Simulation of Fuel Cell Power Generation System Based on AMESim

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Abstract. Fuel cell has become the main power source of the fuel cell electric vehicle due to its advantages of high ideal energy conversion efficiency, low noise, high reliability and maintainability. The fuel cell power generation system is an integrated system including the fuel cell stack. Its physical model covers many subjects such as electricity, thermodynamics, hydrodynamics and electrochemistry, which makes it difficult to change the simulation of fuel cell power generation system. In order to study the characteristics of fuel cell system, the model of proton exchange membrane fuel cell system is set up using AMESim. The model mainly includes fuel cell stack, gas supply subsystem, cooling subsystem and DC/DC converter. On this basis, the characteristics of fuel cell stack and its subsystems under dynamic conditions are analyzed.

1. Introduction
Fuel cell, as a new type of green energy, has the advantages of no pollution, zero emission, high system reliability, strong environmental adaptability and high power density compared with traditional fossil energy [1]. Among different kinds of fuel cells, proton exchange membrane fuel cell (PEMFC) occupies the dominant position in the current market due to its advantages of high fuel conversion efficiency, no waste emission and low requirement for working environment compared with other types of fuel cells [2]. Because PEMFC is a complex dynamic system with nonlinearity and strong coupling, its dynamic characteristics involve electrochemistry, fluid mechanics, thermodynamics, etc., especially in the case of high power and high current, the nonlinear characteristics are serious, so it is very difficult to accurately describe the behavior of PEMFC [3]. In this paper, the fuel cell power generation system is constructed by AMESim simulation software, and there is no need to deeply study the internal computer theory of the module, thus simplifying the modeling process and ensuring the accuracy of the model.

2. Establishment of the fuel cell system model
2.1. PEMFC system architecture
The fuel cell system is a complex system, including stacks, gas supply subsystem, cooling subsystem and DC/DC converter, as shown in Figure 1. The research object of this paper is PEMFC and the gas
sources are hydrogen and air respectively. According to Figure 1, we use the AMESim to build a system-level simulation model, as shown in Figure 2.

![Figure 1. PEMFC system architecture](image1)

![Figure 2. PEMFC system model](image2)

### 2.2. Fuel cell stack

The output power of the fuel cell power generation system studied in this paper is 30kw, and the simulation parameters of the selected proton exchange membrane fuel cell stack are shown in Table 1.

| Parameter       | Value   |
|-----------------|---------|
| Mass of stack   | 17kg    |
| Number of cells | 110     |
| Cell area       | 800cm²  |

### 2.3. Gas supply subsystem

In the air supply subsystem of this AMESim model, the air supply system uses a constant flow source of "air", which is a mixture of 80% N₂ and 20% O₂, instead of an air compressor. The air is humidified...
by the humidifier and then passed into the cathode of the stack, and most of the water produced by the reaction is discharged through the cathode and collected by the condenser for air humidification.

In the hydrogen supply system, the high-pressure hydrogen passes through the gas tank valve and the pressure reducing valve and then drops in pressure, and then enters the stack after it drops to the working pressure. In order to realize the automatic control of the system, a solenoid valve is added after the pressure reducing valve to control the air supply switch of the system. The excess hydrogen in the reaction is pumped back to the intake pipe through the hydrogen circulation pump to continue to participate in the reaction, and the exhaust solenoid valve is opened and closed regularly to remove the nitrogen and water in the hydrogen supply pipe.

Given that the fuel cell has a working time of 1h and an output power of 30kw, the following formula can be used to calculate the hydrogen consumption.

$$m_{H_2} = \frac{P_{FC} \times T}{F \times V_{cell}}$$

Using formula (1), the required amount of hydrogen can be calculated. Where $P_{FC}$ is the output power in W, $V_{cell}$ is the single stack voltage, $T$ is the working duration of the fuel cell and $F$ is the Faraday constant 96485.3C/mol. The mass of hydrogen is calculated to be about 1.66kg.

2.4. cooling subsystem

The cooling subsystem mainly includes cooling water pumps, radiators, cooling fans, thermostats, temperature sensors, etc [4]. When the coolant is lower than 60°C, the cooling system performs a small cycle, that is, the coolant only circulates through the stack, cooling water pump, and thermostat; when the coolant temperature is higher than 70°C, the thermostat is in full open mode, The cooling system closes the small cycle and opens the large cycle. The coolant flows through the radiator and exchanges heat with the air to discharge excess heat to the outside of the system. If necessary, use a cooling fan to increase the heat exchange rate and intensity.

2.5. DC/DC converter

The interleaved parallel Boost converter is widely used because of its low current ripple, high power density, simple structure and high reliability [5]. The circuit structure is composed of two boost inputs and outputs in parallel. By staggering the phases of each drive signal by 180 degrees, each switch tube is switched on alternately, which can effectively reduce the current stress of each power device.

This paper uses the current control method to control the DC/DC converter. According to the error between the DC bus voltage and the reference voltage, the voltage outer loop gives the reference current of the inner loop through PID, and according to the given current of the voltage outer loop, the current inner loop obtains the duty cycle of the switch tube through the inner loop PID.

3. Simulation results

Based on the above model, the fuel cell power generation system is simulated, the simulation duration is set to 3600s, and the external load power demand is 30kw.

3.1. Stack output characteristics

Figure 3 shows the output voltage and output current of the fuel cell stack. According to the power calculation formula, the stack can stably output 30kw power within 1h.
3.2. gas supply subsystem

Figure 4 shows the hydrogen consumption in the hydrogen tank. The simulation results show that when the fuel cell lasts for 1 hour and the output power is 30kw, the total mass of hydrogen output by the hydrogen tank is 1.678kg, which is close to the theoretical calculation value. After 150s, turn on for 2s, causing a small amount of hydrogen to be discharged, the total discharged is 46.8g.

For the air supply part, we focus on analyzing the working performance of the humidifier. The relative humidity of the cathode is shown in Figure 5. The relative humidity of the fuel cell cathode rises first and then drops to about 100% to ensure that the exchange membrane is in a good wet state.
3.3. cooling subsystem
The simulation sets the initial temperature of the coolant to 20°C, and the simulation results are shown in Figure 6. When hydrogen and air are introduced, the electrochemical reaction in the reactor begins, and heat is released during the reaction. The cooling water pump is turned on and the temperature gradually rises. The cooling system is in a small cycle. At this time, the thermostat is closed. At about 16s, the opening degree of the thermostat gradually increases, and the cooling system gradually changes from a small cycle to a large cycle. At 323s, the thermostat is fully opened, the small cycle is closed, and only the large cycle is performed. The temperature difference between the inlet and outlet of the coolant is stabilized at 5°C, achieving a better cooling function.

3.4. DC/DC converter
Figure 7 shows the output voltage and current waveforms of the fuel cell power generation system under the control of "current inner loop + voltage outer loop". It can be seen from the figure that the output voltage has reached stability after 0.035s adjustment, stabilized at about 270V and the DC bus ripple is less than 1%, indicating that the designed two-phase interleaved parallel Boost converter and controller can work well. The steady state performance is good.
4. Conclusion
This paper builds the fuel cell power generation system based on the AMESim simulation software, simulates its working characteristics, observes whether the output voltage and current meet the power requirements, analyses the change trend of the internal temperature of the stack and verifies that the cooling subsystem can keep the fuel cell running at a set optimal temperature.

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