# SIMULATOR

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## Contents

## Summary

The major components of a training simulator are discussed. With respect to configuration such simulators are classified as a full scale replica, computation only and combination of hardware/software. A simulator for an MSF plant is outlined with emphasis on start-up model and simulation. The role of CMPC is elaborated.

## 1. Training Simulator

The conventional methods of training plant operators are class instruction, operation manuals, and, finally, training on the job. With the advent of high-speed computers, innovative modelling techniques, and control systems, a more attractive alternative in the form of simulators has come to the fore in recent years. Training simulators of varying complexities have found considerable application in the process industry as well as in the power plants. A training simulator can be defined as a package of software and hardware components capable of simulating various sets of conditions. It offers the following advantages in comparison to conventional methods.

(a) Training can be arranged repeatedly and progressively.
(b) A single simulator can be equipped with instructor functions, field operator functions, and malfunctions and can provide training for start-up, shut-down, steady-state, and dynamic operations of the plant. Thus, it enables the user to learn about the ramifications of different scenarios in real-life situations and how to respond to them without ever disturbing the operation of the actual plant.

Training can be organized in anticipation of the building of a plant.

On the other hand, the high cost of developing the simulator can be used as an argument against its use. A full scope training simulator can cost as much as 1 per cent of the total capital cost of the plant. However, lower level training can be provided by simulating the process control system and using computer monitors for man-machine interfaces at a much lower cost, almost one-tenth of the maximum. On average, the cost is between 0.3 and 0.5 per cent of the total capital cost (Krause and Hassan 1995).

For the process industry, training simulators are extensively described by Gills et al. (1990), Leins and Eul (1991), Wolgast (1992), Reddy et al. (1993), Morgan et al. (1994), and Zeppenfeld and McCracken (1994) and for power plants by Zanobetti (1989). In some applications, expert systems have been incorporated to instruct trainees (Cordier and Guillermard 1990; Rumpel et al. 1992). For multistage flash (MSF) desalination plants, not much has been reported in this context; Kishi et al. (1987) described a training simulator almost a decade ago. Recently, a real-time training system for an MSF plant has been suggested by Yerrapragada (1995).

### 1.1. Simulator Structure

Basically, the simulator consists of four major constituents, each of them being a combination of certain hardware and software components. These are as follows: (a) system for process simulation, (b) process control system, (c) man-machine interface, and (d) instructor work station.

In turn, the process simulation system is comprised of the software components as under (a) process dynamic model, (b) system for data acquisition and processing, (c) internal and probably external databases, (d) auxiliary and supporting software, and (e) intertask communication.

#### 1.1.1. Dynamic Model

Although most large-scale plants, such as MSF desalination plants, operating continuously are supposed to be at steady-state conditions, any disturbances entering the process will make the situation dynamic. For that reason, the process has to be represented by a dynamic model. Thus, the material and energy balances of the process are expressed by a set of ordinary differential equations (ODE) with time as the independent variable. Obviously such a model is to be supported by auxiliary equations correlating the various physical and thermodynamic properties required, heat and mass transfer coefficients, control parameters, and characteristic data for valves, pumps, pipe fittings, ejectors, etc. The auxiliary equations are usually non-linear algebraic. A combination of both ODEs and algebraic equations is known as a system of differential algebraic equations (DAEs), which provide an analytical model of the process based on physical principles.

When it is difficult to formulate an analytical model, an alternative type of dynamic model, based on a black-box approach, is used. In this case, a model with unknown parameters is selected according to previous experience or through experiments. Then, the unknown parameters are determined experimentally by matching the actual process; the technique is known as identification and can be performed on-line or off-line. The model structure for identification can also be derived by linearizing the analytical model. However, the superiority of the analytical model over a black-box model in understanding the true process behavior is unquestionable.

Here, one has to differentiate between a dynamic model formulated for engineering purposes and the one meant for a training simulator. The former involves more details; therefore, it should be simplified under reasonable assumptions to suit the training purpose. The simulation time is always faster than the real-time needed by the plant and the training simulator should properly match it. For instance, in an MSF desalination plant the liquid holdups, being very large, respond slowly to any disturbances. Hence, the training simulator for such a plant should adequately represent the real-time behavior of the plant.

