Review

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A Comprehensive Review for Electric Vehicles Drive Circuits Technology, Operations and Challenges

Mlungisi Ntombela * , Kabeya Musasa , Katleho Moloi

Posted Date: 29 June 2023

doi: 10.20944/preprints202306.2040.v1

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A Comprehensive Review for Electric Vehicles Drive Circuits Technology, Operations and Challenges

Mlungisi Ntombela *, Kabeya Musasa and Katleho Moloi

Department of Electrical Power Engineering, Faculty of Engineering and the Built Environment, Durban University of Technology, Durban 4000, South Africa; MusasaK@dut.ac.za (K.M.); katlehom@dut.ac.za (M.K.)

* Correspondence: 21210920@dut4life.ac.za

Abstract: The transportation sector is seeing an increased adoption rate of electric vehicles (EV), which comprise battery electric vehicles (BEV), hybrid electric vehicles (HEV) and plug-in hybrid electric vehicles (PHEV). This mode of transportation is likely to displace automobiles powered by internal combustion engines (ICE) in the nearest future, as indicated by the current trend. Each of the key EC components is home to a variety of technologies that are either currently in use or will be in the near future. Electric vehicles have the potential to have a significant impact on a variety of fields, including the economy, the energy infrastructure, and the natural environment. As a result of the production of carbon dioxide gas from the combustion of fossil fuels, transportation is the sector that is responsible for the second-highest amount of greenhouse gas emissions. Electric vehicles, often known as EVs, are getting a lot of attention as a potentially game-changing solution to this issue. It is possible for electric vehicles to produce fewer emissions of carbon dioxide (CO_2) than conventional automobiles due to the fact that an electric motor serves as the vehicle's propeller rather than an internal combustion engine. EVs have the potential to become zero-emission vehicles if they are paired with renewable energy sources. This document presents an overview of the numerous types of EV drive circuits, covering their design as well as the benefits and drawbacks associated with each type. The current state of battery technology, particularly that pertaining to the batteries utilized in electronic vehicles, is discussed in this paper. This article also discusses electric motor efficiency, power density, fault tolerance, dependability, cost, and the best electric motor for EVs. Then, a thorough study of future EV implementation's obstacles and prospects is done. Charging times and battery performance are examples of technological challenges, but government regulation of EVs continues to be a substantial non-technical hurdle.

Keywords: Electric Vehicles; Electric Motors; Batteries; Internal Combustion Engine; Motor Speed

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1. Introduction

The transportation industry is seeing a rise in interest in EVs, which includes battery electric vehicles (BEV), hybrid electric vehicles (HEV), plug-in hybrid electric cars (PHEV), and fuel cell electric cars (FCEV). The current trend suggests that this mode of transportation will eventually displace automobiles powered by internal combustion engines (ICE), and this could happen rather soon. Each of the essential components of EC makes use of a range of technologies, and in the not-too-distant future, they will continue to do so [1,2]. EVs might significantly impact the environment and other businesses like the electrical system. Transportation emits the second-most greenhouse gases after agriculture because fossil fuels release carbon dioxide. Many people believe that electric vehicles, sometimes known as EVs, are an excellent solution to this problem [3]. Electric vehicles have the potential to produce fewer emissions of carbon dioxide due to the fact that, rather than having an internal combustion engine, an electric motor serves as the vehicle's propeller. EVs when combined with alternative forms of energy, have the potential to become emission-free automobiles. This article offers a summary of the numerous varieties of electric vehicle drive circuits, including the design of each type as well as the benefits and drawbacks associated with each [4]. In addition, information regarding the effectiveness, power density, fault tolerance, dependability, and cost of electric motors, as well as the electric motor that is the most effective when used to EV s, is provided. An in-depth discussion on future EV deployment obstacles and rewards follows. Charging time and battery performance are technological hurdles, but government regulation remains a major non-technical obstacle for EVs [5–7].

As a result of the widespread use of EVs, a number of studies have looked into the many types of EVs. Researchers Braun et al. examined the efficiency of electric vehicles by contrasting a battery electric vehicle (BEV) with an internal combustion engine (ICE) passenger vehicle and driving them under a variety of scenarios [8,9]. At Erfurt Germany researchers analyzed how different driving styles, as well as rush hour traffic, affect energy use [10]. Based on the findings, it was determined that the BEV is 69.2 percent more fuel efficient than conventional autos. This significant advantage is the result of the components of the BEV's powertrain that are only activated when traction is necessary to be provided. They convert the kinetic energy created while braking into electrical energy, which is then used to charge the batteries regenerative braking [11,12]. As a result of these characteristics, the BEV is able to capitalize on the varying speeds of the vehicle.

After the development of the electric motor itself came the idea of employing electric motors to power the propulsion of vehicles. Throughout the years 1897 to 1900, EVs were more popular than cars powered by internal combustion engines (ICEs) and made up 28 percent of all automobiles [13]. After that, however, internal combustion engine (ICE) types gained speed, and with exceptionally cheap oil prices, they soon won the market, quickly becoming much more mature and advanced, while EVs sank into oblivion. A glimmer of hope was provided by the EV1 prototype, which was initially released by General Motors in 1996 and almost instantly became incredibly popular [14]. Electric vehicles have also been produced by a number of other major automakers, including Ford, Toyota, and Honda, amongst others. The Toyota Prius was the world's first mass-produced hybrid electric vehicle (HEV), and it made its debut in the Japanese market in 1997 [15–18]. In its first year of production, 18,000 of these cars were sold. Nearly none of these EVs are manufactured or sold today, with the notable exception of the Toyota Prius, which is still in production albeit in an improved form. At the moment, the Nissan Leaf, the Chevrolet Volt, and the Tesla Model S are the most successful vehicles on the market.

This research investigates the most current developments in electric vehicle technology, focusing on such topics as the vehicles' capabilities, the energy sources they draw from, and the prospects for EVs in the years to come. Because the technologies that are associated with electric vehicles and their energy system (production, storage, and use) are always developing, this study investigates the most recent electric vehicle technologies, including those that are connected to autonomous driving and battery storage [19]:

- The first part of this article covers electric vehicle batteries and motors. Moreover, information regarding electric vehicle kinds, battery capacities, and motor drives can be found in this area. A complete analysis of battery technology from lead-acid to LIB is also provided [20]. This section discusses battery technologies, especially electric car batteries. The most prevalent electric motors in EVs and vehicles are presented. EV owners can use this information to select a motor that best suits their needs in terms of energy economy, power density, speed, dependability, size, and cost.
- The second section, which investigates the different configurations of electric vehicles, offers a summary of the numerous categories of electric vehicles, including BEVs, HEVs, and PHEVs. They incorporate the technology as well as the framework of electric automobiles [21].
- The third section makes projections about the future of transportation and discusses the challenges that will be faced by electric vehicles. These challenges include the need for improvements in battery performance, charging times, law and regulation, and an open market for power. By doing so, it is anticipated that updated EV technology will be made available. These challenges are necessary for obtaining a new point of view on EVs and the growing movement towards the future [22].

2. Batteries and Electric Motors

2.1. Battery Engineering

The battery is the primary source of energy for electric vehicles, other sources of energy include the energy produced by regenerative braking, the energy produced by fuels, and the energy produced by various power storages such as a super capacitor [23,24]. The battery features a versatile architecture that allows it to be assembled in either series, parallel, or series-parallel configurations, depending on the required amount of voltage and current. In addition, the battery incorporates the three standard forms of electric vehicle cells, which are cylindrical, pouch, and prismatic cells. While shopping for battery-powered equipment, be sure to give equal consideration to the product's expected lifespan, power density, energy density, capacity, and state-of-charge (SOC). The most potent power sources for EVs are rechargeable batteries like lithium-ion [25]. The lithium-ion battery (LIB) was invented in 1970, the lead-acid battery in 1858, and the nickel-iron alkaline battery in 1908. Compared to the other two batteries, the LIB had a higher specific energy and energy density. Rechargeable batteries were developed as a result.

