Simulation and Integrated Testing of Process Models of PFBR Operator Training Simulator


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Abstract

High fidelity Full Scope Operator Training Simulators play a key role in imparting plant related knowledge to the operating personnel in an effective way. It provides a platform for training the operators on normal and emergency conditions including all types of scenarios that would arise in any Nuclear Power Plant. The scenario based training helps the plant operator to handle a crisis in an efficient manner with the ultimate goal of safe and efficient operation of the plant.

This paper discusses about the general description of PFBR Operator Training Simulator, modeling and simulation of various process models, the complexities involved etc. It also covers the associated process logics, controls, display of alarms and indications, malfunctions and transient incidents related to each process model, integration with other sub systems, individual process model testing, integrated performance testing and verification and validation of models. Simulation of process models are broadly classified into two main categories namely, External Models - that are developed in-house and ported to the simulator environment and Internal Models - that are developed using Simulation Tool. External Models are tested on the desk top for intended functioning and after obtaining satisfactory results, the models are ported to the simulator base wherein the Logical and Virtual Panel Models are built to represent a real system of the plant. Internal Models are built using the Simulation Tools and integrated with the External Models after testing. Combination of External and Internal Model represents the total plant and the performance testing is conducted in an Integrated Mode to qualify the Process Models for training purpose.

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Key words: PFBR, simulation, Integrated testing, hardware

1. Introduction

Plant Safety is given utmost importance in any industrial setup especially in Nuclear Power Industry. This is achieved by training the operators in all possible ways to acquire the knowledge about the plant operation under normal and emergency conditions. Apart from classroom teaching and field training, the simulator training is considered to be a value addition to the operator training program.
Full Scope Training Simulator has become a well accepted medium of knowledge transfer and is a major step towards enhancing the skill set of the operators. The Human Error which is found to be the main cause of major accidents that have taken place in the past history of Nuclear Industry is the main driving force behind setting up such real time training simulators. In the present scenario, major effort is on towards implementing Real Time, High Fidelity Full Scope Simulators with improved Human Machine Interface at a global level to reduce the human error.

2. Brief Description on PFBR Training Simulator

A Full Scope Replica Type Simulator is being developed at Computer Division, IGCAR in collaboration with Reactor Engineering Group (REG). The main objective is to conduct comprehensive training on all reactor subsystems under various plant conditions and enhance the capability of the plant operators.

The **Hardware Architecture** consists of Simulation Computers, Control Panels, Operator Information Consoles, Input/Output systems, Instructor station, Simulation Network, Power Supply and Distribution system as shown in Fig. 1.

![Diagram of Hardware Architecture](image)

**Fig. 1. Hardware Architecture**

Simulation Computer executes various Mathematical Models of the Sub-Systems in Real Time. It takes the Inputs from Control Panels and Operator Consoles through I/O Systems, processes them and responds by giving the information to I/O system for display on indicator/meters, recorders and raise alarms in real time. Control Panels are replica of the Plant Control Room Panels made up of mosaic tiles with grid structure.

Operator Consoles handle overall monitoring of the most important and frequently used control signals. Normally, Reactor startup, power raising, normal steady power operation and shutdown are carried out from operator console. Instructor Station facilitates control and monitoring of Simulator Operations / Operator actions and conduct training sessions [1, 2].
The important commands like RUN, STEP, BACK TRACK, FREEZE, REPLAY, and SNAPSHOT are available on Instructor station. All plant scenarios are loaded from here for carrying out training program for the operators. Communication among various subsystems like Simulation computer, I/O systems, Control Panel / Console Panel etc. in real time is very essential and are connected in a 100 Mbps Local Area Simulator Network.

3. Grouping of Process Models

Process models are broadly classified into two categories, Internal models which are developed using the in built components and devices in a tool and the External models which are developed in-house using system transfer functions considering various transient conditions. Internal Models include Steam Water System simulation and Electrical System simulation and the External Models include Neutronics Model, Primary & Secondary Heat Transport System, Decay Heat Removal System, Core Temperature Monitoring System, Fuel Handling System etc (Refer Fig 3).

