Study on Environmental Adaptability of Metal Plate Fuel Cell

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Abstract—As a main task of national key project (2018YFC081000) "emergency power under the special environment systems research and application demonstration", Study on Environmental Adaptability of Metal Plate Fuel Cell, the paper focus on the key technologies needed to be developed of researching PEMFC system to adapt to the special environment of high temperature, high humidity, high salt, high cold and high altitude; this topic reviews the impact of plasma exchange membrane fuel cell and climate environment on such emergency power supply equipment, and uses Au@TiN as a metal bipolar plate of proton exchange membrane fuel cell. After a series of tests, it proves the excellent operation characteristics of the fuel cell reactor in “4-high” environment. The study showed that after constant 1.0 V (vs SHE) potential polarization, the size order of different coating corrosion currents is: gold plated> stainless steel> carbonization. In a high altitude environment, the optimal air intake parameters are obtained by numerical simulation and optimization of air pressure, air volume, wind speed, air excess coefficient and other parameters; In a high-temperature environment, the problem of the metal bipolar fuel cell supply system can be solved by improving the flow structure of the air side to increase the heat exchange area and the air capacity; In the high-cold environment, the shutdown pulse sweep scheme is adopted, and the rapid start of hydrogen battery supply system is realized by using hydrogen catalytic reaction assisted heating.

1. Introduction

Fuel cell is known as one of the cleanest energy sources in the 21st century, water is the only product of power generation process, and it is quiet power generation and has high efficiency. The new hydrogen fuel cell power supply system has the advantages that high power generation efficiency (about 50%), clean, silent, low infrared characteristics, modular power generation, and strong environmental adaptability. In some technically developed countries, the hydrogen emergency power supply developed is being applied and verified. In recent years, with the strong support of the government and the capital market, the research and development of fuel cells, especially proton exchange membrane fuel cells (PEMFC) in China has made great progress, which has a series of
characteristics of high efficiency, low noise, environmental protection, is a promising energy conversion equipment[1-3].

To satisfy the public security needs of border posts, remote reef scene practical environment in China, and far away from the grid area, "under the special environment of emergency power systems research and application demonstration" especially in the high altitude, high and low temperature, high humidity and high salt is one of the key projects from the establishment of the "national public security risk prevention and control and emergency technical equipment research". Most of the bipolar plates of fuel cells are made of graphite, but the graphite flow filed plate is brittle, which is easy to be damaged under vibration condition and has poor adaptability for field transportation. Fuel cell metal plate has characteristics of good mechanical properties, light weight and easy to mass production which is the key development direction of fuel cell membrane electrode. However, it is one of the key technologies needed to be developed of researching PEMFC system to adapt to the special environment of high temperature, high humidity, high salt, high cold and high altitude. Environmental conditions are divided into five environmental types, including climate environment, chemical environment, electromagnetic environment, biological environment and mechanical environment. Emergency power system is a complex equipment in long-term outdoor service, and these five environmental conditions will affect its operation.

2. Summary

We mainly considers the influence of climate environment on emergency power equipment in this paper. Environmental conditions of different environmental types can be divided into many different environmental factors, such as in the climate environment, temperature, humidity, salt, low pressure, storm, lightning, snow and other severe weather and other environmental elements. In view of the above environmental factors, environmental adaptability of emergency power supply can be improved by taking appropriate protective methods, mainly including the following ways.

1) For high and low temperatures, taking heat prevention, anti-freezing methods. In high temperature weather, considering the impact of temperature rise, for emergency power supply equipment, taking "heat prevention" methods including strengthening ventilation management, to ensure heat dissipation of the equipment area and the equipment itself. Strengthen equipment inspection, timely reflect equipment abnormal temperature rise, sound, vibration, etc. For the power supply equipment that works in an environment with high temperature, the cooling fan can be used for forced cooling. In low temperature weather, it should be noted that the reforming hydrogen production equipment is easy to be unable to start and run normally due to the increase of diesel viscosity. It is necessary to put in the electric heater in advance and take "anti-freezing" methods.

2) Take dehumidification methods for high humidity. The high relative humidity poses a serious threat to the normal operation of power supply equipment. Byungchan et al.[4] prove through experiments that humidity affects the performance and durability of PEMFC. Proper humidity can enhance the performance of PEMFC, but excessive humidity may cause overflow. This paper authors tested I-V performance, linear sweep voltammetry, cyclic voltammetry, and impedance diagrams of microchannel cells with changes in relative humidity (RH). The test data shows that the overflow phenomenon begin at RH=70%, and the ionic conductivity of the membrane reached its maximum value at RH=80%. When the relative humidity is 80%, the effect of ionic conductivity increasing is higher than its decreasing mass transfer, therefore, it is necessary to take reasonable methods to reduce the impact of ambient humidity on the equipment operation and carry out moisture-proof and dehumidification. Effective moisture-proof and dehumidification methods include: ventilation, local isolation, etc, take waterproof cover if necessary, Or install industrial dehumidifier, quickly and automatically solve the moisture problem; To prevent condensation, a heating or drainage dehumidifier can be installed at a proper position in the cabinet.

