Verification and Validation of Simulated Process Models of KALBR-SIM Training Simulator

T. Jayanthi, K. Velusamy, H. Seetha, S. A. V. Satya Murty

***Abstract*—**Verification and Validation of Simulated Process Model is the most important phase of the simulator life cycle. Evaluation of simulated process models based on Verification and Validation techniques checks the closeness of each component model (in a simulated network) with the real system/process with respect to dynamic behaviour under steady state and transient conditions. The process of Verification and Validation helps in qualifying the process simulator for the intended purpose whether it is for providing comprehensive training or design verification. In general, model verification is carried out by comparison of simulated component characteristics with 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 plant process parameters either in standalone mode or integrated mode.

A Full Scope Replica Operator Training Simulator for PFBR - Prototype Fast Breeder Reactor has been developed at IGCAR, Kalpakkam, INDIA named KALBR-SIM (Kalpakkam Breeder Reactor Simulator) where in the main participants are engineers/experts belonging to Modeling Team, Process Design and Instrumentation & Control design team. This paper discusses about the Verification and Validation process in general, the evaluation procedure adopted for PFBR operator training Simulator, the methodology followed for verifying the models, the reference documents and standards used etc. It details out the importance of internal validation by design experts, subsequent validation by external agency consisting of experts from various fields, model improvement by tuning based on expert's comments, final qualification of the simulator for the intended purpose and the difficulties faced while co-coordinating various activities.

***Keywords*—**Verification and Validation (V&V), Prototype Fast Breeder Reactor (PFBR), Kalpakkam Breeder Reactor Simulator (KALBR-SIM), Steady State, Transient State.

I. Introduction

ESSENTIALLY, the Verification & Validation (V&V) certification is a fundamental requirement for qualifying a Training Simulator before the deployment. As addressed by many modeling experts, the Verification and Validation of process models has always been a challenging experience, as it deals with system dynamics under various conditions of the plant. The Verification & Validation technique applied to evaluate the process models certainly, is a complex process when compared to normal software evaluation. In order to achieve higher degree of acceptance level, the process models have to be subjected to number of tests by the model development team, before declaring the readiness for model validation. Normally, the V&V process is used for evaluating the models based on the performance, with respect to steady state and transient state, where the model dynamics play an important role. This is the main factor which differentiates the simulation software from the application software and makes the V&V process more cumbersome. It is highly impossible to achieve 100% accuracy or perfect models in absolute terms. Always the model performance is said to be satisfactory or having better acceptance level, based on the closeness of the model behaviour with respect to the reference plant or unit. The following paragraphs describe, the methodology adopted for evaluating the process models built for PFBR Operator Training Simulator.

T.Jayanthi is with Indira Gandhi Centre for Atomic Research, Kalpakkam, Tamil Nadu, India (Phone -04427480210; e-mail -jayanthi@igcar.gov.in).

Dr.K.Velusamy is with Indira Gandhi Centre for Atomic Research, Kalpakkam, TamilNadu, India (Phone -04427495215; e-mail: kvelu@igcar.gov.in).

II. Brief Description of Prototype Fast Breeder Reactor - PFBR

Prototype Fast Breeder Reactor (PFBR) is a 500 MWe capacity, pool type reactor utilizing sodium as the main coolant and heat transport medium. The reactor core is a compact core containing fuel sub assemblies made up of (Uranium, Plutonium) Mixed Oxide. The heat transport system consists of primary sodium circuit, secondary sodium circuit and steam water system. The schematic diagram of PFBR is shown in Fig. 1 [4].

The heat generated in the core is removed by the primary and secondary heat transport system which is in turn used to produce steam in once through type steam generators. The steam water system produces superheated steam to drive the Turbo Generator to generate 500 MW electric power. The steam water system adopts a reheat and regenerative cycle using live steam for reheating. A Turbine bypass of 60% capacity is provided to facilitate the start up, shutdown and reloading of the turbine. The decay heat system is provided to remove the decay heat generated in the core subsequent to any reactor trip.

III. PFBR Operator Training Simulator (KALBR-SIM)

A Full Scope Replica Type Simulator has been built and commissioned by IGCAR, for imparting plant oriented training to PFBR (Prototype Fast Breeder Reactor) operators. The PFBR Operator Training Simulator is a training tool designed to imitate the operating states of a Nuclear Reactor under various conditions and generate response equivalent to reference plant to operator actions. Basically, the models representing the plant components are expressed by mathematical equations with the associated control logics built into the system as per the actual plant, which helps in

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

replicating the plant dynamics with an acceptable degree of closeness. The operator carries out plant operations on the simulator and observes the response, similar to the actual plant [1].

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) etc. The plant control room is replicated in all aspects so as to provide a smooth change over from training to real plant operation for an operator (Fig. 2).

