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Review

A Review on Drive Train Technologies for Passenger Electric Vehicles

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Abstract: Transportation is the second-largest sector contributing to greenhouse gas emissions due to CO_2 gas generation from the combustion of fossil fuels. Electric vehicles (EVs) are believed to be a great solution to overcome this issue. EVs can reduce CO_2 emissions because the vehicles use an electric motor as a propeller instead of an internal combustion engine. Combined with sustainable energy resources, EVs may become zero-emission transportation. This paper presents an overview of the EV drive train types, including their architecture with the benefits and drawbacks of each type. The aim is to summarize the recent progress of EV technology that always continues to be updated. Furthermore, a comparative investigation on energy density and efficiency, specific energy and power, cost, and application is carried out for batteries as the main energy storage. This discussion provides an understanding of the current development of battery technology, especially the batteries used in EVs. Moreover, the electric motor efficiency, power density, fault tolerance, reliability, and cost are also presented, including the most effective electric motor to use in EVs. The challenges and opportunities of EV deployment in the future are then discussed comprehensively. The government regulation for EVs is still a major non-technical challenge, whereas the charging time and battery performance are the challenges for the technical aspect.

Keywords: electric vehicles; technology; powertrain; passenger car

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1. Introduction

The transportation sector has become the second-largest contributor of greenhouse gas (GHG) emission in the past 20 years, after the heat/electricity sector [1,2] To reduce this GHG emission, electric vehicles (EVs) have been introduced as an effective solution in the mobility sector. Various different EVs currently exist, including battery electric vehicle (BEV), hybrid electric vehicle (HEV), plug-in hybrid electric vehicle (PHEV), and fuel cell hybrid electric vehicle (FCHEV). Together with new green energy sources, the EV deployment does not only reduce the GHG emissions but also increases total energy efficiency. The coupling of green energy technology implementation and EV deployment can maximize the potential to further reduce emissions through smart grid technology, hydrogen-based energy system, big data and artificial intelligence, energy storage, other decarbonization technologies, and CO_2 capture/utilization technologies [3]. Smart grids affect integrating the whole energy (electricity) system, including generation, transmission, distribution, consumption, and storage technologies, to realize an optimal solution for most energy systems. A mutual utilization of electricity and hydrogen can result in an adjustable and adaptable energy system [4]. The use of big data for managing air conditioning, charging, and other power demands is often conducted in additional interactive and adaptive changes in the energy system. Energy storage and other utilization technologies are crucial to balancing and providing supply, demand, and time-shifting delivery of energy systems [5].

As EVs gained popularity due to their high energy efficiency, comfortable driving experience, and zero emissions, the sales of EVs have increased significantly in the past 7 years, especially in Norway, the UK, and Iceland, with more than 45% of the increase in 2020 [6]. The total cost of ownership (TCO) is an important point to support the popularity of EVs. The European Consumer Organization (BEUC) reported that by owning the EVs (case of BEV), consumers can save financially and have a great optimal solution for long-term cost, compared to the ICEs which use diesel and petrol [7]. However, Wróblewski et al. reported that considering the lack of infrastructure supporting the EVs, the operational cost of the ICE vehicle was still lower than EVs [8].

Due to their high popularity, studies on various types of EVs have been conducted by many researchers. Braun et al. studied the energy consumption of BEV by investigating the differences between one BEV and one ICE on passenger cars in various driving situations [9]. Located in Erfurt, Germany, the consequences of driving strategies and peak hour traffic on energy consumption were examined. The results affirmed that the BEV achieves 69.2% fuel consumption efficiency over conventional vehicles. This great advantage emerged because the BEV has power train features that only turn on to generate traction. They absorb the mechanical power during braking and convert it to electricity for charging the battery (regenerative braking). From these features, the BEV can take advantage of the vehicle speed fluctuation [9].

Studying HEVs, Cheng et al. developed an electric-assist control strategy (EACS) by applying particle swarm optimization (PSO) to optimize the federal test procedure (FTP) driving cycle that meets the minimum fuel consumption and emissions of a parallel HEV [10]. Using this method, the fuel consumption efficiency of parallel HEV was increased by 3.1%, and CO_2 emissions were reduced from 1.78 to 1.42 g/km. These results were mainly caused by the PSO algorithm that quickly converged and obtained a globally optimal solution. The authors remarked that this method was the solution to overtake the energy crisis problem and environmental pollution [10].

Additionally, a study for PHEV focusing on the optimization of an energy management system (EMS) was conducted by Zhou et al. [11]. The study optimized an EMS design applied for a PHEV with a hybrid energy storage system (HESS) in two battery packs. The result showed that the PHEV energy efficiency was improved by 1.6–2.9%, and the PHEV energy storage system lifecycle could be improved by 159–173% [11]. These improvements were brought about by the decrease of energy conversion loss in HESS through the application of the proposed EMS.

Lastly, in the case of FCHEV, Lee et al. developed an FCHEV for dustcart with two high-pressure hydrogen tanks, each of which has a capacity of 36 L and a pressure of 70 MPa. A fuel cell system features a maximum output of 33 kW and a lithium-ion battery (LIB) with a nominal capacity of 26.5 kWh. This study claimed that the energy consumption of the FCHEV was 73% lower than a diesel dustcart with an equivalent route [12]. As seen by this result, the FCHEV is a promising EV in the future that has a great energy consumption efficiency. As a fuel of FCHEV, hydrogen can be produced from renewable electricity by splitting the water into hydrogen and oxygen in an electrolyzer. Several studies to produce hydrogen using the electrolysis process have been investigated with electric sources obtained from solar, biomass, geothermal, nuclear, fossil fuels, and wind sources [13,14]. These studies aim to find the optimal cost of hydrogen production and energy production.

Most EV types require batteries for electric energy storage. The batteries are a vital component that must be developed to achieve energy storage that has a high specific energy density. The technology of the battery evolves from lead-acid batteries with the number of the specific energy density of 30–50 Wh/kg, to the nickel-cadmium (Ni-Cd) battery (50–75 Wh/kg), followed by the nickel-metal hydride (Ni-MH) battery (about

40–110 Wh/kg), and sodium-sulfur (NaS) (150–240 Wh/kg). The current evolution of the battery technology is achieved from various lithium-based batteries, with a specific energy density of about 240 Wh/kg [15]. The development of batteries is continuously conducted to seek an energy source with a higher specific energy density, high power capacity, low cost, highly safe, and long-lasting. The highest specific energy density of lithium batteries at present is provided by a complex hydride lithium superionic conductor, $0.7Li(CB_9H_{10})$–$0.3Li(CB_{11}H_{12})$, which has good stability and good conductivity of 6.7×10^{-3} S/cm at 25 °C, with a high specific energy density of more than 2500 Wh/kg [16].

Since the technologies related to EVs and their energy system (production, storage, and utilization) are continuously growing, in this study, we review the updated EV technologies, including their performance, energy sources, and opportunities of EVs within the future in several sections: EVs configuration, key component technologies for EVs, and the opportunities and challenges, as follows:

- Section 2, looking at EVs' configurations, explains an overview of the types of EVs, including BEVs, HEVs, PHEVs, and FCHEVs. These cover EVs' architecture and the technology inside. By doing this, it is expected that the updated technology related to EV types can be provided.
- Section 3, considering key component technologies for EVs, provides detailed explanations of electric motors and batteries used in EVs. This section also describes the EV types, battery capacity, and motor drive types for each EV type. A thorough review of the battery technologies is additionally provided—from the lead-acid battery to the LIB. This point provides an understanding of the current development of battery technology, especially the batteries used in EVs. Furthermore, the most widely used electric motors in EVs, along with the vehicle models, are also presented. This can be used as a reference to determine a suitable electric motor used in EVs based on efficiency, power density, speed, reliability, size, and cost.
- Section 4, looking at opportunities and challenges, predicts the future in transportation and the challenges faced by EVs, such as battery performance improvement, charging time, policy and regulation, and open electricity market. These challenges are important to open a new perspective on EVs and the trend towards EVs in the future.

2. EVs' Configurations

Several types of energy sources are used (such as electricity, hydrogen, and conventional fuels) and ways these sources are attached in EVs (such as battery, capacitor, and tank). EVs can be combined with an ICE or used on their own without the addition of other energy sources. Therefore, in general, EVs can be categorized as BEVs, HEVs, PHEVs, and FCHEVs [17].

2.1. Battery Electric Vehicles (BEVs)

A battery is the only energy source for a BEV to run a power train (Figure 1); therefore, the distance traveled by such a vehicle depends on the battery capacity. A BEV can be considered a fully green vehicle in terms of CO_2 emissions because it has no tailpipe products. Typically, a BEV can cover approximately 100–250 km on a single charge depending on the vehicle specifications, with an energy consumption rate of 15–20 kWh for 100 km. BEV models with a heavier battery pack have a longer driving range, from 300 to 500 km [18].