3) For high altitude and low-pressure environments, an air compressor is needed to increase the oxygen content in the air. When the altitude exceeds a certain value of the area of use, due to the corresponding decrease in atmospheric pressure, air density, and humidity, the air gap and external
insulation characteristics continue to decline. Therefore, the maximum allowable operating voltage of the device should be modified.

(4) Pay attention to prevent corrosion in high salt environment. On the one hand, it is better to use sealed and moisture-proof electrical component areas, or add cooling facilities to slow down the corrosion rate. On the other hand, it is better to treat the metal surface of the equipment to form a protective film, such as adding an anti-corrosion coating to slow down the corrosion rate of salt.

(5) The high cold from “four high” serious environments has the biggest influence on PEMFC start-up. Low temperature start-up at -10℃ is difficult due to MEA stratification. Many studies on start-up operation under high cold conditions have been done at China and abroad. Cappadonia et al. [5] believe that the conductivity temperature of Nafion117 membrane is related to moisture content, and -13℃ is the turning point from point to start-up because water in the membrane froze, and the conductivity of protons in the membrane is closely related to water form in the membrane. Therefore, -10℃ is a critical point for membrane materials. Freezing/thawing process will reduce the toughness of the membrane, and the membrane molecules will be rearranged horizontally, leading to the deceasing of the membrane performance under freezing point. Berning, Mao, and Meng [6-9] have done a lot of work on cryogenic initiation mechanisms and three-dimensional multi-model. Aiming to explore the dynamic change of multi-dimensional temperature field inside the battery during low-temperature starting. However, since the water management of the battery has not been explored in the above studies, there is no mature operation method for low-temperature starting internationally.

The fuel cell which is researched in this study is made of metal plate flow field, the bipolar plate is processed into hydrogen and oxygen monopole plate by extrusion molding technology such as pressing or extrusion of metal sheet, and then the bipolar plate is formed by welding two monopole plates, after welding, the two sides of the bipolar plate are hydrogen and air circulation channels. Looking from the experimental results, the performance indicators are excellent.

3. Research on operation characteristics of fuel cell stack in "four high environment"

3.1. Research on operation characteristics of fuel cell stack in high humidity and high salt environments

In order to enhance the proton conduction ability and improve the performance of hydrogen fuel cell, hydrogen fuel cell needs water to ensure the wettability of membrane electrodes during operation. Therefore, high humidity environment is conducive to the improvement of battery performance [4]. In addition, according to the above mentioned, this fuel cell metal bipolar plate adopts Au@TiN metal surface anti-electrochemical corrosion coating process, which has excellent anticorrosion performance.

![Figure 1 metal bipolar plate anticorrosion performance](image_url)

Test the anticorrosion performance of gold-plated and carbon-plated bipolar plates was tested at pH=2 and voltage 0.8V (vs SHE) and pH=2 and voltage 1.0V (vs SHE). The test result is shown in Figure1 Tafel test result shows that the corrosion potential of the carbon plated plate is the highest and the corrosion current density is the lowest. After 5 hours of testing, the corrosion potential of the gold-
plated plate decreased. It is speculated that pitting corrosion has occurred, leading to an increase in the corrosion current density and the corrosion rate. EIS test also shows that the corrosion resistance of the gold-plated plate decreased after 5 hours test. The three samples have no corrosion after 1 hour and 5 hours of constant 0.8V vs SHE potential. In addition, it can be seen from Figure 2 that after 1 hour of constant 1.0V (vs SHE) potential polarization, the corrosion current of different coatings is in the order of gold plating > stainless steel > carbon plating.

![Figure 2 compare and analysis of corrosion current of different coatings](image1)

After test finished, we can see that, the gloss of plated plate decreases, and the gloss of plated carbon plate increases. With the help of metallographic microscope, we have observed obvious signs of pitting on the gold-plated plate, and the surface morphology of the carbon-plated plate has changed. The test result is shown in Figure 3.