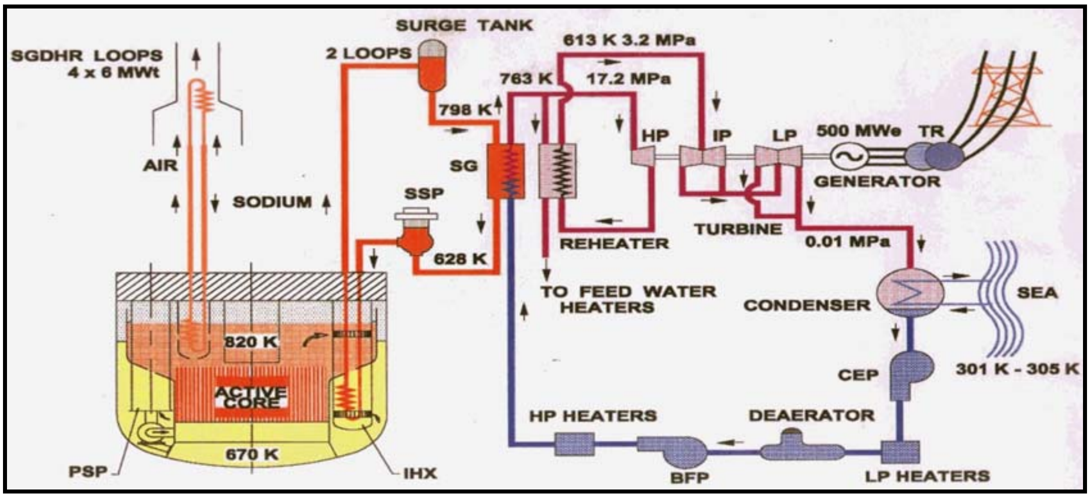

Fig. 1 Schematic Diagram of PFBR

Fig. 2 PFBR Operator Training Simulator- KALBR-SIM

IV. Hardware Architecture

The Hardware architecture (Fig. 3) consists of Simulation Computers, Control Panels, Operator Information Consoles, Input/ Output systems, Instructor station, Simulation Network and Power Supply & Distribution system. 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. Control Panels are replica of the Plant Control Room Panels made up of mosaic tiles with grid structure. Operator Consoles handle overall monitoring the most important and frequently used controls. Normally, Reactor startup, power raising, normal steady power operation and shutdown are carried from operator console. Instructor Station facilitates control and monitoring of Simulator Operations / Operator actions and conduct training sessions [1].

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.

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

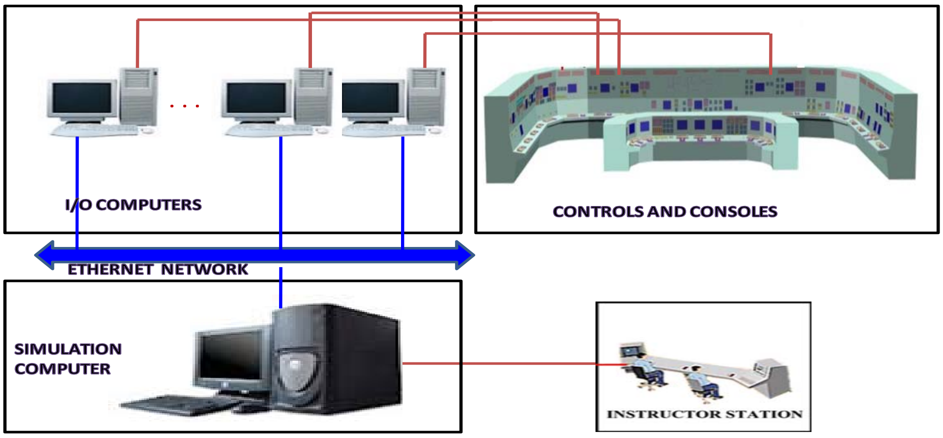

Fig. 3 Hardware Architecture

V. Development of Process Models and Associated Dynamics

The design and development of KALBR-SIM includes modeling of various reactor subsystems (Refer Fig. 4) like Neutronics, Primary & Secondary Sodium, Decay Heat Removal, Steam & Water, Electrical, Fuel Handling and PFBR Instrumentation & Control system in collaboration with various system experts available in the centre. All the plant conditions that are mandatory for training the operators are included in the simulator development. The important plant operating conditions that are taken into account for modeling of PFBR Operator Training Simulator include, Reactor Start up Operation, Power Rise Operation, Full / Partial Power Operation, Reactor Criticality (Hot, Cold and first Criticality), Fuel Handling Operation, Reactor Trip under various conditions, Shut Down of Reactor, Reactor Power Setback etc. [5]. Simulation of Transient Conditions and related incidents and malfunctions such as failure/ tripping of pumps, heat exchangers, malfunction of valves, control systems etc affecting the system performance by altering the normal operation have also been modeled in KALBR-SIM. The data necessary for modeling the components were derived from design documents, operation notes, isometric drawings and Plant Instrumentation Diagrams (PIDs). The system dynamics is tested for compliance with the actual plant dynamics by executing the models in an integrated fashion.

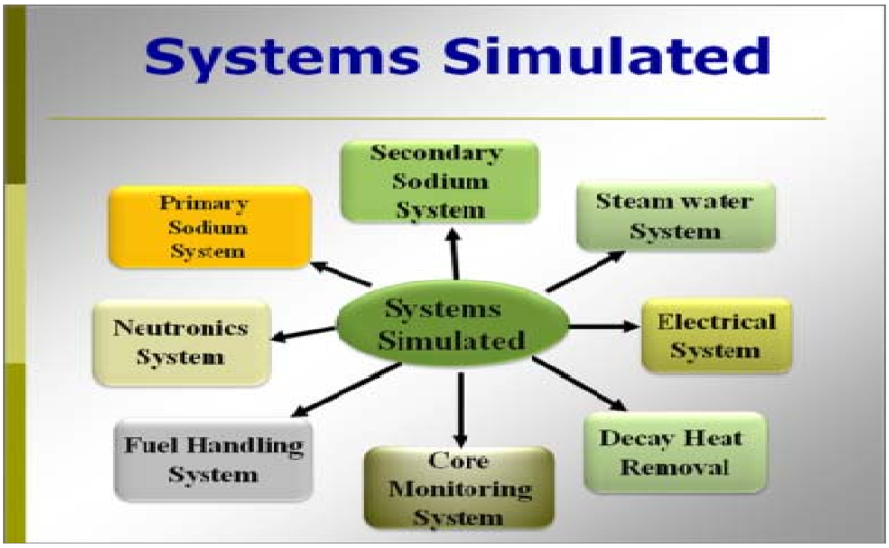

Fig. 4 Simulated Systems

VI. Verification and Validation of Simulated Models

All the developed models are subjected to the scrutiny of V&V expert team before rolling out the Training Simulator for the purpose for which it is built. This is the most important phase of the simulator life cycle. 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 in integrated mode under steady state and transient conditions (Fig. 5). Normally, verification and validation testing is done along with the system experts who

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

are basically system designers.

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. 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 recorded for further corrections, in discussion with the design for appropriate incorporation in the model (Fig. 6). Once again the models are subjected to V&V testing and subsequently the V & V reports are made ready for the systems that are accepted for implementation. In such cases, the models are subjected to V&V once again for compliance.

