Exploring Electric Vehicle Power Supply: Types, Technologies, And Future Prospects

Zhouyu Mo *, Zhujun Yuan and Zhou Ye

Beijing New Oriental Foreign Language School at Yangzhou, Yangzhou, China

* Corresponding Author Email: 100894@yzpc.edu.cn

Abstract. This paper provides a comprehensive exploration of electric vehicle (EV) drive technologies, focusing on battery electric vehicles (BEVs), hybrid electric vehicles (HEVs), plug-in hybrid electric vehicles (PHEVs), and fuel cell electric vehicles (FCEVs). Through a thorough comparative assessment of the drive system technologies utilized in these diverse categories of electric vehicles, our aim is to offer insights into their respective advantages, particularly in terms of environmental sustainability and protection. Additionally, this article seeks to equip stakeholders within the electric vehicle ecosystem with the knowledge required to navigate the evolving landscape of EV technologies effectively. By fostering a deeper understanding of the benefits and limitations of various EV drive systems, stakeholders can develop informed strategies to promote the widespread adoption of electric vehicles and contribute to a more sustainable future. In summary, this paper endeavors to deepen understanding of EV drive technologies, their environmental implications, and their role in shaping the future of transportation. Through informed decision-making and strategic planning, stakeholders can expedite the transition towards a cleaner, more sustainable transportation ecosystem.

Keywords: Battery electric vehicles; Hybrid electric vehicles; Plug-in hybrid vehicles; Fuel cell vehicles.

1. Introduction

With increasing awareness of environmental protection and the looming threat of an energy crisis, traditional energy vehicles, which contribute to energy consumption and environmental pollution, are gradually being phased out. Electric vehicles are garnering increasing attention as a clean and efficient alternative means of transportation.

The drive system technology of electric vehicles stands as one of its core components and is directly linked to its performance, cruising range, and user experience. This article aims to review the drive system technologies of pure electric vehicles, hybrid electric vehicles, plug-in hybrid electric vehicles, and fuel cell vehicles, with the objective of providing reference material for related research and industrial development.

In electric vehicles, the drive motor holds crucial significance. Together with the electronic control system and power battery, it forms the core components often referred to as the "three-electric system." Unlike traditional cars that rely on chemical energy for propulsion, the drive motor in an electric car converts electrical energy into mechanical energy to propel the vehicle. Moreover, it can convert mechanical energy back into electrical energy and store it in the power battery.

The function of the motor controller is to convert the high-voltage direct current provided by the power battery into the high-voltage three-phase alternating current required to drive the motor, enabling the drive motor to generate torque. The drive motor transmits rotational motion to the wheels through the transmission device to propel the vehicle forward. The operation and control of drive motors are critical to the performance and efficiency of electric vehicles. Furthermore, the drive motor can facilitate braking energy recovery. During braking or slow deceleration, the vehicle controller instructs the drive motor to switch to generator mode, converting the vehicle's kinetic energy into electrical energy. This electrical energy is then charged to the power battery through the motor controller. This energy recovery system helps enhance the energy efficiency and driving range of electric vehicles.

In recent years, significant progress has been made in the technological development of electric vehicles (EVs) in China, with important breakthroughs in battery technology. Domestic battery manufacturers continue to enhance the performance of lithium-ion batteries, increasing the energy density and cycle life of batteries. China is also delving into research areas such as sodium-ion and solid-state batteries to further improve battery technology. Additionally, the Chinese government is actively promoting the construction of charging infrastructure, with the number of charging piles in the country growing rapidly, including public charging piles and private charging facilities. Moreover, China is promoting fast charging technology, making charging time shorter and more convenient for users. Chinese automakers and technology companies are actively exploring the application of smart technologies in the EV sector, improving the performance and user experience of electric vehicles.

