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RESEARCH ON POWER OPTIMIZATION CONTROL OF SOLID OXIDE FUEL CELL/LITHIUM BATTERY HYBRID SYSTEM

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ABSTRACT

Solid Oxide Fuel Cell (SOFC) has great scientific significance and market space as a green energy industry. The SOFC power generation system has the characteristics of slow dynamic response of the output power, so the lithium battery is used as an auxiliary power source to cooperate with the SOFC for power generation. In this paper, the 500W pure hydrogen solid oxide fuel cell system is modeled first. Then, the lithium battery state space model is built, and the second-order RC circuit equivalent model is selected to build the SOC estimation model and the SOH estimation model respectively. The Particle Filter (PF) algorithm is used to realize the joint estimation of SOC and SOH of lithium battery. Finally, the T-S fuzzy controller is designed for energy control. By controlling the output current of the lithium battery, the SOC is within a reasonable range in the process of coordinated power generation. In order to simulate the working condition of the hybrid energy system and test the feasibility of the control algorithm, this paper uses dSPACE to build a semi-physical simulation platform, and downloads the control algorithm to the control board to combine with the system model and electrical equipment for online simulation. The validity of the test algorithm is verified by the irregular load power variation, the problem of slow response of SOFC power tracking is solved, and the protection of lithium battery SOC is realized.

Keywords: SOFC, joint estimation of SOC and SOH, T-S fuzzy control, semi-physical simulation

1. INTRODUCTION

The continuous advancement of the human industry has relied mainly on petroleum-based fossil energy, which has led to a growing greenhouse effect. As a new green energy technology, the fuel cell is quiet and noiseless, with no heat and mechanical additional losses. It is known as the most valuable green energy in the new century after thermal power, hydropower and nuclear power. As a kind of fuel cell, SOFC has the advantages of all-solid structure, relatively low cost (no need to use precious metal electrode materials such as Pt), high energy density, and long-term power generation time compared with other batteries. Therefore, SOFC, as a fixed power station or mobile power source, has broad application prospects in the civil field such as large-scale centralized power supply, medium-sized power distribution, and small-scale household heat and power supply, and in the shipbuilding, transportation, and military fields[1].

While SOFC has a slow dynamic response to track changes in external load power during operation, SOFC is usually mixed with other types of power sources such as lithium batteries. In this process, the role of the lithium battery is to cut the peak output of the SOFC output power to achieve energy balance.

Hybrid energy management system is a main direction in the field of SOFC research. The energy management control algorithm comprehensively considers the SOC of the lithium battery and the external load demand power to determine the output power of the SOFC, and at the same time ensure the safety of the system. Many research institutes have done a lot of work in this direction, but most of the research work only considers the SOC state quantity of the lithium battery. By estimating the remaining discharge capacity of the lithium battery, it is used as the output power reference of the SOFC side, but not considering the effect of the amount of state on the system such as SOH. The energy management strategy of this paper incorporates SOH. In addition, the experimental period of the solid oxide fuel cell is long, and it takes a long time to verify the effect of the control algorithm. The verification of the control algorithm by the semi-physical simulation platform can improve the development efficiency of the algorithm, shorten the test period. Besides, the simulation system and the actual load unit can be jointly debugged to simulate complex conditions.

2. METHODS

2.1 Construction of SOFC model

Before the power optimization control of the hybrid system is carried out, the model of the SOFC independent power generation system needs to be built. The main components of the SOFC power generation system include stacks, exhaust gas combustors, heat exchangers (Class 2), blowers, pipes, cold air bypasses, and flow meters. Considering the complexity and achievability of the model, in the process of building the heat exchanger and the stack, the idea of "node" was adopted, and the sub-components were divided into five nodes to build a 1D model. The exhaust gas combustion chamber, pipeline and cold air by pass, etc., based on their input and output relationship, built a lumped parameter model. After each unit component model is established and independently simulated, the system model can be built and integrated according to the connection relationship between the units of the system.

2.2 Lithium battery SOC and SOH joint estimation

Since online testing using actual hardware tends to be long, it is possible to build a lithium battery external characteristic model for simulation experiments, which greatly shortens the test cycle. In order to comprehensively consider the achievability and accuracy of the project, this paper selects the second-order 2-RC circuit model to model the lithium battery. Based on it, the state space models for the SOC estimation and SOH estimation can be established. The SOC is the basis for determining the degree of charge and discharge of the lithium battery[3], and the SOH state quantity can reflect the remaining life of the battery. These two state quantities are the main basis for the subsequent control strategy.

There are many kinds of estimation algorithms for state quantity.In this paper, the Monte Carlo method based PF estimation algorithm is used to jointly estimate SOC and SOH. It uses state of probability statistics to estimate the state, thus achieving the effect of unrestricted noise model, unrestricted system model and high-precision estimation[4].

