

Research on the Theory and Practice of Hydrogen Fuel Cell

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Abstract: Hydrogen energy is a renewable and clean resource, that can promote the transformation of energy use terminals to green and low carbon, alleviate the current problems of energy shortage, respond to China's "double carbon" strategy, and further implement the energy-saving and emission reduction targets. The hydrogen fuel cell is an efficient and environmentally friendly distributed power generation device, with the advantages of high energy density, zero-emission, fast charging speed, etc., and has been widely used in the fields of new energy vehicles, electric power equipment, and portable equipment. This paper analyzes the principle and advantages of hydrogen fuel cells, analyzes the key technology system of hydrogen fuel cells and the application of artificial intelligence in hydrogen fuel cells, proposes to strengthen the research on hydrogen production technology, accelerates the technical research and transformation application of key materials and core components, formulate industrial planning scientifically and actively promote hydrogen fuel cell, and promote the transformation of scientific and technological achievements, to promote the development of the hydrogen fuel cell industry.

Keywords: Hydrogen fuel cell; Power generation principle; Technical system; Key technology; Application path

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1. Introduction

Hydrogen fuel cell is an important subversive technology in the field of new energy, leading a new round of global industrial reform, and are of great significance to optimizing China's strategic layout and implementing the goal of "double carbon." Hydrogen fuel cell uses hydrogen as fuel and adds a specific catalyst to convert chemical energy into electric energy through electrochemical reaction. It has the advantages of high energy conversion rate, zero emission and no noise, and has promoted the development of new energy vehicles, marine power and mobile power. In order to further promote the discovery of the hydrogen fuel cell industry. Enterprises should deepen cooperation with scientific research institutes and universities in technology, jointly overcome the difficulties of hydrogen fuel technology, speed up the transformation of scientific and technological achievements, strive for the

government's funding and policy support, and promote the healthy development of the hydrogen fuel cell industry.

2. The principle and advantages of hydrogen fuel cell

2.1. The principle of hydrogen fuel cell

The principle of hydrogen fuel cell power generation is to make hydrogen and oxygen chemical reaction, and then convert chemical energy into electric energy, and use it to drive the power generation device, which is essentially a kind of electrochemical method to convert the chemical energy of hydrogen into electric energy ^[1]. The core part of the hydrogen fuel cell is the electrolyte membrane, including a positively charged cation exchange membrane and a negatively charged anion exchange membrane. The hydrogen ion and cation are separated, and then through a specific catalyst to accelerate the chemical reaction of hydrogen and oxygen, the cation creates a chemical reaction to produce electrons and hydrogen ions, and anions generate water and electrons. The electrons return to the anode through the external circuit for continuous reaction, to continuously release electrical energy, to achieve zero emission power supply, reduce the noise in the power generation process, and to meet the power needs of different industries ^[2].

Hydrogen fuel cells differ from lithium batteries in several ways. A hydrogen fuel cell consists of two main parts: the reactor and the system components. The reactor is the area where the chemical reaction between oxygen and hydrogen occurs, and it is the core of the entire fuel cell system. It includes the membrane electrode, bipolar plate, collector plate, end plate, sealing rings, and other components. The system components include the air compressor, humidifier, hydrogen circulation pump, and hydrogen bottle, which work together to ensure the smooth operation of the entire hydrogen fuel cell system.

2.2. The advantages of hydrogen fuel cell

2.2.1. Efficient and energy saving

Hydrogen fuel cells differ from traditional fuel engines in that they do not rely on gasoline, oil, or other fossil fuels. Instead, they use cleaner hydrogen as a fuel source. There is no fuel combustion process, leading to lower energy consumption and an electricity conversion rate that can exceed 60% ^[4]. The performance of hydrogen fuel cells includes power density and energy efficiency. By optimizing electrode materials and the battery structure, hydrogen fuel cell performance can be enhanced. For example, the use of nanotechnology to manufacture hydrogen fuel cell electrode catalysts improves battery power density, thereby increasing the chemical energy conversion rate. This highlights the high efficiency and energy-saving advantages of hydrogen fuel cells.

2.2.2. Environmental protection and energy saving

Hydrogen fuel cells produce only water and electrons during the power generation process, without emitting carbon dioxide or other harmful gases. This makes them environmentally friendly and energy-efficient, aligning with current energy conservation and emission reduction goals. Additionally, hydrogen, as a raw material for fuel cells, is a renewable resource that can be obtained from solar and wind energy. This helps to meet the energy needs of various industries while addressing the energy crisis and environmental pollution ^[5]. Currently, hydrogen fuel cells are widely used in new energy vehicles, supporting the development goals of clean, zero-carbon, safe, and efficient transportation. These fuel cells effectively reduce harmful gases such as carbon dioxide and sulfur dioxide produced by conventional fuel vehicles, as well as various types of dust, contributing to the alleviation of air pollution.

