DEVELOPMENT OF A REAL-TIME PLANT SIMULATION SYSTEM FOR BWRs

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Abstract

A real-time plant simulation system for BWRs is presented. The system was developed to validate automatic control systems of BWRs prior to their implementation in plants. It is characterised by the following two points. One is to adopt the same reactor model as used to design the automatic control systems. The other is to run the model in real-time; i.e. it calculates plant behaviour within the sampling period of the automatic control system concerned. The simulation system has been applied to the validation of the Rod Control and Information System (RC & IS) by which control rods are operated automatically. In validations, for example, criticality was established for the same control rod position as required, and the RC & IS was proved to have the designed performance characteristic. The simulation system has also been successfully applied to validations of other functions of the RC & IS. These results show that the simulation system is useful for validation of automatic control systems.

Introduction

Recently, automatic control has been intensively applied to nuclear power plants to reduce operators' physical and mental workloads and to allow operators to concentrate on monitoring plant behaviour. In BWRs the automatic control of power has been performed by the recirculation flow control. Furthermore, automatic control of control rods has been attempted during start-up and shutdown operation [1].

An algorithm of an automatic control system is, in general, developed by using a super computer (or workstation). However, when the developed algorithm is installed in the automatic control system, it is usually necessary to convert the program into one for a micro computer which is customarily used in the automatic control system. This procedure may cause problems. Further, since the performance of the microcomputer may differ from that of the computer used to design the algorithm, there may be deterioration of the functionality of the automatic control system.

In order to attain high reliability of automatic plant operations, it is crucial to validate whether the automatic control system performs as designed prior to its implementation in a plant. To this end, a simulation system is required, which simulates plant behaviours with high fidelity and runs in real-time, interacting with the automatic control system.

In this paper, the requirements and descriptions of a simulation system to validate automatic control systems are described, followed by a validation example.

Requirements for simulation system

Automatic plant operations are carried out by using a combination of automatic control systems. Therefore it is necessary for validations to demonstrate that the automatic control system provides acceptable control as designed. In order to accomplish this, the simulation system for the validations should meet the following requirements:

- *Use a reactor model with fidelity to validate the automatic control system*.
  The simulation system is required to validate all operational modes of the automatic control system. So the reactor model in the simulation system should work with fidelity.

- *Realise real-time simulations*.
  It is essential for the simulation system to perform real-time simulations for the automatic control system. That is, the simulation system receives the operation signals from the control system by sampling periods and simulates the plant behaviour during one sampling period and provides the simulation results for the control system until the next sampling time-point [2].

- *Provide a man-machine interface*.
  A man-machine interface is one of the most important functions of the simulation system. In the simulation system, to improve the efficiency in checking the simulation results, the parameters sent to the automatic control system are represented at every sampling period graphically. This helps operators to intuitively understand the situation.

- *Perform fast simulations using the model of the automatic control system*.
  It is useful to provide reference data for validations by the simulation system alone. So the simulation system is equipped with the model of the automatic control system which it runs instead of the automatic control system. This brings about the following effects. First, it helps to check the installation error, because the simulation conditions of the reference data are the same as that of the validation simulation, except in the manner of executing the algorithm. So, if discrepancies exist, the cause can be specified in the automatic control system. Second, if improvements of the algorithm are needed, the effect of modifications can be found from the reference data. Since these simulations are carried out in the simulation system alone, it is possible to perform them quickly.

Description of system configuration

In order to meet the requirements mentioned above, the simulation system is configured as shown in Figure 1. The reactor model in the simulation system is the same model as that used to design the automatic control system concerned, so the reactor model is guaranteed to simulate all operational modes. The model is based on a one point reactor dynamics model and modified by plant data and detailed calculations. The data of the reactivity, tuned by plant data, make it possible to simulate the plant behaviour with fidelity. The detailed calculations provide the data of the power distributions, so that the local power behaviour, followed by control rod operations, can be calculated.

When validating the automatic control system, the workstation is connected to the automatic control system by the Ethernet through the gateway. The system interface program runs the reactor model from the automatic control system. On the other hand, when preparing the reference data, the system interface program is connected to the automatic control system model and the simulations are performed from it. The simulation results in both cases are displayed on the workstation CRT by the man-machine interface program. This configuration realises real-time simulations in the following manner.

First, the automatic control system gets the simulated plant data at the current sampling time-point from the gateway. Next, as shown in Figure 2, the following series of tasks are processed by the system interface program.

1) The operations produced by the automatic control system are received.

2) The simulation during one sampling period is performed under the received operations.

3) The simulation results are displayed on the CRT by the man-machine interface program.

4) The simulation results are sent to the gateway and the simulation system waits for the next operations from the automatic control system.

5) The above procedures are executed repeatedly at every sampling time-point.

According to this method, the simulation system can perform not only real-time simulations for the automatic control system, but also display the simulation results graphically by itself.

Application to validation of RC & IS

The simulation system has been applied to the validation of the Rod Control and Information System (RC & IS). The RC & IS, by which control rods are automatically operated, is used to control reactor power together with the Recirculation Flow Control System. The RC & IS has several operational modes and one is used according to the plant status. The criticality mode is explained here as a typical case.