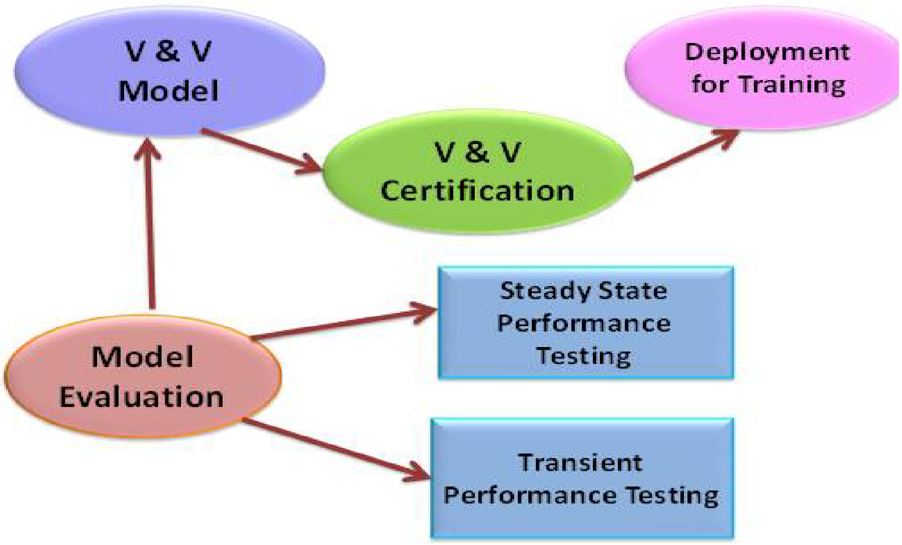

Fig. 5 Model Verification & Validation

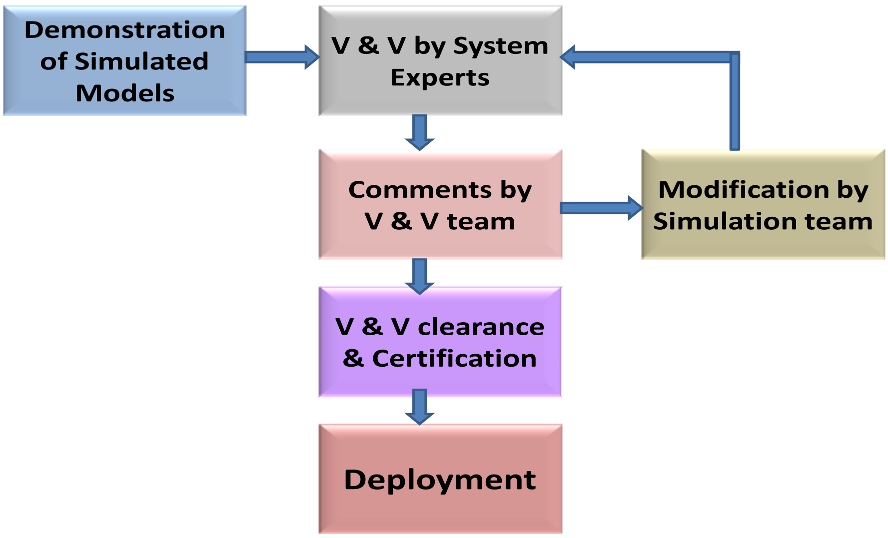

Fig. 6 Steps Involved in Verification & Validation

VII. V&V Approach Adopted for PFBR Simulator (KALBR-SIM)

The Verification and Validation approach adopted for PFBR Simulator is a combination of evaluation by the testing team and the Independent Verification and Validation team. Here, the Simulated Models are evaluated at every stage as a part of model development cycle [6].

In the very first stage itself, the models are evaluated by the development team to their satisfaction using verification and validation process. It includes, checking of resources from where the simulation data is collected, the usage of component data in configuring & building the models, the boundary conditions and assumptions made wherever data is not available, checking the performance of individual components, integrated components as per the design philosophy before passing on to the Independent Verification and Validation Team. The V&V team in turn checks the model correctness, accuracy and the model suitability for the intended purpose (Fig. 7).

