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APPLICATION OF DYNAMIC SIMULATION FOR THE PULP AND PAPER INDUSTRY

ABSTRACT

In recent times, the pulp and paper manufacturing process has become so complicated that it has become increasingly difficult for process engineers and operators to keep up with the technology advancements. Limited raw materials, globalization and environmental concerns have all forced the decision makers to continuously look for smarter and more intelligent ways of operation. In an Indian context, diminishing quality of the feedstock and excess energy consumption per unit of product manufactured add another dimension to worry about. Apart from the reasons cited above, the knowledge and skill levels of the operation personnel are decreasing year by year.

All the trends mentioned above force us to continuously think of smarter and more structured ways in which we operate and perform our tasks. Performing a dynamic simulation of the complete project can be an effective tool to address all the concerns mentioned above. This paper discusses how a virtual plant developed using simulation techniques can be used for enhancing the product quality,predicting the control or process response, training a new generation of operators, transferring the knowledge of ageing and retiring work force, enhancing the troubleshooting skills and standardizing the operating procedures.

In addition, this paper also briefly describes how the simulation models can be used for designing and validating the control logic, predicting the interaction of all the equipment working together, and achieving a smooth start-up. Further, these models can be used to support operations by testing the effect of the process changes, including the process configuration or equipment changes and predict any unforeseen circumstances.

Keywords: Dynamic Simulation, Quality, Design Validation,Pulp and Paper, Operator Training Simulator (OTS)

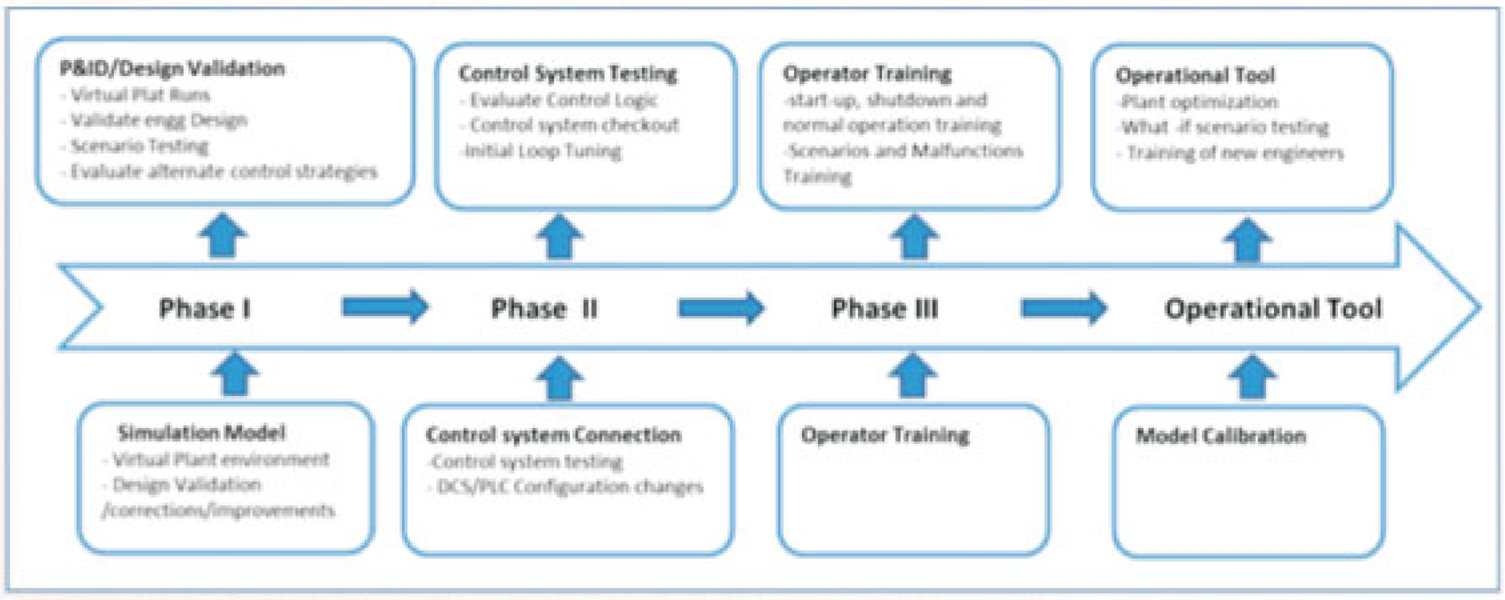
INTRODUCTION

The pulp and paper industry converts fibrous raw material into pulp after going through several steps in the manufacturing process. These steps comprise mainly of wood preparation, pulping (Chemical or Mechanical Pulping), bleaching, chemical recovery and papermaking.