However, compared to other EV types, BEVs face a major problem with their relatively shorter driving range and requirement for longer charging time. The development of an efficient EMS for BEVs is an ideal solution to deal with that problem. For example, one study has successfully developed a kind of regenerative braking strategy for three-wheel EVs, and gained a satisfying result to extend mileage to about 20 km/kWh compared to three different braking strategies: full mechanical braking (19.2 km/kWh), serial regenerative braking (19.3 km/kWh), and parallel regenerative braking (19.5 km/kWh). This modified braking strategy could increase the mileage by about 4.16% km/kWh higher than the full mechanical braking [19].

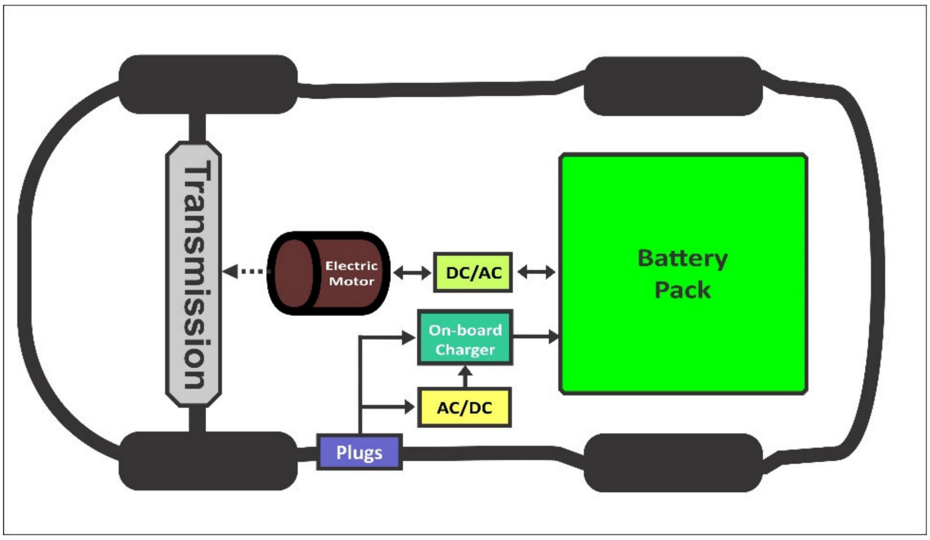

Figure 1. A BEV architecture.

Enlarging the capacity of the battery pack is also a possible solution to extend the range of BEVs. However, a large-capacity battery pack might not be beneficial because it occupies an enormous space and greatly increases the vehicle weight, which directly impacts vehicle performance and the fuel economy and increases the total vehicle cost [20]. A 16 kWh LIB attached to an electric three-wheel vehicle with a full load (300 kg) decreases the vehicle mileage by around 12.5% (from 200 to 175 km) when compared to a half-load (150 kg) [21].

Another method to extend the BEV range without increasing the battery capacity is to consider driving strategies. This method can be performed by managing energy and power flows during driving. For example, Baek et al. introduced runtime power management to extend the BEV range [22]. Dovgan et al. proposed an algorithm to minimize the traveling time and fuel consumption. This algorithm achieves better results than other tested algorithms since the proposed algorithm is based on a multiobjective algorithm [23]. Ozatay et al. proposed an optimal control algorithm to minimize energy consumption based on the velocity profile optimization problem. By managing the velocity and driving time, the proposed algorithm saved energy consumption by 8–10% [24]. These references provide a satisfying result on energy consumption saving without increasing the battery capacity.

2.2. Hybrid Electric Vehicles (HEVs)

The International Electro-Technical Commission's Technical Committee 69 (Electric Road Vehicles) defines an HEV as vehicles using two or more energy sources, storage, or converters, as long as a minimum of one among those provides electricity. HEVs have become a preferable solution to the BEVs issues within the limited driving range by combining ICE and battery strategy [25].

As shown in Figure 2a, a series HEV only uses an electric motor as the propulsion source. In contrast, a parallel HEV mechanically connects an electric motor and ICE to the transmission and simultaneously discharges the power to rotate the wheels (see Figure 2b). Some studies were conducted to compare fuel consumption and fuel economy between series and parallel HEVs. For example, Canbolat and Yaşar compared the fuel consumption between a series HEV and a parallel HEV of road sweeper vehicles for the same power and travel distance. Their comparison showed that fuel consumption in series hybrid configuration (3.8 L/h) was lower compared to the parallel hybrid (6.2 L/h). This was due to the fact that the ICE in a series hybrid mode ran at a constant speed during the transport mode, while in the parallel hybrid mode, the engine speed varied [26]. In contrast, another study conducted by Li showed that parallel HEV configurations gained higher efficiency than series HEV configurations by modifying the hybridization factor (HF) [27]. Technically, parallel HEVs had fewer power conversion losses compared to the series HEVs due to mechanical–electric–mechanical conversions. Using the power splitting mode, the drive train, engine, and braking losses could be reduced, resulting in an increase in the fuel efficiency (0.3–36.7%) [28]. Furthermore, the fuel economy of the parallel HEVs is also improved significantly (up to 68%) compared to a conventional vehicle. One of the reasons for this tremendous fuel economy improvement was the usage of regenerative braking, representing the recovery of free energy [29]. From these studies, series HEVs have been effectively applied in transport mode; meanwhile, parallel HEVs require further modification of the drive train to gain higher energy efficiency.

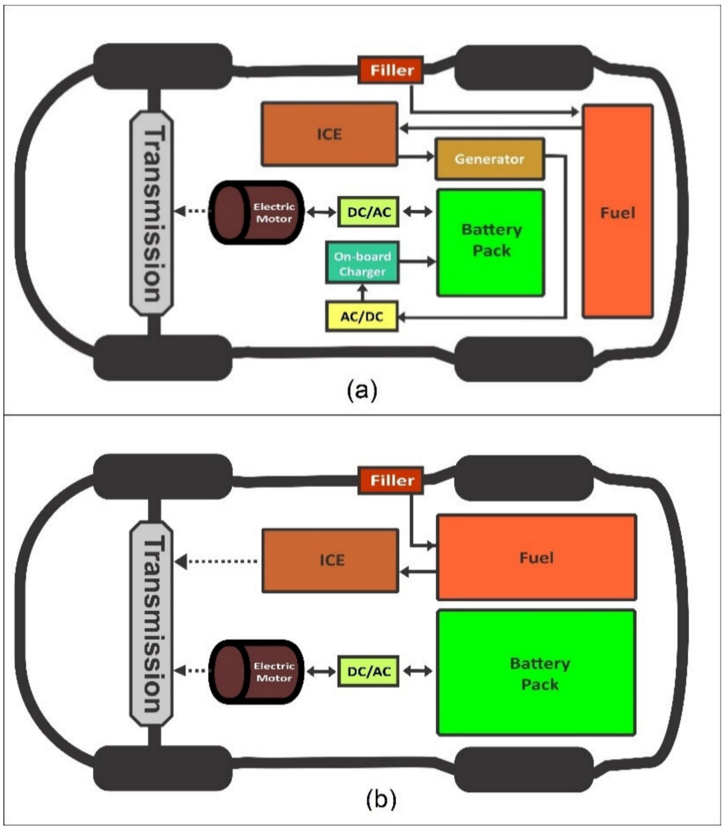

Figure 2. An HEV architecture: (**a**) series HEV and (**b**) parallel HEV.

Another type of HEV that is equipped with a relatively smaller capacity of the battery and an electrical motor (10–20 kW) is a mild hybrid electric vehicle (MHEV) [30]. Although this type of EV has no significant difference in hardware configurations with other types of HEVs, they have differences in the control algorithms. In other words, an MHEV is a hybrid vehicle but with lower power of hybridization (about 15%), and it has a smaller size of driving electric components than other types of HEVs because the production of propulsion energy mainly depends on the ICE [31].

The main issue of HEVs is the energy source management caused by the multiple energy sources and optimization. To obtain energy consumption as a pattern of a driving cycle, it requires an entire model system and needs to be validated by test run data and proven commercial simulator software [32].

2.3. Plug-In Hybrid Electric Vehicles (PHEVs)

PHEVs were developed to increase the range of HEVs. Similar to HEVs, PHEVs utilize an electric motor, an ICE, a generator, and a battery. However, the battery can be charged via the utility grid, apart from the regenerative braking strategy. PHEVs are basically a combination of BEVs and HEVs. Figure 3a,b shows a series and parallel PHEV, respectively. The terms of series and parallel represent whether ICE is only used for charging the battery or providing traction to the vehicle, respectively, which are identical to HEVs.

