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Development of Modern Power Plant Simulators for a Operators Training Center

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Abstract—**The change of the human machine interface from hard panel to personal computers in power plants nowadays, demands a modernization of the training simulators, so the trainees can utilize a suitable operation interface during their training. To accomplish this goal, a new hardware-software platform based on personal computers with Windows XP was developed. This platform was customized to update two hard panel simulators of fossil-fuel units. Additionally, the same platform was utilized to develop a new simulator for a coal-fired unit, and to expand a gas turbine power plant to a combined cycle power plant. The main feature of the platform is that its human machine interface is based on interactive process diagrams, so the operators of modern power plants can practice in a similar interface like they have in their actual plant. All of these simulators are installed in a training center for operators and have been tested and validated by qualified instructors. Currently the simulators are utilized as a part of the training courses for power plants operators.**

Index Terms— **power plant simulator, operators training.**

I. Introduction

One of the most important parts of the training programs of power plant operators is carried out through simulators, a big number of these simulators are of the type called full-scope. Full-scope simulators incorporate detailed modeling of those systems of the referenced plant with which the operator interacts in the actual control room environment. Usually, replica control room operating consoles are included [1]. In these simulators, the responses of the simulated unit are identical in time and indication to the responses received in the actual plant control room under similar conditions. A significant portion of the expense encountered with this type of simulator is the high fidelity simulation software that must be developed to drive it. The completeness of training using a full-scope simulator is much greater than that available on other simulator types since the operator is performing in an environment that is identical to that of the control room. Experienced operators can be effectively retrained on these simulators because the variety of conditions, malfunctions, and situations offered do not cause the operator to become bored with the training or to learn it by rote [2].

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In recent years the power increase of computers, their reliability and variety of graphical interfaces, added to the continued search to cut costs caused a new technological trend. In this trend, the power plants have replaced their former control boards with a local area network of personal computers (PCs) with graphical user interfaces [3]. In this way, new or modernized power plants have a human machine interface (HMI), where all the supervising and operation actions are carried out through interactive processes diagrams and another auxiliary functions as graphical trends and alarm displays are also included. Naturally, the operators of these plants need a suitable training because they face a complete change in their operation paradigm, and because of this, the training simulators also require HMIs as the ones in the actual plants.

The Ixtapantongo National Training Center for Operators (CNCAOI) of the Mexican Federal Commission of Electricity (CFE) is devoted to train fossil-fuel power plant operators in order to satisfy the CFE requirements of highly qualified operation personnel; to accomplish this goal, the CNCAOI has: simulators based on control boards, classroom simulators, portable simulators, and recently as a consequence of the new HMIs of the power plants, the CNCAOI updated and built simulators in accordance with their current training demands. The main requirements for these simulators were: 1) The simulators must have modern hardware-software platform. 2) The HMI of simulators must be suitable for operator training in modern power plants. 3) The simulators must be full-scope.

This paper deals with the main features of a hardware-software platform developed to upgrade two fossil-fuel power plant simulators, to build a coal-fired power plant simulator, and to expand a gas turbine power plant to a combined cycle power plant.

II. Simulator Architecture

As one of the aims of the project is to have a simulator with a modern hardware-software platform, and based on the computing power and low cost of personal computers, their selection as a computer platform offers great advantages. Regarding the operating system, Windows XP was selected based on aspects of: portability, ease of coding and available software to develop graphical interfaces.

A. Hardware Architecture

The computer platform consists of at least three PCs interconnected through a Fast Ethernet local area network (a typical configuration has five). Each PC has one processor, 1 GB memory and Windows XP operating system. Fig. 1 shows a diagram of this architecture. In this Figure, the IC station is an instructor console with two 19” monitors; OC1 and OC2 are the operator consoles, each one with two 19” monitors and one 50” monitor. The operator can use any one of the OC1 and OC2 to observe and control any process of the power plant. Additionally, and depending on the selected configuration, the simulator can include a station to supervise the boiler flames and customized digital displays, and a maintenance station, which serves as a backup if the IC is out of service, or as a test station. This means that any software modification is tested and validated in this station before any change can be made in the simulator.

B. Software Architecture

The required features for the new simulators involved the development of original simulation software (instructor console, IHM, executive real time). The mathematical models of the upgraded simulators were migrated to the new platform, and the mathematical models for the coal-fired and the combined cycle simulators were fully developed. The software architecture of the simulation environment has three main parts - the real time executive, the operator module and the instructor console module [4]. Fig. 2 shows the general structure of the software architecture. Each one of these modules can be hosted on a different PC, and they are connected through the TCP/IP protocol. All the modules of the simulation environment are programmed in C#, while the electrical and processes mathematical models are programmed in Fortran. In the case of the control models they are programmed according to the simulator, the updated simulators have their models in Fortran, and the new ones have their models programmed in C#.

