NUCLEAR POWER PLANT SIMULATORS FOR EDUCATIONAL PURPOSES

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Abstract

This paper illustrates some educational values of simulators in NPP research. It consists of three major sections: 1. Systems and Operations: A brief description of major sections of NPP simulation including reactor simulation, heat transport system and steam generation system. The description is focused on a CANDU-specific reactor design. 2. Simulator application and instruction: including a visual procedure of a sample simulator operation and data collection, and 3. A brief visual description of several simulators for different types of nuclear power plants is also provided.

I. Introduction

Computer-based tools and simulators have become an inevitable and essential component of nuclear-related research and training. Simulators are also becoming the most significant component of nuclear power plant education in academic institutions. Simulators can provide understanding and insight into the operational characteristics of nuclear power plants. They are designed to visually simulate the operational response characteristics of a specific type of nuclear power plant. Their responses can include the normal operation or different accident conditions in a power plant. Today, the fidelity of full-scope simulators can be brought to high-end desktop machines. It provides opportunities for students to gain full understanding of nuclear power plant operational characteristics in classrooms and academic institutions.

The objective of this paper is to present the educational aspect of NPP simulators and to illustrate various applications of simulators for this purpose. Simulators for different types of reactors have been considered in this paper. The similarities and differences between these NPP simulators are presented and discussed.

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II. Principle of CANDU based Nuclear Power Plants

The CANDU reactor is a pressurized-heavy water natural-uranium power reactor designed in the 1960s by a partnership between Atomic Energy of Canada Limited and the Hydro-Electric Power Commission of Ontario as well as several private industry participants. CANDU is a registered trademark and stands for "CANada Deuterium Uranium" [4].

CANDU design consists of three major components: reactor design, heat transport and steam generation systems. Each of these components has a unique CANDU design and characteristics. Following is an overall view of a CANDU power plant.

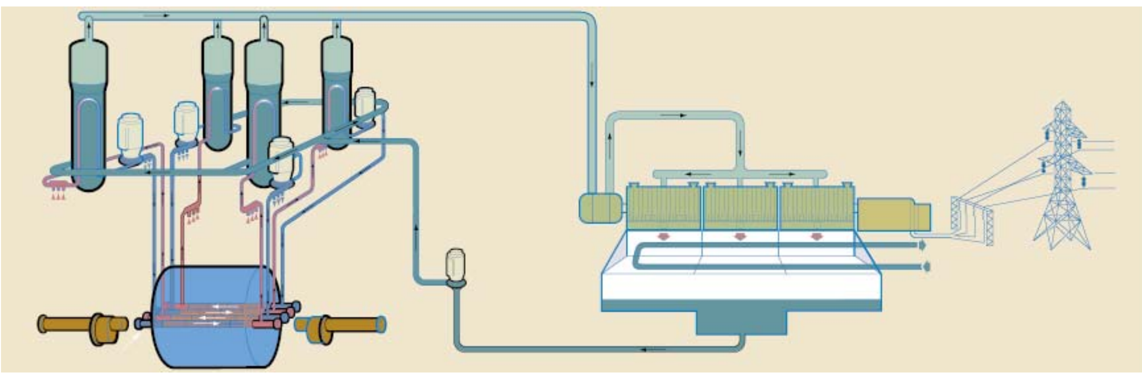

Figure 1: CANDU power plant design

Some of the unique characteristics of CANDU, as compared with other power reactors, include horizontal calandria and pressure tubes, natural uranium fuel bundles, heavy water moderator and coolant and light water reactivity control. The overview of a CANDU plant is shown in Figure1.

The main responsibility of the heat transport system in a nuclear power plant is to cool the fuel and provide the means to protect reactivity from being released to the environment. Steam system consists of three key elements: Steam Generator, Turbine and feedwater system. The heat transported from the reactor by the means of heavy water is transferred to the secondary side's light water in steam generators and the light water leaves the boiler as dry steam. The steam produced will pass the turbine which consists of a high pressure stage followed by four parallel low pressure stages. Finally, the Feedwater and Feedheating unit pumps and heats the condensate and feeds it back to the steam generators.

2.1 CANDU Compact Simulator

The original development of CANDU Compact Simulator was to assist Atomic Energy of Canada Limited (AECL) in the design of the plant display system. The simulator is designed to operate in real time in order to simulate the dynamic response of the plant in a realistic manner.