![Figure 3 The compare and analysis of corrosion of different coatings after test](image2)

### 3.2. Operation characteristics of fuel cell stack in plateau environment

The two-phase flow in the membrane electrode will be affected to some extent when the air becomes thinner in the plateau environment. It is necessary to improve its pressure to ensure the performance of cell. To prove that, this topic adopts the method of installing a fan inside the hydrogen cell stack, which can improve the speed of the fan and the air pressure at high altitude. However, the battery needs to consume additional auxiliary power. In order to achieve high power generation of the cell, the intake parameters of the cell need to be optimized. At the same time, with the increase of altitude,
oxygen content in the air also decreases significantly (shown in Figure 4), which is must to affect the supply of cathode reaction gas for hydrogen-air fuel cell.

![Figure 4 Atmospheric pressure and oxygen content in plateau environment](image)

In order to ensure stable power output and high utilization rate of hydrogen, it is necessary to increase air volume to improve air excess coefficient. With the increase of air volume and air excess coefficient, heat and mass transfer processes and water and gas distribution in the cell at high altitude will be significantly different from normal conditions. Therefore, the influence of low atmospheric pressure, oxygen content and high air excess coefficient on heat and mass transfer and water and gas transfer in the battery should be analyzed deeply, and the change rule of electrochemical reaction mechanism of the membrane electrode module should be studied more. By studying the parameters of air pressure, air volume, wind speed and air excess coefficient, the optimal inlet parameter conditions are finally obtained.

The determination of optimal intake parameters adopts numerical simulation and optimization algorithm, which is used to effectively seek the optimal operating conditions of fuel cell performance from the global range. First, the fuel cell model is established, select the variables to be optimized and evaluate the fuel cell performance and treat the optimized variables to the initial value, import the calculated target function value into MATLAB by the genetic algorithm, inherit the good performance to the next generation, eliminate the poor performance, then produce new variable values, and then enter the COMSOL Multiphysics for continuous calculation, and finally get the best fuel cell parameters.

### 3.3 Study on high-temperature environmental operation characteristics of fuel cell reactor

In high-temperature environment, metal bipolar fuel cell is difficult to heat dissipation. About 50% of the chemical energy of the fuel cell is directly converted into thermal energy discharge. Fuel cell membrane electrode is sensitive to temperature, local temperature may lead to membrane electrode perforation, cause the cathode and anode poles gas string, and then cause fuel cell performance parasitic crab, seriously may cause hydrogen and oxygen should be too intense and explosion, bring safety problems, so must be the fuel cell operating temperature strictly controlled.
In view of the problem of heat dissipation difficulties of metal bipolar fuel cell supply system in heat temperature environment, the following two solutions: on the one hand, prepare bipolar metal material with high thermal conductivity to enhance heat exchange, while improving the air side, increase the heat exchange area and increase the heat exchange area, as shown in Figure 5; On the other hand, similar to the plateau environment, the air volume is increased by the built-in fan of the hydrogen battery stack, thus achieving the purpose of strengthening the heat exchange. Enhance the heat exchange through the above scheme to realize the long-term and stable operation of the hydrogen fuel cell in a high heat environment.

Figure 6 shows the cathode cycle voltamn contrast before and after the fuel cell accumulates after 60h operation. We can see that both the cathode hydrogen adsorption peak and detachment peaks were decreased, and the cathode electrochemical activity area was reduced.
Figure 6  Voltaman contrast of the membrane electrode cathode cycle before and after 60h operation

Figure 7 shows the comparison of the polarization curve before and after 60h operation. After 60 hours of experimental accumulation, the performance of the battery first decreased, then gradually increased, and the current density was 2.3% when the current density was 0.6A/cm$^2$.

Battery performance decay was 1.2% at a current density of 5.2A/cm$^2$

![Figure 7 Comparison of the polarization curves before and after running 60h](image)

3.4 Study on cold environment of fuel cell reactor

On cold environment, hydrogen fuel cells are facing the problem of storage and start difficulties, water in the process of battery cathode and external transmission, if the environmental temperature is less than 0℃, there may be freezing phenomenon, and water ice will produce 9% volume expansion, when the battery heat after the start will melt ice into water, volume will reduce, repeated phase change will have a great impact on the battery material structure, battery performance and life. Therefore, it is necessary to establish the reactor preheating and control technology, combined with the shutdown purging strategy, to realize the reactor low temperature storage and start. After shutdown, the residual water vapor inside the reactor to reduce the membrane electrode components for the next start. The schematic diagram of the shutdown blow scheme is shown in Figure 8.