2.3 Power Optimization Control of Hybrid Power System

The actual system experiment verifies that the control algorithm often has a long test period, while the pure simulation system can not simulate the actual system working condition well. Therefore, this paper adopts the method of using German dSPACE hardware-in-the-loop simulator to build a semi-physical platform. The upper computer Simulink simulation software runs the system model, and the control algorithm is verified by the dSPACE signal control board combined with the electric unit.

The energy management algorithm adopts multi-input and single-output T-S fuzzy model. The model is suitable for systems with small-scale linearization and segmentable control, and the output is clear, eliminating the F/D module, so it can drive directly external controller. This facilitates the experimenter to perform data analysis on the control effect[5].

The SOC, SOH and current are fuzzified into the expert knowledge base, and the lithium battery current setting value is output through the fuzzy control rule. Finally,the system can quickly track the sudden change of power outside the system while ensuring that the lithium battery is in a healthy state and the SOC is within a reasonable range. And it can ensure the output power of the SOFC is relatively stable.

3. RESULTS AND DISCUSSION

3.1 Analysis of PF algorithm results for joint estimation of SOC and SOH in lithium batteries

As shown in Figure 1, the SOC estimation results, the blue line represents the actual SOC, and the red line represents the filtered estimated SOC. The filter estimation curve is basically coincident with the actual SOC estimation curve, indicating that the estimation result is almost equal to the true value, and the algorithm filtering effect is good; Fig 2 is the SOC estimation error curve, and the curve indicates that the absolute value of the estimation error does not exceed the maximum 0.035, which is only 3.5% of the estimated range, further verifying the high-precision characteristics of the particle filter estimation algorithm.

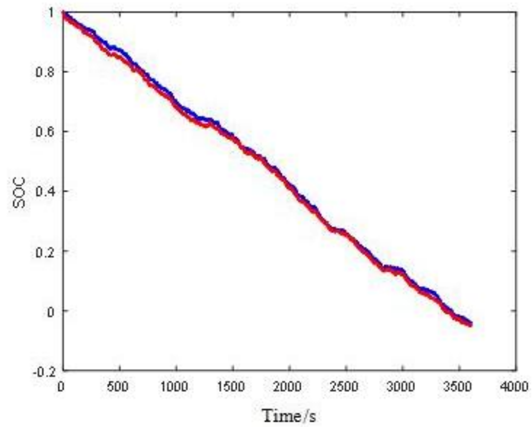

Fig 1 SOC estimation result

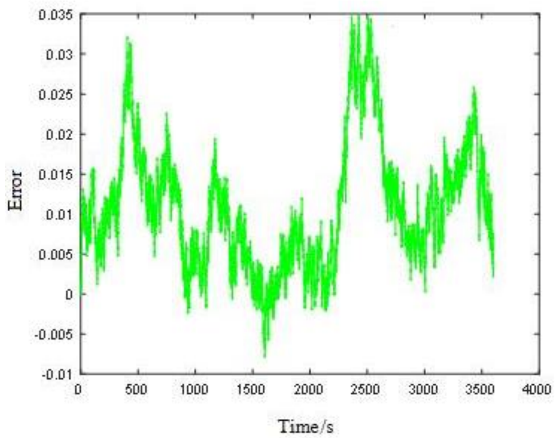

Figure 2 SOC estimation error

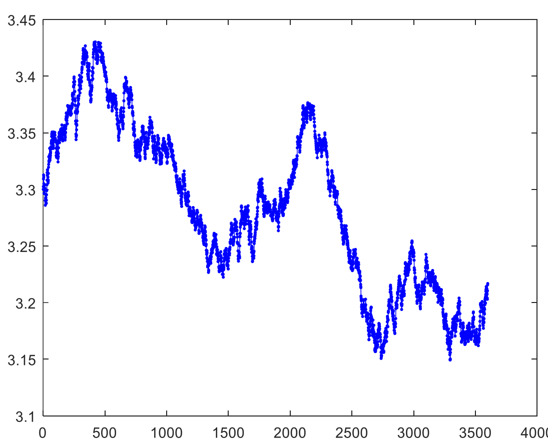

Figure 3 Filter estimates the maximum battery capacity

Figure 3 shows the maximum capacity of the filter estimation. It can be seen from the figure that the battery capacity tends to decrease overall in 3600 sampling periods, but there is a local capacity increase in the 500th sampling period. This is because the capacity-based lithium battery state equation simulates the increase in transient charge capacity due to local complex electrochemical reactions during actual use. The battery capacity of the lithium battery used in this paper should be greater than 2.64 Ah in the normal SOH range, and the estimated minimum value of the capacity is about 3.15 Ah. Therefore, the battery SOH is greater than 0.8 in the 3600 sampling periods of this experiment, and it can always work normally.

