Application of Fuzzy Control in Ocean Nuclear Power Plant Control

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Abstract—In marine nuclear power plants based on molten salt reactors, the complexity of core nuclear reactions, fuel fluidity, and the “false” water level characteristics of the steam generator water level make it unrealistic to establish an accurate mathematical model, so it is difficult to implement traditional PID control methods. This has increased substantially. The fuzzy control has a good solution to this feature. Therefore, combined with the fuzzy control that does not depend on the precise mathematical model of the controlled object, the fuzzy controller of the nuclear power plant is designed, and the control research of the core power is obtained respectively through MATLAB/Simulink simulation. It shows that the designed fuzzy controller can achieve good control of nuclear power plants.

1. Introduction

The liquid molten salt reactor uses molten fluoride salt as fuel and does not need to prepare fuel elements. It is the only liquid fuel reactor among the six candidate reactors of the fourth-generation advanced nuclear energy system. At present, various research work has been carried out on molten salt experimental reactor (MSRE) and molten salt breeder reactor (MSBR) at home and abroad. The complexity of reactor core reactions, fuel fluidity, and the "false" water level characteristics of the steam generator water level have made it unrealistic to establish accurate mathematical models, and the difficulty of implementing traditional PID control methods has also increased significantly.

Fuzzy control does not rely on the precise mathematical model of the controlled object and has good robustness. It can often achieve better control effects when dealing with complex systems [1]. Ruan Jian [2] and others applied fuzzy control to the temperature control of molten salt system, and the research showed that the fuzzy control method is suitable for molten salt loop system; Qian Hong [3] and others applied fuzzy adaptive control to the voltage stabilization of pressurized water reactor nuclear power plants. In the reactor pressure control, the control effect is good; Yang Kaijun [4] and others applied fuzzy control to the core power control of nuclear reactors, and studies have shown that the core power has a good stability process under fuzzy control.

In this paper, considering the nonlinearity of the core system and the fluidity of the core fuel, in order to study the power control control based on the molten salt reactor, a simulation system is established in MATLAB/Simulink, and based on the fuzzy control toolbox, the fuzzy controller is designed and carried out. The simulation analysis under core power load tracking is presented.

2. Offshore floating nuclear power plant system

A simplified schematic diagram of an offshore floating nuclear power plant based on molten salt
reactors is shown in Figure 1. It can be seen from the figure that the characteristics of the steam generator as a bridge between the reactor and the cooler will greatly affect the core. The precise description of mathematical models increases the difficulty of the control system.

Fig. 1 Schematic diagram of an offshore nuclear power plant based on molten salt reactors

3. fuzzy controller

3.1 Fuzzy control theory

Fuzzy control is an intelligent control method with fuzzy set theory as its mathematical foundation. The core power fuzzy controller is designed based on the Mamdani-type two-dimensional fuzzy controller, and its structure is shown in Figure 2.

![Structure diagram of two-dimensional fuzzy controller](image)

The fuzzy controller is mainly composed of fuzzification, fuzzy inference, and defuzzification based on the knowledge base. The structure diagram is shown in Figure 2. The fuzzy controller is designed based on the MSBR core transfer function, and the relative power error e (relative The difference between the power setting value and the feedback value) and the relative power error rate of change ec are the input, and the control rod speed u is the output.

a. Fuzzification: The controller converts the non-fuzzy input quantity, that is, the relative power error value and the relative power error change value into fuzzy quantities that can be used for fuzzy logic inference, and select {negative large (NB), negative medium (NM), negative Small (NS), zero (ZO), positive small (PS), median (PM), and large (PB)} are used as fuzzy sets.

b. Fuzzy reasoning: The controller performs fuzzy logic inference on the fuzzy control input according to the formulated fuzzy rule table, and finally obtains the required control rod speed fuzzy output.

c. Defuzzification: The fuzzy output obtained by fuzzy inference is converted into a non-fuzzy output, that is, an accurate output value, through the area-gravity method or the average maximum method.
3.2 Design of fuzzy PID controller based on MATLAB platform