A brief description of each module is shown in the following paragraphs.

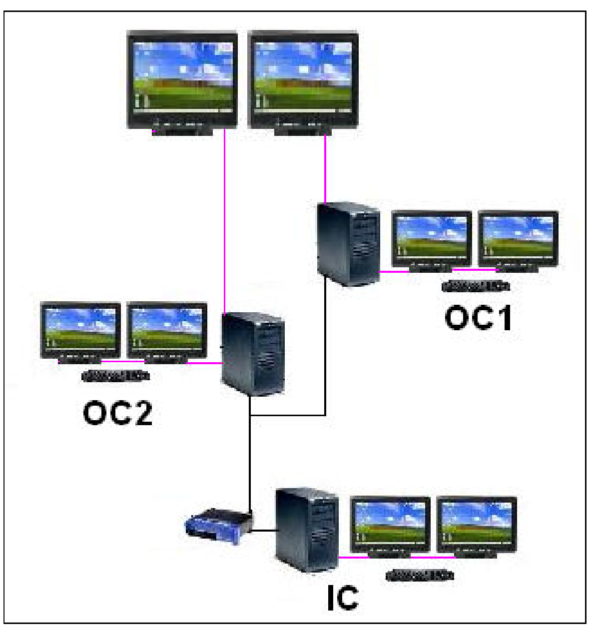

Figure 1. Hardware Architecture

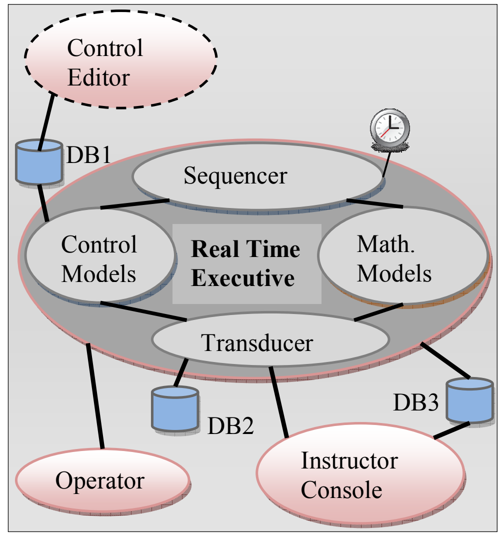

Figure 2. Software Architecture

1) Executive real time: The executive real time module coordinates all simulation functions and its main parts are: a) the mathematical model launcher; b) the manager module for interactive process diagrams; c) the manager module for the global area of mathematical models; d) the manager module for the instructor console; e) data base drivers.

2) Sequencer. This is in charge of sequencing in real time all the functions which require a cycling execution, these are: mathematical models, control models and another additional functions like historical trends.

3) Mathematical models. Almost all these models are formulated on the basis of lumped parameters (one exception is the modeling of the warming and cooling processes of the turbine metals). The mathematical models include electrics and process areas. In the first group are the models of electric generator and electric grid, their mathematical formulation is based on Park theory and Kirchof’s law, the main variables calculated for these models are: power generation; turbine-generator speed and power plant voltages. The process models consist of the water cycle and its auxiliary services, their main components are: boiler; combustion process, main and reheated steam; turbine; main condenser and feedwater system (naturally, the water cycle and its services are specifics of each one of the simulators); all these models are formulated on the basis of momentum, heat and mass conservation principles. To customize the models to the actual power plant, each one of the equipment (tanks, valves, pumps, fans, heat exchangers, etc.), are characterized with design information and operation data.

4) Control models: They simulate the digital and analog control loops of the actual plant. The digital loops deal with all the required conditions to turn on/off any equipment like: pumps, fans, valves. On the other hand, the analog control is devoted to maintain process variables (pressures, temperatures, etc.) in pre-set values. Examples of the major control loops simulated are: boiler level, main steam temperature and combustion control. In the case of the coal-fired power plant simulator, and the combined cycle power plant, the control models are integrated through the dynamic assembly of predesigned components, in the case of

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the other two simulators the controls were translated from their original computer platform.

5) Transducer: This module adapts the flow information between the mathematical models and control models.

