Process Simulation of Nuclear Power Plant Using Latest Techniques

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Abstract

One of the most significant developments in Nuclear Power Plant training methodology is the adoption of Full Scope Replica Simulators in the training programme. Full Scope Replica Simulator is a major step towards enhancing the operator capability and significantly improving the safety of the plant. Nuclear Power Plant Simulator is proved to be an effective and efficient training tool for imparting plant knowledge. Advances in Computer Science and Digital technology have paved a way for implementing new trends in simulation techniques like Full Scope Replica Simulators, Virtual Reality, 3-D Visualization etc. and promise to incorporate additional capabilities and bring about considerable change in training methodologies. The computer based programs representing mathematical models, simulate variety of plant conditions giving control room operator an opportunity to practice by responding to normal and routine conditions as well as emergency and abnormal conditions of the plant. Modelling, simulation combined with visualization techniques can solve many of the challenges brought forth by the emergency conditions in the plant. Presently, there is a strong trend for Full Scope Simulators to pierce into the world of Nuclear Power Plant Operations where they can be used to provide newer insights for operational decision-making. This paper discusses the Process Simulation of Condensate and Feed Water System of a Nuclear Power Plant. Both the systems put together make up the regenerative feed water heating system in order to improve the steam cycle efficiency. The main function is to draw the condensate from the condenser, heat and feed it to once through type of Steam Generators. Feed heating is done at six stages consisting of three low pressure heaters, deaerator and two high pressure heaters using bled from Low Pressure / Intermediate Pressure / High Pressure turbine steam extracts. The real time process simulation includes process modelling of all the components associated with the system, incidents and malfunctions and its significance for which the operators need to be trained. It also covers the connected process logics, controls, display of alarms and indications, interconnection with other sub systems of Steam Water System etc.

Key words : Neural Network, Integral square error, fault diagnosis

I. PROCESS SIMULATORS FOR TRAINING PURPOSE

The role of Process Simulators has taken a new shape and brought in a lot of change in the training methodologies particularly in the Nuclear Power Plant Scenario. Of late the process simulators are put into use for various purposes like general understanding of the system, design verification and validation, checking and evaluating operating procedures, operator training etc. Among all the Operator Training Simulator has gained more importance in the Nuclear Industry.

After the Three Mile Island incident, the international body for Nuclear Power Reactors has decided to incorporate this new methodology for training the Nuclear Power Plant Operators using Process Simulators. This is used mainly to reduce the human error and enhance the efficiency of the operators by increasing the reflexes. Part Task simulators are in use by many countries since two decades. Presently all are switching over to Full Scope Replica Simulator because of the advantage of having Control Room environment simulated and at the same time horizontal coverage of all the systems connected to the Nuclear Power Plant. This gives more clarity to the operator after the class room and field training.

A Full Scope Replica Type Simulator is being built at IGCAR for training the PFBR (Prototype Fast Breeder Reactor) operators. The operator carries out plant operations on the simulator and observes responses as they would occur in the real plant. PFBR training simulator is a training tool designed to replicate the steady state and dynamic responses of the plant to operator actions. It consists of mathematical models representing the plant components and generates input and out put signals that trigger the control system into thinking mode as if it is controlling the real plant, control system emulation and man- machine interface [7].

The Full Scope Replica Simulator for PFBR operator training consists of various reactor sub systems like Neutronics system, Primary Sodium system, Secondary Sodium system, Electrical system, Steam Water System (SWS) (Refer Fig. 1). The plant control room is replicated in all aspects so as to provide a similar environment during the operator training programme using simulator. The plant console of the simulator is identical to the operator console and control room panels of the reactor. Operator's console handles overall monitoring and most frequently used controls of the plant. Control room panels are provided on system basis. The display, indications and control switches in the operator console will be identical to the actual plant console. The instructor station provides the mode of operation of the simulator, monitoring of various process parameters and other facilities.

