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Examining Electric Vehicle Drive Train Technologies in Depth

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Abstract: *Transportation is the second-largest source of greenhouse gas emissions because it produces CO2 gas through the burning of fossil fuels. One potential remedy for this issue is thought to be electric automobiles, or EVs. Electric automobiles can reduce CO2 emissions since they use an electric motor as a propeller rather than an internal combustion engine. EVs have the potential to become zero-emission vehicles when paired with renewable energy sources. The numerous varieties of electric drive trains are discussed in this paper along with their designs, benefits, and drawbacks. The objective is to outline the latest developments in the rapidly changing field of electric car technology. Additionally, the energy density and efficiency, specific energy and power, cost, and application of batteries—the main energy storage system—are compared.*

Keywords: Transportation

I. INTRODUCTION

Over the past ten years, electric vehicles, or EVs, have become more and more popular. The steady depletion of fossil resources, including coal, natural gas, heavy oil, and crude oil, which are sought after by expanding populations in both industrialized and developing nations, is driving up demand [1]. Electric cars have developed into a class that is further divided into Hybrid Electric Vehicles (HEVs)2 and Plug-in Hybrid Electric Vehicles (PHEVs)3 as a result of continuous efforts and innovative research activities in the Battery Management System (BMS) for applications in EVs. While the majority of EVs on the market now are either HEVs or PHEVs, PHEV demand is unquestionably higher. This is because the cars can run on both conventional fuels like gasoline and electric power that is stored in a battery (energy storage device).

Because EVs are so popular, many scholars have conducted research on different kinds of EVs. The energy consumption of BEVs and ICEs in passenger cars under different driving conditions was examined by Braun et al. [2]. In Erfurt, Germany, the impact of driving decisions and traffic during peak hours on energy use was examined. The results show that the BEV performs 69.2 percent better in terms of fuel efficiency than traditional cars. The BEV's power train features, which are only employed when propulsion is necessary, resulted in this notable benefit. They use regenerative braking, which absorbs the mechanical energy produced during braking and transforms it into electrical energy that charges the battery. By optimizing the federal test procedure (FTP) driving cycle to meet the lowest fuel consumption and emissions of a parallel HEV, Cheng et al. conducted research on HEVs and developed an electric-assist control strategy (EACS) [3]. This method reduced CO2 emissions from 1.78 to 1.42 g/km and increased the fuel efficiency of parallel HEVs by 3.1 percent. These results were mostly caused by the PSO approach, which quickly converged and discovered a globally optimal solution. The authors claim that this approach is the most effective means of resolving the energy problem and lowering pollution [3]. Another study for PHEVs that concentrated on energy management system (EMS) optimization was conducted by Zhou et al. [4]. For a PHEV with two battery packs and a hybrid energy storage system (HESS), the study optimized an EMS design. The findings showed that a PHEV energy storage system's lifespan could be extended by 159–173 percent and PHEV energy efficiency could be raised by 1.6–2.9 percent [4]. These improvements were the consequence of the proposed EMS's reduction of energy conversion loss in HESS.

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ELECTRIC VEHICLE CONFIGURATIONS :-

Electric vehicles (EVs) use a range of energy sources, including conventional fuels, hydrogen, and electricity, and they can be connected to these sources in a number of ways, including through tanks, batteries, and capacitors. EVs can be used independently without the need for additional energy sources or in combination with an ICE. The four categories of electric vehicles are FCHEVs, PHEVs, HEVs, and BEVs [8].

