Technology and limitation of electrification of transportation

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Abstract. In the modern world, electric vehicles (EVs) are becoming more and more prevalent, and many individuals are beginning to consider getting one for their mobility. In comparison to traditional internal combustion engine vehicles, EVs are more environmental-friendly, have higher energy conversion efficiency and produce lower noise. However, in terms of electrification of transportation, EVs also have some inherent limitations. This paper provides an overview of electrification of transportation. First, this paper will focus on the related technologies such as motor drive technology, power electronic technology and battery management. In addition, the limitations of the electrification of transportation, include range anxiety, long charging time, charging station accessibility and unsatisfactory performances in extreme temperatures, will also be presented. Despite these challenges, EVs still exhibit promises for further development and will play a leading role in transportation electrification. Considering the technological factors will help address the issues and push the future development of EV forward.

Keywords: electric vehicles, power, limitation, electrification.

1. Introduction

In the modern world, electric vehicles (EVs) are becoming more and more prevalent, and many people are beginning to consider getting one for their transportation needs. Actually, EV was also prevalent for about one and a half centuries ago. Thomas Davenport created the first electric vehicle in 1834. In the late 1890s, electric cars outsold gasoline cars 2:1. A company called Pope Manufacturing Company carried out the first large-scale operation in the US automobile industry. An interesting fact is that the first speeding ticket in the world was counted on an electric vehicle in 1903.

For now, there are a large variety of applications of electric transportation in the world. Famous EV company Tesla has produced many generations of their private EVs and Tesla has limited their cars' price to a decent range. For example, buying a Tesla model 3 only costs about $45,000, which is pretty acceptable. With the super charge technology from Tesla, to fully charge a battery pack will only take for around 15 min which is much better than home charger [1]. For example, as a more ecologically responsible alternative to flying, many countries are investing in high-speed rail systems. For instance, China now boasts the largest high-speed rail network in the world, and there are also major high-speed rail networks in Japan, France, and Spain. In comparison to airplanes, these railways use electric power, are more energy-efficient, and produce fewer greenhouse pollutants. Moreover, electric buses are replacing conventional buses in several cities' public transportation networks [2]. Compared to

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conventional diesel buses, these ones are more energy-efficient, quieter, and less polluting. Several cities, like Shenzhen in China, have completely switched over to electric buses from diesel ones.

However, there is still a range of limitations that are related to electric transportation. Most importantly it is the scarcity of source of battery pack: lithium. Although there is a lot of lithium on earth, it is not enough to make the number of batteries that can replace all the internal combustion car in the world. Second, the short driving range of electric cars is one of their main drawbacks [3]. Even while EVs' range has substantially increased recently, it still falls short of that of conventional gasoline-powered cars. For those who have a lot of distance to travel, this could be an issue. Coupled with those advantages and downsides, electric transportation is now a controversial topic.

2. Approaches to achieving electrification

2.1. Motor drive technology

To transform electrical energy into mechanical energy to move the wheels, it is necessary for EVs to have motor drive technology [4]. The 3 fundamental forms of motor drive technologies used in EVs are permanent magnet synchronous motor drives, alternating current (AC) induction motor drives, and direct current (DC) motor drives [4].

Electric vehicles (EVs) typically use permanent magnet synchronous motors (PMSMs) because of their maximum reliability, a high density of power, and high starting torque capacity. PMSMs have a stator with windings which are powered by a three-phase AC current and a rotor with permanent magnets. The rotor's permanent magnets interact with the magnetic field of the stator to produce torque, which rotates the rotor. In terms of the use of PMSMs in EVs, there are a lot of articles available. For instance, a study focused on the ideal PMSM design of an electric car [5]. The 48-slot, 8-pole motor with a skewed rotor design and a high magnetic flux density was determined by the authors to be ideal for the application using finite element analysis. Another researcher focused on the application of PMSMs with dual stators in an EV in another study [6]. The performance of a regular PMSM and a dual-stator PMSM were compared using a simulation model by the authors, who discovered that the dual-stator design increased the motor's efficiency and torque capacity.

Two other motor types that are frequently utilized in electric vehicles are AC induction motors (ACIMs) and DC motors (DCMs). Because of their durability, great reliability, and inexpensive price, ACIMs are widely used. Because of their straightforward design and lack of brushes, they require almost no upkeep. Applications requiring high power and strong torque at slow speeds are a good fit for ACIMs [7]. They are also ideal for regenerative braking, a crucial component of EVs. DCMs, on the other hand, are straightforward to use with variable-speed drives and have a simpler control system [8]. They are suitable for applications that call for precise control of speed and torque because to their linear torque-speed curve. DCMs are excellent for usage in EVs with limited space because they are lightweight and compact.

2.2. Power electronic technology

In order to transmit energy between the battery and the motor efficiently, power electronic technology is essential to the operation of EVs. The electrical power flow in EVs is converted and controlled by power electronics equipment like inverters and DC-DC converters [9].

Due to their excellent efficiency, modern inverters minimize energy losses during power conversion [10]. This is crucial for EVs as it enhances the overall effectiveness of the vehicle. Inverters are able to produce great power output in a small package thanks to their high power density [11]. This is significant for EVs because they have a small interior and need to lose weight to increase performance and economy. Therefore, when specifically focusing on the characteristics of DC-DC converters, due to their excellent efficiency, modern inverters minimize energy losses during power conversion. This is crucial for EVs as it enhances the overall effectiveness of the vehicle. The development of more compact and lightweight inverters has been made possible by developments in semiconductor and power electronics technology. This lessens the weight of EVs and increases their range, both of which are crucial for EV

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2.3. Battery management

EVs depend heavily on battery management to guarantee the battery system operates safely and effectively. Here are some aspects that EVs benefit from battery management.