Lead-acid batteries have a specific gravimetric energy density of 30–50 Wh/kg, making them the least efficient. The lifespan of a lead-acid battery is 500–1000 cycles [26,27]. To go two hundred kilometers, a lead-acid battery that weighs at least five hundred kilo-grams is needed to generate one kilo-watt-hour (kWh) of electricity. Lead-acid batteries are inexpensive (varying from $300 to $600 per kilowatt-hour) and recyclable, which is one of the most significant aspects of any battery technology. Low-performance, tiny cars can use lead-acid batteries. Since their invention, lead-acid batteries have been recycled. As usual. This battery's recycling rate is close to 100% in Western countries and elsewhere [28]. Lead-acid batteries use 85% of the world's lead, and 60% of it is recycled. Lead-acid batteries are easily damaged; thus their components can fall out of their plastic containers with their acid. Ni-MH batteries outperform lead-acid batteries. This battery has a gravimetric energy density between 40 and 110 Wh/kg, far higher than lead-acid batteries. In the early 1990s, Ni-MH batteries were widely used in EVs (Prius) due to their environmental friendliness. The main drawbacks of this battery technology are its poor cold performance and memory effects. Another issue is the battery's long recharge time and high self-discharge rate when idle. The battery's poor charge and discharge efficiency is the biggest issue [29–31].

Ni-Cd batteries need high charge and discharge rates and are memory-prone. The substance is toxic and possesses 60–80 Wh/kg specific energy density. Recharging nickel-hydrogen (Ni-H) batteries was studied by Chen and colleagues. It was difficult to develop a low-cost grid storage material with a longer battery cycle and calendar lifespan. Material needs more cycles. This paper proposed a 10,000-cycle manga-nese-hydrogen battery for grid energy storage. Mn2+/MnO2 redox cathodes and H+/H2 gas anodes comprise the battery [32,33]. The battery's areal capacity loading was projected to improve tenfold to 35 mAh/cm2 by replacing the Mn2+/MnO2 redox with a nickel-based cathode. In place of an expensive platinum catalyst, a less expensive nickel-molybdenum-cobalt alloy was used to catalyze the evolution of hydrogen into oxygen in alkaline electrolytes for the anode. The Ni-H battery is recommended since it has a gravimetric energy density of 140 Wh/kg and can be recharged more than 1500 times. Both specifications are included in the following Table 1 [34,].

The sodium-nickel chloride (Na-NiCL2) batteries, also known as the Zero Emissions Batteries Research Activity (ZEBRA) batteries, are regarded as safe and inexpensive. Additionally, they are able to have nearly all of their capacity depleted without having a negative impact on the amount of time they will last. In addition, the energy that is contained within the battery. a value that is around 150 Wh/kg. Because a ZEBRA battery may operate at temperatures ranging from 245 to 350 degrees Celsius, the thermal management and safety challenges associated with this battery are under a significant amount of strain [35]. As a storage source, ZEBRA batteries are a good example. Due to the cell's chemical reactions' intrinsic safety, multiple tests, including immersion in 900 liters of saltwater with a 5% salt content, seismic and vibratory testing, and a 30-minute external fire expo-sure test that did not harm the modules or cells, showed that fire risk is low. So, it's suitable for stationary energy storage. This technique is good for load leveling, voltage management, time shifting, and renewable energy power swing reduction due to its three-hour rate discharge length [36].

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The latest battery technology is lithium. Its energy, light weight, low cost, non-toxicity, and rapid charging make them the most promising batteries. These batteries have a gravimetric energy density ranging from 118 to 250 Wh/kg; however, their specific energy capacity is now being improved so that it can be increased even further [37]. Anode electrodes in lithium-ion batteries are typically made of silicon nanoparticles (SiNPs) due to the high energy density of this material. Lithium batteries have the lowest equivalent mass and maximum electrochemical potential. It's also efficient and durable. However, it costs over 700 USD per kWh and can cause fires and property damage if overheated [38]. Mass transport constraints in the electrolyte and electrodes will cause severe polarization in lithium batteries with improved performance. Polarization is affected differently by each activity due to the dynamic and kinetic properties of the material, as well as the design of the battery and the mechanism for charging and discharging it. To reduce solid phase diffusion polarization, Chen and colleagues reduced the active material's particles. If half of the active material particles were present, LIB concentration may be significantly reduced [39]. When the active material particles were twice as large, the Li-ion concentration difference was much greater.

Several lithium-ion batteries (LIBs) have been made worldwide. LTO, LCO, LMO, NMC, and LFP are some of them (LFP). LIBs employ a different electrolyte than lithium-polymer batteries (Li-Po). The LIB, in contrast to the LB, possesses a higher energy density, a cheaper cost, and does not have a memory effect. LIBs are cheaper and memory-free [40–42]. In contrast, the Li-Po battery features a structure that is both flexible and adaptable, as well as a low profile and a reduced chance of electrolyte leakage. Because doing so improves the efficiency of packaging, it is typically cut into multiple different sizes. On the other hand, Li-Po batteries have a lower energy density, a shorter lifespan, and a manufacture cost that is significantly higher than average. The characteristics of electric vehicle batteries that are now in use are outlined in Table 1, which may be found here. Figure 6 also illustrates a correlation between the batteries' specific power and specific energy levels.

Table 1. A comparison of the energy storage capacities of the various batteries found in EVs.

SPECIFICATION	LEAD-ACID BATTERY	NI-MH BATTERY	NA-NICL$_2$ BATTERY	LIBS
Nominal voltage (V)	2.00	1.20	2.40	3.60
Energy efficiency (%)	>80	70	80	>95
Volumetric energy density (Wh/L)	100	180–220	160	200–400
Gravimetric energy density (Wh/kg)	30–50	40–110	150	118–250
Lifecycle	500–1000	<3000	>1200	2000
Cost (USD/kWh)	100.00	853–1700	482–1000	700.00
References	[53–55]	[56,57]	[58–61]	[62–67]

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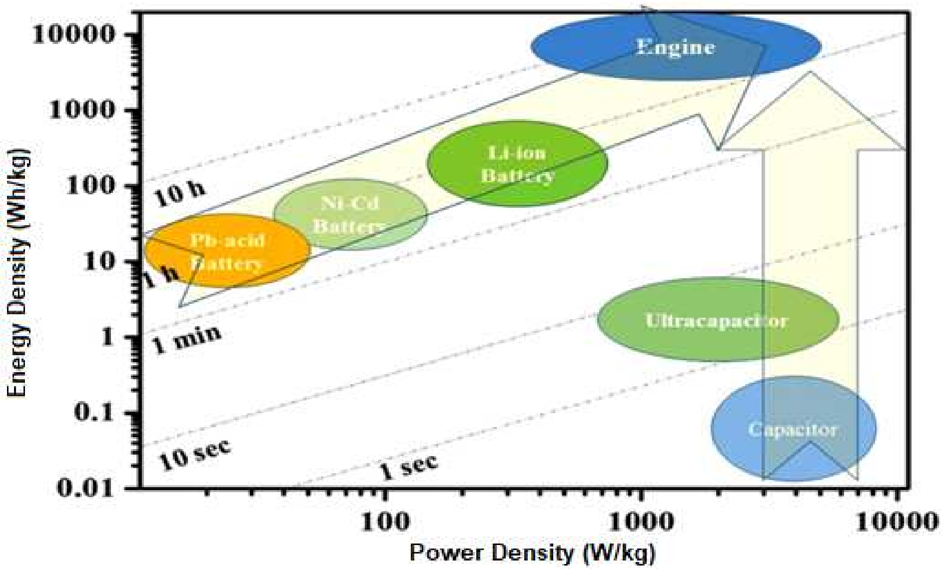

Figure 1. Graphs showing the power output versus the energy output of a given battery storage device [68].

2.2. Electric Motor Engineering

Due to the fact that it is a necessary component, electric motors are impossible to produce without the electric motor. To convert electrical energy from its work form into its mechanical form and vice versa, what is needed is something called an electric motor. The transmission or differential may receive high power and torque from an electric motor, which may subsequently be put to use for the vehicle's propulsion [69]. Because the electric motor in EVs may be able to provide instantaneous power and torque in comparison to the internal combustion engine (ICE), the transmission may not be necessary in EVs [70]. In addition, electric motors have an energy conversion efficiency that is significantly higher than that of internal combustion engines (between 80% and 95% efficient), making them the more desired of the two options. Propulsion in EVs can come from a wide variety of different types of electric motors as follows;

- IM=Induction motor
- PM-SM=Permanent magnet synchronous motor
- PM-BLDC=Permanent magnet-brushless DC motor; and
- SRM=Switching reluctance motor

Because of the high levels of efficiency and power density that they provide, IM and PM-SM motors are regarded as the most appealing possibilities for usage in EVs. This is due to the fact that they are the most common types of motors used in EVs. Electric motors are assessed and compared with regard to their installation space, power density, machine weight, dependability, efficiency, torque-speed relationship, overload capability, and cost before they are used in EVs [71,72].

