# *EPRI Compact Simulator Technology for Operator Training and Control System Engineering*

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# EPRI COMPACT SIMULATOR TECHNOLOGY FOR OPERATOR TRAINING AND CONTROL SYSTEM ENGINEERING

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## ABSTRACT

Faced with more sophisticated power generation technology, expanding environmental regulation, and increasing competition, utilities are seeking ways of making best use of their existing generation assets. EPRI compact simulator technology provides many opportunities to do just this, as more than a dozen utilities have already discovered. Applying simulators to power plant control system engineering can reduce capital costs, shorten commissioning time, and lesson the risk of equipment damage. Application to operator training can improve plant availability, reduce fuel costs, extend component life, and enable operation closer to environmental limits. Compact simulator technology can provide these benefits by virtue of its effectiveness, flexibility, and timely use of various technologies to lower cost and enhance capabilities.

## INTRODUCTION

As computer and control system technologies progress and plants age, fossil plant operators are presented with new operating complexities and higher performance expectations. Many utilities are striving to meet these new demands through extensive programs of modernization for their existing fossil stations. A major portion of these modernization programs consists of replacing older pneumatic and analog hard panel control systems with new state-of-the-art distributed control systems (DCS). This wholesale changeout results in dramatic differences in the control room layout and the operators "feel" for controlling the power plant, while the new technology provides the capability for more complex control logic and increased plant automation.

Safe, efficient operation of a power plant following a control system replacement requires that control room operators be knowledgeable of the power plant and control philosophy, experienced with the unit response to control actions, and confident in their expertise. In the past, this knowledge, confidence, and expertise was developed primarily through on-the-job training with some classroom education. Although the knowledge of the plant systems will remain, the control philosophy and unit response will change significantly following the control system replacements. Therefore, the operator's confidence has to be re-established. Given the continual change in computerized control technology and the demands for efficient, reliable generation in the new competitive utility environment, on-the-job training would not meet most utilities needs, even if it were an effective training method.

In addition, new control systems require substantial debugging, modification, and fine-tuning as the plants are being brought back on-line following the replacement outage. Control logic errors not only prolong the commissioning time and expose the unit to damage, but the frequent trips erode the operator's confidence in the new systems. Therefore, in any modernization program, utilities should consider use of simulation technologies that provide realistic, plant-specific operator training and a platform for control system debugging and fine-tuning.

## COMPACT SIMULATOR TECHNOLOGY

For the past several years, the Electric Power Research Institute (EPRI), has been involved in a research initiative to enhance and expand the use of simulators in the fossil generation industry. This effort has resulted in software tools, display systems, and interface technologies that allow fossil plant simulators to be developed and operated on a network of personal computers (PCs) or workstations. In addition, the use of digital controls and computer-based operator interfaces eliminates the need to duplicate large control panels for a realistic simulation environment. Therefore, fossil plant simulators can now be designed to operate on as little as a single PC. Hence, the term "compact simulator".

EPRI's compact simulator technology provides low cost, high-fidelity simulators for operator training and control system engineering. It is composed of a real-time, unit-specific dynamic simulation, emulated or actual operator display screens, emulated or actual control hardware and software, vendor specific keyboards, and a full set of instructor functions. In addition to providing a training tool upon which the trainee sees the same screens, pushes the same keys, and experiences the same dynamics as would be experienced in the actual control room, the simulation includes the scope and fidelity to allow detailed engineering analysis and control system studies.

Compact simulators in use today are more effective than past simulators due to their fidelity, unit specific modeling, and wide scope. The realism and accuracy stems from the dynamic simulation--the transient thermal-hydraulics model that predicts the dynamic behavior of plant processes and control systems. Using first principle models formulated from mass, energy, and momentum balances, compact simulators can simulate plant conditions from "cold metal" to 100% load. This fidelity is a key element in the simulators applicability to control system engineering and testing. In addition, rather than hand crafting a model of each power plant component, compact simulator technology allows simulation system designers to draw from libraries of existing component models and tailor them to the specific plant. Using this object-oriented approach, utilities can build models more quickly, with less labor, and at lower cost, using point-and-shoot techniques with a mouse.

Compact simulator technology has been applied to simulators with several different configurations. Any of the simulator configurations would utilize a network of PCs or workstations to run a simulation executive and a model-based simulation that provides an accurate, plant-specific process representation in both steady-state and dynamic operation. As model complexity increases, additional PCs or workstations can be added to the network to provide real-time response, or calculational speeds five to ten times faster than real-time.