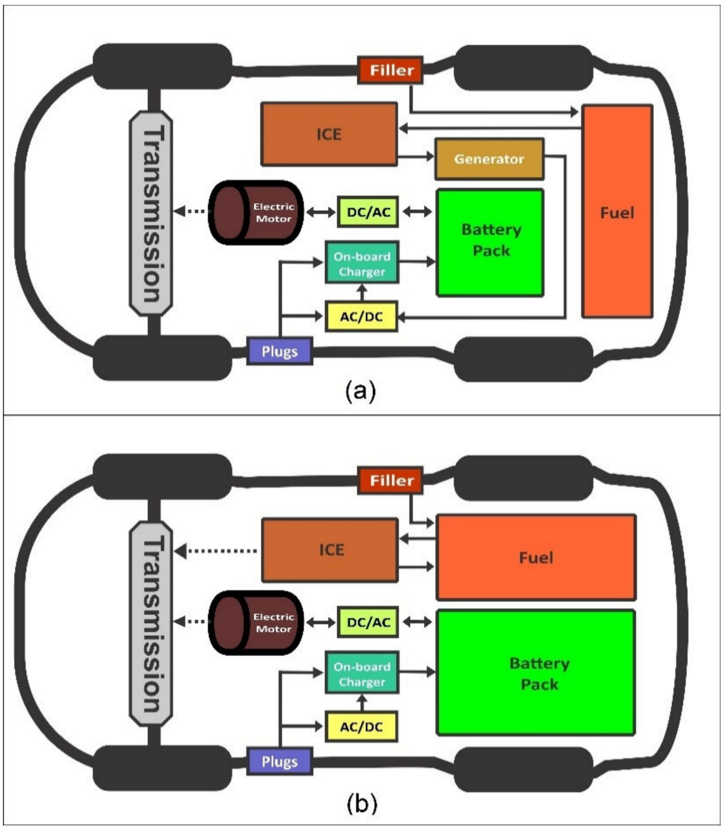

Figure 3. A PHEV architecture: (**a**) series PHEV and (**b**) parallel PHEV.

Compared to HEVs, PHEVs can specifically charge the battery from the utility grid and have bigger battery packs. Additionally, while the HEVs are only permitted to operate in charge sustenance (CS) mode (the battery state of charge (SOC) can operate within a narrow/specific range), the PHEVs can also be operated in charge depletion (CD) mode, which is the ability to operate in pure electric mode or blended mode (prioritize using the electric motor over ICE). A study about charge depletion mode has been conducted by Taherzadeh et al. with the purpose of enhancing the fuel consumption of parallel PHEVs [33]. By using the urban dynamometer driving schedule (UDDS) drive cycle and various trip distances, the fuel consumption of parallel PHEVs was reduced by 7.1% over a 64 km trip distance, by 6.3% over a 48 km trip distance, and by 5.6% over a 32 km trip distance [33]. This study remarked that the longer the trip distance, the better PHEV performance using the CD control strategy.

Similar to BEVs, as the battery capacity of PHEVs becomes larger, the charging time becomes the main issue; thus, charging strategies are essential for supporting the performance of the vehicle. One of the ways to tackle the issue is by using a fast charger, which is able to provide a larger capacity of DC electricity to charge the vehicles. There are several fast DC charging standards, including CHAdeMO (charge de move) and Combo, which are able to provide a fast-charging mode, generally up to 80% of the capacity within 30 min depending on the rate of power delivery (6–200 kW) [34]. Furthermore, since both CHAdeMO and Combo support a fast-charging process, they have a good prospect for the vehicle-to-grid (V2G) technology. Rumale et al. have developed and analyzed the V2G system architecture, implementation, and testing [35]. The result showed that a vehicle equipped with a CHAdeMO interface (VCI) that was fully implemented by the physical and protocol level of the CHAdeMO standard was able to facilitate and well-manage both communication and electricity transfer between the vehicle and the charger. In the future, both PHEV and BEV can play an important role by allowing the vehicles to store power from the grid into the battery and also feed it back to the distribution network when needed.

Other issues such as power losses, stability systems, and robustness are also some concerns of PHEVs. A unique smart-charging scheduling algorithm (SCS Algorithm) could potentially beat these issues, especially related to the case of robustness. By coordinating multiple PHEVs (30 EVs) in a smart grid system, optimal scheduling of PHEV charging was obtained. The results showed that it was robust enough, and it provided consistent values with a standard deviation of below 1 ($\sigma = 0.8425$) [36].

Figure 4 shows the powertrain configuration of series-parallel HEVs and PHEVs. Series-parallel HEVs/PHEVs gain all the benefits from series and parallel modes, such as longer travel mileage, high efficiency, and fuel economy improvement [37]. A study related to fuel consumption efficiency for series-parallel PHEVs was conducted by Zhao and Burke. Their study showed that the fuel consumption of a series-parallel PHEV with the UDDS (city driving) strategy was lower (20.8 km/L) compared to the same type of car with series-shaft PHEV (20.4 km/L). The same result was also obtained by the HW-Interstate (freeway driving at speeds up to 120.7 km/h) strategy, in which a series-parallel PHEV gained a better fuel consumption efficiency [38]. Another study about the energy efficiency of series-parallel PHEVs using the blended power-split mode strategy also showed a significant improvement. Due to energy allocation and power management in a driving system, it provided a practical case on the control method of the power management for series-parallel PHEVs. The result significantly improved the entire system's efficiency from 19.3 to 24.6 km/L (27.53%) [39]. However, this vehicle type is more expensive, has a complex design, and is heavy.

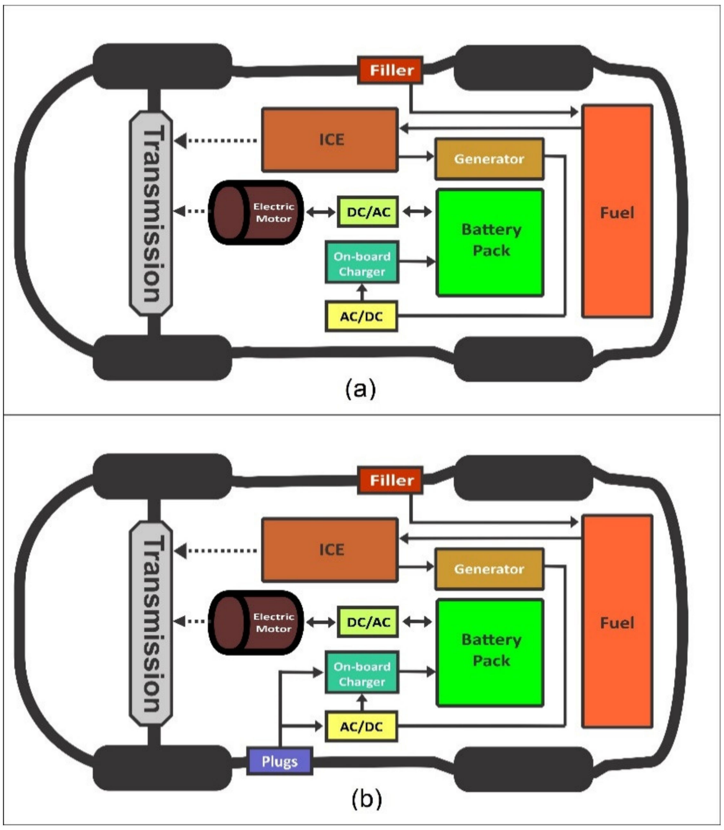

Figure 4. A series-parallel hybrid electric vehicle architecture: (**a**) a series-parallel HEV and (**b**) a series-parallel PHEV.

Another type of PHEV is an extended-range electric vehicle (EREV). The difference with other types of PHEVs is that the electric motor continuously moves the wheels, and the engine works as a generator to recharge the vehicle's battery when it depletes or as it moves the vehicle [40]. The EREV has great preferences in decreasing mineral resource consumption and fossil energy consumption. Liu et al. revealed that the consumption of mineral resources of EREV is 14.68% lower than that of HEV, and the consumption of fossil energy of EREV is 34.72% lower than that of ICEV [41]. The low consumption of mineral resources may be caused by the smaller size and fewer components of the vehicle. Low fuel consumption can be achieved because the fuel is only used for operating the generator, which has constant rotational speed and torque for battery charging. The speed and torque of the generator can be set at maximum energy efficiency to save fuel. Compared with BEV, EREV can have a longer distance due to the range extender, but it must be considerably compact to compete with BEV in terms of energy efficiency [42].

2.4. Fuel Cell Hybrid Electric Vehicles (FCHEVs)

In the transportation sector, FCHEVs use fuel cells and energy storage systems (ESSs) (Figure 5), and they have many advantages, including zero pollution, high efficiency, satisfactory driving range, and independence from fossil fuel. They also only produce water as a byproduct through the tailpipes, which can become a potential solution to the energy crisis and environmental pollution. FCHEVs' refueling time is quicker than the charging process of a battery at the station and almost the same as a conventional vehicle refueling time at a gasoline station [43]. The refueling time of an FCHEV depends on the operating pressure of the tank. For example, a 350-bar tank requires 8 min to refuel the hydrogen for a travel distance of up to 300 km. Meanwhile, a 700-bar tank requires around 14 min to refuel the hydrogen for a travel distance of up to 600 km [44].