In the criticality mode, the RC & IS must withdraw control rods while preventing supercriticality and judge the criticality approach and then, subsequently criticality at a suitable control rod position. So the RC & IS evaluates the reactor period and reactivity, at every sampling time-point, from the data of in-core neutron monitors. These parameters are used to determine permission for withdrawal of control rods and to judge the criticality approach and criticality.

In calculations of the reactor period and reactivity, logarithmic operations of neutron data are included. Since the RC & IS performs the logarithmic operation in a different way when developing the algorithm, the difference may cause deviations in the simulation results.

Figure 3 shows reference data of total lengths of withdrawn control rods and reciprocal numbers of the reactor period in the criticality mode. In this figure, the control rod positions and times at criticality approach and at criticality are added for both the reference data and the validation results. The control rod positions at criticality approach and criticality were the same positions. Therefore, the RC & IS evaluated the reactivity correctly and determined the operations of control rods appropriately. However, for the times at criticality approach and criticality, there were small deviations. These were mainly caused by the differences in calculating the reactor period. Since the RC & IS uses the reactor period to decide permission for withdrawal of control rods, small differences of the evaluated reactor period led to small deviations of the waiting times and the accumulated differences resulted in the deviations of times.

In validations of the criticality mode, the simulation system provides an expression on the CRT by the man-machine interface program, as shown in Figure 4. It displays local power behaviour according to control rods operations; including control rod positions neighbouring neutron monitors, reciprocal numbers of the reactor period, and values of neutron monitors. So it was possible to validate the RC & IS in the criticality mode, by monitoring reactor responses corresponding to control rod operations.

For other operational modes, the simulation system has also been successfully applied to the validations. The simulation system was found to be useful for validation of automatic control systems, such as the RC & IS.

Conclusion

A real-time plant simulation system for BWRs has been developed for validation of automatic control systems prior to their implementation in plants. The simulation system has the same reactor model as used to design the algorithm and runs the reactor model in real-time for the sampling period of the automatic control system concerned. The simulation system provides functions to produce reference data and to display simulation results for operational modes.

The simulation system has been applied to the validation of RC & IS. In the criticality mode, criticality approach and criticality were established at the same control rod position as that of the reference data. The simulation system was also successfully applied to other operational modes. The simulation system was judged useful for validation of automatic control systems, such as the RC & IS.

REFERENCES

[1] Yoshida, *et al.*: Recent Trends of New Technologies for BWR Power Plant Instrumentation and Control (in Japanese), The Hitachi Hyoron, 77, 4, pp. 13-18 (1995).

[2] J.L. Ryan and S.K. Chan: Plant Control System Test Facility, Proceedings of the Topical Meeting on Nuclear Plant Instrumentation, Control and Man-machine Interface Technologies, pp. 348-350 (1993).

