Mathematical Modeling and Simulation of Pressurizer Pressure Control System

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Abstract-**The data of pressurizer dynamic characteristics was obtained by the test on simulator. The test included disturbances of spray valve and electric heater power. The transfer function of the pressurizer pressure was established upon the data. The control system was simulated by the use of Simulink simulation package. The simulation result shows that the pressurizer model and its pressure control system are correct and have the reasonable dynamic trend. The pressurizer model can be used on other research.**

Keywords-Pressurizer，Pressure control system，Transfer function，Simulation

I. INTRODUCTION

The pressurizer is one of the primary equipments in primary loop of the PWR nuclear power plant; its dynamic characteristic has been researched since the 1960s. The early supposed model was equilibrium state model, simple calculation, but inapplicability to rapid change transient. Redfield and Margolis [1]、Baron and Abdallah [2] proposed the two-area nonequilibrium model which exposed its shortcomings due to the existence of stratification after super-cooled water entered pressurizer while positive fluctuation. Baggour、Martin and Baek proposed the three-area nonequilibrium model [3]. The model divides liquid water area into main water area and wave water area, and it can reflects stratification, but the wave water area, devoid of meaning, the selection for initial volume has certain arbitrariness. Besides, it is hard to determine the partition coefficients which have great effect on the model accuracy. You Hong-jun and others proposed the multi-areas nonequilibrium model[4], where the volume was used as state variable instead of the quality, and the whole water area was used as the only volume state variables, eliminating redundancy state variable maximum, enhancing the efficiency and stability of solving the model. Reference [5] made some simulations on working and control process of the pressurizer pressure control system, and Reference [6] studied the steady-state and dynamic properties for the step change ± 3 ℃ in the coolant average temperature and external load ± 10% step change in voltage rated power , but the pressurizer transfer function of the mathematical model is not mentioned.

The purpose of this paper is to use system identification methods to get the transfer functions of pressurizer pressure control system, and then make simulations for its dynamic characteristics.

II. MATHEMATICAL MODEL OF PRESSURIZER WITH PRESSURE CHANGE

Usually,there are tow methods to establish mathematical model, for one, the model is derived according to the structured data of system and fundamental theorem, conservation of matter, energy conservation and equation of continuity, this method is called mechanism model or analytical model; another is called system identification to describe SISO linear system with transfer function [7], established by the data of systems operation. Besides, the nuclear power unit model can be established upon numerical calculation program Relap5 [8].

In this paper, some curves were obtained by simulation test in 900MW PWR nuclear power plant simulator; the mathematical models of pressurizer pressure change were established by studying the two channels, proportional heater and proportional spray.

The system was set in full load conditions in plant original rational simulator, the Initial system parameters see Table.1

A. Transfer function of sprinkler valve control channel

The spray valve opening was changed from 0% to 5% when all switches were set to M (manual), the pressure curve was shown in Figure 1

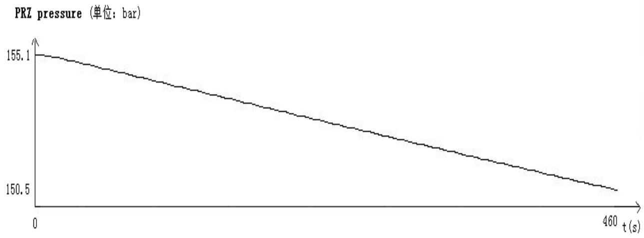

Figure 1. Spray valve opening's test curve

According to the curve data, the transfer function of controlled object was got, its input was spray valve opening and the output was pressurizer pressure:

$$G(s) = -\frac{0.92}{460s} \qquad (1)$$

The step response curve was obtained according to the transfer function (1) as shown in Figure 2, the coordinates were listed in Table 2 with the coordinates corresponding experimental step response curve.

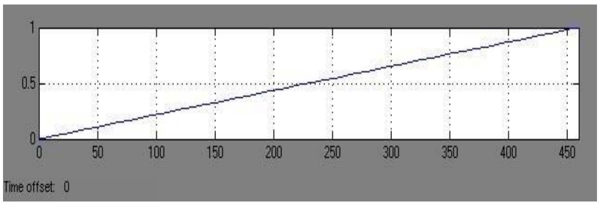

Figure 2. Calculated curve for step response of spray valve

B. Transfer function of electric heater control channel

The power of electric heater increased by 130KW when all switches were set to M (manual), the pressure curve was shown in Figure 3.

