Simulation for Remote Operation for REX10 Nuclear Reactor

Sim Won Lee, Dong Su Kim, Man Gyun Na*, Yoon Joon Lee, Yeon-Gun Lee, Goon Cherl Park
Department of Nuclear Engineering, Chosun University
375 Seosuk-dong, Dong-gu, Gwangju 501-759, Republic of Korea
Corresponding author : magyna@chosun.ac.kr

1. Introduction

The newly designed REX10 (Regional Energy Reactor, 10MWth) is an environmentally-friendly and stable small nuclear reactor for a small-scale reactor based Multi-purpose regional energy system. The REX10 has been developed to maintain system safety in order to be placed in densely populated region, island, etc. In addition, it is significantly hard to recruit many operation and maintenance personnel for small power reactors differently from usual commercial reactors because of its remote location and of economic reasons. In order to overcome these constraints, to decrease the operation cost by reducing operation and maintenance personnel, and to increase plant reliability through autonomous plant control, it is needed to design the control system of the small power reactors and to establish its unmanned remote operation system. In this study, the REX10 reactor core thermal power controller is designed by using a REX10 code analyzer. The remote control facility through man-machine interface (MMI) design and interface between programming languages was established and it was used to verify remote operation of REX10.

2. Remote Control Facilities

To provide information about the operation status of REX10 to operators in the remote control facility more effectively, special ways are required. Among them, the visual effect has a variety of features and benefits. At first, it can improve the ability to interpret the operating situation and shorten the analysis time. This enables the operating situation to be visualized quickly. MMI section of REX10 remote control facilities was constructed using LabVIEW [1]. In addition, the LabVIEW DSC (Datalogging & Supervisory Control module) is utilized to design the MMI of the facility. The control algorithm of the REX10 is programmed by using MATLAB. The communication protocol uses VI server in LabVIEW. VI server can create server VI and client VI using TCP/IP to pass data between each other.

The remote control facilities can simulate the overall system of REX10 and allow the operators to monitor and control the operation condition. The monitoring and control panel were designed by LabVIEW.

The control panel allows the remote operators to control the operation of REX10 at steady-state or accidents. In addition, the remote operators can receive information about the states of the system effectively.

Fig 1 shows the display of control panel. The control panel was developed to control the physical parameters such as power, temperature, water level, flowrate, N_2 gas, and etc.

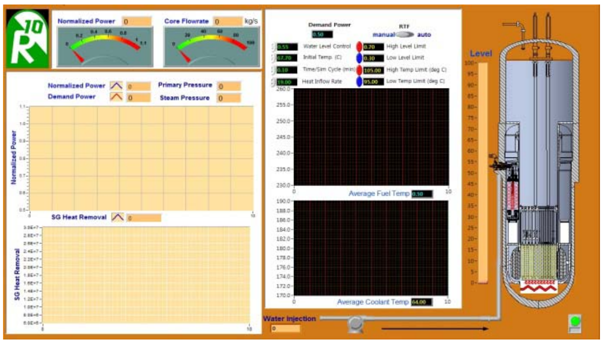
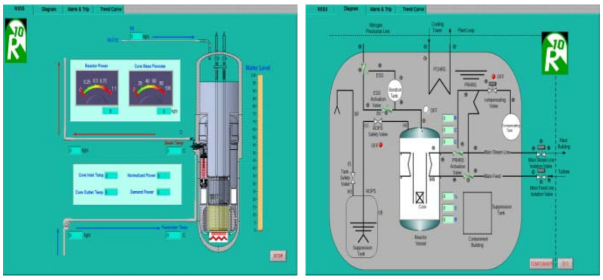
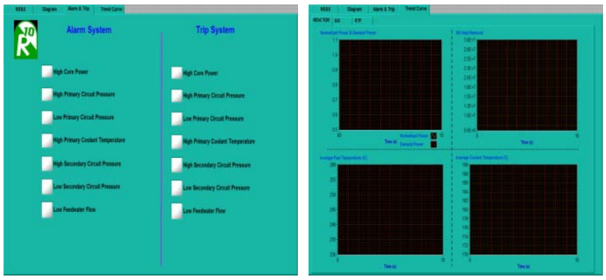


Fig 1. Display of Control Panel



(a) Reactor System (b) REX10 System



(c) Alarm System (d) Trend Curve

Fig 2. Display of Monitoring Panel

The monitoring panel can make the system independent by using the tab control function of the LabVIEW. The tabs such as safety systems, critical parameters of the danger signals and trend curves are mainly composed of the dynamic parts. The important physical parameters are represented by the digital values and their trend curve is expressed as a graph. Danger signals and the operation status of valves were displayed by LED.

