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RESEARCH ARTICLE

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A Comprehensive Analysis of Electric Vehicles Models and Design Methodologies

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Abstract. Considerable attempts have been undertaken to resolve these issues as environmental harm caused by human activity has come to light. These projects include encouraging the use of bicycles as an alternative to conventional cars and recycling and reusing goods. Concurrently, the automobile sector is leading the way in the creation of pollution-free vehicles. In this paper, the mechanics of electric vehicles (EVs) is examined, as well as their advantages, disadvantages, difficulties, and the current debate about social standardisation. Several factors affect the acceptance of EVs, including their technological underpinnings, their effects on society and the environment. In addition to examining several different battery technologies, this study offers an in-depth comparison of lead-acid and lithium-ion batteries, given how important batteries are to electric cars (EVs). Besides looking at power control and battery energy management techniques, it also discusses the many standards that are presently being established for electric vehicle charging. As EVs advance, the paper examines new technologies that may improve their performance, dependability, and safety.

1.Introduction

According to a study published by the European Union, the transportation industry is responsible for around 28% of global carbon dioxide (CO2) emissions, with transportation on roads accounting for more than 70% of all these emissions [1]. There has also been support from Governments in many industrialised countries that are pushing for the widespread adoption of electric Vehicles (EVs) in an effort to lower the concentration of air pollutants, such as CO2 and other greenhouse gases. The majority of funding for these initiatives comes from a variety of programs, including tax breaks, buy-back programs, and unique policies like free parking in public spaces or toll-free access to highways for electric vehicles [1].

EVs provide a real solution for the future of transportation and propose a replacement for internal composition engine vehicles. Provide numerous advantages with the most highlighted being their ability to lessen air pollution with having no emissions at all;

they don't release carbon dioxide (CO2) or nitrogen dioxide (NO2). Although first hand EVs are more pricey, in the long run maintenance costs are reduced due to having fewer engine components and having a similar design. Because the engines are smaller and simpler, they don't need a clutch, gearbox, or noise-cancelling components [11].

EVs offer a number of benefits, but they also have a number of disadvantages. The limited range for driving, which typically varies from 200 to 350 kilometres when fully charged, is a major cause for worry. However, there is constant work being done to expand this range. One major issue is that it might takes many hours to fully recharge the batteries. Using Tesla's Superchargers, for instance, a Model S can be charged to 50% capacity in about 20 minutes or to 80 percent of its capacity in 30 minutes [1].

In the upcoming decades, electric vehicles (EVs)—along with shared mobility, public transportation, etc.—will play a significant role in the development of smart cities. Therefore, understanding EVs functionalities, economic impact, benefits and drawbacks is essential to maximising their incorporation into establishing policies and urban planning. Such insight will assist in making it possible for EVs to successfully support sustainable development objectives, enhance air quality, and lessen the overall environmental impact of smart city transportation networks.

This review research will cover EVs in great detail, giving readers a technical foundation to help them understand the history and operation of EVs. Comparing and contrasting them with internal combustion engine cars to have a deeper comprehension of their features and advantages. Issues with infrastructure and accessibility that impede the adoption of EVs will also be discussed. Given the importance of batteries in electric vehicles (EVs), this study offers a thorough analysis of various battery technologies. Along with the suggested techniques for power regulation and battery energy management, this research additionally looks at multiple specifications that are applicable for the EV charging process [10].

A key part of sustainable transportation is advancing through the use of electric vehicles (EVs), particularly in smart cities. Through a thorough examination of EV technology, including battery systems, charging standards, and power management, the paper offers an in-depth comparison with internal combustion engines. It highlights the revolutionary potential of EVs to reduce air pollution and contribute to global sustainability while discussing the economic, environmental, and infrastructure difficulties and advantages of EV adoption. Since batteries are essential to the functionality and viability of EVs, more research and funding are required. This thorough research aims to give policymakers and urban planners important insights into how EVs will be integrated into transportation networks in the future [1].

2.Technical Background

2.1 History of Electric Vehicles

The history of hybrid automobiles goes much beyond the modern world of companies like Tesla Motors or even the General Motors EV1 popularity of the late 1990s. Developing road-worthy and economically viable electric vehicles is a steady endeavour among enthusiasts, whose genesis predates their internal-combustion counterparts. Understanding the historical background in an in-depth manner is essential to understanding the process that led to the current situation. This retrospective journey encourages investigation as it shows the development that gave rise to contemporary society. In the last 150 years, transportation innovation and expertise have seen a remarkable transformation in society. The story begins with Nicholas Joseph Cugnot's Damp Wagen, a steam-powered tricycle that he created in the latter half of the 18th century and is widely acknowledged as the first vehicle in history [4]. The "first" electric car did not appear until 1884, according to British inventor Thomas Parker. This invention, although ground breaking, was hampered by its short range, illustrating the difficulties associated with early electric transportation [10]. The idea of the "first" in this context is surrounded by quotation marks because of the complicated historical tapestry that makes attribution difficult to determine [4].

