A Full Scope Nuclear Power Plant Training Simulator: Design and Implementation Experiences

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ABSTRACT

This paper describes the development of a full scope training simulator for a Spanish nuclear power plant. The simulator is based on a client/server architecture that allows the distributed execution in a network with many users to participate in the same simulation. The interface was designed to support the interaction of the operators with the simulator through virtual panels supported by touch screens with high fidelity graphic displays. The simulation environment is described including the extension added to facilitate an easy operation by instructors. The graphical interface has been developed using component software technology. The appropriate selection of hardware for visualization and interaction, in terms of cost and performance, resulted in a facility much less expensive than the classic hard panels replica simulators and, at the same time, able to fulfill most of the training requirements. The main features of the simulator are the distributed execution control of the models and the flexibility of design and maintenance of the interface. The benefits of virtual panels approach are the automatic switch reposition and tagging, configuration flexibility, low maintenance requirements, or capability to support multiple users distributed across the corporate intranet. After exhaustive validation and testing, the training sessions are being conducted successfully.

Keywords: Simulation, Human-machine interaction, distributed simulation, visualization software and hardware, component software, soft panels.

1. INTRODUCTION

The training of the personnel is a main subject in the security and reliability of many industrial processes. In order to fulfil this objective it is necessary to develop applications that support distributed interactive simulation with an interface near the real world. There are many approaches to accomplish this task: the replica simulators that reproduce by real hardware the same elements in the control room, the virtual simulators that use soft panels and hybrid simulators that use a mixture of both. This paper describes the development of a full scope training simulator for a Spanish nuclear power plant (named TSG++) that belongs to the virtual simulator class and it is on operation since November 2000. The objective of the simulator was to improve training capacities and satisfy the regulatory commission requirements during the anual formation plan of the operation personnel. Before this simulator, the training program included the use of a interactive graphic simulator [1] to exercise the emergency procedures and the Safety Parameter Display System (SPDS).

The novelty of this simulator is that it is entirely made by software elements (soft panels) and is capable of reproducing the operation and functionality of every element at the real control room. This allows that a facility with the same capabilities of a hard panels simulator is available at the plant site without the need of large investment. Moreover, the flexibility offered by software products could be exploited to obtain additional benefits from the simulator, as we will mention later.

Soft panels have been used first by flight simulators, to reproduce almost any kind of instrumentation in different fields. Although soft panels concept is not new, it had not been applied so far to the entire representation of such a complex system as the control room of a nuclear power plant with full operational capabilities. Another uses of it is in desktop simulators and control room design or human-machine interface analysis.

As we mentioned before, training of personnel is not only a question of improving reliability and efficiency in plant operation, but also a question of safety in the nuclear industry. Because of it, training is regulated, approved and monitored by governmental regulatory commission and the soft panel technology shall have to be evaluated as a valid tool during the formation. We have seen that after less an hour of adaptation to the new interface, operators use the simulator to learn, as in a typical replica simulator, the functionality and behavior of their plant.

The background of this simulator has been presented in [2], [3]. The focus of this paper is summarize the information on the desing, implementation and final result of the project, drawing the experiencies from this process and to include the feedback from the users' opinions. One of the main conclusion is that with current software and visualization technologies of medium level can support the very demanding requests, such as the training of nuclear plant operators, commonly accomplished with more complex and expensive tools. The same approach could be applied to other industrial processes.

The paper is organized as follows. In section 2 we outline the aspects related to the software architecture of the

simulator with a brief description of the OpenSim NT environment and a discussion of the simulator specification and the adopted software development techniques. Next section is devoted to the simulator capabilities, stressing those features that differentiate it from a classic replica simulator. In section 4 we explain the process that lead to the final outcome of the project with mention of the alternatives regarding the hardware responsible for visualization and interaction. Section 5 shows the experiences undergone while running the system, from the initial prototype to the complete installation. Finally, the main conclusions are mentioned.

2. ARCHITECTURE OVERVIEW

Simulation Environment

The OpenSim NT environment [4] was chosen as the kernel for the simulator because it allows to take full advantage of the Windows PC technology, not only in order to run the simulator, but also during the development process. This means that low-cost equipment and well-known standard software tools could be used to build the simulator.

