ADOPTING MODERN COMPUTER SYSTEM TECHNOLOGY TO NUCLEAR POWER PLANT OPERATIONS

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Abstract: Instrumentation, control and monitoring systems in operating nuclear power plants generally utilize analog technology. As these systems age and become obsolete, utility companies are beginning to incorporate digital technology due to its proven record of high reliability in other industries, as well as wide spread availability. One of the major choices facing utilities in the I&C upgrade process is the use of digital computer-based systems to replace the existing analog control systems. Digital computer-based control systems provide improved functional control capabilities and the potential for communications with other plant control and monitoring systems. In addition, new challenges are associated with digital technology that must be faced by the utility. These include items such as evaluating the effects of electromagnetic and radio frequency interference on the system reliability, the need for software verification and validation, the review of abnormal conditions and events analysis (ACEs), as well as overall licensing aspects and the need to increase use of commercial-grade equipment to decrease cost, particularly for safety systems. This paper will review these aspects of adopting digital control technology and improvements in plant monitoring and network communications to nuclear power plants.

Keywords: Nuclear power stations, Control systems, Digital control, Communication networks, Man/machine interfaces

1. INTRODUCTION

Operating nuclear power plants were designed 20 to 40 years ago with analog instrumentation and control (I&C) technology. Today, most plants continue to operate with the original I&C equipment. This equipment is approaching or exceeding its life expectancy, resulting in increasing maintenance efforts to maintain system performance. Surveys of Licensee Event Reports in the United States show that a majority are related to I&C issues. Decreasing availability of replacement parts and the accelerating deterioration of the infrastructure of the manufacturers that support analog technology intensify obsolescence problems. As a result, operation and maintenance (O&M) costs are increasing.

Instrumentation and control systems in nuclear power plants need to be upgraded in a reliable and cost-effective manner to replace obsolete equipment, reduce operation and maintenance costs, improve plant performance, and enhance safety. The major drivers for the replacement of the safety, control, and information systems in nuclear power plants are the obsolescence of the existing hardware and the need for more cost-effective power production. Analog hardware that was designed 20 to 40 years ago is no longer fully supported by the original equipment manufacturer. Therefore the procurement of replacement modules and spares is costly, time consuming and, in some cases, not even possible. The increasing competition among power producers requires more cost-effective power production. The increasing operation and maintenance costs to maintain many of the analog I&C systems is counter to the needs for more cost-effective power production and improved competitiveness.

Technological improvements, particularly the availability of digital (computer-based) I&C systems, offer:

- Improved functionality, performance, and reliability;
- Solutions to obsolescence of analog equipment;
- Reduction in operation and maintenance costs; and
- Potential to enhance safety.

However when digital upgrades have been performed in nuclear power plants, problems with proprietary system architectures and new licensing and design issues have resulted in high implementation costs. There is a need for a systematic approach, leading to the identification, prioritization, and implementation of alternative I&C solutions in nuclear power plants. Viable alternatives range from extending the useful life of existing equipment to the complete and cost-effective system replacement.

Reliable, integrated information is a critical element for protecting the utility's capital investment and increasing availability and reliability. Integrated systems with integrated information can perform more effectively to increase productivity, enhance safety, and reduce O&M costs. A plant communications and computing architecture is the infrastructure needed to allow the implementation of I&C systems in an integrated manner. Current technology for distributed digital systems, plant process computers, and plant communications and computing networks support the integration of systems and information. However, even with the inherent technical advantages, digital systems will be implemented in nuclear power plants only if they support reduced power production costs and acceptance is achieved by the licensing authorities.