In recent times, a number ofunit operations have been addedto the paper manufacturing process in the never-ending pursuit for getting higher efficiency and higher return on investment. As a result, the papermaking process and the process control philosophies are becoming more and more complex and integrated. In addition, in the Indian context, pulp and paper industry is struggling with many other issues like limited feedstock, global competition, excess energy and water consumption per unit of manufactured output, and various other environmental regulations.

All these factors make paper manufacturing a very challenging job for the operators and the process engineers alike.Any mistake or negligence in plant operation leads to asubstantial loss in productivity, efficiency and product quality.The new simulation-based training approach is a proven method for faster and efficient operator training, which will help tackle the challenges listed above. Such off-line training procedures and modules significantly improve the process and plant know-how leading to increase in production and operation efficiencies.

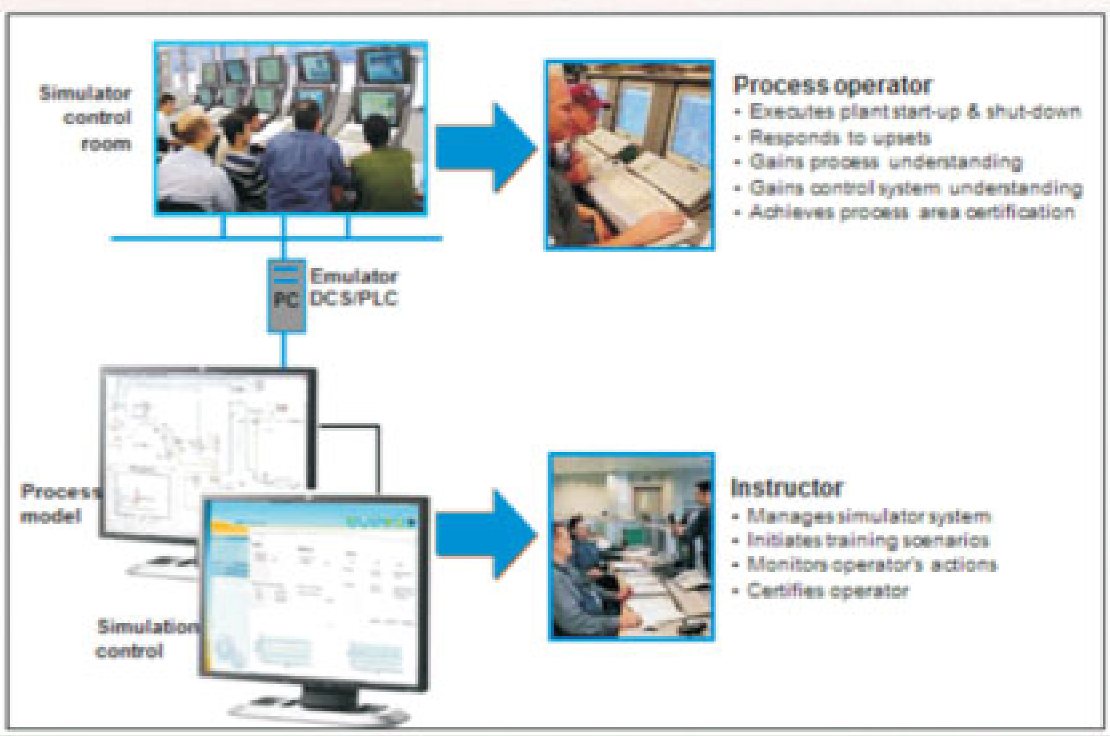
These high-fidelity simulation models can play a significant role during the entire project lifecycle - starting from process design verification, control logic checkout, and knowledge transfer from process experts to lesser experienced operators. Further, they can be used as a tool for decision-making, production planning and scheduling, predicting the process response under unforeseen circumstances, standardizing the operating procedures, etc. The simulator can also be used as a cross-training tool for the plant engineering, technical, and maintenance staff.The following diagram depicts the entire lifecycle of the process simulation models in a project.



TECHNICAL DETAIL

The Operator Training Simulator is essentially a virtual plant which offers a close-to-real-plant environment. It consists of process models which simulate the real process, and a DCS emulator which emulates the DCS database of the actual plant. It also has an Instructor, which provides a training module to preconfigure various tests for the operators and their performance assessment tools.

A simplified view of the overall architecture has been presented below:



The Simulator allows the plant DCS configuration to be loaded into the training system, so that operators will be trained using the same interface and control logic as the real plant. The operators can practice start-up, shut down and steady-state operation just as the real process operation.

The emulator sends the command to the simulator workstation and the changes in the process variables are reflected back on the operator screen.