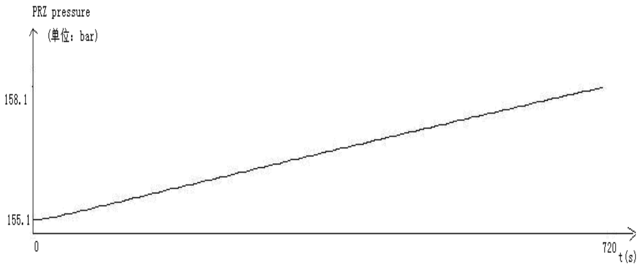

Figure 3. Electric heater's test curve

The transfer function of controlled object was obtained by calculation. Its input was power of electric heat and the output was pressurizer pressure:

$$G(s) = \frac{0.02308}{748s} \qquad (2)$$

The step response curve was got according to the transfer function (2) and shown in Figure 4. The coordinates were listed in Table 3 with the coordinates corresponding test step response curve.

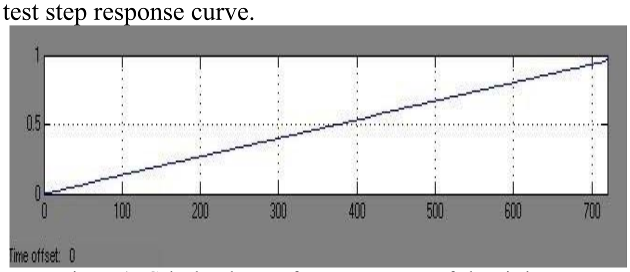

Figure 4. Calculated curve for step response of electric heater

The table 2 and table 3 showed that, the transfer functions we got were consistent with test data.

III. PRESSURIZER PRESSURE DYNAMIC CHARACTERISTIC'S SIMULATION AND ANALYSIS

The main function of the pressurizer pressure control system is to keep pressure at its setpoint 155 bar, so that emergency shut-down will not appeare at normal transient, nor will the safety valve work.

The principle block diagram pressurizer pressure control system is shown in Figure 5, the system is a single parameter, multi-channel control system. The deviation ΔP is the difference between the pressure measurement signal P and the pressure setting Pref. The pressure conditioning regulator signal ,known as the compensation differential pressure △P_C, is gained by using PID regulator which adjusted deviation ΔP. The signal △P_C is sent to four adjustment channels,which are proportional heater, proportional spray, on-off heater and power pressure relief valve. The four channels take actions by a certain pressure deviation signal [9]. The pressurizer pressure control characteristics are shown in Figure 6

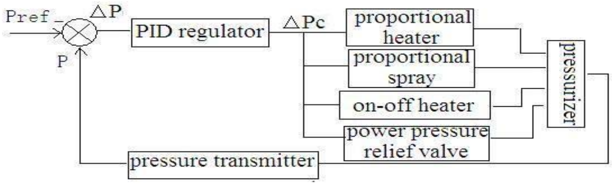

Figure 5. Functional block diagram of pressurizer pressure control system

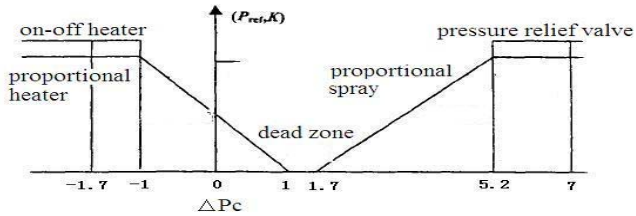

Figure 6. Pressure control properties of pressurizer

The electric heater is started when the pressure is low, then the pressurizer water is heated to vaporize which leads the pressure rises; If the pressure is high, the spray valve opens, the spray water is sprayed into the pressurizer so that the steam condenses, temperature decreases, the pressure also falls, the pressurizer pressure is maintained constant, thus the primary loop pressure constant.

The module diagram of the pressurizer pressure control system was constructed in Simulink and shown in Figure 7 according to the Figure 6 and the transfer function from the preceding context. In the module, if t = 2500s, r (t) = 2; else if t = 4000s, r (t) 1 =-2.

The simulation result was shown in Figure 8 From the changed pressure curve and pressure output curve we can see, 2500s~ 4000s, under the r(t) ,the pressure change value can quickly track to the set value, and there are no deviations. After 4000s， under the r(t)1, the pressure change value can still track to the setpoint.

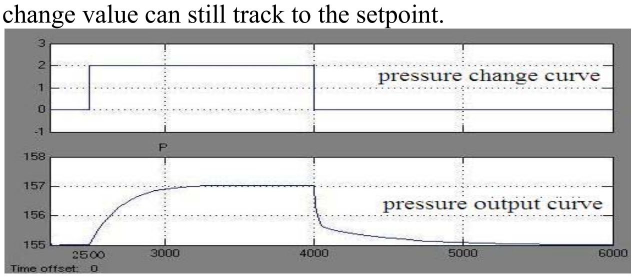

Figure 8. Response curves of the pressurizer pressure control system

A. Spray valve control

According to the Figure 6 and the transfer function of the spraying control channel, the module diagram was constructed as shown in Figure 9

