Power Control for a Research Reactor using MATLAB/SIMULINK

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1. Introduction

Programmable power controller should be tested before installation at reactor site by the computer simulation in order to verify the various functions under normal operating conditions. MATLAB/SIMULINK was used to develop the power control algorithm for a research reactor under development in Korea. The program consists of two major parts: a reactor model and a power controller. The reactor model produces process signals such as neutron power, thermal power, and reactivity feedback by solving kinetic and dynamic equations of the reactor. The power controller receives the process signals from the reactor model and manipulates the reactor power on a controlled manner by the execution of control rod movements.

2. Methods

In this section, some of the techniques used to model the reactor and design controller are briefly described.

2.1 Reactor Model

The reactor model describes behaviors of the neutron and precursors, iodine and xenon, decay heat by fission products, and fuel, coolant, and reflector temperatures by means of the well-known point kinetics and dynamics model. Rather than using the equations directly, variables were normalized in this study.

The simulation program used to implement the control system is *SIMULINK* that is an *MATLAB* - based GUI environment for multi-domain simulation and model-based design for dynamics. It provides an interactive graphical environment and a customizable set of block libraries that let user design, simulate, implement, and test a variety of linear/nonlinear systems.

The mathematical model of the reactor is as follows. The expression bar(`-`) denotes the variables normalized by full-power value. For the procedure of derivation and nomenclature, see [7].

Neutron Point Kinetics:

$$\frac{d\bar{N}}{dt}=\frac{1}{\Lambda}\left[(\rho-\beta)\bar{N}+\sum_{i=1}^{6}\beta_i\bar{C}_i\right],\quad \frac{d\bar{C}_i}{dt}=\lambda_i(\bar{N}-\bar{C}_i),\ i=1,\ldots,6,$$

Iodine and Xenon Kinetics:

$$\frac{d\bar{I}}{dt}=\lambda_I(\bar{N}-\bar{I}),\quad \frac{d\bar{X}}{dt}=\frac{\lambda_X+\lambda_e}{\gamma_X+\gamma_I}(\gamma_X\bar{N}+\gamma_I\bar{I})-(\lambda_e\bar{N}+\lambda_X)\bar{X},$$

$$\lambda_e=\sigma_{aX}\phi_0,$$

Fission Product Decay Heat and Reactor Power:

$$\frac{d\bar{W}_k}{dt}=\lambda_{Wk}(\bar{N}-\bar{W}_k),\quad \bar{N}_R=\bar{N}-\sum_{k=1}^{K}\gamma_{Wk}(\bar{N}-\bar{W}_k),$$

Thermal Power:

$$Q_C=\bar{N}_R Q_T\eta_C,\quad Q_R=\bar{N}_R Q_T(1-\eta_C),\quad Q=Q_C+Q_R,$$

Primary Cooling System:

$$M_{FE}C_{FE}\frac{dT_{FE}}{dt}=\eta_F Q_C-H_F(T_F-T_C),$$

$$M_C C_C\frac{dT_C}{dt}=(1-\eta_F)Q_C+H_F(T_F-T_C)-W_C C_C(T_{CO}-T_{CI}),$$

Reactivity Feedback:

$$\rho_F=\alpha_F[T_F(t)-T_{F0}],\quad \rho_C=\alpha_C[T_C(t)-T_{C0}],\quad \rho_X=\alpha_X\bar{X}(t).$$

Figure 1 shows MATLAB/SIMULINK model. At every sampling time, the reactor model provides information about reactor status to the power controller.

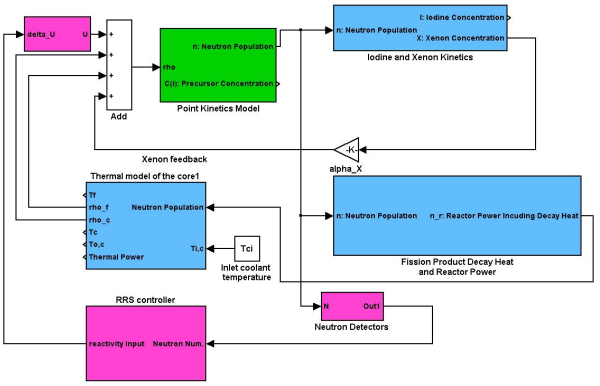

Fig. 1. MATLAB/SIMULINK Model of Reactor Control

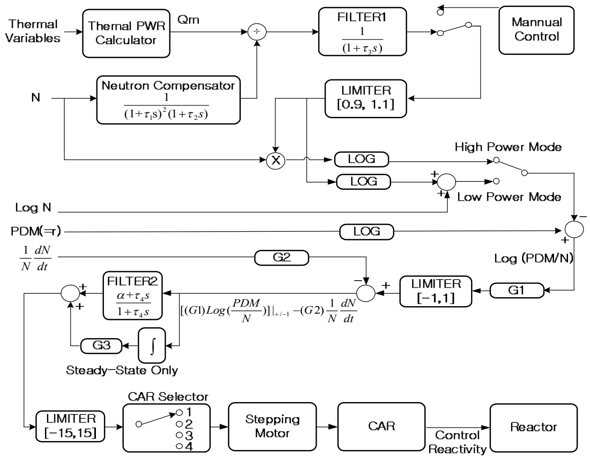

Fig. 2. Power Control Algorithm.