3.2 Implementation of Energy Management Algorithm

Figure 4 and Figure 5 show the SOFC output power and load power curve, mixed energy system power and load power curve respectively. For the effectiveness of the verification algorithm, the load power adopts an irregular variation to increase the control difficulty. In the figure, the SOFC power in the startup phase within 1000s cannot meet the load demand. The lithium battery is used as an auxiliary energy storage component to quickly supplement the power shortage of the DC bus, so that the output power of the whole system can meet the load demand. After 1000s, the SOFC enters the working stage of the load-carrying power generation, but its output power fluctuates greatly. The lithium battery continuously switches between the charge and discharge state and the SOFC co-generation to control the output power steadily .

Besides, in order to simulate the T-S fuzzy controller's SOC control effect on the lithium battery, the initial SOC is set to be 0.2 and 0.9, respectively, and the protection effect of the controller on the SOC is tested under the same load current change.

In the two experiments with different initial values of SOC, the output current of the lithium battery instantaneously increases at the time when the load current rises step by step, thereby making up for the shortcoming of the slow electrical characteristics of the SOFC output. When the load current step drops, the lithium battery is instantaneously charged to absorb excess power on the DC bus, and the SOC is maintained between 0.4 and 0.8. In addition, as shown in Fig 6, the change of SOH during the whole operation of the lithium battery, it can be seen from the figure that the SOH value is always maintained between 0.8-1, so the battery is kept in a healthy working state.

4. CONCLUSIONS

This paper designs a SOFC hybrid electric energy system and uses a lithium battery as an auxiliary energy storage device. The PF algorithm is designed to jointly estimate the SOC and SOH. Finally, the T-S fuzzy controller is designed to protect the state of charge of the lithium battery, and the control algorithm is verified on the self-built dSPACE semi-physical simulation platform. The specific research results are as follows:

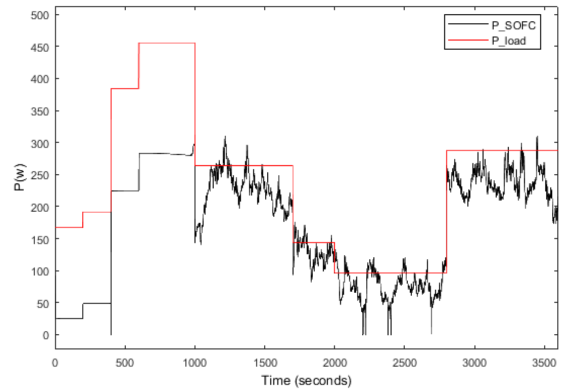

Figure 4 SOFC output power and load power curve

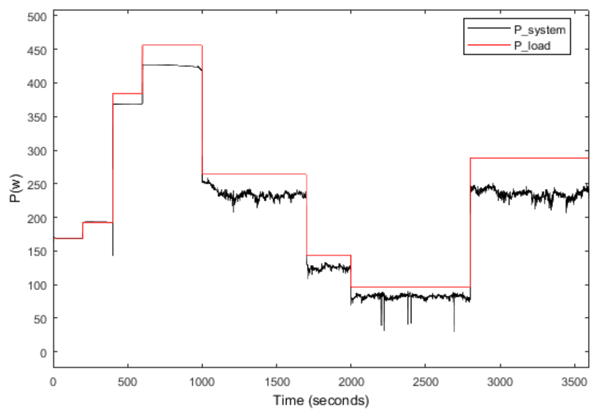

Figure 5 Hybrid energy system power and load power

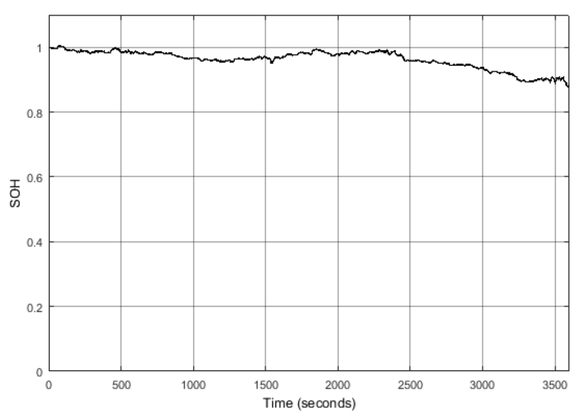

Figure 6 SOH curve of lithium battery

(1) Based on the 2-RC equivalent circuit, the SOC and SOH estimation state space models of lithium batteries are established respectively. Based on the battery model and the particle filter algorithm is used to realize the joint estimation of SOC and SOH, the absolute value of SOC estimation error is less than 0.035. The SOH estimation results show that the battery has a SOH greater than 0.8 in 3,600 test cycles, so the battery is in a healthy working state.

(2) Design the T-S fuzzy controller to manage the output current of the lithium battery to protect the SOC. Based on dSPACE, the semi-physical simulation platform simulates a hybrid energy system. The SOFC model, lithium battery model, particle filter estimation algorithm and T-S fuzzy control algorithm are run in dSPACE. The efficiency of the energy management strategy is verified by the step-up and reduction of the load to simulate the variable load conditions. By controlling the charge and discharge of the lithium battery, the SOC is in the range of 0.4-0.8, and the system can quickly and stably track the load power.

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