Design of the U-PANTHER Desktop Nuclear Plant Simulator

Alex M. Schaefer[1], Samuel J. Dickerson[1], Larry R. Foulke[2], Daniel G. Cole[2], Steven P. Levitan[1]

[1]*Department of Electrical and Computer Engineering*
[2]*Department of Mechanical Engineering and Material Science*
University of Pittsburgh
Pittsburgh, PA 15261
levitan@pitt.edu

INTRODUCTION

The goal of this project is the development of a dynamic simulation environment for nuclear power plants designed and implemented by graduate students in our nuclear education program and for use in undergraduate and graduate nuclear engineering educational programs. The University of Pittsburgh Advanced Nuclear Training for Higher Education Reactor (U-PANTHER) desktop simulation system has been developed in a new graduate course and then refined by graduate students in several "special topics" courses. It is ready to be used in both undergraduate and graduate courses focused on studying and modeling advanced pressurized water reactors (PWR).

One key requirement for the simulator is that it provides a framework for teaching, research, and development that will encourage interactions between students, faculty, and practitioners and provide better understanding of the operation of nuclear power plants. Knowledge of commercial nuclear plant operations is often cited by employers as one of the major missing competencies in new employees and even experienced engineers. The U-PANTHER desktop simulator is designed to promote improved competency and address the NRC mission of rebuilding the national educational infrastructure in nuclear engineering.

Design Requirements

Several key requirements and fundamental assumptions guided the design of the simulator.

- The simulator must run on a desktop/laptop computer so that it is accessible to most students without expensive or proprietary software.
- The simulator must run in "near" real-time. Students must be able to see the results of changes in plant controls on the operation of the reactor as the behavior occurs.
- The simulator must be developed using an open source model so that researchers, educators, and students can examine all the underlying models, change parameters (and functional capabilities), replace models, change the structure of the plant, and extend the simulator to encompass more plant sub-systems.
- The simulator software will be limited to providing general response characteristics similar to advanced pressurized water reactors such as the Westinghouse AP-1000 nuclear reactor system but it will not be intended for plant-specific purposes such as design, safety evaluation, licensing, or operator training.
- The simulator should be developed and tested incrementally, using it as an ongoing design project spanning several courses as part of a graduate curriculum in Nuclear Engineering.

DESIGN OF THE SIMULATOR

The mathematical models for the simulator have been implemented in MATLAB / Simulink™ and configured to run on a personal computer so that students can both see the underlying models and use the simulation program in laboratory-like sessions to observe plant dynamic behavior and study the effect of design changes on plant dynamic behavior.

To the best of our knowledge, the only other existing desktop simulation of an advanced PWR widely used in nuclear engineering education is the one developed by the International Atomic Energy Agency (IAEA)[1]. However, at this stage of its development, it does not provide high fidelity simulation of a PWR when control systems are placed in manual operation mode. Further, that simulator is not "open source" and does not provide users the ability to examine or modify the internal models.

In this work we have modeled the reactor core (3D space-time model) and two heat transfer circuits in the primary system – e.g., the AP-1000. Each loop has one steam generator, one hot leg, and two cold legs for circulating reactor coolant for primary heat transport. The pressurizer is in one of the two loops together with the makeup and charging systems as required to control the reactor water inventory. Two canned motor pumps are simulated in the channel head of each steam generator. Therefore, the overall model has similar components, but it is not a high-fidelity simulation of AP-1000.

Figure 1 shows the high level Simulink schematic of the initial release of the U-PANTHER simulator. In the figure one can see the simulation blocks for the major primary systems and their interconnections. These include Reactor Core Physics and Reactor Core Thermal Coupled

Models in one high level block, Rod Control System, Reactor Coolant System, Pressurizer and Pressurizer Control Systems, Primary Reactor Pumps, and Steam Generators. Not shown are the Nuclear Instrumentation and Plant Protection Systems.

Each of these blocks is a Simulink model. However, inside, the Reactor Core Physics model has been re-coded in C, compiled, and linked into the simulator for faster simulation. Also, the Reactor Coolant System has been coded directly in MATLAB to include a multi-physics simulation of the thermal/mass balance required for correct simulation convergence. Simulink cannot solve conservative systems with bi-directionality and Simscape (the conservative sub-domain in Simulink) could not solve the coupled domains needed for this task.

Graphical User Interface

Interaction between the user and the U-PANTHER simulator is controlled with a custom graphical user interface (GUI). The MATLAB built-in GUI tool ("GUIDE") did not support all the requirements we had for interactive monitoring of the simulation and was not flexible enough to provide the functionality we needed. In the GUI parameter monitoring and plant operator controls are represented in a style similar to that as in a real control room. Control panel instruments and controls, such as push-buttons and hand-switches, are shown as stylized pictures and operated via special pop-up menus and dialogue boxes in response to user inputs.

