Instrumentation and Control

Program Overview

Program Description

Instrumentation and control (I&C) systems affect all areas of plant operation and can profoundly impact plant reliability, efficiency, and operations and maintenance costs. Plants are facing changes that involve serious I&C-related challenges—equipment is getting older and cost-effective operation is more critical.

The Electric Power Research Institute’s (EPRI’s) Instrumentation and Control program provides the technical bases to apply advanced I&C and information technologies so that existing and new nuclear plants can tap into functionality and capabilities underutilized to date in the nuclear sector. These capabilities will enable nuclear plants to maintain safe operation while managing I&C obsolescence with higher equipment reliability and personnel productivity. EPRI research focuses on improving the reliability of existing I&C systems and components, enabling the implementation of replacement I&C systems and advancing the use of I&C to enhance plant health and productivity.

Research Value

Research results from the Instrumentation and Control Program enable nuclear plants to apply I&C systems in an effective manner that supports safe, reliable plant operation. Advanced I&C research provides the technology and knowledge base so plant owners can potentially realize direct and indirect cost savings, make technically sound system- and component-level decisions, and comply with regulatory requirements. Instrumentation and Control Program participants gain access to the following:

- Strategic roadmaps outlining research gaps confronting key issues—such as digital I&C implementation—and the collaborative actions needed to address these gaps
- Life-cycle management and maintenance guidelines for generic existing I&C systems and components
- Technical bases for the generic resolution of regulatory issues for new and operating plants, such as risk-informed defense-in-depth and diversity assessment guidance, cyber security guidance, and guidelines for electromagnetic interference testing and digital upgrades
- Technical evaluations for new technologies in nuclear applications, such as programmable controllers, “smart” sensors, and wireless communications
- Guidance in setting up automated asset- and equipment-monitoring systems that will improve overall plant reliability
- Improved decision-making tools such as control room human factors guidelines, improved information access and visualization, and visualization-enhanced approaches for tacit knowledge capture and training
- Training, operating experience, and lessons learned on I&C replacement projects that will enable plants to avoid costly mishaps and electromagnetic interference events and to implement plant strategies to cost-effectively manage I&C obsolescence

Approach

The I&C Program is designed around three main initiatives:

- Improve Reliability of Existing Systems and Components: I&C systems such as printed circuit cards must be reliable to avoid unplanned plant trips and down-powers. This project develops generic technical bases for effective maintenance and life-cycle management of I&C systems and components already installed in the plant, which will always be required to maintain and improve the reliability of the existing I&C systems and equipment. Key research products include life-cycle maintenance guidance for analog and digital circuit card systems and industry-accepted preventive maintenance guidelines for digital systems to reduce failures and inappropriate maintenance activities.
Enable Replacement System Implementation: As the nuclear industry transitions from analog to digital technology, there are several I&C-related issues for which the available technical and regulatory guidance is unclear, incomplete, or evolving. Examples include failure analysis, cyber security, defense-in-depth and diversity, various design considerations for control rooms, and the impact of new technologies such as field programmable gate arrays. This project develops the technical bases to support the deployment and licensing of I&C and human system interface (HSI) replacement systems; develops guidelines for implementing new I&C, information, and HSI technologies in nuclear applications; and documents operating experience and lessons learned.

Use Advanced I&C to Improve Overall Plant Health and Productivity: Existing plant I&C equipment and functionality do not accommodate up-to-date features and techniques that can reduce costs and enhance reliability and productivity. Expanded capabilities can streamline many plant tasks and procedures to reduce operations and maintenance costs while improving reliability and extending component lifetimes. This project will pursue advanced technologies such as remote monitoring, wireless communication, early prognosis, and data visualization, which could yield benefits such as calibration interval extension, on-line equipment condition assessment, self-testing and diagnostics, and improved access to plant data.

To address strategic objectives established for each of its programs, EPRI has developed roadmaps to plan, coordinate and execute needed research among multiple entities. For the I&C Program, a roadmap has been developed to address the technical barriers that have precluded widespread digital I&C implementation. Additional roadmaps are under development for circuit card aging and obsolescence management, I&C reliability, and continuous on-line monitoring.