Dynamic models of the MSF process with brine recirculation have been reported by Glueck and Bradshaw (1970), Delene and Ball (1971), and Husain et al. (1992, 1994a, 1994b) and for the once-through process by Fukuri et al. (1988) and Rimawi et al. (1989); all of them were meant for the process analysis. Marquardt (1996) attempted dynamic modeling in terms of electrolyte thermodynamics. The sole attempt at a simplified model for a simulator was made by Kishi et al. (1987). Yokoyama et al. (1977) studied start-up characteristics of the MSF plant through a dynamic model. The model solution procedures involving DAEs are reviewed in section 8 (See: Dynamic Model).

### 1.1.2. Control Systems

A real process control, its emulation, or a combination of both can be used. The emulated control system will, of course, be represented by a model of the real system, which has all the important control features built into it. Moreover, the emulated system enables the implementation of different training functions like start-up, shut-down, restart, backtrack, etc. However, deviations between the actual process control system and the emulated one cannot be eliminated completely. For more complicated controls, the development cost of the emulated system could be very high and the system could become remunerative only when several applications are considered.

The incorporation of a real control system into the simulator will no doubt lead to more accurate process behavior simulation. However, it is difficult to restart the simulator since the control system has to be initialized every time a restart is made, which is not possible in the real control system.

Malfunctions in the plant must also be modeled, which requires extensive experience and systematic analysis to select major malfunctions. In addition, precise sequences and networks of events must be considered in order to diagnose malfunctions. The malfunctions that generally occur, including in an MSF plant, are as follows.

(a) Utility and supply failures: failure of seawater supply, of low pressure steam supply to ejectors, of cooling water, etc.

(b) Abnormal conditions in valves: fully closed or open, blocked.
(c) Abnormal conditions in pumps: output flow variation, failure of bearing lubrication, etc.
(d) Pipe and tank leakages: leakages from brine recirculation pump, storage tanks, etc.
(e) Product contamination: distillate contamination in the MSF plant or condensate contamination in the brine heater.
(f) Faulty measurement devices, transmitters, etc.

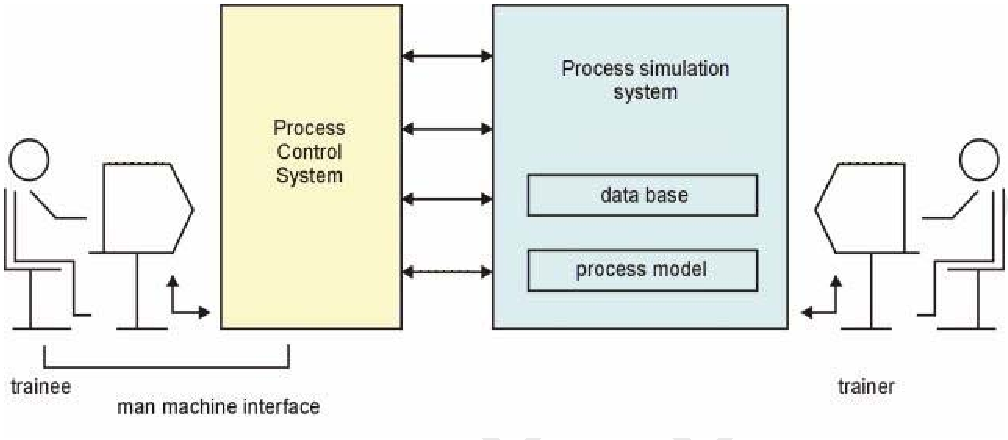

Figure 1. Hardware and software of a training simulator with a real process control system.

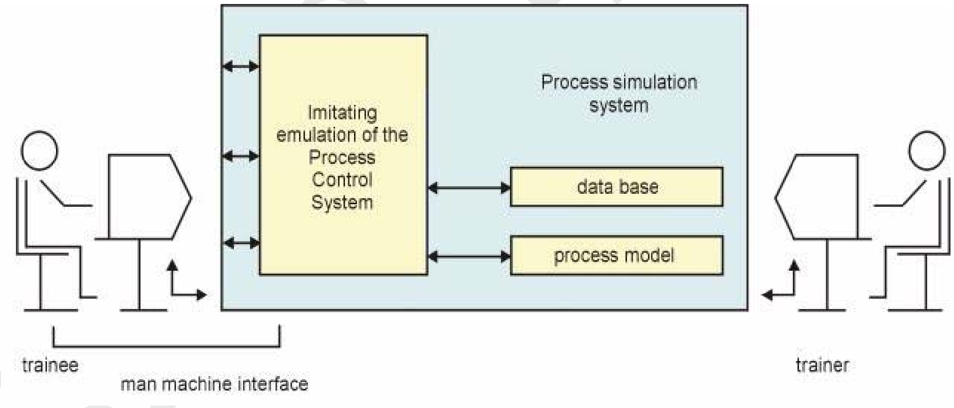

Figure 2. Hardware and software of a training simulator with an emulated process control system.

