APPLICATION OF BUILDING EQUIPMENT INTELLIGENT MANAGEMENT AND CONTROL SYSTEM IN RENEWABLE ENERGY THERMAL ENERGY MODELLING

by

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Original scientific paper
https://doi.org/10.2298/TSCI2302075S

In order to solve the dynamic characteristics of fuel cell thermal energy in building equipment intelligent control system, this paper proposes the application research of building equipment intelligent control system in renewable energy thermal energy modelling. A cold water proton exchange membrane fuel cell cogeneration scheme was proposed. The heat produced by the installation is carried out by the cooling system, and the heat is exchanged between the heat exchanger and the hot water always heated in the heat exchanger. At the same time, a water tank is used to store hot water for heat recovery. Based on MATLAB simulation coupling software platform, the simulation model of fuel cell cogeneration system was established, including reactor model, power system model, heat exchanger model, etc. The simulation model of fuel cell cogeneration system was built up, including the reactor model, power system model, and so on. The experimental results show that the system can achieve good response performance and anti-disturbance by using fuzzy PID controller to control and simulate the system. At the same time, the simulation results show that the optimal efficiency of the system in the power load is about 83%. In conclusion, it can meet the modern family's thermal power demands and improve the power consumption.

Key words*: proton exchange membrane fuel cell, intelligent building, combined heat and power supply, fuzzy PID control, thermal energy, icontrol technology*

Introduction

In recent years, the atmospheric environment in China has deteriorated day by day, which has aroused people's concern for the environment, triggered people's motivation explore more energy-saving, environmental protection and optimization measures, and made efforts to improve the environment. As one of the industries with environmental pollution, the construction industry especially needs to pay attention energy conservation and consumption reduction [1]. The development of intelligent building concept is also based on this. Only by doing a good job in intelligent building equipment control technology and analyzing and studying the energy conservation of buildings can we better ensure the further development of buildings, promote the harmonious coexistence between our buildings and the environment, ensure the sustainable development of our buildings, and enable our buildings to embark on the road of economization, humanization, ecology, intensification and harmlessness. Therefore, relevant personnel

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need to carry out in-depth analysis on intelligent building equipment control technology and building energy conservation promote greater progress.

With the increase of population, China's resources and environment are facing unprecedented pressure and challenges. That is to say, rational utilization of resources is not only an important way to solve the energy crisis, but also an effective means to achieve harmonious coexistence between resources and environment and human development. In this case, in the process of building intelligent control and management, it is not only necessary to achieve humanized management and services to meet the needs of different people, but also to effectively upgrade and manage the system to achieve energy conservation. The system is not only the trend of the times from the perspective of control and management, but also can effectively prevent the energy loss in the building. It is an important means to save energy and reduce consumption and realize energy optimization management [2].

There is a considerable contradiction between the continuous growth of population and the relative scarcity of the earth's resources. Especially for a large population country like China, people's constantly improving living standards and quality of life will inevitably lead to greater energy consumption. In this way, there are new requirements for the form and function of modern buildings. When planning and building a modern city, relevant departments should supervise the construction enterprises to fully consider the intellectualization of building equipment and energy saving technology in architectural design. Only when the building equipment is intelligent and the management is intelligent, can people's living be intelligent, which improves people's living standards and quality of life, and at the same time, improves people's satisfaction with living.

Literature review

With the rapid development of construction industry, the demand for electricity is also growing. The situation of energy consumption tightening will exist for a long time, so it is urgent to save energy and reduce pollution. Fuel cell is a clean and efficient energy distribution system, which can directly convert chemical energy of hydrogen into electrical energy. Proton exchange membrane fuel cell (PEMFC) has the advantages of low efficiency and high current density, and has a very wide application. In the process of fuel cells, about half of the energy is generated in the form of heat energy. Research and development of energy and reduction of energy consumption have become important issues. As the first industry to bear the brunt, economic development is especially needed to achieve its own energy efficiency and reduce emissions. Through the exploration of intelligent building equipment control technology and building energy conservation, we can make the design and construction of buildings more meet the needs of the environment, more meet the needs of people's use, and promote the sustainable development of China's construction industry [3].

Mitigating the energy crisis has become a global strategic issue, especially for China, a populous country, how to realize the rational use of energy is not only related to whether people can have a good living environment, but also affects social harmony, and even affects the development of the national economy. Therefore, in modern building construction and management, while providing people with human functions and services, efforts should be made to make building equipment intelligent, ensure intelligent management of electromechanical equipment and intelligent control of energy consumption, and effectively prevent excessive energy consumption inside the building body.

