DEVELOPMENT OF A NUCLEAR PLANT ANALYZER FOR CANDU REACTOR

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ABSTRACT

A nuclear plant analyzer (NPA) has been developed for Canada deuterium uranium (CANDU) reactors in Korea to provide a convenient simulation environment capable of reproducing various plant transients including normal operations and accidents. The NPA is a desktop real time interactive simulator and consists of a process model simulating the actual behaviors of nuclear power plant, a graphical user interface (GUI) providing the graphics system for schematically visualizing the plant systems at a computer screen, and a simulation executive. The process model containing overall CANDU plant systems has been developed. It includes point kinetics model, primary and secondary heat transport systems, control and safety systems, and various auxiliary systems. Driven by a first-principles set of thermal-hydraulic models, its simulation capability covers a wide range of plant operations. The GUI system composed of various system mimics and control panels vividly displays in-depth plant information and simulation results in real time. In addition, it provides a full range interaction between the user and various systems and components through graphics. Developed process model and GUI on SUN workstation were put together with the simulation executive to complete the NPA. Comparisons of simulation results for various transient operations including accidents with those of actual plant' s test data and given in the design documents confirmed the performance of the NPA and its applicability. The NPA can be used not only as an analysis and education tool for plant designer and operator but also in the performance and safety analysis to provide information for regulation judgements.

1. INTRODUCTION

An accurate analysis of the operating characteristics of nuclear power plants provides valuable information for both normal and abnormal operations. The information can be used for the enhancement of plant performance and safety. Usually, such an analysis is performed using computer codes used for plant design or full scale simulators. However, their usage is limited because special expertise is required to use the computer codes and the simulators are not portable. Therefore, it is deemed necessary to develop an NPA which minimizes those limitations and can be used for the analysis and simulation of nuclear power plants[1].

The purpose of this study is to develop a real time best estimate NPA for the Wolsong 2/3/4 CANDU reactors in Korea. The NPA is an interactive, high fidelity engineering simulator. It has advantages of both safety analysis code and full scale simulator by providing accurate and convenient simulation environment based on the GUI system.

Figure 1 shows the schematic structure of the NPA consisting of a process model simulating plant system, a GUI and a simulation executive. UNISYSTEM[2] serves as the simulation executive which manages the overall simulation of the NPA. It provides advanced features for simulation such as real and fast time execution mode, interactive modification of data, and saving and restoring plant data at any moment (snapshot) during simulation. It also has a malfunction list containing the predefined scenarios of selected transients including accidents and produces sequence of event (SOE) file recording important events occurred. The process model simulating the plant behavior and the GUI providing an easy-to-use and easy-to-understand simulation environment have been developed through this study.

2. DEVELOPMENT OF THE CANDU NPA

2.1 DEVELOPMENT OF THE PROCESS MODEL

The process model determines how accurately the NPA can simulate the actual plant. It consists of about 50 Fortran programs simulating 15 plant systems including point kinetics model[3], primary and secondary heat transport systems, reactivity control systems such as control rods and liquid zone control, and safety systems of emergency core cooling system and shutdown systems 1&2. Turbine, electrical system, and digital computer control system including reactor regulating system and various pressure and level control systems also were developed. Each plant system was developed and tested independently based on the design documents [4, 5, 6, 7] and the actual plants' operating characteristics.

In the point kinetics model, six delayed neutrons with Xenon and Iodine were used. Reactivity variation due to control rod movement and liquid poison concentration change as well as feedback from the temperature change of fuel and heavy water were considered. In thermohydraulic modeling, such simplifications as homogeneous flow, phase equilibrium, perfect mixing and fully developed turbulent flow were used to make the real time simulation possible. Driven by a first-principles set of thermal-hydraulic models, its simulation capability covers a wide range of plant operations including normal and accident conditions. Control nodes where the pressure is calculated from conservation equations are located wherever major flow junctions exist or on links where major pressure drops can occur (across pumps, heat exchangers). Since the execution time in a simultaneous solution is a strong function of the number of nodes, the number of nodes was tried to be kept a minimum.

Individual system models were tested independently to verify and validate their intended functions and then integrated into the plant process model using the UNISYSTEM.