A crucial step forward was made in 1859 when French scientist Gaston Planté popularised lead-acid batteries. As a result of this breakthrough, electric vehicles were able to advance further, resulting in revolutionary changes in the field. A series of incremental improvements resulting from the collaborative efforts of a number of scientists and engineers. At a pivotal point in time, chemist Pedro G. Salom and Henry G. Morris coordinated the building of the first working electric car in 1894, which was accomplished in Philadelphia, Pennsylvania [10].

2.2 How Electric Vehicles Work

Any vehicle that receives all or a portion of its power from the electric grid is referred to as an "electric car," occasionally referred to as an electric vehicle (EV). All-electric cars (AEVs), which run only on electricity, and plug-in hybrid electric vehicles (PHEVs), which combine plug-in charging with gasoline derived from petroleum, are the two main types of electric vehicles. Regenerative braking is another feature of electric vehicles (EVs) that preserves part of the energy wasted while stopping a traditional gas-powered vehicle and turns it into electrical power. This technique increases the amount of time that the car may be charged, especially in urban driving situations when stopping frequently is necessary [11].

The engine of an electric vehicle (EV) is propelled by a large battery pack that powers the vehicle's motor. This battery is refilled by activating a special charging device or plug that is located in the user's home. Electric cars may appear on the outside to be similar to conventional gasoline-powered automobiles, but they are fundamentally quite different. One unique aspect of the world of electric vehicles is the function of fuel cells. These complex systems coordinate the production of electricity, acting as the motor for electric cars. Moreover, fuel cells' efficiency much outperforms modern techniques, resulting in a roughly 75% increase in efficiency. Fuel cells work by combining oxygen and hydrogen to create water, then using this changed water to produce electricity [10]. This dynamic is similar to how rechargeable batteries work, in which the possibility of recharging is guaranteed by a constant intake of hydrogen and oxygen. Electric motors power electric cars, which stands in stark contrast to traditional automobiles that run on gasoline. These electric motors are powered by a controller that communicates with a group of rechargeable batteries, or fuel cells, in technical terms. Electric automobiles use an electric motor that is controlled by a controller that communicates with a group of rechargeable fuel cells, as opposed to the combustion-driven mechanism of gasoline engines.

3. Electric Engine vs. Internal Combustion Engine

3.1 Environmental

Discussions on the possible benefits of electric cars for the environment and society as a whole are common in the field of ecological science. When comparing the internal combustion engine to its electric equivalent, the energy yield is where the key difference appears. To be more precise, the internal combustion engine produces more energy per unit of fuel density. In addition, refuelling an internal combustion engine takes a lot less time than refuelling an electric engine. A typical gas station will just require you to refill for about five minutes. Comparing electric vehicles to traditional internal combustion engine vehicles reveals a number of benefits. First off, electric vehicles (EVs) have no emissions at all; they don't release carbon dioxide (CO_2) or nitrogen dioxide (NO_2) [9]. Although the construction of batteries does increase the carbon footprint, overall, the manufacturing procedures for EVs are more environmentally benign. Second, because EVs have fewer engine components and a simpler design overall, maintenance costs are reduced. The engines are simpler and more compact, meaning they don't require a clutch, gearbox, cooling system, or noise-cancelling parts [11].

Despite these apparent benefits, it is also necessary to recognize the intrinsic limits that the internal combustion engine bears. One significant downside is the creation of toxic pollutants, particularly carbon dioxide, which is exceedingly detrimental to the environment. Furthermore, the operating dynamics of internal combustion engines are less efficient than those of electric motors, needing more energy for vehicle propulsion. Electric vehicles (EVs) have several advantages, but their power source architecture poses a number of major challenges. One major concern is the short driving range, which normally ranges between 200 and 350 km on a full charge. However, improvements are always being made to broaden this range. For example, the Nissan Leaf has a potential range of 364 kilometres, but the Tesla Model S can travel over 500 km [10].

In addition, due to the pollutants produced during the extraction, refinement, and distribution of fuel, internal combustion engines have a substantial negative impact on the environment during their entire lifecycle. Due to the development of renewable energy sources, electric vehicles can further reduce their overall carbon footprint when the power they require to charge comes from clean energy. Additionally, internal combustion engines emit more noise than electric cars, reducing urban noise pollution and improving the quality of life in densely populated areas compared to electric cars [9].

