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Advanced Power Plant Training Simulator For VVER-440/V230 Nuclear Power Plants¹

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ABSTRACT

An advanced, workstation based, nuclear power plant simulator has been developed for use in training the operational staff of the Bohunice Nuclear Power Plant. This training simulator uses state-of-the-art computer hardware and software and provides the capability to simultaneously include six members of the power plant operating staff in the training sessions. A detailed reactor model has been developed, representing the Bohunice VVER-440/V230 plants, for use with the RELAP5 simulation software. In addition, a comprehensive validation program has been completed that compares the simulation results of the advanced simulator with the results from a current VVER-440/V230 simulator. A summary of the training features and capabilities of the simulator is also provided.

INTRODUCTION

The Nuclear Power Plant Research Institute, Trnava has developed a PC-based training simulator for use as a cost effective method for training the operational staff of VVER/V230 nuclear power plants. This training simulator has been operational at the Institute since 1991 and is used for training the staff from the Bohunice nuclear power plant and from other Central European reactor sites. Brookhaven National Laboratory (BNL), through the sponsorship of the U.S. Department of Energy, has been implementing a program at the Institute to upgrade the PC-based simulator with enhanced computer hardware and

software that reflect the technological advances that have been accomplished since the original simulator configuration in 1991. This program has also benefitted from the on-going participation and contributions from the Institute staff.

CURRENT VVER-440/V230 PC-BASED SIMULATOR

The existing VVER-440/V230 Training Simulator consists of a network of 6 PC/AT's (386 and 286) that are configured in the following arrangement:

Reactor Operator	Two PC's
Turbine Operator	Two PC's
Shift Advisor	One PC
Network File Server	One PC

In this arrangement (as shown in Figure 1), the current simulator allows for simultaneous training of three members of the operational staff. The PC's provide a functional model of the operators' work station for each of the trainees. The current simulator has been effectively used for the following training:

Demonstration of applied theory and system interactions related to reactor operation;

Individual training on performing reactor operating procedures; and

Preparation for full-scope simulator training.

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Figure 1
PC-Based VVER-440/V230 Training Simulator Configuration

The simulation software is based on the SLAP4 thermal-hydraulic computer code. The reactor response to various transients is displayed for the trainees in approximately real time. The actions of important system controllers, interlocks, and protection devices are included in the simulation. Trainees have the capability to interactively initiate or inhibit these control and protective devices.

UPGRADED VVER-440/V230 SIMULATOR

Since the development of the PC-based simulator, the technology of simulation hardware and software has significantly advanced such that more detailed and higher fidelity simulations can be used for training purposes. Thus, BNL, with the technical cooperation of the Institute staff, has implemented a program developing an advanced, workstation based, simulator for VVER-440/V230 operational staff training. This advanced simulator includes six trainee stations such that all members of the shift operating staff can participate in the training simultaneously. The hardware configuration includes (as shown in Figure 2):

Reactor Operator	Two Terminals
Turbine Operator	Two Terminals
Shift Supervisor	One Terminal
Electrical Operator	One Terminal
Shift Engineer	One Terminal
Emergency CR Operator	One Terminal
Instructor Station	One Terminal

Computer Hardware

The computer hardware for the advanced simulator includes an IBM RISC-6000, Model 55L workstation. This hardware is networked with eight X-terminals

through a 10-Base-T Ethernet system to provide the trainee stations. The main system configuration controller and graphical interface is provided by the SAMMI software. This computer system is dedicated to the operation of the advanced simulator.

Simulation Software

The simulation is driven by the RELAP5/MOD3.1 computer code. RELAP5 has been used extensively for the analyses of reactor transient events and abnormal occurrences for both U.S. and Soviet designed reactors. In addition, a comprehensive validation program has been completed for RELAP5 by the U.S. regulatory authorities.

RELAP5 solves the conservation equations of mass, momentum, and energy for each of two thermodynamic phases in a user-specified network or nodalization scheme. Considerable flexibility is available in the specification of the nodalization for the representation of complex systems. In addition, RELAP5 includes specialized models to represent various components of pressurized water reactors. These components include main coolant pumps, turbines, valves, and reactor control functions. RELAP5 was selected for this application based on the extensive previous analysis experience and the excellent code capabilities and adaptability. It should be noted that RELAP5 has not been used extensively in the training simulator environment and this project represents one of the first applications.

Reactor Model Description

A detailed reactor representation has been developed for use with the RELAP5 software. The model includes 96 control volumes and 108 flow junctions to represent both the primary and secondary reactor systems. The VVER-440/V230 has six primary coolant loops; these loops have been represented by two loops in the RELAP5 model. One loop in the model represents one VVER loop and the second loop is a lumped representation of five VVER loops. This approximation has been implemented to improve the

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Figure 2
Advanced VVER/V230 Training Simulator Configuration

computational speed of the calculation. Several important details of the modeling are described in the following paragraphs:

Pressure Vessel Model: The pressure vessel is represented with seven control volumes with additional detail in the heated core region discussed below. The downcomer has been split to provide individual connections to the lumped and single loop inlet nozzles.