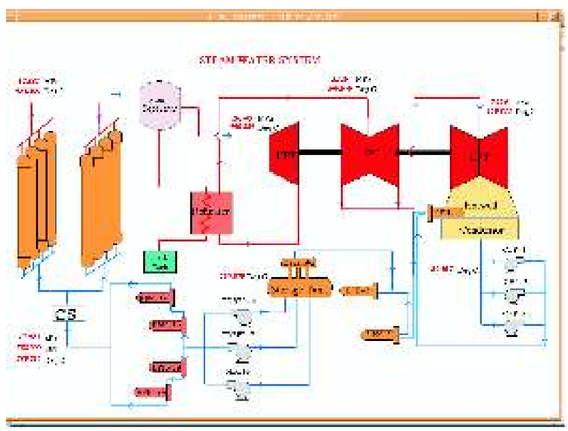

Fig. 1. Steam water system

II. BRIEF DESCRIPTION OF CONDENSATE & FEED WATER SYSTEM OF PFBR

The Condensate and Feed Water System is a part of Steam Water System in PFBR (Prototype Fast Breeder Reactor) which produces superheated steam using (OTSG) once through steam generators to drive the Turbine Generator and produces 500 MWe power [5]. The main function of Condensate and Feed Water System is to maintain the cycle flow and thermodynamic requirements of the system by supplying water from condenser hot well to deaerator and then to Steam Generator. This is achieved through various stages of low pressure and high-pressure regenerative feed heating [3]. It also maintains continuous supply of feed water to the Steam Generator to meet the system demand during various plant operating conditions.

The condensate from the hot-well of the Condenser is extracted by the Condensate Extraction Pumps and pumped to Deaerator through Condensate polishing Unit, Gland Steam Condenser, Drain Coolers and Low Pressure heaters [2]. The feed water system circulates water from Dearator to Steam Generators at required pressure and temperature using Boiler Feed Pump. Steam cycle employs regenerative feed heating based on steam bled from High Pressure / Intermediate Pressure/ Low Pressure turbine extracts. Condensate drain from the High Pressure heaters is cascaded to the Deaerator feed storage tank and the drain from Low Pressure heaters is cascaded to the Condenser [4].

III. DESCRIPTION OF CONDENSATE AND FEED WATER SYSTEM SIMULATOR

The process simulator for Condensate and Feed Water System refers to the hydraulic part of Steam Water System simulator. The process simulator covers normal system functioning and status under various plant operating conditions, related incidents and malfunctions, logics and controls, alarms and indications.

The general functioning of the simulator represents the actual Condensate and Feed Water System functioning in all respects. The process simulator takes the input signals from the interconnected reactor sub systems. It also accepts the plant stimuli such as Start/Stop signal of Boiler feed pump, Condensate extraction Pump, Close/Open signal of steam / water side valves etc from the Control panel and feed back signals from the processes [1]. The simulator then processes the parameters, generates the desired response and system output parameters, display the various system parameters, trip and alarm conditions of all the important components of the system on the Virtual / Control Panel through Meters, Indicators, Window annunciations, Lamp indications and Audio alarms [7].

The Simulator is controlled from the Instructor Station from where various plant scenarios / operating conditions, connected to the system are loaded for training the operator. The operator undergoing training is expected to respond to the incident by operating the components and devices using the controls knobs/switches available in the Control Panel. All the events are recorded for review by the Instructor for qualifying the operator. (Refer Fig. 2)

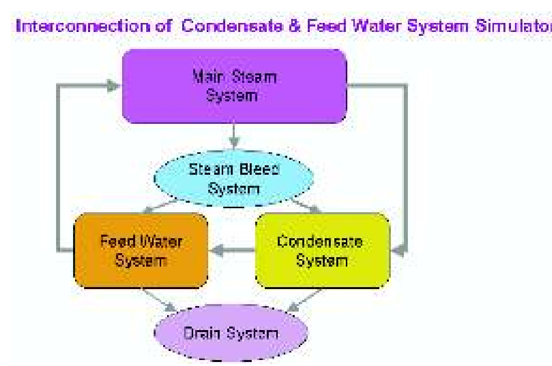

Fig. 2. Interconnection of condensate & feed water system

IV. HARDWARE ARCHITECTURE OF SIMULATOR

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 the figure (Refer Fig. 3). Simulation Computer executes various Mathematical

Models of the Sub-Systems in Real Time. It takes Inputs from Control Panels, Console panels 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. Instructor Station facilitates control and monitoring of Simulator Operations / Operator actions and conduct training sessions. 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 conducting training for the operators [6].

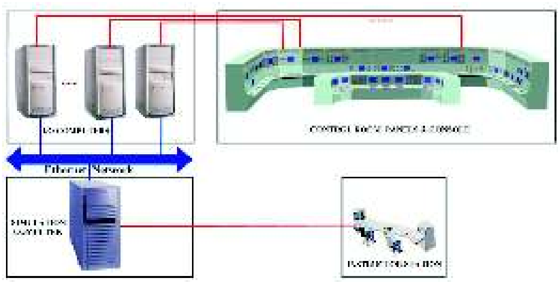

Fig. 3. Hardware architecture

V. DESIGN AND DEVELOPMENT OF PROCESS SIMULATOR

Development of Process Simulator requires good system knowledge, understanding of various connected processes and associated equipments in each system and overall view about the plant. It is gained through work experience, attending technical lectures, discussions with operation & design experts and detailed study of related design and operation notes.