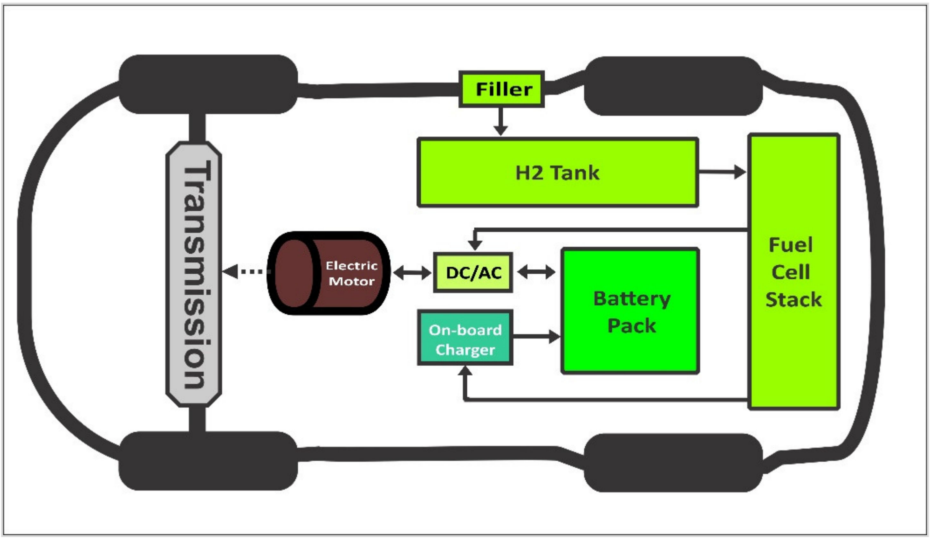

Figure 5. An FCHEV architecture.

An FCHEV gains more advantages compared to a traditional vehicle that has an internal combustion engine or to an HEV because an FCHEV only uses one propulsion system instead of an internal combustion engine or a combination between an electric motor and an internal combustion engine. In addition, the combination of the power energy sources used in the FCHEV will increase its efficiency. Fathabadi proposed a novel hybrid power source of a fuel cell and a supercapacitor to be utilized in an FCHEV [45]. The main power source used was a 90 kW proton exchange membrane fuel cell stack and a 600 F supercapacitor bank as the auxiliary energy. This study demonstrated that the FCHEV gained a power efficiency of 96.2% around the rated power and highly accurate DC-link voltage regulation. The study also showed that an FCHEV with a load of 1880 kg could travel in the range of 435 km on one tank of hydrogen with a fuel capacity and tank pressure of 5.4 kg and 345 bar, respectively, and with a maximum speed of 158 km/h. The researcher remarked that compared to the state-of-the-art fuel cell/battery, another fuel cell/supercapacitor, and fuel cell/battery/supercapacitor hybrid power sources used in FCHEVs, the novel hybrid FCHEV gained better parameters, such as higher power efficiency, speed, and acceleration [45]. The drawback of FCHEVs is the dependency on the storage capacity and high-speed dynamic response that should be utilized as an auxiliary energy storage device along with the fuel cell (FC) stack. An FC stack in a vehicle cannot provide appropriate responses during the acceleration and deceleration of the vehicle [46,47]. The FC stack also cannot store the regenerative energy produced during deceleration and braking; therefore, it needs an additional energy storage device such as a rechargeable battery or supercapacitor bank with the energy management systems implemented into it [48].

3. Key Component Technologies for EVs

The popularity of EVs is not detached from the technologies supporting the EVs inside. The technologies can be applied to EVs to satisfy the driving requirements and demand.

3.1. Battery Technologies

Among energy sources, such as energy from regenerative braking, energy from the fuels, and energy from some power storages (e.g., supercapacitor), the battery is the main energy supplier used in EVs. The battery has a flexible design, and it can be configured corresponding to the voltage and current demand either in a series, parallel, or series-parallel arrangement. The battery also has three types of cells that are commonly used for EVs: cylindrical, pouch, and prismatic cells [49]. The selection of battery devices should be carefully considered in various vital features, such as lifecycle, power density, energy density, capacity, and SOC. Among other types of batteries, rechargeable batteries are introduced as one of the most powerful sources for the electric automobile, e.g., lithium-ion. The initial formation of the rechargeable battery was derived from the lead-acid battery in 1858, followed by the nickel-iron alkaline battery in 1908, and the LIB in 1970, which had higher specific energy and energy density than the others [50].

The battery's lowest specific gravimetric energy density comes from lead-acid batteries, with only between 30 and 50 Wh/kg. The lifecycle of a lead-acid battery is also short, only 500–1000 cycles. Considering that 1 kWh of electricity provided by the battery can supply the energy consumed to travel 8 km, a minimum of about 500 kg lead-acid battery is required to travel 200 km. However, lead-acid batteries are low priced (around 300–600 USD/kWh), suitable for small and low-performance vehicles [15], and recyclable, which is one of the most important aspects of any battery technology. Recycling lead-acid batteries have been a longtime practice since it was first used until now. Recycling rates for this type of battery are almost 100% in Western countries and high rates are also achieved in other countries. Lead-acid batteries utilize 85% of the lead produced around the world and recycled lead speaks to 60% of the total lead production. The lead-acid battery is easily broken; therefore, the components might be separated from the plastic containers and their acid [51].

Another type of battery with better performance compared to the lead-acid battery is Ni-MH. This battery has specific gravimetric energy density within the range of 40–110 Wh/kg, which is higher than lead-acid batteries [15]. Nickel-based batteries, especially Ni-MH batteries, were popular for utilization in EVs (Prius) in the early 1990s, because Ni-MH batteries provide better environmental compatibility [52,53]. However, this battery technology has some weaknesses, such as poor performance in cold weather and memory effects. Additionally, the biggest weakness is its poor charge and discharge efficiency: it has a longer recharging time and has a very high self-discharge rate when the battery is not used [54].

A similar type of battery, nickel-cadmium (Ni-Cd), also has a memory effect and requires high charge and discharge rates. Furthermore, its specific energy density is quite low, only between 60 and 80 Wh/kg, and it is toxic to its components [54]. Chen et al. conducted a study to improve the rechargeability of nickel-hydrogen (Ni-H) batteries. The challenge was to find a low-cost material with an extended cycle and calendar lifetime of battery chemistries to be used within the grid storage. This study introduced the idea of a manganese-hydrogen battery with a Mn^{2+}/MnO_2 redox cathode paired with an H^+/H_2 gas anode, which featured a long life of 10,000 cycles for the grid energy storage. The idea was to replace Mn^{2+}/MnO_2 redox with a nickel-based cathode, which enabled ten times higher areal capacity loading, reaching 35 mAh/cm^2. The researcher also replaced a high-cost Pt catalyst on the anode with a low-cost bifunctional nickel-molybdenum cobalt alloy, which could successfully catalyze hydrogen evolution and oxidation reactions in alkaline electrolytes. The result was that the proposed Ni-H battery has a specific gravimetric energy density of 140 Wh/kg and excellent rechargeability of over 1500 cycles [55].

The sodium-nickel chloride (Na-$NiCL_2$) batteries, or Zero Emissions Batteries Research Activity (ZEBRA) batteries, are considered safe and low-cost batteries, and they can be discharged almost completely without degrading their lifecycle. Moreover, the specific energy of this battery is about 150 Wh/kg. A ZEBRA battery can be operated in extremely high temperatures, ranging from 245 to 350 °C; therefore, this battery has much pressure on its thermal management and safety concerns [56].

The application of ZEBRA batteries as a storage source technology may be a perfect case [57]. They are at negligible danger of fires due to the intrinsic safety of the cell's chemical reactions, which was confirmed by several tests performed: an immersion in 900 L of 5% saltwater test, seismic and vibrational test, and an external fire exposition test for 30 min, which had no damage to the cells and the modules. Therefore, at the moment, this technology is highly applicable to stationary energy storage. The three-hour rate discharge time also makes this technology very attractive for load leveling, time-shifting, voltage regulation, and the power fluctuation mitigation of renewable energy sources [57].

The latest technology of batteries is lithium batteries. They are considered the most promising battery due to their specific energy, light, low cost, non-toxicity, and fast charging. These batteries have a specific gravimetric energy density of about 118–250 Wh/kg [15] and are still under development to gain higher specific energy. Lithium-ion employs silicon nanoparticles (SiNPs) as anode electrodes that carry the potential for higher energy density [58]. A lithium battery also has both the highest electrochemical potential and a low equivalent mass. Furthermore, it has high efficiency and a long lifespan [59]. On the other hand, it is expensive (more than 700 USD/kWh) and may cause fires and destruction when overcharged [60].

