INL/CON-12-27428
PREPRINT

Design and Validation of Control Room Upgrades Using a Research Simulator Facility

Winter Meeting of the American Nuclear Society

Ronald L. Boring
Vivek Agarwal
Jeffrey C. Joe
Julius J. Persensky

November 2012

Design and Validation of Control Room Upgrades Using a Research Simulator Facility

Ronald L. Boring, Vivek Agarwal, Jeffrey C. Joe, and Julius J. Persensky

Idaho National Laboratory, Idaho Falls, Idaho, USA
{ronald.boring,vivek.agarwal,Jeffrey.joe,Julius.persensky}@inl.gov

INTRODUCTION

Since 1981, the United States (U.S.) Nuclear Regulatory Commission (NRC) [1] requires a plant-specific simulator facility for use in training at U.S. nuclear power plants (NPPs). These training simulators are in near constant use for training and qualification of licensed NPP operators.

In the early 1980s, the Halden Man-Machine Laboratory (HAMMLab) at the Halden Reactor Project (HRP) in Norway first built perhaps the most well known set of research simulators. The HRP offered a high-fidelity simulator facility in which the simulator is functionally linked to a specific plant but in which the human-machine interface (HMI) may differ from that found in the plant. As such, HAMMLab incorporated more advanced digital instrumentation and controls (I&C) than the plant, thereby giving it considerable interface flexibility that researchers took full advantage of when designing and validating different ways to upgrade NPP control rooms. Several U.S. partners—the U.S. NRC, the Electrical Power Research Institute (EPRI), Sandia National Laboratories, and Idaho National Laboratory (INL) – as well as international members of the HRP, have been working with HRP to run control room simulator studies. These studies, which use crews from Scandinavian plants, are used to determine crew behavior in a variety of normal and off-normal plant operations. The findings have ultimately been used to guide safety considerations at plants and to inform advanced HMI design—both for the regulator and in industry.

Given the desire to use U.S. crews of licensed operators on a simulator of a U.S. NPP, there is a clear need for a research simulator facility in the U.S. There is no general-purpose reconfigurable research oriented control room simulator facility in the U.S. that can be used for a variety of studies, including the design and validation of control room upgrades.

CONTROL ROOM MODERNIZATION

Commercial NPPS in the U.S. need to modernize their main control rooms (MCRs). Many NPPs have completed partial upgrades, but none of the 104 commercial reactors in the U.S. have completed a full control room modernization effort. Existing control rooms are almost entirely analog, hardwired, and manually operated control systems. Since analog technologies are no longer readily available, digital control systems are the required replacement systems for modernization. In the course of analog-to-digital upgrades, it is first necessary to develop a digital backend in which sensors and controls are digitized on a supervisory control and data acquisition (SCADA) system. Once it is possible to monitor and control the plant digitally with potential redundant analog and mechanical backup instrumentation and control (I&C), the MCR HMI can be addressed. Digital technologies introduce the opportunity for new functionality in the form of advanced displays and automated or soft controls.

Yet, such new functionality may go beyond the current licensing basis of plants and require significant licensing amendments. Moreover, although there is operating experience with digital technologies in other safety critical process control environments, advanced digital I&C is largely untested in the MCRs of NPPs. There are unique challenges to nuclear power plants, including the close proximity of the MCR to the actual plant, which makes it difficult even to find adequate space to stage the components of a replacement control room. Additionally, the short outage windows of the plants require rapid changeout of components in order to maintain targeted production levels for each plant. In many cases there may be no readily available commercial I&C solutions that generalize from other industries to meet the requirements of nuclear power plants. The one-of-a-kind nature of many plants further requires extensive customization by vendors.

There are significant hurdles in adopting new technologies as part of a MCR modernization strategy in nuclear power plants. As such, utilities must decide the extent of modernization that is desired and needed and prioritize the process by which they will achieve that modernization. The plant's endstate vision outlines both the extent of digital upgrades and the course of deployment. For example, a utility may decide to keep its existing panel-based control room and phase in digital control system (DCS) displays to replace aging analog I&C. Another utility may decide to adopt a complete control room update—doing away with panels completely and moving toward soft controls and plant overview displays at local operator workstations. Yet a third strategy might find a graded approach in which the utility plans for introduction of a DCS backend in the short-term with an eventual goal of introducing a completely new control room concept as part of long-term plant sustainability.