OpenSim is an integrated software package supporting the development, execution and validation of nuclear power plant simulators. OpenSim is divided in two parts: the simulator executive and the Instructor Station.

The main components of the OpenSim are:

− Model source code modules: all model codes are written normally in Fortran language although some are in C language, using subroutine or function modules. These modules are normally created in separate files. The development of a system model prototype is done using special software tools such as Matlab, Modelica or EcoSim.
− Fscan/Cscan: language processors to compile the source modules so they can be integrated in the OpenSim NT executive.
− Database: contains all the constants and variables used in the source modules.
− Database Manager: provides a method to manage and display the information in the database.
− Initial Conditions: provide initial variable data when the simulator is started or reset.
− Master Simulation Task: executes synchronously the system plant models and controls the simulation (run, freeze, backtrack, replay).
− DirServer: provides information regarding the distributed capability configuration of the simulation.
− DbaServer: provides access to the main database.
− Dynamic Data Exchange: allows outside software to connect the simulator through the DDE protocol.

Another interesting features of OpenSim are the structure of the simulator executive that supports multithreading and is frame-based to maintain real time; the client/server architecture, with a set of servers providing different services to clients distributed across the network; and the database system that supports centralized data management and can be maintained with ODBC compliant packages, such as SQL Server or MS Access. The interprocess communication is also performed by means of standard protocols (DDE and ONC RPC) granting that third party software can be linked to the simulator.

The schematic representation of the whole system of the simulator is shown in figure 1. The different components will be explained in the following sections.
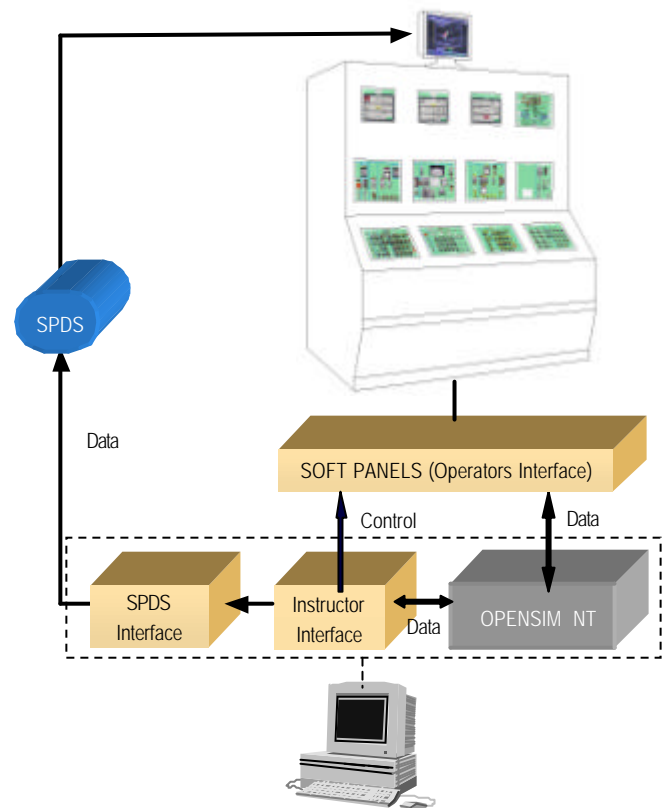

Figure 1. Schematic representation of the simulator.

Soft Panels

The requirement specification for the simulator stated that every element present at the control room should be reproduced, being accessible by a single action of the operator as in the real world or, at least, in the most similar way. This meant that we couldn´t use any navigation method to go from one panel to another, as happens with the desktop simulators and the control room devices should be visualized all at once. On the other hand, there was a limited space to

accommodate the simulator at the plant facilities with less than half the size of the real control room.

With these conditions we devised the approximate shape and layout of the soft panels that would constitute the simulator. The dimensions of a 21'' monitor were taken as a reference. We found out that the scale of the visualized elements would be roughly 50% of the actual size. More than fifty panels would be needed to display the entire control room. We also analyzed the devices present on the real panels and realized that there were more than two thousand elements to reproduce with very different appearance and functionality. A large variety of push buttons, keys, switches, knobs, lamps, gauges, recorders, annunciators and so on filled the panels.