The higher performance of lithium batteries will end in serious polarization caused by mass transport limitations within the electrolyte and electrodes. The impact of every process on the polarization depends on the dynamic and kinetic material properties, the battery design, and the charging-discharging mechanism. Chen et al. decreased the particle size of the active material to scale back the solid phase diffusion polarization. Half (from the original) of the active material particles could significantly reduce the concentration difference of the LIB. On the contrary, the concentration difference of Li-ions significantly increased when the active material particles were two times larger than the initial value.

Various LIBs have been established worldwide, including lithium-titanate-oxide (LTO), lithium-cobalt-oxide (LCO), lithium-manganese-oxide (LMO), nickel-manganese-cobalt-oxide (NMC), and lithium-iron-phosphate (LFP). LIB is different from lithium-polymer batteries (Li-Po), especially in the used chemical electrolyte. They have their own features: the LIB has higher energy density, lower cost, and no memory effect. On the other hand, it prioritizes the security aspect, which is susceptible to thermal failure resulting in flame or explosion. Meanwhile, the Li-Po battery features the flexibility of shape, a lower chance of electrolyte leaking, and low profile. It is often managed into various sizes for better packaging optimization. However, Li-Po batteries suffer from a relatively expensive manufacturing cost, less energy density, and a shorter lifecycle [61]. Table 1 summarizes the specification of existing batteries in EVs. In addition, Figure 6 shows a plot between the specific power and specific energy of the batteries.

From Figure 6, it can be seen that the specific power and specific energy of batteries tend to increase along with the development of the batteries (starting from lead-acid to Li-ion). Thus, the challenge now is to develop a battery with higher specific power and density for the future.

Table 1. Comparison of energy storage specifications from batteries in EVs.

Specification	Lead-Acid Battery	Ni-MH Battery	Na-NiCl$_2$ Battery	LIBs	References
Gravimetric energy density (Wh/kg)	30–50	40–110	150	118–250	[54,62]
Volumetric energy density (Wh/L)	100	180–220	160	200–400	[62,63]
Nominal voltage (V)	2	1.2	2.4	3.6	[64–66]
Lifecycle	500–1000	<3000	>1200	2000	[62,67,68]
Energy efficiency (%)	>80	70	80	>95	[62,67]
Cost (USD/kWh)	100	853–1700	482–1000	700	[62,66]

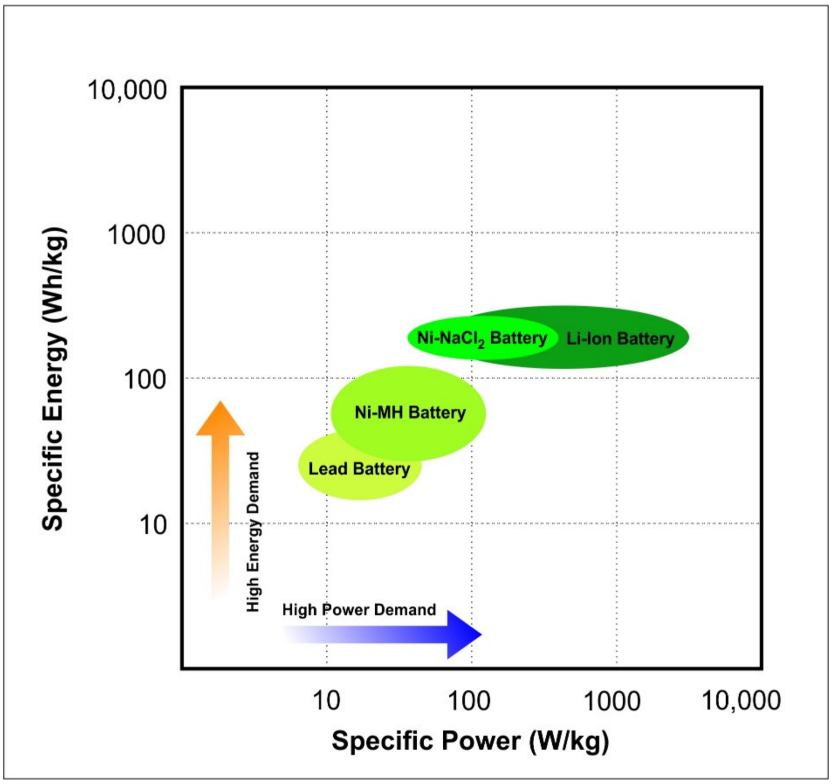

Figure 6. Plots of specific power versus specific energy of a battery storage device.

In addition to the battery, the supercapacitor is also an important energy storage option. It is an electromagnetic system where the static energy is stored in electrodes and electrolytes. The storage capacity and performance of the supercapacitor are basically influenced by materials for both electrodes and electrolytes, ionic size, and electrolyte decomposition voltage [68]. Due to its capability to provide high energy density and surface area, activated carbon is generally adopted as an electrode material, while high conductive material is installed between the electrode and the contact in order to collect the current. Moreover, an electrolyte membrane is also adopted to separate the electrode and facilitate ion-charge mobility, as well as to avoid an electronic interaction [69]. Supercapacitors can be categorized into three types: (a) electrochemical double-layer supercapacitor (carbon nanotube, activated carbon, and carbon aerogels), (b) pseudo supercapacitor (metal-conductor, polymer-metal oxide), and (c) hybrid supercapacitor (battery, asymmetric, composite) [70,71]. Supercapacitors can be combined together with the battery to provide higher and responsive power output. A typical supercapacitor has a power density of 300–5000 W/kg [72], and an efficiency cycle of 90–95% (higher than battery) [73]. Recharging time for supercapacitors is very short, in the range of seconds to several minutes [74], because of their low internal resistance, which finally reduces the internal resistance of the cells [75].

3.2. Electric Motor Technologies

The electric motor is another important part of EVs. The electric motor is used to convert the energy from electricity to mechanical work, and vice versa. An electric motor is able to provide high power and torque to the transaxle or differential for propulsion. Compared to ICE, the electric motor can generate instant power and torque; thus, the transmission in EVs might not be required. Electric motors also have high energy conversion efficiency (between 80% and 95%), which is much higher than the ICE [76].

Different types of electric motors, including induction motor (IM), permanent magnet-synchronous motor (PM-SM), permanent magnet-brushless DC motor (PM-BLDC), and switched reluctance motor (SRM), are used as an electric drive in EVs [77]. Among them, IM and PM-SM are considered as the most preferred motors to be applied in EVs due to their high efficiency and power density [78]. Some features of electric motors that are demanded EVs and compared before being applied for EVs include installation space, power density, machine weight, reliability, efficiency, torque-speed relationship, overload capability, and cost [79].

IM has high efficiency, starting torque, and power, simple construction, low cost, roughness, low maintenance, and high reliability. IMs can operate in any hostile environment and do not suffer from any speed limitation problems [80]. However, the control system of the IM is quite complex and still has a problem with the power density. The energy efficiency of this motor depends on the amount of the total losses, which can be partitioned into losses in the magnetic circuit (iron losses), losses in windings (copper losses), losses in the converter (commutation and stray losses), and mechanical losses. A study regarding the losses of IM motors was conducted by Mahmoudi et al. [81]. In their study, they used a finite element analysis to estimate the efficiency of an IM motor based on mapping of losses [81]. The study showed that each loss map determined the efficiency map of the IM motor. Lumyong et al. also proposed a technique to increase the efficiency of an IM motor by decreasing the number of stators turns by about two times (0.75, 2.25, and 3.7 kW IM motors were used) [82]. As a result, the efficiency of the proposed motor was significantly increased compared to the original motor control. For the 0.75 kW motor, the efficiency increased from 78% to 85.39%, for the 2.25 kW motor, the efficiency increased from 83.23% to 86.22%, and for the 3.7 kW motor, the efficiency increased from 86.25% to 87.62% [82].

PM-SM offers several featured abilities to generate constant torque and offer high efficiency, high power density, and low energy consumption. PM-SM provides robustness for an electrical balance and ensures a reliable overall performance as PM-SM increases the motor efficiency by about 10% [83]. PM-SM is quite small and has more compact mechanical packages. Furthermore, the rotor of PM-SM has no coil and brushes, so it produces a low heat generation. PM-SM also has highly conductive materials and high permeability on the permanent magnets, so it is suitable for EVs and HEVs [77]. On the other hand, the initial cost of this motor tends to be high because of the permanent magnet inside, and the availability of PM material resources is limited and expensive [84]. Moreover, the energy loss issue of PM-SM during conversion is still a matter to be overcome. Guo et al. proposed a novel global loss model of PM-SM to calculate the fundamental and harmonic losses using double Fourier integral analysis [85]. The main objective of this study was to gain a minimum energy loss total (the fundamental iron loss, fundamental copper loss, harmonic iron loss, and harmonic copper loss) for a better performance of EVs. This study achieved the minimum energy loss with an efficiency of 94% [85]. To determine the PM-SM motor's optimal parameter, Wang et al. proposed a method of electromagnetic parameters matching those applied to the interior PM-SM [86]. This strategy provided a simple solution for deciding the electromagnetic motor parameters with different field-weakening ratios and saliency ratios. The results indicated that the optimal parameter value of the saliency ratio was 2–2.73, with the range of the field-weakening ratio of 1–1.37 [86].