Development of Process Simulator involves modelling of various devices and components connected in the specified system. The basic simulator model includes Process Model, Logical Model and Virtual Panel Model. The process model represents the actual system functioning, the process models components and devices are selected and configured. The components and devices are connected to form a network. Each network is a representative of a sub-system of the plant. The Logical Model represents the interlocks and controls and the Virtual Panel represents Control Panel / Control console in the Control Room. The interface between the Process, Logic and the Virtual Panel are established by passing the input /output / feed back signals as given in Fig. 4.

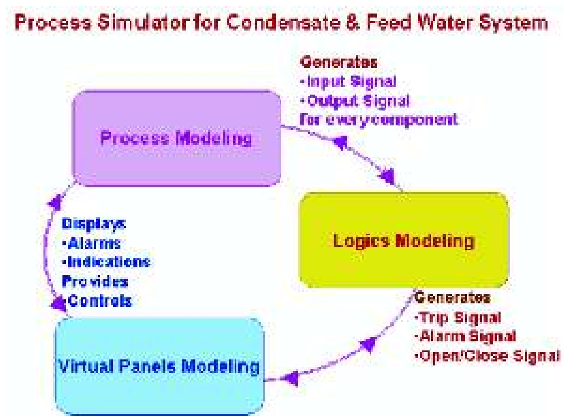

Fig. 4. Process simulation for condensate & feed water system

VI. PROCESS MODELING OF CONDENSATE AND FEED WATER SYSTEM

Process Modelling of Condensate and Feed Water System involves development of Hydraulic Networks and integration of the same to the Main Steam System. The Process Modelling starts with the System Requirement Specification Document which is drawn by referring to Design and Operation notes of the systems concerned. Various steps involved in the design and development of process Model is described in the following paragraphs (Refer Fig. 5).

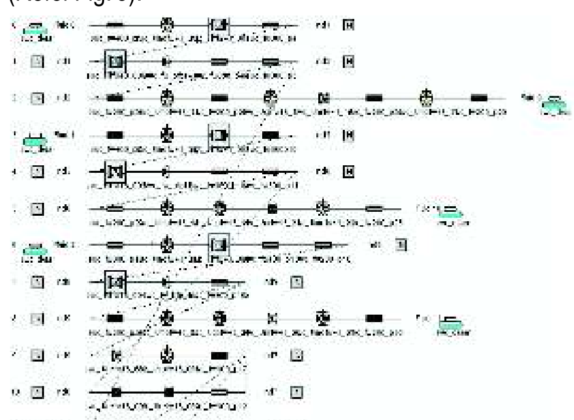

Fig. 5. Feed water process network

A. Identification of main Components of the sub system

Development of process networks requires modelling of components and devices. Each sub system consists of number of components and devices connected together to represent a process function. The major components that are included in the modelling of

Condensate and Feed Water System Simulation are Steam Generators, Main Condenser, Condensate Extraction Pumps, Boiler Feed Pumps, Low Pressure Heaters, High Pressure Heaters, and Connecting Pipes, Feed water Control Station, Filters, and Valves.

B. Collection of component specification and device data

Component specifications are collected from the design documents of Condensate & Feed Water System towards building up of process simulator. The isometric drawings of the system concerned are collected for general understanding of the system layout and component location. Relevant data pertaining to pipes / valves/ filters / other components about elevation, diameter, and length are collected and documented. The process parameters are also collected from the relevant design and operation notes of the systems to be simulated.

C. Creation and configuration of components and devices

The identified system components and devices are created using the Techcomm Integrated Configuration & Simulation System modelling tool and configured using the data collected. This includes all the major components and the connecting devices like pipes, valves, filters etc.

D. Naming convention followed

Each process model consists of number of components and devices which need to be identified in a unique and easily identifiable manner. Proper naming convention is to be followed for easy identification of system Components and devices. For this purpose a set of rules are followed while naming the models in order to fall in line with the existing names of components of the actual system.

The naming convention adopted is as follows:

Main System Name _ Sub System Name_ Component /Device name

Swc_fw_....... Devices of the Feed water sub-system

swc_ce_........ Devices of the Condensate sub-system

Note : swc - Steam water system; fw - Feed water system; ce - Condensate system

E. Generation and testing of process simulation networks

The components and devices are connected to form a network representing the actual condensate & feed water systems. The network is created using branch connection table by defining the nodal points and the sequence in which the list of components are to be connected. Once the network is ready it can be visualized using the mimic display available in the tool. The circuits are tested for its performance and compared with the actual system.