IM is well-known for its effectiveness, starting torque, power, simplicity, inexpensiveness, roughness, and little amount of required maintenance. IMs can operate in any hazardous environment without speed limits. The IM's complex control system struggles with power density [73]. Iron, copper, commutation, and stray losses in the magnetic circuit, windings, converter, and mechanical components affect this motor's energy efficiency. IM motor losses were examined. In order to determine the effectiveness of an IM motor, they utilized a finite element research to map out the losses. According to the findings of the study, the motor's efficiency map was decided by each loss map. To improve the performance of the IM motor, one researcher advises reducing the spins of the stators by one-half 0.75,2.25, and 3.7 kW IM motors were employed [74,75]. So, the new motor control is more efficient than the previous one, which led to an increase in motor performance. The 0.75 kW motor changed from having a power output of 78% to 85.39%, the 2.25 kW motor went from having an output of 83.23% to having an output of 86.22%, and the 3.7 kW motor went from having an output of 86.25% to having an output of 87.62% [76,76,77].

By utilizing PM-SM, users are able to achieve consistent torque while also achieving high efficiency, high power density, and low energy consumption. By enhancing motor efficiency by 10%, PM-SM ensures reliable performance and electrical balance. PM-SM mechanical packages are smaller than those of previous variants [78]. Since it has no coils or brushes, the PM-SM rotor doesn't generate much heat. PM-highly SM's conductive materials and high-permeability permanent magnets make it ideal for electric and hybrid electric cars. Nevertheless, because it has a permanent magnet, this engine is more expensive to buy initially, and PM material supplies are few and expensive. Moreover, energy loss during PM-to-SM conversion has yet to be solved. Double Fourier integral analysis can quantify fundamental and harmonic losses to construct a unique global loss model of PM-SM, according to a study. To improve electric car performance, this research sought to reduce total energy loss (including fundamental iron loss, fundamental copper loss, harmonic iron loss, and harmonic copper loss) (EVs). 94% efficiency lost the least energy, according to this study [79].

Another form of motor, known as PM-BLDC, is one that is started by rectangular AC and features significant pulsing in its torque output. This motor might be able to deliver the highest torque in the constant-torque area because it keeps the flux angle between the stator and the rotor relatively close to 90 degrees [80]. Maintaining constant power can be accomplished through careful manipulation of the phase-advance angle. High power density, efficiency, and heat dissipation characterize the PM-BLDC motor. This motor's traits are these. The PM-BLDC motor's initial cost is considerable due to the magnet in the rotor, and the device's field-weakening capability is limited by the permanent magnetic field. This method was applied to the two motors that show the most promise for usage in hybrid electric vehicles (HEVs) by means of a sophisticated software application that simulates vehicles (IM and PM-BLDC) [81]. The fuel usage of each motor was 11.8 liters per 100 kilometers; the PMBLDC used 11.7 liters, and the IM used 11.9 liters. In addition, PM-BLDC had fewer overall pollutant emissions than IM did, which came up at 2.68 g/km compared to 2.72 g/km for IM. According to the findings, the PM-BLDC motor is more suitable for application in hybrid EVs than the IM motor is.

The SRM is the newest motor type that can be found in EVs. This arrangement is simpler than the others. It has a rotor (moving part) and a stator (non-moving part), with windings exclusively on the stator. SRM motors are more cost-effective than PM motors since they do not have a permanent magnet [82]. In addition to this, SRM is fault-tolerant, which means that if there is a problem with one phase, it will not influence the functioning of the other phases. SRM is still regarded as a physically robust choice for electric vehicles and hybrid electric vehicles (HEVs) due to its low cost and sturdy design, despite the fact that it needs to overcome concerns such as acoustic noise, torque ripple, converter topology challenges, and electromagnetic interference (EMI). In [83] a study investigated the functionality of SRM 10/8 (SRM 5 phases) drives for EVs when subjected to abnormal conditions such as open- and short-circuit failures. The SRM is designed to be fault resistant and possesses outstanding dynamic reactivity. When evaluating the performance of SRM-powered EVs, speed, torque, and state of charge were taken into consideration. Under normal circumstances, SRM was able to accomplish the reference speed in 1.23 seconds [84]. While the SOC dropped by 0.04% at 1.26 seconds into a 1-phase short circuit scenario, the torque remained the same at 485.3 Nm throughout the whole event. The benefits and drawbacks of the electric motor are summarized in Table 2, and the efficiency maps of the SRM motor, the IM motor, and the PM-SM motor are shown in Figure 7.

Table 2. The electric motors utilized in EVs each have their own set of advantages and disadvantages.

PARAMETERS	IM	PM-SM	PM-BLDC	SRM
Size	+++	+++	+++	+++
Torque ripple	+	+	+	+++++

Efficiency	+++	++++	+++++	++++
Power density	+++	++++	++++	++
Acoustic noise	+	+	+	++
Reliability	++++	+++	+++	++++
Fault-tolerant	++	++	+++	++++
Simple construction	++	++	+++	+++++
Cost	+++	+++++	+++++	++++
Technological maturity	+++++	++++	++++	++++
Opportunity	Automotive market penetration	EVs and HEVs' preferred option	EV drivers' first choice.	Attracting scientists and industry.
Challenge	A novel technology control for minimizing fault tolerance and slide.	Precision torque ripple position feedback	External transmission devices like chain drives and fixed gears are needed.	Non-linear control current switching angle identification
References	[85–87]	[88–90]]	[91,92]]	[93–97]]

Figure 2 shows that every electric motor has a unique best efficiency area for both the driving and braking cycles. A study analyzed the different types of electric vehicle (EV) motors and drives in terms of their effectiveness, maximum speed, relative cost, and level of dependability (IM, PM-BLDC, PM-SM, SRM). The PM-BLDC motor was the most efficient type of motor, while the SRM motor had the highest possible speed Figure 3 [100]. Nonetheless, the brushless DC motor and the induction motor were the types of motors that were used the most frequently, and the induction motor was the type of motor that was the type of motor that was the type of motor that was the most cost-effective.

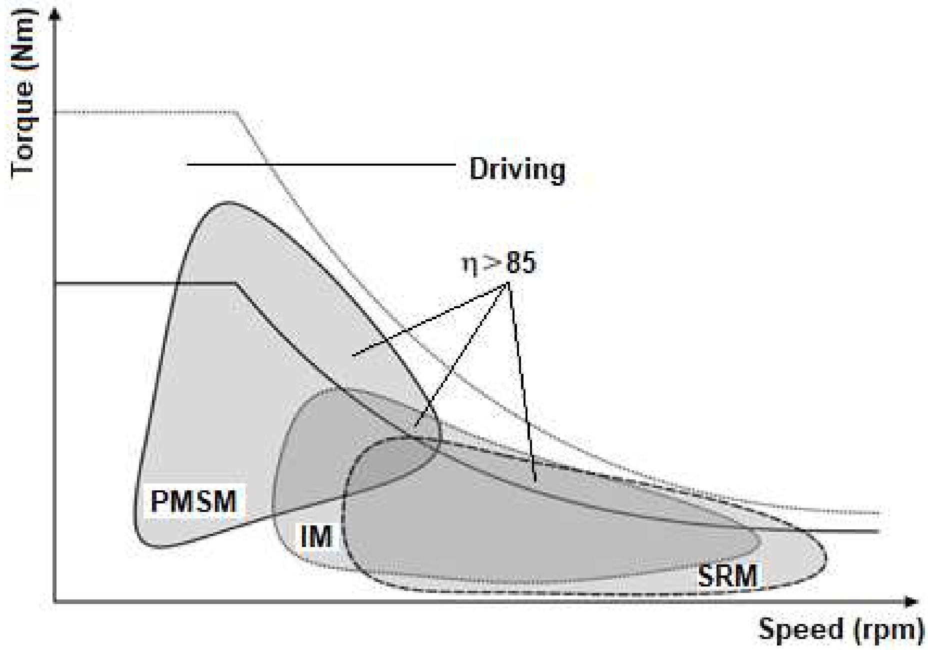

Figure 2. The effectiveness of electric motors and its components [100].