Another motor type initiated by rectangular AC which has a significant torque pulsation is PM-BLDC. This motor can produce the maximum torque in the region of constant-torque operation by keeping close to 90° between the stator and the rotor flux. The constant power can be obtained by the phase-advance angle control method [87]. The main features of the PM-BLDC motor are high power density, high efficiency, and good heat dissipation. The drawbacks of the PM-BLDC motor are the expensive initial cost because of the magnet in the rotor and the presence of a permanent magnetic field causing the field-weakening capability to be limited [88]. Sharifan et al. investigated automotive standard features such as speed/accelerating characteristics, grade ability, fuel consumption, pollutant emission, and state of charge of batteries. This method was implemented to the two best-candidate motors for utilization in HEVs (IM and PM-BLDC) using an advanced vehicle simulator software package. The fuel consumption of each motor per 100 km was 11.8 L for PM-BLDC and 11.9 L for IM. The total pollutant emission for PM-BLDC was also lower than IM (2.68 g/km for the former and 2.72 g/km for the latter). The results show superior performance of PM-BLDC for the utilization in hybrid EVs, compared to the IM motor [89].

The last motor type used in EVs is SRM. It has the simplest configuration compared to the others. It only consists of a rotor (moving part) and a stator (non-moving part), where the winding is only on the stator. Since the SRM has no permanent magnet, it is cheaper than the PM motors. Furthermore, SRM has a fault-tolerant operation, meaning that one phase fault will not affect the other phases. Despite some problems needing to be resolved, such as acoustic noise, torque ripple, converter topology issues, and electromagnetic interference, SRM is still considered a physically strong candidate for EVs and HEVs due to the robust construction and the cost [90]. Kumar et al. analyzed the performance of SRM 10/8 (SRM 5 phases) drives for EVs under abnormal conditions, such as open-circuit faults and short-circuit faults [91]. The SRM possessed a good dynamic response with the feature of great fault-tolerant behavior. The indicators used to analyze the performance of SRM-driven EVs were speed, torque, and SOC. In a normal condition, SRM reached the speed reference at 1.23 s. Meanwhile, in a 1-phase short circuit condition at 1.26 s, the SOC decreased by 0.04%, and the torque was constant at 485.3 Nm [91]. The benefits and drawbacks of the electric motor are shown in Table 2, and the efficiency map of the SRM motor, IM motor, and PM-SM motor in Figure 7.

Table 2. Benefits and drawbacks of electric motors used in the EVs.

Parameters	IM	PM-SM	PM-BLDC	SRM
Efficiency	+++	++++	+++++	++++
Power density	+++	++++	++++	++
Size	+++	+++	+++	+++
Acoustic noise	+	+	+	++
Torque ripple	+	+	+	+++++
Fault-tolerant	++	++	+++	++++
Simple construction	++	++	+++	+++++
Reliability	++++	+++	+++	++++
Technological maturity	+++++	++++	++++	++++
Cost	+++	+++++	+++++	++++
Opportunity	Real market penetration in the automotive industry	As the preferred option in current EVs and HEVs	High possibility to be used for initial choice for driving EVs	Gaining intensive attraction from the scientific and industrial community
Challenge	A new technology control for reducing fault tolerance and slip	Accurate continuous position feedback for the torque ripple	Requirement of external transmission systems, e.g., fixed gear and chain drives	The identification of current switching angle for non-linear control
References	[79,88,92,93]	[79,88,94]	[78,79,88]	[79,88,94,95]

+ low; ++ medium low; +++ medium; ++++ medium high; +++++ high.

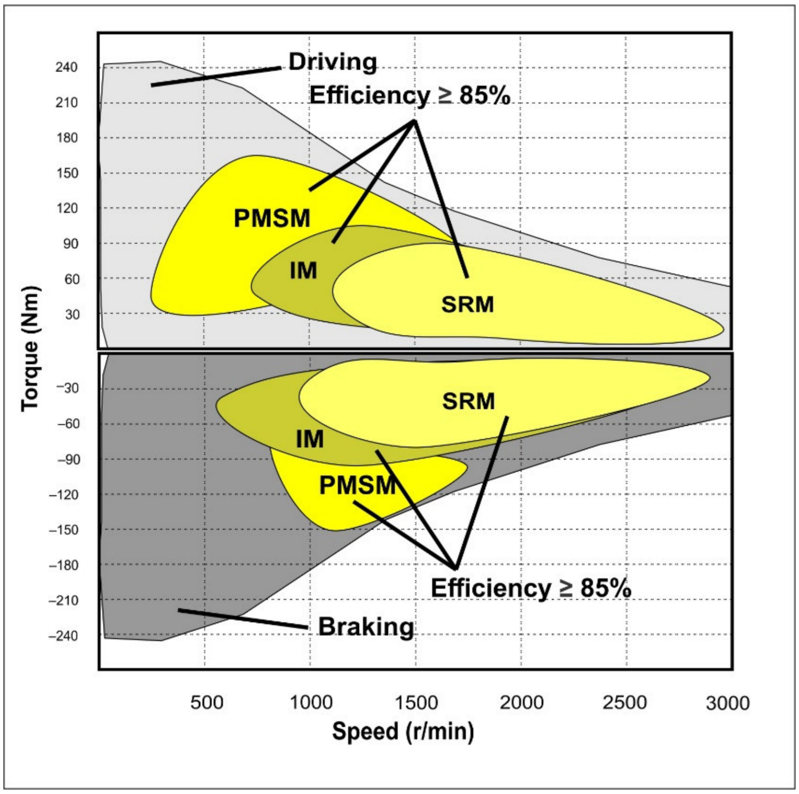

Figure 7. The efficiency of electric motors [80,96–98].

As shown in Figure 7, each electric motor has its optimal efficiency area for both the driving cycle and the braking cycle. Aliasand and Josh discussed motor types and their drives regarding the efficiency, maximum speed, cost, and reliability used in EVs (IM, PM-BLDC, PM-SM, SRM) [77]. This study found that compared to other types of motors, the most efficient one was the PM-BLDC motor, the highest speed was the SRM motor (Figure 8), the most generally utilized motors were the induction motor and the brushless DC motor, and the most cost-effective motor was the induction motor [77]. Table 3 summarizes the model specification of EVs in the market, including the EV types, battery capacities, the electric motors used, motor rating, and travel distance.

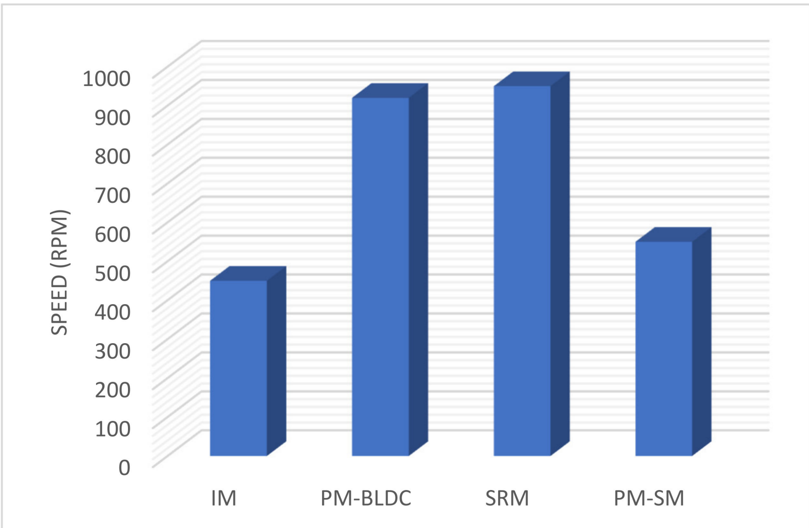

Figure 8. Speed comparison of motors [77].

Table 3. The specifications of commercially available EVs.