2.2 DEVELOPMENT OF THE GUI

The GUI composed of various system mimics and control panels displays the dynamic behavior of plant systems and calculated results in real time. In addition, it provides the user with the capability of interactive control of simulation and system components through graphics. It has window characteristics such as pop-up menu, selection list, mouse button, and editing window. SL-GMS2[8] was used in the preparation of graphics with associated graphic control programs. System mimics includes primary heat transport (PHT) system (Figure 2), PHT pressure and inventory control system, core and control rod system, emergency core cooling system, secondary system, etc.

Together with the simulation executive controlling the simulation and network communication, the GUI provides an easy-to-use and easy-to-understand simulation environment.

2.3 VERIFICATION OF THE NPA

The CANDU NPA has a list of malfunctions containing 47 predetermined scenarios properly chosen to simulate the actual plant during the normal and accident operations. To verify the integrated process model of the NPA, the malfunctions were tested and the simulation results were compared with actual plant test data or those given in the design documents. Three cases of test data from Wolsong Unit 4 - reactor trip at full power (FP), stepback from 95% FP, and turbine trip at FP - were used in the verification. The system variables' initial value contained in the NPA database were finely tuned and the process model was also updated in other to produce better comparison results with measured data during the verification with the plant data. Other accidents where measured data are not available also were simulated to qualitatively evaluate the performance of the NPA by comparing the simulated results with the designer's predictions [9, 10, 11].

Figures 3 and 4 compare the simulated results with actual plant data for a turbine trip at FP. At this event, the condenser steam discharge valves (CSDVs) are required to actuate properly in order to protect the over pressurization of steam generator and prevent the main steam safety valves (MSSVs) from opening. The CSDVs were fully opened promptly by process interrupt as shown in Figure 3. After the reactor was stepback to 60% FP, their positions were adjusted based on the differences between the setpoint and measured value of the steam generator pressure, and the errors between reactor and turbine powers. Atmospheric steam discharge valves (ASDVs) were also opened by steam generator pressure control (SGPC) to maintain the steam generator pressure at a setpoint and closed after 60 seconds. Steam flow rate was reduced promptly with the initiation of turbine trip and started to increase according to the opening of discharge valves. Steam flow rate came to a stable condition after 100 seconds as the reactor power settled down and ASDVs closed. Behaviors of steam generator pressure, reactor outlet header pressure and pressurizer level predicted by the NPA also agree well with test data as shown in Figure 4. As a whole, the NPA reproduced this event following the actual scenario quite closely in spite of the persisting discrepancies in such variables as the CSDVs' position after the reactor stepback. Those differences come from deficiencies in the plant database and approximations in the process modeling. NPA also provided similar level of comparison results with plant test data for the reactor trip and stepback events.

Figures 5 and 6 show the predicted variation of major parameters during postulated steam generator tube rupture (SGTR) accident. It started with a initial leak flow rate of 80 kg/sec into the secondary side after 100 seconds' steady state operation. Turbine was tripped due to a steam generator's high level signal and steam discharge valves were opened simultaneously. After few seconds, reactor power was stepback to 60% FP and ended up trip because of the low level of pressurizer. Constantly reducing primary pressure initiated the LOCA signal and steam generator crash cooldown signal. The crash cooldown made the MSSVs opened and primary circuit pressure were dropped on account of the excessive heat removal from the secondary side. The emergency core cooling water was injected into the primary circuit after the pressure was dropped below the setpoint. The system variables' trends according to time during the SGTR provide quite similar results with those predicted in the design calculation on the whole. Simulated results for other postulated accidents included in the malfunctions also have shown that the NPA are capable of reproducing the accidents' scenarios predicted at design stage quite well.

3. CONCLUSIONS

A CANDU NPA has been developed by combining the plant process model and GUI with the simulation executive to provide the convenient simulation environment for the analysis of various plant transients including normal operations and accidents. The NPA has been verified through comparisons of simulated results with actual plant test data and those given in the design documents. The NPA reproduced the transient operations quite accurately and simulations of accidents also confirmed the performance of NPA and its applicability. It is expected the NPA to be used as an analysis and education tool for plant designer and operator. It can also be applied to the performance and safety analysis to provide information for regulation judgements.

