International Journal of Scientific Research in Engineering and Management (IJSREM)
Volume: 06 Issue: 12 | December - 2022 Impact Factor: 7.185 ISSN: 2582-3930

A Comprehensive Review on Electric Vehicle Drive Train Technologies

AUTHOR NAME : Pancham Arun Chaudhari

ELECTRICAL ENGINEERING
KCE Society's College of Engineering and management, jalgoan

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Abstract - Due to CO2 gas creation from the burning of fossil fuels, transportation is the second-largest contributor to greenhouse gas emissions. Electric vehicles (EVs) are seen to be a viable solution to this problem. Because electric cars utilize an electric motor as a propeller instead of an internal combustion engine, they can cut CO2 emissions. EVs, when combined with renewable energy sources, have the potential to be zero-emission vehicles. This paper provides an overview of the many types of electric drivetrains, covering their design as well as the advantages and disadvantages of each type. The goal is to describe the most current advancements in electric vehicle technology, which is constantly evolving. Furthermore, batteries as the primary energy storage are compared in terms of energy density and efficiency, specific energy and power, cost, and application.

Key word – Maximum Power Point, Wind Energy Conversion System, Fuzzy Logic Control.

1. INTRODUCTION

Electric vehicles (EVs) have grown in popularity over the previous decade. Demand is rising due to the gradual depletion of fossil resources such as crude oil, coal, natural gas, and heavy oil, which are desired by growing populations in both developed and developing countries [1]. Due to ongoing efforts and pioneering research activities in the Battery Management System (BMS) for applications in EVs, electric automobiles have evolved into a class that is further separated into Hybrid Electric Vehicles (HEVs)2 and Plug-in Hybrid Electric Vehicles (PHEVs)3. Although both HEVs and PHEVs make up the bulk of EVs currently on the market, the demand for PHEVs is definitely stronger. This is due to the automobiles' fuel flexibility, which allows them to run on both traditional fuels like gasoline and electric power stored in a battery (energy storage device).

Many academics have undertaken investigations on various types of EVs as a result of their widespread appeal. Braun et al. investigated the differences in energy consumption between a BEV and an ICE on passenger automobiles in various driving circumstances [2]. The effects of driving choices and peak-hour traffic on energy usage were investigated in Erfurt, Germany. According to the findings, the BEV outperforms conventional automobiles by 69.2 percent in terms of fuel economy. This significant advantage arose as a result of the BEV's power train characteristics, which are only used when traction is required. They absorb the mechanical energy generated during braking and convert it to electricity, which is then used to charge the battery (regenerative braking). The BEV can take advantage of vehicle speed fluctuations because to these features [2].

Cheng et al. studied HEVs and devised an electric-assist control strategy (EACS) by optimising the federal test procedure (FTP) driving cycle to satisfy the lowest fuel consumption and emissions of a parallel HEV [3]. The fuel economy of parallel HEVs was raised by 3.1 percent using this technology, and CO2 emissions were lowered from 1.78 to 1.42 g/km. The PSO method, which swiftly converged and found a globally optimum solution, was primarily responsible for these outcomes. This strategy, according to the authors, is the best way to solve the energy issue and reduce pollution [3].

Zhou et al. [4] also did a research for PHEVs that focused on the optimization of an energy management system (EMS). The study optimised an EMS design for a PHEV with two battery packs and

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a hybrid energy storage system (HESS). The results revealed that PHEV energy efficiency could be increased by 1.6–2.9 percent, and the lifetime of a PHEV energy storage system could be increased by 159–173 percent [4]. The suggested EMS reduced energy conversion loss in HESS, which resulted in these gains.

Finally, Lee et al. built an FCHEV for dustcart with two high-pressure hydrogen tanks, each with a volume of 36 litres and a pressure of 70 MPa. A fuel cell system with a maximum output of 33 kW and a notional capacity of 26.5 kWh includes a lithium-ion battery (LIB). According to this study, the FCHEV consumed 73 percent less energy than a diesel dustcart on a comparable journey [5]. As evidenced by this finding, the FCHEV is a future-oriented electric vehicle with excellent energy efficiency. Hydrogen may be made from renewable power as an FCHEV fuel by splitting water into hydrogen and oxygen in an electrolyzer. Several research have been conducted to manufacture hydrogen utilising the electrolysis process using electric sources such as solar, biomass, geothermal, nuclear, fossil fuels, and wind [6,7]. The goal of these investigations is to determine the lowest cost of hydrogen and energy generation.