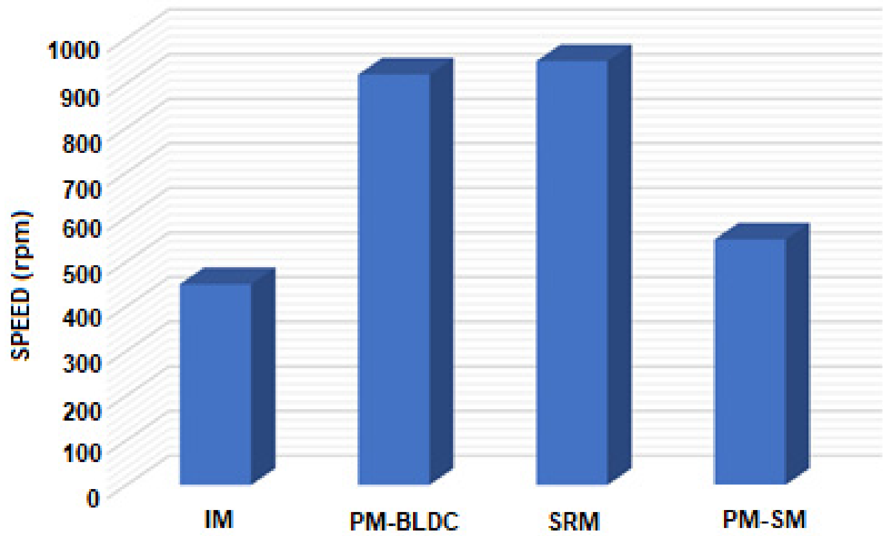

Figure 3. Comparative analysis of the speeds of several motors [101].

2. Configurations of EVs

EVs have the ability to run solely on electric propulsion or in conjunction with an internal combustion engine (ICE). The simplest sort of electric vehicle (EV) relies just on batteries as its source of energy; however, there are many variants that make use of a variety of other types of energy sources. These automobiles are hybrid electric models (HEVs) [102–104]. The Technical Committee 69 Electric Road Vehicles (ERV) of the International Electrical Technical Commission proposed that cars with two or more forms of energy source, storage, or converters can be classified as HEVs as long as at least one of them provides electrical energy [105,106]. This recommendation was made in response to a question posed by the Technical Committee 69 ERV of the International Electrical Technical Commission. This specification makes it possible to combine ICE and batteries, batteries and flywheels, batteries and capacitors, batteries and etc. in a number of hybrid electric vehicle configurations. As a result, regular people and industry professionals started referring to hybrid

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electric cars (HEVs), ultra-capacitor-assisted electric vehicles (FCEVs), and fuel cell electric vehicles (FCEVs) to describe automobiles that have both an internal combustion engine and an electric motor. These terminologies have garnered a significant amount of support, and on the basis of this standard, EVs can be categorized as follows [107–109]:

- Electric Battery Vehicle (BEV)
- Hybrid Electric Vehicle (HEV)
- Plug-in Electric Hybrid Vehicle (PHEV)

2.1. Batteries Electric Vehicles (BEVs)

Given that a battery is the only source of energy for the powertrain of a BEV Figure 1, the range that may be achieved by such a vehicle is directly proportional to the capacity of the battery. A BEV is completely carbon dioxide (CO_2) emission free because it does not have a tailpipe or other source of exhaust emissions. BEVs have the potential to go between 100 and 250 kilometers on a single charge, while using 15 to 20 kWh for every 100 kilometers driven [110–113]. This range is determined by the characteristics of the vehicle. There is a range of between 300 and 500 kilometers for battery electric vehicle models that have larger battery packs. However, battery electric vehicles (BEVs), in comparison to other types of electric vehicles (EVs), have a substantial disadvantage due to their significantly reduced driving range and dramatically increased charging periods. The most effective way to address this issue would be to design and implement an EMS that is suitable for BEVs [114,115].

One study devised a three-wheel electric vehicle regenerative braking method that extended range to around 20 km/kWh compared to complete mechanical braking (19.2 km/kWh), serial regenerative braking (19.3 km/kWh), and parallel regenerative braking (19.5 km/kWh). Compared to three previous braking techniques, this one increased range to 20 km/kWh. This innovative braking technique could increase range by 4.16 km/kWh compared to mechanical braking alone. One technique to expand the range of battery electric vehicles (BEVs) is to increase the battery pack's capacity [116–119]. However, it is possible that a battery pack with a large capacity is not useful because it requires a significant amount of space and significantly increases the weight of the vehicle. This has a direct impact on the vehicle's performance as well as its fuel economy, and it also raises the total cost of the vehicle [120]. An electric three-wheel vehicle that is fully loaded (300 kg) and has a lithium-ion battery pack (LIB) that is 16 kWh has a range that is approximately 12.5% less than it would have with a half-load (150 kg) (from 200 to 175 km).

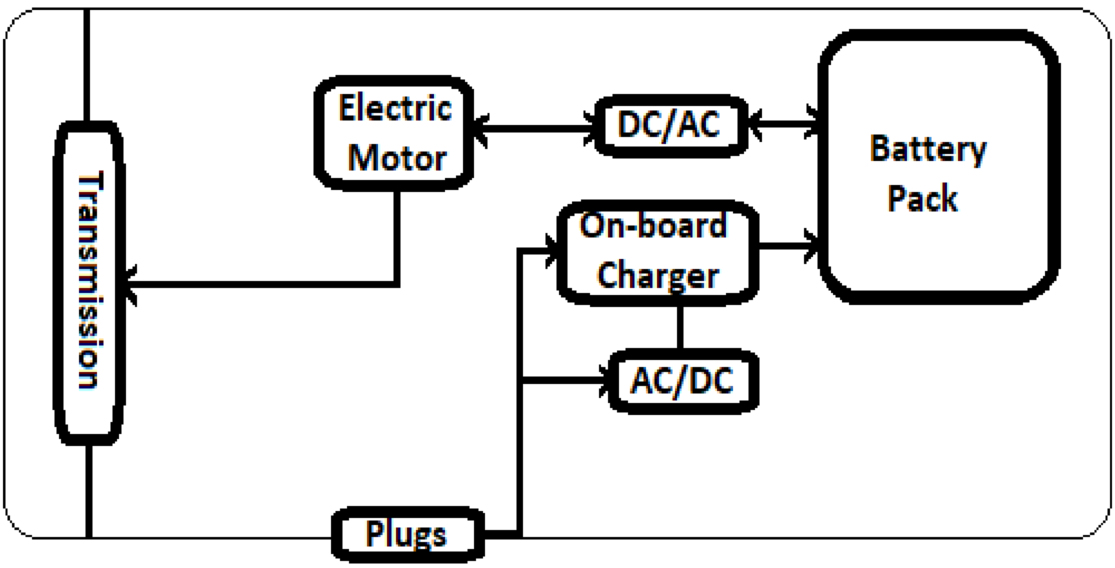

Figure 4. The structure of BEV circuit.

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Examining different driving styles is another method that can be used to extend the range of a battery-electric vehicle (BEV) without having to increase the capacity of the battery. Controlling the flow of energy and power is one way that one might put this method into action when driving. Runtime power management was developed by in [121,122] order to extend the range of battery electric vehicles. An algorithm was proposed to cut down on journey time and the amount of gasoline used [123,124]. The fact that this technique is based on a multi-objective algorithm enables it to produce results that are superior to those produced by other algorithms that have been examined. In [125] a study suggested a velocity profile optimization-based optimal control method to reduce energy consumption. The proposed algorithm was able to cut energy consumption by between 8 and 10%, thanks to its management of driving duration and speed. These citations provide a workable answer to the problem of lowering battery capacity while maintaining a lower overall energy consumption.