The PEMFC is a new low carbon fuel cell. In normal operation, the energy output of PEMFC group is about 40-60%. This means that about 50% of hydrogen participate in electrochemical reaction in fuel cell group is converted into thermal energy. The optimal operation temperature of low temperature PEMFC is 60-80 °C, and excess heat in the reactor must be discharged during operation. Because too high temperature will lead to dehydration and cracking of proton exchange membrane, which will affect the service life of the stack and even cause danger [4].

Methods

Structure and working principle of cogeneration system

The fuel cell coogenation system is mainly composed of two parts. The left side of the heater is the coolant, and the right side is the circulation faucet. The coolant circulation system is mainly composed of electric stack, load, three-way diverter valve, radiator, water pump, temperature sensor, *etc*. The tap water circulating system is mainly composed of heat storage tank, water pump, solenoid valve, liquid level sensor, mixing valve, temperature sensor*, etc.* When putting energy to the load, the system releases heat generated in the pile by the cooling device and exchanges it in the heat exchanger. The heat has been recycled for heat storage tank in the form of hot water for household use.

On the side of the coolant circulation system, when the stack is working, the system controls the flow of coolant W_1 through the circulating water pump M_1. According to thermodynamic equation:

$$Q = W_1 c_{\mathrm{cl}} \Delta T \tag{1}$$

where ΔT is the temperature difference at the entrance and exit of the stack, c_{cl} – the specific heat capacity of coolant, and W_1 – the coolant flow.

The smaller the flow W_1 is, the higher the temperature. When the cooling rate of the reactor inlet is constant, the cooling temperature of the reactor outlet is higher and similarly, the larger the flow W_1, the smaller the temperature, and the lower the reactor cooling voltage. Cooling machines carry too much heat on the masses and exchange it in heat exchangers. The cooling system, driven by the circulating pump M_1, flows into the furnace again, constantly carrying out excess heat from the furnace.

When the water supply is on the right side making the electricity transfer to the outside, the temperature on the left side is usually cooled by the heat exchanger, and then flows back to the stack through the three-way diverter valve, across the radiator. According to the Second law of thermodynamics, heat can be automatically transferred from high temperature materials to low temperature materials, and the temperature of tap water in the system is lower than the temperature of coolant, so the high temperature coolant automatically transfers its heat to tap water flowing through the heat exchanger. At this time, the larger the tap water flow W_2 is, the more heat will be taken away from the heat exchanger, and the greater the drop in coolant temperature will be. Therefore, in order to reduce the inlet stack cooling rate, the flow of tap water on the right can be controlled by adjusting the speed of pump M_2. The tap water on the right can reach the standard of domestic hot water after continuous circulation and heat transfer.

When the water supply system on the right side stops circulating heat transfer, the high temperature coolant on the left side enters the radiator through the heat port of the heat exchanger and the three-way diverter valve for cooling. This can keep the cooling of the reactor inlet within a certain range.Through the aforementioned method, the stack can provide users with electricity and hot water during operation realize the combination of heat and energy of fuel cell system [5].

Model establishment

Fuel cell stack voltage model

The ideal standard electromotive force when the single cell reacts to generate liquid water is 1.229 V. Due to the existence of ohmic overvoltage $V_{\rm ohm}$ in the membrane, activation overvoltage $V_{\rm act}$ in the cathode side catalyst and concentration polarization overvoltage $V_{\rm con}$, which represents the static relationship between current and voltage, the actual potential decreases with the decrease of the balance potential. According to the established empirical formula of PEMFC output characteristics, the basic expression of single cell output voltage:

$$V_{\rm cell} = E_{\rm Nernst} - V_{\rm act} - V_{\rm ohm} - V_{\rm con} \tag{2}$$

where $E_{\rm Nernst}$ is the Nernst open circuit voltage, which can be expressed:

$$E_{\rm Nernst} = \frac{1}{2F}\left\{\Delta G - \Delta S\left(T - T_{\rm ref}\right) + {\rm R}T\left[\ln p\left({\rm H_2}\right) + \frac{\ln p\left({\rm O_2}\right)}{2}\right]\right\} \tag{3}$$