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

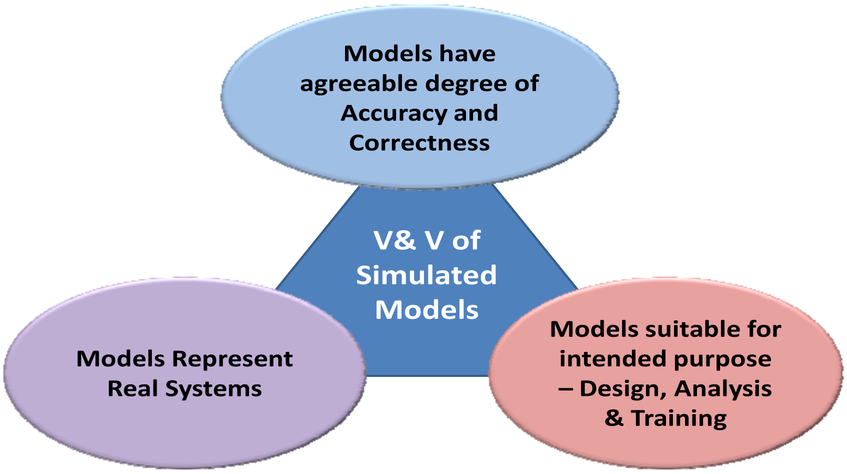

Fig. 7 Verification & Validation of Simulated Models

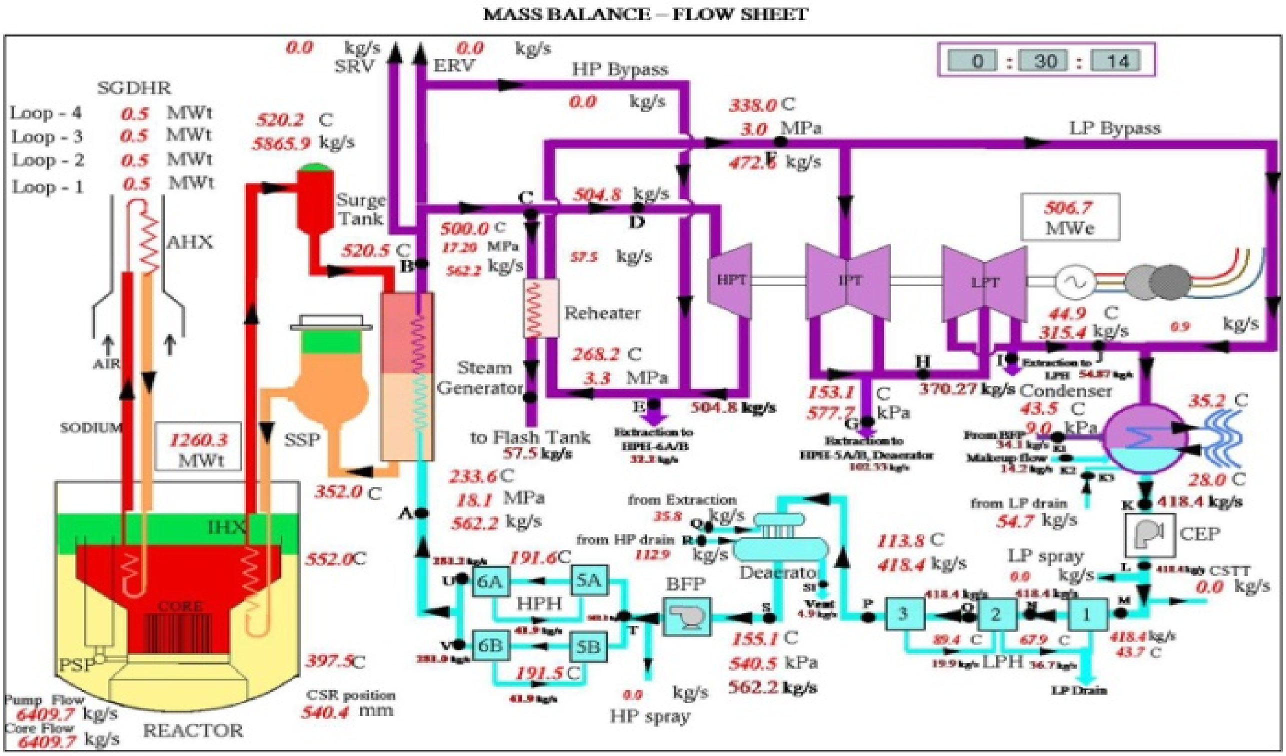

Fig. 8 PFBR Main Flow Sheet

A. V&V on Model Performance Testing

The Steady State performance testing is the primary level of qualification for the simulated process models to be accepted for incorporation in the training simulator. It is a process of meticulous checking of Mass and Thermal Balance of the simulated process network in the initial stage and the simulated process parameters of each and every component in detail in the subsequent stage. This includes various plant states like plant start up, full power raise, steady state and emergency conditions.

B. Steady State Performance Testing

Normally, the steady state performance testing is carried out as per the standards, minimum of two different power levels and preferably at power levels of 100% and 50%. For qualifying KALBR-SIM Training Simulator, the performance testing was checked for 100% and 60 % power levels. At the very first stage itself, the mass balance and thermal balance checking were carried out as a thumb rule for both the power levels as detailed below.

C. Mass Balance Checking

The mass balance is checked for the simulated process models running in integrated mode under full power, steady state condition. By applying the simple conservation of mass equation i.e. Mass in = Mass out, the mass balance of a circuit

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

is checked. Mainly, the input and the output parameters of each component in the process circuit were checked for conservation of mass. It was done by measuring the appropriate system parameters like flow and level. Wherever flow difference is observed, it will be crossed checked for any level difference, if a volumetric component is involved in the circuit, in order to compensate the mass difference.

The following flow sheet (Fig. 8) indicates steady state parameters at full power condition. The procedure applied for mass balance checking includes checking of flow at the inlet and the outlet of each component. Here, the mass balance checking is carried out for steam water system models.

The steam water system consists of number of sub-systems, namely main steam system, condensate extraction system, feed water system, turbine by-pass system, heater drain & vent system etc. The system comprises of major components like steam generator, turbine, governor, condenser, condenser extraction pumps, low pressure heaters, deaerator, boiler feed pumps, high pressure heaters, feed water flow controller etc. The condition shown below is for full power operation with the turbo-generator operating to producing 500 MWe power, two condenser extraction pumps and two boiler feed pumps running at full capacity to deliver the required flow and the low/high pressure heaters, the flow control stations and the steam generators fully functional. The points marked in the flow sheet indicate, check point for the simulated parameters for mass balance. The mass balance is checked by observing the flow parameters at the entry and exit of each component by applying the simple equation Mass in = Mass out. In case of components with volumes, the levels are taken into account for the mass calculation. The following example shows the mass balance checking carried out for steam water system components.