Chinese automakers have demonstrated strong competitiveness in the field of electric vehicles, with both traditional automakers and new EV manufacturers actively transitioning. These manufacturers continue to introduce new electric vehicles to improve product performance and quality, driving technological innovation and development across the industry. The progress in battery technology, the construction of charging infrastructure, the application of smart technology, policy support, and competition and innovation among manufacturers have jointly propelled the rapid growth and technological progress of China's electric vehicle market. With further technological advancements and policy support, China's electric vehicle industry is expected to maintain a strong development momentum.

EVs have witnessed significant technological advances in many countries, fueling the rapid development of the electric vehicle industry.

The United States stands as one of the leaders in electric vehicle technology, boasting well-known electric vehicle manufacturers and technology companies. Tesla, a prominent electric vehicle manufacturer in the United States, has made major breakthroughs in battery technology, autonomous driving technology, and intelligent in-vehicle systems. Additionally, other companies in the United States such as Ford and General Motors are actively promoting the development of electric vehicle technology.

Germany has also made significant strides in the field of electric vehicle technology. German automakers such as BMW, Audi, and Volkswagen have launched electric vehicle product lines and continue to innovate in battery technology, charging infrastructure, and smart technology applications. Furthermore, the German government has introduced a series of policies to support the development of new energy vehicles, promoting the popularization of electric vehicles in Germany.

Japan holds a leading position in electric vehicle technology, with automakers such as Toyota and Nissan dedicated to its development and promotion. Toyota's hybrid model, the Prius, is one of the world's leading electric vehicles. Japan has also made important progress in battery technology, charging infrastructure, and smart technology applications.

The advancements made by these countries in electric vehicle technology have provided invaluable experience and momentum for the global electric vehicle industry, driving the popularization and market development of electric vehicles. With ongoing technological advancements and global cooperation, the momentum of electric vehicles on a global scale is expected to continue to advance.

2. Analysis of the Current Situation

2.1. BEV

The three primary components of a battery electric vehicle's configuration are illustrated in Fig. 1. Energy storage, electric propulsion, and auxiliary systems constitute the three primary subsystems. Components of the electric propulsion system encompass electronic controllers, power converters, electric motors, mechanical gearboxes, and drive wheels. Energy management systems, energy storage devices, and charging equipment are encompassed within the energy storage section. Examples of auxiliary systems include power steering, temperature control units, and auxiliary power supplies. Control links are denoted by thin arrows, while electrical connections are represented by thick arrows.

To activate or deactivate the power devices in the power converter and assist in controlling the power flow between the electric motor and the energy storage device, the system issues the appropriate control signals based on inputs from the accelerator and brake pedals as well as an electronic controller. The energy management unit collaborates with the electronic controller to oversee energy recovery for regenerative braking and monitor the availability of the energy storage device.

Temperature control and power steering devices, in particular, necessitate electricity at multiple voltage levels, which is furnished by an auxiliary power supply. Another critical control input is the steering wheel. The power steering unit determines the speed at which the car should turn based on the angular position of the steering wheel.