2.2 Power Controller

The control logic for reactor power control is demonstrated in Fig.2. The control action is defined as the movement of the CAR(Control Absorber Rod) that result in reactivity insertion to reactor. If the control action(controller output) is positive, then the CAR is pulled up and the positive reactivity is inserted and vice versa.

Since the amount of reactivity per unit distance of CAR varies according to the present height of CAR, the total reactivity worth has been obtained in advance and curve-fitted into the simulation.

The main idea of power control algorithm is to calculate mismatch between the demand power (PDM) set by an operator and the actual power(N) detected by fission chambers. The control logic operates as follows.

The logarithm of the ratio of the demand power to the current power should be equal to zero at a steady state and, therefore, this value is used as an error signal for controller.

The maximum reactivity change per unit time should be limited and, for this purpose, the controller is designed in such a way that the log-rate signal($(1/N)(dN/dt)$) will not exceed 5% PP(Present Power) rate of change for the whole control process. To implement this function, we define the error signal for P-control as

$$ERROR = [(G1)Log(\frac{PDM}{N})]|_{+/-1} - (G2)\frac{1}{N}\frac{dN}{dt}.$$

Then, when the reactor output N is small, ERROR grows up and the P-control(FILTER 2) generates relatively big control action and $(1/N)(dN/dt)$ also grows big. Since The first term $(G1)Log(PDM/N)$ is limited in the rage [-1,1], control action grows up before $(G2/N)(dN/dt)$ becomes 1. Since we want the log-rate to be maintained below the 5%PP bound, we set as $G2$ =0.2. Then, the control action stops growing up when log-rate becomes 5%PP.

The integral control action was also adopted to minimize steady-state error. This term, however, is activated only at steady-state since, if used always, it can result in log-rate limitation violation.

To avoid integrator wind-up, the integrator can be reset when necessary or switched-over to a stable dynamics via proper anti-windup schemes.

The output of thermal power calculation is obtained in RRS control computers. But, it is used for calibration purpose only.

3. Results

Test program-based simulation before reactor construction plays an important role for evaluation of the control performance at the various plant conditions. For brevity however, we show a simple model-based result here. The case is the power-up from 20% FP to 100% FP via automatic control mode. Simulation has been performed for the model with the proposed control. Simulation result shows that the proposed control performs reactor power control properly with the maximal log-rate below 5%PP. Reactivity converges to zero and the temperature of fuel and coolant converge to steady state values relatively fast.

4. Conclusion

In this study, it is shown that KMRRSIM, the FORTRAN program developed for the design of HANARO research reactor in late 1980's, can be implemented by modern MATLAB/SIMULINK program. Additionally we used normalized model and PI-control scheme. We expect that the proposed method and simulation tools will surely enhance the efficiency, visibility, accessibility of programming.

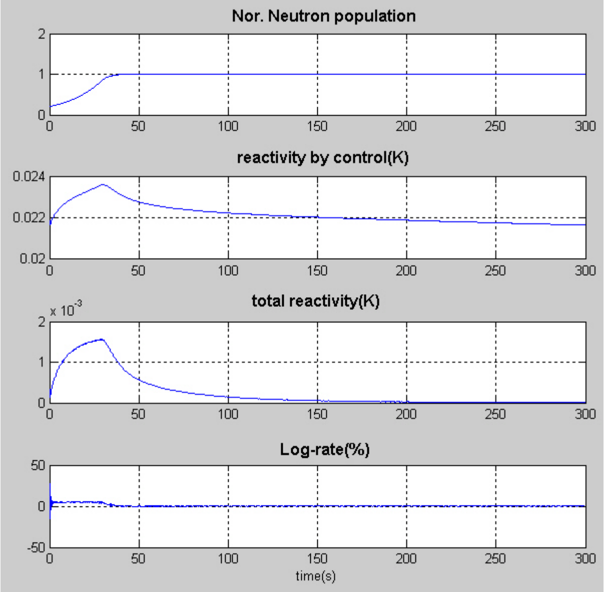

Fig. 3. Simulation Result

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