The control system and operator interface can either be emulated using simulation programming and graphic display software, or the actual control system hardware and software can be interfaced to the process simulation. If the unit being simulated has hard panel manual/auto stations, panels can be fabricated and interfaced to the simulator, or the hard panels can be emulated using graphic software programs. The emulated hard panels provide substantial benefit over the older style hard panel simulators in that they can be easily modified to account for changes in the actual plant control room.

A more complete description of the compact simulator technology is available in a paper entitled "EPRI Compact Simulator Technology--An Update" (4).

## OPERATOR TRAINING

An operator needs to be trained on the process cycle, the control system philosophy, and the control room layout, prior to taking control of the unit. The process cycle and control system philosophy can be effectively learned through classroom instruction and plant walkdowns. However, as distributed control systems are being implemented, the control room layout and required operator functions are changing dramatically. With the existing control systems and panels, experienced operators knew exactly where to look for necessary system indications during steady-state or transient operation, where to find the right handles and switches to make unit adjustments, and how to properly manipulate the controls. Now, with 20 feet of familiar hard panels being completely replaced by several 20 inch CRTs, even seasoned operators will initially be very uncomfortable operating an otherwise familiar unit. In addition, the new digital controls perform many functions automatically that used to require manual interaction. Therefore, the operator must become comfortable simply monitoring and supervising the control system rather than manually controlling the plant. This new operating knowledge needs to be developed in a cost-effective manner that minimizes the probability of personnel injury and equipment damage during the learning process.

Operator training on high-fidelity simulators has been shown to be a very effective method for training new operators and helping seasoned operators make a smooth transition from hard panel control to computer-based "soft" control operations. However, even though research has indicated that 20 to 25 percent of all forced outages are the direct result of operator or maintenance errors, it was estimated from an informal survey in the late 1980s that fewer than 10 percent of all fossil plant operators had received any simulator-based training. This was attributed to the high cost of replica simulators ($5 - $10 million). Most utilities could not justify such an expense to enhance their fossil plant operator training programs.

EPRI's compact simulator technology offers extensive capability and flexibility for training fossil-fuel power plant operators, at a fraction of the cost of the traditional replica simulator. Application of this technology results in operators who are more knowledgeable and less prone to error. As a result, plant performance improves and O&M costs decrease. Documented benefits have included improved thermal performance, increased availability, extended component life, and enhanced environmental compliance. Also, given the flexibility provided by EPRI's compact simulator, one simulator can provide similar benefits to several unique operating units, further increasing the return on investment.

## ENGINEERING APPLICATIONS

Utility engineers can use compact simulators to design new control systems or modify existing ones. The capability of *simulating* complete control systems at very low cost or *stimulating* complete control systems before they are commissioned provides a powerful engineering tool for verifying, testing, debugging, and pretuning control systems. This allows utilities to substantially reduce capital costs, shorten commissioning time, and lessen the risk of equipment damage. Also, utilities will be making more use of simulators as research test beds to develop, test, and demonstrate control room technologies, such as advanced control schemes, automation systems, and knowledge-based systems.

Although engineering benefits can be obtained from any compact simulator configuration, a "stimulated" system has the most direct application to designing, developing, debugging, and fine-tuning a new control system. In the stimulated system, the plant process simulation is interfaced to a duplicate set of plant control hardware. Therefore, the exact same control software can be used in both the actual plant and on the simulator. Once the control logic and operator screens are validated and tuned on the simulator, they can be readily moved to the plant control system, without additional modification.

Stimulation of actual control system hardware requires that the process models include some representation for every input and output (I/O) variable included in the control system. To this end, the compact simulator process models represent all major and most auxiliary systems in the plant, including electrical and lube oil systems. Some of the less critical support systems can be modeled using a less complex approach, but, again, each I/O must be represented.

Actual interface to the control hardware has been accomplished in variety of ways. For example, Duke power company developed a mobile simulator, based on EPRI's compact simulator technology, as an engineering test-bed to design, debug, and tune replacement control systems. Duke's simulator is configured with process model running on PC platforms interfaced to a full Westinghouse WDPF control system. The data interface was accomplished by implementing a system that allowed the simulation PCs to communicate with the control system through a memory-mapped, high speed parallel interface. Memory mapping permits the PC to directly address the control processor memory as though it were local memory within the PC. Communication between the two systems can then be accomplished through random access memory reads and writes. Since the control system I/O is received from and sent to the process simulation, there is no need for I/O cards. However, the control logic residing on the control processors can be moved without modification from the simulator to the plant and visa-versa.