2.2. Hybrid Electric Cars (HEVs)

The International Electro-Technical Commission's Technical Committee 69 (Electric Road Vehicles) defines a hybrid electric vehicle (HEV) as a vehicle with two or more energy sources, storage, or converters, at least one of which generates electricity. HEVs use two or more energy sources, storage, or converters [126]. Because BEVs have a limited driving range, hybrid electric vehicles (HEVs), which combine a traditional internal combustion engine (ICE) with a battery system, have become an appealing option. An electric motor is the only source of propulsion for a series hybrid electric vehicle, as shown in Figure 2a. In contrast, both an internal combustion engine (ICE) and an electric motor are connected to the gearbox of a parallel hybrid electric vehicle (HEV), which transmits power to the wheels simultaneously (see Figure 2b). Many studies have been conducted to determine the amount of fuel that parallel and series hybrid electric vehicles consume as well as how efficiently they use their fuel (HEVs). In [127] for instance, compared the amount of gasoline that was consumed by series and parallel HEV road sweeper trucks while keeping the same amount of power and traveling the same amount of distance.

Based on the findings of the comparison, the series hybrid design (3.8 L/h) had a lower fuel consumption rate than the parallel hybrid design (6.2 L/h). When the vehicle was operating in the series hybrid mode, the internal combustion engine (ICE) kept its speed constant throughout the transport mode. On the other hand, when the vehicle was operating in the parallel hybrid mode, the engine speed fluctuated. By altering the hybridization factor, Li demonstrated in a separate study that parallel HEV topologies are more energy-efficient than series HEV designs (HF) [128,129]. Due to the fact that there are three different conversions that take (place mechanical, electric, and mechanical), parallel HEVs are theoretically considered to have smaller power conversion losses than series HEVs do. When the power splitting mode is engaged, it is possible to cut losses in the drive train, the engine, and the braking system. This could lead to a gain in fuel economy that ranges from 0.3 to 36.7% [130]. In addition to this, the fuel efficiency of parallel HEVs can be up to 68 percent better than that of a traditional automobile. This substantial improvement in fuel efficiency was made possible, in part, by the implementation of regenerative braking, which refers to the recuperation of energy that would have otherwise been lost. As a consequence of these studies, series hybrid electric vehicles (HEVs) have been successfully deployed in transportation mode. On the other hand, parallel hybrid electric vehicles (HEVs) require further changes to the drive train in order to achieve improved energy efficiency [131].

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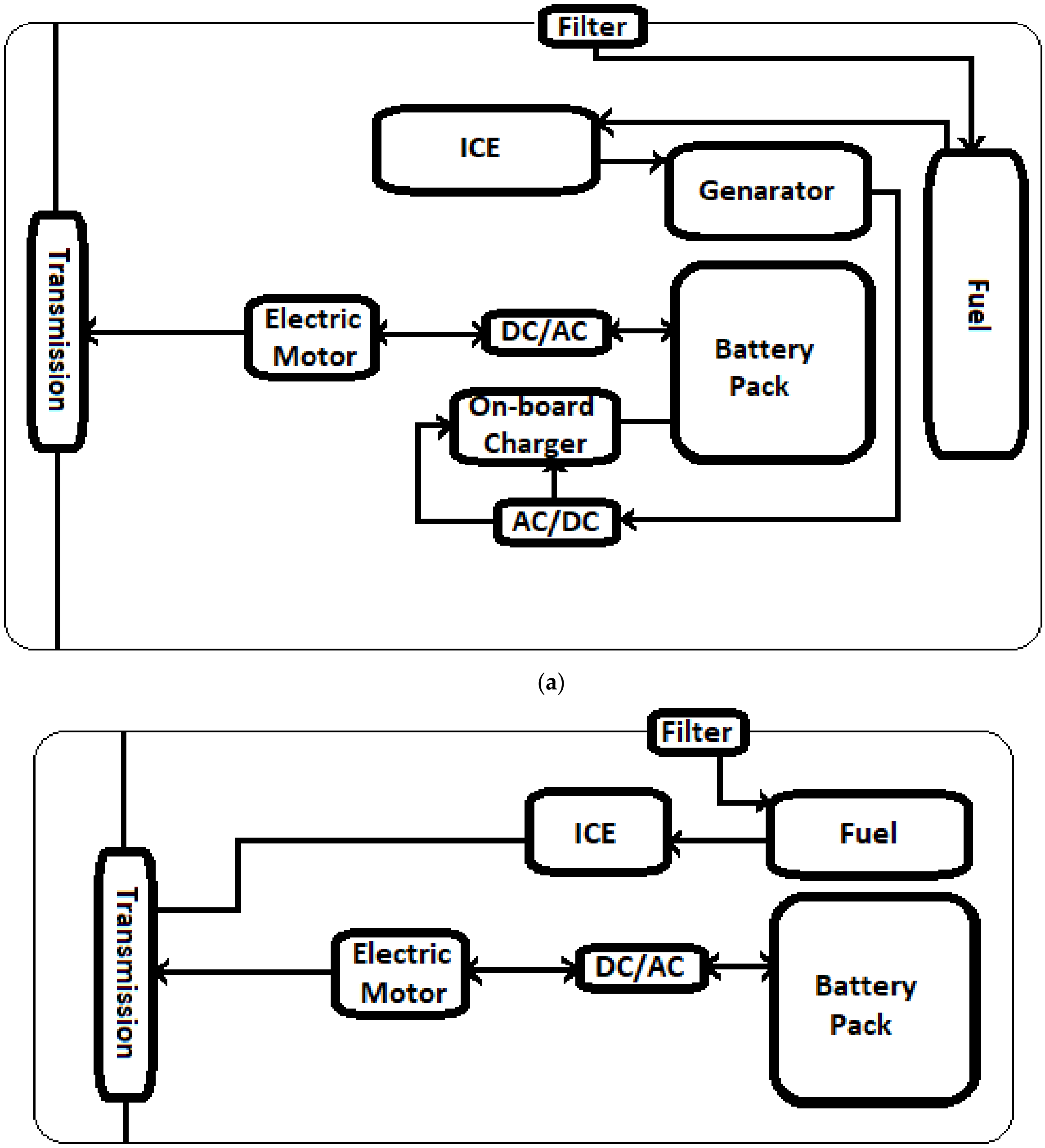

(**a**)

(**b**)

Figure 5. (**a**) The structure of series HEV circuit and (**b**) The structure of parallel HEV circuit.

Mild hybrid electric cars, also known as MHEVs, are another form of hybrid electric vehicle (HEV) that are equipped with an electric motor and a battery that has a capacity that is on the lower end of the spectrum (10–20 kW). Although the hardware components of this form of EV and other types of HEVs are identical, the control algorithms used by each of these categories of vehicles are very different. Because the internal combustion engine is responsible for the majority of the production of the vehicle's propulsion energy, a gasoline-powered hybrid electric vehicle (MHEV) is distinguished from other types of HEVs by having a lower hybridization power approximately 15% and smaller driving electric components. This is due to the fact that the internal combustion engine is responsible for the majority of the production of the vehicle's propulsion energy [132]. When it comes to energy management, the most difficult obstacle for HEVs to overcome is likely going to be the combination of many energy sources and optimization. In order to determine a pattern of a driving cycle's energy consumption, a comprehensive modeling system, data from test runs, and