2. . Electric Vehicle Configurations

Electric vehicles (EVs) employ a variety of energy sources (such as electricity, hydrogen, and conventional fuels) and attach these sources in a variety of ways (such as battery, capacitor, and tank). EVs can be utilised in conjunction with an ICE or on their own without the usage of other energy sources. BEVs, HEVs, PHEVs, and FCHEVs are the four types of electric vehicles [8].

2.1 Hybrid Electric Vehicles (HEV):

HEVs are defined as vehicles that use two or more energy sources, storage, or converters, with at least one of them providing electricity. By integrating ICE and battery strategies, HEVs have become a preferable solution to BEV concerns within the limited driving range [9].

A series HEV, as shown in Figure 2a, relies only on an electric motor for propulsion. A parallel HEV, on the other hand, mechanically links an electric motor and an internal combustion engine to the gearbox and concurrently releases power to move the wheels (see Figure 2b). Some research has been done to examine the fuel consumption and economy of series and parallel HEVs. C anbolat and Yasar, for example, tested the fuel consumption of road sweeper trucks with a series HEV and a parallel HEV for the same power and trip distance. Fuel consumption in a series hybrid arrangement (3.8 L/h) was lower than in a parallel hybrid setup (6.2 L/h), according to their comparison. This was because the ICE in a series hybrid mode ran at a constant speed throughout the transport mode, but the engine speed changed in the parallel hybrid mode [10]. In contrast, Li found that altering the hybridization factor (HF) increased the efficiency of parallel HEV topologies over series HEV designs [11]. Because of mechanical–electric–mechanical conversions, parallel HEVs have lower power conversion losses than series HEVs.

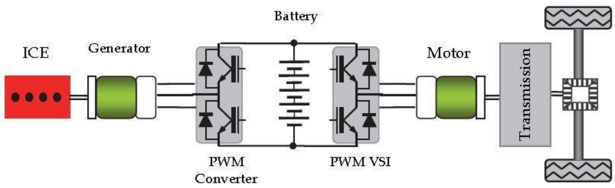

Figure 1: Series Hybrid Electric Vehicle Configuration

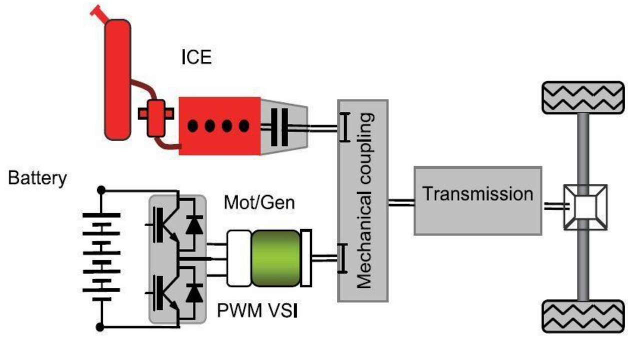

Figure 2: Schematic of a Parallel Hybrid Electric Vehicle

2.2 Plug

in Hybrid Electric Vehicle (PHEV):

PHEVs were created in order to extend the range of HEVs. PHEVs, like HEVs, have an electric motor, an internal combustion engine (ICE), a generator, and a battery. Apart from the regenerative braking approach, the battery may be charged via the utility grid. PHEVs are hybrid electric vehicles that combine the benefits of both BEVs and HEVs. A series PHEV is shown in Figure 3a, whereas a parallel PHEV is shown in Figure 3b. The phrases series and parallel denote whether an ICE is exclusively used to charge the battery or to provide propulsion to the vehicle, and are interchangeable with HEVs.

In comparison to HEVs, PHEVs can charge their batteries directly from the power grid and have larger battery packs. While HEVs can only run in charge sustenance (CS) mode (the battery state of charge (SOC) can only operate within a narrow/specific range), PHEVs may also operate in charge depletion (CD) mode, which allows them to operate in either pure electric or mixed mode (prioritize using the electric motor over ICE). Taherzadeh et al. did a study on charge depletion mode with the goal of improving the fuel consumption of parallel PHEVs [33]. The fuel consumption of parallel PHEVs was lowered by 7.1 percent over a 64 km travel distance, 6.3 percent over a 48 km trip distance, and 5.6 percent over a 32 km journey distance utilising the urban dynamometer driving schedule (UDDS) drive cycle and various trip durations [12]. The longer the journey distance, the better the PHEV performance utilising the CD control approach, according to this study.