6) Operator: The operator module is in charge of the operator HMIs and manages the information flow with the executive system. The HMI consists of interactive process diagrams, which are Flash movies; the Flash movies have static and dynamic parts. The static part is constituted by a drawing of a particular flow diagram whereas the dynamic part is configured with graphic components stored in a library which are related to each one of the plant's equipment, e.g., pumps, valves, motors, etc. These components have their own properties and which are established during the simulation.

7) Instructor console: This module is the instructor HMI and consists of five parts: a) a main module for carrying out all the tasks related to the graphical interface of the instructor; b) a module to retrieve the static information of the simulation session, e.g., malfunctions, internal parameters, etc; c) a module to store information in a data base using SQL; d) a module to dynamically update the instructor console with the simulation information; e) a module to communicate the instructor console with the executive real time.

8) Control editor: This module provides a graphical interface to model modern control systems. In these systems, the control algorithms are organized in basic components with a very specific function (PID, Set/Reset, Dead Band, Limiters, etc), and they are represented through a hierarchical components network. This module is required only when it is necessary to develop new control models, like the coal-fired power plant simulator and the combined cycle power plant, in the case of the other two simulators this module was not utilized because their controls were migrated from their original computer platform

C. The Human Machine Interfaces

With the continuing progress in recent years of personal computer technology, graphical user interfaces have become an indispensable tool in day-to-day business, these interfaces thanks to their multi-window environment provide an easy-to-understand and easy-to-use HMI to power plant operators [5].

A typical training session with a simulator is guided by a qualified instructor of the CNCAOI, the instructor is in charge of establishing the initial condition and directing the simulation session of the trainees. In each one of the simulators, the HMI instructor is only executed at the IC. This HMI is a windows-friendly application with pull-down menus and icons, as it is shown in Fig. 3. The main functions of the IC are: Run/Freeze, Initial Conditions, Malfunctions, Local Actions, Automatic Training Exercises, and Time Scale, additionally, and as a part of its IHM, the instructor can visualize the same interactive process diagrams as the operator does.

On the other hand, the HMI trainee (operator) is also completely graphical and based on a multi-window environment with interactive process diagrams, these diagrams are organized in hierarchical levels following the organization of the power plant systems, i.e. boiler, turbine,

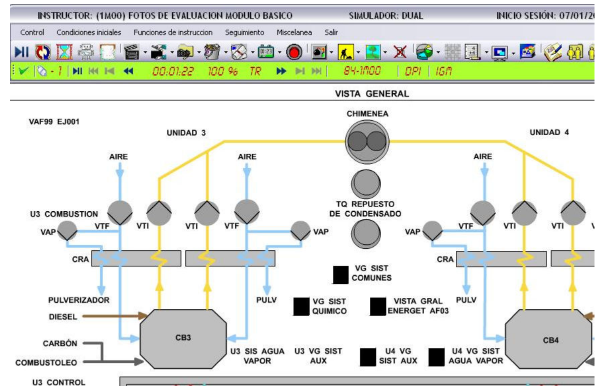

Figure 3. IHM instructor

electric generator, etc. There are two main types of diagrams: information diagrams and operation diagrams. The first ones show values of the selected variables by the operator, or a predefined set of variables. The values are presented as bar or trend graphs. The operator utilizes the operation diagrams to control and observe the whole process, with them, he can: turn pumps, fans and compressors on/off; open/close valves; modify set points of automatic controls and carry out any feasible operation in a similar way as he would do in the actual power plant. When the operator needs to perform an action, he selects the suitable pictogram with the cursor, and then a pop-up window appears with the corresponding operation buttons. This window can be moved anywhere on the screen or it can even be shifted among any monitor in the four screen station. At any one time the operator can open all the pictograms he wants, and can do this in any operation console.

In the operation diagrams, the operator easily visualizes the off-service equipment because it is shown in white and the equipment on-service has a specific color depending on its working fluid. To this end, green equipment handles water, blue equipment handles air, red equipment handles steam, and so on. The main features of these diagrams are very similar for each one of the simulators, but there are some differences due to the customization carried out for each one of them as a result of the CFE requirements.

III. The Simulators

The upgraded fossil-fuel simulators correspond to fossil-fuel power plants of 300-MW (Fig. 4) and 350-MW (Fig. 5). The first one handles 1879 communication signals between the control boards and the mathematical models, and the second one has 4539 signals. The big difference is that this simulator has a distributed control system, which is completely simulated. Each one of the control board simulators were hosted in a Compaq Work Stations with UNIX Tru64 operating system. The 300-MW simulator had three control boards and the 350-MW simulator had five control boards. These boards are connected to their corresponding Work Station through an input/output system based on RTP controllers.