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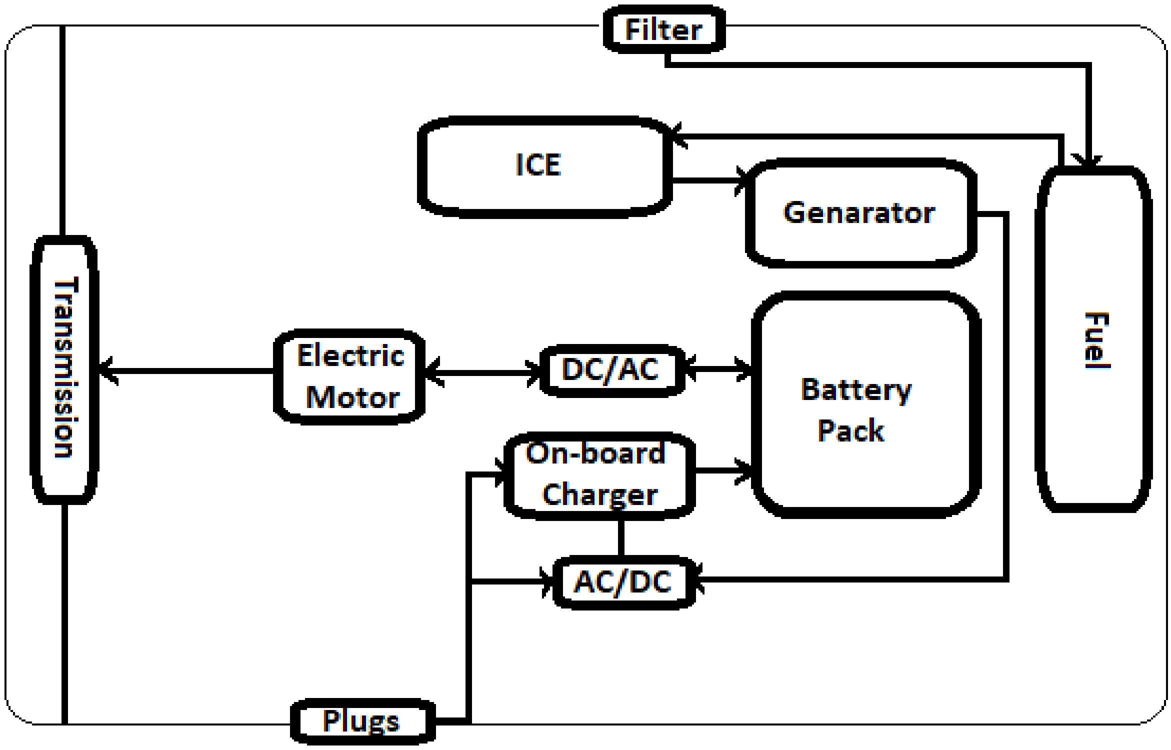
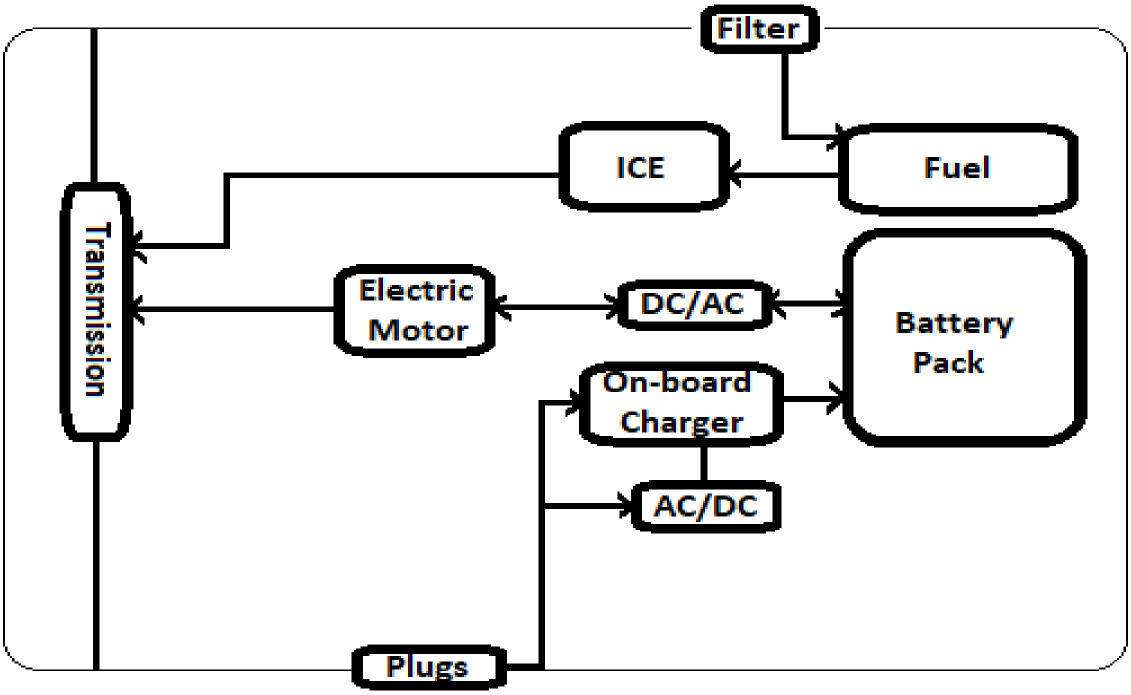
simulator software that has been approved for commercial use are required. In addition, the data from the test runs are necessary in order to obtain the energy consumption.

2.3. Plug-In Electric Hybrid Cars (PHEVs)

The range of HEVs may be increased, which led to the development of PHEVs. Like HEVs, plug-in hybrid electric vehicles (PHEVs) have an internal combustion engine (ICE), an electric motor, a generator, and a battery [133,134]. Regenerative braking can be replaced with utility grid charging. PHEVs are BEV/HEV hybrids. Figure 3a,b show different plug-in hybrid electric automobiles (PHEVs). Hybrid electric vehicles use "series" or "parallel" ICEs to charge the battery or provide traction (HEVs).



(a)



(**b**)

Figure 6. (**a**) The structure of series PHEV circuit (**b**) The structure of parallel PHEV circuit.

Unlike HEVs, plug-in hybrid electric vehicles (PHEVs) may get their battery charges from the grid, which results in larger battery packs. HEVs are required to operate in charge sustenance mode (CS), which caps the amount of charge the battery can hold (SOC). Plug-in hybrid electric vehicles (PHEVs) have the capability of operating in either pure electric or blended mode when in charge depletion (CD) mode (prioritize using the electric motor over ICE) [135,136]. A study for charge depletion mode to reduce parallel PHEV fuel consumption. The urban dynamometer driving schedule (UDDS) reduced parallel PHEV fuel consumption by 7.1% over 64 km, 6.3% over 48 km, and 5.6% over 32 km [137]]. This study found that the PHEV's CD control technique effectiveness increased proportionally with the test distance.

In the same way as with BEVs, when the battery capacity of PHEVs increases, the primary issue shifts to the charging time; as a result, charging strategies are required to maintain the vehicle's performance. A fast charger can give a higher DC current capacity for car charging. Rapid DC charging methods like CHAdeMO (charge de move) and Combo may charge up to 80% of the capacity in 30 minutes, depending on power delivery rate (6–200 kW) [138]. CHAdeMO and Combo also have promising vehicle-to-grid (V2G) technology futures. Both standards support quick charging. In [139] a study developed, implemented, and tested the V2G system. A vehicle with a fully functional CHAdeMO inter-face (VCI) at the physical and protocol levels was able to control communication and electrical transfer between the car and charger. The VCI was fully implemented at both the physical and protocol standards. Plug-in hybrid electric vehicles and battery electric vehicles could shape the future of transportation by storing energy from the grid in their batteries and feeding it back into the distribution network when needed [139].

Power losses, stability systems, and resilience are some of the additional difficulties that are linked with PHEVsThe SCS Algorithm, a smart-charging scheduling algorithm, may alleviate these problems, especially robustness. It was possible to achieve optimal charging timing for plug-in hybrid electric vehicles (PHEVs) by synchronizing a number of plug-in hybrid electric vehicles (PHEVs) inside a smart grid system. The findings revealed that it had an adequate level of robustness and provided values with a standard deviation that was less than 1 (= 0.8425) [140]. Figure 4 illustrates the configuration of the powertrain used in series-parallel hybrid electric vehicles and plug-in hybrid electric vehicles. HEVs and PHEVs that run in a series-parallel mode are able to take use of all of the