The concept of software reusability, promoted by object oriented design, came as the ideal solution for the development of the simulator interface. Moreover, the application of component software technologie [5], such as the ActiveX controls in the Microsoft technology, would allow a fast development of panels. We selected commercial libraries for most of the instrumentation and decided to develop specific controls for buttons and switches. These components support complex functionality and communicate directly with the simulator. They act as small stand-alone programs that send data to the OpenSim executive through a DDE server. For the best performance they were programmed with Visual C++.

On the visual aspect, most components may display digital pictures as background. However, in some applications detailed drawings of the elements are used instead. We preferred to create a photographic catalog of the devices found in the real panels and incorporate these images onto the components. Nowadays this job can be easily accomplished thanks to the digital cameras at hand. Usually, the pictures needed to be modified by means of image processing tools, such as Adobe Photoshop, in order to improve quality or, for instance, to obtain the image of a handle in certain position that cannot be observed during normal plant operation. In any case, the effort was always less than if we had to draw the entire device and the result much more realistic. Figure 2 shows some examples of the components present on the simulator panels.

Every soft panel is a container of the Active X controls arranged as the real ones. Moreover, the soft panels are also responsible for refreshing the indicators and controlling that the position of all the elements always match the evolution of the scenario being simulated, despite a new initial condition had been set or the current sequence restarted. They communicate with the kernel using the same DDE server that the components, given that a single instance of this server is executed in the computer running each panel.

The soft panels have also been programmed with Visual C++, making extensive use of the MFC libraries to provide full

Windows functionality. After some testing, we designed a general template for the source code and a procedure to adapt it to the particular requirements of each panel. This method allowed that anyone programmer could begin developing panels readily. Some panels with special component functionality, like the feedwater control system, were programmed within the container. Special attention was paid to the layout and physical aspect of the components so that consistency in terms of scale, alignment, fonts and colors was assured. Figure 3 shows an image of a composition of four soft panels.
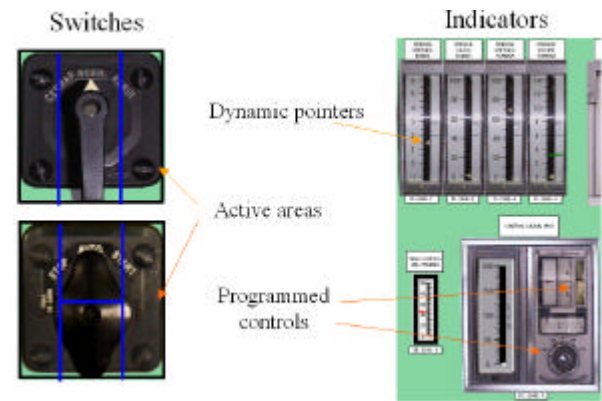
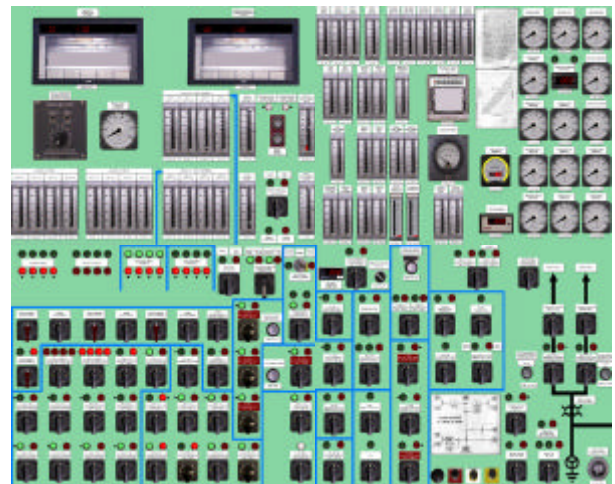**Figure 2**. Types of components used in the soft panels.

Figure 3. Composition of four soft panels used to display the turbine control system and electric generator.

Management and Communication Tools

We developed tools able to manage the whole simulator from a unique console, i.e. the Instructor Console, to control the computers and displays, and also to ensure fluid communications among all the involved applications. The main goal was to provide an easy way to operate the simulator

by the instructors, making them confident about its reliability. For instance, we automated at maximum the simulator initialization and shutdown processes. We also added a module that sent data from the simulator to a process computer that hosted the Safety Parameter Display System that would be used during the training sessions.