(1) Fuzzy language

For control systems, generally speaking, the input and output of the fuzzy controller will be divided into two levels, large and small, according to the size, and more refined control systems will be divided into three levels, large, medium, and small, or even more. Consider the positive, negative and zero values at the same time, so you can get 5 fuzzy languages. Namely:

{Positive big, positive small, zero, negative small, negative big}

For convenience, letters are often used instead:

{PB, PS, ZO, NS, NB}

Obviously, the greater the number of fuzzy languages, the more delicate the description of the original accurate value, and the more rapid the response of the control system. However, this does not mean that a system with more fuzzy languages will have a better control effect. In fact, with the increase of fuzzy languages, the number of rules and the parameters of the membership function will also increase sharply, greatly increasing the rule base. And the difficulty of determining the related parameters makes the fuzzy control system unable to effectively use the expert experience, so this paper chooses five fuzzy languages.

(2) Membership function

The fuzzy logic toolbox is integrated in MATLAB, which can be directly called by using fuzzy commands. The toolbox can intuitively realize the establishment of membership function, and it can also be described by the MATLAB command group. The main interface of the fuzzy logic toolbox is shown in Figure 4.

![Fuzzy Logic Toolbox](image)

Fig. 4 Fuzzy Logic Toolbox

Because it is a two-dimensional fuzzy PID controller, the system has two input quantities and three output quantities. For simplicity, the same membership function is selected for the five quantities. The
The membership function constructed by the fuzzy inference system is shown in Figure 5. The abscissa in the figure is the input clarity, and the ordinate is the output blur.

Fig.5 Five-stage membership function

(3) Fuzzy control rules
Fuzzy control rules are the core content that reflects expert experience in a fuzzy control system, and their number is related to the number of fuzzy language, input and output, and membership functions. Fuzzy rules can be directly written in the fuzzy logic toolbox of MATLAB, as shown in Figure 6.

Fig.6 Fuzzy rule editing interface of Fuzzy Logic Toolbox

According to the selection of the membership function and the characteristics of the molten salt pile, the fuzzy rules shown in Table 1 are formulated.

(4) Reasoning method
Nuclear reactors pay more attention to their safety. Therefore, the selected fuzzy reasoning method is relatively conservative inference (Mamdani method), which can increase the stability of the system, but it will reduce the response speed. The defuzzification method is the most widely used COG method.
Table 1 Fuzzy control rule table

| Output u | Relative power error e |
|----------|------------------------|
| NB       | NB NB NB NB NM NS PS PM PS |
| NM       | NB NB NB NM NM NS ZO PS PM |
| NS       | NB NM NM NS ZO PS PM PM |
| ZO       | NM NM NS ZO PS PM PM PB |
| PS       | NM NS ZO PS PM PM PB |
| PM       | NS ZO PS PM PB PB PB |
| PB       | ZO PS PM PB PB PB |

4. Results and analysis

Use MATLAB/Simulink to build a fuzzy controller, as shown in Figure 7.

Fig. 7 Control system based on core power feedback

At 100% FP power level, the simulation system runs at 100% FP power before 100s, and the target load is linearly reduced to 90% FP at a rate of 5% FP/min at 100s. Then, after 280s of stable operation, at the time of 500s, the target load linearly rises to 100% FP at a rate of 5% FP/min. The simulation results are shown in Figure 8. It can be seen from the figure that the change trend of the relative power of the core under the action of the fuzzy controller is the same as the change trend of the target load, and there is no big deviation between the two. It can be seen that the fuzzy controller can achieve good tracking of the relative power of the core.

Fig 8 Core relative power response of 100%FP-90%FP-100%FP
5. Conclusions
This article is based on molten salt reactor-based offshore floating nuclear power plants. Taking into account the nonlinearity of the molten salt reactor core system and the fluidity of the core fuel, and the false water level of the steam generator have a great influence on it, the design based on the core Power fuzzy controller, rationally designed the fuzzy controller's variable universe, membership function and rule library, and built the fuzzy controller and core power control system in the MATLAB/Simulink environment. The simulation results show that the designed fuzzy controller obviously shortens the time for adjusting the relative power of the core, has a fast control speed, reduces overshoot, has good static stability, and can effectively realize core power control.

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