The simulator includes 16 interactive display screens and contains 21 plant alarm and annunciation. In addition, the values of the following parameters are always displayed on the screen of the simulator:

1. Reactor Neutron Power (%)
2. Reactor Thermal Power (%)
3. Generator Output (%)
4. Main Steam Header Pressure (kPa)
5. Steam Generator Level (m)
6. OUC Mode (‘Normal’ or ‘Alternate’)

An overview of the display of the simulator is shown in Figure 2, which shows a line diagram of the main CANDU systems and parameters.

In addition, six dynamic graphs are displayed in the overview page. The values presented in these graphs are calculated based on the dynamic model of the simulator. The values presented by the graphs are as follows:

1. Reactor Neutron Power and Reactor Thermal Power (0-100%)
2. Turbine Power (0-100%)
3. Boiler Levels - actual and setpoint (m)
4. Main Steam Header Pressure (kPa)
5. Pressurizer and Reactor Outlet Header (average) Pressure (kPa)
6. Pressurizer Level - actual and setpoint (m)

By default, the simulator is loaded to 100% full power. However, this value can be changed and the respond can be monitored as presented later in this paper. A wide range of configuration and properties can be manipulated and the respond in verity of areas can be simulated and studied. One of the most primary manipulations implemented is altering the unit power in the system and observing the respond of such transform.

In Figure 3, the default unit power of 100% full power is changed to 90% at a rate of 1.0%/sec. The figure shows the “Unit Power Rate (UPR)” display screen which includes four dynamic graphs: “Reactor Power & Thermal Power”, “Main Steam Hdr Pressure & SP”, “Current Target Load & Turbine Power “and “Boiler Level”. The scale chosen for these graphs is to enable to show the entire trend in this particular experiment.

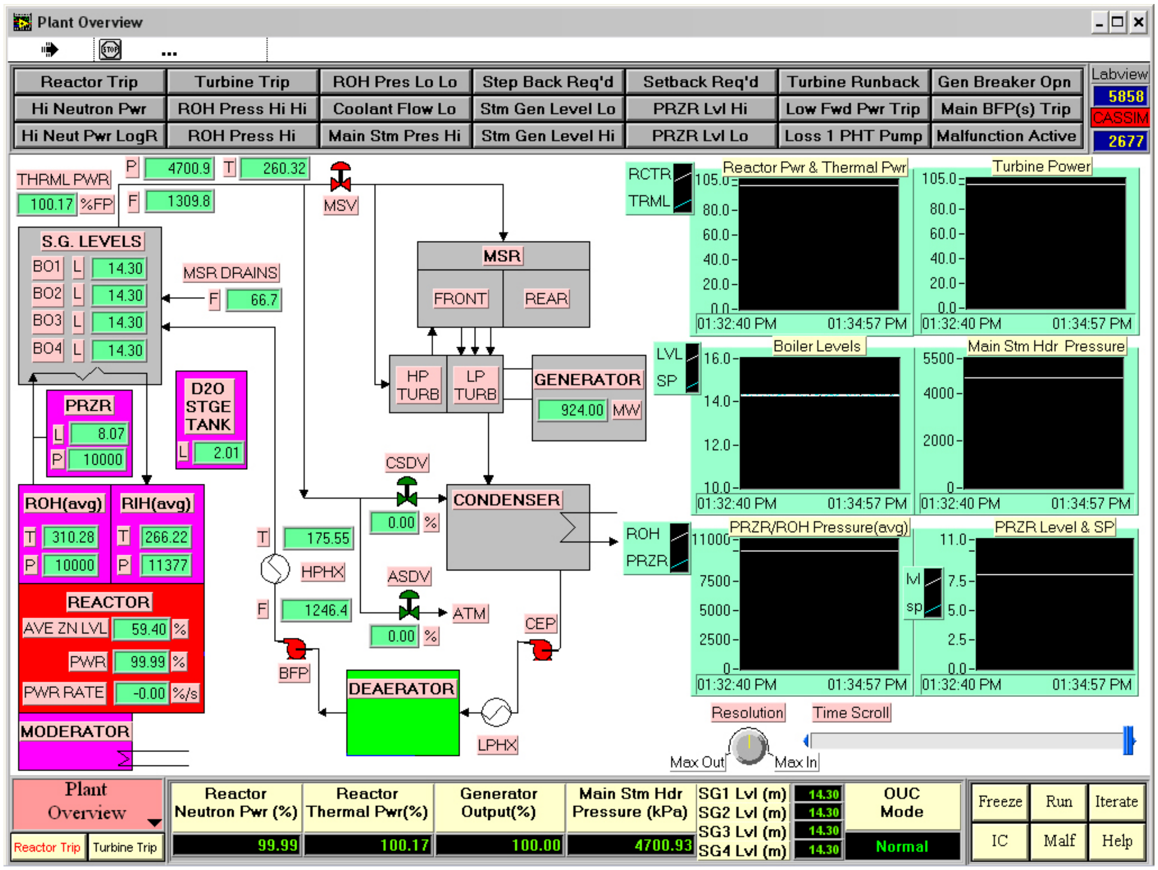

Figure 2: An overview of CANDU compact simulator

The graphs of figure 3 presents the trend observed during a four-minute interval of decreasing the unit power from 100% to 90% at a rate of 1.0%/sec. Note the overshoot experienced in the Reactor and Thermal Power before reaching the intended 90% unit power.