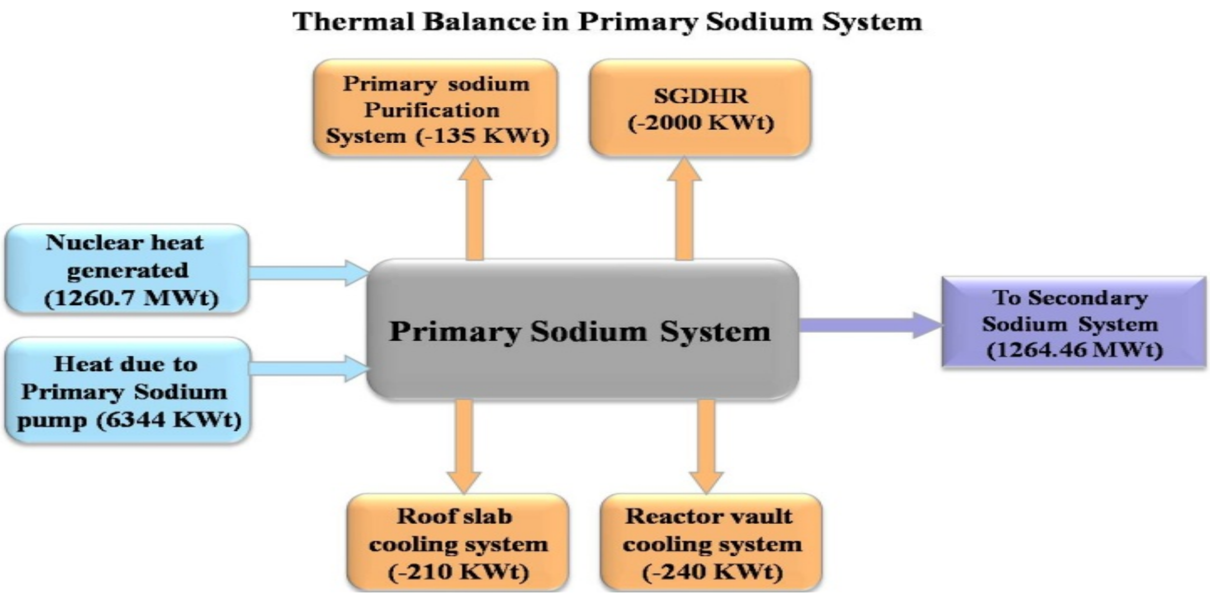

Fig. 9 Thermal Balance of Primary Sodium System

Mass Balance Calculation Based on the above Flow Sheet

- Flow rate at point A = Flow rate at point B
(562.2 kg/s) (562.2 kg/s)
- Flow rate at point B= Flow rate at point C + D
(562.2 kg/s) (57.5+504.8 kg/s = 562.3 kg/s)
- Flow rate at point D= Flow rate at point E + F
(504.8 kg/s) (32.2+472.6 kg/s = 504.8 kg/s)
- Flow rate at point F= Flow rate at point G + H
(472.6 kg/s) (102.33+370.27 kg/s = 472.6 kg/s)

Similarly up to point V it is calculated.

- Flow rate at point T= Flow rate at point U + V
(562.2 kg/s) (281.1 + 281.3 kg/s = 562.2 kg/s)
- Flow rate at point U + V = Flow rate at point A
(281.2 + 281.0 kg/s = 562.2 kg/s) (562.2 kg/s)

All the input sources and the out sources are taken into account which includes main flow, spray water flows, extraction flows, drain flows etc.

D. Thermal Balance Checking

Thermal balance here refers to the heat energy transported from the nuclear source to the adjoining process circuits. The heat generated in the nuclear core due to nuclear fission is carried away by the primary sodium flowing through the core in primary sodium circuit. The heat in turn is transferred to the secondary sodium flowing in the secondary sodium circuit. The secondary sodium gives away the heat to the water flowing through the steam generator tubes, producing high pressure super-heated steam. The steam produced in the steam generator is used to drive the Turbo Generator set to produce electricity. The unused steam is condensed in the condenser by cooling through sea water cooling system using condenser cooling water pumps. The calculations are as shown below and the thermal balance is carried out from Neutronics to Primary sodium system, Primary to Secondary sodium circuit (Fig. 9) and then from Secondary sodium circuit to steam water circuit.

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

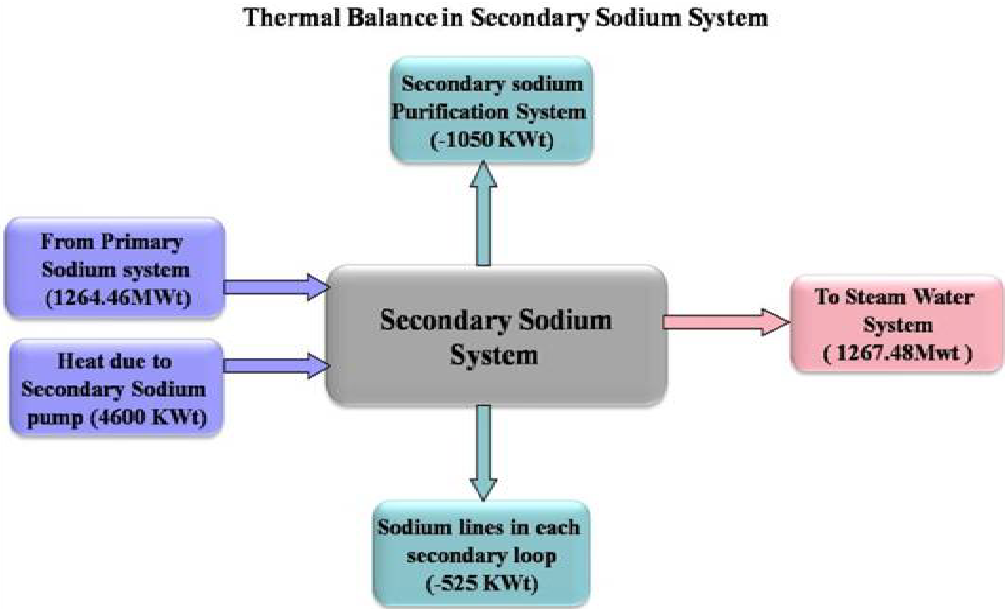

Fig. 10 Thermal Balance of Secondary Sodium System

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

The general formula adopted for calculating the thermal balance is as follows:

- Net heat gained in primary sodium system = Total Heat gained – Total Heat loss

The heat gain component for primary sodium system is calculated based on the flow and the pressure drop where as heat loss component is calculated based on mass flow rate, specific heat and the temperature difference of the medium.

- Heat Loss = M * Cp * ΔT
- Heat Gain = Q * ΔP

The diagram in Figs. 10 and 11 depicts the heat gain components which include Neutronic power and heat generated by primary sodium pumps 2 nos. The heat loss components include primary sodium purification system, safety grade heat removal system, roof slab cooling system and reactor vault cooling system. Similarly, the thermal balance is calculated for the secondary sodium system and steam water system.

- Net Heat in Steam Water System = Total Heat gained – Total Heat loss

The heat gain component includes, the total heat gained due to heat transfer from secondary sodium system through steam generator where as the heat loss component includes heat loss due to condenser cooling.