Battery monitoring is the first one. Battery management systems (BMSs) monitor the temperature of the battery, state of charge (SOC), and state of health (SOH) in order to maximize battery performance and ensure its safety [13]. BMSs safeguard the battery from overcharging, overdischarging, and overheating, which can shorten the battery's lifespan and cause irreparable damage [13]. Another one is battery balancing, to ensure that the battery runs at its maximum capacity and to prevent premature aging of the battery, so that each battery cell charge levels are balanced by BMSs [13].

Battery Diagnosis is also an aspect of battery management inside EVs [14]. BMSs diagnose battery defects such as short circuits, open circuits, and damaged cells in real-time and take the necessary steps to save a battery's catastrophic failure. Last but not least, here comes the Predictive Maintenance [15]. To maximize battery performance and lengthen its longevity, BMS employs predictive analytics to forecast the battery's lifespan and plan maintenance tasks like cell or module replacement.

3. Limitations about EVs

3.1. Range anxiety

Compared to gasoline-powered vehicles, EVs have a shorter range, which can cause range anxiety [16]. As mentioned at the beginning of the introduction of this paper, for the cars of about $45,000, EV has about half the range of those car having internal combustion engine. The energy capacity of an EV's battery pack, which is currently constrained by the amount of energy that can be stored in a lithium-ion battery, determines the vehicle's range. Although lithium-ion batteries' energy density has increased consistently over the past few years, it is still less than that of gasoline. To reach the same range as a gasoline-powered vehicle, an EV must have a larger battery pack, which increases weight and lowers efficiency. EVs also consume more energy at greater speeds and when uphilling, thus further reducing the range. An EV's range is further decreased by the use of accessories like air conditioning and heating. This problem is prominent, the limited range of EV will probably be unable to suit consumers' needs. Thus, the limited range of EV will further influence the sale of electric vehicle. Although from a higher price range consumer might find electric cars that are having a much more decent range like for Mercedes's EQS which has a range for about 720 km, but for that price range, there will still be internal combustion car that has a fur more decent range than EQS. The limited range problem is almost inevitable for EVs.

3.2. Charging time

Compared to refueling a gasoline-powered vehicle, EVs require more time to recharge. Even while rapid charging technology is advancing, recharging an EV still takes longer than filling up a gas tank. Take Tesla's model 3 as an example, in a home charging power for about 120 - 240 kilowatts, model 3 requires for about 3 hours to fully charge its battery. Nowadays an alternative technology from Tesla has been produced which is Tesla's supercharging station. With the help of the supercharging station, model 3 can be fully charged in just 15 minutes that is much quicker than before with the home charging. However, the two problems arise. The first one is that to pull gasoline into the tank of an internal combustion car only costs for 2 minutes and it is still much quicker than supercharging. The second is that the distribution of supercharging stations is relatively scarce at least in America. EV Charging Points Around the U.S. Mapped, a recent report claims, the number of electric charging stations is about one third of that of petrol stations in America. It is not practical for people to expect to enjoy fast charging everywhere.

3.3. Charging station accessibility

It can be difficult for drivers to locate a location to recharge their vehicle's battery due to the limited availability of charging infrastructure for EVs in many locations. As previously indicated, there are roughly one third as many electric charging stations as there are petrol stations, according to a recent post about EV Charging Stations during whole U.S. Mapped [17]. Unlike in some other nations, the US government has not made significant financial contributions to the construction of an infrastructure for charging electric vehicles. Because of concerns about profitability, private enterprises have been slower to invest in the development of charging infrastructure as a result. Furthermore, constructing electric vehicle charging stations can be pricey, particularly for fast charging stations that require considerable improvements to the local electrical grid. Some businesses can be discouraged from investing in this infrastructure due to the expense of installation and continuing maintenance of charging stations [18]. In addition, lack of standardization has resulted in a disjointed charging infrastructure in the US, with numerous alternative charging connector types and networks [19]. Due to issues regarding compatibility and interoperability, this may make it difficult for EV owners to locate charging stations and may discourage businesses from investing in charging infrastructure. Last but not least, because electric car adoption is so low in the US, there is less of a need for infrastructure to support charging stations. This, in turn, might deter private businesses from spending money on charging infrastructure. In summary, as it is harder for people to find electric charging stations on roads compared to gas stations, people will not prefer to drive EV to highways where EV would have to be charged frequently. While home charging plan is kind of a compensate for this situation, people are not possible to use home charging tech on highways outside home.

3.4. Unsatisfactory performance in extreme temperatures

EVs may operate less efficiently in extremely hot or extremely cold weather, which can have an impact on the battery's range and overall performance. EVs commonly employ lithium-ion batteries, which are susceptible to temperature fluctuations [20]. Reduced performance and range may result from the battery's inability to produce the same amount of power and energy in cold weather. The battery may degrade more quickly in warmer weather, lowering its overall capacity and longevity. Extreme temperatures may also have an impact on the vehicle's electric motor's efficiency. Due to greater friction and thicker oil in colder temperatures, the motor may be less effective, resulting in a decrease in output power. The engine may become overheated in hot weather and need cooling, which might lower its overall efficiency.

4. Conclusion

Due to their advantages for the environment, electric vehicles are growing in popularity; yet, battery technology still has several drawbacks, especially in very hot or cold climates. The most popular battery technology for EVs today, lithium-ion batteries, have limits in extremely cold temperatures that affect both their performance and safety. However, methods like BTMSs, the use of more durable battery materials, and the creation of novel battery chemistries can lessen these restrictions. There are several other aspects that can be considered to help improve the development of electric vehicles such as battery technology, infrastructure, incentives, education and awareness and collaboration. For electric vehicles to become widely used, battery technology research and development must continue.

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