LIGHT WATER REACTOR SUSTAINABILITY

The U.S. Department of Energy (DOE) is sponsoring research, development, and deployment on light water reactor sustainability (LWRS), in which the Idaho National Laboratory (INL) is working closely with nuclear utilities to develop technologies and solutions to help ensure the safe operational life extension of current reactors. One of the main areas of focus is control room modernization. As noted, current analog control rooms are growing technologically obsolete, and it is difficult for utilities to obtain replacement parts. Industry must safely and smoothly transition to digital control room interfaces. As technologies are introduced that change the operation of the plant, the LWRS project can help identify their best advanced uses and help demonstrate the safety of these technologies. This research needs to be definitive and timely due to the rigor and duration of the regulatory review process. Also, early testing of operator performance given these emerging technologies will ensure the safety and usability of systems prior to large-scale deployment and costly verification and validation at the plant.

Several NPPs in the U.S. are committed to MCR modernization programs that include modernization of I&C systems and new HMIs. Control room modernization, either as a complete overhaul or a stepwise change to a hybrid digital-analog control room, is a challenging task involving I&C and HMI integration issues such as: merging soft controls with existing hard controls, managing increased data availability to the operators, improved alarm management, and computerized procedures, to name a few examples. To help NPP operators and vendors plan, specify, design, implement, operate, maintain, and train for the MCR modernization in a way that takes advantage of digital system and HMI technologies, EPRI developed 31 guidelines and technical bases for them [2]. These guidelines are grouped in the five areas of (i) plant-specific control room modernization planning, (ii) human factors engineering (HFE) design analyses, (iii) detailed HFE guidelines, (iv) regulatory and licensing activities, and (v) special topics related to operations and maintenance.

HUMAN SYSTEM SIMULATION LABORATORY

There exists no research simulator configured specifically to address the redesign of legacy control rooms in the U.S. nuclear industry. In light of this fact, the INL has undertaken the conversion of a legacy training simulator for use in control room modernization. To allow the simulator to display a variety of analog hard controls and allow the operators maximum interaction with the simulator, digital displays with touch interfaces are a viable and desirable solution. Popularly known as glass top displays, such displays can be set up in number of ways to mimic any control room configuration.

At the INL Human System Simulation Laboratory, the glass top panels are linked together in a horseshoe shape that approximates the shape found in current control rooms. A total of 15 glass top bays are linked together (see Fig. 1), representing faithful mimics of five hardware panels found in a current control rooms. Three bays chained together accurately represent the content of each physical panel in the control room. Each glass top bay serves as a client to a central simulator model. The panels represent functions related to plant auxiliary services, electrical energy, waste heat removal, primary and secondary energy, reactor support systems, and safety systems. The design requires that all analog I&C be represented on the control panels and that multiple operators may work on the composite simulator at the same time.

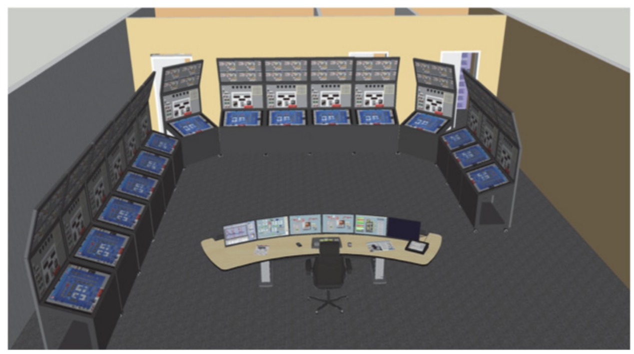

Fig. 1. INL reconfigurable simulator.

The key advantage of mimicking current control rooms comes from the ability to implement prototypes of new digital function displays into the existing analog control environment. Prior to full-scale deployment of technologies such as control room upgrades, it is essential to test the performance of the system and the human operators' use of the system in a realistic setting. In control room research simulators, upgraded systems can be integrated into a realistic representation of the actual system and validated against defined performance criteria. In this manner, control room upgrades are being designed, usability tested, and safety validated without the need to use the plant's training simulator.

RESEARCH PATH FORWARD

The control rooms at current nuclear reactors feature analog I&C technology in many cases dating to the 1970s. Although this aging control room technology is adequately maintained to ensure reliability and safety, the cost to maintain such obsolete equipment is approaching or even exceeding the cost of replacement. Yet, there exist financial and regulatory hurdles to modernize control rooms, and vendors have been slow to provide comprehensive solutions that meet industry needs. The time required to perform a full-scale control room upgrade is significant, and the cost of loss of production for utilities reaches up to $2 million per day for a commercial reactor. Thus, wholesale modernization in the form of complete replacement of these control rooms is not likely in the U.S., and plants are adopting a piecemeal or system-by-system approach to upgrades.