3.2. Economical

Internal combustion engine automobiles already dominate the market; thus their costs are much more affordable to the typical customer. While discussing the benefits of EVs, it is essential to highlight one of their main drawbacks: their relatively expensive cost. The necessity for society to adopt electric vehicles requires contemplation, but the cost narrative offers a different picture. The financial aspect of buying electric cars presents significant differences. Even with their fluctuating purchasing cost, they typically outperform automobiles that run on gasoline. However, compared to traditional gas-powered automobiles, electric vehicles admirably offset this higher initial price with reduced maintenance costs. An approximate $6,000 difference in maintenance costs between standard gasoline automobiles and electric vehicles is found in a six-year comparison [9].

Due to the high cost of batteries, electric vehicles have a significantly higher initial purchase price than conventional vehicles. Because electric vehicles (EVs) do not require fuel, they can save consumers considerable amounts of money over the long term. In September 2023, the average price of a new electric vehicle was $14,300 less than it was in September 2022, according to Cox Automotive statistics. This came to a mere $2,800 more expensive than the typical price for a brand-new gas-powered car. Considering how rapidly the EV industry is growing, the price margin is expected to decrease even further in the upcoming years as manufacturers create more accessible models and advance battery technology [7].

The affordability of having an electric car may be further improved by adding an EV charger to your house. About 32 miles of additional range may be added by charging overnight from a typical 120-volt outlet, which is sufficient for everyday driving needs. By using electricity, you may cut down on costly gas station trips and associated operating costs. According to 2018 research by the Transportation Research Institute at the University of Michigan, the median yearly price of fuelling an electric car was $485 as opposed to $1,117 for a gas-powered vehicle. In a comparable manner, 2020 Consumer Reports research revealed that EV owners spend around 60% less annually on gasoline than owners of gas-powered vehicles. Based on real-world statistics gathered by the U.S. Department of Energy (DOE), these savings can be attributed in large part to the fact that existing EVs are 2.6 to 4.8 times more efficient at driving a mile than gasoline internal combustion engines [2].

It's crucial to remember that these savings estimates might change depending on a number of variables. When comparing EVs, one may determine their efficiency by looking at how many kWh (kilowatt-hours) they use for every 100 miles. For instance, the more affordable 2023 Chevrolet Bolt EUV gets an efficiency rating of 29 kWh/100 miles, whilst the 2023 Hyundai Ioniq 6 claims an efficiency of 24 kWh/100 miles. The cost of charging might also differ greatly depending on the area and time of day. It is possible to cut expenses by taking advantage of the lower charge rates that many electric providers provide during off-peak hours. Public charging stations provide quicker, higher voltage charging alternatives than home charging, although being more costly. Fuel prices might go up if you only use these stations. Furthermore, even though they don't need complicated gearboxes, spark plugs, or oil changes to maintain, electric cars still need some routine upkeep like tire rotations and service checks. Regenerative braking, an exclusive characteristic of electric vehicles, also lessens the need for brake pad repairs. Long-term economic benefits of electric vehicles are mostly due to their lower maintenance and repair costs as compared to gas-powered automobiles.[10].

3.3 Social Impact

- Advantages

As the main topic of this paper, electric vehicles are chosen due to their inherent ability to improve people's quality of life. The increasing popularity of electric vehicles will lead to a paradigm shift in transportation that will attempt to create a better environment for human habitation, despite the dominance of gasoline-powered cars. The growing public awareness of climate change, sparked by greenhouse gas emissions, highlights the need for change. In terms of environmental improvement, electric cars represent a critical step forward.[11].

Since electric cars function on rechargeable power sources instead of gasoline, they are independent of the damaging pollutants that are frequently emitted from the rear of the car and add to pollution. The dominant societal norms around fuel-powered vehicles can be attributed to the longer-term growth trajectory of electric automobiles. As such, it took an extensive amount of time and effort to coordinate the development of an efficient, economically viable electric vehicle.[7].

- Disadvantages

Electric cars have specific drawbacks even while they contribute to making the environment much more secure, healthier, and less polluted generally. Electric cars have several risks due to their battery-powered operation, including the possibility of electric shock accidents, extremely high temperatures, and the possibility that the electromagnetic waves they emit might aggravate pre-existing health issues such as cancer. When evaluating electric vehicle technology, these factors must be carefully considered. The time needed to completely recharge the batteries—which can take four to eight hours—presents another difficulty. The procedure can take up to 30 minutes, even with rapid charging technologies that are capable of charging the battery to 80% capacity. [9].

