Transactions of the Korean Nuclear Society Spring Meeting
Jeju, Korea, May 7-8, 2015

Power Control Method for Research Reactor
(연구용 원자로의 출력제어 기법)

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1. Introduction

A power control method for research reactor is designed, simulated, and applied to actual reactor in this study. Considering safety-oriented design concept and other control environment, we developed a simple controller that provides limiting function of power-change-rate as well as fine tracking performance. The design result has been well-proven via simulation and actual application to a TRIGA-II type research reactor. The proposed controller is designed to track the PDM(Power Demand) from operator input as long as maintaining the power change rate lower than a certain value for stable reactor operation.

2. Methods and Results

2.1 Controller Design

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 [4]. Rather than using the equations directly, variables were normalized and used 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. Symbols are well-known, thus omitted in this paper.

Neutron Point Kinetics:

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

Iodine and Xenon Kinetics:

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

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

Fission Product Decay Heat and Reactor Power:

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

Thermal Power:

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

Primary Cooling System:

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

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

Reactivity Feedback:

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

Figure 1 shows MATLAB/SIMULINK model.

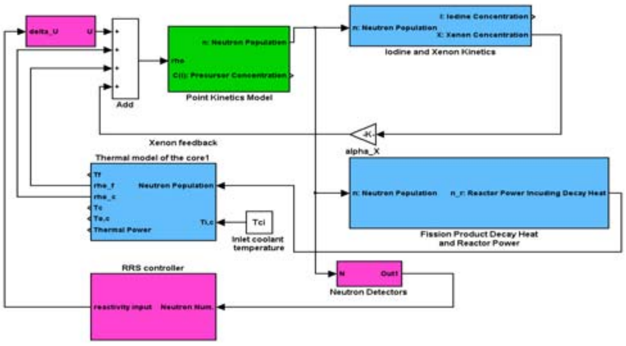

Fig. 1. MATLAB/SIMULINK Simulation Structure

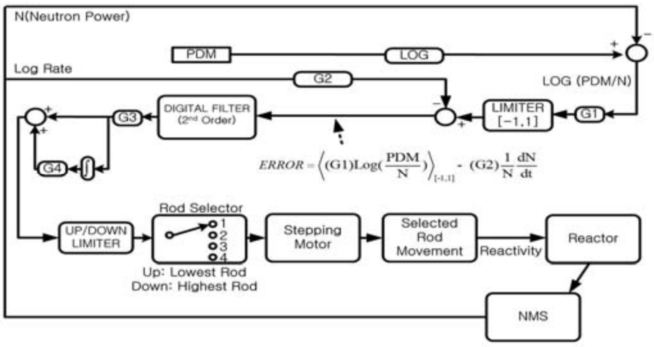

Fig. 2. Proposed Power Control Algorithm.

2.2 Power Controller

The overall simulation structure and the reactor power control logic is demonstrated in Fig.1 and Fig.2, respectively. 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 reactivity is inserted, and vice versa.

Since the amount of reactivity per unit distance movement 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 discrepancy between the Power Demand(PDM) set by operator, and the actual power(N) detected by fission chambers(neutron detector). 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 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 reduce steady-state error. The up/down limiter finally limits the CAR speed to the permitted range.

2.2 Application to TRIGA-II Reactor

The designed controller has been simulated (omitted in this paper), and applied to an actual research reactor (TRIGA-II reactor). The RPT (Reactor Performance Test), one of the commissioning tests, shows that the proposed scheme tracks various PDMs from 0.1%FP(full power) to 100%FP properly(Fig. 3) even though there is relatively large measurement noise in neutron detectors(Fig. 4). The performance at low power level such as 0.1% and 1% (Fig.5) shows large overshoot due to the measurement noise, but this is acceptable since reactor protection system does not shutdown the reactor at low power level. Thus, overall, it is concluded that the control performance of the proposed scheme shows fine performance for research reactor power control.

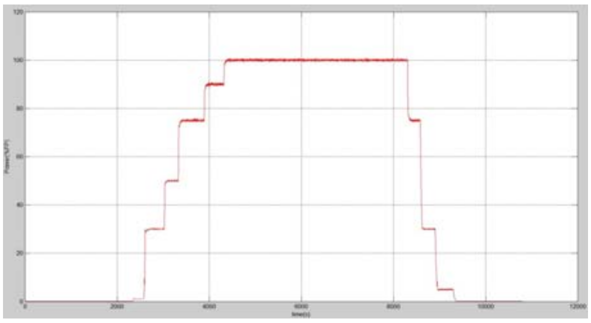

Fig. 3. Power control performance in commissioning test(during 12,000s) with the PDM changes in sequence: 0.1%, 1%, 30%, 50%, 75%, 90%, 100%, 75%, 30%, 5%, and 0.1%.

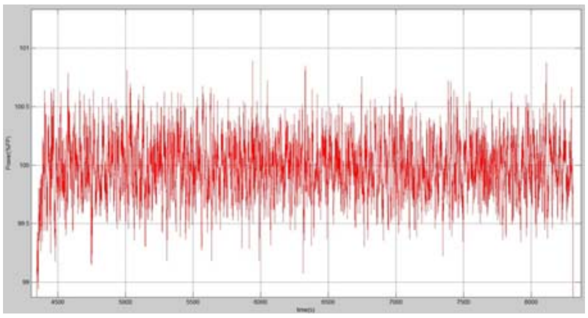

Fig. 4. Power oscillation (measurement noise) around 100%FP

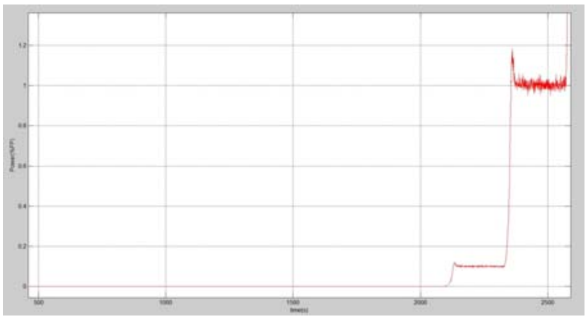

Fig. 5. Power control performance around 0.1% and 1% of power

3. Conclusion

A power control method for a TRIGA-II type research reactor has been designed, simulated, and applied to actual reactor. The control performance during commissioning test shows that the proposed controller provides fine control performance for various changes in reference values (PDM), even though there is large measurement noise from neutron detectors. The overshoot at low power level is acceptable in a sense of reactor operation. Further research may include model-based approach with proper robustness to disturbances.

ACKNOWLEDGEMENT

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MSIP) (No. 2012M2C1A1026912)

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