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Auto-Startup and Operation Scheme for Research Reactors

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1. Introduction

The conceptual design and simulation results for automatic startup scheme for RR (Research Reactor), is presented in this study.

The automation of reactor startup and operation has been studied for NPPs, but actual application to NPP was not found in literature. The proposed auto-startup logic is aimed to automate the reactor startup and operation for RRs. It includes the adjustable set of operational parameters in order to utilize the operational experience from human operator. A part of the automation logic regarding power increase has been implemented and tested on a RR simulator, showing fast and accurate power increase performance without human input.

2. Methods and Results

The motivation, configuration, functions, and simulation result are presented in this section.

2.1 Human Error in Conventional Reactor Operation

Nuclear reactors have been generally operated by human operators, and human-error often results in un-planed reactor trip or accidents. This is mainly because the operational performance varies according to human operator's mental and health conditions. In order to cope with the performance reduction due to human error, [1] generally recommends the usage of automatic control for repetitive and precise works. Table I shows the recommended works for human and automatic control[2], where the underlined properties are considered as typical features in nuclear reactor operation. Table I implies that the usage of automatic control is recommended for typical, normal reactor operation.

Table I: Proper Works for Human or Automatic Control[2]

	Human	Automatic Control
Work Load	Normal	<u>High</u> or Very Low
Time Limit	Large	<u>Small</u> or Very Large
Repeatability	Normal	<u>High</u> or Very Low
Complexity	<u>Simple</u>	Complex
Decision making feature	Non-Structural	<u>Structural</u>

Now let us define the considered automation logic as a software program that generates operator input, instead of human operator.

2.2 Configuration of MO

We first discuss the logic configuration in I&C (Instrumentation and Control) system design. The proposed auto startup and operation logic is named MO (Machine Operator), and its configuration is shown in Fig. 1.

In this design, the MO logic is a part of the OWS (Operator WorkStation) software. The human operator can select whether the operator input is to be generated by HO (Human Operator), or by MO using a proper switch. If MO is selected the MO generates operator inputs and delivers it to existing systems, instead of HO. The existing systems do not need to recognize the source of the input. They perform their designed functions regardless of the operator input source, which means that the integrity of other systems is not affected by MO logic.

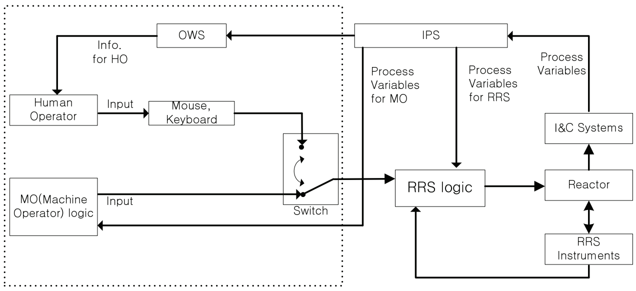

Fig. 1. Configuration of MO in I&C systems.

2.3 Functions of MO

The design purpose for MO functions is basically to invent a software logic that replaces HO's actions. As a first step the MO logic was designed to follow the normal operation procedures of reactor. The MO logic basically performs the followings for reactor startup. Detail may vary according to each RR.

1) At reactor shutdown, HO chooses the operator(HO or MO)
2) (If MO is chosen), the MO loads the set of operation parameters into memory. Almost all data for each MO action will be obtained from this parameter data.

3) MO operates auxiliary systems such as electricity, service water, and compressed air by generating command signals to valves/pumps/heaters.
4) MO operates the main fluid systems similarly.
5) MO checks the reactor conditions for startup. If all control rods are fully down, reactor power is very low, and all trip conditions are cleared, then MO declares the beginning of reactor startup.
6) MO withdraws shutdown rods, and control rods in a one-by-one manner.
7) MO declares the criticality and increases power up to a level and sends control mode switching request. The control mode is switched from manual to auto.
8) In auto control mode, the MO stops rod control, and sends demand power values to power control system instead. The power control system moves the control rods to regulate the reactor power at the demand power.
9) MO waits until each power signal is stabilized, and sends larger demand power values. Thus the reactor power is increased by power control system in a step-by-step manner, and finally the reactor achieves full-power operation.
10) For reactor shutdown, HO pushes a shutdown button and MO inserts all control rods instantaneously into core and the reactor is shutdown.

The MO functions described in the step (1)~(9) is similar to normal operation procedure. Experienced HO would perform reactor operation according to these steps, but for MO programming, the detail values or criteria should be invented for each step of operation. Table II shows an example of data needed for each step.