Assuming that all single cells are the same, the fuel cell voltage $V_{\rm st}$ and power $P_{\rm st}$ can be expressed:

$$V_{\rm st} = NV_{\rm cell} \tag{4}$$

$$P_{\rm st} = V_{\rm st} I_{\rm st} \tag{5}$$

Thermal model of fuel cell

According to the conservation of energy, the energy entering the stack is equal to the energy leaving the stack. Therefore, the fuel cell system meets the following transient equilibrium equation of state:

$$m_{\rm st} c_{\rm st} \frac{{\rm d}T_{\rm st}}{{\rm d}t} = Q_{\rm gen} - Q_{\rm dis} = \left(Q_{\rm tot} - P_{\rm st}\right) - \left(Q_{\rm gas} + Q_{\rm cl} + Q_{\rm atm}\right) \tag{6}$$

where $M_{\rm st}$ [kg] is the mass of the stack, $c_{\rm st}$ [kJkg^{-1}K^{-1}] – the specific heat capacity of the stack, $T_{\rm st}$ [K] – the working temperature of the stack, $Q_{\rm gen}$ [kW] – the heat generating power of the stack, $Q_{\rm dis}$ [kW] – the heat dissipation power of the stack, $Q_{\rm tor}$ [kW] – the chemical energy stored by reactants participating in the reaction in unit time, $P_{\rm st}$ – the output power of the stack, $Q_{\rm gas}$ [kW] – the heat of reaction gas in unit time, $Q_{\rm cl}$ [kW] – the heat carried out by the coolant in unit time, and $Q_{\rm atm}$ [kW] – the heat of the ideal environment thermal radiation of the stack in unit time.

Heat recovery model

The ideal heat transfer process between circulating coolant and tap water can be calculated according to the energy conservation relationship:

$$Q_{\rm cw} = \frac{W_1}{m\left({\rm H_2O}\right)} c\left({\rm H_2O}\right)\left(T_{\rm cw,in} - T_{\rm cw,out}\right) \tag{7}$$

Tap water endothermic:

$$Q_{\rm w} = \frac{W_2}{m\left({\rm H_2O}\right)} c\left({\rm H_2O}\right)\left(T_{\rm w,out} - T_{\rm w,in}\right) \tag{8}$$

Conservation of energy:

$$Q_{\rm cw} = Q_{\rm w} \tag{9}$$

where $T_{cu,out}$ is the outlet temperature of the coolant exit in the heat exchanger, which determines the inlet temperature of the stack. The fuel cell system is configured to control the temperature difference between the coolant inlet and outlet, namely ($T_{ow,in} - T_{cu,out}$ = 5 °C). For tap water, the tap water inlet temperature T_{win} of the heat exchanger depends on the living environment of the user. It can be considered that the storage temperature of hot water is determined by the tap water temperature $T_{w,out}$ entering the tank [6].

Model of heat storage tank

Set up water supply capacity *S* as 200 L. According to the law of energy conservation, the heat transfer of hot water can be expressed accordingly:

$$m_{ht}c_{p,ht}\frac{dT_{ht}}{dt} = Q_{recovery} - Q_{loss} - Q_{demand} \tag{10}$$

where $c_{p,ht}$ [kJkg^{-1}K^{-1}] is the average specific heat capacity of the heat storage tank, m_{ht} [kg] – the quality of hot water, Q_{loss} [kW] – the heat loss caused by heat dissipation of the heat storage tank, and Q_{demand} [kW] – the required thermal load.

Efficiency calculation

The power supply and heat recovery system of fuel cell cogeneration system:

$$\varepsilon_E = \frac{P_{st}}{Q_{H_2}} = \frac{I_{st}V_{st}}{\dfrac{0.5}{NC\Delta H}} \tag{11}$$

$$\varepsilon_T = \frac{P_{water}}{Q_{H_2}} = \frac{M(H_2O)c(H_2O)\Delta T}{0.5I_{st}NC\Delta H} \tag{12}$$

where P_{water} is the heat recovered from tap water, Q_{H_2} – the energy consumption of hydrogen, ΔH [kJkmol^{-1}] – the lower calorific value of hydrogen, ΔT [K] – the water temperature difference, N – the number of sheets of the stack, $M(H_2O)$ [kgs^{-1}] – the hot water flow at the secondary side, and $c(H_2O)$is the specific heat capacity of tap water.

The performance of fuel cell cogeneration system:

$$\varepsilon_{CHP} = \varepsilon_T + \varepsilon_E \tag{13}$$

System control strategy design and temperature controller design

System control strategy

The cooling outlet of fuel cell group is mainly realized by controlling circulating pump M_1 to control cooling water. The tap water flow through the heater is controlled by controlling the water pump M_2 or the temperature of the cooling inlet group is achieved by controlling the speed of the radiator fan. At the same time, the system must have good power and be able to quickly eliminate interference when they occur. Selection and control of the hot box operating mode are shown in fig. 1.