3. Simulation for Remote Operation

3.1 REX10 Analyzer

REX10 analyzer was coded with FORTRAN and the model predictive control (MPC) algorithm [2] of thermal power was coded with MATLAB. The interface between the code analyzer and the control algorithm was programmed using visual C++. So, it should be able to pass variables between the languages. By estimating core dynamics applying the recursive parameter estimation algorithm each time step, the proposed controller controls the reactivity so that the reactor power follows the demand load. The point kinetic equation of REX10 analyzer is expressed as follow and other thermo-hydraulic equations are omitted in this paper.

$$\frac{dN(t)}{dt} = \frac{\rho(t)-\beta}{\Lambda(t)}N(t) + \sum_i \lambda_i C_i(t) \qquad (1)$$

$$\frac{dC_i(t)}{dt} = \frac{\beta_i}{\Lambda(t)}N(t) - \lambda_i C_i(t) \qquad (i = 1, 2, \cdots, 6) \qquad (2)$$

3.2 Model Predictive Control

The MPC method solves an optimization problem for finite future time steps at current time and to implement the first optimal control input as the current control input. At the next time step, new values of the measured output can be obtained, the control horizon is shifted forward by one step, and the same calculations are conducted repeatedly. The purpose of taking new measurements at each time step is to compensate for unmeasured disturbances and model inaccuracy, both of which cause the measured system output to be different from the one predicted by the model. At every time instant, MPC requires the online solution of an optimization problem to compute optimal control inputs over the fixed number of future time instants, known as the control horizon.

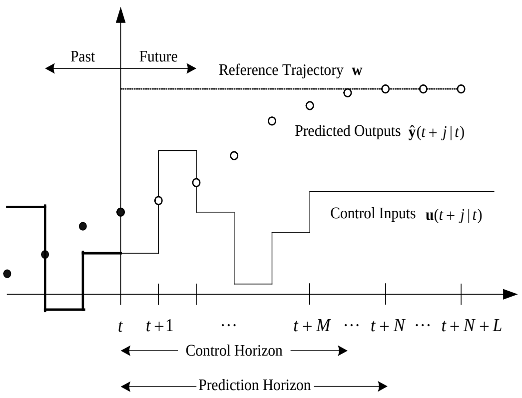


Fig.3 MPC Concept

The process is described by the following controlled auto-regressive and integrated moving average model:

$$A(q^{-1})y(t) = B(q^{-1})u(t-1) + \frac{1}{\Delta}D(q^{-1})\xi(t) \qquad (3)$$

The dynamics of reactor core changes according to reactor power, a variety of control rod positions, and so on. Therefore, it is required to estimate the reactor core dynamics every time step in order to reflect these various conditions and nonlinear characteristics. Using the matrix inversion lemma, the recursive parameter estimation is expressed as follow:

$$\hat{\boldsymbol{\theta}}(t) = \hat{\boldsymbol{\theta}}(t-1) + \boldsymbol{\Sigma}(t)\boldsymbol{\varphi}(t-1)\left[y(t) - \hat{\boldsymbol{\theta}}^T(t-1)\cdot\boldsymbol{\varphi}(t-1)\right] \qquad (4)$$

$$\mathbf{F}(t) = \frac{1}{\lambda(t)}\left[\mathbf{F}(t-1) - \frac{\mathbf{F}(t-1)\boldsymbol{\varphi}(t-1)\boldsymbol{\varphi}^T(t-1)\mathbf{F}(t-1)}{\lambda(t)+\boldsymbol{\varphi}^T(t-1)\mathbf{F}(t-1)\boldsymbol{\varphi}(t-1)}\right] \qquad (5)$$

3.3 Application

The MPC control algorithm was applied to the remote control facilities including the REX10 analyzer. Figure 4 shows the simulation results of the demand load and the reactor power. It is shown that the reactor power follows the demand load well.

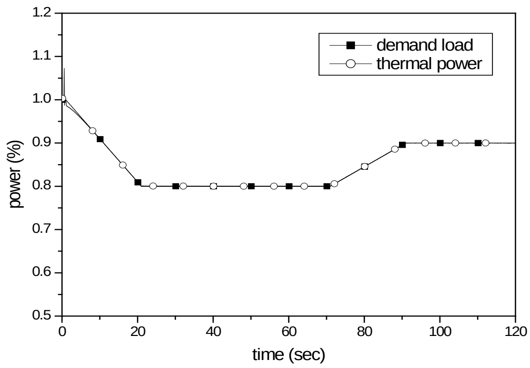


Fig.4 Demand Load and Reactor Power

4. Conclusions

In this study, simulations for remote operation of REX10 were conducted by establishing the remote control facilities. The method of communication between the server and the client for the LabVIEW was studied. The remote control facility through MMI design and interface between programming languages were constructed to verify remote operation of REX10, and to conduct the integrated assessment of the remote control capability. This study was conducted to assess remote control and operation for REX10 and to accomplish the full automation of REX10 controlled by advanced algorithms. This study will provide a new paradigm for applying the unmanned remote operation to nuclear power plants.

REFERENCES

[1] Park, H. P., LabVIEW 8, Graphical Programming, Jeongiksa, 2006.
[2] C.E. Garcia, D.M. Prett, and M. Morari, “Model Predictive Control: Theory and Practice – A Survey,” 2007*Automatica*,**25**, pp.335-348, 1989.