Through separate supplemental projects, nuclear plant owners can gain access to additional research opportunities, including implementation support for I&C maintenance and life-cycle management programs, development and demonstration of new technologies for improving I&C productivity, and forums for sharing lessons learned on reliability, digital I&C implementation, and fleet-wide monitoring.

Accomplishments

EPRI’s Instrumentation and Control Program has provided much of the fundamental basis supporting digital implementation in the nuclear industry and in identifying and overcoming many of the barriers to implementing newer technology. These include the following:

- Developed a life-cycle management guidance document for circuit cards. The report provides guidance to increase the reliability and operating life of existing circuit cards and components, such as guidelines for the proper handling of printed circuit cards and their components.
- Assessed the benefits of I&C defense-in-depth and diversity from a risk perspective. Higher-frequency events such as turbine trip and loss-of-feedwater showed greater safety benefits than rarer accident sequences such as loss-of-coolant.
- Developing a failure analysis guideline for digital systems that can be used to inform decisions on I&C architecture and overall system reliability.
- Obtained U.S. Nuclear Regulatory Commission approvals in safety evaluation reports on various guidelines/requirements (digital platforms, commercial off-the-shelf components, electromagnetic interference testing).
- Issued technical guideline for cyber security requirements and life-cycle implementation of nuclear plant digital systems. This guideline details 138 areas of security, covering everything from passwords and wireless connections to encryption and intrusion detection. Two appendices lay out exact steps to follow to address cyber security when designing and installing a new digital I&C control system.
- Developed technical guidelines for using field programmable gate arrays (FPGAs) in nuclear safety-related applications.
- Produced a Nuclear Sensor Roadmap that describes sensor-related issues, needs, and technologies relating to aging and obsolescence, I&C retrofits, power uprates, long-term operations, and new builds. A key conclusion is that the relatively small market for nuclear-grade sensors leaves the industry vulnerable to near-term supply shortages and may lead to under-investment in emerging technologies.
• Developing implementation guidance and summary of all research to date on instrument calibration extension.
• Issued guidance for the implementation of wireless networks in nuclear power plants, with a secondary emphasis on the use of wireless sensors for asset condition monitoring. Guidance includes technical details and real-life experiences from industry and addresses concerns such as cyber security and electromagnetic and radio frequency interference.

Current Year Activities
I&C Program research and development for 2012 will focus on life-cycle management, new I&C system implementation, equipment reliability, and plant productivity. Specific efforts will include the following:
• Update failure modes and mechanisms report for printed circuit card systems
• Develop guidance on replacement of analog circuit cards with FPGA based substitute cards
• Develop guidance for maintenance of programmable digital based systems
• Update computer-based training modules on implementing digital I&C to facilitate utility application with reduced cost and greater convenience
• Develop algorithms and techniques to integrate modeling and monitoring results to provide better indication of equipment health

Estimated 2012 Program Funding
$3.3 million

Program Manager
Robert Austin, 704-595-2529, raustin@epri.com

Summary of Projects

<table>
<thead>
<tr>
<th>Project Number</th>
<th>Project Title</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>P41.05.03.01</td>
<td>Roadmap</td>
<td>Digital I&amp;C implementation (Existing Plants)(Roadmap) (QA)</td>
</tr>
<tr>
<td>P41.05.03.02d</td>
<td>I&amp;C Productivity Improvements (supplemental)</td>
<td>The ability to improve plant performance and reduce operations and maintenance costs over the extended life of plants is becoming increasingly difficult with current technology and workloads. The I&amp;C Productivity Improvements project will identify implementation opportunities through new technologies and new work task definitions that can cost-effectively improve performance, reduce costs, and lead to new plant capabilities.</td>
</tr>
<tr>
<td>P41.05.03.03a</td>
<td>Digital I&amp;C Implementation (supplemental)</td>
<td>The Digital I&amp;C Implementation project group coordinates at least one workshop per year to promote discussion and resolution of problematic digital I&amp;C implementation issues and development of new solutions, guidance, and training materials when needed.</td>
</tr>
<tr>
<td>P41.05.03.04</td>
<td>I&amp;C Reliability (supplemental)</td>
<td>Instrumentation and control (I&amp;C) maintenance and life-cycle management has emerged as a critical reliability issue for operating nuclear plants. The I&amp;C Reliability project provides participants with implementation support for I&amp;C maintenance and life-cycle management programs and a forum for sharing experiences and identifying research needs to address emerging problems.</td>
</tr>
</tbody>
</table>
Digital I&C implementation (Existing Plants)(Roadmap) (QA)

**Key Research Question**

Operating nuclear plants are gradually transitioning much of their aging and obsolete instrumentation and control (I&C) equipment from analog to digital technology. However, despite significant safety, reliability and performance advantages, its acceptance and use have been slow to develop in the nuclear power industry. Plants have experienced significant unanticipated costs, delays and operating events associated with digital system implementations. As a result, the risks associated with I&C upgrades are often judged to be greater than the risks of continuing to operate with obsolete analog equipment.