E. Steady State Parameter Checking

After conducting the mass balance and thermal balance testing, the steady state parameters are checked for compliance with the design data. The simulator is made to run for a minimum period of half an hour by loading the full power IC (initial Condition). The parameters are recorded only after ascertaining that the simulator has stabilized by observing the system profiles. The input and output parameters of each component in the simulated network are recorded and analyzed for stability. The parameters are checked and compared with the values obtained from the design documents and operating documents. The deviation between the simulated parameters and the design parameters are calculated to check the error levels and for compliance with the standard i.e. 1-2% error limit for critical parameters, 2 - 5 % error limit for normal system parameters. Neutronics system, primary and secondary sodium systems fall in the first category and steam water system and electrical system fall in the second category. Table I gives the details of parameter checking.

F. Recording of Test Results

The results are recorded by capturing the data electronically, during the performance testing. The profiles are plotted and hard copy of the profiles is taken with respect to time for further evaluation with the reference plant data. The data collection is done over a period in order to provide sufficient parametric time resolution to check the compliance with testing criteria. Essentially, the performance testing ensures that no noticeable difference exists between the simulated systems when evaluated with that of the reference unit. In the absence of plant data, design data is taken as the reference for evaluating the models in the initial stage. Table I indicates the data comparison between the simulated data and the design data.

Whenever the observed deviation is more than the limit specified, parameter tuning is carried out for the respective component in order to comply with the specified error limit.

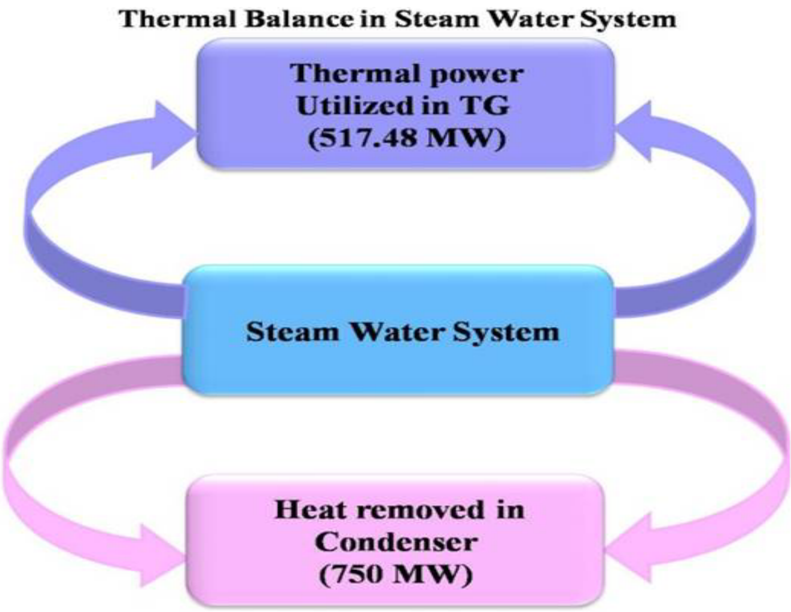

Fig. 11 Thermal Balance of Steam Water System

TABLE I
COMPARISON TABLE

Signal name	Unit	Design value	Simulated value
SG inlet - Pressure	MPa	18.1	18.16
Temperature	Deg C	235	235.95
Flow	kg/s	562	562.3
SG Outlet - Pressure	MPa	17.2	17.19
Temperature	Deg C	493	496.52
Enthalpy	kJ/kg	3257	3266.19
Flow	kg/s	562	562.3
LPT inlet - Pressure	MPa	0.6	0.58
Temperature	Deg C	166.9	162.5
Enthalpy	kJ/kg	2773	2749.24
Flow	kg/s	377	368.45
Condenser Pressure	MPa	0.0089	0.0086
Temperature	Deg C	45.5	45.06
Hot well level	m	2.155	2.1
Flow	kg/s	411.93	418
CEP Outlet Pressure	MPa	2	2.06
Temperature	Deg C	45.7	45.15
Flow	kg/s	411.93	418.42
Deaerator - Pressure	MPa	0.56	0.54
Temperature	Deg C	155.6	154.05
Flow	kg/s	562.6	562.3
Level	m	2.4	2.4

VIII. DESIGN DATA VS PLANT DATA

As per the prevailing conditions, the Nuclear Power Plant Training Simulator has to be commissioned much ahead of the commissioning of the actual plant. This is mainly to train and qualify the plant operators in advance for ready deployment. Hence, initially, for verification and validation purpose, the design data is used for checking the consistency under steady state and transient state. Once the plant is commissioned and made operational, the Training Simulator is validated with the plant data with the V& V carried out in integrated mode and a new version is released for training the operators.

IX. TRANSIENT TESTING

Transient testing is carried out to ensure that the dynamic performance of the simulated models comply with the reference plant performance as specified in the Plant Safety Analysis Report. Transient Simulation and Analysis is the most important phase in the integrated performance testing of a PFBR Operator Training Simulator [3]. Transient Analysis is performed as per ANSI 3.5 standard to analyze the dynamic behaviour of the simulated process models. The degree of accuracy of the models is checked before the deployment of the simulator. Here, the Event Analysis Report prepared by the design engineers forms the basis for evaluating the simulated models. Generally, under any transient condition, the design safety features incorporated in the plant will ensure that the plant reaches a new equilibrium i.e. safe state including low power operation or safe shut down state.

Normally, the Plant Safety Analysis Report is prepared and submitted by a team of design engineers to an Apex committee of Atomic Energy Regulatory Board (AERB) for getting the first level of clearance for going ahead with the programme.

X. BENCH MARK TRANSIENTS

In order to evaluate the models under various disturbed conditions of the plant, Bench Mark Transients (important plant transient conditions) are chosen, covering the total plant dynamics. The Events/Transients are selected in such a way that the plant behaviour under worst possible scenarios is evaluated for the models.