- **HYBRID ELECTRIC VEHICLES (HEV):** Vehicles that use two or more energy sources, storage, or converters—at least one of which provides electricity—are referred to as hybrid electric vehicles (HEVs). In light of the restricted driving range of BEVs, HEVs have emerged as a better option by combining ICE and battery techniques [9].As seen in Figure 2a, a series HEV is powered solely by an electric motor. In contrast, a parallel HEV releases power to move the wheels simultaneously by manually connecting an internal combustion engine and electric motor to the gearbox (see Figure 2b).
  The fuel efficiency and consumption of series and parallel HEVs have been studied. Road sweeper vehicles with a series HEV and a parallel HEV for the same power and trip distance, for instance, were examined for fuel consumption by C. Anbolat and Yasar. Based on their comparison, the series hybrid setup used less fuel (3.8 L/h) than the parallel hybrid setup (6.2 L/h). In the parallel hybrid mode, the engine speed fluctuated, but in the series hybrid mode, the ICE operated at a steady speed during the transport mode [10]. On the other hand, Li discovered that the efficiency of parallel HEV topologies was higher than that of series HEV designs when the hybridization factor (HF) was changed [11].

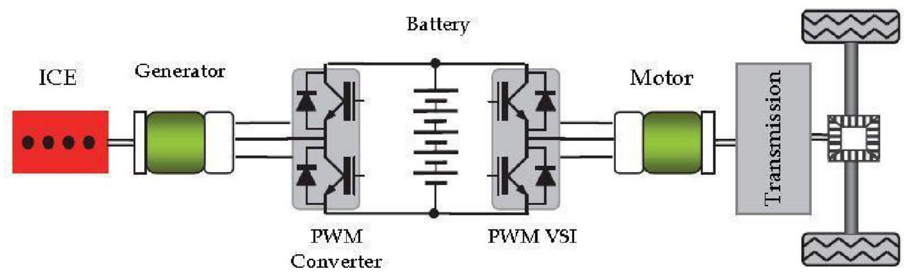

Figure 1: Series Hybrid Electric Vehicle Configuration

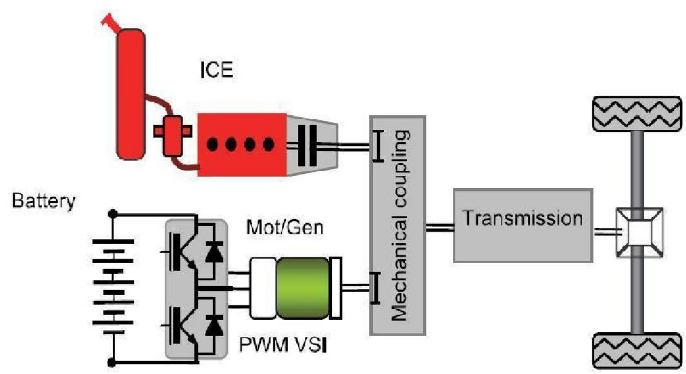

Figure 2: Schematic of a Parallel Hybrid Electric Vehicle

- **PLUG IN HYBRID ELECTRIC VEHICLE (PHEV):** To increase the range of HEVs, PHEVs were developed. Similar to HEVs, PHEVs are powered by an internal combustion engine (ICE), an electric motor, a generator, and a battery. In addition to using regenerative braking, the utility grid can be used to charge the battery. Hybrid electric cars, or PHEVs, combine the advantages of BEVs and HEVs. Figure 3a displays a

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series PHEV, while Figure 3b displays a parallel PHEV. The terms series and parallel, which are synonymous with HEVs, indicate whether an ICE is solely utilized for battery charging or for driving the vehicle.
PHEVs feature larger battery packs than HEVs and are able to charge their batteries straight from the power grid. PHEVs can operate in charge depletion (CD) mode, which enables them to operate in either pure electric or mixed mode (prioritize using the electric motor over ICE), whereas HEVs can only operate in charge sustenance (CS) mode (the battery state of charge (SOC) can only operate within a narrow/specific range). To improve the fuel consumption of parallel PHEVs, Taherzadeh et al. conducted a study on charge depletion mode [33].

