hurdles by consumers include a limited driving range, high maintenance costs, battery issues and limited charging infrastructure, particularly over in many Asian markets. Other key factors include technology acceptance and the comparatively high cost to own an EV. On the technical side, the biggest challenge is the use of lithium-ion batteries. Today's lithium-ion technology is reaching its physicochemical limit. On average, it takes 17 hours to charge a car and for today's consumers, this is a huge turn-off. Therefore, hybrid vehicles, which run on both battery and gasoline, are more popular than EV. There is still work to do in this field, fundamentally due to its impact, as the improvement of batteries can accelerate EVs success and the worldwide deployment of these vehicles in a remarkable way. At present, new technologies and components are being researched. Some of them are the following:

• **Lithium iron phosphate (LiFePO4)** : In this battery lithium iron phosphate is used as the cathode material, and a graphitic carbon electrode with a metallic backing as the anode. Because of their lower cost, high safety, low toxicity, and long cycle life (2000 and 10,000 cycles) with an energy density of approximately 220 Wh/L, these batteries are finding a number of roles in vehicle use and this type of battery is starting to be tested in EVs. However, it still can be found in an early stage of research and development. As of September 2022, LFP type battery market share for EV's reached 31%, and of that, 68% was from Tesla and Chinese EV maker BYD production alone [20].

• **Magnesium-ion (Mg-Ion)** batteries change the use of lithium over magnesium, succeeding in storing more than double the charge and increasing its stability. It is expected that this type of battery can have a 6.2 kWh/L energy density which would imply 8.5 times more than the best lithium batteries, which are currently able to apply up to 0.735 kWh/L. A magnesium–air battery has a theoretical operating voltage of 3.1 V and energy density of 6.8 kWh/kg. A significant advantage of magnesium cell is their use of a solid magnesium anode, allowing a higher energy density cell design than that made with lithium, which in many instances requires an intercalated lithium anode [21].

• **Lithium-metal batteries**: In these batteries a fine lithium-metal layer is used to replace graphite-anode, which will be able to store double of the power than a traditional lithium battery. Literature [22] reported that this type of batteries are deployed in drones and is under research to include in EVs .

•**Lithium-air (Li-air) batteries: It** is a metal–air electrochemical cell that uses oxidation of lithium at the anode and reduction of oxygen at the cathode to induce a current flow. This is about 5 times greater than that of a commercial lithium-ion battery, and is sufficient to run a 2,000 kg electric vehicle for approximately 500 km on a single charge using 60 kg of lithium (i.e. 20.4 kWh/100 km) [22]. However, the practical power and life cycle of Li–air batteries need significant improvements before they can find a market niche.

• **Aluminum-air Batteries** that are developed with this technology produce electricity from the reaction of oxygen with aluminum [23]. Their main advantage is that this type of battery reaches very large energy densities attaining 6.2 kWh/L and they are recyclable.

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• **Sodium-air (Na_2O_2)**. The company BASF created a Sodium-air battery with an energy density of 4.5 kWh/L . In electric vehicles, this type of battery can multiply the autonomy of the current lithium batteries at least thirteen times [24]. A great advantage of this type of batteries is that sodium is the sixth more abundant element in our planet.

• **Graphene**. Graphene is a material that is formed by pure carbon, which has a high thermal conductivity and it is extremely light. One of the major assets of graphene -based batteries is that they barely heat, enabling fast or ultra-fast charges without significant power losses due to heat [25]. In a high power plug, this battery could be charged in only 5 min. This kind of battery is in an early phase of development a prototype with a specific power of 1 kWh/kg, and it is expected to reach 6.4 kWh/kg soon.

Aside from the novel application, the interesting thing about these batteries is that they are lithium–sulfur (Li–S) batteries. Li–S batteries have long been touted for commercial use because of their high energy density, but the sulfur electrodes have often suffered from "polysulfide shuttling"a process whereby the sulfur ions leave the electrode, react, and form long–chain molecules, degrading the electrode and battery performance in the process

Charging of Electric Vehicles

The infrastructure element that provides the crucial link between an electric vehicle with a depleted battery and the electrical source that will recharge those batteries is the Electric Vehicle Supply Equipment (EVSE). EVSE delivers electrical energy from an electricity source to charge an EV's battery and communicates with the EV to ensure that an appropriate and safe flow of electricity is supplied. EVSE units are commonly referred to as charging stations. The basic EVSE equipment is connected to an electrical power source that provides the alternating current (AC) or the direct current (DC) to supply the electrical charge to the vehicle's traction batteries. EVSE charging capacity options are an important consideration as they have a direct bearing on how fast the batteries can be recharged.