Vehicle Model	Type	Battery Capacity (kWh)	Motor Drive	Motor Rating (kW)	Electric Range (km)	Year	References
Audi A3 e-Tron	PHEV	95	PM-SM	75	50	2018	[96,99]
Audi Q5	HEV	10	PM-SM	182	-	2009	[78]
BMW i3	BEV	33	PM-SM	125	180	2011	[87,96]
BMW i8	HEV	82	PM-SM	265	-	2014	[78]
BYD e6	BEV	82	PM-SM	90	-	2016	[6,78]
Cadillac CT6	PHEV	18.4	PM-SM	250	50	-	[96]
Chery eQ	BEV	23.6	PM-SM	41	250	-	[87,96]
Chevy Bolt	BEV	60	PM-SM	150	380	2019	[87,98,99]
Chevy Volt	PHEV	18.4	PM-SM	87	675	2018	[6,96]
Citröen E-Mhari	BEV	-	PM-SM	50	-	2016	[78]
Ford Focus Electric	BEV	33.5	PM-SM	107	185	2017	[87,96]
General Motor EV	-	26.4	-	-	-	2000	[6]
GM prototype	BEV	-	SRM	-	-	1990	[87]
Honda Clarity	-	25.5	-	100	-	2017	[6]
Hyundai Ioniq and Kona	BEV, HEV, P-HEV	28	PM-SM	88	200	2018–2021	[6,98,99]
Kia Soul EV	BEV, P-HEV	30	PM-SM	81	180	2016	[98,99]
Mahindra Reva	BEV	16	IM	35	120	-	[96]
Mercedes Clase B ED	BEV	28	PM-SM	132	-	2015	[6,78]
Mercedes SLS AMG ED	BEV	-	PM-SM	550	-	2014	[78]
Mitsubishi i-MiEV	BEV	-	PM-SM	132	-	2011	[78,87]
NIO EP9	-	90	PM-SM	1000	430	-	[6,96]
Nissan LEAF	BEV	40	PM-SM	110	240	2009	[87,98,99]
Renault Zoe	BEV	41	PM-SM	80	400	2012	[87,96]
Skoda Favorit	-	10	-	-	-	1988	[6]
Smart FortoWo ED	BEV	17.6	PM-BLDC	55	90	2009	[6,87,96]
Tazzari Zero Classic	BEV	-	IM	20	-	2009	[78]
Tesla Model 3	BEV	75	PM-SM	192	350	2016	[87,96]
Tesla Model S 70D	BEV	100	IM	100	380	2018	[87,98,99]
Tesla Model X	BEV	100	IM	193	520	2016	[87,98,99]
Tesla Roadster	BEV	80	IM	185	-	2014	[6,78]
Toyota Prius	PHEV	8.8	PM-SM	50	60	2018	[96]
Volvo C30	-	24	-	-	-	2010	[6]
Volvo V70	PHEV	11.3	-	-	-	2010	[6]
VW e-Golf	BEV	35.8	IM	100	200	2017	[96]

4. Opportunities and Challenges of EVs in the Future

EVs are predicted to be the future of transportation, mainly for the following three reasons: (1) their market share in this industry has been growing rapidly, (2) they are believed to be environmentally friendly and can become a new lifestyle for automotive enthusiasts, and (3) they are a leader in advanced technology. EV-related stocks grew from 3.7 million USD in 2017 to 13 million USD in 2020, and the International Energy Agency (IEA) predict that it will reach 130 million USD by 2030. Furthermore, EV sales are expected to grow 24% on average during the forecast period. Sales grew from 1.4 million in 2017 to 4 million EVs in 2020, and are predicted to reach 21.5 million in 2030 [100,101].

Although EVs have clear advantages over the conventional vehicle, there are still five main challenges to this mode of transportation: (1) vehicle as a future technology, (2) the charging time and the vehicle to grid technology, (3) the battery performance improvement, (4) policy and regulation, and (5) open electricity market.

4.1. Future Technology Vehicle

The EV, as the future technology vehicle, has many opportunities of new technologies to increase its performance and communicate with other EVs as well as its environment. One feature that should be implemented in EVs is the internet-of-vehicles paradigm. With this feature, the interconnected systems among every internal component as well as the connection between the vehicle and the surface world through roadside units and the vehicle to other vehicles can be achieved. Mansour et al. in 2020 attempted to create a smart car that could park by itself (Autonomous Parallel Car Parking) [100]. This prototype could find a suitable empty parking lot and parallel park itself into it, but it needed multiple sensors, such as infrared sensors and ultrasonic sensors, to gather information from the environment. Several benefits could be obtained from this project: decreased accident rate, increased safety from human error, enhanced mobility for the elderly, less skilled and disabled drivers, and reduced driving time [100]. Wang et al. in 2020 proposed an intelligent vehicle for the smart car control system, using the smart phone as the remote wireless control terminal. The smart car utilizes Bluetooth communication and a microcontroller (MCU) as the intermediate bridge. It could facilitate automatic direction control, gravity induction control, voice control, automatic tracking system, automatic anti-collision, and other support functions [101]. This study effectively reduced the cost of equipment, such as wired control and remote-control equipment. Furthermore, Noh et al. in 2021 introduced a new analytical framework for a crosswalk safety assessment with the various vehicle/pedestrian behaviors and surrounding features [102]. This model can improve pedestrian safety for future accidents.

Several cars that have implemented the smart car technology for an increase in performance are Volvo, BMW, and Nissan. In Volvo, the sensors notice the lanes and other automobiles behind, and the pilot assist permits the system to acknowledge the usage of the adaptive controller. In BMW, a new i-Series automobile embodies a variety of machine-controlled driving, such as Wi-Fi, high-definition digital maps, sensor technology, cloud technology, and computing facilities. Lastly, in Nissan, the cars have safety shield-inspired technologies that monitor almost 360 degrees around the vehicle for risks, warn the driving force, and take actions. If necessary, this technology can help the driver in avoiding crashes [100].

4.2. Charging Time

In the current charging process, ultra-fast charging and/or extremely fast (ultra) charging could deliver high-power rate charging power into the EVs, as much as 80% of the battery vehicle in as little as 15 min [98,99]. In 2020, Elma et al. analyzed the existence of an ultra-fast charging system (450 kW) for public buses to determine the dimension of the battery used. In this scenario, a single terminal with a charging station of 450 kW was provided to overtake 100 different routes of between 10 and 20 km in the distance. This scenario showed that for a route length of 17.22 km, the bus consumed 413.28 kWh. If a 450 kW ultra-fast charging station was placed in the terminal, the bus only consumed 190.63 kWh for one charge. This study concluded that the battery size can be reduced by 222.64 kWh (from the initial 413.28 kWh) by placing an ultra-fast charging station at the terminal [103]. For understanding the charging technologies, Table 4 shows the charging power level, charger location, voltage level, maximum power, standard, and charging time.

Table 4. Charging power levels, standards, and configurations.

<table>
<tr><th rowspan="2">Charging Level [104]</th><th rowspan="2">Charger Location [105]</th><th rowspan="2">Voltage Level (V) [98,99]</th><th rowspan="2">Maximum Power (kW) [96]</th><th rowspan="2">Charging Time (h) [96]</th><th colspan="4">Standard [96]</th><th rowspan="2">Cost (USD) [106]</th></tr>
<tr><th>China</th><th>Europe</th><th>Japan</th><th>North America</th></tr>
<tr><td>Level 1 (Slow)</td><td>On-board</td><td>120 AC</td><td>3.7</td><td>10–15</td><td colspan="3">Private outlets (not specific for EVSE)</td><td>SAE J1772 (Type 1)</td><td>500–880</td></tr>
<tr><td>Level 2 (Slow)</td><td>On-board</td><td>220 AC</td><td>3.7–22</td><td>3.5–7</td><td>GB/T 20234 (AC)</td><td>IEC 62196 (Type 2)</td><td>SAE J1772 (Type 1)</td><td>SAE J1772 (Type 1)</td><td>75</td></tr>
<tr><td rowspan="3">Level 3 (Fast)</td><td>On-board</td><td>3-φ 480 AC</td><td>22–43.5</td><td rowspan="3">0.16–0.5</td><td>GB/T 20234 (AC)</td><td>IEC 62196 (Type 2)</td><td></td><td>SAE J3068</td><td rowspan="3">76
-</td></tr>
<tr><td rowspan="2">Off-board</td><td rowspan="2">200–600 DC</td><td><200</td><td>GB/T 20234 (DC)</td><td>CCS Combo 2</td><td>CHAdeMO</td><td>CCS Combo 1</td></tr>
<tr><td><150</td><td colspan="4">Tesla and CHAdeMO</td></tr>
<tr><td>Extra Fast</td><td>Off-board</td><td>>800 DC</td><td>>400</td><td>~gas refueling</td><td colspan="4">CCS/CHAdeMO</td><td>-</td></tr>
</table>

The energy distribution network utilizing EVs—V2G technology—is a promising challenge in the energy sector as the number of EVs increases [107]. Different studies have been conducted to understand the advantages of using these technologies. Aziz and Budiman evaluated the integration of EVs' energy supply to the small-scale EMS to measure the feasibility of ancillary energy services of V2G, especially peak shaving. Five EVs, Mitsubishi i-Miev G, were used as a testbed for this study. This study resulted in reduced grid load and was maintained up to the peak shaving threshold area, proving that the application of EVs to support EMS was feasible and promising [108]. Kriukov and Gavrilas also analyzed the efficiency and the impact of the V2G function [109]. They used energy losses as the parameter to determine the V2G efficiency. The total energy loss from the V2G process was 827 W for the 10 kW energy source used. These results were obtained from various parts, such as off-board charger losses, DC/DC converter losses, heating ventilation and air conditioning power consumption, electronic control unit power consumption, and battery losses. This study obtained a global V2G efficiency of 84.1% [109].