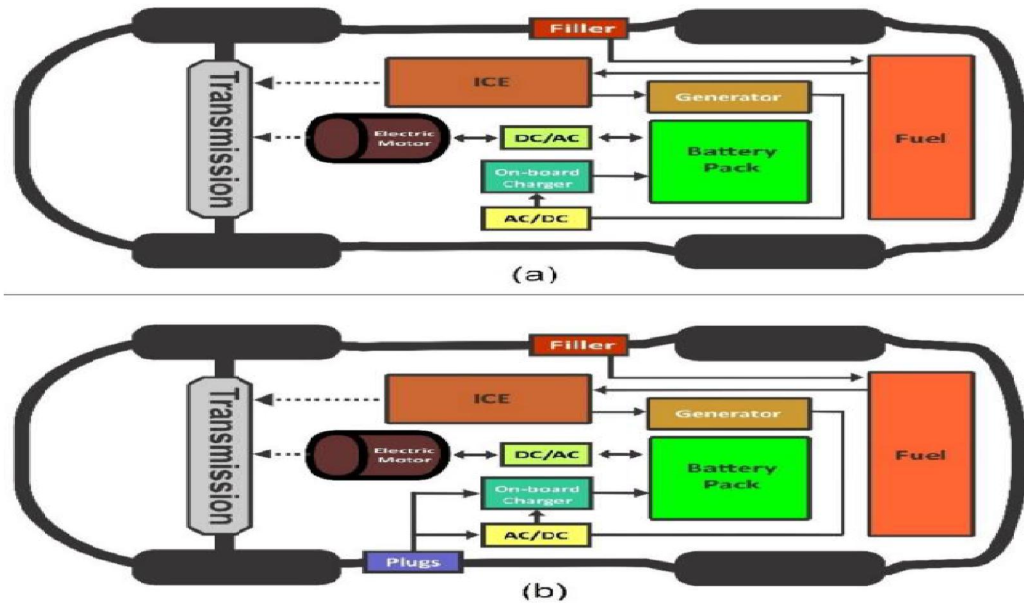

Figure 3: Schematic of a Plugin Hybrid Electric Vehicle

- **BATTERY ELECTRIC VEHICLE:** The range of a BEV is constrained by the battery's capacity since the battery serves as the main energy source for the vehicle's power train (Figure 1). In terms of CO2 emissions, a BEV can be considered a completely green vehicle since it has no tailpipe emissions. With an energy consumption rate of 15–20 kWh per 100 kilometers, a BEV can normally go 100–250 kilometers on a single charge, depending on the vehicle specifications. Greater driving range, between 300 and 500 kilometers, is provided by BEVs with larger battery packs [13]. However, in terms of driving range and charging time, BEVs are significantly less efficient than other EV kinds. One great solution to this problem is the development of an efficient EMS for BEVs. When compared to three distinct braking strategies—full mechanical braking (19.2 km/kWh), serial regenerative braking (19.3 km/kWh), and parallel regenerative braking (19.5 km/kWh)—one study, for instance, successfully developed a type of regenerative braking strategy for three-wheel EVs, yielding a satisfying result of extending mileage to around 20 km/kWh. This modified braking strategy could increase mileage by 4.16 percent km/kWh when compared to full mechanical braking [14].