CHARGING MODES

When charging EVs different standards are being used in different countries. In North America and in Pacific Zone the standard for loading vehicle is SAE-J1772 and the standard for China is GB/T 20234, which is classified according to the power type AC or DC. IEC-62196 is an international standard created by International Electrochemical Commission based on the charging power involved for charging of vehicle in China and Europe [26] and the mode of charging is detailed below.

Mode 1- **Slow charging: It is** also called domestic charging mode which can be obtained from a single or three phase power outlet. The current and voltage level charging ratings of the IEC-62196 for single phase AC: 16 A and 230-240 V with maximum power 3.8KW and for AC -3-phase 16A, 480 V with maximum power 7.6kW.

Mode 2- **Semi-fast charging: These** charging stations require increasingly higher quantities of electricity and the charging time is lesser that Mode-1. These stations can be set up at work places or at other similar places. The current and voltage level charging ratings of the IEC-62196 for single phase AC: 32 A and 230-240 V with maximum power 7.6 KW and for AC -3-phase 32 A, 480 V with maximum power 15.3kW.

Mode 3 – **Fast charging** : These charging stations are commercial charging stations that provide the fastest charging but require highest quantities of electricity. The current and voltage level charging ratings of the IEC-62196 for single phase AC: 32– 250 A and 230-240 V with maximum power 60 KW and for AC -3-phases 32 – 250 A, 480 V with maximum power 120kW. It requires the use of EVSE for charging electric vehicle.

Mode 4 – **Ultra fast charging** defines a direct connection of the EV to the DC supply network. The current and voltage level charging ratings of the IEC-62196 for DC: 250-400A and 600-1000 V with maximum power 400 KW. One of the most significant benefits of ultra-fast charging is that it offers room for up gradation as the devices are often modular, so they could be expanded with growing demand. It also requires the use of EVSE for charging electric vehicle.

EV ADOPTION IN VARIOUS COUNTRIES

Despite the several efforts taken by the Indian government under NEMMP 2020, the adoption in the case of EVs is very low as compared to other developing economies. The main demand for the EVs in India is coming in the electric vehicle segment (less than 1% of total vehicle sales) is dominated by electric 2 wheelers (62%) and electric 3 wheelers (37%). Several literature [27] highlight consumer adoption theories, factors effecting the adoption of electric vehicles and effect of government schemes on electric vehicle adoption both by consumer and the manufacturer.

Bansal et al., 2021 [28] report reveal that Indian consumers are willing to pay an additional US$10–34 in the purchase price to reduce the EV fast-charging time by one min, US$7–40 to add a kilometre to EV driving range at 200 km, and US$104–692 to save US$1 per 100 km in future operating cost.

Rajive kumar and Alok, 2021 [29] findings show that the governments in countries with socio-economic and cultural conditions similar to Portugal should give primacy to financial incentives when implementing green tax reforms.

Adhikari et al., 2020 [30] explained that technical, policy, economic, infrastructure, absence of a tax exemption policy and social attitude are the major barriers against the diffusion of EVs in Nepal.

Adnan et al., 2018 [31] concluded that if the consumers have more concern towards the environment, they will have more attraction towards adopting PHEVs. The prevailing doubts regarding the improvement of the attitudes towards Fuel cells as well as hydrogen-powered vehicles in the upcoming years seem to permit a more substantial research work in this domain.

Hao et al., 2016 [32] showed that bureaucratic challenges in establishing charging stations, as well as costly initial investment and long wait times, are impeding EV adoption in China.

Mukherjee et al., 2020 [33] results show that the distance to charging points is a significant and positive factor in determining BEV ownership, underlining the fact that people who can charge at home are more likely to own a BEV. Adoption is also lower for rental accommodation, as the investment in the infrastructure for vehicle home charging is less likely to occur.

CONCLUSION

With the depletion of fossil fuels and constant hike in fuel prices, there is a need for energy transition in vehicles in India. Government has taken initiative to fight pollution levels by promoting EVs and giving subsidies on purchase. To boost its production, government has eased the FDI norms. Various emerging brands are launching EVs in India. The Government and manufacturers should join their hands to build the infrastructure and create positive environment for EVs. Though respondents are aware of global climate conditions and are ready to change their preference from conventional to eco-friendly vehicles, cost is an important factor while considering the purchase of EV.

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