As per the design philosophy of PFBR, The Design Basis Events are classified into four main categories namely, Category-1- Normal events, Category-2 - Events with less severity, Category-3 Events with more severity and Category-4 Events with very high severity. Bench Mark transients are identified from all the four categories (Cat-1, Cat-2, Cat -3 and

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

Cat-4) for qualifying PFBR Operator Training Simulator meant for training the operators [2]. Transients/Events associated with each process are simulated in order to train the plant operators to handle the unusual occurrences in a more confident manner. The main motto behind building such training simulators is always to enhance the reflex of the operators thereby increasing their efficiency and ensuring plant safety and equipment availability.

Thus, the Bench Mark Transients include, events related to One Primary Pump Trip, One Secondary Pump Trip, One Primary Pump Seizure, One Boiler Feed Pump Trip, Both Boiler Feed Pump Trip, One Condensate pump Trip, Loss of Heating, Loss of feed water supply to Steam Generator etc. [2]. One of the Bench Mark transients qualifying the process simulator is described below.

A. One CEP Trip with Standby Not Taking over

Condensate system which is a part of Steam Water System consists of, Condenser, Condensate Extraction Pumps (CEPs) 3 Nos., Condensate polishing unit, Drain cooler, Low Pressure Heaters (LPHs), and Deaerator. The water quality is maintained by this system. Here, the Condensate Extraction Pumps are the major components that provide the required condensate flow to the deaerator. In PFBR, steam water system, 3 Nos. of CEP pumps with 50% capacity is used. Under normal operation two CEPs will be running, taking suction from the Condenser Hot well. The CEP discharge, flows through the LPH s of 3 Nos. connected in series for preheating the condensate water and finally enters Deaerator located at a higher elevation. When one of the running CEP pump trips, as per the system logics, the standby CEP pump is expected to take over.

In case the standby pump does not take over, the event is considered as a Cat-2 event. The incident subsequently reduces the condensate flow to the Deaerator to 60% while the Boiler Feed Pumps (2 Nos.) which takes suction from Deaerator continues to deliver 100% feed water flow to Steam generator. This will result in gradual decrease of condensate level in the deaerator and increase in condensate level in the Condenser and finally initiate Power Setback due to Deaerator Level Low (Figs. 12, 13). Power Setback is the state where the plant is made to run at reduced power level due to disturbance originated from the balance of plant. The following profiles indicate the CEP flow variation, Hot-well Level Variation, and Deaerator Level variation as a result of the incident.

Figs. 14 and 15 indicate the profiles captured on the occurrence of One boiler feed pump trip and both the boiler feed pump trip with standby not taking over.

XI. Verification and Validation Report

A Verification and Validation Report based on the demonstration made to the V&V team of experts is prepared by capturing the profiles relevant to each state (steady state / transient state) in line with the Plant Safety Analysis Report and submitted for approval by the V&V committee. On getting the approval, the next phase of work is started i.e. deployment.

XII. Deployment of PFBR Operator Training Simulator

The qualified simulation software is migrated to the training platform located at BHAVINI, Training Centre .The software is integrated with the simulator control room panels and tested for satisfactory performance. The total performance is evaluated once again by the V&V committee for required level of performance and finally cleared for training the plant operators.

XIII. Standards Followed

The standard followed for the development of Operator Training Simulator is ANSI 3.5 – 1998 i.e. American National Standard. It establishes the criteria for the degree of simulation, performance, and functional capability of the instrumentation and controls of the simulated control room.