2.2 Desktop Simulator in OPG

OPG CANDU Simulator is a commercial CANDU simulator provided by Ontario Power Generation. This simulator is capable of accurate and real-time simulation of Darlington nuclear power plant for training purposes. (Appendix A.1)

2.3 Pressurized Water Reactor Simulator

600 MW(e) Pressurized Water Reactor (PWR) simulator is designed for educational purposes with training applications for academic institutions involved in teaching topics in nuclear power plants. This simulator is used to facilitate understanding of PWR transients and power plant dynamics and respond characteristics. (Appendix A.2)

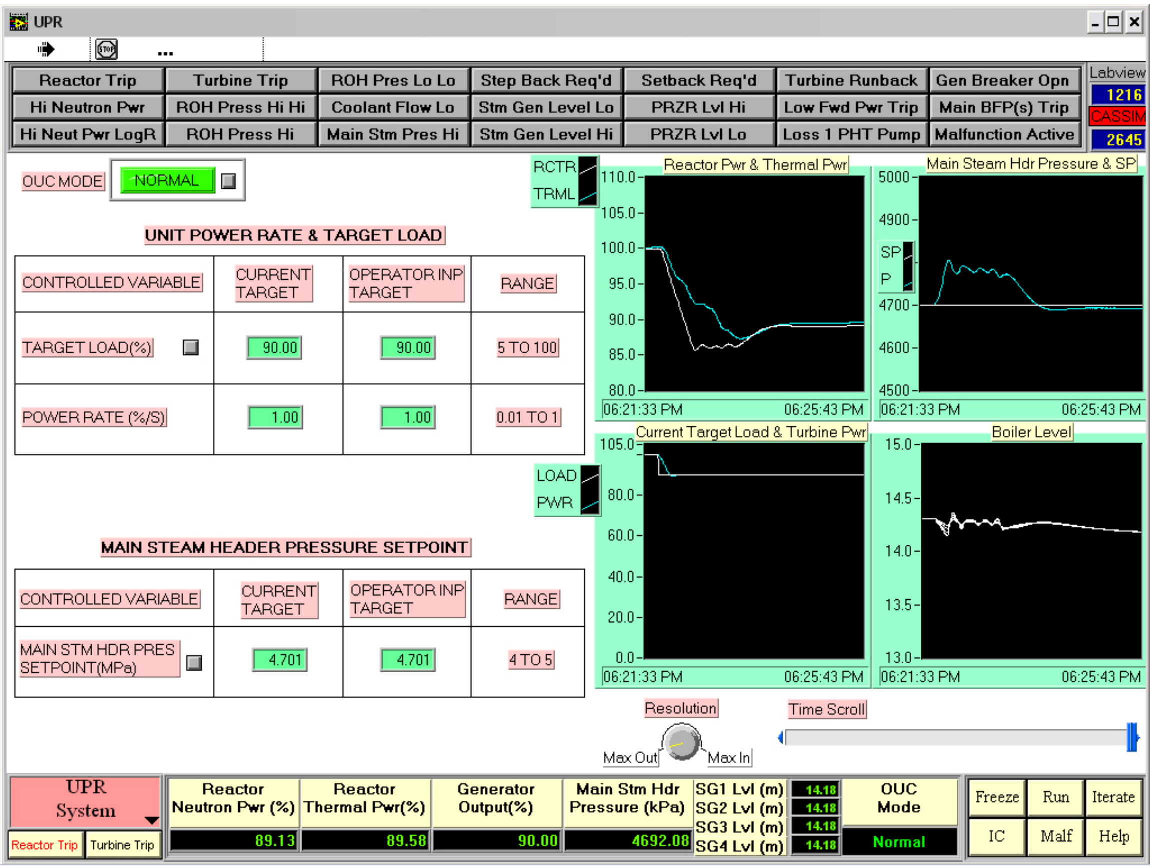

Figure 3: Unit Power Decrease

2.4 Boiling Water Reactor Simulator

Boiling Water Reactor (BWR) simulator is designed to provide insight and practice in BWR reactor operational characteristics and the response to perturbations and accident situations in this specific reactor type. (Appendix A.3)

