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APPLICATION OF DIGITAL 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. Korea Electric Power Corporation (KEPCO) has planned to adopt the modern digital technology to the Instrumentation and Control (I&C) systems of KEPCO's nuclear power plants based on the I&C Planning and Evaluation Methodologies that have been developed by EPRI and demonstrated in several nuclear plants in the United States. This paper will review the aspects of adopting digital control technology and improvements in plant monitoring and network communications to Korean nuclear power plants.

1. INTRODUCTION

Some of the nuclear power plants in Korea were designed 20 to 30 years ago with analog I&C technology. Today, these 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. 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 in these plants.

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 30 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 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 I&C UPGRADE PROGRAM

The Electric Power Research Institute (EPRI) I&C Upgrade Program was established over a decade ago to respond to concerns of nuclear power plant operators with escalating operating and maintenance costs and obsolescence associated with I&C systems. The primary objectives of the Program are: to reduce the I&C contribution to escalating operating and maintenance costs, to support utility consideration and evaluation of improved control and monitoring functions offered by modern technologies, to provide utilities with a methodology for evaluating if it is more cost-effective to maintain existing equipment or to upgrade the system using new equipment, to promote standardization in order to minimize the uniqueness of individual systems and plants, and reduce costs of replacement equipment, and to promote the use of open data communications technologies in order to promote interconnectivity and avoid reliance on particular vendors.

A set of methodologies was developed for use by the utilities (EPRI 1994, 1995, 1996a, 1996b). The methodologies were developed, applied, and tested on a series of "Demonstration Plants". These plants were selected to represent various reactor vendors and types, and included Prairie Island 1&2, Browns Ferry Unit 2, Calvert Cliffs 1&2, Arkansas Nuclear One 1&2, and Fort Calhoun. The methodologies that resulted from the I&C Upgrade Program are: Life Cycle Management Plan Methodology, Plant Communications and Computing Architecture Plan Methodology, System Maintenance Methodology, and Upgrade Evaluation Methodology.

In addition to the basic methodologies, EPRI has developed a number of implementation guidelines that support the I&C system upgrade planning and implementation process. These guidelines cover such subjects as: Verification and

Validation, Licensing, Electromagnetic and Radio Frequency Interference, Commercial Grade Dedication, Abnormal Conditions and Events Analysis, and Functional Requirements Specifications for Digital Systems. These generic methodologies and guidelines are applied in the preparation of plant and system specific documents during the planning and upgrade process. Fig. 1 illustrates how the methodologies and guidelines provide the basis for both plant-specific and system-specific documents.

Application of the methodologies and guidelines at the Demonstration Plants has resulted in a test of the process which was used to improve the generic EPRI documents. It has also demonstrated the effectiveness of the process in improving I&C performance and providing cost-effective I&C maintenance and improvements.