As part of the LWRS Program, the INL is working with utility partners to develop a strategy for long-term control room modernization that will guide the development and deployment of new digital-based control room systems at existing U.S. nuclear power plants. The strategy will address how best to achieve an end-state vision for the control room based on the plant concept of operations. This will include all aspects of operations such as procedures, degree of automation, and potential operator support systems. The INL is reviewing various control room modification strategies and management system principles and technologies for discussion with plant personnel to determine which strategies are most applicable to plants for incorporating digital controls and operator interface design into a traditional analog control room. Based on these discussions, the INL will propose an appropriate approach to establishing an endstate vision for the plant control room and work with the utility partner to develop the vision.

While performing this task, INL personnel will conduct a needs analysis at a representative plant to determine concepts of operation and control room usage patterns and better establish an understanding of how operators use the current panels, displays, and controls and how they interact in a realistic setting. Initially, this will be done in the plant training simulator and will include documentation review, event reviews, procedure review, operator observations, and interviews with operations and maintenance staff, as well as engineering and modification team members and management. The needs will be prioritized in cooperation with the plant modification team.

The goals of this research include:

- Developing guidelines for standardizing operator interface screens based on human factors engineering principles
- Developing an endstate vision for transitioning to a fully modernized MCR
- Developing, prototyping, and evaluating diverse I&C systems in a step-by-step fashion toward overall control room modernization
- Developing integrated digital I&C displays that combine the systems developed in step-by-step upgrades
- Providing first-of-a-kind proof-of-concept demonstrations of innovative HSI concepts

Integrated system validation (ISV) is a well-established concept in the nuclear industry. Prior to full-scale deployment of technologies such as control room upgrades, it is essential to test the performance of the system and the human operators' use of the system in a realistic setting. Where simulator facilities are available such as in control room training simulators, upgraded systems can be integrated into a realistic representation of the actual system and validated against defined performance criteria. Less common, however, is the use of the training simulator as the development platform for novel interface elements.

In this research, the INL is using a full-scope training simulator for design and pretesting of proof-of-concept interface elements. The system in question is a copy of a nuclear power plant's active training simulator. Instead of buying commercial-off-the-shelf digital replacement systems or contracting custom systems that are developed offsite and only later integrated into the control room, the present approach uses the glass top training simulator as the development platform and test bed. The approach affords considerable advantages over traditional ISV:

- The design process is formative, meaning it is possible, due to the reconfigurability of the soft panels, to change ineffective elements of system design prior to full scale integration
- The design process is iterative, meaning it is possible to collect operator feedback at early stages of development and apply insights on operator performance into early-stage redesign
- The design process is environmentally driven, meaning it captures and mitigates constraints of the control room and aspects of the conduct of operations that might otherwise hinder successful implementation of an interface
- The design process converges on a standard, meaning the development of system-by-system upgrades affords the opportunity to create a style guide that may be used to drive a consistent design across the control room
- The design process is cost effective, meaning it is possible to take advantage of in-house engineering and human factors expertise to design and evaluate systems as they will actually be used.

CONCLUSION

While many utilities in nuclear industry have performed upgrades to their control room I&C systems, very few higher risk/higher reward upgrades have been performed. This is due, in part, to the lack of a reconfigurable research control room simulator. A reconfigurable control room simulator will allow utilities to conduct the research needed to determine how to perform large scale modernizations of their control rooms.

The INL is meeting this need by developing a multi-use reconfigurable control room simulator. With this simulator capability, the INL serves as a neutral test bed to develop and test the implementation of new digital control room system technologies, and is a key resource for testing emerging technologies for their application in NPP control rooms. In this paper, we offer an example framework for using a training simulator as part of integrated system design in control room modernization projects. The simulator, when repurposed for research, provides the ideal platform for designing, prototyping, and validating new I&C concepts.

DISCLAIMER

REFERENCES

1. U.S. NUCLEAR REGULATORY COMMISSION, "Nuclear Power Plant Simulation Facilities for Use in Operator Training and License Examinations," Rev. 3, *Regulatory Guide 1.149*, (2001).

2. ELECTRIC POWER RESEARCH INSTITUTE, "Human Factors Guidance for Control Room and Digital Human-System Interface Design and Modification: Guideline for Planning, Specification, Design, Licensing, Implementation, Training, Operation, and Maintenance", *Technical Report TR-1008122*, (2004).