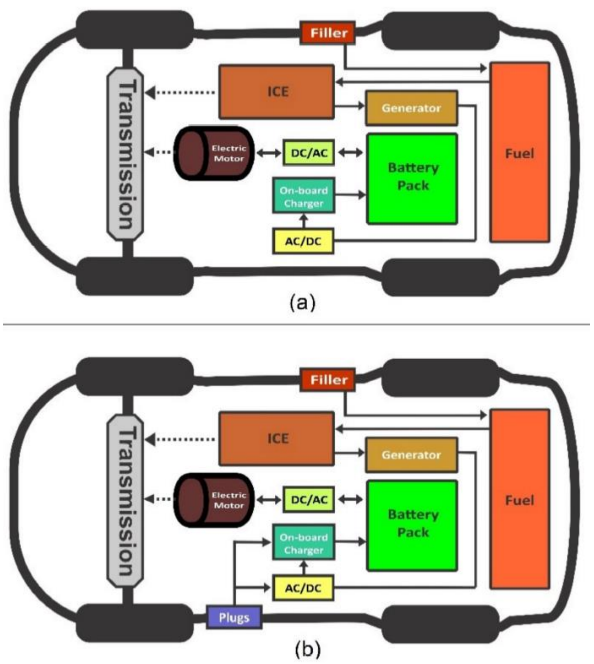

Figure 3: Schematic of a Plugin Hybrid Electric Vehicle

2.3 Battery Electric Vehicle:

Because a battery is the primary source of energy for a BEV's power train (Figure 1), the vehicle's range is limited by its battery capacity. Because it has no tailpipe emissions, a BEV may be regarded a totally green car in terms of CO_2 emissions. Depending on the vehicle specs, a BEV may typically go 100–250 kilometres on a single charge, with an energy consumption rate of 15–20 kWh per 100 kilometres. BEVs with a larger battery pack offer a greater driving range, ranging from 300 to 500 kilometres [13].

However, when compared to other types of EVs, BEVs have a significant disadvantage in terms of driving range and charging time. The creation of an effective EMS for BEVs is an excellent way to address this issue. One study, for example, successfully developed a type of regenerative braking strategy for three-wheel EVs, achieving a satisfying result of extending mileage to around 20 km/kWh when 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). Compared to complete mechanical braking, this modified braking approach might boost mileage by 4.16 percent km/kWh [14].

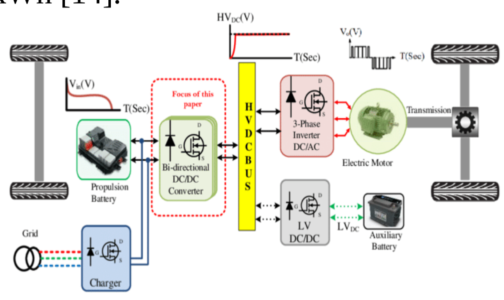

Figure 4: Schematic of a Battery Electric Vehicle

2.4 Fuel Cell Hybrid Electric Vehicle (FCHEV):

FCHEVs employ fuel cells and energy storage systems (ESSs) in the transportation sector (Figure 5), and they offer a number of advantages, including zero emissions, high efficiency, enough driving range, and fossil-fuel independence. They also only create water as a byproduct through the tailpipes, which might be a solution to the energy issue and pollution. The refuelling time of FCHEVs is faster than the charging time of a battery at the station and roughly identical to the refuelling time of a normal vehicle at a gas station [15]. The time it takes to refill an FCHEV is determined on the tank's operating pressure. For example, refuelling a 350-bar tank with hydrogen for a 300-kilometer journey takes 8 minutes. Meanwhile, refuelling a 700-bar tank with hydrogen for a travel distance of up to 600 kilometres takes roughly 14 minutes [16].