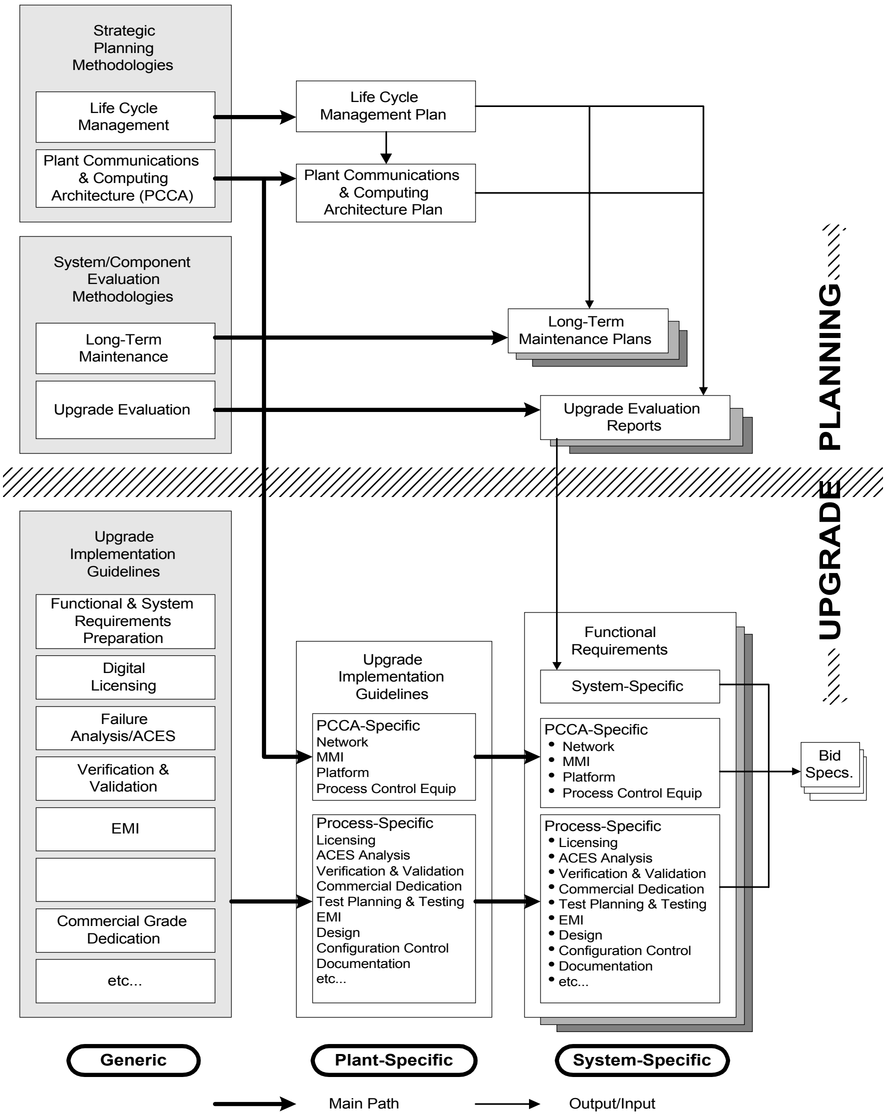

Fig. 1 Preparation of plant and system specific documents from the generic methodologies.

If the I&C planning and evaluation process results in a decision to upgrade the system, licensing aspects must be considered, particularly in the application of computer-based systems. As the I&C guidelines relating to licensing aspects were prepared, they were reviewed with the U.S. Nuclear Regulatory Commission (NRC) in order to incorporate techniques which could be used by the utilities in the licensing process. As a result, the NRC has endorsed EPRI's Guidelines for Licensing Digital Systems and the guidelines for the commercial dedication process (EPRI 1993).

3. APPLICATION TO KORI-2 PLANT

KEPCO has followed the nuclear power activities of EPRI for many years, and had joined EPRI Nuclear Power Group from 1996 to 1998 in order to directly participate in the research programs and benefit from the results. After review and evaluation of the EPRI research and development programs, KEPCO and its research division, Korea Electric Power Research Institute (KEPRI) have identified the EPRI I&C Upgrade Program as being beneficial to the operation of KEPCO's nuclear power plants. Having evaluated I&C upgrade methodologies developed by EPRI, KEPRI started a two-phase effort jointly with EPRI to develop an I&C upgrade plan for Kori-2.

The first step of this effort was an Initial Scoping Study of the I&C systems of the Kori-2 plant (KEPRI 1996). This study recommended a list of twenty systems to be included in the baselining effort. These systems were assigned preliminary categories as upgrade candidates (UC), retained systems (RS) or future systems (FS). Based on this recommendation, KEPRI and EPRI agreed to implement the cooperative research and development work for Kori-2 I&C Upgrade Planning project in December 1996.

The project was organized into two phases. The first phase included: development of system status reports for selected systems, development of the initial Life Cycle Management Plan (LCMP) which listed the selected systems as either upgrade candidates or retained systems to be supported with long term maintenance plans, and Plant Communications and Computing Architecture Plan (PCCAP). The second phase of the project included: development of the Upgrade Evaluation Methodology for Kori-2, which was derived from the corresponding generic EPRI methodology, development of the Upgrade Guidelines Manual, and development of an Upgrade Evaluation Report for the S/G Main Steam Pressure System.

3.1 Life Cycle Management Plan

The LCM Plan is the result of Phase 1 of a multiphase project designed to provide the KEPRI with the technology of I&C life-cycle management as developed by the EPRI. Its purpose is to provide a strategic plan that will allow the unit to perform I&C upgrades and maintenance in the most cost-effective manner. The LCM Plan includes: an overview of the I&C LCM project for Kori-2, the objectives, constraints and assumptions that define the process, a description of the interfacing plans and project, a description of existing I&C systems that are considered to be candidates for upgrade, a description of existing I&C systems that are expected to be retained, and a discussion of the maintenance strategy.

Information on the baseline systems was gathered by interviews with I&C and operations personnel during the Baseline Interview process. Based on that information, evaluation of plant data bases, and follow-up questions, system Status Summaries were prepared for the baseline systems. These Status Summaries are included in the Kori-2 LCMP (KEPRI 1998a).