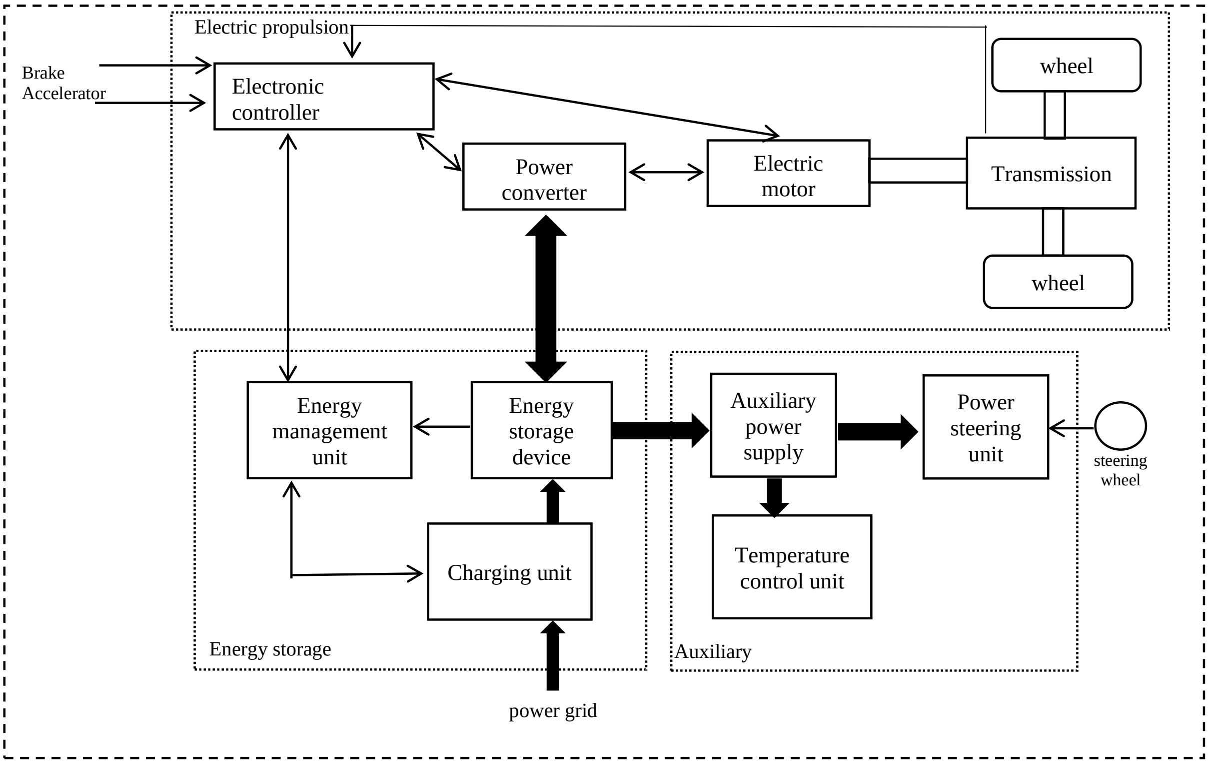

Fig. 1 General EV system configuration [2].

2.2. HEV

A hybrid-electric vehicle (HEV) is a vehicle equipped with two or more power sources, with the most common configuration being a petroleum-electric vehicle powered by both an engine and a motor battery pack [3]. HEVs offer a blend of advantages, combining the long-lasting working hours and dynamic performance of fuel engines with the pollution-free operation and low noise characteristic of electric engines. Additionally, they address the technical limitations of pure BEVs, such as limited storage capacity and low battery durability.

HEVs consist of various components, including an electric drive system, body, chassis, and electrical equipment. Their primary distinction from conventional cars lies in the driving system, which varies depending on the type of hybrid configuration. The driving system encompasses components such as the engine, drive motor, integrated starter-generator (ISG) motor systems, power source, motor speed control device, and others. Additionally, it facilitates energy recovery during braking [4].

Hybrid electric vehicles can be categorized based on their power-driven connection method and level of hybridization. Different connection methods result in hybrid driving modes classified as series, parallel, and parallel-series hybrids, as well as micro, medium, and strong hybrids [5].