Before the stack starts to operate, open valve J_1 to inject water into the heat storage tank. When the liquid level in the water tank reaches 50% of the rated capacity, close valve J_1 and open valve J_2 at the same time, then the electric stack and water pump M_2 start to operate. The tap water and high temperature coolant in the heat exchanger are continuously circulated to exchange heat, reaching the service temperature of domestic hot water of 45 °C, and family

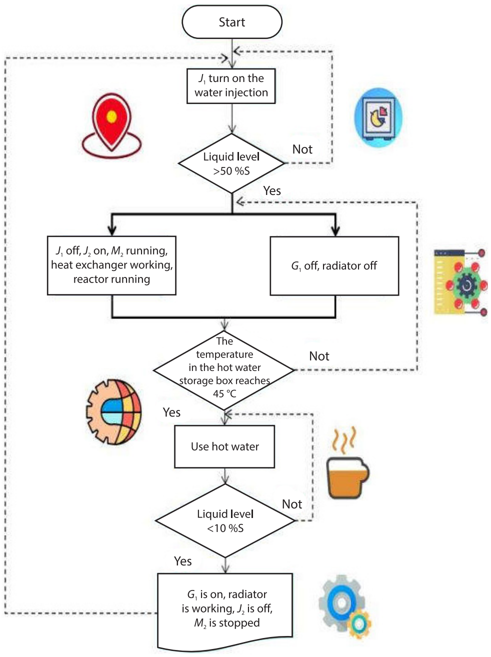

Figure 1. Operation mode selection and control strategy of heat storage tank

users can start to use hot water. When the water level in the water tank is only 10% of the test capacity, reopen valve J_1 to make water.

When it is no longer necessary to use hot water or make up water, the tap water flow is too small to absorb the heat of high temperature coolant. At this time, it is necessary to open the three-way diverter valve to allow high temperature coolant to pass through the radiator for heat dissipation, the inlet temperature of the stack is ensured by regulating the speed of the radiator fan [7]. Its control strategy is shown in fig. 2.

The inlet temperature of the electric pile is realized by controlling the flow of the water pump M_2. It can be seen from eq. (7) that when the reactor inlet temperature is constant, the higher the coolant flow, the more heat is obtained from the reactor in the unit time, and the lower the reactor outlet temperature is. On the contrary, the smaller the coolant flow is, the higher the coolant temperature of the reactor. As shown in fig. 3, by obtaining the difference between the actual temperature at the reactor inlet and the setting value, fuzzy PID is used to control the speed of pump water M_1 and adjust the inlet coolant flow W_1 to control the reactor outlet temperature. Similarly, by obtaining the difference between the actual temperature of the reactor outlet cooling rate and the configuration reference value, and adjusting the tap water flow W_2, the reactor inlet temperature can be controlled.

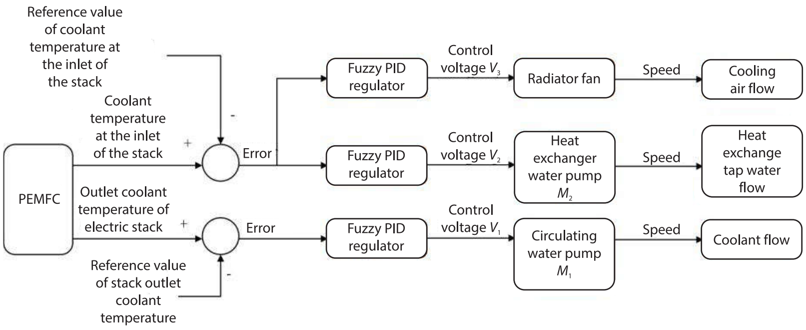

Figure 2. Temperature control strategy

Design of temperature controller

The thermal management of the stack is constantly affected by the load and ambient temperature, and the dynamic changes are more frequent. The robustness of the conventional PID controller is poor. Therefore, it is necessary to design a controller (*i.e.* fuzzy controller) that can automatically change the proportion, integral and differential parameters according to the operating conditions of the stack. Its principle is shown in fig. 3.