Figure 1. Construction of the simulation system

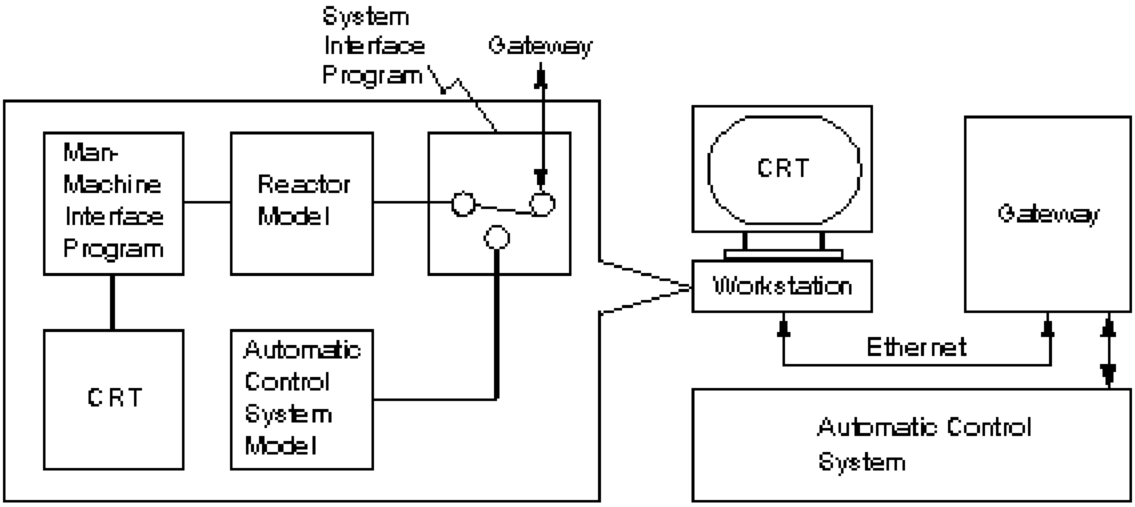

Figure 2. A series of tasks in the simulation system for real-time simulation

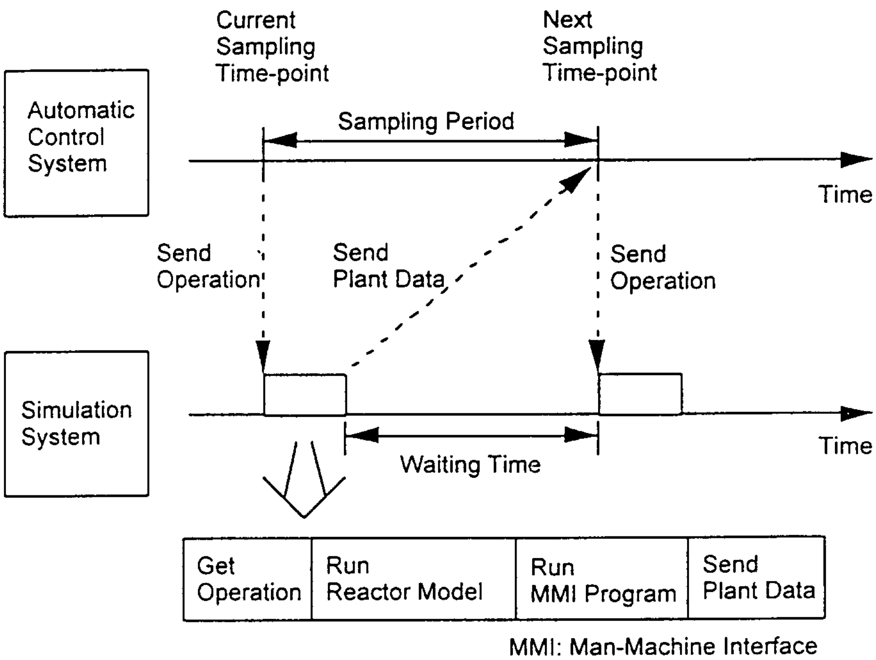

Figure 3. Simulation results for the criticality mode

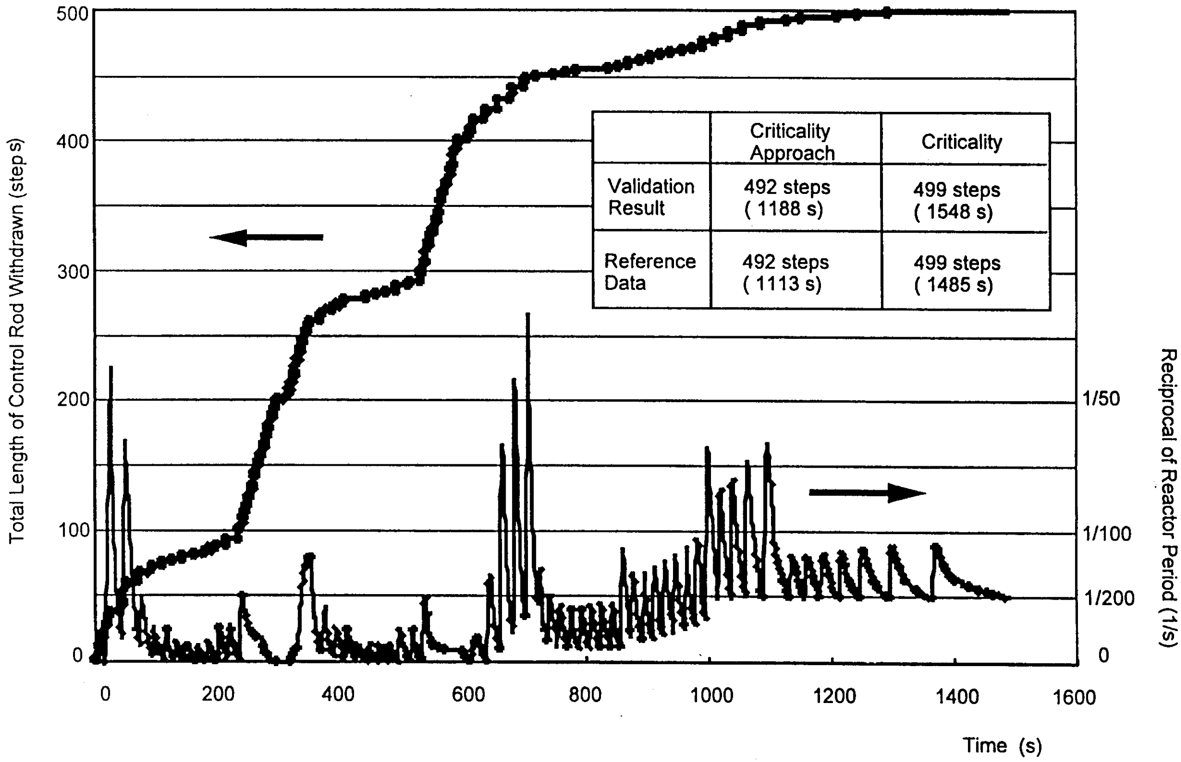

Figure 4. Display on CRT in the criticality mode validation