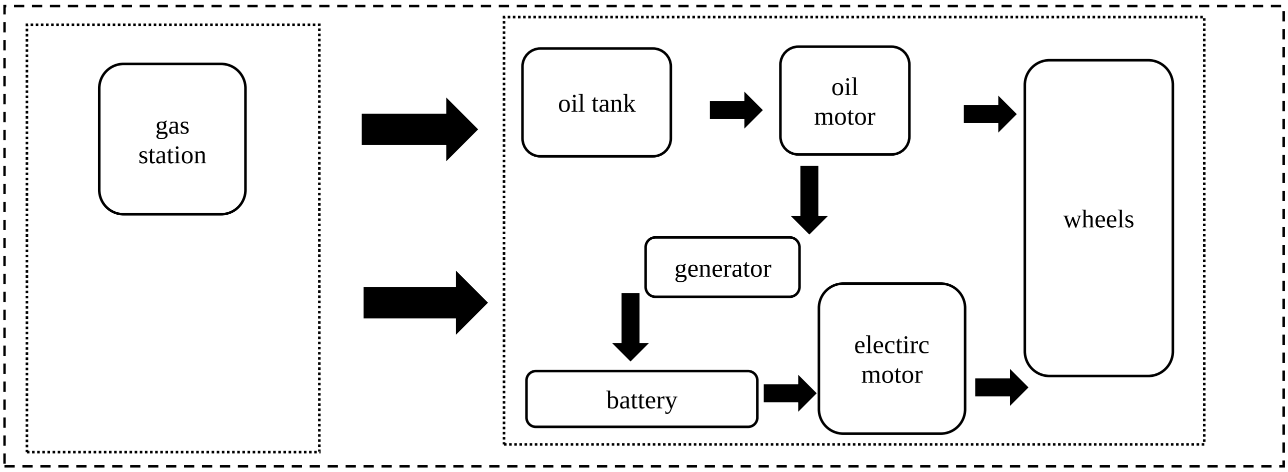

Fig. 2 Energy flow in HEV.

As depicted in Fig. 2, a Hybrid Electric Vehicle (HEV) utilizes a conventional internal combustion engine as its primary drive, complemented by an electric motor serving as a secondary drive, all powered by a high-capacity battery installed within the vehicle. Notably, HEVs do not support plug-in functionality, and the electric motor exclusively operates using electricity generated by the engine.

Honda's Intelligent Multi-Mode Drive (i-MMD) system serves as a notable example of hybrid vehicle technology. Featuring an electric motor capable of delivering up to 135 kW of power, this system boasts impressive fuel efficiency, with official data indicating consumption rates as low as 4.4 liters per 100 kilometers. Such efficiency surpasses that of similarly priced fuel-efficient vehicles on the market.

2.3. PHEV

The plug-in hybrid-electric vehicle (PHEV) typically integrates both an internal combustion engine and an electric motor powered by batteries. While it shares similarities with conventional hybrid electric vehicles (HEVs) in utilizing both gas and electric power, there are notable distinctions in their operational mechanisms [6].

The primary disparity between PHEVs and HEVs lies in their off-vehicle energy sources, as illustrated in Fig. 3 [6]. PHEVs possess two distinct energy supply methods: refueling and charging. Consequently, PHEVs generally feature larger battery capacities compared to HEVs. This battery enhancement enables PHEVs to achieve extended travel distances using electric power. PHEVs can adopt various drive configurations through the coordination of electric motor and fuel engine intervention algorithms, including pure electric mode, pure fuel engine mode, and hybrid mode combining both motor and fuel engine power. Moreover, PHEVs have the capability to operate solely on electric power when convenient charging is available and power levels are sufficient, thereby conserving energy and reducing overall vehicle costs. In instances of inadequate power charging, PHEVs seamlessly transition to fuel-driven mode to ensure continued range.

In recent years, there has been a notable increase in the battery capacity of PHEVs, prompting the integration of fast charging interfaces. For instance, the BYD Han DMi 2022 model features a battery capacity of 37.5 kWh, enabling a pure electric working range of up to 242 km. Additionally, it is equipped with an 80 kW DC fast charging interface to facilitate rapid charging capabilities.