2. EPRI NUCLEAR POWER PLANT I&C UPGRADE PROGRAM

The Electric Power Research Institute (EPRI) and its member nuclear utilities are working together under the Integrated Instrumentation and Control Upgrade Program (EPRI, 1992*d*) on a three pronged approach to address I&C issues. The three prongs of the program consist of research and development activities, utility demonstration plant activities, and licensing stabilization activities. The research and development activities support the development and implementation of digital systems for cost and performance improvements, as well as providing a technical basis for qualification and licensing responses. It also provides part of the bases for the requirements and methodologies needed to design, develop, qualify, implement, operate, and maintain digital systems. The demonstration plant activities identify utility's needs, provide part of the bases for requirements and methodologies mentioned above, provide a test bed for and feedback on requirements and methodologies for upgrading systems, support the development of specifications for digital systems, and capture experience from implementing new digital systems. The licensing stabilization activities have provided technical support, as requested, for the industry licensing positions with the United States Nuclear Regulatory Commission (USNRC) on digital systems which have been developed by utility working groups and facilitated by the Nuclear Energy Institute (NEI).

Part of the research and development activities, in conjunction with the demonstration plant activities, has been to define and develop a set of generic methodologies and guidelines that assist utilities in identifying, prioritizing, and implementing I&C solutions more effectively. The EPRI Instrumentation and Control Upgrade Program has developed a life-cycle management program for I&C systems. Life-cycle management involves the optimization of maintenance, monitoring and capital resources to sustain safety and performance throughout the plant life. Life-cycle management for I&C systems and components additionally may require the use of digital technology, when analog equipment cannot be cost-effectively maintained or when an improvement in performance is desired. The main product of the life-cycle management program is a set of methodologies and guidelines that, as part of the utility's overall life-cycle management effort, will enable nuclear power plants to fully consider I&C cost and performance improvements, including the application of digital technology. Specific examples of system specification and designs will also be developed through the application of the upgrade implementation methodologies to safety-related and non safety-related systems and system prototypes.

2.1 *Planning Methodologies*

Four strategic planning methodologies have been developed. The first two methodologies enable the utility to prepare an I&C life-cycle management program plan (EPRI, 1995*d*) and a plant communications and computing architecture plan (EPRI, 1994*e*). The last two methodologies enable the utility to perform long-term maintenance planning (EPRI, 1996*b*) and detailed upgrade evaluations (EPRI, 1996*a*) for I&C systems or components.

The Life-Cycle Management Plan is a long-term, strategic plan for managing the I&C systems over a selected planning period. The Life-Cycle Management Plan Methodology (EPRI, 1995*d*) guides a designated team of utility personnel through a comparison of I&C life-cycle management strategies and through existing and planned life-cycle management program activities to identify interfaces and integration options. On the basis of this comparison, the I&C Life-Cycle Management Plan is prepared. This plan includes:

- Identification of systems and components to be included in the program;
- Development of bases for upgrade or long term maintenance options;
- Initial cost and performance improvement estimates, prioritization for detailed upgrade evaluation, and deferred-upgrade maintenance planning; and
- Identification of related programs and organizational interfaces including key personnel and responsibilities.

The methodology is accompanied by a workbook which contains various outlines, worksheets, and generic interview questions and topics that aid in the development of a Life-Cycle Management Plan. The document describing the methodology also explains the overall process for planning and implementing the various elements of I&C life-cycle management, and the relationship of the other EPRI planning methodologies and guidelines. A plant-specific version of the life-cycle management plan is given in reference (EPRI, 1992*b*).

The Plant Communications and Computing Architecture Plan Methodology (EPRI, 1994*e*) provides utilities with a detailed set of instructions for preparing a Plant Communications and Computing Architecture Plan that will allow them to upgrade their I&C systems in a logical, cost-effective, and non-disruptive fashion. The Plant Communications and Computing Architecture Plan Methodology provides all of the information necessary to allow utilities to develop their strategic architecture plans in the most cost-effective manner possible. It guides a designated team of utility personnel through an assessment of the existing plant data network architecture, corporate communications architecture life-cycle management plans, and I&C life-cycle management implementation guidelines with respect to the communications architecture. On the basis of the assessment results, a Plant Communications and Computing Architecture Plan is prepared to address:

- Characterization of the existing network architecture;
- Characterization of the future network architecture in terms of a network model and communication standards for connectivity and interoperability of network elements;
- Set of network architecture requirements regarding the physical configuration, network access, network add-on provisions, network performance monitoring, and I&C equipment communications interfacing;
- Set of consistent human-machine interface guidelines for I&C systems; and
- Guidelines for process control equipment and computer platforms.