Figure 2 shows the U-PANTHER GUI with two interactive simulation screens: on the left is the Plant Overview screen and on the right is the Plant System Status screen. There are a total of five interactive screens: Overview, Control Rod Drive, Pressurizer, Nuclear Instrumentation, and Plant System Status. Each screen can be selected by the user to appear in either the left or right panel of the GUI. Screens for Power Generation, Nuclear Instrumentation, and Plant Protection have not been implemented at this time. Plant controls are summarized in Table 1, where we see the Rod Control, Pressurizer, and Pump Control interfaces.

In the next release of the software, the display screens will also have plant alarms and annunciators that indicate important status changes in plant parameters that may require operator action.

DISCUSSION

U-PANTHER can be used as a "live" dynamic simulation to complement undergraduate classroom lectures as well as introducing experienced engineers to advanced PWR technology. Concepts can be demonstrated with graphical plant mimics. In addition to normal operations, transients and accidents may also be demonstrated as the simulators' capabilities evolve.

In follow on projects, code developed by graduate students in the nuclear program at the University of Pittsburgh will focus on modeling elements of the secondary system. This will include the steam lines, turbine, generator, steam generator, water level control, and the feedwater system to the degree necessary to model steam line ruptures and feedwater failures. Continued future development will evolve this project

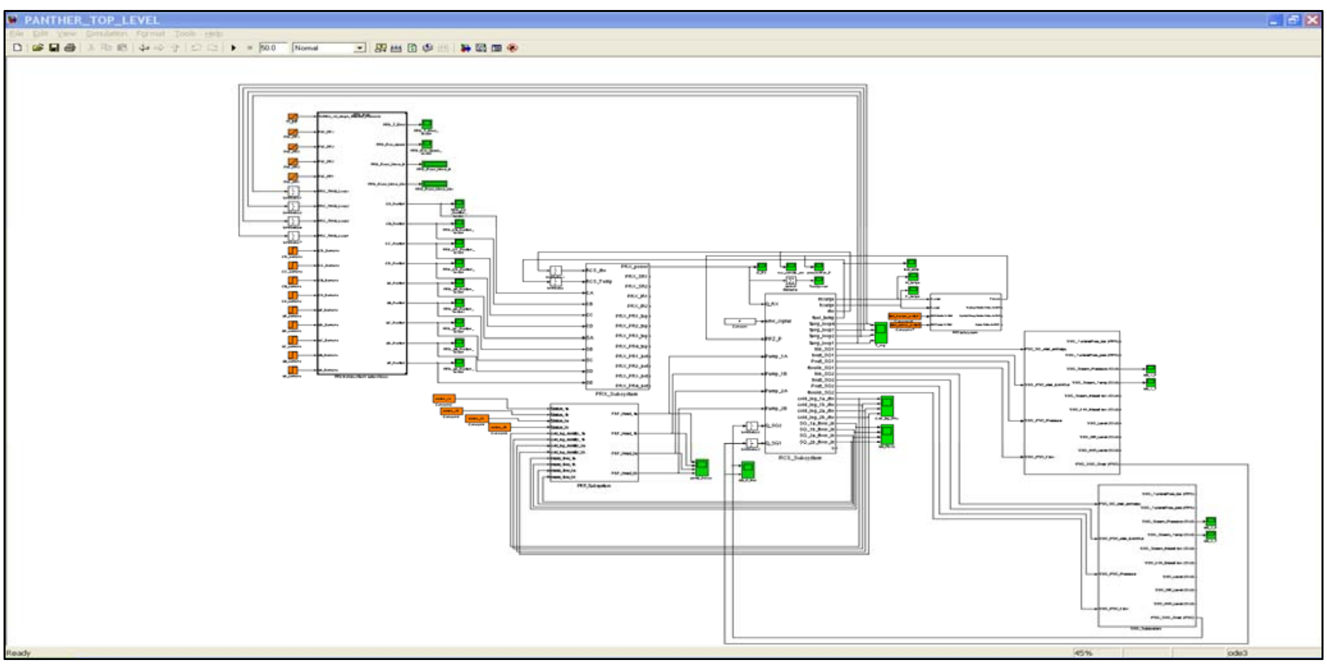

Fig 1. U-PANTHER MATLAB/Simulink Model of Pressurized Water Reactor

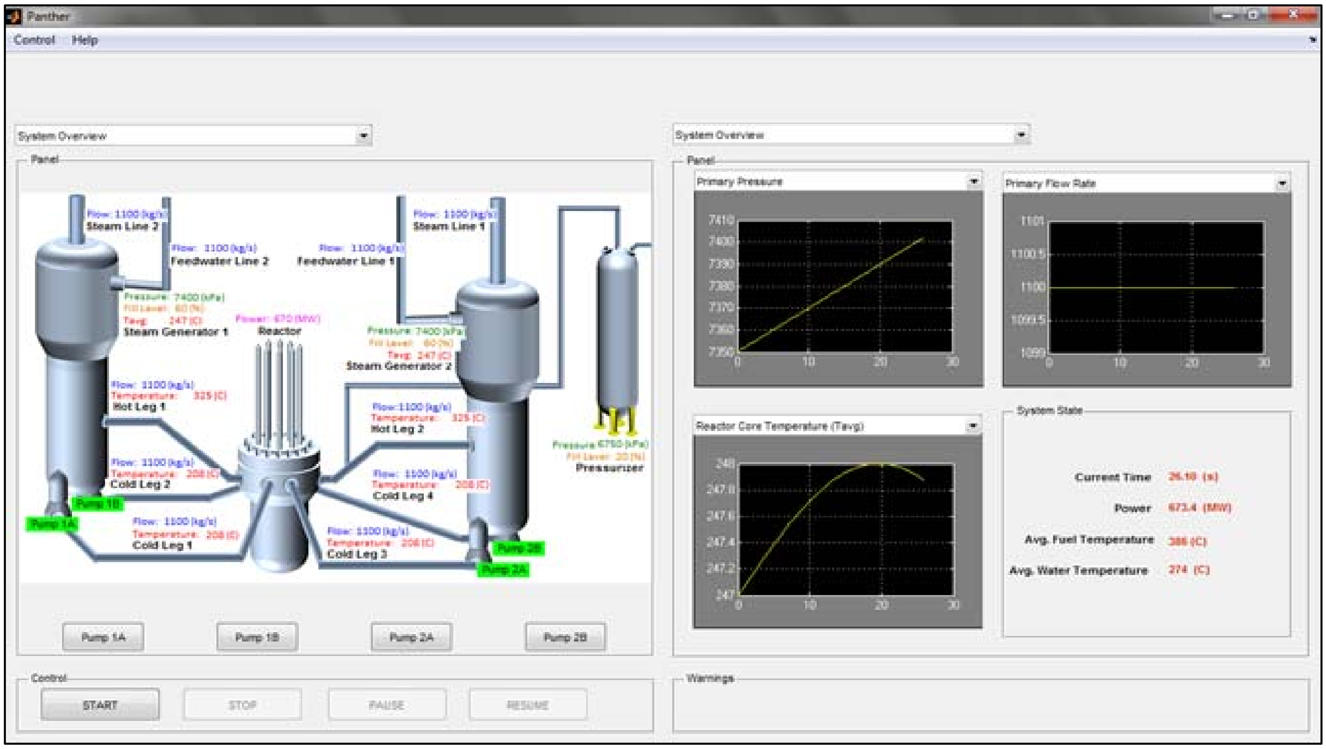