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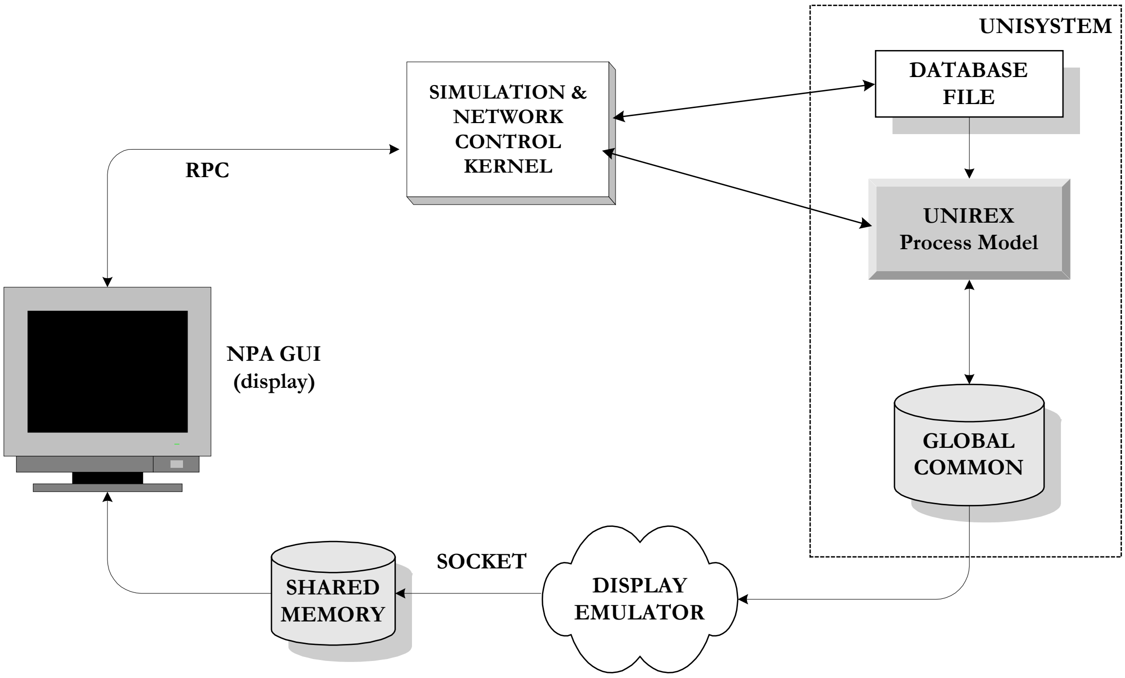