1) The PRESSURE SETPOINT disturbance

At t = 100s the constant disturbance r (t) was added, then the differential pressure began to change gradually, and the valve opened wider, the P gradually decreased along with this the differential pressure decreased. According to pressurizer pressure control features, the valve opened for smaller, finally the pressure tended to stability. The simulation result was shown in Figure 10

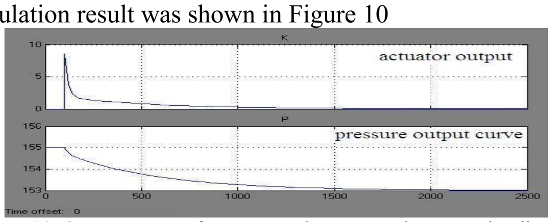

Figure 10. Output curves of actuator and pressure when set point disturbs

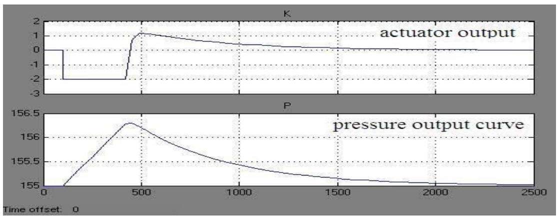

Figure 11. Output curves of actuator and pressure when spray valve's disturbs

2) Spray valve opening disturbance experiment

The initial pressure was 155bar. At t = 100s the spray valve opening disturbance was added, then the P increased, $\triangle P_C$ changed, the valve began to work when the $\triangle P_C$ increased to 1.7, the pressure P decreased, along with smaller pressure the valve opened for smaller until the pressure stabilized at set point. The simulation result was shown in Figure 11

B. Electric heater control

The pressurizer electric heater has 60 heating tubes, each is 24KW, divided into 6 groups, the two are proportional, and the other four are on-off style. According to the pressurizer pressure control features and the transfer function (2), the system block diagram was set up as Figure 12

1)The given value disturbance

According to the control characteristics of electric heater, the initial value of the transfer function was set at 150bar and the Pref was 155bar. At the beginning, $\triangle P_C$<-1, the proportional heater and the on-off heater worked at the same time, the power was 1440KW. At 100s the $\triangle P_C$>-1, then the electric heater closed, by this time electric heater power was 480KW. Between the 100s and 500s, the proportional heater worked until the $\triangle P_C$ reached to 1.

Follow on, constant disturbance was added so that the set pressure increased by 2bar. The proportional heater worked so that the P increased, $\triangle P_C$ dwindled, the heater power slowly decreased and pressure eventually stabilized. The simulation process was shown in Figure 13

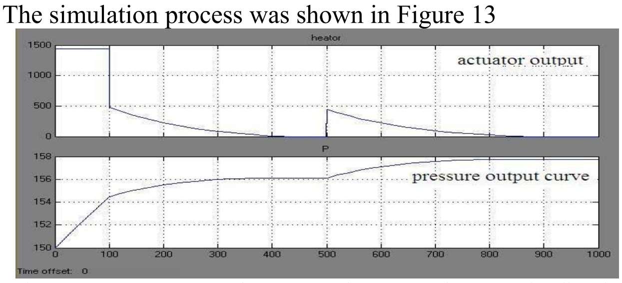

Figure 13. Output curves of actuator and pressure when set point disturbs

2)Electric heater power disturbance experiment

Between 0s and 500s, the process was the same as the constant disturbance. At 500s the measurement disturbances was added so that the input power of transfer function decreased by 300KW. This moment the P decreased and the electric heater began to work, then the heating power increased so that the P increased too, because the $\triangle P_C$ decreased the heating power also decreased , and finally the P stabilized at set pressure 155bar. The simulation process was shown in Figure 14

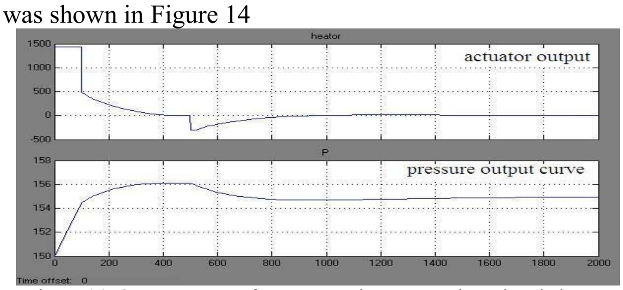

Figure 14. Output curves of actuator and pressure when electric heater power decreases by 300KW

From all above, when the set pressure changed, the pressure of pressurizer control system can rapidly track to the setpoint; it proved that the model has better performance characteristics.