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2.5 WWER-1000 Reactor Simulator

The WWER-1000 is a Russian based PWR reactor. The simulator was originally developed for personnel training. It is executed on a personal computer in real time and provides dynamic responses with sufficient fidelity. After reducing the scope of modeling to the systems essential for overall correct response and fidelity and cutting out a number of auxiliary systems the simulator becomes suitable for educational and information purposes. The present configuration of the Simulator is able to respond to operating conditions normally encountered in WWER-1000 power plant operation. [2] (Appendix A.4)

III. Conclusion and Discussion

Simulation tools are an essential component of modern research and education. These tools assist researchers and academic institutions in order to experiment a more realistic study on variety of subjects. The illustrated simulators along with the other nuclear power plant simulators available (please see Appendix A for graphic samples) are suitable simulation tools for real-time simulated experiments with realistic and dynamic presentation of the respond characteristics. Brief description of some of these simulators is presented in this paper.

Acknowledgment

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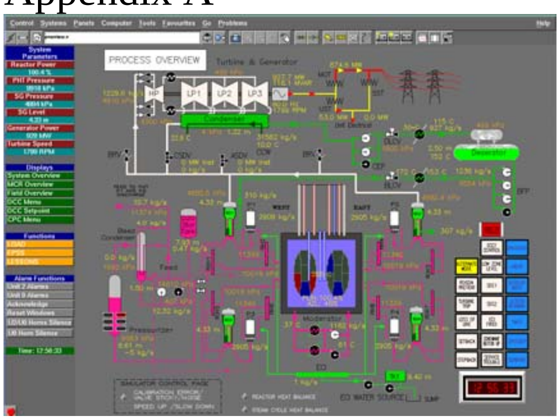
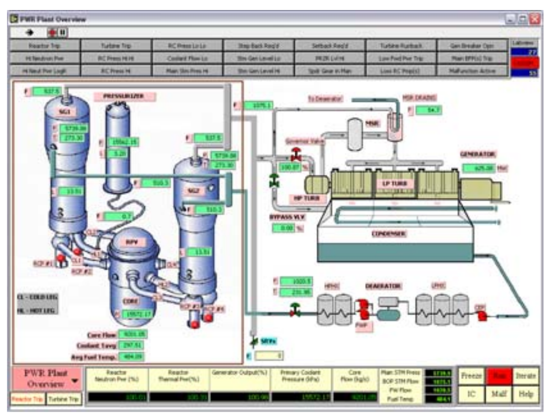
Appendix A



1. OPG CANDU Simulator



2. Pressurized Water Reactor Simulator

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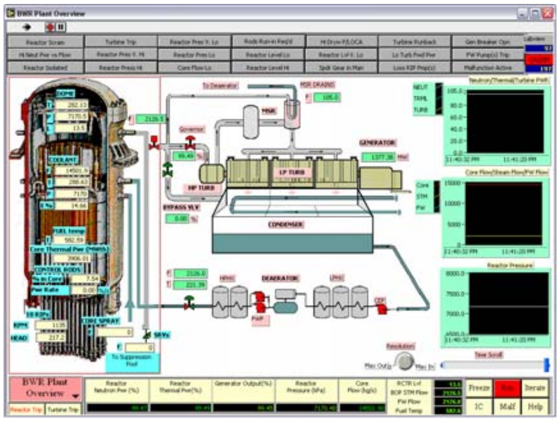
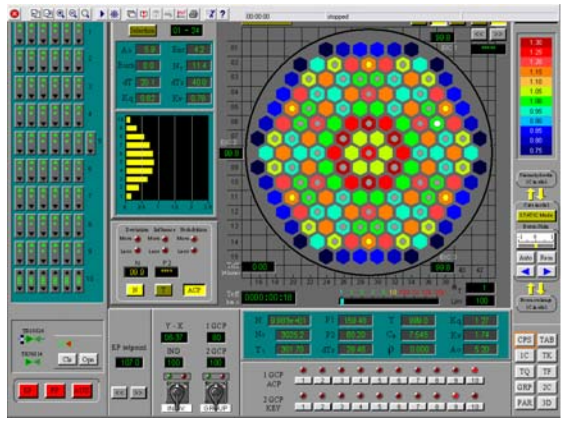


3. Boiling Water Reactor Simulator



4. WWER-1000 Reactor Simulator

References

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