Some nuclear power utilities have used the need to upgrade their plant process computer (EPRI, 1992*e*) as an opportunity to develop a new plant communications and computing architecture. An example of a plant-specific architecture plan is given in reference (EPRI, 1993*b*).

The Systems Maintenance Plan Methodology (EPRI, 1996*b*) addresses long-term maintenance planning for systems or components where the initial screening in the Life-Cycle Management Plan indicates that detailed upgrade evaluation is not justified by cost and performance improvement potential, over the planning period. The Systems Maintenance Plan Methodology contains a process for developing a comprehensive System Maintenance Plan for each identified system. The Systems Maintenance Plan will present the most efficient approach for maintaining the operational goals and life expectancy of the system. The Systems Maintenance Plan Methodology will describe how to:

- Develop long range maintenance objectives,
- Baseline and analyze the existing maintenance process,
- Analyze failure rates, inventory practices, and obsolescence issues, and
- Implement maintenance related problem solving techniques.

The System Upgrade Evaluation Methodology addresses (EPRI, 1996*a*) a detailed evaluation of the I&C system when upgrading is indicated by the cost and performance screening in the Life-Cycle Management Plan. The Upgrade Evaluation Methodology is used to analyze each candidate system upgrade to determine if the upgrade is justified from a cost/benefit perspective. The Upgrade Evaluation Methodology is used to produce an Upgrade Evaluation Report for each candidate upgrade. The Upgrade Evaluation Report describes high level system functionality, upgrade alternatives and associated cost/benefit evaluations, and the recommended alternative. The upgrade evaluation process includes detailed cost and performance analysis; conceptual design options analysis; cost/benefit analysis; and upgrade recommendations. Analysis of conceptual design options includes the consideration of digital design basis changes, associated technical specification changes, and equipment selection candidates. If the system is to be upgraded, the Upgrade Evaluation Report forms the basis for the Functional Requirements Specification.

2.2 *Integrated Plant Systems*

As tasks become more complex, involving large numbers of subsystem interrelationships, the potential for human error increases. Therefore, reliable, integrated information is a critical element for protecting the utility's capital investment and increasing availability and reliability. Integrated systems with integrated information access can perform more effectively to increase productivity and enhance safety. Traditionally, systems upgrades have been implemented in a stand-alone manner, which has resulted in increased operation and maintenance costs. The modern technology available for distributed digital systems, plant process computers, and plant communications and computing networks is fully capable of supporting integration of systems and information. In fact, this capability has been proven in other process industries and in nuclear power plants outside of the United States.

Integration of the plant systems and information is essential to cost-effectively enhance cooperation between systems and to reduce unnecessary duplication of functions and information. The objectives of integrating plant systems and information are to:

- Improve plant availability and reliability,
- Reduce operations and maintenance costs,
- Reduce safety challenges, and
- Improve performance with existing and new equipment systems.

The plant communications and computing architecture of the plant supplies the infrastructure which allows the integration of systems and information. This infrastructure supports integrated upgrades, provides access to all of the plants information sources, and facilitates common interfaces between the human and the machine. This architecture will support the interoperability of systems and the interchangeability of equipment. It will also be designed to be easily expandable. This architecture is defined by a plan that includes a migration strategy to get from the current plant architecture to the final, desired architecture.

2.3 *Issues Regarding Computer-Based Systems*

Design and licensing issues have prevented utilities from benefiting from the cost and performance improvements possible with digital technology. Examples of the areas of concern for digital systems in nuclear power plants are licensing, software verification and validation (V&V), hardware qualification including electromagnetic interference compatibility and seismic, reliability, performance, separation, redundancy, fault-tolerance, common-mode failures, diversity, human-machine interfaces, and integration of systems and information through communications networks. Commercial-grade dedication of digital systems is an approach for more cost-effective implementations that is of considerable interest to the nuclear utilities. As part of the EPRI Instrumentation and Control Upgrade Program and other EPRI activities, approaches to address many of these concerns have been developed and the results are given in recent EPRI reports (1988, 1992*a*, *c*; 1993*a*, 1994*a*, *b*, *c*, *d*, *f*, *g*, *h*, *i*, *j*, 1995*a*, *b*, *c*, *e*).