The development of all these applications was performed under the client/server architecture and use standard methods for interprocess communication (DDE and Windows sockets) programmed with Visual C++.

3. SIMULATOR CAPABILITIES

Simulators used to train nuclear power plant operators must verify detailed regulations. The simulator has been developed to meet the ANSI 3.5 requirements. The only uncertain issue relates to the physical fidelity of the simulator. Soft panels may offer all the functionality of a full-scope replica simulator except that the interaction is done through tactile displays with animated images. This fact could be considered as a drawback but it can be overcome by the time that operators spend working on the real control room everyday.

Even with the requirement of accommodating all the elements on an acceptable number of screens, we could maintain the relative position of more than 95% of them. Regarding interaction, the components displayed on the panels offer predefined active areas. By using touch-screens, the operator only needs to press on the required part of the corresponding control to open/close a valve or start/stop a pump. All the elements respond to the interaction and the evolution of the simulated sequence as the real ones. We also included sounds associated to the interactive components in order to give the operator instant feedback from his actions. Panels with annunciators generate audible alarm signals that were recorded at the control room.

The simulator also incorporates additional features that can only be provided by a simulator with soft panels. Some of them serve to simplify the course of training sessions. For instance, every time the instructor set a new scenario or reset the initial conditions, all the devices are adjusted automatically to their new correct positions. Even the traces on the 'virtual' paper rolls of recorders are erased before they begin to register data from the new simulation. Other capability is the automatic tagging of selected devices when it is declared out of service for the ongoing sequence by means of yellow or red tags according to the associated malfunction.

Further, the instructor has remote control from his own console over all machines that integrate the simulator. At any time, he can launch or close any of the panels, restart the Windows session running in any of the computers or even shutdown or reboot any of the PCs. When booting, the operating system enters directly to the simulator session and the required servers start automatically. In this way, the computers are always ready to display their corresponding panels.

Another set of features is useful for the maintenance and fast development of the soft panels. For instance, the legends contained in the numerous labels that describe the panels' devices are fully configurable from a text file. This file is read when the panel is launched and includes all the information related to fonts, colors and text of every label. Hence, they can be modified as needed without rebuilding the application. The same happens to the panels with annunciators. In this case, the variables associated with every annunciator are read from the file too. Thus, the same executable with different configuration files is used for all these panels involving great savings in programming effort.

A standard Windows setup program in which the user only has to introduce the name of the panel to be executed in that machine, solved the installation of the software required to run the panels and all the necessary files to be copied to their correct locations.

Finally, the flexibility offered by the installation and execution of panels in whatever PC connected to the simulator computer through the company Intranet expands the range of application making possible other sections of personnel use the simulator.

4. HARDWARE CHOICE AND INSTALLATION

Three factors determined the final configuration of simulator. First, the training requirements demanded a facility that resembled, as much as possible, the actual control room. Second, the available space to accommodate the system was limited. And third, the expenses on equipment for the entire project had to be under control and to sum a small proportion of the cost of a full scope replica simulator. Obviously, the satisfactory performance of the new simulator must also be guaranteed.

Concerning interaction only touch-screens remained as the only valid option. After some tests, the resistive technology was chosen because they offer high resolution and can be activated by any object, not only the fingers. Unfortunately, their thickness can affect the quality of the displayed image.

With regard to visualization we paid attention to large sized CRT monitors, different types of rear projectors, flat LCD monitors and plasma displays. We wanted to arrange the panels very close to each other, in order to save space and suppress artificial gaps among them. This could be better achieved with projectors or plasma displays, but these systems are often designed for distant vision while, in reality, the operators always stand close to the panels. Their resolution is poor and cannot be used to display a detailed

image of many small objects to be seen from short distance. So, we chose a combination of CRT and LCD monitors. CRTs offer very high resolution and are available at low cost with the acceptable size of 21". A high number of these displays are used in the interactive panels with a resolution of 1600x1200 pixels. The flat LCD monitors are lighter and easier to handle although much more expensive and with less resolution. We use them for panels with annunciators and SPDS displays.

Since the computers that would support the soft panels needed to run the Windows NT operating system we use Pentium PCs with no especial requirements. As for the simulator computer, main server and instructor console, we chose a dual processor Pentium platform able to perform all these functions simultaneously. Finally, a conventional Ethernet network would connect all the computers.