Although removing the liquid water in the battery component structure during shutdown, reduces the free water content in MEA and avoiding the damage caused by ice to MEA, not the lower the water content inside the battery, the stronger the low temperature start performance. If excessive drainage may seriously dewater the proton exchange film and also reduce the battery performance. This topic determines the best purge parameters by monitoring the changes in the battery resistance online, as shown in Figure 9. It can be seen that the purge flow, purge time and purge times will have a great impact on the internal resistance of the fuel cell, and the change of internal resistance is the internal water content change and redistribution of the battery.

![Figure 8 Schematic diagram of the shutdown blow scheme](image)
Therefore, in the process of low temperature storage, the microstructure and performance of the key materials of dry air purging and the reactor startup failure mechanism, and then analyze the impact of dry air purge flow and time parameters on the residual water vapor inside the battery, and finally obtain the optimal purging strategy.

Due to the less heat generated by the electrochemical reaction in the initial stage of the fuel cell start, the water generated by the electrochemical reaction in the high cold environment is easy to freeze, block the flow channel and membrane electrodes, and prevent the electrochemical reaction, leading to the failure of the fuel cell cold start. Fuel cell in the cold environment, its core work is to avoid ice formation in the process of ice and gas channel blocked, so this project adopts a main and auxiliary two schemes to start fuel cell, the auxiliary scheme for the reforming hydrogen heat direct heating reactor, to ensure that the system can still safely and quickly start operation, not detailed here.

The main scheme adopts the rapid start of the metal bipolar hydrogen battery power system by the hydrogen catalytic reaction auxiliary heating. The basic principle is in the initial stage mainly by
inputting a certain proportion of hydrogen and oxygen mixed gas in the anode, the volume ratio of hydrogen is usually about 95% (far higher than the explosion limit of hydrogen), the hydrogen electrochemical gas reaction under the catalyst, because the energy is not output, the electrochemical reaction is converted into heat, and then heating the reactor. The reaction gas input and control method during the cold start process are shown in Figure 10.

Figure 10 A cold start scheme based on the hydrogen catalytic reaction-assisted heating

Specifically, the temperature inside the fuel cell before cold start is less than 0℃, when the system is in the battery stack self-heating-preheating stage, the valves 2,3,4 open, the anode directly into a certain proportion of hydrogen and oxygen mixed gas, and electrochemical reaction under the catalyst, the heat generated for heating the reactor; meanwhile, the anode exhaust gas through the pipeline and the valve, the anode hydrogen and oxygen mixed gas is not fully reacted in the cathode, on the other hand, the high temperature exhaust gas can heat the reactor again. When the reactor temperature is higher than the set value, the valves 1,3 and 5 are open, the valves 2 and 4 are closed, the mixed gas supply of the anode is stopped, and the fuel cell is started and operated normally.

At different temperatures, the cold start process of the metal bipolar hydrogen battery power system by hydrogen catalytic reaction assisted heating is shown in Figure 11 and 12, which show that the fuel cell can complete the battery start process of about 82s under-20℃ and the battery temperature of about 71s can be increased to 0℃ under-25℃ environment.

Figure 11 Temperature change of the fuel cell during the 20℃ cold start process under the main scheme
4. Conclusion
The research and development of hydrogen fuel cells, especially proton exchange membrane fuel cells (PEMFC) in China has made great progress in recent years, and fuel cell is the most key component in hydrogen power generation, and strong environmental adaptability of fuel cell is very important, basic on the need of project “emergency power under the special environment systems research and application demonstration”, we studied on Environmental Adaptability of Metal Plate Fuel Cell, came to the Conclusion. uses Au@TiN as a metal bipolar plate of essential subexchange membrane fuel cell, after a series of tests, proved the excellent operating characteristics of the material under high humidity, high salt, high altitude, high temperature and high temperature, from which the following conclusions can be obtained:

1. Studies in high wet and high salt environment showed that after constant 1.0 V (vs SHE) potential polarization, the size order of different coating corrosion currents is: gold plated> stainless steel> carbonization.

2. In a high altitude environment, the optimal air intake parameters are obtained by numerical simulation and optimization of air pressure, air volume, wind speed, air excess coefficient and other parameters, and the fuel cell performance can achieve the optimal operating conditions.

3. In a high-temperature environment, the problem of the metal bipolar fuel cell supply system can be solved by improving the flow structure of the air side to increase the heat exchange area and the air capacity.

4. In the high-cold environment, the shutdown pulse sweep scheme is adopted. The best purge parameters were determined by monitoring the hydrogen battery supply system by using the method of hydrogen catalytic reaction assisted heating.

Above study found the way to solve the basic problem Environmental Adaptability of Metal Plate Fuel Cell, but we still continue research and improvement, and to do the reliability testing, through the application demonstration to form forming products.

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