Core Model: The VVER-440 core is represented as a single channel with five axial nodes. The heated region has three nodes; a chopped cosine function has been used to model the axial power distribution. Reactor power is calculated with a point kinetics model.

Steam Generator Model: The model developed for the VVER horizontal steam generators includes ten primary side control volumes and ten heat slabs that transfer heat to the secondary system. Each of the heat slabs was sub-divided into 3 radial regions to allow the calculation of a temperature distribution through the walls of the steam generator tubes.

Secondary System Model: Each secondary system was represented by a single control volume, sub-divided into three vertical regions. All heat from the primary side was transferred to the middle, two-phase region; feedwater flow enters the bottom region that was initially filled with subcooled liquid.

Balance of Plant Systems Modeled: The current RELAP5 model represents the secondary steam systems up to the main steam turbines. The following systems are included in this model:

- Feedwater system
- Feedwater control valves
- Auxiliary feedwater system
- Auxiliary feedwater control valves
- Steam generator safety valves

- Main steam isolation valves
- Turbine throttle valves
- Fast acting turbine valves
- Steam dump to condenser
- Steam dump to atmosphere

Each of these systems have been implemented with the appropriate initiation and control functions.

Additional Primary Coolant Systems Modeled: The current VVER simulation model includes the following safety and auxiliary systems that interact with the primary coolant system:

- High pressure coolant injection
- Low pressure coolant injection
- Primary makeup system
- Emergency makeup system
- Letdown system
- Pressurizer spray system
- Pressurizer heaters
- Pressurizer relief valves
- Pressurizer safety valves

The appropriate control functions have been included in the modeling of each of these systems.

Reactor Protection System Models: The current reactor model includes functions to simulate various reactor protection system actions. Automatic and operator initiated signals are available for reactor scram, controlling rod group scram, main coolant pump trip, feedwater pump trip, turbine isolation valve closure, and auxiliary feedwater initiation.

Current Capabilities of the VVER Simulation Model

The initial version of the upgraded VVER simulator has been designed to display important reactor parameters at each trainee station during the following

transients:

- Reactor coolant pump trip
- Reactor scram
- Feedwater pump trip
- Turbine trip
- Pressurizer surge line rupture
- Inadvertent pressurizer relief valve opening
- Cold leg main coolant pipe rupture

Each of these transients can be initiated from the Instructor Station shown in Figure 2. In addition, the instructor and each trainee has the capability to initiate actions effecting the reactor performance from the terminal. For example, the following actions can be initiated from the Reactor Operator Station:

- Main coolant pump trip
- Reactor scram
- Control rod positioning
- Selection of pressure control mode
- Selection of power level
- Selection of power level control mode

In addition, the reactor operator trainee has operating data available for observation in a manner similar to the actual control room situation.

The instructors station has the overall control of the events of the training session. This includes special features such as playback for detailed analyses of the training session.

Trainee Terminal Display Design

The terminal displays available to each trainee have been designed to encourage a thinking process similar to that of the experienced operator. This concept requires the use of relative position, colors, and shapes on the computer terminal displays that are representative of the actual control room equipment being simulated. Each display has been designed to develop an atmosphere for the trainees similar to the actual control room setting.

Validation and Verification

Following completion of the reactor model and integration with the displays developed for the trainee terminals, a detailed validation and verification (V&V) program was completed for the upgraded VVER simulator. This program included a comparison of the original specification with the features and performance of the completed simulator. Following successful completion of the specification review, the V&V program continued with a validation of the simulator fidelity. Four transients had been identified in the specification for comparison of results between RELAP5 and SLAP4. The following acceptance criteria were developed for this comparison:

1. Time dependent trends in key output variables correspond, in direction, to the trends of the V&V standards;
2. The alarms and automatic actions identified in the V&V standards shall be predicted by the simulator; and
3. Key output variables must be accurate to within 10% of the absolute value of the standard; in addition, observable parameter gradients shall correspond, in direction, to the gradients of the standard.

The specification has defined the V&V standards as the following transients calculated by SLAP4:

1. A .0314 m**2 primary coolant leak in the cold leg piping;
2. A trip of one of the six main coolant pumps;
3. Opening of the power operated pressurizer relief valve; and
4. Trip of one of the two turbine generators.

In addition, for each standard transient, data for up to twelve reactor variables have been specified. Detailed comparisons of the RELAP5 results with the standard data has shown that the acceptance criteria have generally been satisfied. In a few cases, some discrepancies have been identified; however, technical analyses of the discrepancies have indicated that the RELAP5 results are more accurate. Examples of the comparison of the RELAP5 results with the SLAP4 results are shown in Figures 3-5.

Figure 3
Reactor Power Comparison

Figure 4
Pressurizer Pressure Comparison

Figure 5
Reactor Average Temperature Comparison

SUMMARY

An advanced, work station based, training simulator has been developed for training the operational staff of the Bohunice VVER-440/V230 nuclear power plant. This simulator utilizes software that provides high fidelity and flexibility to enhance the current reactor modeling and expand the training capabilities. Implementation of this simulator is a cost effective way to supplement full scope simulator training.