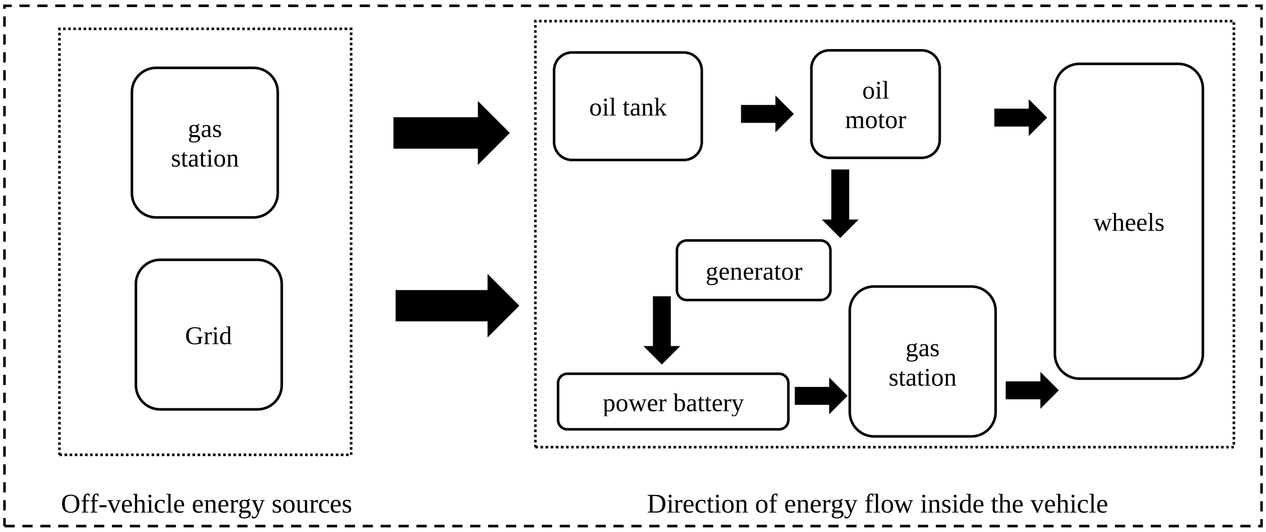

Fig. 3 Energy flow in PHEV.

2.4. FCEV

The hydrogen fuel cell vehicle (FCEV) operates by facilitating the reaction between hydrogen or hydrogen-containing substances and oxygen in the air within the fuel cell. This process generates electricity to power the motor and propel the vehicle forward. The widespread adoption of hydrogen fuel as a transportation energy source is a crucial element of the hydrogen economy.

One primary advantage of utilizing hydrogen as an energy source is its reaction with oxygen in the air, resulting in the emission of only water vapor, thus achieving zero emissions. This characteristic effectively mitigates the air pollution associated with traditional gasoline vehicles, distinguishing hydrogen energy vehicles from pure electric/hybrid vehicles. However, despite these advantages, FCEVs have not achieved the same level of popularity as pure electric vehicles, hybrid vehicles, and plug-in hybrid vehicles [7].

3. Advantage and Disadvantage

In-depth scientific research delves into the environmental costs associated with battery production and use, revealing various corresponding CO2 equivalent emissions (Table 1). These changes are primarily attributed to battery chemistry, with metallic lithium playing a crucial role. Furthermore, it has been reported that the purification process of lithium is not energy-intensive [8], indicating that lithium is not associated with relatively high resource consumption.

Table 1. CO2-equivalent emissions due to the LI-ion battery production [8].

Source	**CO_2 - equivalents Kg/KWh battery**	**Battery chemistry investigated**	**Remarks**
Notter et al. 2010	52	LiMn2O4	Bottom-up LCA approach (Althaus 2011)
Lshilhara el al.	75	Li-Ni-Co and Li-Mn	Bottom-up LCA approach (Althaus 2011)
Zackrisson el al. 2010	166	LiFePO4	Top-down modeling from producers (Althaus 2011)
Frishknecht 2011	134	Not specified	Top-down modeling from producers (Althaus 2011)
Majeau-Bettez et al. 2011	250 200	$LiFePO_4$ $LiFe_{0.4}CO_{0.2}Mn0.4O_{0.2}$	Industry data considered (remark by Majeau-Bettez)
Data range presented by five different groups on the 43rd discussion forum on LCA,Zurich,2011(reviewed by Frischknecht and Flury 2011)	(66 to 291)[a]	diverse	