**Approach**

EPRI will develop its guidance and training modules on a topic-by-topic basis, using technical advisory groups (TAG) comprised of knowledgeable utility, INPO, NEI, and industry representatives. The TAGs will guide product development and act as reviewers and contributors to ensure that the products have appropriate scope, detail, and practical utility for their intended users. Products will be updated on an as-needed basis as new information and operating experience become available and new technical and regulatory issues come to light. When appropriate, EPRI products may be forwarded to others, for example to NRC for endorsement, to the Advisory Committee on Reactor Safeguards (ACRS) for information, to standards organizations for incorporation into their guidance, to NEI for use in supporting regulatory positions, and to INPO for training or further distribution through their channels.

Topic prioritization will be based on input from the I&C Integration Committee. Preference will generally be given to products with greater near-term need/impact and/or broader applicability across reactor types and countries. Specific topics of interest will include the following:

- Computer-based training modules
- Failure analysis of digital systems
- Protecting against common-cause failure (CCF)
- Design and use of field programmable gate arrays (FPGA) in high-integrity applications
- Lessons learned and case studies based on operating experience in the United States, Korea, Canada, France, Japan, and other countries
- Human factors engineering (HFE) for digital interfaces
- Cyber security
- Application of risk methods to digital equipment
- Electromagnetic compatibility (EMC)
- Technical bases for resolution of regulatory issues (for example, CCF, HFE, cyber, risk, EMC, failure analysis)

**Impact**

Several factors drive the need for a comprehensive plan to resolve issues currently discouraging the implementation and successful application of digital I&C in nuclear plants, including the following:

**Negative Experiences with Digital Implementations.**—Digital upgrades at several plants have incurred significant unanticipated costs due to problems such as inadvertent plant trips, extended outages to correct startup issues, project delays, and cancellations. Key factors include inexperience with digital technology and the need for a paradigm shift to foster awareness of the issues and adapt utility and vendor processes, organizations, and skill sets accordingly.

**Regulatory Uncertainty.**—Licensing uncertainty on key issues has resulted in open-ended regulatory reviews with significant delays and increased project costs. Many plants now avoid digital implementations that involve unsettled regulatory issues or prior acceptance by the regulator.
Increasing Performance and Reliability Demands—Aging analog systems are becoming less reliable and more difficult to maintain, while expectations for equipment reliability and plant availability are increasing. Analog I&C plants have many single point vulnerabilities that could be eliminated using digital technology, with corresponding improvements in reliability and safety. Further, new operating conditions associated with power uprates could introduce functions and I&C performance requirements (for example, accuracy, response time) that require digital technology capabilities.

Obsolescence—In many cases, the old analog equipment has become difficult or impossible to maintain. Suppliers have discontinued support, spare parts are no longer available, and expertise on the old equipment has been lost through attrition and retirement. License renewal and extended fuel cycles exacerbate this problem. Further, while it is possible to extend the lives of some analog I&C systems for many years using enhanced maintenance practices and reverse-engineered replacement parts, this approach becomes more costly and less effective over time. Also, it typically cannot provide key digital technology benefits, such as performance improvements and elimination of single point vulnerabilities.

How to Apply Results

Upon completion of this work, nuclear utilities, their key equipment suppliers, and system integrators will be prepared to cost-effectively implement and maintain digital I&C in all types of plant applications. Digital I&C implementation will become routine, and most plants will have long range plans for I&C obsolescence management. Utility engineers will have convenient access to all needed guidance and training on the technical and regulatory issues. Utility processes and personnel will address the technical, programmatic, and ‘digital’ issues with predictable costs and schedules and with minimal risk of unexpected and undesired behaviors.