The Guideline on Licensing Digital Upgrades (EPRI, 1993*a*) was developed to be consistent with the established process in the United States for plant changes under the US Code (10 CFR 50.59). It helps utilities design and implement digital upgrades, perform safety evaluations, and develop information to support licensing submittals. It suggests a failure analysis-based approach that encompasses digital-specific issues and other possible failure causes, addressing both according to their potential effects at the system level. Abnormal conditions and events (ACES) (EPRI, 1995*a*), as described in ANSI/IEEE ANS 7-4.3.2-1993 ”Application Criteria for Programmable Digital Computer Systems in Safety Systems of Nuclear Power Generating Stations,” play an integral role in this approach.

Guidance for electromagnetic interference susceptibility testing of digital equipment (EPRI, 1994*b*) and a handbook for electromagnetic compatibility of digital equipment (EPRI, 1994*c*)) have been developed. These reports integrate the current knowledge and understanding of the electromagnetic issues concerning the installation of digital equipment in power plants. They direct the utility toward practical and economical solutions for dealing with electromagnetic interference. The handbook also helps eliminate some misconceptions that questioned the reliability of digital equipment subjected to the electromagnetic environment of nuclear power plants.

Guidelines and a handbook for software V&V have been developed (EPRI, 1994*d*, 1995*c*, *e*). These products describe approaches to categorize the software systems in terms of importance and consequences of failure. They then identify levels of V&V consistent with these categorizations. The guidelines for V&V (EPRI, 1995*c*) developed a set of 16 V&V guideline packages based on the system category, development phase, and software system component which is being tested. For V&V methods in the guidelines that do not have a good description elsewhere in literature on how to use them, 11 sets of procedures have also been developed. The report identifies 153 V&V methods for software systems which can be used on the 52 identified software defect types. The guidelines developed were based on the attempt to identify the methods which were most successful in finding various types of defects, on the attempt to assure that the different guidelines catered to the different needs of different systems, and on the attempt to emphasize the practicality and cost-effectiveness of the methods recommended.

A process for the commercial-grade dedication of hardware has been developed (EPRI, 1988, 1994*i*) and proven very successful. The basic concepts of this process are being used as the starting point for proposed commercial-grade dedication processes for digital I&C systems. The use of commercial-grade programmable logic controllers (PLCs) for safety related systems is described in reference (EPRI, 1995*b*).

Guidelines for evaluating and dedicating commercial-grade PLCs have been developed (EPRI, 1994*f*, *g*). Considerable concern has been raised about annunciator systems and the magnitude of alarms that an operator must be aware of during a transient. The large number of alarms and the presentation of them make the operators job more difficult and can potentially contribute to human errors. Work has been done on more intelligent alarm systems and the methods for presenting them (EPRI, 1992*a*, *c*, 1994*a*). Additional areas that have been addressed are pressure transmitters (EPRI, 1994*h*), radiation monitoring systems (EPRI, 1994*j*), and wireless monitoring systems (EPRI, 1993*c*).

2.4 *Demonstration Plant Projects*

The utility demonstration plants essentially are the laboratories where I&C cost and improvement options are being researched and developed. There are five utility demonstration plant projects in progress which are providing the primary inputs, as well as testing, validation and refinement activities for the methodology and guideline development under the I&C Initiative.

Activities at each of the five demonstration plants may include the preparation of I&C life-cycle management plans and plant computing and control architecture plans; system screening, deferred-upgrade maintenance planning, and detailed upgrade evaluations; testing, validation, and refinement of various plant-specific methodologies and guidelines; and development of options and plans for integration of I&C cost and performance improvement activities with related life-cycle management efforts.