Table 2 illustrates the data collected for conventional fossil fuel vehicles and two types of EVs. Under the same conditions of a passenger load of 400kg and an annual mileage of 10,000km, due to their high electricity dependence, PHEVs exhibit extraordinary fuel economy performance, up to 560km/L. Among the other three types, HEVs lead with an economy of 23.25km/L, while the remaining two types of hovers around 10km/L. The fuel prices and taxes for different vehicles are generally at the same level (around $0.8/L), with gasoline having a slight price advantage at $0.63/L. As HEV and PHEV rely on electricity, their tank capacity is slightly smaller than that of the other two fossil fuel vehicles. Moreover, they have a maintenance cost of around $0.009/km, which is higher than gasoline vehicles but lower than diesel vehicles.

Table 2. Information data of Gasoline, Diesel, HEV and PHEV vehicles [9].

	Unit	Gasoline	Diesel	HEV	PHEV
Weight	Kg	1690	1935	1385	1880
Passenger (5*80kg)	Kg	400	400	400	400
Average annual mileage	Km	10000	10000	10000	10000
Fuel economy	Km/liter	10.00	11.20	23.25	560
Fuel price	$/litter	0.63	0.80	0.86/0.9	0.86/0.9
Fuel taxes	$/litter	0.03	0.04	0.04	0.04
Tank Capacity	Liter	55	68	36	45
Maintenance cost	$/Km	0.00851	0.01355	0.0096	0.0099

Because hydrogen has a substantially higher energy density than batteries in terms of both mass and volume, it improves the vehicle's storage capacity and affects its driving range. Despite these benefits, hydrogen fuel cells or internal combustion engines running on hydrogen can be utilized in buses, vans, lorries, and other types of vehicles. In compact passenger cars with relatively low daily mileage limits, BEV systems can be employed. The adoption of FCEVs begins to yield significant benefits when it comes to trucks. Compared to electrochemical batteries, fuel cells require a significantly lower number of raw materials during production. Additionally, the use of less cobalt and platinum (compared to internal combustion engine vehicles) provides an additional benefit [10].

4. Conclusion

It is true that EVs are becoming more commonplace globally. People are increasingly conscious of the significance of reducing carbon footprints and tailpipe emissions, as well as the growing worldwide concern about climate change and environmental damage. Electric vehicles are considered a key component of the solution to lower carbon emissions and enhance air quality because they are emission-free modes of transportation.

EV technology has advanced significantly in recent years, with ongoing advancements in battery science leading to longer ranges and faster charging periods for EVs. Additionally, the cost of producing electric cars is steadily decreasing, making them more accessible to a wider range of buyers. To encourage the advancement and widespread use of electric vehicles, numerous nations and regions have implemented a variety of laws and financial incentives. These policies reduce the cost of purchasing and operating electric vehicles, encouraging people to acquire them. Examples of these policies include tax rebates, free parking, free charging, and automobile subsidies.

With the continuous improvement of charging infrastructure, the number and coverage of charging stations are constantly expanding, providing more convenient charging services for electric vehicle users. This progress has led to a gradual reduction in people's anxiety about charging electric vehicles. Furthermore, the construction of more public charging stations and private charging facilities has made charging electric vehicles more convenient and reliable. In summary, the ongoing improvement in charging infrastructure, coupled with the expansion of charging station numbers and coverage, has led to a gradual reduction in people's anxiety about charging electric vehicles.

In summary, factors such as increased environmental awareness, technological progress and cost reduction, policy support, charging infrastructure, and the investment and promotion of manufacturers have all contributed to the gradual emergence of electric vehicles in the mainstream around the world. With further technological development and increasing adoption, the market share of electric vehicles is expected to continue to grow.

Authors Contribution

All the authors contributed equally, and their names were listed in alphabetical order.

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