As such, the majority of the mathematical models of each one of these simulators based on control boards were utilized

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to integrate two new simulators on PCs with Windows XP as the operating system. Therefore these simulators instead of control boards, have a completely redesigned hardware-software platform and IHM interface. The tasks carried out to upgrade each one of these simulators can be summarized as:

• Migrating the mathematical models (process and control). These models are written in Fortran.

• Migrating the databases (models, instructor console, input/output signals, etc).

• Customizing the simulation environment to the particular features of each simulator.

• Designing and developing of the interactive process diagrams.

• Integrating all simulator components and to validate its behavior, instruction functions and real time operation.

Additionally, in the case of the 300-MW simulator, the mathematical models of turbine and control turbine were replaced by models with a wider scope [6]. Fig. 6 shows the hardware architecture for the new 300-MW simulator, the architecture utilized for the other simulators is very similar.

The coal-fired simulator has as reference a 350-MW power plant and, therefore, this simulator and the fossil-fuel simulator of 350-MW have some similar systems, in this way the tasks carried out to build this simulator can be summarized as:

Figure 4. 300-MW control board simulator

Figure 5. 350-MW control board simulator

• Developing the mathematical models related with the coal systems (process and control).

• Adapting the current mathematical models of the 350-MW simulator to the requirements of the coal-fired simulator

• Adapting the databases of the 350MW simulator to the requirements of the coal-fired simulator

• Designing and developing of the interactive process diagrams.

• Integrating of all simulator components and to validate its behavior, instruction functions and real time operation.

The combined cycle power plant simulator has a reference a 450-MW power plant, and it has as a starting point a 150-MW Gas Turbine Full Scope Simulator [7], therefore the main activities developed to integrate the combined cycle simulator were:

• Developing the mathematical models (process and control) related to:

- Steam turbine
- Heat Recovery Steam Generator (HRSG)
- Process auxiliary systems (feedwater, lubrication oil, etc).
- Electric systems (main generator and electric grid)

• Integrating the former gas turbine model with the HRSG

• Developing the databases required for the combined cycle power plant simulator.

• Designing and developing of the interactive process diagrams.

• Integrating of all simulator components and to validate its behavior, instruction functions and real time operation.

For each one of the simulators, the design of the Interactive Process Diagrams (IPD) was very important because they are the operators' interface when they are being trained in the simulator, therefore, such design was done having as a guide the actual process diagram of the reference power plant, so the simulator diagrams have a similar appearance to the actual diagrams, and this enhances the training quality.

Fig. 7 shows a partial view of an IPD for the 300-MW simulator, this Figure shows two pop-up windows which are opened by trainee request to carry out the operation action required. With these windows the trainee can operate the same devices like he usually does in the actual plant e.g. open/close valves, modify set points of automatic controls, etc.