The process variables like temperature, pressure, Kappa number, active alkali, density, etc.,are calculated by first principles-based mathematical models and pressure – flow solvers inside the simulator.

The entire process needs to be modeled using an integrated Pressure-Flow (PF) network in combination with mathematical models for each unit operation. The

PF solvers and dynamic simulation models are used for calculating the variables like pressures temperature, flow, etc., throughout the network at each time step of the simulation. In most of the process simulators, theseobjects fall under two main categories. The first class of objects isthe pressure objects for which pressure is calculated at each step of the simulation and then updated in the pressure – flow network as follows:

$$P_{k+1} = P_k + \Delta F_k \sum_{i=1}^{N} \frac{\partial Pi}{\partial Fi}$$

Where, $\frac{\partial Pi}{\partial Fi}$ = the partial derivative for the flow objects connected to the pressure objects

N = Number of flow objects connected to the pressure object

k = Number of iterations until the following flow continuity equation is satisfied

$$\left|\frac{\sum F_{in} - F_{out}}{\sum F_{in}}\right| < e$$

Where, e = maximum flow error allowed or specified in the pressure flow solver

The second class of objects is the flow objects. In this class of objects, the mass flow rate is calculated on the basis of the pressure difference across them and other object-specific parameters like pipe dimensions, fitting resistances, elevation difference, etc. Most of the blocks like pipes, valves, dampers, pumps, compressors, fans,blowers, etc.,are flow objects.

For this class of objects, object-specific equations are used to calculate the flow rates across them. For example, the flow rate through a centrifugal pump is governed by the following momentum balance equation with modifications, which takes into account the pressure change across the pump:

$$\frac{dF}{dt} = \frac{A}{L}\left(P_{up} - P_{down} - \rho gh + \Delta P_{pump}\right) - \frac{fL}{2\rho DA^2}|F|F - Fitting\_losses$$

Using the present day high capacity processors, it has become possible to simulate highly complicated processes, which emulate the correct process dynamics and give the operators a real feel of the plant control system. Models built using the first principles of momentum balance, mass balance, and heat balance enable a modeler to replicate the plant on a simulator with a very high level of accuracy.

The fidelity (low, medium and high) level and scope (full scope, reduced scope and generic simulator)of the process model has to be aligned with the end objective of the model development. The model fidelitymay vary based on the application of the process simulator.Some of the applications are listed below:

Operator Training Simulator : A high-fidelitysimulation model developed based on actual process configuration provides a life-like, dynamic response. Such a model provides accurate representation of the process and its associated process variables, incorporating detailed engineering data. The models then will be connected to the control system to create a virtual plant environment. In such a case, a model with ±3 % accuracy should be able to meet the training objective.

Process Design and Optimization Studies : Steady-state models can be used to perform heat and mass balance study of the complete process, feasibility and optimization studies and decision-making in the design phase. The dynamic models can further be used to validate that design.

Control System Validation and Testing : High fidelity simulator testing helps detect and correct control logic errors before the actual field implementation.For this to be accomplished, simulation models need to be developed and implementedbefore the actual commissioning of the process.

Logic Verification Feature	DCS Control Loop Test	Simulation Model
I/O and loop testing	√	√
Process wide logic testing	×	√
Tuning constants known before the start-up	×	√
Realistic process models	×	√√
Remove control logic errors	×	√√
Remove process intent errors	×	√√
Verify advanced control logic	×	√

As per statistics, more than 80 percent of logic errors can be identified and corrected using the simulator. This translates into a smoother plant start-up, lesser downtime and better control system, saving a lot of actual commissioning time and cost.

Process and Equipment Design Validation : If the purpose is to design the process and equipment, then we requirea very detailed and high-fidelity model describing all the physical means of the process. In such case, the model should be able to predict the process behaviors under different operating conditions. Theses predictive models help the engineers realize the process behavior before it is taken to the field and used to perform all kindsof testing, heat and mass balance, and control studies.

Generic Operator Training Simulator : If the need is to train the operators on how to run a plant and make them aware of the standard process control philosophies and interlocks, then generic pulp and paper simulators can be used effectively. These generic pulp and paper simulators are based on most commonly used control philosophies and have the control logics and interlocks incorporated in them. These models can be customized according to the varying needs of the different customers. The operator interface is prepared using some standard software and the process models run in the back ground. They can be used as an efficient tool for operator training for a running plant.

INSTRUCTOR STATION

The Instructor model of OTS enables to track individual operator performance and training management. The instructor station plays a vital role in operator training through various inbuilt features. Some of the most common features of Instructor are:

Synchronize the simulator station with the emulator : The Instructor station synchronizes the OTS station with the emulator station by performing various commands like Run, Freeze and Stop. Running from Instructor ensures that the simulation model and the emulator start simultaneously and are synchronized.