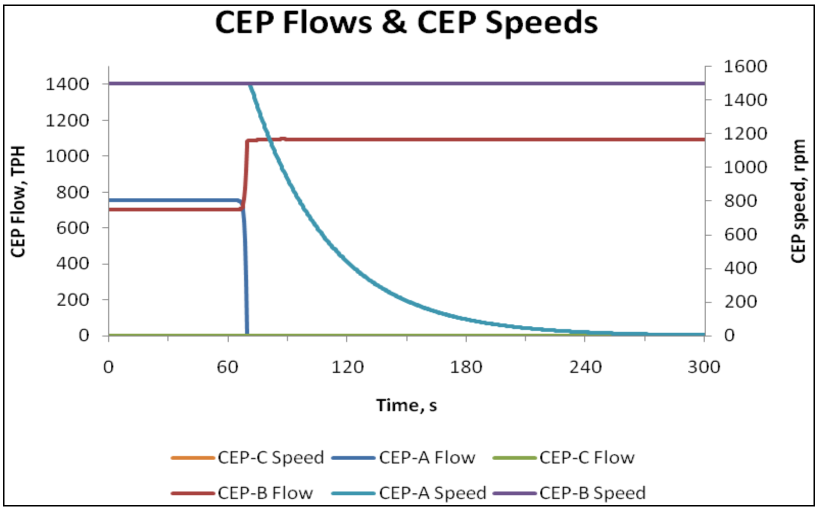

Fig. 12 Parametric Profiles of One CEP Trip Event

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

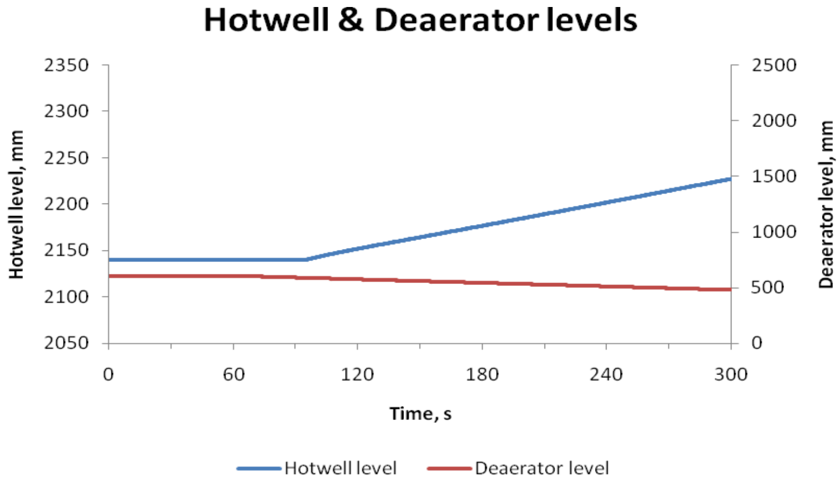

Fig. 13 Levels of Hotwell and Deaerator on One CEP Trip Event

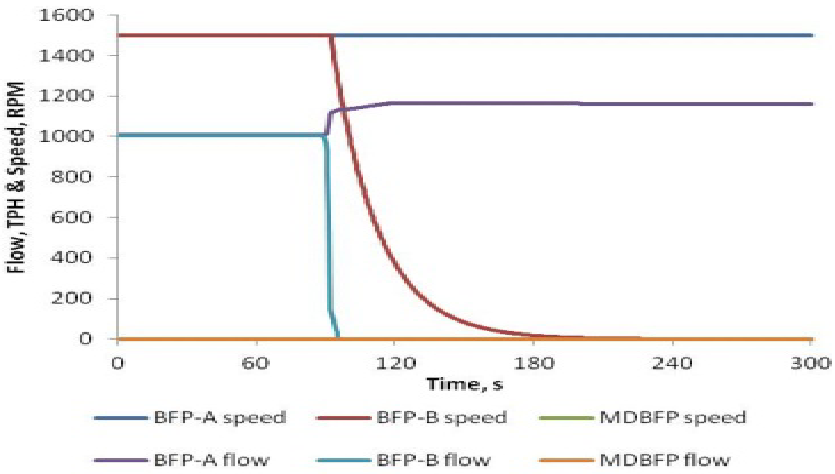

Fig. 14 Parametric Profiles of One BFP Trip Event

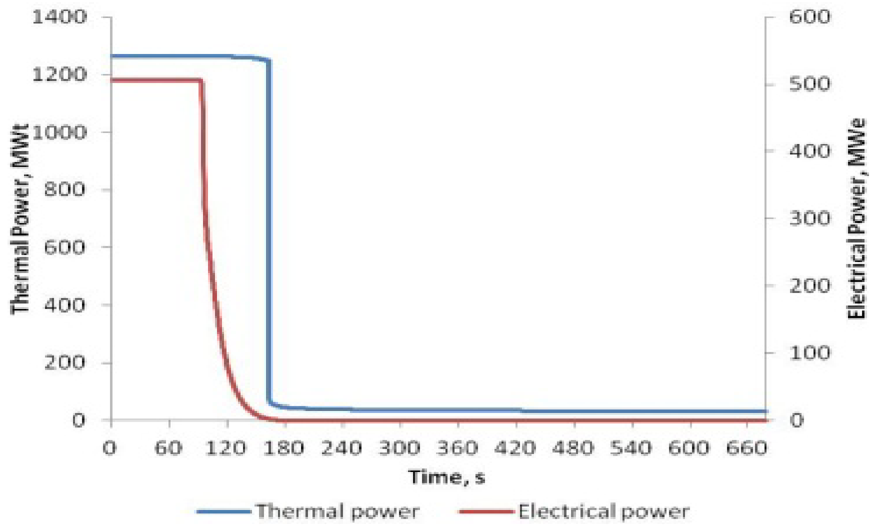

Fig. 15 Parametric Profiles of Both BFP Trip Event

XIV. Conclusion

The Real Time Operator Training Simulators play a key role in providing comprehensive training to the plant personnel. Human resource with enriched plant knowledge is considered to be an asset to Nuclear Power Industry. However, the safe operation of the plant is ensured by deploying

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

Open Science Index, Humanities and Social Sciences Vol:9, No:2, 2015 publications.waset.org/10000558.pdf

qualified operators possessing good understanding of plant dynamics. This is achieved by implementing an advanced training platform using Full Scope Replica Training Simulators covering various main system process models which are certified by an independent Verification and Validation committee of experts. The Verification and Validation process of a Real Time Operator Training Simulator is highly challenging and complicated process. Unlike the V&V process of a software, the qualification of a Plant Operator Training Simulator calls for checking of system dynamic performance in compliance with the reference unit. The V&V process ensures that the process models developed represent the real plant to an acceptable level of accuracy. This is highly essential as the operators are required to 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.

ACKNOWLEDGMENT

The authors gratefully acknowledge the support and guidance provided by the colleagues from Reactor Engineering Group. The authors are greatly indebted to the constant guidance & motivation provided by the Dr. S.A.V. Satya Murty, Group Director and Dr. Vasudeva Rao, Director, IGCAR.

REFERENCES

[1] Scope Document on PFBR Operator Training Simulator , PFBR/ 08610 / DN / 1000 /Rev A, (2003)
[2] Plant Safety Analysis Report, Chapter 14, PFBR Events Analysis Report
[3] T. Jayanthi, K.R.S.Narayanan, K.Natesan, L. Satish Kumar, Tanmay Vasal, P.Selvaraj, K.K.Kuriakose, S.A.V.Satyamurty ," Transient Simulation and Performance Analysis of KALBR Simulator for PFBR Operator Training" ,Proceedings of International Conference on Advances in Engineering and Technology, AETAEE, Elseveir-2013, 615-628.
[4] T. Jayanthi, H. Seetha, K.R.S. Narayanan, N. Jasmine, Rashmi Nawlakha, Bindu Sankar, Jaideep Chakraborty, S.A.V SatyaMurty, P. Swaminathan," Simulation and Integrated Testing of Process Models of PFBR Operator Training Simulator", *Asian Nuclear Prospects 2010 &Energy Procedia-7 (2011) 653-659 by Elsevier Publications.*
[5] N.Jasmine, H. Seetha, K.R.S. Narayanan, Rashmi Nawlakha, Bindu Sankar, Jaideep Chakra borthy,T. Jayanthi, S.A.V SatyaMurty, P. Swaminathan,"Simulation of Control Logics for Plant Transition State for PFBR Operator Training Simulator", Presented at ICRTIT-2011 held at MIT, Chennai and published in IEEE Xplore.
[6] Sargent, R. G. 1996," Verifying and Validating Simulation Models", Proc. of 1996 Winter Simulation Conf., pp.55–64.