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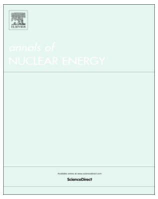

Hybrid nuclear plant simulator design requirements to enable dynamic diagnostics of plant operations

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With nuclear plant full scope simulator technology reaching maturity, the possibility of using its capabilities in expert systems such as online plant diagnostics has become a reality. The effectiveness of plant diagnostics using real-time simulated measurements as a plant reference has been shown in previous papers. However, in order to implement these systems, the full scope plant simulator needs to be designed specifically with this application in mind. This will help in maximising the effectiveness and scope of use of the system. This paper investigates the various simulator technologies available as well as the development strategies and focus areas to establish the design requirements of a single, full scope engineering and training nuclear plant simulator. This can be implemented to provide a real-time dynamic reference to the plant diagnostic system.

1. Introduction

Owing to the risks involved with the training of operating personnel on a live nuclear plant, all plants are equipped with a full scope simulator that is designed to provide an accurate representation of all plant operations for training purposes. In fact, all nuclear plants are required to be equipped with a plant simulator and a simulated control room for training purposes. Accurate simulator codes for engineering, maintenance planning and analysing postulated accidents have been in use in the nuclear industry since the 1980s (IAEA-TECDOC, 2004).

With developments in data-processing system speed and improved accuracy of real-time calculations, these simulators can now be combined to provide a single full scope training and engineering simulator as well as a maintenance planning function. The accurate, real-time simulator can also be used to provide a dynamic reference for plant operations during steady state and transient conditions.

The advancements in processor speeds, parallel processing, and the development of more sophisticated numerical algorithms enable the simulation of plant processes in real time. This has long been anticipated, but it has only been very recently that the possibility has been put into practice (AC02591847, 1999) by combining the training and engineering simulator to develop an accurate real-time simulator.

The benefits of real-time simulation of systems have not yet been fully exploited, as these would only be realised if real-time simulations could continuously be compared to all measured information, and decisions based on the expected behaviour of the plant could then be made. This plant diagnostic system was developed and established in previous work (Cilliers et al., 2011; Cilliers and Mulder, 2012; Cilliers, 2013a,b). The principles of combining real-time plant data and data from a plant simulator operating under the same conditions not only aids the detecting of faulty plant behaviour while the operating point is still within the structural safe boundaries of the plant, but it also allows the description of the fault condition up to a certain level. For this process to be successful, a modern nuclear plant simulator needs to provide specific functionality and adhere to a number of requirements related to modelling methods, interfacing and fidelity.

The ultimate goal of this research is the implementation of the full scope engineering simulator for a fault identification system to be implemented as a supervisory system in the Koeberg Nuclear Power Plant (NPP) as well as including it into the control and instrumentation systems to be implemented in South Africa and other proposed new building programmes in Africa and beyond.

This paper is organised into five sections. The first part is the introduction, followed by the second section which describes the existing simulation technology and uses. The reason for hybrid full scope is discussed in the third section. The fourth section is an overview of the integrated simulator. The fifth section contains the hybrid full scope engineering simulator requirements, followed lastly by the conclusion.

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2. Existing simulation technology and uses

Simulation technology has advanced with time as the data processing speed keeps increasing, which was about 0.5 Mflops in the 1980s and has risen to 1000Mflop in the 21st century (Miettinen, 2008). This increase has tremendously affected the advancement and the applications of the simulation systems in the nuclear industry. The different types of simulators presently in the nuclear industry, according to IAEA-TECDOC (2004), are:

Full scope simulators: They are also known as full replica simulator, the full scope (FSS) is a physical representation of the control room that fully replicates the control room for the purpose of training. The FSS completely models systems of the referenced plant with the operator interfaces in the actual control room environment. Most nuclear power plants are equipped with an FSS.

Basic principle simulators: These simulators, unlike FSS, do not fully replicate the control room but only provide a simulation of general concepts relevant to the operation of the nuclear plant. They can be used in training at the system operation level.

Partial scope simulators: This type of simulator only represents specific systems or part of the actual plant and are used for training on specific aspects only of the plant operation.