4. Modeling and Simulation of Process Models

Development of PFBR Simulator includes modeling of various reactor subsystems like Neutronics, Primary and Secondary Sodium, Decay Heat Removal, Steam and Water, Electrical, Fuel Handling and PFBR Instrumentation & Control system in collaboration with various divisions of Reactor Engineering Group (Refer Fig: -4 for details).
The various plant operating conditions that are envisaged for modeling of PFBR Operator Training Simulator include, Shut-down State of Reactor, Preparation for Start-up, Reactor Start-up Operation, Reactor Criticality (cold shut-down and first criticality), Power Rise Operation, Full / Partial Power Operation, Preparation for Fuel Handling Operation, Fuel Handling Operation, Reactor Setback, Reactor Trip under various conditions and subsequent start up. Bench Mark transients representing Design Basis Events of four categories (Cat-1, Cat-2, Cat-3 and Cat-4) starting from more frequently occurring incidents to less frequently occurring incidents are also being modeled under each subsystem [3].

5. Integration and Performance Testing of Process Models

Integration and Testing of Process Models is the most challenging part of the simulator as it brings out the inadequacies that are overlooked during the individual stage of modeling and testing. The main aspect of Integration and testing is to check and verify the communication between various process models, cycle time of each process, logical conditions of various components, display of associated alarms and system parameters, correct functioning of process, logics and controls etc (Refer Fig 5).
Simulator performance testing is conducted in a fully integrated mode to check the correct functioning of the process models. Successful integration makes the performance testing much easier and smoother. Normally in any simulator, most of the valuable time of modeling is utilized in integration and testing when compared to process model development. Therefore, the process, logic and virtual panel models are integrated only after reaching a satisfactory level of individual testing. Integration will bring out any major problems associated with the process model. Integration and testing is carried out in two stages namely, integration of process model with the logic and virtual panel model and integration of process model with other reactor sub system models. They are carried out mainly to check the performance of the process model and associated logics along with alarms, parameter indications and controls.

6. Performance Testing

Simulator performance testing is mainly classified into two categories namely, System Operability testing and Scenario-Based testing. The performance testing is normally conducted in a fully integrated mode to check the correct functioning of the process models. The main intent is to demonstrate the overall simulator model completeness and integration, simulator steady-state performance and simulator transient performance for a set of benchmark transients.

7. System Operability Testing

The System Operability Testing refers to Steady State Performance Testing and mainly ensures that no noticeable difference exists between the simulated systems when evaluated with that of the original intended design or the reference unit. The Steady State performance testing is carried out at 100 and 50% power levels. At each level, the profiles are captured through continuous operation over a power range by recording the input and output parameters of the components which include variations of flow, temperature, level changes, pressure variations etc. The recorded simulated parameters are compared with the reference unit data. A comparison table is prepared as shown in Table 1 for evaluation of the performance testing.

Table 1: Simulator Performance testing

<table>
<thead>
<tr>
<th>Signal Name</th>
<th>Design Value</th>
<th>Simulation Value</th>
<th>Deviation $^\text{(+/-)}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Reactor Power</td>
<td>1253 MWt</td>
<td>1255 MWt</td>
<td>0.2%</td>
</tr>
<tr>
<td>Core Flow Up-to Blanket Region</td>
<td>5996 kg/s</td>
<td>5992.6 kg/s</td>
<td>0.1%</td>
</tr>
<tr>
<td>Hot Pool Sodium Temperature</td>
<td>547 deg C</td>
<td>557.8 deg C</td>
<td>2.0%</td>
</tr>
<tr>
<td>Reactor Inlet Temperature</td>
<td>397 deg C</td>
<td>392.8 deg C</td>
<td>1.1%</td>
</tr>
<tr>
<td>Primary Pump – 1/2 speed</td>
<td>590 rpm</td>
<td>588.8 rpm</td>
<td>0.2%</td>
</tr>
<tr>
<td>Theta M</td>
<td>557 deg C</td>
<td>567.0 deg C</td>
<td>1.8%</td>
</tr>
<tr>
<td>Theta CSA</td>
<td>580 deg C</td>
<td>579.2 deg C</td>
<td>0.1%</td>
</tr>
<tr>
<td>Sec. Pump – 1/2 speed</td>
<td>960 rpm</td>
<td>955.6 rpm</td>
<td>0.5%</td>
</tr>
<tr>
<td>Secondary Sodium IHX</td>
<td>355 deg C</td>
<td>351.0 deg C</td>
<td>1.1%</td>
</tr>
<tr>
<td>Inlet Temperature</td>
<td>235 deg C</td>
<td>235 deg C</td>
<td>0.0%</td>
</tr>
<tr>
<td>SG Steam Outlet Temperature</td>
<td>493 deg C</td>
<td>493.8 deg C</td>
<td>0.2%</td>
</tr>
</tbody>
</table>
The percentage error indicates the closeness of process simulation with the reference unit. Lower the error higher the closeness indicating successful integration of the models.