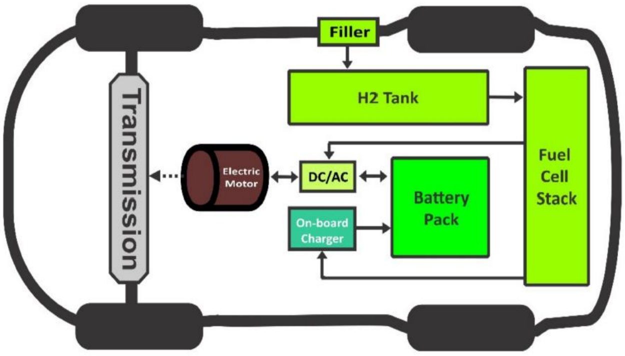

Figure 5: Schematic of a Fuel Cell Hybrid Electric Vehicle

Because an FCHEV employs only one propulsion system instead of an internal combustion engine or a combination of an electric motor and an internal combustion engine, it offers more benefits than a standard vehicle with an internal combustion engine or a HEV. Furthermore, the FCHEV's efficiency will be improved by combining the various electric energy sources. Fathabadi proposed a new hybrid power source for FCHEVs that combines a fuel cell with a super capacitor [17]. A 90 kW proton exchange membrane fuel cell stack was employed as the primary power source, with a 600 F super capacitor bank serving as supplemental energy. The FCHEV achieved a power efficiency of 96.2 percent around the rated power, as well as very precise DC-link voltage control, according to this study. An FCHEV with a load of 1880 kg could travel 435 kilometers on one tank of hydrogen with a fuel capacity and tank pressure of 5.4 kg and 345 bar, respectively, with a top speed of 158 km/h, according to the research. The novel hybrid FCHEV gained better parameters, such as higher power efficiency, speed, and acceleration, when compared to 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, according to the researcher [17]. The disadvantage of FCHEVs is their reliance on storage capacity and high-speed dynamic reaction, which should be used in conjunction with the fuel cell (FC) stack as an auxiliary energy storage device. During vehicle acceleration and deceleration, an FC stack in a vehicle cannot give adequate reactions [18,19]. The FC stack also lacks the ability to store the regenerative energy generated during deceleration and braking, necessitating the use of an extra energy storage device, such as a rechargeable battery or super capacitor bank with integrated energy management systems [20].

3. Electric Motor Technologies

Another significant component of EVs is the electric motor. The electric motor is a device that converts electrical energy into mechanical work and vice versa. For propulsion, an electric motor may deliver a lot of power and torque to the transaxle or differential.

In comparison to internal combustion engines, electric motors may provide instantaneous power and torque, hence transmission in EVs may not be necessary. Electric motors also have a high energy conversion efficiency (between 80% and 95%), which is significantly higher than that of an internal combustion engine (ICE) [21].

Induction motors (IM), permanent magnet synchronous motors (PM-SM), permanent magnet-brushless DC motors (PM-BLDC), and switching reluctance motors (SRM) are all employed as electric drives in electric vehicles [22]. Due to their great efficiency and power density, IM and PM-SM are regarded the most recommended motors for use in EVs [23]. Installation space, power density, machine weight, dependability, efficiency, torque-speed relationship, overload capability, and cost are some of the qualities of electric motors that are requested by EVs and compared before being used in EVs [24].

IM has a high efficiency, beginning torque, and power, as well as a simple construction, cheap cost, roughness, and minimal maintenance. IMs may function in any hostile environment without experiencing any speed limitations [25]. The IM's control system, on the other hand, is highly complicated and still has a difficulty with power density. The quantity of overall losses, which may be divided into losses in the magnetic circuit (iron losses), losses in the windings (copper losses), losses in the converter (commutation and stray losses), and mechanical losses, determines the energy efficiency of this motor.

Mahmoudi et al. [26] performed research into the losses of IM motors. They employed a finite element analysis to determine an IM motor's efficiency based on mapping of losses in their study [26]. The efficiency map of the IM motor was calculated by each loss map, according to the research. Lumyong et al. have developed a method for improving the efficiency of an IM motor by halving the number of stators turns (using 0.75, 2.25, and 3.7 kW IM motors) [27]. As a consequence, the suggested motor's efficiency was greatly improved over the original motor control. The efficiency of the 0.75 kW motor went from 78 percent to 85.39 percent, that of the 2.25 kW motor increased from 83.23 percent to 86.22 percent, and that of the 3.7 kW motor increased from 86.25 percent to 87.62 percent [27].

PM-SM has various unique capabilities, including the ability to provide consistent torque while maintaining high efficiency, high power density, and low energy consumption. Because PM-SM boosts motor efficiency by around 10% [28], it offers resilience for an electrical balance and assures a dependable overall performance. PM-SM is a smaller model with more compact mechanical components. Furthermore, because the PM-SM rotor lacks a coil and brushes, it generates very little heat. PM-SM is appropriate for EVs and HEVs because it has highly conductive materials and excellent permeability on the permanent magnets [22]. On the other hand, owing of the permanent magnet within, the initial cost of this motor is considerable, because PM material supplies are restricted and expensive [29]. Furthermore, the energy loss problem with PM-SM during conversion is still a problem to be solved. Guo et al. suggested a new global loss model for PM-SM that uses double Fourier integral analysis to determine fundamental and harmonic losses [30]. The study's major goal was to achieve a low overall energy loss (fundamental iron loss, fundamental copper loss, harmonic iron loss, and harmonic copper loss) for improved EV performance. With a 94 percent efficiency, this study was able to achieve the lowest energy loss [30]. Wang et al. presented a technique of electromagnetic parameters matching those applied to the interior PM-SM to calculate the PM-SM motor's ideal parameter [31]. With varying field-weakening ratios and saliency ratios, this technique provided a straightforward way for determining the electromagnetic motor settings. The results showed that the ideal saliency ratio parameter value was 2–2.73, with a field-weakening ratio range of 1–1.37 [31].