VII. LOGICAL MODEL

Simulation of process logics and controls of various components and devices are done by generating Logic Models representing the actual system interlocks and controls. Logic models are generated using logic gates and related algorithms. The input process signals are taken from the Process Model, processed by the logic model as per the set points / thresholds and interlocks. The logic model generates output signal and sends it for displaying on the Virtual Panel / Control panel and automatic control of the process components and devices (Refer Fig. 6).

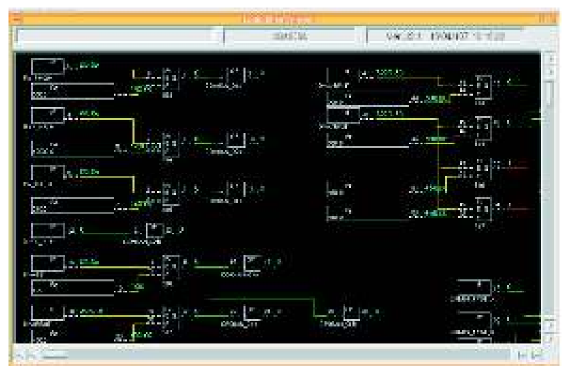

Fig. 6. Feed water system logic

VIII. VIRTUAL PANEL MODEL

Virtual Panel Models are used mainly to monitor the input and output signals of the process models during the development stage of the Simulator. The Virtual Panel representing the Control Room Panels is used for Control and Indication of process parameters. The Virtual Panels are created using the built in instrument and display models. It consists of alarm display unit, signal indicators such as Temperature/Level Indicators, Controllers, Meters indicating flow, temp, pressure, current and Voltage etc. and is mainly used for display of Input / Output parameters, raising alarms and ON /OFF control of various components (Refer Fig. 7). The virtual panel models can be integrated with process , logic models as well as with external models through messaging and data sharing mechanism available in simulator environment.

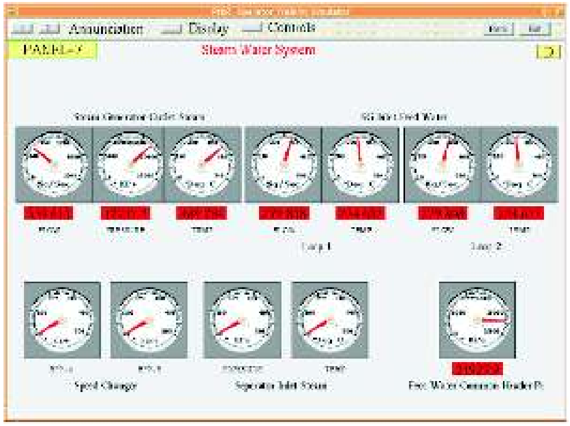

Fig. 7. Steam water system virtual panels

IX. INTEGRATION AND TESTING

The main purpose of Integration and testing is to check and verify the communication between various processes, cycle time of each process, alarm and display of system parameters, logics and controls etc (Refer Fig. 8). Integration and testing involves integration at three stages, namely:

- Integration of Process Model with the Main System
- Integration of Process Model, Logical Model and Virtual Panel.
- Integration of Process Simulator with all other reactor sub systems.

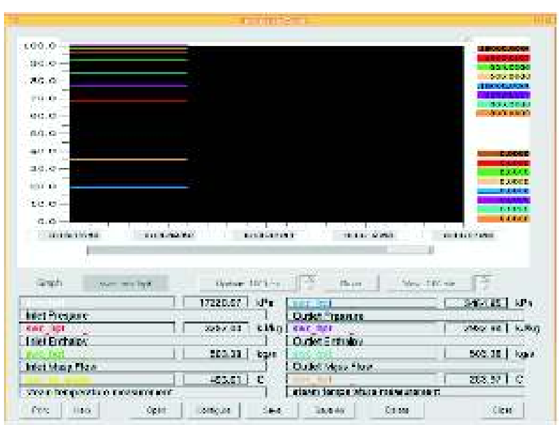

Fig. 8. Feed water system parameter monitoring

X. INTEGRATION AND TESTING OF PROCESS MODEL WITH THE MAIN SYSTEM

The Process Models are tested independently and then integrated with the Main system and tested thoroughly. Here the process networks are linked using stub connections available which allows the input / output / feedback signal to flow between the networks. The input and output process parameters are then checked and compared with the actual process parameters. The deviation in Simulator output parameters from the actual process parameter are narrowed down by tuning the network components.