4. Challenges

4.1.Accessibility

Electric cars have the capacity to fundamentally alter the transportation sector by significantly lowering carbon emissions and paving the way for significant environmental advancements. Manufacturers of electric vehicles have a challenge that goes beyond cost: convincing prospective customers. Not everyone agrees that electric vehicles fit well with personal lifestyles; this is partly because of the range of unanswered questions.

The main concern underlying these worries is the question of how far an electric car can travel before its battery runs out. The problem lies in the fact that recharging an electric car takes longer than it does for a gasoline-powered vehicle, even while running out of fuel may be easily resolved with a quick trip to the gas station. Most of the electric cars that are now on the market can travel around 100 miles on a single charge, which takes about eight hours if a dedicated charging station is had.[9].

The availability of charging infrastructure is another important aspect that should be taken into account. This component is crucial in reducing customer concerns about electric automobiles. Although there is no denying the importance of electric cars in reducing their environmental effect, a diverse strategy is required to achieve their broad acceptance. Most importantly, this means that manufacturers must promote more customer inclusiveness while the government makes investments to provide dependable and easily accessible charging stations that can encourage the use of electric vehicles.[6]. Prospective owners of electric cars would benefit from spending time investigating the economic feasibility of electric vehicles as an option in both the short- and long-term settings as they navigate this rapidly changing terrain [11].

4.2 Infrastructure

The growth of electric vehicles (EVs) will surely have a transformational effect on global infrastructure. Specifically, this change would need the construction of an expanded global network of charging stations, which would act as a vital conduit to provide improved accessibility for owners of electric vehicles who wish to recharge their vehicles. The financial driving force behind the implementation of this extensive charging network would probably come from public funds, and businesses would also have to bear the responsibility of supplying the necessary energy supply to these expanding charging networks [9].

The current model change has a lot to offer electric car producers, who should take advantage of it to improve the functionality of their electric vehicle products. It is expected that technological developments will propel the development of electric vehicles, improving their environmental compliance, battery capacity, and operating efficiency. Manufacturers may create cutting-edge solutions that further lower the carbon footprint of EVs and increase their environmental friendliness by investing in research and development [6].

5.Electric Vehicle Batteries

5.1.EV Batteries Technology

Since traction batteries are what power an EV's propulsion system, advancements in traction battery technology have a significant influence on the EV market. An EV was equipped with a rechargeable lead-acid battery once it was discovered. A growing variety of power battery types have entered the market as a result of advancements in battery technology. The specifications for the traction battery have not changed all that much in spite of advancements in battery technology. EV batteries require constant electricity, unlike batteries used for lights, ignition, and starting. A greater energy capacity is therefore crucial. High energy density, high specific power, and high specific energy are also essential. Nickel-metal hydride, lithium-ion, and lead-acid batteries are currently the three primary kinds of rechargeable batteries used in electric vehicles (EVs) [9].

5.1.1.Lead-Acid Batteries

Gaston Planté, a French scientist, created the rechargeable lead-acid battery in 1860. There are two plates in this battery: a lead metal negative plate and a lead dioxide positive plate. These plates are submerged in a diluted sulfuric acid electrolyte solution. The way lead-acid batteries work is that electrical energy is stored and can be transformed into chemical energy [1]. The most common type of rechargeable battery is still the lead-acid battery, which was invented first. Flooded lead-acid batteries were previously the most often used power source since they were among the most affordable batteries available. Deep cycle batteries and engine starting batteries are the two categories under which these batteries fall. Engine starter batteries are recharged by the car's alternator and offer a brief but powerful surge current when an engine is started. Deep cycle batteries, on the other hand, are utilised in electric vehicles like golf carts and forklifts and are intended to be frequently thoroughly depleted [11].

The valve-regulated lead-acid (VRLA) battery is an additional variety of lead-acid battery that has a pressure-regulating valve [1]. VRLA batteries, often known as maintenance-free batteries, don't need to have their electrolyte content checked on a regular basis. Lead-acid batteries are used in some electric cars because of their low cost, great availability, and excellent dependability. Because lead is extremely harmful to human health, the main concern with lead-acid batteries in the past has been how they affect the environment throughout production, use, disposal, and recycling. Nonetheless, lead-based battery collection and recovery rates have exceeded 99% in several places, including the US and the EU, which is an exceptionally high percentage when compared to other goods. 95% to 99% of spent lead-acid batteries are recycled in the majority of affluent nations [11].