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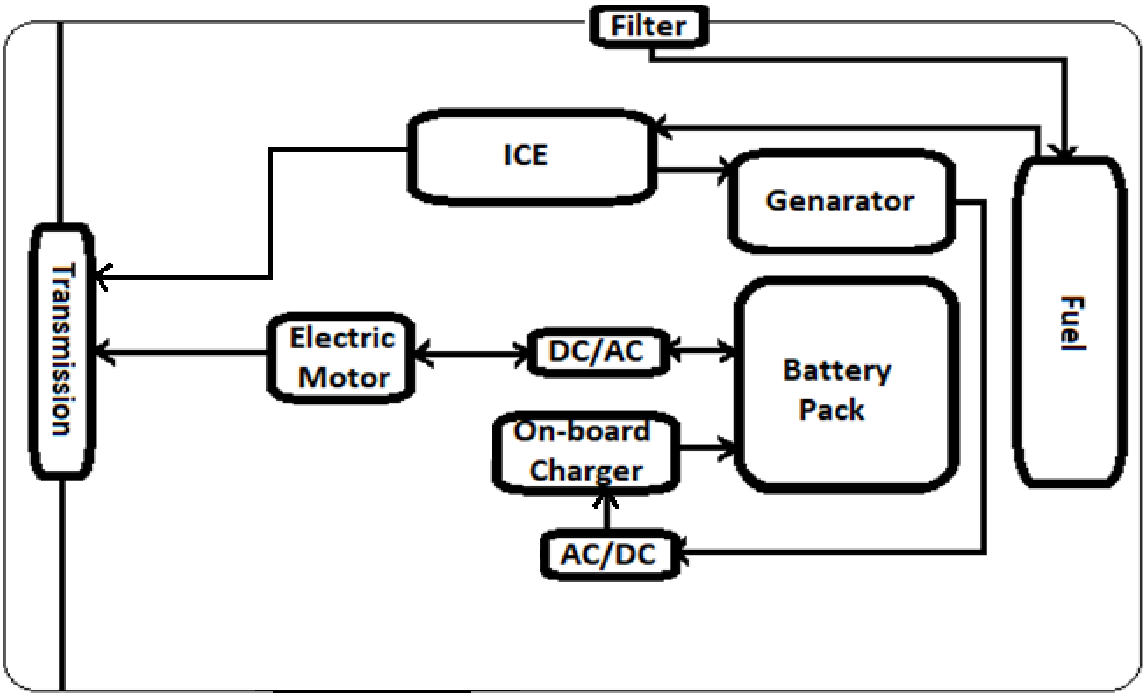
benefits that are associated with running in either the series or the parallel mode. These benefits include increased fuel economy, increased range, and increased efficiency. A study on the efficiency of fuel usage in series-parallel plug-in hybrid electric vehicles was carried out by Zhao and Burke [141].

According to the findings of their investigation, the rate of fuel consumption for a series-parallel PHEV utilizing the UDDS (city driving) strategy was 18.1 kilometers per liter less than that of a series shaft PHEV of the same kind, which was 20.4 kilometers per liter. This information was derived from comparing the two types of PHEVs using the same driving strategy. The HW-Interstate method (highway driving up to 77 miles per hour; 120,7 kilometers per hour) demonstrated the same conclusion, with a series-parallel PHEV achieving a lower fuel consumption efficiency. An additional study that used the approach of blended power-split mode to investigate the energy efficiency of series-parallel plug-in hybrid electric vehicles (PHEVs) found a considerable improvement [142]. As a result of energy allocation and power management in a drive system, it provided a real-world example of the control method for series-parallel plug-in hybrid electric vehicle (PHEV) power management. This was possible since it was based on a drive system. The result brought the overall system's efficiency up by 27.50 percentage points, from 19.3 to 24.6 km/L. Nonetheless, this type of vehicle is heavier, has a less sophisticated look, and carries a higher price tag [143].



(a)

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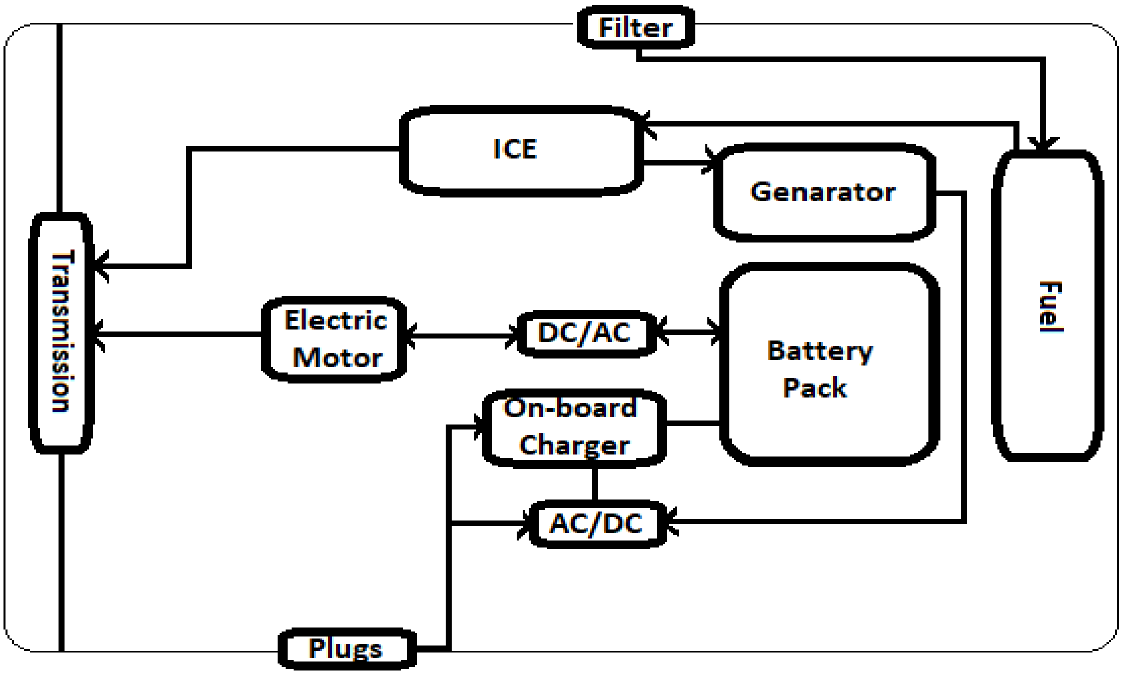

(**b**)

Figure 7. Series-parallel hybrid electric vehicle circuit structure: (**a**) series-parallel HEV (**b**) series-parallel PHEV.

Another type of plug-in hybrid electric car is an extended-range electric vehicle (EREV). In contrast to other types of PHEVs, the electric motor always powers the wheels, and the internal combustion engine doubles as a generator to keep the vehicle's battery charged whenever it runs low or when the vehicle is in motion [40]. The EREV has strong preferences for reducing the use of mineral resources and fossil fuels to the absolute minimum possible [144]. According to the findings of Liu et al, the consumption of mineral resources by EREV is 14.68 percentage points lower than that of HEV, and the consumption of fossil fuels by EREV is 34.72 percentage points lower than that of ICEV. It's possible that the decreased consumption of mineral resources is due to the vehicle's smaller size and the fact that there are fewer components overall [145]. It is possible to achieve minimal fuel consumption since the gasoline is only required to run the generator. This generator has a constant rotational speed and torque for charging the batteries, so it does not require much fuel. The fact that the generator is the solitary component that is used in the process of providing electricity to the vehicle makes this outcome conceivable. The generator's speed and torque can both be adjusted to achieve the highest possible levels of energy efficiency in order to cut down on the amount of money spent on fuel. Because of the range ex-tender, EREVs are able to travel further than BEVs; nevertheless, in order to compete with BEVs in terms of energy efficiency, they need to be much more compact [146].

3. Upcoming Opportunities and Challenges of EVs

EVs are considered the vehicles of the future for several reasons, including their expanding market share, their environmental friendliness, and their cutting-edge technology. The value of EV-related stocks rose from $3.7 million in 2019 to $13 million in 2020, and the International Energy Agency (IEA) predicts it will reach $130 million by 2030. Also, during the period under consideration, it is estimated that sales of EVs will rise by an average of 24 percent. The number of EVs sold climbed from 1.4 million in 2019 to 4 million in 2020, and it is anticipated that the number would reach 21.5 million by the year 2030 [147,148]. Notwithstanding the obvious benefits that EVs offer over traditional automobiles, this means of transportation must nevertheless overcome the five key challenges listed below:

 doi:10.20944/preprints202306.2040.v1

- The automobile as a type of emerging technology
- Charging times and technology for connecting vehicles to power grids;
- An increase in the efficiency of batteries;
- Public policy and regulatory frameworks; and
- A free and open market for power.