Snapshots : Snapshots are the running conditions of a process captured at any point of time. They are a very useful tool for operator training. The operator can save a snapshot at any point of time. By doing this, the standard properties of all the blocks, streams and equipment are stored in the computer memory. In the emulator station, all the properties like control variables, internal variables, and controller parameters are stored in the internal memory. Whenever the operator / trainer needsto take the process to that starting point, he can retrieve the snapshot, and all the properties are initiated by the values present at the time when the snapshot was taken.

Malfunctions or plant upsets : Malfunctions can be any abnormal condition or unforeseen situation that may arise during the normal operation of a process. Malfunctions form an important part of an operator training simulator and are instrumental in training the operators on how to react under such scenarios. Plant managers cannot wait for their operators to be trained on emergency situations by letting suchsituations arise in the plant. In a functional operator training simulator, as many malfunctions as per the requirement can be configured.

Malfunctions are programmed into the process models based on the standard inputs from the process experts and the experienced mill operators. They are initiated / triggered from the Instructor station, and the corrective actions from the operators are recorded by the trainer. Some of the commonly observed malfunctions in a pulp mill are mentioned below:

- Rapid leak into the furnace
- Steam drum level disturbance
- Drop in primary air fan pressure
- Low black liquor solids concentration
- Fall in green liquor density
- Emergency shutdown activated
- Safety relief valve malfunction

Grading and certifying operators : Instructor-led OTS can be used efficiently for training and certifying the inexperienced and eager-to-learn operators. Operators can be asked to take the start-up and shutdown of a process, and their performance can be monitored and recorded by the trainer. Malfunctions or abnormalities can be created by the trainer, and the operators will be asked to bring back the process to normalcy. Based on the operator action, they can be certified to operate the given process.

In the pulp and paper industry, high-fidelity simulation models could be developed for the following modules:

Cooking : High-fidelity simulation models can be developed for the cooking area, which mainly involves chip bin network, chip bin feeding system and digester network.

Fiber-line : Fiber-line area mainly consists of two main networks:brown-stock washing and bleaching. Simulation models can be developed for these networks which mainly comprise anO2 delignification network, screening network, white liquor oxidation network and different stages of the bleaching process.

Recovery area : Recovery area is the most complicated part of the paper manufacturing process. It mainly comprises therecovery boiler, power boiler, white liquor plant and evaporation plant. Using the present day simulators, it has been possible to simulate complicated steam / water networks, accurately predict the process response in complex pressure-flow networks, and simulate their interaction with the combustion air and flue gas networks. Models built based on first principles help greatly to train the operators on the boiler start-ups, shutdowns, making them confident to handle the process upsets and malfunction.

Ina white liquor plant, high-fidelity simulation models can be developed for green liquor network, lime slaking and causticizing network, and white liquor and lime mud filtration networks. Similarly, in an evaporation plant, using these models, it is very much possible to test the complicated start-up sequences that otherwise cannot be done easily by an emulator alone. These models can also be used to check other sequences like soot blowing system, checking the start-up, load burner logics, etc.

Paper-making area : Simulation models for this area can be used to test the complicated sequences and to train the operators on the pulp drying process.

Thus we see that fully functional simulator training allows the trainees and operators to get familiar with the process, the different units and their operations, functions and interactions with the control system. The simulation models can further be used by the process maintenance team to study the effects of any proposed process change. The detailed effects of any proposed process change or a change in process control philosophy can be studied even before they are implemented.

RESULTS AND CONCLUSION

It has been observed from successful implementation of high-fidelity dynamic simulators in pulp mills throughout the world that a simulation-based training program will provide the following benefits:

- Enhance operators' technical know-how and process expertise
- Speed up operators' training process and bring themon par with the experienced operators in much lesser time
- Improve operators' actions to any process upset and make themready to handle any unforeseen / emergency situations
- Smooth operation of the plant and lesser number of upsets
- Enhanced product quality and much lesserprocess downtime

The simulator investment is well worth when used in the early stages of a project, enabling significant cost and commissioning time savings as a result of the DCS logic check out and improves the possibility of reliable, safe and profitable operation through simulator-based operator training.A number of pulp mills all over the world are successfully and effectively using the simulators to train their operators and members of the plant engineering team.

Operator Training Feature	Not connected to the DCS	Simulator connected to the DCS
Operator Tracking	√	√
Training on Process	√	√
Operator Certification Possible	√	√
Exact Operator Screens	x	√
Exact Control Logic	x	√
Models Customized to Site	x	√
Train on Real Startup / Shutdown logic	x	√