

# Analysis of the Current Status and Prospects of Extended Range Electric Vehicle Powertrain under the Background of Carbon Peaking and Carbon Neutrality Goals

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## ABSTRACT

With increasing global concern about environmental protection and climate change, the automotive industry is also under stress to reduce emissions and improve energy efficiency. In this context, extended range power technology, as a hybrid solution that integrates traditional internal combustion engine and electric drive system, has attracted much attention. At present, the extended range power technology has made some progress and has been applied in the market. By combining an internal combustion engine with a battery pack, extended-range vehicles can achieve longer driving ranges and lower exhaust emissions. In addition, in low-speed driving situations such as urban traffic, pure electric mode can play an advantage, thereby improving energy efficiency. Looking ahead, as the automotive industry moves towards carbon neutrality, extension-range power technology is expected to become one of the mainstream options. Through continuous innovation and improvement, it can be predicted that it will make more breakthroughs in energy conservation and emission reduction, improve driving experience, and eventually become one of the important engines to promote the sustainable development of the automotive industry.

## KEYWORDS

Extended Range Hybrid Powertrain; Carbon Peaking; Carbon Neutrality; Energy Efficiency; Emission Reduction; Automotive Industry.

## 1. INTRODUCTION

In 2020, China put forward the goals of "carbon peak" by 2030 and "carbon neutrality" by 2060. Traditional fuel vehicle exhaust emissions are a major culprit in today's environmental pollution, in order to achieve the "double carbon" goal, lower carbon emission of new energy vehicles came into being. Because of its huge advantages of energy saving and environmental protection, electric vehicles have been paid much more attention by governments around the world. However, the current power battery has many problems, such as high price, long charging time, and low energy density, which limits the promotion and application of electric vehicles. Under the background that the power battery can not obtain a large performance improvement in the short term, various forms of hybrid electric vehicles came into being. Among them, as a smooth transition model of pure electric vehicles, extended range electric vehicles have been widely concerned for their advantages of high efficiency, reasonable battery capacity design, and will not break down due to lack of power. Extended-range electric vehicle is a kind of plug-in series hybrid electric vehicle with pure electric drive. Its power system includes power range extender and vehicle control system, power drive system and battery system. The range extender power source of the generalized range extender electric vehicle should include fuel cell, engine and other forms. Compared with the traditional fuel vehicle, the engine of

the range extender can be controlled in the optimal working state and has the characteristics of small emissions. Compared with pure electric vehicles, the battery capacity required is much smaller, the cost is lower and there is no shortage of power and breakdown. In contrast to strong hybrids, the motor is not mechanically coupled to the engine, avoiding frequent switching of operating modes. Moreover, the current of the range extender and the output power are controllable, and more flexible battery charging and discharging strategies can be adopted, which is conducive to extending the service life of the battery [1]. Compared with pure electric and traditional hybrid electric vehicles, the range extender electric vehicles have both technical versatility and special features. This paper will analyze the power mode principle, advantages and disadvantages of extended-range power vehicles, and put forward ideas and opinions on the prospect and research direction of extended-range power mode.

## **2. INTRODUCTION OF EXTENDED RANGE HYBRID POWERTRAIN**

The extended range electric vehicle power system has four important components: range extender and vehicle control system, power drive system, power battery system. The driving system provides power output for the vehicle, and the motor controller controls the vehicle by receiving the command of the vehicle controller. The power battery system not only provides power for the motor drive system, but also provides reverse drag current for the starting of the range extender engine. A range extender consists a small-displacement engine and a generator directly connected with it. The AC current of the generator is rectified into a DC which matches the voltage of the power battery to charge power battery. The vehicle control system provides the vehicle control functions including the driver input information management of the range extender and the coordination control of each power component. Because the engine is not very open and does not directly participate in power output, extension-range electric vehicles have certain differences in power configuration with other hybrid vehicles. Unlike conventional series hybrid models, larger engines are used to provide all power sources, and smaller pools are used to achieve improved energy efficiency. The plug-in charging module of the extended-range electric vehicle enables external charging of the battery, and only a low-power generator is configured to meet the needs of extended range. The battery capacity is smaller than that of pure electric cars and larger than that of other hybrids. Due to the increase of power components and the change of power system structure, the selection standard of power components for extended range electric vehicles has its own characteristics. Although the reduction of dynamic coupling reduces part of the energy loss; But frequent power switching also brings a loss of efficiency. [2] How to choose the type of power components, configure the parameters of power components, and optimize the economic performance under the condition of ensuring the dynamic performance of the system has become the first problem to be solved for extended range electric vehicles.