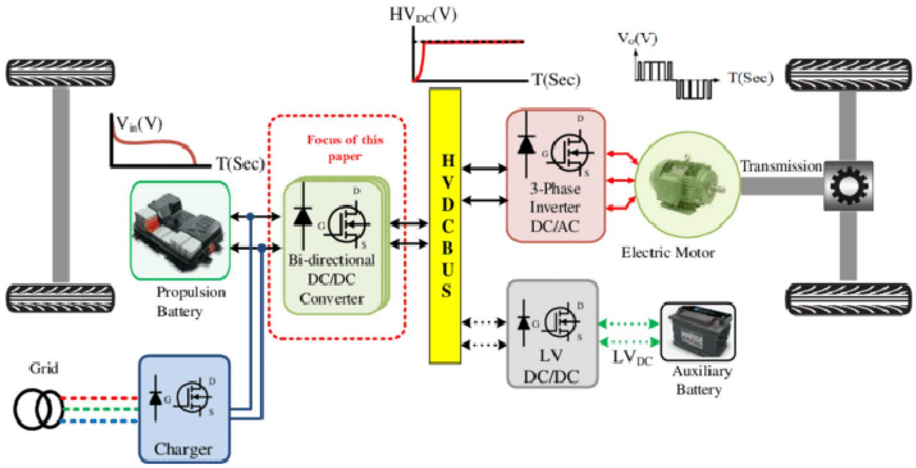

Figure 4: Schematic of a Battery Electric Vehicle

- **FUEL CELL HYBRID ELECTRIC VEHICLE (FCHEV):** In the transportation industry, FCHEVs use fuel cells and energy storage systems (ESSs) (Figure 5). These vehicles have several benefits, such as being emission-free, highly efficient, having a sufficient driving range, and not relying on fossil fuels. Additionally, they only produce water as a byproduct through their tailpipes, which could help with pollution and the energy problem. Refueling an FCHEV takes about the same amount of time as refueling a regular car at a gas station, and it is quicker than charging a battery at the station [15]. The operating pressure of the tank determines how long it takes to replenish an FCHEV. For instance, it takes eight minutes to refill a 350-bar hydrogen tank for a 300-kilometer trip. An FCHEV has more advantages than a typical car with an internal combustion engine or a hybrid electric vehicle (HEV) since it uses a single propulsion system rather than an internal combustion engine or a combination of an electric motor and an internal combustion engine. Moreover, integrating the several electric energy sources will increase the FCHEV's efficiency. For FCHEVs, Fathabadi suggested a novel hybrid power source that combines a super capacitor with a fuel cell [17]. The main power source was a 90 kW proton exchange membrane fuel cell stack, with additional energy coming from a 600 F super capacitor bank. According to this investigation, the FCHEV achieved exceptionally precise DC-link voltage management and a power efficiency of 96.2 percent around the rated power. The study found that an FCHEV with a weight of 1880 kg could travel 435 kilometers on a single hydrogen tank with a fuel capacity of 5.4 kg and tank pressure of 345 bar, respectively, with a maximum speed of 158 km/h. According to the researcher, the new hybrid FCHEV outperformed the state-of-the-art fuel cell/battery, another fuel cell/super capacitor, and fuel cell/battery/super capacitor hybrid power sources used in FCHEVs in terms of power efficiency, speed, and acceleration [17]. The drawbacks of FCHEVs include their dependence on high-speed dynamic reactions and storage capacity, which should be utilized as an auxiliary energy storage device in conjunction with the fuel cell (FC) stack. An FC stack in a car is unable to provide sufficient responses while the vehicle is accelerating or decelerating [18,19].