Other than full scope control room simulators: These simulators closely mimic plants, but unlike the other categories of simulators, the human-machine interface is different from the referenced plant. Generally, for a simulator of this type, the human-machine interface is provided through computer-driven displays and either touchscreens or mouse-control on screen buttons.

2.1. Simulators classifications based on their uses

The dedicated nuclear power plant training simulators have limitations which include its limited availability, limited flexibility, limited data collection, and limited human-machine interface (Boring et al., 2012). These factors result in the development of simulators which can be used for other specific purposes. These simulation systems have been developed with various uses in mind; these uses often dictate the focus being put on speed, accuracy, human-machine interface, realism, or a combination of these. The most common below:

2.1.1. Engineering

Engineering simulators are usually focused on the development of detailed studies of industrial processes. The aim of engineering simulators is to evaluate and compare alternative process and control solutions. The engineering simulator relies on a plant model that is a complete, integrated, dynamic representation of the behaviour of all the plant systems controlled by the Digital Control System in their various states of operation. The mathematical models are the most important part of the simulator, and they are usually very accurate. The human-machine interface is of less importance than in other simulators (L-3-MAPPS, 2013b).

2.1.2. Training and demonstration

Training and demonstration simulators are aimed at training of the operation personnel of the nuclear plant. This is usually a continuous process as operators require to be trained constantly. Training and demonstration scenarios are designed to instruct individuals and teams in the operation and control of unit systems and equipment during normal, abnormal and emergency conditions. The human-machine interface is crucial, while the accuracy of the mathematical models can be lower. When the simulator is used in other disciplines (for example, maintenance), the accuracy can be even lower (IAEA-TECDOC, 2004).

2.1.3. Testing

Test simulators are applied in the design and implementation of process and automation to test its performance in normal operating and transient conditions. The accuracy requirements vary depending on the test case. In automation tuning, the process model needs to give a realistic dynamic response. In testing the automation implementation, qualitative behaviour is often enough (Carrasco and Paljakka, 2004).

2.1.4. Operation support

Simulators are used in supporting operative tasks. By using predictive simulators, operators can estimate consequences of alternative actions, and production management can test and optimise production plans. As the simulation speed must be faster than real time, the accuracy requirements cannot be very strict. It is sufficient if the simulation model can predict potential problems and estimate production measures (Workshop on NPP Simulators for Education, 2007).

2.1.5. Severe accidents

They are used in training nuclear power reactor operators on how to respond to severe accident situations. Before the Fukushima Daiichi accident, simulating severe accidents was regarded as optional, but since the accident, interest has been renewed in the severe accident simulator and much work has gone into it. The Modular Accident Analysis Program (MAAP) is one example of a widely accepted model used for severe accident analysis. These simulators are designed to be used in an off-line, stand-alone, non-continuous and non-real-time application (L-3-MAPPS, 2013a). The Sandia National Laboratories also developed the MELCOR for severe accidents simulations (Osborn et al., 2015).

2.1.6. Human performance

Control room simulators are used in assessing human performance by evaluating operators and crews. This simulator allows for help in conducting research in areas of human factors and human reliability. For this simulator, the human-machine interface is crucial (Blanc et al., 2001). The OECD Halden Reactor Project (HRP) has extensively used the nuclear power plant simulator on the research of simulation for human performance for over 25 years (Skjerve and Bye, 2011).

2.1.7. Research simulators

Notable work by renowned laboratories have been done in the development of research simulators. One of such is the Idaho National Laboratory in which there is currently a Light water reactor sustainability (LWRS) project which has involved the development of the Human Systems Simulation Laboratory (HSSL) used to conduct research in the design and evaluation of advanced reactor control rooms, integration of intelligent support systems to assist operators, development and assessment of advanced human performance models, and visualisations to assess advanced operational concepts across various infrastructures (Boring et al., 2012). The Sandia National Laboratories research focussed majorly on severe accidents and the Halden research project on has focussed majorly human performance.

From the above descriptions, it is clear that implementing a simulator as a reference model would require a focus on speed and accuracy, which in many cases exist as a trade-off between each other. A simulator designed for use in on-line control and protection applications should have the following focus:

2.1.8. Real-time control and protection

Simulators are used in predicting plant behaviour in parallel to the actual plant, and faulty plant behaviour can be recognised by measured values and simulated values drifting outside predefined