INTERACTIVE GRAPHIC SIMULATION: AN ADVANCED METHODOLOGY TO IMPROVE THE TEACHING-LEARNING PROCESS IN NUCLEAR ENGINEERING EDUCATION AND TRAINING

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ABSTRACT

Nowadays, computer simulators are becoming basic tools for education and training in many engineering fields. In the nuclear industry, the role of simulation for training of operators of nuclear power plants is also recognized of the utmost relevance. As an example, the International Atomic Energy Agency sponsors the development of nuclear reactor simulators for education, and arranges the supply of such simulation programs. Aware of this, in 2008 Gas Natural Fenosa, a Spanish gas and electric utility that owns and operate nuclear power plants and promotes university education in the nuclear technology field, provided the Department of Nuclear Engineering of Universidad Politécnica de Madrid with the Interactive Graphic Simulator (IGS) of “José Cabrera” (Zorita) nuclear power plant, an industrial facility whose commercial operation ceased definitively in April 2006. It is a state-of-the-art full-scope real-time simulator that was used for training and qualification of the operators of the plant control room, as well as to understand and analyses the plant dynamics, and to develop, qualify and validate its emergency operating procedures.

The IGS provides the plant responses during normal operation, transients and accident conditions, based on the TRAC code and a set of very illustrative alive screens as well as a set of alarms in a panel similar to the real one at the control room of the nuclear power plant, allowing the real-time automatic and manual normal and emergency operation of the components of the full system. As a result, the IGS plays an important role in the education and training of the students in the nuclear technology field at Universidad Politécnica de Madrid, providing an attractive virtual space that allows them to explore and operate a real nuclear power plant, improving the in-depth understanding of how the whole plant and its safety systems work. On one hand, simulation can attract, motivate and retain students within the nuclear science; on the other hand, simulation emerges as a new way to improve the quality of the nuclear engineering education, creating a more active and participative teaching-learning process, replacing the simple passive memorization of the complex nuclear operational processes by an active and meaningful learning.

This paper presents the work performed at the Department of Nuclear Engineering of Universidad Politécnica de Madrid to turn the IGS professional simulator into a university teaching/learning tool, as follows: first, the methodological aspects of simulation are discussed; then, the developed material to help, guide and evaluate the student during the learning process is presented, and some examples of normal and emergency operation simulation are given; and finally, an assessment of the effectiveness of the simulation based on the lessons learned in the teaching-learning process is discussed. As a conclusion, based on the team-working obtained experience, the advantages, disadvantages and limitations of training simulation for educational purposes in nuclear engineering are presented, as well as the main guidelines to make an interactive graphic simulator an adequate tool for advanced education and training in nuclear engineering.

1. Introduction

The International Atomic Energy Agency (IAEA) sponsors the development of nuclear reactor simulators for education, or arranges the supply of such simulation programs [1]. Aware of this, the Department of Nuclear Engineering of the Universidad Politécnica de Madrid was provided in 2008 with the Interactive Graphical Simulator of the Spanish nuclear power plant *José Cabrera*, whose operation ceased definitively in 2006. According with the IAEA-TEC-DOC-1411 [2], the simulator is a Graphical Simulator, used for training of main control room personnel, technical support engineers, and operations management. This paper presents all the work performed at the Department to turn the simulator into a teaching/learning tool, to be use in the nuclear engineering studies following guidance found in [3].

First of all, the nuclear power plant of origin was a PWR reactor with only one loop. This makes the installation simpler in order to be used for teaching purposes, that other nuclear plant with 3 or 4 loops.

The simulator provides the real plant responses and the physical behaviour during the normal operation, and simulates several maneuvers, a series of malfunctions, and operational transients, and also allows the training in the emergency procedures under accident situations. With the simulation of these situations the student is trained in the plant behaviour, and in the nuclear and thermohydraulic phenomenology in the nuclear reactor and in the components of the whole plant. For that purposes includes the TRAC-PWR and RELAP5/MOD3.2 codes as the software package, that simulates the whole plant behaviour.