2.2.3. Intelligent management

Hydrogen fuel cell systems can achieve intelligent management and optimize operating conditions by integrating deep learning algorithms. For instance, operational data is collected through a network of sensors and analyzed using machine learning models to predict the optimal working parameters, ensuring the system operates efficiently. Deep learning algorithms can also monitor battery status, provide early warnings of potential failures, reduce maintenance costs, and extend the system's service life.

3. The application of artificial intelligence in hydrogen fuel cells

3.1. Material design and discovery

Deep learning can be used for high-throughput calculations and simulations to accelerate the development of core materials, such as new catalysts, Membrane Electrode Assemblies (MEA), and Gas Diffusion Layers (GDL). By training neural network models, the most promising combinations of new materials can be identified from the vast chemical space, significantly shortening the research and development cycle [7].

3.2. Process optimization

Deep learning or evolutionary algorithms can be applied to explore optimal manufacturing process parameters, such as temperature, pressure, and humidity, to enhance production efficiency and ensure consistent product quality.

3.3. Performance prediction and simulation

A hybrid model combining physical rules and data-driven approaches is constructed to accurately simulate the complex reaction processes within hydrogen fuel cells. This aids in better understanding the battery's working mechanism, guiding experimental design, and providing a theoretical foundation for developing new products.

3.4. Fault detection and diagnosis

Develop an intelligent monitoring system to track the health status of the battery in real-time, quickly identify abnormal patterns, and provide detailed failure cause analysis. This significantly reduces unplanned downtime and enhances the reliability and safety of the system.

4. Hydrogen fuel cell technology development path

4.1. Actively research and develop key materials and components to optimize the functions of hydrogen fuel cells

Although China's hydrogen fuel cell industry started relatively late, the development momentum is very rapid, and the development prospect is bright. Firstly, China actively develops high-pressure gaseous storage technology and low-temperature liquid hydrogen storage technology to ensure the safety of hydrogen storage, control the cost of hydrogen storage, meet the development needs of the hydrogen fuel cell industry, achieve mass production as soon as possible, and further promote the sustainable development of hydrogen fuel cells [8]. Hydrogen fuel cell gas diffusion layers (GDL) have been a significant focus of research and development in recent years. Efforts are being made to develop and optimize materials such as carbon fiber, carbon paper, and carbon cloth for use in GDL production. These advancements aim to meet the requirements of reactors, resistance, and electrical energy

conversion, fostering the integration of the carbon fiber and hydrogen fuel cell industries and promoting high-tech industry development. Domestic production of graphite bipolar plates (BPs) has been achieved, significantly improving durability and reliability. The stack power density has reached 3.8 kW/L, and these systems can operate normally under low temperatures as extreme as -30°C , meeting the operational needs of hydrogen fuel cells. Additionally, research and development efforts should focus on hydrogen fuel cell catalysts and bipolar plate technologies, as well as common technologies that enhance stability and safety. Currently, hydrogen fuel cells are widely used in the field of new energy vehicles. By improving endurance and low-temperature resistance, hydrogen fuel cell technology can be further advanced, driving the sustainable development of the new energy vehicle industry^[9].

4.2. Accelerating the research and development of core components and promoting the transformation of scientific and technological achievements

Firstly, research and development (R&D) teams need to actively devote themselves to the development of key materials for hydrogen fuel cells, including membrane electrodes, hydrogen circulating pumps, air compressors, and catalysts, to break through the bottleneck of hydrogen fuel cell technology. For example, hydrogen fuel cell research and development enterprises should take the initiative to establish cooperative relations with research institutes and universities to jointly develop hydrogen fuel cell catalysts, new materials, and new technologies for bipolar plates. At the same time, advanced materials such as carbon fiber and graphite will be applied to the research and development of hydrogen fuel cells to solve the problems of uneven porosity and low water vapor transmission efficiency of the gas diffusion layer (GDL), to accelerate the research and development process of the core components of hydrogen fuel cells^[10].

Secondly, enterprises need to increase investment in scientific research, and actively adopt the latest scientific research results of universities and research institutes, to accelerate the transformation of scientific and technological achievements, enhance the competitiveness and innovation ability of products in the market, and then enhance the economic benefits of hydrogen fuel cells. For example, enterprises can introduce the latest catalyst technology, control the production cost, accelerate the chemical reaction of hydrogen and oxygen, improve the conversion efficiency of chemical energy to electric energy, and enhance the electric storage capacity of hydrogen fuel cells, to improve the overall performance^[11].

To sum up, the development of the hydrogen fuel cell industry cannot be separated from the close cooperation of the government, enterprises, scientific research institutes, and universities. On the one hand, it is necessary to actively research and develop core components to optimize system performance; On the other hand, it is necessary to overcome the core technical problems, improve the comprehensive performance of hydrogen fuel cells, and gradually enhance the competitiveness and market share of Chinese enterprises in the international market.