Table II: Example of data needed

No	Item	Data needed
1)	Permission on switching from HO to MO during operation	True or False
3), 4)	Criteria for judgement of Pumps/Valves/Heaters' normal operation	Process values setpoints
5)	Minimum Reactor power value for startup	Value
6)	Control rod withdrawal Speed/direction/distance/limit of level difference between each rod	Value
6)	Distance/Velocity for fast-move	Values
7)	Waiting time between moves around criticality	Values
7)	How to determine criticality	Criteria
9)	How to decide if each power level is stabilized	Criteria
9)	Sequence of demand powers that MO generates	Values
…	…	…
Other	Control when MO is terminated by HO during operation	Criteria
Other	MO actions in alarms	criteria

Problem is that most of this data is not written in the operation procedure in detail. Thus the HO has been operating reactor using their knowledge and experience about the options such as speed, direction, judgment of criticality, relative position between control rods, and the decision of signal stabilization, etc.

Therefore the aim of MO functions design is to utilize HO's knowledge and experience and records it into program logic, so that consistent operation performance is obtained for every reactor operation.

Thus we designed a set of adjustable parameters that contains the needed data including the ones in Table-II. This parameter set is saved in the software and is updated to reflect operational experience mainly throughout commissioning tests. The MO logic should be designed to load this parameter set at the beginning of each operation.

Since this study is at its early stage, the proposed MO logic has been implemented and tested partially. Next section shows the implemented logic and its simulation results.

2.4 Design and Simulation Result of MO

he MO logic was designed and implemented for the power increase case in automatic control mode. The data for the two items (9) in table II were determined as follows, reflecting current operational experience:

1) Sequence of demand powers that MO generates (Values):
1e-3 → 1e-1→1e0→10→30→50→80→100%FP
where %FP denotes "% of the Full Power".

2) How to decide if each power level is stabilized(Criteria):
MO declares that the power at a level is stabilized if the power maintains within the range 95~105% of the demand power value for at least 10 seconds.

Therefore the MO logic was programmed to generate a new demand power according to the sequence in 1), if current power is evaluated to be stabilized by using the criteria in 2).

To test the MO logic, we need a reactor model and power controller that interact with MO. The implemented research 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 [5],[6]. The simulator was developed using MATLAB and LABVIEW as in Fig.2. Symbols are well-known, thus they are 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:

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

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:

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

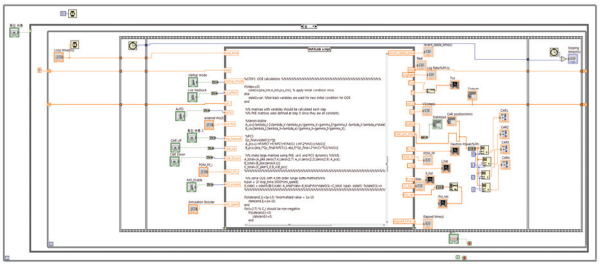

Fig. 2. MATLAB/LABVIEW Simulation

The simple user interface for this simulator is shown in Fig.3. It demonstrates the trend of reactor power, demand power, and control rod position, etc.

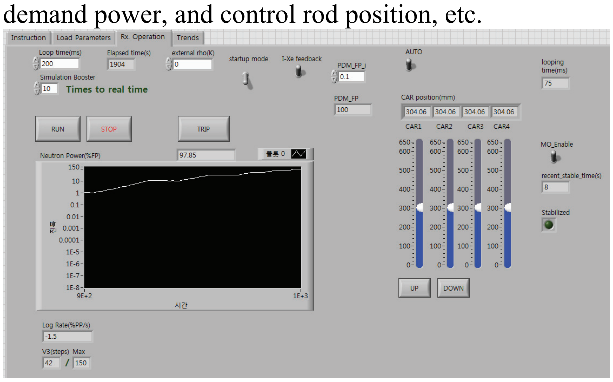

Fig. 3. Performance of MO for power ascension

The result in Fig.3 showed fast (about 350s) and accurate power ascension from 1e-3%FP up to full power, since the MO properly determines the stability of power and generates the next demand power.

3. Conclusions

The auto-startup scheme for research reactors has been studied. The basic design feature, aim of the logic, configuration, functions, and a simulation result for a power ascension case have been discussed and shown. Future woks include the parameterization of the other operational experience for more advanced MO design, and consideration of abnormal operation.

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