2. Methodology

The Nuclear Engineering Department dedicates two technicians to be responsible of the installation, one for the hardware and equipment, and other for the use of the simulator, and the students assistance. The Department has also the support of the Gas Natural - Union Fenosa company through the assistance of the technician who was the power plant operator trainer in the *José Cabrera* power plant, in order to solve the doubts and problems that may appear during the use of the installation. Also the Tecnatom company that developed the whole installation assist in order to solve punctual hardware and software problems.

A Commission integrated by members of the Nuclear Engineering Department (2 persons) and the Gas Natural - Union Fenosa company (2 persons), has been created to follow the work performed in the Simulator, and make proposals to improve when necessary, the teaching-learning process.

Aware of the advantages that the use of a simulator as SGI can provide for an active and independent training of our students, different material is under preparation for the development of practical classes. The aim is to provide students with the tools necessary to be able to acquire, following an active methodology, scientific knowledge and technology related to the design, safety and economical operation of a nuclear power plant. The intention is to encourage the student giving him a greater role in their learning, by providing a virtual environment that allows operating the plant as if an operator is involved.

In the preparation of this material contribute teachers and technical staff of the Department as well as students who are in different stages of their studies.

Three types of students can be described regarding the use of the simulator:

- Undergraduate students that use the Simulator for the practices period of the topics that are part of the Grade level curricula: *Nuclear Power Plants, Nuclear Technology, and Nuclear Safety.*
- Master degree students that work for a period of 6 months in the Simulator, normally supported by a fellowship of the Consejo de Seguridad Nuclear (CSN, the Spanish nuclear regulatory commission), and develop the Master Final Project in the Simulator. This project provides 15 ECTS (European Credit Transfer System) for the *"Nuclear Science and Technology Master".* Also the Industrial Engineering Master Final Project may be carried out in the Simulator.
- Visiting and collaborating students that spend part of their time learning the use of the simulator and afterwards helping in the development of the material needed for its productive used from the Teaching-Learning objective point of view. The first ones are coming from foreign universities, the second ones are students from the Naval and Industrial Engineering Schools.

The graduate students that use the Simulator should start with the identification and understanding of the existing documentation, and then they may contribute providing more detailed documentation, description of the screens and components, or simulation of different situations. They generate the related documentation with the analysis of the results that have been obtained. Also they may prepare standard and simple practices to be run by the undergraduate students during the teaching-learning period at the grade level studies. Each student has a tutor or director of the project, which analyses the developed material, in order to help, guide and evaluate the student during the learning period.

The students have access to the manuals that the power plant operators have used in the continuous training they have followed [5,6], and the Nuclear Regulatory Commission in Spain demand. The documentation includes the description of the power plant systems, the emergency operation procedures, as well as the description of the Simulator, the initial conditions available, and the malfunctions that may be simulated.

The material that is being prepared for each class or group of classes that constitute a practice for the undergraduate students is divided into three parts according to their purpose in the development of work by the student. These are:

- Practice Manual: objectives and theoretical basis, systems involved in the maneuver and main variables to be monitored, guide implementation of the maneuver, with detailed actions that students must carry out.
- Monitoring material, that the student must complete during the practice: tables for data collection, graphical representation of the temporal evolution of the significant variables, graphical analysis.
- Material self-assessment that the student must complete following the practice: issues related to the development of practical and theoretical foundations.

3. Main results and experience

The standard operational situations that have been prepared for the moment and run by the students are:

- Normal operation in nominal power.
- Nuclear power variations and turbine demand follow.
- Identification of the operational states in the plant: Cold-Zero-Power, Hot-Zero-Power, Hot-Full-Power, Nominal operation.
- Plant start-up, from Cold-Zero-Power to Full-Power.