Demonstration project activities have taken place at the Tennessee Valley Authority's Browns Ferry Unit 2, Baltimore Gas and Electric Company's Calvert Cliffs Units 1 and 2, Northern States Power Company's Prairie Island Units 1 and 2, Entergy Company's Arkansas Nuclear One Units 1 and 2, and Omaha Public Power District's Fort Calhoun. An example of a plant-specific plan developed under the demonstration program is the architecture plan for the plant data network at Browns Ferry (EPRI, 1993*b*).

3. APPLICATION TO KORI-2 PLANT

Recognizing that the EPRI I&C Upgrade initiative could have potential significant benefits for the operation of nuclear power plants in Korea, the Korea Electric Power Research Institute (KEPRI) has entered into an agreement with EPRI to adopt the I&C planning and evaluation methodologies for use in evaluating the I&C systems of Korea Electric Power Corporation's (KEPCO) nuclear power plants. Science Applications International Corporation (SAIC) has supported EPRI in the development of the methodology in the U.S., and will provide the initial support and technology transfer to KEPRI. A three phase effort has been adopted that will provide KEPCO with plans and reports on the I&C systems at Unit 2 of the Kori Nuclear Plant, and at the same time, provide for a transfer of the technology to KEPRI. Application of the methodology to other KEPCO nuclear plants may then be made by KEPRI.

The first phase of the effort was initiated in mid 1996, when EPRI and SAIC performed an initial scoping study of the I&C systems at Kori-2. Based on an initial review of the various systems, twenty were selected for further evaluation. The remainder of the efforts in phase 1 have now been contracted with EPRI and SAIC and are now underway.

Interviews with plant and utility personnel and reviews of plant documentation and records will result in status summaries of the twenty selected I&C systems. Maintainability assessments on the systems will provide the basis for a preliminary categorization into systems that are candidates for upgrade and systems that can be maintained for the planning period. This information is incorporated into the Life Cycle Management Plan. Responsibility for these activities are shared between SAIC and KEPRI in order that KEPRI can acquire the appropriate experience. EPRI provides a review function and the benefit of the experience from the demonstration plants. In addition to the system status summaries, subjects such as man-machine interfaces, plant networks, and computing platforms are documented. In order to prepare for potential replacement of plant monitoring systems, the Kori Plant Communications and Computing Architecture Plan will be produced as a part of the Phase 1 effort.

The second phase of the effort is a transition phase in which responsibility for the evaluations shifts from SAIC to KEPRI. Two upgrade candidate systems and two systems to be maintained are selected from the initial 20 systems. SAIC will provide the first system upgrade evaluation and Upgrade Evaluation Report. KEPRI will assume the lead role for the second system. Maintenance Plans will be developed for each system that is to be maintained using the same philosophy. KEPRI may then develop additional upgrade evaluations and maintenance plans with assistance from SAIC and EPRI.

In Phase 3, the Upgrade Evaluation Reports are used to develop functional specifications that are used in the procurement of replacement systems. The results of the process will eventually be realized when upgraded I&C systems are installed at Kori-2 that provide increased performance and lower O&M costs.

4. CONCLUSIONS

The implementation and integration of digital I&C systems enhances the ability to achieve the goals of improved availability and reliability, enhanced safety, reduced operations and maintenance costs, and improved productivity in nuclear power plants. The plant communications and computing architecture provides the infrastructure which allows the integration of systems and information. The modern technology of distributed digital systems, plant process computers (both monolithic and distributed), and plant communications and computing networks have proven their ability to achieve these goals in other industries and in nuclear power plants in other countries. The use of this modern, proven technology is a key contributor to improved competitiveness in nuclear power plants. EPRI has established an Integrated Instrumentation and Control Upgrade Initiative to support its member nuclear utilities in developing strategic plans and taking advantage of this modern technology to improve nuclear power plant competitiveness. KEPRI is beginning the process to apply this methodology to the Korea nuclear program.

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