## **3. SELECTION OF POWER COMPONENTS FOR EXTENDED RANGE ELECTRIC VEHICLES**

### **3.1. Selection of Drive Motor**

The configuration of the drive motor of extended-range electric vehicles is relatively similar to that of pure electric vehicles [3]. Electric vehicles are more efficient, and the frequently used drive motors are AC three-phase induction motors (hereinafter referred to as induction motors), built-in permanent magnet synchronous motors, surface permanent magnet synchronous motors, switched reluctance motors, etc. Induction motor has the advantages of easy maintenance and wide application. There are disadvantages such as low power factor, complicated variable voltage and variable frequency control as well . Permanent magnet AC synchronous motor has better dynamic characteristics and higher efficiency. However, there are some problems such as large cost impact and complicated

manufacturing process. For permanent magnet AC synchronous motor, the built-in permanent magnet synchronous motor has better characteristics than the surface permanent magnet synchronous motor, but the motor complexity has increased a lot. Switched reluctance motor has simple structure and strong disturbance immunity, but there are noise, vibration problems and torque pulse [4]. The stator permanent magnet motor represented by the double salient pole permanent magnet motor integrates the advantages above, and although it aggrandizes the complexity, it is still one of the optional schemes of the motor [5]. Extended-range electric vehicles use pure electric drive as the main form of power on urban roads, so motor efficiency and power density are considered as the main criteria. Because of the performance of the motor affected by air gap, polar arc coefficient, magnetic steel performance, pole number and other factors, the comparison of the advantages and disadvantages of the motor has a great argument. In spite of this, the built-in permanent magnet synchronous motor owns the advantages of wide speed regulation range and high efficiency, and is a better choice for the current extend-range electric vehicle drive motor [6].

### **3.2. Selection of Range Extender Engine**

Since the range extender engine of the extended range electric vehicle is only mechanically connected with the generator, the working condition and performance requirements of the engine are reduced, and the freedom of engine selection is increased. Single-piston rotor engine and two-cylinder four-stroke gasoline engine are considered to be the most promising engines in extended range power generation applications. Although the rotor engine costs less than the two-cylinder four-stroke gasoline engine, the two-cylinder four-stroke platform is more universal than the rotor engine, reducing the manufacturing cost. The mature technology of two-cylinder four-stroke engine makes it have obvious advantages and is the ideal choice for the current range extender engine. With the increasing application of rotor engines, their superior performance in on-board power generation will gradually be reflected [7]. In addition to commonly used engines, there are many novel options for prime movers, such as Stirling engines, small steam turbines, linear engines, etc. [8]. The engine using the homogeneous hybrid pneumatic combustion technology is also expected to be applied in the future range extender because it combines the advantages of diesel and gasoline engines. Since the operating point of the extended range engine is relatively single, the system can be greatly simplified, and the overload and overspeed and complex transient working conditions can not be fully considered. Both cranks and valves can be optimized to reduce friction and mass. Being independent of load and speed requirements also allows for optimization of emissions during start-up and catalyst heating [9].

### **3.3. Selection of ISG Start Generator**

The selection basis of the starting power generation machine is similar to the drive motor, and the permanent magnet motor with the integrated design of power generation and starting provides two different working conditions. Induction motor has the characteristics of high reliability and low cost. Switched reluctance generator has robustness and high speed operation capability, but the generation condition is low efficiency and there is large ripple. Permanent magnet motors are more efficient, but there is a risk of overspeed voltage control. The integrated starting generator has strict requirements on the installation size, operating temperature range, output voltage and current quality, and starting torque. In the application of range extender, the generating speed can be controlled by the engine speed regulation, and the permanent magnet motor with higher efficiency is a better choice. However, wire-wound rotor synchronous generators with rotating transformers and hybrid rotor motors with permanent magnet and excitation windings have also received greater attention due to their special characteristics [10]. Compared with the drive motor working in the drive condition, the ISG motor works in the power generation condition mostly. The coordination and optimization of engine and generator operating conditions, as well as the integrated consideration of efficient working area and power factors, are the keys to improving the fuel performance of EV with extended range [11].