Lead-acid batteries are not widely employed in electric cars despite these developments because of their lower specific power and energy density. Batteries made with lead acid store less energy per unit mass or volume than lithium-ion batteries. For electric cars, the mass and volume of the batteries are essential since smaller or lighter batteries enable longer travel lengths before requiring recharging. At the moment, low-speed electric cars are the main users of lead-acid batteries [1].

5.1.2.Nickel-Metal Hydride Batteries

A nickel-metal hydride battery (NiMH) contains nickel hydroxide in its positive electrode, a variety of materials in its negative electrode, and potassium hydroxide as its electrolyte. The diversity of negative electrode materials has led to the development of nickel-iron batteries (Ni-Fe), nickel-cadmium batteries (Ni-Cd), nickel-zinc batteries (Ni-Zn), nickel-hydrogen batteries (Ni-H2). Since the 1990s, Ni-MH batteries have become the preferred choice for electric vehicles (EVs) [11].

There is a significant difference between a Ni-MH battery and a lead-acid battery in terms of specific energy and energy density [11]. There are, however, a few drawbacks to Ni-MH batteries, including poorer charging efficiency compared to other types of batteries and a greater rate of self-discharge under hot conditions. Recent years have seen a stagnation in the use of NiMH batteries in EVs due to patent encumbrance. In heavy-duty vehicles, patent encumbrance refers to the obstacles to commercialization of Ni-MH battery technology caused by the patent system, which is designed to protect business interests. Potentially, Ni-MH batteries could be important for EVs, which may explain the obstacle [1]. Other people consider it to be a result of the technology's inability to compete with other batteries, such as lithium batteries [11].

5.1.3.Lithium-ion Batteries

In 1991, Sony Company introduced lithium-ion batteries for energy storage and movable electric products to the market. They offer a high-power storage capacity while being tiny and lightweight. Furthermore, because lithium-ion batteries offer excellent energy efficiency, a low memory effect, a long cycle life, and a high-power density, they are currently the most competitive energy storage solution for EVs [11]. As a result, lithium-ion batteries now account for the majority of commercialised automobile batteries.

Lithium-ion batteries are utilised in charging EVs such as the BMW i3, Tesla, Nissan Leaf, BYD, and others. Lithium cobalt oxide (LiCoO2) batteries, lithium manganese oxide (LiMn2O4) batteries, lithium iron phosphate (LiFePO4) batteries, lithium nickel-manganese-cobalt oxide (LiNiMnCoO2 or NMC) batteries, lithium nickel-aluminium-cobalt oxide (LiNiCoAlO2 or NCA) batteries, and lithium titanate (Li4Ti5O12) batteries are among the various materials utilised for positive electrode lithium-ion batteries [1].

In contrast to other lithium-ion batteries, LiFePO4 batteries are thought to offer a high discharge current at a relatively cheap cost. They are also commonly used in EVs and have strong chemical and thermal stability. NMC and NCA are the other batteries that auto manufacturers have effectively embraced. One of the top competitors for automotive applications is NMC. Tesla has used NCA technology, which is anticipated to become much more prevalent [1].

6. Conclusion

To conclude, the utilisation of EVs into the modern transportation systems represents a crucial step towards achieving a sustainable and environmentally friendly future. In addition to having the ability to save the planet from the forthcoming disasters brought on by global warming, electric vehicles (EVs) have enormous capacity to become the means of transport of the next generation. They are a viable alternative to conventional cars, which are solely dependent on finite fossil fuel supplies. Although they are initially expensive, EVs reduce hazardous pollutants and are later regarded as cost-effective due to their cheap fuel and maintenance expenses. Even though there are still certain challenges, such as limited charging infrastructure, longer charging periods, and higher initial costs, EVs are expected to play a significant role in urban mobility in the future. Electric cars will play a significant role in the long-term development of more environmentally friendly, quieter, and more efficient smart cities [11].

Additionally, it is critical to keep funding research and development, especially in the areas of battery performance and recharging technologies. With regard to the progress of battery technology, which is essential to the adoption of electric cars (EVs), it is anticipated that EVs will constitute an even more appealing alternative to conventional automobiles. Electric cars now come with a wider range of battery types in addition to traditional lead-acid batteries. Batteries for electric vehicles (EVs) have a higher power density, better specific energy, and less environmental impact. These batteries come in Zebra, nickel-metal hydride, and lithium-ion varieties. Right now, lithium-ion batteries are the most widely used kind. Supercapacitors and metal-air batteries are still being researched, but someday all EVs could utilise them.

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