- Plant down, from Full-Power to Cold-Zero-Power, and evolution during the Zero-Power period.

The simulator also allows the simulation in hypothetical accidents, those which are complex and with a very low probability to happen. This is used in the training, in order to understand the optimal way to drive the plant to an stable and safe situation. For the simulation of the accidents, the best-estimate and realistic codes are used. Codes that have been validated previously. The evolution is done in real time, reason why the student take conscience of the time and the risk of these potential situations, and the high reliability needed in order to limit the global risk.

These accidental and complex situations provide the student the detailed understanding of the head transmission and fluids mechanics, the kinetic reactor behaviour and the coupling among them. These situations are for the moment under testing. They should be carried out by the students when the simpler transients and maneuvers are completely understood .

The accident situations are very extend, and as a sample may be simulated the following:

- Loss of electric feed, with failure of external electrical feed and Diesel Generator.
- Steam generator tube break, with or without the safety injection system.
- Reactor scram signal with failure in the control rod insertion, and success boration.
- Main pump rotor stop, with pressurizer valves opening.
- Small LOCA with safety injection, 0,5” primary circuit break.
- Essential services water loss, and auxiliary feed-water system.
- Components cooling system loss, and auxiliary feed-water system.
- Main steam line break in the auxiliary building, with safety injection system failure.

Until now several projects have been performed by the postgraduate students, under four Collaboration fellowships, and three Master Final Projects, covering the following topics:

- Preparation of the SGI Documentation and User’s Manual (systems descriptions, transient and operational modes, systems identification, screens and alarm panel description)
- Preparation of the SGI Malfuctions Manual (in particular for the Loss of coolant accident)
- Transient analysis due to primary circuit changes (Simulation of Loss of coolant accident in cold leg, user’s guide preparation, analysis of the Emergency Operation Procedures)
- Transient analysis due to malfuctions in the valves (pressurizer shower valve, pressurizer relief valve)
- Optimized Plant Start-up and Initial conditions.
- Optimized Plant down and drive to the cold conditions. Identification of the Xenon peak during the stop period.
- Loss of coolant accident simulation with a guillotine break in the cold leg.

And the practices programmed for the undergraduate students until now have been the following:

- *Nuclear Power Plants*, with 50 students: Nominal operation simulation, and thermal power variation simulation
- *Nuclear Safety* with 40 students: Loss of coolant accident simulation

For these practices the students have the Practice Guide Manual, and as a sample the following documentation is available for the *Nuclear Safety* practice [7] : Practice Manual (description of the practice, systems involved, and variables to follow, and realization guide), Follow-up material (Tables to feel-up, Graphic representations to prepare), and auto-evaluation material (questions to answer).

The students are trained through the simulations in the interpretation of the screens that are showed in the workstations, and the plotted variables and its temporal evolution. The adviser professor examines the results obtained by students in order to assess if the simulation has been effective.

4. Conclusions

The experience obtained so far with the use of the simulator has been very successful. The graduate students involved in the development of the projects, practices and documents related with the simulator show a great interest for the work that they are doing making that the laboratory where the simulator is installed to be busy place. Regarding the undergraduate students, the practices in the simulator encourage them to follow the Nuclear Energy studies in the Engineering Schools, what is very rewarding for the Department professors.

The simulator has proved to be an optimal tool to transfer the knowledge of the physical phenomena that are involved in the nuclear power plants, from the nuclear reactor to the whole set of systems and equipments on a nuclear power plant. It is also a relevant tool for motivation of the students, and to complete the theoretical lessons. This use of the simulator in the learning-teaching process meats also the criteria recommended for the Bologna adapted studies, as it helps to increase the private hands-on work of the student, and allows them to experience the work inside a team, in a practical and real installation.

It should be noticed that this type of simulator is only available in selected universities and Nuclear Engineering Departments in the world, and that it helps to reach the excellence in the nuclear engineering programs studies.

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