The overall configurations of the training simulator with the real and emulated process control systems are shown in Figures 1 and 2, respectively. The data acquisition system works in an assigned cycle for the collection of data which can be displayed, as desired, through the man-machine interface. The connection between the real process control system and the dynamic model is through a local database, which is also used for storing simulated cases as well as a history of simulations as a sequence of states. This database has to be real time-based and memory resident. In addition, an external database can be used. In real-time simulation, mailboxes and other intertask communication facilities are necessary. Input and output devices are provided between the computer, the real control system, and the man-machine interface.

Suitable logic models are developed to convert malfunction signals into alarm signals on the panel or workstation display. These can range from simple Boolean equations representing interlocks to the complicated real-time ones, which are model based. For example, in the MSF plant the cause of an interlock can be a disturbance or decrease in the recirculating brine flow to the brine heater, which can generate the necessary reaction by interrupting the steam supply to the unit.

### 1.1.3. Man-Machine Interface

The man-machine interface refers only to the trainee user interface, which can be built with different levels of sophistication. It belongs partially to the process control system, therefore it can be a real or emulated one. On the simpler side, the man-machine interface consists of a workstation equipped with a keyboard enabling the display of important data. In high level simulators the man-machine interface contains an operator panel; the trainees use the same keyboard, process graphics, and displays for the process control system as used in the actual plant. However, no hardware deviations will be applicable to the real operator panel; instead additional functions will manipulate the course of simulation. In between these two limits, there can be a large number of possible versions to include different hardware, special functions, etc.

The instructor is normally provided with a workstation with a facility for the display of the main signals.

## 1.2. Classification and Realization

The training simulators can be classified according to their main criteria, namely configuration, specific versus generic type and the level of details incorporated. With respect to configuration, they are classified as follows.

(a) Full scope replica: the exact representation of the real plant with a detailed and highly specific dynamic model with all necessary special functions included.
(b) Only computation: excluding any hardware similar to that used in the actual plant, the process control system is emulated by software. The user interfaces, both for the trainees and trainer, are executed by graphical monitors.
(c) Hardware/Software: combinations of the first two types.

A specific simulator is developed for a specific plant, including the features and design of a process control system as fixed in the plant design. On the other hand, multiplant simulators are developed to simulate a process without considering the specific details.

The final criterion for classification is the amount of detail included such as the number of malfunctions, special functions, etc.

A training simulator can be developed in two parallel multi-step activities, as shown in Figure 3. Activity 1 is mainly concerned with a feasibility study since the simulator scope, its learning effect, and user friendliness should first be evaluated in order to determine the hardware:software ratio and to calculate the cost. In this phase, it is ascertained whether the simulator would offer sufficient benefit and return in relation to its cost. The process control system is then emulated. Malfunctions, emergency cases, alarms, and interlocks are also identified and considered in the emulation scheme.

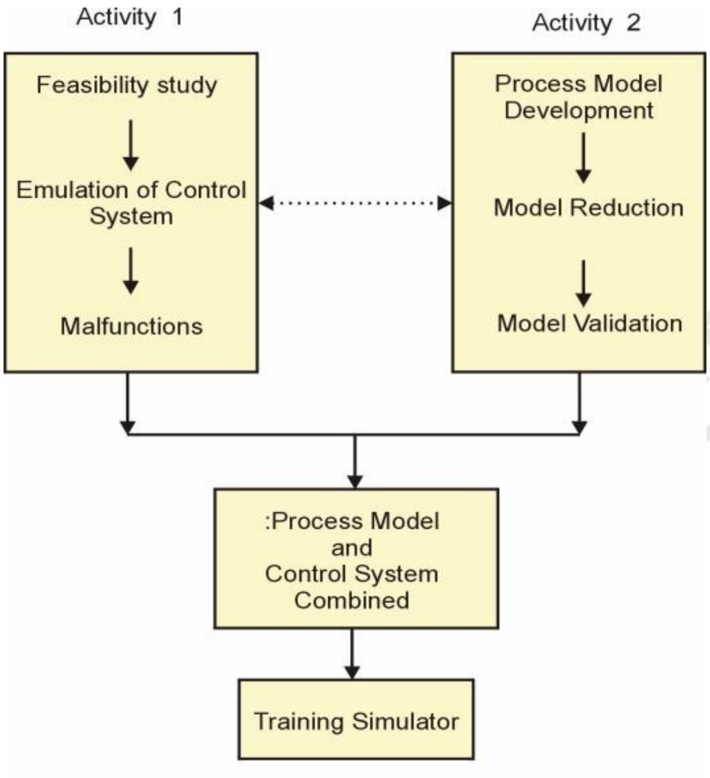

Figure 3. Steps in developing a training simulator.