Also, the regulatory environment for digital I&C will be well-understood and stable; it will consider the safety significance of I&C in the context of overall plant risk and will allow I&C solutions that are practical, cost-effective, and well-engineered to meet safety and reliability goals. Regulatory reviews will have demonstrated cost and schedule predictability, with timely resolution of requests for additional information and issuance of safety evaluation reports. The review process will not create unacceptable project and schedule risks. EPRI products will include technical reports, guidelines, and companion training modules to help resolve the issues described above, addressing topics such as failure analysis, cyber security, software common-cause failure, human factors engineering, configuration management, and lessons learned from operating experience. EPRI will make its computer-based training (CBT) modules available for use through INPO-WANO on-line training systems by the end of 2011, with additional modules later if needed. Much of this material also will be applicable to new plants and will be used accordingly. EPRI also will provide technical input to inform regulatory issues under the existing EPRI/NRC memorandum of understanding.

Industry Oversight—Organizations such as INPO and World Association of Nuclear Operators (WANO) will make the EPRI digital I&C CBT modules available to utility engineers. They also will ensure that utility engineers maintain competence on digital issues, that utility processes are updated to address specific digital system concerns such as configuration management and common-cause failure, and that the processes are being applied appropriately. Industry operating experience will be monitored to detect emerging digital I&C issues and share lessons learned.

Regulatory Interfaces—Organizations such as the Nuclear Energy Institute will use EPRI results in assessing regulatory uncertainty concerns, such as the content and timing of information needed in licensing submittals involving digital upgrades and the possible update of existing regulator-endorsed guidance on common-cause failure in critical non-safety applications. Pilot application projects will be used to demonstrate the utility of proposed solutions and regulatory guidance.

Utilities/Suppliers—Utilities will apply EPRI and INPO guidelines and training materials along with relevant regulatory guidance and industry standards to develop and maintain proficiency in managing digital I&C, from specification to design evaluation, implementation, operation and maintenance, and obsolescence management planning. They will require suppliers, integrators, and contractors to apply these materials on an as-needed basis. In some cases, operating plants may elect to wait for key regulatory and project issues to be resolved via
new plant builds, and then apply the proven solutions and experience to reduce regulatory, cost, and schedule risks.

Selected reports and products may be prepared in whole or in part in accordance with the EPRI Quality Program Manual that fulfills the requirements of 10CFR50 Appendix B, 10CFR21 and ANSI N45.2-1977. Reports and products developed under the EPRI QA program will be marked and identified as such.

I&C Productivity Improvements (supplemental)

Key Research Question

The nuclear power industry is concerned about its ability to maintain current high plant performance levels due to aging and obsolescence, knowledge drain, and fewer plant staff. Current plant operations are labor-intensive due to the vast number of operational and support activities required by the current technology. These concerns increase as plants extend their operating life.

To further improve performance while reducing human errors, nuclear plants increasingly focus on operations and maintenance costs, of which labor is typically the largest contributor. New productivity improvement capabilities with measurable economic benefits are needed so that a successful business case can be made for their use.

Approach

Improved and new instrumentation and control (I&C), human-system interface (HSI), information, and communications technologies can address concerns about cost-effectively maintaining current performance levels and enable shifts to even higher performance levels. This project will facilitate new technology implementation to improve productivity. Efforts will include demonstration of new technologies and how they can be used for plant and personnel productivity improvements, as well as providing pros and cons of their uses. Based on member input, required guidance for the application of technologies and pilot demonstration applications will be developed or requested to be developed.

Impact

Implementation of modern technologies can provide multiple benefits:

- Automation of appropriate tasks will reduce workload and human stress levels, remove human error-prone activities, and perform repetitive and time-consuming activities more effectively, allowing humans to better focus on essential activities requiring human capabilities.
- Simulation and visualization will support planning and decision-making, improve designs and facilitate early input from users, support development and testing, facilitate knowledge capture and training, improve job performance, and reduce the likelihood of human errors.
- HSIs and information technology will provide better user-friendliness, reduce the likelihood of human error, improve situation awareness, enable rapid access to data, and support decision-making.
- Communications technologies will enable collaborative activities, including rapid access to remote expertise, which will be even more effective with the use of visualization and simulation.