Using the mobile simulator at a plant that had been operating with computer-based controls for several years, persisting control system problems were identified and corrected and control and operating procedure modifications were validated. For example, simulator engineers were having difficulty maintaining the heater drain tank level in certain operating regions when running the plant simulation. Discussions with unit operators confirmed that the problem also occurred in the actual plant. Modifications were made to the heater drain tank control valve tuning parameters and tested on the simulator throughout the unit's operating range, and the verified control system modification was recommended to the station. In addition, the simulator was used to test a new approach for controlling the HP and LP generator exciters. Control modifications were developed and tested on the simulator, and control room operators were able to work with the new control approach and provide feedback prior to plant implementation. Using the simulator to perform these functions avoided unit startup costs, variable load testing (removing the unit from dispatch control), and equipment and startup problems associated with control logic errors.

On another Duke unit, the mobile simulator was used to design, debug, and fine-tune the control logic prior to implementation in the actual plant. In addition, the simulator was used to expose the unit operators to the new control system and changes in unit operation and response through a detailed, simulator-based training program. A primary goal was to obtain reasonable DCS tuning values on the simulator to reduce the time spent on control checkout and tuning on the actual unit before it could be reliably returned to service. The unit was put back on-line substantially ahead of schedule and the initial startup was accomplished without a single operator error. A sister unit was upgraded the following year using the same approach. This unit was also returned to service ahead of schedule, and it maintained an unheard of 100 percent availability for the first few months immediately following the control system upgrade outage.

At another utility that used compact simulator technology in support of a control system upgrade, problems were identified in the delivered control logic that resulted in the forced draft fans tripping when the unit reached full load. Using the simulator, the same scenario was run several times prior to identifying the exact problem and correcting the control logic. The simulator was then used to ensure that the modified control logic did not have any negative impact in other areas of operation. Given the extensive amount of data that is available on the simulator for debugging this type of problem, which is not readily available in the actual plant, it was projected that, without the simulator, the unit would have tripped from full load in excess of six times prior to identifying the problem in the control logic.

Slightly different approaches have been used to interface to other control systems. However, a primary focus in all cases has been to allow the control software to be readily moved between the simulator and the plant. In every application, control problems have been identified and corrected on the simulator prior to implementation in the plant. These problems have ranged from something as simple as I/O discrepancies and operator displays improperly interfaced to plant data to improperly configured safety logic.

## OTHER ENGINEERING TOOLS

Although the stimulated systems offer the most straight forward approach to control system engineering, their application is limited to a site where the duplicate control hardware is located. To further extend application of the simulator, the control logic must be emulated in a simulation language that can be run on the same platform as the process simulation. Developing the control functionality through direct simulation programming can be time consuming and complex. Further, manual development of the control logic can result in inaccuracies due to human error.

To make control logic emulation more cost effective and accurate, EPRI has developed control logic translators for several control systems. These translators convert the control logic configuration software from the actual plant control system into a functionally equivalent program that can be run on the simulation system. This direct translation not only reduces the cost of producing an emulation of the control logic, but it also eliminates the opportunity for human error in its development. Translators for DCS displays have also been developed such that a fully simulated system (complete simulation of the process, control logic and operator interface) can be readily produced for operator training and control system engineering without the need for duplicate control hardware. In addition to easing simulator initial cost, these translators save utilities money when changes to the simulator are necessary to reflect control system changes.

Although the fully simulated systems may not reproduce all of the "bells and whistles" of the control system or the operator interface, they still provide a very effective tool for control system engineering and analysis. Where the control logic is running on the same platform as the process simulation, a control engineer has more direct control of the system operation and input variables. For example, the engineer could prepare an input file that repeatedly ran the same dynamic analysis using an array of different control tuning parameters. The analysis could be run in a batch mode with no need for operator interaction, then the results reviewed at the completion of the run to identify the optimum configuration. Further, a fully simulated system can be used simultaneously at different locations with a minimal hardware requirement.

EPRI has also produced a computer program, the Cycling Advisor, which a utility can use in conjunction with the compact simulator technology for the quantitative evaluation of startup procedures and plant modifications for cycling operation. This evaluation involves the use of a performance index referred to as a cost function. The cost function determines the dollar value of life expended for various components in the plant due to a particular operation and combines those costs with the direct costs of fuel, auxiliary steam, and generation error to get a total cost of the operation. This allows a direct quantitative comparison of one operating procedure with another, or one plant modification with another to obtain the optimum approach for transient operation.

## PROJECTED BENEFITS

There are substantial savings in capital cost when simulators are used for operator training and to design, verify, test, and pre-tune control systems. Simulator-trained operators can reduce the number of operator preventable trips, increase thermal efficiency, and operate closer to environmental limits. Simulator-based control system engineering can significantly reduce startup time and reduce the chance of equipment damage. On the basis of experience from the Host Utility Group, several weeks of expensive startup time can be eliminated by control system shakedown using a compact simulator. In fact, many compact simulator projects have resulted in a complete return on the capital investment of the simulator development within weeks of starting a unit with a new distributed control system.