PM-BLDC is a motor type that is started by rectangular AC and has a large torque pulsation. By maintaining the flux between the stator and the rotor flux near to 90_, this motor can provide the highest torque in the constant torque area. The phase-advance angle control technique [32] can be used to generate constant power. High power density, high efficiency, and efficient heat dissipation are the major characteristics of the PM-BLDC motor.

The PM-BLDC motor's disadvantages include a high initial cost due to the rotor's magnet and the presence of a permanent magnetic field, which limits field-weakening capabilities [33]. Sharifan et al. looked at speed/accelerating characteristics, grading ability, fuel consumption, pollutant emission, and the level of charge of batteries in automobiles. Using a sophisticated vehicle simulator software programme, this strategy was applied to the two best-candidate motors for use in HEVs (IM and PM-BLDC). For each engine, the fuel consumption per 100 km was 11.8 L for PMBLDC and 11.9 L for IM. PM-BLDC also had lower overall pollutant emissions than IM (2.68 g/km for the former and 2.72 g/km for the latter). In comparison to the IM motor, the results demonstrate that the PM-BLDC motor performs better in hybrid EVs [34].

SRM is the latest motor type utilised in electric vehicles. In comparison to the others, it has the simplest setup. It just has a rotor (moving portion) and a stator (non-moving part), with the stator being the sole part with winding. The SRM is less expensive than PM motors since it lacks a permanent magnet. Furthermore, SRM is fault-tolerant, which means that a problem in one phase will not affect the other phases. Despite various difficulties like as acoustic noise, torque ripple, converter topology challenges, and electromagnetic interference that need to be addressed, SRM is still regarded a physically good contender for EVs and HEVs due to its sturdy construction and low cost [35]. Kumar et al. investigated the performance of SRM 10/8 (SRM 5 phases) EV drives under abnormal situations such as open-circuit and short-circuit failures [36]. The SRM has a superb dynamic responsiveness as well as excellent fault-tolerant behaviour. Speed, torque, and SOC were used to evaluate the performance of SRM-powered EVs. SRM attained the speed reference under normal conditions in 1.23 seconds. Meanwhile, the SOC declined by 0.04 percent in a 1-phase short circuit scenario at 1.26 s, while the torque remained constant at 485.3 Nm [36]. Table 2 lists the advantages and disadvantages of electric motors, while Figure 7 depicts the efficiency maps of the SRM, IM, and PM-SM motors.

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4. COMPARATIVE ANALYSIS

A comparison Table 2 is produced after analysing several electric motors for EV applications. Different performance indices are compared, such as efficiency, power density, size, torque ripple, reliability and cost

TABLE II

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

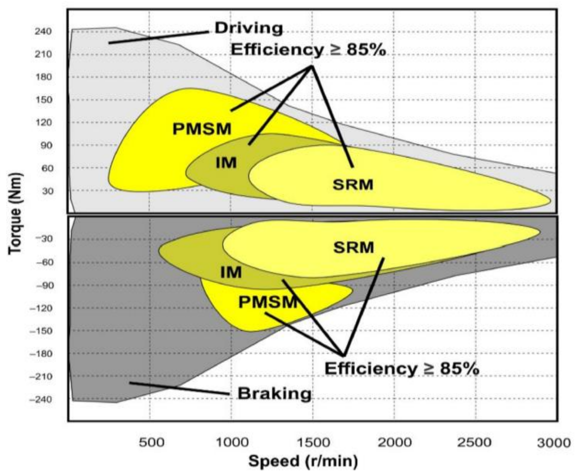

Figure 6: Efficiency maps of motors [80, 96-98]

5. CONCLUSION

This study provided an overview of the many types of electric vehicles, including their benefits and drawbacks, as well as potential and problems. It can be stated that electric vehicles will continue to evolve by incorporating cutting-edge technology, boosting energy efficiency, and enhancing performance. The efficiency, power density, fault-tolerance, reliability, and cost characteristics are used to determine which electric motor to utilise in EVs. Infrastructure and legislation are critical to the growth of the electric vehicle sector. Customers' fears will be alleviated by the infrastructure's coverage and capabilities, and suitable government regulations can help to establish a healthy atmosphere for EVs. However, the research of charging development is still a unique problem that has to be studied in order to achieve a faster charging time than the current one while avoiding considerable battery stress.

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