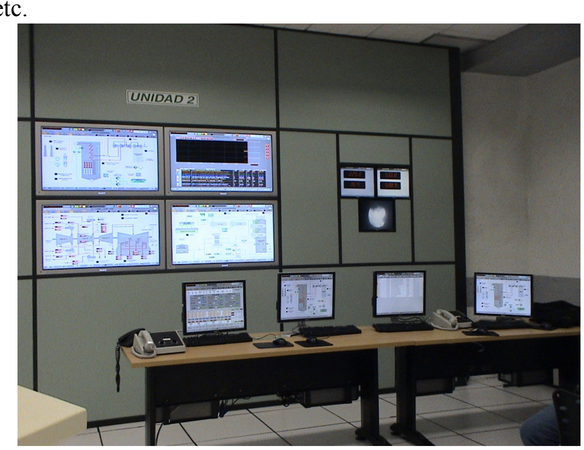

Figure 6. Updated Simulator

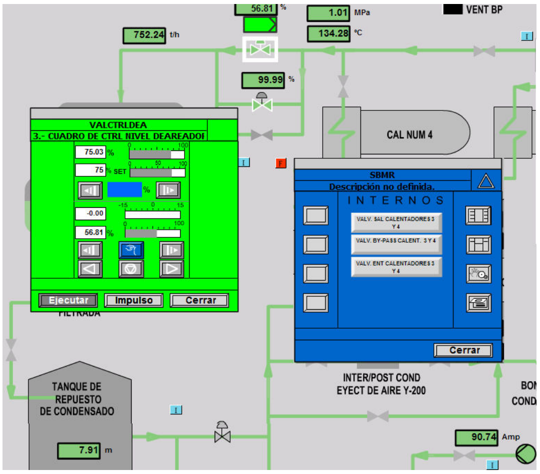

Figure 7. Feed water diagram

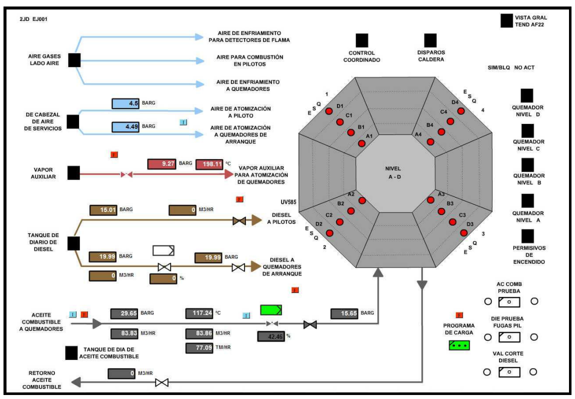

Figure 8. Combustion diagram

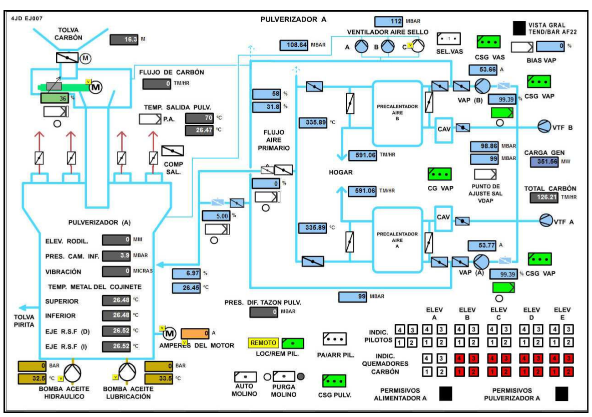

Figure 9. Coal diagram

Fig. 8 and Fig. 9 show one IPD for the 350-MW and coal-fired simulators, respectively. The look of the IPDs for these three simulators is very similar due to the CFE specifications.

Fig. 10 shows a partial view of an IPD for the combined cycle simulator, in this case the look of the diagram is different to the other simulators, but it keeps the concept of pop-up windows as operation tool.

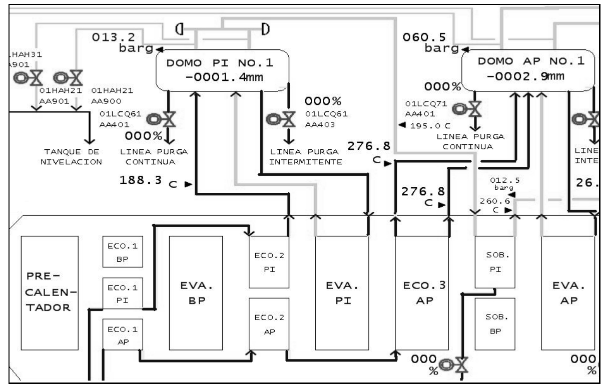

Figure 10. HRSG diagram

IV. Results

In order to test and validate the right operation of each simulator, its hardware and software were exhaustively tested; the tests were carried out by qualified CNCAOI personnel with technical support of the Electric Research Institute (IIE). In brief, these tests were:

- Carrying out a complete installation of all the software required.
- Verifying the right communication among the stations of the local area network.
- Validating each one of the functions of the instructor console and the functioning of the operator HMI, according to the expected effects.
- Carrying out availability tests with no aborts in any simulator task.
- Operative tests from cold iron to full-load generation, shutdown operations and malfunctions.

Once all the tests were finished for each one of the simulators, they began its operation as part of the training courses for power plants operators of the CFE.

V. Conclusions

A methodology to integrate new simulators for operators' training has been successfully tested with four different cases. Because of its computer platform based on PCs and Windows XP operating system, it is expected that these simulators will have fewer operative and maintenance costs, compared to control board simulators.

The simulators keep their full-scope and their real time features, and provide HMIs suitable for modern power plant operators, where they no longer use control boards. Additionally, the CNCAOI instructors have a user-friendly HMI, with all the required functions for leading and tracking the training sessions.

The hardware-software architecture described in this paper was customized to the requirements of particular projects, but the simulation environment is flexible enough to be adapted to a stand-alone simulator, a multi-session simulator or any other simulator.

Finally, and according to the CNCAOI instructors' experience, the main challenge for the simulator users (operators) is the cultural change, because now operators have to utilize a modern tool like a PC instead of a control board, and therefore the operators must forget their former operation habits and adopt novel operation techniques for a fluent and safe navigation in a different IHM.

VI. Future Work

As a complement to the available simulators at the CNCAOI, currently, new self-training tools are under development, so the operators will be able to practice on site.

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