Fig. 2. U-PANTHER Graphical User Interface Showing Two of Five Information Screens

towards a more complete simulation of AP-1000 including passive safety systems. We also plan to include selected malfunctions that are within the scope of simulation such as a turbine trip, reactor trip, loss of reactor coolant pump, loss of feedwater, and loss of inventory events such as a LOCA or a stuck-open safety relief valve.

ACKNOWLEDGEMENTS

This work was supported, in part, by a grant from the Nuclear Regulatory Commission: NRC-38-10-964. The authors would like to thank the work of the Faculty Mentors: David Helling, David Aumiller, John Metzger, Justin Pounders, Richard Siergiej; and the students in the graduate classes who developed the bulk of the code: Jesse Randall (Reactor Core Physics), Venugopal Nair (Reactor Core Thermal), Patrick Sebastiani (Nuclear Instrument and Rod Control), Mark Gray, John Bartocci, Erik Hinkler (Reactor Coolant), Thomas Meikle V (Pressurizer and Pressurizer Control), Ricardo Rivera-Lopez (Primary Reactor Pumps), Scott Fortune (Steam Generator), Katie Swab (Plant Protection), Joseph Jezak and Jeffrey Brinkhus (User Interface).

This work was supported, in part, by a grant from the Nuclear Regulatory Commission: NRC-38-10-964.

REFERENCES

1. www.iaea.org/NuclearPower/Education/Simulators/

Table I. U-PANTHER Summary of Operator Controls

INPUT	*DETAIL*	*SOURCE*	*DEST - U-PANTHER BLOCK*
Steam Demand	*Slider 0-100%*	*Plant Overview*	*Steam Generators*
Rod Bank CA-SE Demand	*Button IN/OUT/STOP*	*Control Rod Drive Mechanism*	*Control Rod Drive Mechanism*
Pressurizer Spray	*Button ON/OFF*	*Pressurizer/Reactor Coolant Pumps*	*Pressurizer*
Pressurizer Heater	*Button ON/OFF*	*Pressurizer/Reactor Coolant Pumps*	*Pressurizer*
Reactor Coolant Pumps	*4x Button ON/OFF*	*Pressurizer/Reactor Coolant Pumps*	*Pumps*