How to Apply Results

Members will apply the results of this project by learning how to implement advanced technologies for productivity improvements into plant modernization and workload definition plans. Potentially, pilot projects will be developed from which members can implement plant-specific applications.
Digital I&C Implementation (supplemental)

Key Research Question

Digital upgrades at several plants have involved significant unanticipated costs due to problems coping with various implementation issues. Examples of problematic issues with digital upgrades include unanticipated behaviors of digital equipment, software verification and validation, configuration management, evaluation of failure modes and effects, commercial grade dedication, and inadequate vendor oversight. Adverse impacts have included the following:

- Large increases in vendor and utility staff costs
- Significant project delays, as much as one or two refueling cycles
- Plant trips
- Extended outages to correct problems
- Additional engineering to correct problems
- Increased regulatory scrutiny

The problems are typically caused by inadequate knowledge and processes at the utility and its suppliers that prevent utility staff from managing the issues cost-effectively. In some cases, emerging instrumentation and control (I&C) and human-system interface (HSI) technologies include standard features that can eliminate or mitigate problems.

Approach

Many nuclear plant operators have requested EPRI assistance in improving plant programs for managing the problematic issues associated with digital upgrades. In some cases, industry guidance and good practices already exist, but have not been broadly communicated or widely practiced. In other cases, practical guidance for utility engineers is simply not available.

This project coordinates two meetings per year to address one or two specific application issues that are proving problematic for current digital upgrade projects. Topics include ensuring high reliability in non-safety systems, performing failure modes and effects analyses (FMEA) for digital systems, vendor interaction and oversight, and factory acceptance testing. Participants propose meeting topics, share plant experiences, discuss lessons learned, and identify areas that need additional research or guidance for utility engineers. Where appropriate, participants may develop or request new guidance and/or technical transfer mechanisms to provide practical, useful tools to plant engineers.

Impact

This interest group develops and promulgates practical guidance that will help utilities anticipate, detect, and mitigate potential problems before they result in expensive learning-curve events that can cost millions of dollars. The group promotes technology transfer of the latest industry and EPRI guidance on key issues and opportunities to identify current and future research needs for solutions that will smooth the transition to digital instrumentation and control (I&C) and ensure its long-term viability. Specific technical benefits include the following:

- Practices that will improve utility handling of problematic digital system issues
- Practices that will increase utility engineers’ ability to detect and manage weaknesses in suppliers’ designs and processes for key issues, such as failure analysis, software verification and validation, and software configuration management
- Technologies, strategies, and guidance that enable plant engineers to ensure long-term obsolescence management of digital systems using “design for replacement” approaches
- Practical guidance and training materials for utility engineers
How to Apply Results

Members will incorporate the lessons learned, guidelines, and training materials generated in this project into their processes, procedures, and training for digital upgrades.

I&C Reliability (supplemental)

Key Research Question

Aging or poorly maintained instrumentation and control (I&C) systems have resulted in numerous plant trips and power derates and have compelled nuclear plants to take repair or replacement actions to maintain plant availability and reliability. The Institute of Nuclear Power Operations has identified I&C components, in particular circuit cards, as an "Area for Improvement" at many plants. Because of the time and resources required to replace older I&C systems with modern systems, it may never make business sense in some instances to upgrade these systems. Plants will have to maintain existing systems long past the period where effective vendor support is available. In addition, replacement systems will require maintenance and life-cycle planning for eventual replacement.

Approach

Many nuclear plant operators have requested EPRI assistance in developing programs for managing I&C obsolescence focused on maintaining existing components. The I&C Reliability project provides a forum to exchange plant experience, best practices, and lessons learned. Such interactions support the implementation of effective I&C maintenance and life-cycle management technology and approaches for generic I&C maintenance issues that cut across multiple systems and/or suppliers. The group ensures that EPRI research and guidance documents respond to, and evolve with, the expanding knowledge base regarding I&C maintenance and life-cycle management.

Impact

I&C system and component failures are expected to increase as plants age, unless aging is carefully managed. This project provides many benefits:

- Broad cross-section of operating experience from which to capture lessons learned
- Identification of high-priority research activities to resolve I&C maintenance and life-cycle planning issues
- Opportunity to advise EPRI on I&C research to ensure activities address industry needs

How to Apply Results

Members apply the results of this project by adapting industry lessons learned into their plant I&C programs to more effectively maintain existing I&C systems and components.