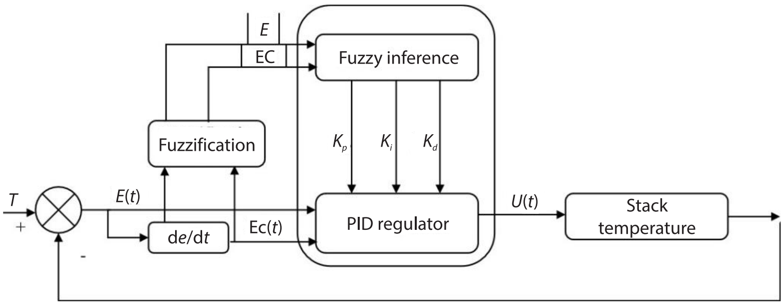

Figure 3. Fuzzy PID control principle

Therefore, the fuzzy control rules designed according to the aforementioned control rules are shown in tabs. 1 and 2. The control signal is output by the fuzzy PID controller and converted into PWM signal, therefore, the speed of radiator fan and circulating water pump can be adjusted to control the temperature of PEMFC by regulating the speed.

Table 1. Fuzzy control rules of K_p

|EC|	|E|			
	B	M	S	Z
B	M	S	M	M
M	B	M	B	B
S	B	M	B	B
Z	B	M	B	Z

Table 2. Fuzzy control rules of K_p

|EC|	|E|			
	B	M	S	Z
B	Z	S	M	B
M	Z	Z	B	B
S	Z	Z	B	B
Z	Z	Z	B	Z

Experimental analysis

Based on MATLAB/SIMULINK simulation platform, the model of fuel cell cogeneration system is built. It mainly includes stack model, radiator model, heat storage tank model, fuzzy PID controller*, etc.* The simulation parameters of the stack are shown in tab. 3 [8].

Table 3. Stack parameters

Parameters	Numerical value
Number of stacks	80
Activation area [cm^2]	200
Output power rang [W]	0-5000
Voltage range [N]	40-70 (DC)
Cathode partial pressur [kPa]	1.6
Anode partial voltage [kPa]	1.8

Results and discussion

In the simulation process, set the inlet coolant temperature group using value as 60 °C and the outlet coolant group using value as 65 °C. The fig. 4 shows the steady-state voltage distribution and the characteristics of the energy curve of the proton exchange membrane fuel cell.

Figure 5 shows the thermal efficiency, power efficiency and power efficiency of the fuel cell cogeneration system [9]. In the greatest condition, for example, the electrical efficiency of the system is zero when it is in standby, but it still consumes a small amount of hydrogen and generates a certain temperature. This means that if the fuel cell system uses a cooling fan to cool the stack, the efficiency of the fuel cell system is zero. Furthermore, it can be seen from the diagram that the efficiency of fuel cell cogeneration system increases with the increase of external load. Within the maximum load energy range, the maximum heat and energy coefficient are approximately 83% [10].

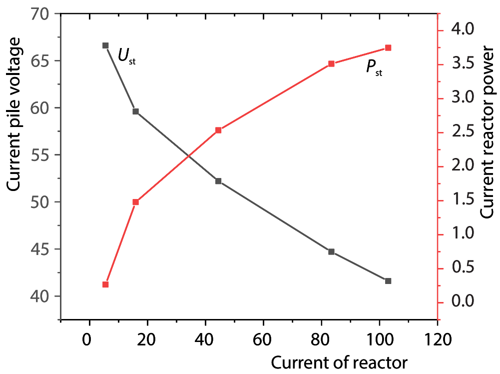

Figure 4. Voltage and power characteristic curve

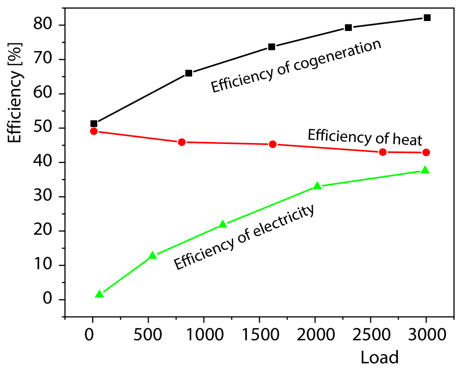

Figure 5. Efficiency curve

Conclusion

This paper proposes the application research of building equipment intelligent management and control system in renewable energy thermal energy modelling. The heat inside the pile is carried by the cooling machine and exchanged with ordinary tap water through the heat exchanger. The tap water heater enters the heating tank for domestic use. This makes the heat of fuel cell efficient, and greatly improves the utilization of energy. When the load suddenly changes, the stack temperature can automatically and quickly recover to the set value after a short fluctuation, which shows that the system has good dynamic performance and verifies the feasibility and effectiveness of the system design scheme.

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Paper submitted: July 4, 2022
Paper revised: August 30, 2022
Paper accepted: September 16, 2022