3.2 Plant Communication and Computing Architecture Plan

In addition to the preparation of LCMP and the associated Status Summaries, Phase 1 of the project includes the preparation of the PCCAP (KEPRI 1998b). The PCCAP supports the LCMP and serves as a reference document in the generation of functional requirement specifications for any upgraded I&C systems. This PCCAP summarizes the practices, standards, and techniques to be employed in the standardization of I&C systems and their communications networks, and involves developing architecture plans and strategy statements for the upgrade of networks, MMI, computer platforms, and process control equipment. These guidelines have been developed using the baseline systems identified in the Kori-2 I&C Upgrade Planning Project to support the plant computing architecture, plant communications architecture, and the MMI strategy.

The existing architecture at Kori-2 may be segmented into three functional categories: safety, control, and monitoring. The three architectures are independent, hierarchical structures with defined modes of communication within and between the functional hierarchies. The future computing architecture will remain segregated by function, similar to the existing architecture. The segments are safety, control, and monitoring. The architecture of the safety systems and control systems shall remain identical to the existing architecture. The future architecture of the monitoring systems will evolve in steps to a fully distributed computing environment with nodes having cooperative peers on a standards-based communication network. This future monitoring system architecture is based upon a hierarchical computing and communication environment. The hierarchical levels are shown in Fig 2.

The existing plant communication architecture has very limited communications between the individual systems. Further, the information from systems other than the OACS (e.g., P2500 Replacement, Chemistry, etc.) is not communicated to the OACS and therefore, not available to the users on the RPMS. Fig. 3 illustrates the future high-level network data flow after all future systems and upgrades have been completed. The future Integrated Computer System (ICS) network for Kori-2 I&C is intended to provide information from each of the I&C systems servers to the user stations on the ICS LAN. The ICS Information Server will receive and manage data from all ICS monitoring systems (OACS, P2500 replacement, RCP&TM, etc.). The ICS Information Server will poll the various systems at predetermined frequencies to gather information. The ICS Information Server will make the information gathered available to users on the ICS LAN.

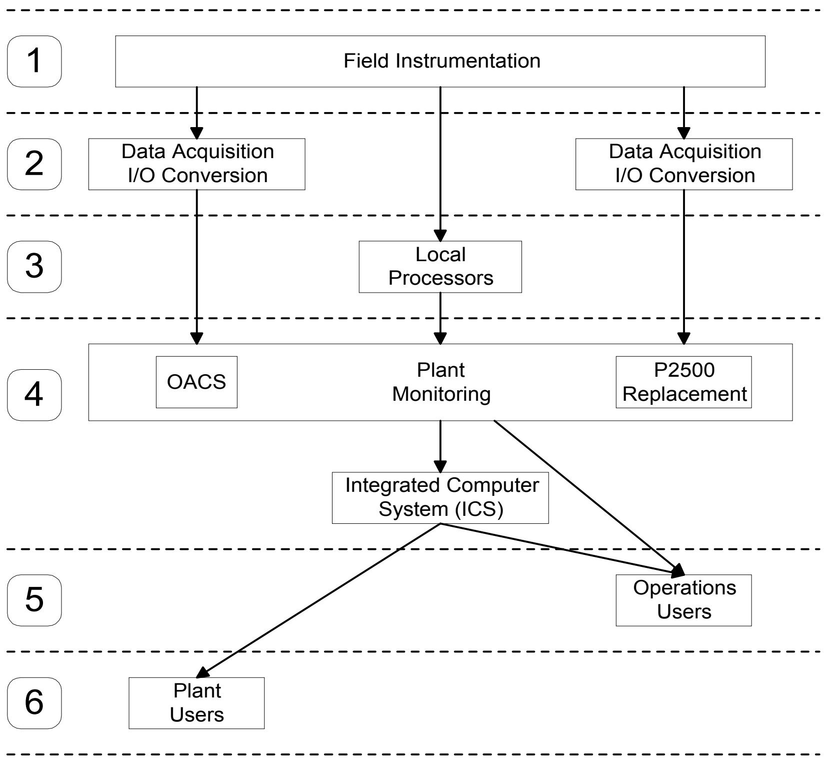

Fig. 2 Future computing architecture hierarchy for monitoring systems.