For example, in 1991, Duke Power Company estimated that use of their mobile simulator for training operators at 18 units would result in a savings of $76 million over a period of 15 years (8). These savings were primarily attributed to reduced operator-preventable trips and quicker startups. Later, Duke estimated that use of the simulator for control system engineering would reduce outages by four weeks for the first unit to which it was applied, and two weeks for each sister unit. This engineering use of the simulator for control system replacements at 15 units is expected to result in additional savings in excess of $100 million over a seven year period (9).

Consolidated Edison used a compact simulator to verify a new control system design for its Waterside Station, pretune the system for optimal performance, and train operators on the new control system--all before startup of the new control system. Benefits of the simulator include reduced commissioning schedule, improved thermal efficiency, avoided trips, earlier restart, faster recovery from trips, and fewer life-shortening cycles. Through improved control system design and better operator performance, Con Edison expects to save an estimated $3 million at Waterside Station. The results of this project are expected to be applicable to about a dozen other units on the Con Edison system, with expected additional savings of $41 million (6).

Illinois Power Company used compact simulator technology to train operators and validate control system software prior to installation of a new control system at Hennepin unit 2. The high-fidelity process simulation is interfaced to actual control-system operator consoles, so the operators see the same process graphics and experience the same dynamics as they will in the control room. The utility estimates savings of $1,439,000 over the next 15 years attributable to avoided trips, faster startups, increased unit efficiency, and reduced auxiliary loads. Illinois Power expects an additional savings of $3,574,000 from simulator-based controls engineering that will shorten control-system commissioning time and reduce annual outages and low-load testing of control modifications (7).

## FURTHER TECHNOLOGY DEVELOPMENT

EPRI is continuing to develop new tools and technologies to further reduce the cost, expand the scope, and increase the flexibility of compact simulators.

Advanced display technology and hard panel emulation are key areas of EPRI focus for enhancing compact simulators. While many fossil power plants are being upgraded to soft control system interfaces, a large number of plants with hard panel interfaces will continue to operate into the next century. Physical replication of hard panels is very expensive and will continue to be so, however, visual replication has proven to be less expensive and more flexible. In the recent past, visual replication has been accomplished using single or ganged CRTs with touch screens or pointing devices. While this approach has been effective, the dollars-per-square-foot of display hardware is high. Therefore, it is still prohibitively expensive to purchase enough hardware to display an entire hard panel control system. This results in a limited portion of the panel being displayed at any one time and the use of panning and zooming techniques to view other sections of the panel which reduces realism.

In response, EPRI has recently developed and delivered a rear projection system with touch-sensitive screens to provide visual replication of the control board. Projected images are developed by digitizing photographs of the panel and interfacing the dynamic portions of the panel instruments (e.g., needles on gauges, alarm lights, etc.) to variables within the process simulation. This technology substantially lowers the per-square-foot price of display hardware making it affordable to visually replicate the entire control board, thus increasing the realism of the simulator. Visual replication of hard panels also increases the simulator's flexibility in that it allows one set of simulator hardware to represent several units.

Advanced display and hard panel technology also show great potential for use in the control rooms of the future. From a human factors standpoint, advanced displays provide advantages over CRTs, including a wider simultaneous view of plant controls. The instrumentation displayed can be redesigned via a programming change, rather than a hardware replacement--opening the door to use of new ways of representing controls.

Another area of EPRI focus, and perhaps the most significant advancement in simulator instructor functions, is the development of an intelligent tutoring system (ITS). The ITS applies expert system techniques to capture instructor expertise and provides this expertise as an extension to the simulator. Using the ITS, operators can receive training even when instructors are unavailable, enabling them to train during "dead time". By supplementing a utility's limited ability to schedule instructors, the ITS has been shown to enhance the already substantial benefits of compact simulators by as much as 25%.

## CONCLUSION

A significant breakthrough for utilities, compact simulator technology has reduced the cost of replica simulators by a factor of five to ten. The compact simulator has found application across the spectrum of control system suppliers and over a wide range of plant designs, including pulverized coal, fluidized-bed, and combined-cycle units. EPRI has demonstrated that use of these simulators for operator training and controls engineering analyses can result in substantial savings. The Institute's efforts to expand and enhance the use of simulators in the fossil industry, while reducing simulator cost, make this technology readily accessible to all member utilities.

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