II. ELECTRIC MOTOR TECHNOLOGIES

The electric motor is another important part of EVs. An apparatus that transforms electrical energy into mechanical work and vice versa is an electric motor. An electric motor may provide the differential or transaxle with a significant amount of power and torque for propulsion. Since electric motors can produce power and torque instantly, transmissions may not be required in EVs when compared to internal combustion engines. Additionally, compared to internal combustion engines (ICEs), electric motors have a far greater energy conversion efficiency (between 80% and 95%) [21]. Electric drives used in electric cars include switching reluctance motors (SRM), permanent magnet synchronous motors (PM-SM), permanent magnet-brushless DC motors (PM-BLDC), and induction motors (IM) [22]. IM and PM-SM are among the most recommended motors for usage in EVs because of their high power density and efficiency [23]. Some of the characteristics of electric motors that EVs require and compare before being utilized in EVs are installation space, power density, machine weight, reliability, efficiency, torque-speed relationship, overload capability, and cost [24].In addition to its straightforward design, low cost, roughness, and low maintenance requirements, IM boasts good efficiency, starting torque, and power. IMs can operate without any speed restrictions in any hostile situation [25]. In contrast, the IM's control system is quite complex and still struggles with power density. The energy efficiency of this motor is determined by the total amount of losses, which may be separated into mechanical losses, commutation and stray losses in the converter, losses in the windings (copper losses), and losses in the magnetic circuit (iron losses).Researchers Mahmoudi et al. [26] investigated IM motor losses. In their investigation, they used a finite element analysis to map losses and calculate the efficiency of an IM motor [26]. According to the study, each loss map was used to calculate the IM motor's efficiency map. By reducing the number of stator turns by half (using 0.75, 2.25, and 3.7 kW IM motors), Lumyong et al. have created a technique for increasing an IM motor's efficiency [27]. Consequently, the efficiency of the proposed motor was significantly higher than that of the first motor control. Efficiency increased from 78 percent to 85.39 percent for the 0.75 kW motor, from 83.23 percent to 86.22 percent for the 2.25 kW motor, and from 86.25 percent to 87.62 percent for the 3.7 kW motor [27]. The ability to deliver steady torque while preserving high efficiency, high power density, and low energy consumption is only one of PM-SM's many specialties. PM-SM provides resilience for an electrical balance and ensures a reliable overall performance because it increases motor efficiency by about 10% [28]. The PM-SM variant has more compact mechanical parts and is smaller. Moreover, the PM-SM rotor produces relatively little heat due to the absence of a coil and brushes. Due to its good permeability on the permanent magnets and highly conductive materials, PM-SM is suitable for EVs and HEVs [22]. However, because PM material supplies are limited and costly, the initial cost of this motor is high due to the permanent magnet inside [29]. Additionally, there is still work to be done to address the issue of PM-SM energy loss during conversion. A new global loss model for PM-SM was proposed by Guo et al. [30] that calculates fundamental and harmonic losses using double Fourier integral analysis. Achieving a low total energy loss (fundamental iron loss, fundamental copper loss, harmonic iron loss, and harmonic copper loss) for better EV performance was the main objective of the study. This study achieved the lowest energy loss with an efficiency of 94 percent [30]. In order to determine the appropriate parameter for the PM-SM motor, Wang et al. proposed a method of matching electromagnetic parameters to those applied to the inside PM-SM [31]. This method offered a simple method for figuring out the electromagnetic motor settings with different field-weakening ratios and saliency ratios. According to the findings, the field-weakening ratio ranged from 1 to 1.37, while the optimal saliency ratio parameter value was between 2 and 2.73 [31].

The PM-BLDC motor type has a high torque pulsation and is started by rectangular AC. This motor can deliver the maximum torque in the constant torque region by keeping the flux between the stator and the rotor close to 90_. Constant power generation can be achieved by using the phase-advance angle control technique [32]. The PM-BLDC motor's main attributes are its high power density, high efficiency, and effective heat dissipation. Due to the rotor's magnet and the persistent magnetic field that restricts field-weakening capabilities, the PM-BLDC motor has a high starting cost [33]. The speed/accelerating features, grading ability, fuel consumption, pollution emission, and battery charge level in cars were all examined by Sharifan et al. The two best-candidate motors for usage in HEVs (IM and PM-BLDC) were subjected to this method using an advanced vehicle simulator software application. For PMBLDC and IM, the respective fuel consumption per 100 kilometers was 11.8 L and 11.9 L. Additionally, PM-BLDC emitted fewer pollutants overall than IM (2.68 g/km versus 2.72 g/km for the latter). The results show that the PM-BLDC motor gives higher performance in hybrid EVs than the IM motor [34].The most recent motor type used in electric vehicles is SRM. It is the easiest to set up compared to the others. It just has a stator, which is the only component with winding, and a rotor, which is the moving part. Because the SRM doesn't have a permanent magnet, it costs less than PM motors. Additionally, SRM is fault-tolerant, meaning that issues in one phase won't impact the others. Due to its robust design and affordable price, SRM is still considered a physically strong candidate for EVs and HEVs despite a number of issues that need to be resolved, including as acoustic noise, torque ripple, converter topology issues, and electromagnetic interference [35]. The performance of SRM 10/8 (SRM 5 phases) EV drives under unusual circumstances, including open-circuit and short-circuit failures, was examined by Kumar et al. [36]. The SRM has exceptional fault-tolerant behavior and dynamic reactivity. The performance of SRM-powered EVs was assessed using

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speed, torque, and SOC. Under typical circumstances, SRM reached the speed reference in 1.23 seconds. In a one-phase short circuit situation, the torque was constant at 1.26 seconds, while the SOC decreased by 0.04 percent. [36] steady at 485.3 Nm. The benefits and drawbacks of electric motors are listed in Table 2, and the efficiency maps of the SRM, IM, and PM-SM motors are shown in Figure 7.