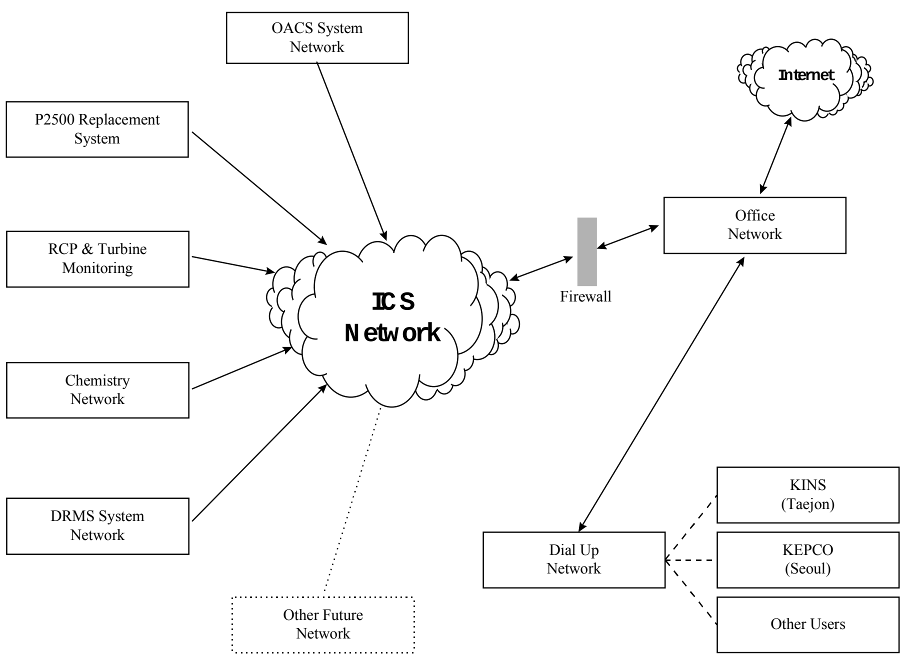

Fig. 3 High-level future network data flow.

3.3 Upgrade Evaluation

Phase 2 of the project begins with the development of an Upgrade Evaluation Methodology and Upgrade Guidelines. The methodology and guidelines are then used in the evaluation of highest priority Upgrade Candidate system - S/G Main Steam Pressure System. The S/G Main Steam Pressure System is one of the functional systems of the Westinghouse 7300 Control and Protection System. The 7300 system includes three basic functional areas: 1) the reactor protection functions, 2) the reactor control functions, and 3) the balance of plant control functions. The S/G Main Steam Pressure System was chosen as representative of the 7300 subsystems.

Three upgrade alternatives were evaluated for S/G Main Steam Pressure System. The minimum alternative is simply to continue the present practice of maintaining the existing system by replacing the 7300 electronic circuit cards as they fail, or on a scheduled preventative maintenance replacement cycle, whichever occurs sooner. The replacement cards would continue to be procured from the sole supplier Westinghouse. This alternative does not do anything to upgrade the system, or to address any of the problems that have been identified for this system or address any of the objectives that were listed for evaluation of this system. The median alternative is to replace the 7300 cards with a new card design that uses modern digital technology. Cards of this type are currently nearing commercial availability from a development, testing and qualification program that was jointly supported by the Westinghouse Owners Group, Westinghouse, and EPRI. The cards incorporate Application Specific Integrated Circuit (ASIC) technology. The ASIC cards can replace existing 7300 cards, on a card-for-card basis. The ASIC cards are intended to be used without requiring any rewiring, cabinet modifications or license amendment. The maximum alternative is to completely replace the existing system with a modern digital system. This can be completed by procuring such a system from any of several suppliers. This evaluation was based on the Foxboro Spec 200 Micro system, since that is the product that was used recently for upgrade at Kori-1.

According to the economic evaluation of the alternatives, it was recommended that KEPCO join the WOG ASIC project and use the new ASIC boards for future replacement of 7300 boards in the Kori-2 steam generator main steam pressure system.

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 PCCAP provides the infrastructure which allows the integration of systems and information. The modern technology of distributed digital systems, plant process computers, 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 I&C Upgrade Program to support its member nuclear utilities in developing strategic plans and taking advantage of this modern technology to improve nuclear power plant competitiveness. KEPRI established the project to apply this methodology to Kori-2 nuclear power plant.

Kori-2 I&C Upgrade Planning was based upon I&C Upgrade Methodologies developed by EPRI. EPRI I&C Upgrade Methodologies were successfully applied to develop LCMP that classifies the selected systems as either upgrade candidates or retained systems, the PCCAP, and the Upgrade Evaluation Report for the highest priority upgrade candidate system for Kori-2. The completion of this project does not mean the completion of Kori-2 I&C Upgrade Planning. It needs to be continued to update Kori-2 LCMP periodically to incorporate any changes in system priorities or performance and develop the UER for the second and third highest priority upgrade candidate systems. The experience and technology gained in this project will be applied to other KEPCO's nuclear power plants in the future.

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