8. Scenario Based Testing using Instructor Station

The Instructor station is mainly meant for conducting training sessions and all the plant scenarios are loaded from here for training for the plant operators. This facility is utilized for conducting the Scenario Based Testing in order to evaluate the models. The benchmark scenarios include Uncontrolled Withdrawal of One Control Rod, One Primary Sodium Pump trip, One or Both Primary Pump Acceleration, One Secondary Sodium Pump Trip, One Primary / Secondary Sodium Pump seizure, IHX sleeve valve closure, Primary Pipe Rupture, One CEP Trip, Both CEPs Trip, One BFP trip and not taken over by standby, Both BFPs Trip, One or Both CWP trip, Turbine Trip, Reactor Power Set Back, Loss of Feed Heating due to failure of heaters, Generator Trip, Class IV Power Supply Failure, Station Blackout, etc [4].

9. Capturing of Simulated Parameters

The simulated plant parameters are captured electronically while conducting the Steady State and Transient performance testing and the profiles are plotted. The Hard copy of the profiles is taken with respect to time and a report is generated for further evaluation with the reference unit data. The profiles captured and plotted for One Primary Pump Trip are shown in Fig. – 6 and 7.

Fig.6. One PSP Trip - Flows

![One PSP Trip at - Sodium and Feedwater Flows](image)

Fig.7. One PSP Trip – IHX Temperature

The simulated profiles are compared with the event analysis report and checked for closeness [5].
10. Generation of Test Reports

Test report is generated by recording the details of Alarms and Trip Signals that are appearing on the hardware panels while initiating the transient conditions, the corresponding Log Messages, indicating the time of occurrence and cause of initiation of the event, the dynamic behavior of the process models by capturing the profiles of Temperature, Pressure, Level, Flow etc.

11. Scrutiny by Design Experts

The Process Models and their dynamic behavior under various conditions are demonstrated to the Design Experts who are identified for validating the Training Simulator. The expert’s comments are recorded and implemented into the system towards perfecting the model. Thus the process models are validated by the design experts by observing the steady state and transient state performance and scrutinizing the reports submitted on the test results and configuration data of process models.

12. Verification and Validation Testing of Process Models

A committee of experts from various units, NPCIL, BARC and IGCAR with specialization in design analysis and similar field experience participate in Verification and Validation of Process Models. All the developed models are subjected to the scrutiny of expert team for qualifying the models. The developed process models are simulated and demonstrated in detail to the team of experts of the V&V Committee. The comments if any are discussed with the design experts for appropriate incorporation in the model. Subsequently the V & V reports are made ready for the systems that are accepted for implementation. This is the most important phase of the simulator which qualifies the simulator for training.

13. Conclusion

A systematic integrated performance testing helps in building a robust Operator Training Simulator. The simulator performance testing covering, steady state and transient state ensures the required functionality of the process model in line with the design and safety analysis report.

The operators can be trained on all the plant operating and emergency conditions, handling procedures, and various incidents to increase the reflexes and the efficiency of the operators. Human Resource possessing enriched plant knowledge is an asset to Nuclear Power Programme of our country.

Acknowledgement

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References

[1] Preliminary Safety Analysis Report, Chapter 8 - Instrumentation & Control System