Before the physical installation of the simulator a prototype with twelve displays was built at our offices (figure 4). Different people, many of them from the plant, used this prototype. Its design was continuously improved taking their opinions into account until the entire system could be installed at the plant. The installation process was laborious but fast. Every computer and their peripherals should be labeled, placed at their exact locations and have the right software loaded. Besides, a careful study of the power supply required by all this equipment was carried out in order to set up the appropriate electric wiring on the simulator room. To avoid reflections on the soft panels screens room lighting was carefully studied too.

Figure 4. Prototype built to accommodate twelve soft panels.

Installation of all panels was distributed as in the real control room with a final scale of 65% in length. There was room enough for a shift of operators moving as they actually do when controlling the plant. The rear of the structure allowed accessing all the computers and peripherals easily. Some final details served to improve the simulator look. For instance, the frames of the CRT monitors were covered with plastic pieces and painted as the rest of the structure to increase the feeling of continuity among the soft panels. A series of sticky tags reproducing actual control room labels were also added for greater realism (figure 5).

Figure 5. The operation crew during a training session on the simulator.

5. SIMULATOR PERFORMANCE

The space limitations and the hardware selected for visualization implied that the whole simulator displayed a reduced scale image of the control room. Moreover, there were relatively large useless areas amid the soft panels that do not exist in reality. However, despite these drawbacks we have observed that when the simulation starts and the operators began acting on the soft panels following their procedures, they forget about the interface and are fully immersed on the ongoing scenario.

The simulator has been validated and tested as any full scope simulator. The first part of this process was carried out at the prototype installed at the university. This initial experience discovered some of the troubles that should be fixed. The images of some elements were so small that it was difficult to press over the desired active area. We learnt soon that the general user is reluctant to substitute his finger by a pointer or any kind of stylus. Nevertheless, in most cases these objects could be enlarged without altering the panels' layout. Other objects included some components embedded in others, for instance the knobs of the feedwater system and recirculation analog controllers. In these rarely cases it is provided a zooming feature. When the user press on one of these objects the inner knob is displayed on a new small window over the panel, large enough to rotate the knob using the finger. If the object is pressed again the window

disappears. We also checked the performance of the touch-screens after many hours of operation. We realized that periodic calibration was convenient.

When the installation of the simulator was completed a team of new operators was assigned to perform the final validation. These young people were used to computers and had no trouble with the soft panels interface. In a few minutes they were familiarized with the new training environment and knew how to deal with the system. However, when the real training sessions began we noticed that it was not so intuitive for everybody. Brief explanations about the interface and a bit of previous practice were enough to solve the problem. Once the user has accepted that there are no physical handles or switches to operate, the only complain is about the size of the virtual objects.

Regarding the equipment supporting the simulation and the communication between processes, there were no major problems with the configuration explained in section 4. From his console, which at the same time acts as the main server and simulator computer, the instructor commands the training sessions as had been devised and has full control of all the involved computers. The procedures associated to reset or shutdown the simulator are easy and friendly. The same happens with the system maintenance and, also, with the introduction of modifications that reflect changes on the real control room or serve to test new instrumentation that could be implemented in reality.

6. CONCLUSIONS

A new simulator with soft panels interface, is being used to train the operators of Sta. María de Garoña nuclear power plant. This demonstrates that current visualization hardware and software of medium level can perform the same tasks that, until now, were reserved to much more complex and expensive systems as the classic full scope replica simulators of nuclear control rooms.

Furthermore, the soft panels approach provides additional benefits that facilitate its use and expand its functionality and range of application. If the plant already has a replica simulator, this type of simulator would be useful to complement the regular training and give access to others sections of personnel to such a powerful tool as a full scope simulator.

Hybrid systems could be considered too. The most convincing would incorporate a series of hard panels containing a physical copy of the interactive devices while the instrumentation and annunciators remain in soft panels. For other more specific applications, such as the training on the numerous rear panels that are not included in the scope of traditional replica simulators, a soft panels interface appears as the most suitable solution.

We note, finally, those technologies related to soft panels design, development and rendering are evolving continuously while their costs decrease. We are undoubtedly convinced that, in the next years, the quality of this kind of systems would be largely improved.

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