IV. SUMMARIES

According to the experimental data of Nuclear Power Plant Simulator, we established the spray valve channel and the electric heater channel transfer functions of pressurizer system. On this basis, a pressurizer pressure control system was established upon Simulink; the disturbance experiments were performed such as setting value disturbance, spray valve opening disturbance experiments etc. The results show that the pressure control system of pressurizer is correct and has the reasonable dynamic trend. Above all, this paper made the mathematic models of controlled objects on the pressurizer pressure control system in order to offer effective references to further researches on this issue.

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TABLE I. INITIAL DATA OF THE SYSTEM

Pth(MW)	Tave (℃)	Lpzr (%)	P (bar)	Pele (MW)	LSG (%)	PSG (b)	TSG (℃)
2775	304	63.1	155.1	925	44.0	55	270.1

TABLEII. TEST AND CALCULATED VALUE FOR STEP RESPONSE OF SPRAY VALVE

	0(s)	100(s)	185(s)	254(s)	293(s)	402(s)
Test value	0	0.2	0.39	0.546	0.63	0.87
Calculated value	0	0.215	0.4	0.55	0.63	0.87

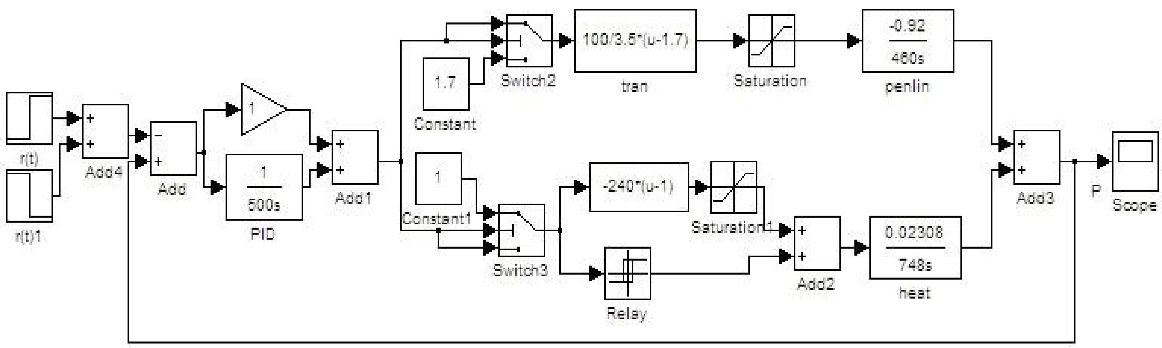

Figure 7. Simulation module diagram of the pressurizer pressure control system

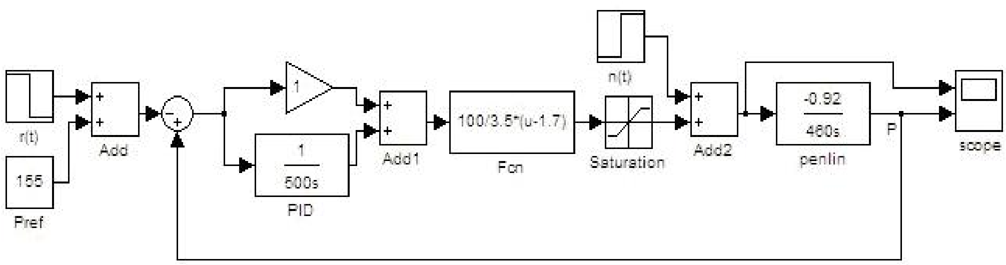

Figure 9. Simulation module diagram when spray controls

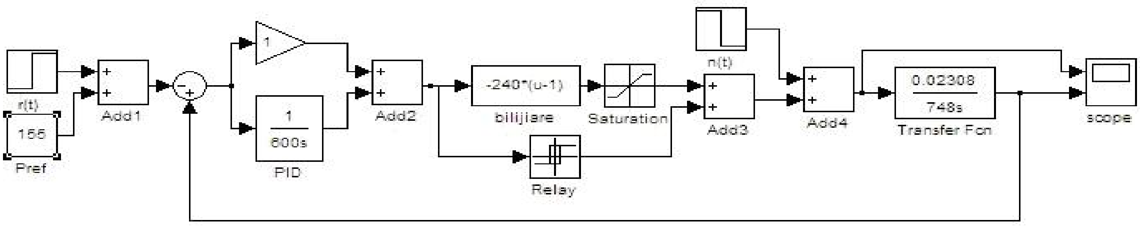

Figure 12. Simulation module diagram when electric heater controls

TABLE III. TEST AND CALCULATED VALUE FOR STEP RESPONSE OF ELECTRIC HEATER

	0(s)	**100(s)**	**295(s)**	**414(s)**	**481(s)**	**651(s)**
Test value	0	0.117	0.39	0.549	0.63	0.862
Calculated value	0	0.132	0.394	0.55	0.64	0.87

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