Figure 1: NPA Structure

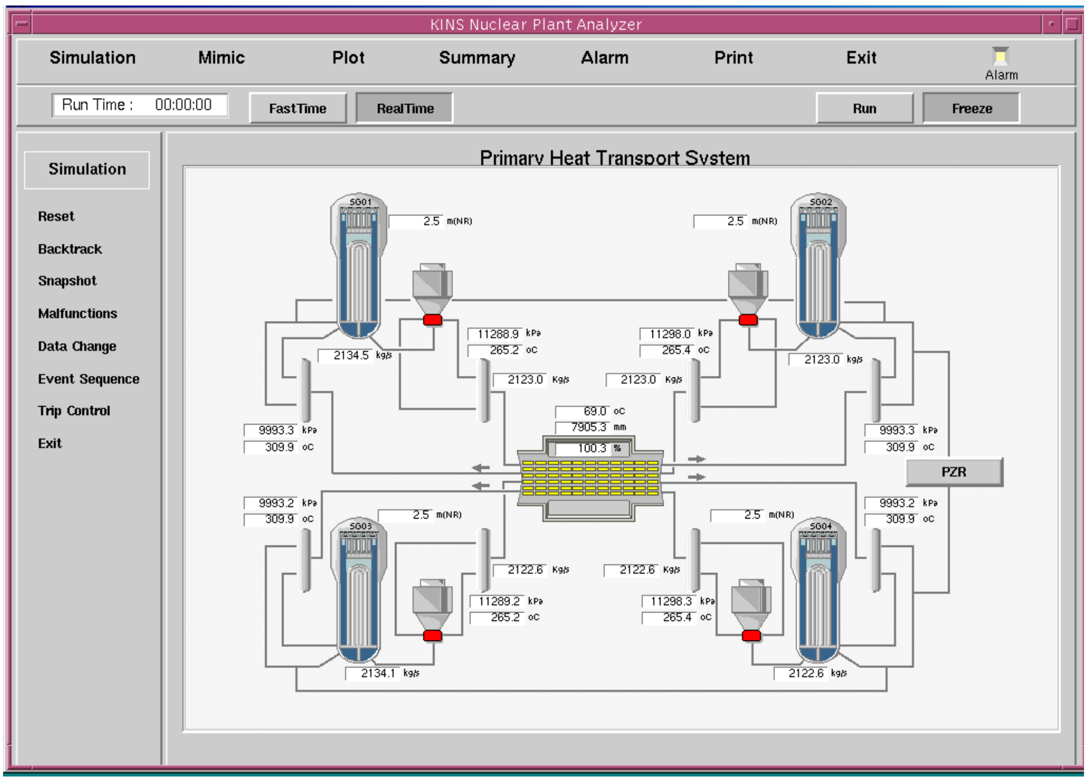

Figure 2: Main Menu and Primary Heat Transport System Mimic

Figure 3: Comparison of Variables at Turbine Trip (1/2)

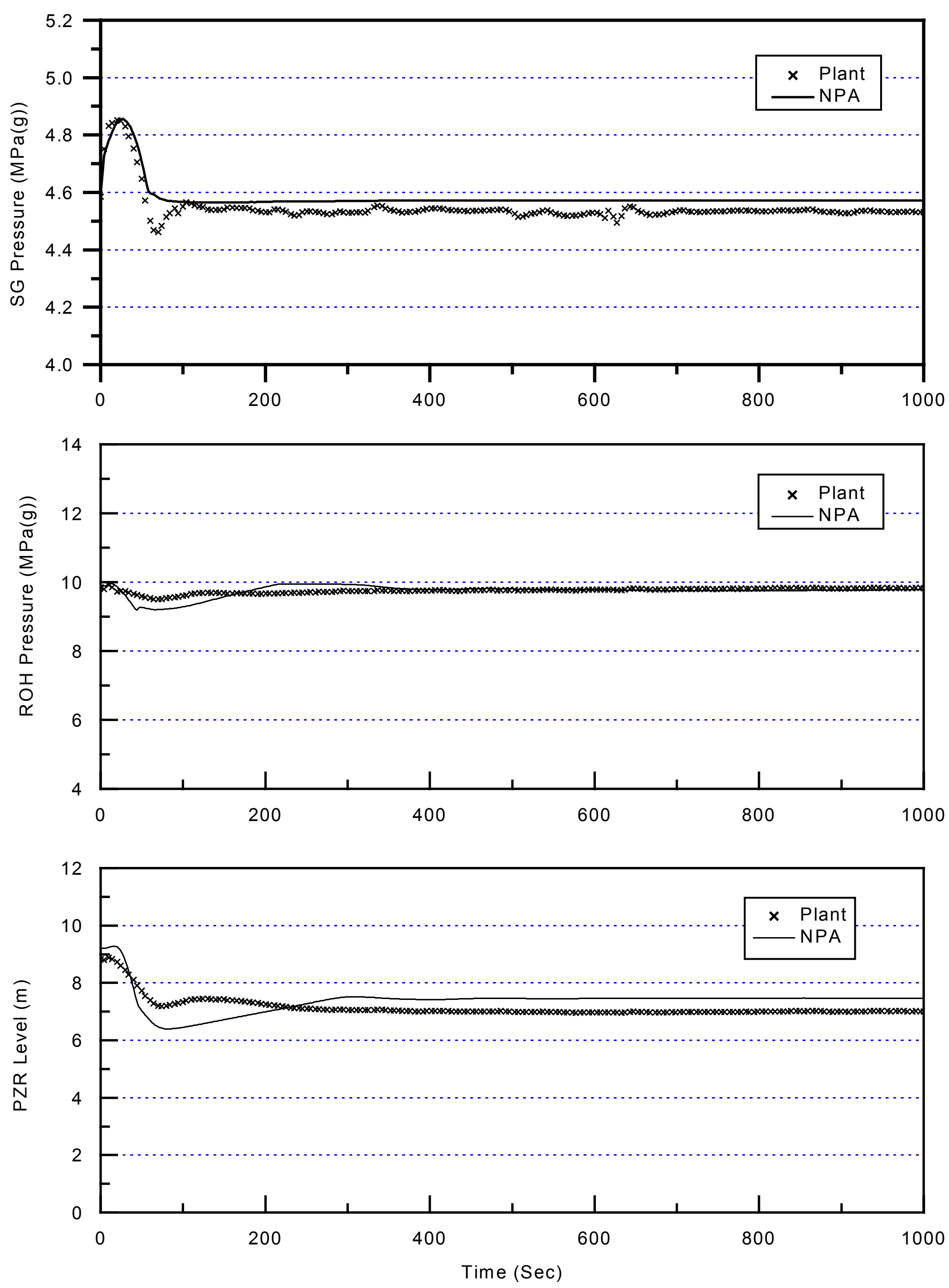

Figure 4: Comparison of Variables at Turbine Trip (2/2)