A. Integration of process model, logical model and virtual panel.

The integration of Process / Logical /Virtual Panel Model allows signal communication between the simulator models to be established. Here all the system logics and controls can be tested and the response of the process model can be checked using Virtual Panel indications & controls. The interlocks and control signals flow from the process to logic for checking and applying automatic corrective action for starting / tripping / stopping / opening / closing action according to the process requirement. The generated input /output parameters and the status of various components / devices of the process simulator are displayed on the Virtual Panel.

B. Integration of SWS simulator with all other Reactor sub systems

This is the third phase of integration. Here the Process Simulator is integrated with the other reactor sub system simulators which are built by different teams. The communication between the processes is checked and verified here. This integration helps to test the overall functioning of the simulator representing plant dynamic behaviour under various plant operation conditions.

C. Verification and validation testing

This is the most important phase of the simulator which qualifies the simulator for implementation to do the intended function. Verification testing is performed by comparing the simulated component to the original requirement to ensure that each step in the model development process completely incorporates all the design requirements.

Validation testing is performed by comparing the simulated process parameters to the actual system parameters of the plant either in stand-alone mode or integrated mode. Normally, verification and validation testing is done along with the system experts who are basically system designers.

XI. SIMULATION OF PLANT DYNAMICS

Simulation of Plant Dynamics is the most essential part of simulator for which it is being built. The transients, incidents and malfunctions which are likely to happen in the system are considered for simulation. They are classified as Category -1, 2, 3 & 4, based on the frequency of occurrence in the plant.

The incidents and malfunction here refers to tripping/ failure/ malfunctions of components like pumps, valves, control systems, sensors etc affecting the system performance by altering the normal operation of the system. Such incidents and events connected to each process are simulated and the plant operators are trained to handle the situation to safe guard the plant.

The list of transients include Main Boiler Feed Water Pump trip, Loss of Steam supply to deaerator, Tripping of condensate extraction pump, Malfunction of isolation valves, level sensors etc (Refer Fig. 9).

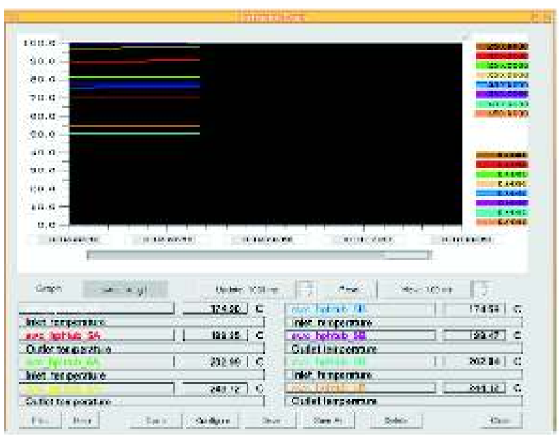

Fig. 9. Plant Dynamic

XII. LATEST TECHNIQUES CONSIDERED FOR IMPLEMENTATION

Latest Techniques like 3D Visualization and Virtual Reality are planned to be incorporated along with the Full Scope Training Simulator. 3D Visualization will be used for visualizing plant dynamic characteristics and component behavior. Virtual Reality will be used to generate full immersive Plant Walkthroughs which will be helpful to the Operator to have complete knowledge on plant layout details and component locations.

XIII. CONCLUSION

The role of Process Simulator is quite significant in the present scenario of training the Nuclear Power Plant Operators. To ensure safety of operation of any Nuclear Power Plant, comprehensive training of its operators in all phases of power plant is essential. A well trained operator is an asset to a plant who can handle any emergency situation in a controlled manner without panic and safeguard the equipments and personnel in the plant. Here the real time simulators i.e. Full Scope Replica Training Simulators play an essential role in imparting extensive training to the operators and plant personnel. Analytical and functional simulators are no longer considered adequate for training. The significant advance in Computer Science & Technology has brought forth cost effective high performance computers and paved a way for establishing real time Full Scope Training Simulators. Now advanced tools and techniques are available in the market to meet the high end requirements of training methodologies like 3D Visualization and Virtual Reality. The operators can be trained on all the plant operating and emergency conditions, handling procedures, various incidents (which will not be possible in the actual plant) to increase the reflexes and hence the efficiency of the operator [7]. It helps the operator to have a smooth change over to the actual plant after completion of training.

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