### **3.4. Selection of Battery**

Battery is the most important bottleneck technology in the development of electric vehicles. With the development of advanced materials and updated processes for the main components of batteries such as anode materials, cathode materials, membranes and electrolyte materials, battery performance has been continuously improved. Lithium iron phosphate, lithium cobalt oxide, lithium manganate and their composites are the mainstream cathode materials for power batteries at present. Nevertheless, lithium iron phosphate batteries have longer life cycle, higher specific capacity and lower cost than lithium cobaltate and lithium manganate. Among the negative electrode materials, carbon and graphite materials are the mainstream, and lithium titanate and lithium elemental negative electrode materials have also been applied. The battery monomer which is made up of lithium iron phosphate and carbon material is a relatively perfect choice for the extended range electric vehicle battery currently [12]. With the promotion and improvement of batteries composed of solid solution materials and ternary composite materials, as well as air lithium battery technology composed of metal lithium materials, the performance of power batteries will be improved apparently, and it is also the development trend of future extender range and pure electric vehicle power batteries [13].

## **4. ENERGY REGULATION AND EFFICIENCY OPTIMIZATION OF EXTENDED RANGE ELECTRIC VEHICLES**

### **4.1. Energy Supply for Extended Range Electric Vehicles**

The independent energy supply of the range extender provides a variety of operating modes. In daily use, the range extender can be turned off and driven only by the battery. In this way, the power performance of the vehicle is likely to be improved by increasing the power output of the range extender, and the state of charge (SOC) can be maintained according to the power consumption, and the battery life can be increased by power compensation. Under the corresponding control mode, the coordination of each power component can be realized either by manual demand input or by state recognition of vehicle driving conditions. No matter which mode of operation is adopted, it is very important to adopt the appropriate strategy to ameliorate the energy efficiency of the vehicle while coordinating the work of the power components.

### **4.2. Control Strategy Study**

As a kind of series-mixed vehicle, extended-range electric vehicles, like series-mixed vehicles, need to realize energy management of extended-range electric vehicles through engine operating point switching in order to achieve the overall optimal state [14].

Because the power battery has a larger capacity of small current discharge than high current discharge, shallow charge and shallow discharge can effectively extend the battery life. The existence of range extender enables the energy flow direction of the power system to be optimized through certain control strategies to achieve the goal of extending the range of driving and improving battery performance [15]. The effectiveness of the optimization has been verified, and the appropriate optimization strategy can improve the system efficiency by 10%~15% compared with the single point efficiency optimal charging.

### **4.3. Charging Efficiency and Thermal Management**

Charging efficiency is related to the load, and with the change of battery SOC and other states and the change of power output, the charging efficiency will also change accordingly. The latest zero-voltage interlaced boost circuits, with appropriate strategies, have been able to achieve relatively

efficient AC to DC conversion [16]. How to improve energy efficiency under changing working conditions is an exigent problem to be dealt with in the control of extended-range electric vehicles.

Since the power battery is charged and discharged not only by the driving motor, but also by the auxiliary power unit (APU), the charge and discharge of the power battery become more frequent, and the relaxation and hysteresis effects of the battery are more obvious [17]. Temperature has a great influence on battery charging and discharging, and batteries exhibit different charging and discharging characteristics at different temperatures [18]. Under different charged states, the charge and discharge power of the battery will change with the change of temperature. In order to ensure the temperature adaptability of the battery pack in the case of frequent charge and discharge, the control system strategy needs special consideration. Special battery management systems and temperature control systems also help improve battery efficiency. Battery equalization devices and hybrid energy storage systems are also options [19]. It is worth noting that the heat treatment of batteries requires a comprehensive consideration of the influence of multiple factors [20].

## 5. PROSPECT

With the continuous improvement of technology and the continuous reduction of costs, it is the general trend for environmentally friendly and efficient electric vehicles to replace traditional fuel vehicles. However, in the case that the battery capacity and charge and discharge time can not fully meet the current demand for pure electric vehicles, the use of pure electric drive extended-range electric vehicles has a larger application background. If the following points can be achieved, extended-range electric vehicles are bound to have a bright future.

- 1) Application research of modular and detachable range extension unit. Modularity can greatly improve the production efficiency of extend-range electric vehicles, while reducing the maintenance cost of extend-range electric vehicles, increasing environmental adaptability and improving controllability.
- 2) Further improvement of energy conversion efficiency. Although in pure electric conditions, the economy of extended-range electric vehicles is better than other hybrid vehicles. However, under charging conditions, the current-coupled extender range electric vehicle can not reach the level of the mechanically coupled hybrid electric vehicle, and still has a large room for improvement.
- 3) Lightweight, the increase in vehicle weight brought by two sets of energy power systems is bound to lead to the decrease in driving maneuverability of electric vehicles with extended range power systems. If the weight of the vehicle can be further reduced, the maneuverability advantage of traditional fuel-powered vehicles will be further weakened, and the extender-range electric vehicles will become a milestone in the era of carbon neutrality and carbon peak in the automotive industry.

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