In parallel activity 2, the process model is developed, reduced by making reasonable assumptions and possible linearization and it is validated against available plant data; if the plant for which the simulator is being developed is not under operation, data from a similar plant can be used for model validation. Figure 3 shows that activities 1 and 2 have to interact with each other, since in making the final decision, information about the dynamic model would be needed particularly about the run time and the real-time features. In that way, the selection process has to be iterative until a satisfactory result is obtained in order to make an investment decision. Ultimately, the combination of the reduced model and the emulated control system will lead to the simulator.

Special functions and a time scale are required to perform the training sessions in a reasonable amount of time. These functions can have a pedagogic impact by intensifying the learning effect. The main requirements for such functions are outlined below.

(a) Speeding up the simulation for certain process steps such as the filling of an MSF plant, load changes, etc.

(b) Similarly, slowing down the simulation to follow the changes in the parameter values for a detailed analysis.
(c) Possibility to start, stop, freeze, restart, and terminate the simulation.
(d) Repetition of complicated operations.
(e) Snapshooting, i.e. saving a simulation state without stopping the simulation.
(f) Periodic storage of simulation results.
(g) Stepwise backtracking.
(h) Option of introducing a malfunction by the trainer.

### 1.3. Training Strategy

In order to derive the maximum benefit from a simulator, the training program should be organized in well-thought-out steps of increasing complexity such as those suggested below.

(a) The trainees should first gain an understanding of the process structure, measurements available, and the effect of various parameters on the production and process efficiencies.
(b) Familiarity with the functions of the operator panel and man-machine interface.
(c) Handling the control system for the steady-state operation of a continuous process.
(d) Managing start-up, shut-down, and load change in the plant.
(e) Handling malfunctions and emergency situations such as utility failure, product quality deterioration, trouble shooting for failure in pumps, valves, etc.

The man-machine interface can be used by the trainees (a) for routine monitoring on the condition of the plant at any time, (b) to change setpoint values in the controllers, and (c) to react to alarm signals, malfunction messages, change of process parameters, etc., in considering and rectifying equipment failures.

The training is an interactive process between the trainees and the instructor, who should mutually act and react with a high degree of understanding between each other. Then the training scheme can be run in the following steps.

(a) Specify data for a steady-state performance simulation:
(i) Dimensional details.
(ii) Mode of operation: summer or winter.
(iii) Seawater: flow rate, temperature, and salt concentration.
(iv) Recycle and make-up flow rates.
(v) Top brine temperature (TBT) desired.
(vi) Steam conditions: temperature and pressure.

The steady-state model will provide the following output.
(i) Various temperature, concentration, and pressure profiles.
(ii) Distillate production rate.
(iii) Steam supply rate and performance ratio (PR).
(iv) Blowdown rate and concentration.

The above output will serve as initial conditions for the dynamic model.

(b) Introduce any load change (e.g. in seawater flow rate), disturbance (in the steam supply), or change in the setpoint value (e.g. TBT). The dynamic model will calculate new profiles and indicate how the production rate, PR, and brine levels are affected.

(c) Introduce time-dependent changes such as an increase in the fouling factor in the evaporator tubes or brine heater and study the effect on heat transfer.

(d) Insert malfunctions and fault conditions, enter and generate alarm signals, etc.

## 2. Simulator for an MSF Plant

The simulator for a typical MSF plant comprises the following.

(a) A steady-state model of the process.
(b) A dynamic model of the process including the conventional control system.
(c) A start-up model of the plant.
(d) An integrated simulator in the real-time dynamic simulation environment.
(e) Real-time implementation including advanced control strategies such as the constrained model predictive control (CMPC).

The steady-state and dynamic process models based on physical principles are described in detail in section (MSF Steady-State Model and MSF Dynamic Model) respectively. The next three items are dealt with in the following sections.

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## Biographical Sketch

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He taught at the Technical Faculty of the University of Indonesia at Bandung (1952 -1959) and at the Delhi Polytechnic, Delhi University (1959 – 1961). Then he joined as the Research Scientist in the Regional Research Laboratory (now known as IICT) in his hometown Hyderabad – India, a constituent of the Council of Scientific and Industrial Research (CSIR – Delhi).

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