III. ANALYSIS & CONCLUSION

A contrast After examining a number of electric motors for EV applications, Table 1 is generated. Efficiency, power density, size, torque ripple, dependability, and cost are among the various performance metrics that are compared.

COMPARATIVE CHART OF DIFFERENT EV MOTORS

PARAMETERS	INDUCTION MOTOR	PERMANENT MAGNET SYNCHRONOUS MOTOR	BRUSHLESS DC MOTOR	SYNCHRONOUS RELUCTANCE MOTOR
Efficiency	Good	High	Excellent	High
Power Density	Good	High	High	Low
Size	Average	Small	Small	Average
Torque Ripple	Low	Low	Low	High
Construction Complexity	Simple	Simple	Average	Complex
Reliability	High	Good	Good	High
Cost	Low	High	High	Average

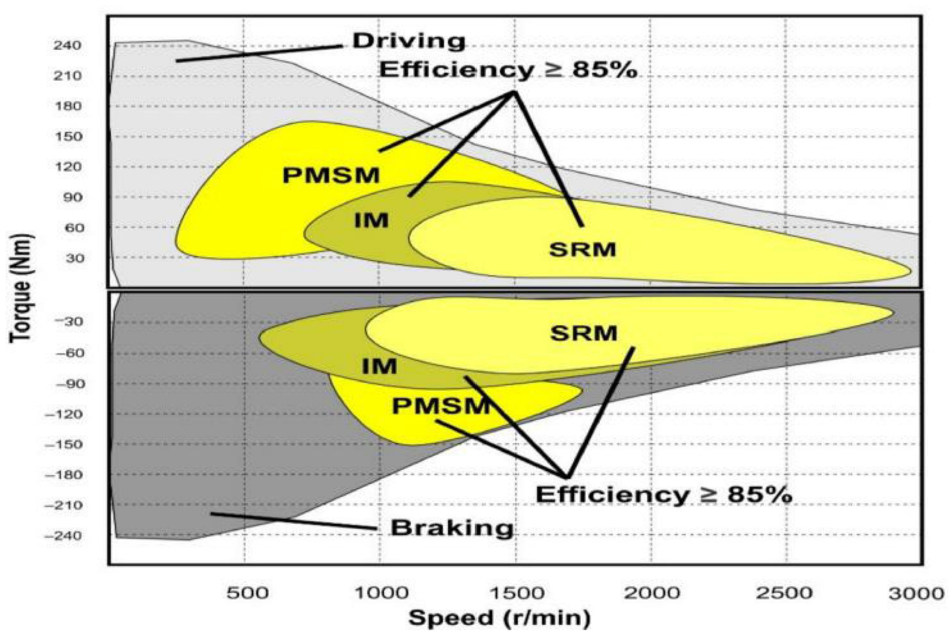

Figure 6: Efficiency maps of motors [80, 96-98]

An overview of the many kinds of electric vehicles, together with their advantages and disadvantages, potential, and issues, was given by this study. It can be said that by integrating state-of-the-art technology, increasing energy efficiency, and improving performance, electric vehicles will continue to develop. The electric motor to utilize in EVs is chosen based on its efficiency, power density, fault-tolerance, dependability, and cost. Legislation and infrastructure are essential to the expansion of the electric vehicle market. The infrastructure's capabilities and coverage will allay customers' concerns, and appropriate government policies can contribute to creating a positive environment for EVs.

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