At the same time, the key role of artificial intelligence (AI) in accelerating the transformation of laboratory results into actual products is emphasized. For example, using AI platforms to accelerate the testing, validation, and optimization of new materials to bring them to market at a faster pace.

4.3. Formulate industrial plans scientifically to promote the development of hydrogen fuel industry

The government should leverage the goals of “carbon peak” and “carbon neutrality” to optimize the energy industry’s layout, strongly support the development of the hydrogen fuel cell industry, and formulate medium and

long-term development plans. Initiatives such as encouraging the establishment of hydrogen fuel industrial parks across various regions, overcoming technical challenges, and enabling China's hydrogen fuel cells to compete globally should be prioritized.

For example, the education and energy departments could establish a national special project on hydrogen fuel cells, providing research funding to institutes, enterprises, and universities. This would encourage technicians, educators, and students to actively participate in hydrogen fuel cell research and development. Efforts should also focus on strengthening the connection between industries, including hydrogen production and storage, hydrogen fuel cells, new energy vehicles, and electrical equipment, to enhance the hydrogen fuel cell industry chain. These measures aim to drive the high-quality development of the hydrogen fuel cell industry^[12].

In addition, local governments should offer preferential policies to hydrogen fuel cell-related enterprises, including support in areas such as land allocation, taxation, and technical standards. These measures can attract more high-tech hydrogen fuel industries and research institutes to invest in factories, establish research and development centers, and promote the growth of the hydrogen fuel industry chain.

For example, governments should actively provide hydrogen fuel enterprises with loan support, talent acquisition programs, and tax relief. Collaborating with research institutes, industry associations, and experts to develop safety construction standards for hydrogen fuel stations, performance testing standards for hydrogen fuel cells, and other technical regulations will help standardize the hydrogen fuel market. Additionally, strengthening the supervision of related enterprises will ensure large-scale and standardized production of hydrogen fuel cells, promoting the steady and sustainable development of China's hydrogen fuel industry^[13].

4.4. Promoting hydrogen fuel cell technology and the development of new energy industries

Firstly, the application field of hydrogen fuel cells is expanding steadily, which not only promotes the steady development of China's new energy industry but also gradually enhances the competitiveness of China's new energy vehicles and electrical equipment in the global market. Currently, the application of hydrogen fuel cells in the field of new energy vehicles is particularly notable. Their advantages, such as long driving range, high energy density, zero-emission operation, and high safety, have gained significant favor in the automotive industry^[14].

For example, well-known domestic enterprises such as Build Your Dreams (BYD), Great Wall, Huawei, and Xiaomi have adopted hydrogen fuel cells as a power source, significantly enhancing the overall performance of new energy vehicles. Additionally, hydrogen fuel cells are being widely used in the marine industry, where they replace traditional fuel-powered systems, effectively reducing harmful gas emissions and improving the stability of battery systems. The physical properties of key hydrogen fuel cell materials, such as catalysts, electrodes, bipolar plates, collector plates, and end plates, have been significantly improved. Consequently, the thermal, mechanical, and electrochemical stability of these components has been enhanced, making them suitable for meeting the power demands of ships. However, the high cost of basic hydrogen fuel cell technology for ships currently limits its large-scale adoption, necessitating further optimization by researchers^[15].

In addition, researchers can continue to explore and advance hydrogen fuel cell solutions with the assistance of artificial intelligence. The application of this technology is not limited to the automotive sector but extends to various scenarios, including smart homes and industrial automation, aiming to improve user experience and adaptability.

5. Conclusion

In short, hydrogen fuel cells offer significant advantages, including environmental protection, high safety performance, high energy conversion efficiency, and a wide range of applications. These features contribute to advancing China's new energy industries, such as vehicles, ships, and electrical equipment. By utilizing clean hydrogen energy as a replacement for fossil fuels, hydrogen fuel cells can help address the current energy crisis and environmental pollution issues while supporting the transformation and upgrading of China's energy and manufacturing sectors.

Researchers should actively focus on the development of key materials and components, optimize hydrogen fuel cell functionalities, and enhance overall performance. Strengthening collaboration between enterprises, universities, and research institutions is essential to accelerate the development of core components, facilitate the transformation of scientific and technological achievements, and drive the growth of the hydrogen fuel cell industry.

Simultaneously, local governments should develop well-structured industrial plans, provide increased support to hydrogen fuel cell enterprises in areas such as taxation, land allocation, and talent acquisition, and promote the hydrogen fuel industry. Efforts should also focus on advancing hydrogen fuel cell technologies and expanding their applications in new energy vehicles, ships, and other industries. This will foster the growth of the new energy sector and further contribute to the development of China's high-tech and clean energy industries.

Disclosure statement

The authors declare no conflict of interest.

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