Another semi-fast charger, Wallbox, played an important role in charger management, such as energy control used with the real-time monitoring, charging planning, remote control (lock/unlock and output current), settings for specific tariffs, energy consumption and cost statistics data, and also compatible with the iOS and Android system operation. It could facilitate charging with a capacity of up to 22 kW and assist the users in managing their EVs' energy consumption [110]. Aziz et al. have developed a fast-charging system for EVs equipped with the battery in order to minimize the stress of the grid due to the high demand of EVs' charging and to avoid the high cost of charging during peak time [111].

The hydrogen station also provides a fast-charging time, in terms of FCHEV. It can refuel an FCHEV in less than 5 min for 3–5 kg hydrogen for an approximately 480 km driving range [112], however, the hydrogen vehicles and infrastructure are far from assured. Kurtz et al. built an adaptive hydrogen demand model to predict the hydrogen station requirements and operation. The results were valuable inputs to station builders and operators for providing more information on requirements, operation, future needs, and maintenance strategies that affect the future and economics of hydrogen infrastructure [112]. Three additional aspects that should be considered for developing hydrogen stations are station and equipment sizing, maintenance strategies, and operation strategies [113].

4.3. Battery Performance

To enhance the battery performance, a pulsed current is considered to improve the performance of the LIB. In the study by Huang et al., a LIB cell was charged by applying a 0.05 Hz pulsed current [114]. By varying the duty cycles, the current rates (C-rates) and ambient temperatures obtained a transparent impact of the pulsed current on the battery performance during charging. The result was the pulsed current could improve the charging capacity (30.63%) and reduce the maximum rising temperature (60.3%) compared to the constant current, respectively [114]. Low-temperature preheating technology is also a potential prospect for improving battery performance and preventing battery accidents. Biao et al. conducted an external preheating method by using the electrothermal plate at the bottom of the battery and by adopting the temperature field distribution [115]. Based on this method, the temperature inside and outside (case) of the battery was not uniform: the case temperature was high, while the temperature inside the battery was still low [115].

The challenges faced by battery technology come from both internal and external aspects. The internal aspect is affected by energy density and lifespan. The energy densities of the battery determine the driving range of the vehicle: the higher the energy densities, the longer the distance the vehicle can be driven. Since the energy density is the amount of energy stored per unit volume or weight, space and weight in EVs are the main constraints for increasing the densities. This aspect is still the major challenge of future batteries [116]. Another challenge of the battery technology is the lifespan, which is targeted to be higher than 15 years with the durability against environmental conditions, such as impact, temperature, and vibration, while the external aspect is focused on both the cost of materials and the manufacturing processes, as these two aspects tend to have a high cost [116]. Figure 9 shows the development of battery performance in the volumetric and gravimetric energy density of cylindrical, pouch, and prismatic batteries.

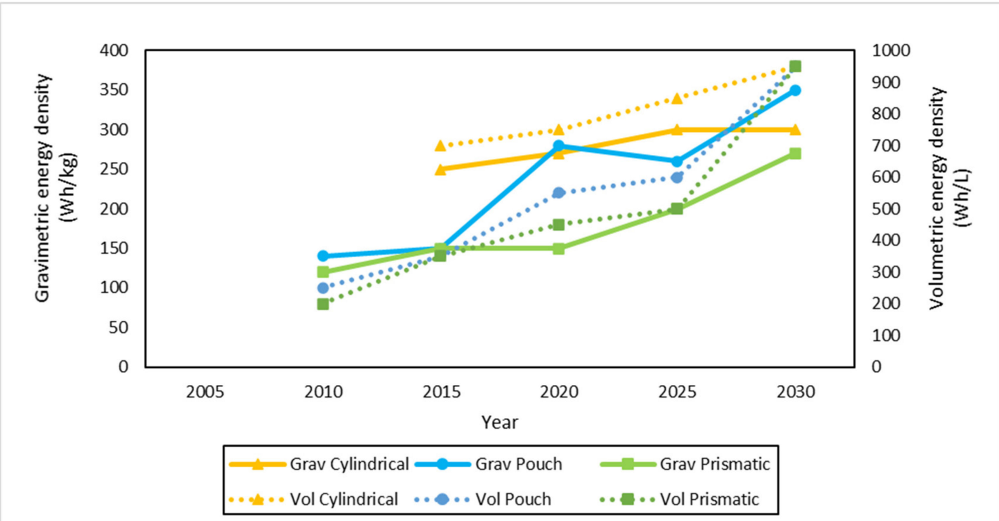

Figure 9. The development of battery performance in the volumetric and gravimetric energy densities for cylindrical, pouch, and prismatic batteries [117].

4.4. Policy and Regulations

The EVs have become an increasingly attractive alternative in recent years. This EV dissemination is highly dependent on the policy intervention [118–120], which is usually only justified to promote technological innovation aspects aimed at reducing negative externalities (such as emissions reduction). Meanwhile, the infrastructure support and regulations of EVs are more of a determining factor for the adoption level of EVs. The Asia-Pacific Economic Cooperation (APEC) investigated the policies of four basic features of the EVs: (1) the charging network, (2) the increasing demand for these vehicles, (3) industrialization, research, and development programs, and (4) the introduction of EVs in sustainable mobility programs. Aimed at enhancing the efficiency of the policy instruments for new energy vehicles, the article described the public policies that had been implemented around the APEC economies to overcome the barriers for adopting the EVs [121]. Another study by Bruckmann et al. examined two types of policy: focusing on purchase subsidies and charging infrastructure expansion. These policies affect the adoption and usage of EVs in the future [122]; thus, the increase in the EV market requires both technology innovation and charging infrastructure advancement, as well as government regulations. Good coverage and capability of charging stations would reduce customers' concerns further, and appropriate government policies could create a healthy environment for the EV market to grow [116].

4.5. Open Electricity Market

The ever-increasing use of EVs will also increase the energy demand for EV charging. In this case, the power system of EV charging stations increases and elevates the cost of energy in open electricity markets, whose prices fluctuate greatly even within the same day. The price of electric energy at peak time is about three times the price at off-peak times [123]. To overcome this issue, EV charging stations that use a hybrid energy system (i.e., the system consists of renewable resources such as PV and conventional sources such as energy markets) are needed. The use of renewable energy sources is important to reduce environmental pollution, but these resources are limited and are not available every hour. Therefore, they are usually combined with conventional ones to make the overall system operation more effective. The challenge of using such a system is that it requires careful study to make its operation optimal, and in turn, it reduces the EV charging costs [124]. Huang et al. have proposed a blockchain-based market mechanism to optimize both charging and discharging behaviors of EVs [125].

Abuelrub et al. presented a multi-mode optimization technique for EV unidirectional charging stations to address this challenge [123]. It can be realized by finding the optimal schedule for charging in the available time horizon in the three modes: normal mode, eco mode, and boost mode. This charging station combines a conventional charging station and PV system. The result showed the effectiveness of this technique as the cost was cut by more than 50% [123].

5. Concluding Remarks

This paper presented an overview of the types of EVs with both advantages and disadvantages, as well as opportunities and challenges. It can be concluded that EVs continue to be developed by continuously implementing cutting-edge technologies, improving energy efficiency, and increasing performance. The selection of which electric motor to use in EVs is based on efficiency, power density, fault-tolerant, reliability, and cost parameters. Adequate infrastructure and appropriate policy play an important role in growing the EV market. Good coverage and capability of EVs' infrastructure will reduce customers' concerns, and appropriate government policies can create a healthy environment for the EVs. However, the study of charging development is still a special topic to be discussed to obtain a shorter charging time than the existing one that does not cause significant stress to the battery.

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Abbreviations

The following abbreviations are used in this manuscript:

BEV	Battery electric vehicle
CHAdeMO	Charge de move
EMS	Energy management system
EV	Electric vehicle
FCHEV	Fuel cell hybrid electric vehicle
GHG	Greenhouse gas
HEV	Hybrid electric vehicle
ICE	Internal combustion engine
IM	Induction motor
LIB	Lithium-ion battery
$NaNiCl_2$	Sodium nickel chloride
Ni-Cd	Nickel-cadmium
Ni-MH	Nickel-metal hydride
PHEV	Plug-in hybrid electric vehicle
ZEBRA	Sodium-nickel chloride batteries with zero emissions batteries research activity

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