Figure 5: Variation of the System Variables at Steam Generator Tube Rupture (1/2)

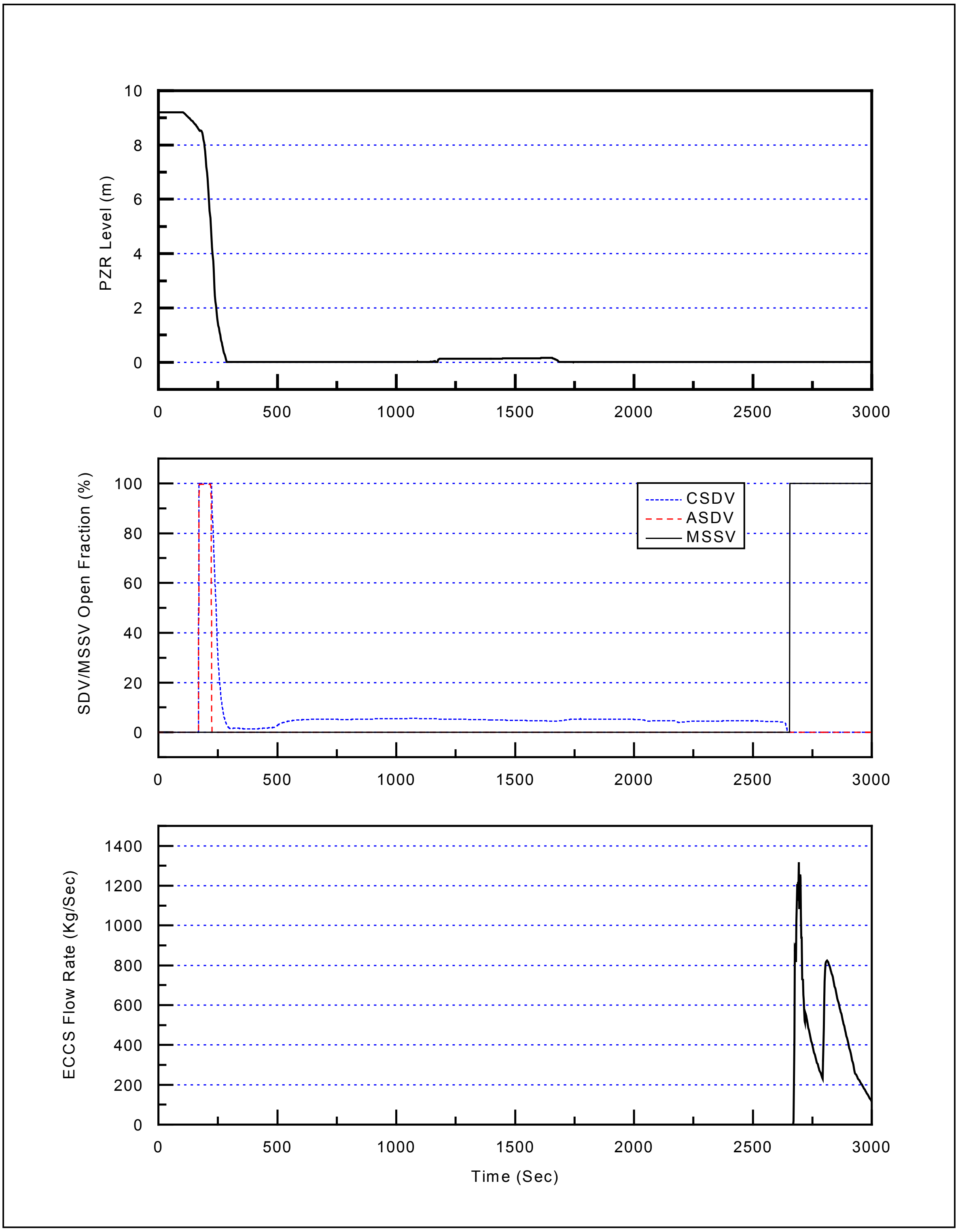

Figure 6: Variation of the System Variables at Steam Generator Tube Rupture (2/2)