3.1. The Automobile as a Type of Emerging Technology

The EV which is widely regarded as the vehicle of the future, presents a wealth of opportunities for the development of cutting-edge technologies that can enhance both its performance and its ability to communicate with both other EVs and the surrounding environment. The internet-of-cars paradigm is a feature that ought to be included in EVs. This capability allows integrated systems between all internal components, roadside unit connections, and vehicle-to-vehicle connections. By the year 2020, Mansour et al. hoped to have created an intelligent self-parking vehicle Autonomous Parallel Car Parking [149]. This prototype was able to identify an available parking spot and parallel park itself, but it required a large number of sensors, including infrared and ultrasonic sensors, in order to gather information about its surroundings. This may reduce accidents, human error safety, mobility for elderly, inexperienced, and disabled drivers, and driving time. In 2020 an intelligent car with a smart car control system was introduced. The remote wireless control terminal in this vehicle was a smartphone. The intelligent vehicle acts as a bridge between Bluetooth and a microcontroller (MCU) [150]. It may provide automatic direction control, gravity induction control, speech control, an automatic tracking system, automatic collision avoidance, and other support features. This inquiry cut the pricing of equipment with wired and remote controls. In [151] study created a new analytical approach for analyzing the safety of crosswalks in 2021. This methodology is based on the multiple behaviors of vehicles and pedestrians, as well as the components that are in the surrounding area. In the case of an accident in the future, the safety of pedestrians and cyclists may be improved thanks to this model.

Companies producing automobiles such as Volvo, BMW, and Nissan are some examples of businesses that have improved the performance of their vehicles by applying technology that is exclusive to "smart cars”. A Volvo's sensors can detect lanes and vehicles behind it, and the pilot assist feature lets the system know when the adaptive controller is being used. A Volvo's sensors can also identify vehicles in front of it. Machine-controlled driving is standard on new BMW I-Series cars. Wi-Fi connectivity, high-definition digital maps, sensor technology, cloud technology, and processing facilities are among these capabilities [152]. Last but not least, all Nissan cars come standard with shield-shaped safety equipment that can scan a 360-degree area around the vehicle for potential risks, warn the driver, and take any necessary precautions. If accidents must be avoided, this technology can help the driver [153].

3.2. Charging Times and Technology for Connecting Vehicles to Power Grids

The wall-box, which functioned as an additional semi-fast charger, was an essential component in the system for managing the chargers. It came pre-configured with features such as energy control with real-time observing, charge planning, remote control (lock/unlock and output current), settings for individual tariffs, energy consumption and cost statistics data, and connectivity with the operation of iOS and Android system devices [154–156]. These features allowed wall-box to play a significant role in the management of chargers. It might make charging with a maximum capacity of 22 kW possible and assist consumers in controlling the amount of energy their EVs use. Researchers have developed a method of rapid recharging for battery-equipped EVs in order to alleviate the strain that the increased demand for EV charging is having on the power grid and to circumvent the exorbitant costs associated with charging during peak hours. The findings helped station builders and operators understand industry economics, requirements, operation, future demands, and maintenance approaches. While constructing charging stations, three more elements, including the dimensions of the station and its equipment, maintenance procedures, and operation strategies, should be taken into consideration [157].

3.3. An increase in the Efficiency of Batteries

With ultra-quick charging, EVs can charge up to 80% of their batteries in 15 minutes. A study evaluated whether public buses will have ultra-fast charging infrastructure with 450 kW in in the nearest future. Because of this, they were able to determine the capacity of the battery [158]. In this particular situation, a single terminal equipped with a 450-kW charging station traveled 100 different routes that were between 10 and 20 kilometers in length. In this scenario, the bus traveled 17.22 kilometers and consumed 413.28 kWh of energy. If the terminal featured an ultra-fast charging station of 450 kW, the bus would only require one charge with a total capacity of 190.63 kWh. According to the findings of our research, the battery capacity might be reduced from 413.28 kWh to 222.64 kWh [159,160]]. This reduction in travel time can be accomplished through the utilization of an ultra-fast charging station at the terminal.

Pulsed current is being considered to increase LIB battery performance. Huang et al. pulsed a LIB cell at 0.05 Hz to activate it. By changing duty cycles, C-rates, and ambient temperatures, the pulsed current's influence on battery charging may be determined. Pulsed current, when compared to steady current, increased charging capacity by 30.63 percent while simultaneously reducing the maximum temperature rise by 60.37 percent [161]. There is also the possibility of preheating the battery at a low temperature in order to improve its performance and reduce the risk of accidents involving the battery. An external pre-heating method was developed by Biao and colleagues. The battery's electro thermal plate and a temperature field distribution are used in this procedure. The battery's inside and outside case were different temperatures due to this method. The battery's temperature was modest despite the case's high temperature [162].

3.4. Public Policy and Regulatory Frameworks

EVs have emerged as a viable option in recent years and continue to garner significant interest. So, the diffusion of EVs is significantly dependent on governmental action, which is often justified primarily for the purpose of stimulating technological innovation features aimed at reducing negative externalities (such as emissions reduction). In the meanwhile, the rate of adoption of EVs is largely dictated by the infrastructure support for EVs as well as the legislation surrounding EVs. The Asia-Pacific Economic Cooperation (APEC) examined electric vehicle (EV) policy, focusing on the charging network, boosting demand for these vehicles, industrialization, research, and development initiatives, and the incorporation of EVs into sustainable mobility plans [163]. This paper describes APEC public policies to overcome barriers to electric vehicle adoption to improve policy instruments for new energy cars. The goal of this effort is to increase the efficacy of policy instruments for new energy cars. In a separate piece of research, Researchers investigated and assessed two other forms of policy: the priority placed on purchase subsidies, and the expansion of charging infrastructure. These rules will have an effect on the rate of EV uptake and use in the future. So, the expansion of the market for EVs necessitates the creation of new charging infrastructure, technological advancements, and government restrictions [164]. Customers' fears would be alleviated further if charging stations had adequate coverage and capabilities, and appropriate government laws may encourage the expansion of the electric EV sector.

3.5. A free and Open Market for Power

The need for electricity to charge EVs is expected to rise in tandem with the growing popularity of EVs. In open electricity markets, where prices fluctuate daily, the power system of electric vehicle charging stations raises energy prices. When compared to the price of electricity during off-peak hours, the price of electricity during peak hours is typically three times higher. In order to solve this problem, it will be necessary to install charging stations for EVs that make use of a hybrid energy system. This type of system includes both conventional and renewable energy sources, such as photovoltaic panels and energy markets [165]. To prevent environmental contamination, renewable energy sources must be used, but they are scarce. To improve system performance, they are often employed alongside traditional components. The use of such a system presents a challenge due to the fact that achieving its optimal operation calls for a significant amount of research, which, in turn, brings down the price of charging an EV. EVs can have their charging and discharging processes made more efficient thanks to a market mechanism that has been devised in [166]. based on the block chain technology. A multi-mode optimization method was proposed by. This charging point is a hybrid of a traditional charging station and a photovoltaic system. Both components work together to provide power. The effectiveness of the strategy was demonstrated by the fact that initial costs were cut by more than fifty percent as a direct consequence of its implementation.

4. Concluding Remarks

EVs have the potential to not only become the future of transportation but also to save the globe from the oncoming calamities related to global warming. Conventional automobiles, which are wholly reliant on the ever-decreasing reserves of fossil fuels, have little chance of competing with these vehicles, which offer a workable alternative. In this article, the several types of EVs, their configurations, energy sources, motors, power conversion, and charging systems are dissected in great detail. The fundamental technologies of each segment as well as the characteristics of those technologies have been analyzed and outlined. The implications that EVs have on a variety of businesses have also been investigated, as have the tremendous prospects that EVs bring for promoting a cleaner and more efficient energy system by collaborating with smart grids and making it easier to include renewable sources. The shortcomings of currently available EVs have been outlined, as have some of the potential solutions for addressing those shortcomings. In addition to that, the many optimization approaches and control methods that are now in use have been presented. This study provides a condensed overview of the current electric vehicle market. Following an analysis of current tendencies and potential avenues for future growth is a discussion of the article's conclusions, which serve to summarize the preceding material, paint an accurate picture of the sector in question, and highlight the research gaps that still need to be filled.

Author Contributions:.

Funding:.

Institutional Review Board Statement:.

Informed Consent Statement:.

Data Availability Statement:.

Conflicts of Interest:.

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