IMPACT OF DIGITAL INFORMATION AND CONTROL SYSTEM PLATFORM SELECTION ON NUCLEAR POWER GENERATING PLANT OPERATING COSTS

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ABSTRACT

Information is presented on the benefits of a well-planned information and control systems (I&CS) replacement approach for aging nuclear power generating plants' I&CS. Replacement of an aging I&CS is accompanied by increases in plant profitability. Implementing a structured I&CS replacement with current technology allows improved plant electrical production in parallel with reduced I&CS operations & maintenance cost. Qualitative, quantitative, and enterprise management methods for cost benefit justification are shown to justify a comprehensive approach to I&CS replacement. In addition to the advantages of standard I&CS technologies, examples of new I&CS technologies are shown to add substantial cost benefit justification for I&CS replacements. Focus is upon I&CS replacements at nuclear power plants, however the information is applicable to other types of power generating facilities.

INTRODUCTION

It is well known that information & control system (I&CS)[1] technology is important to the operation of power generating plants because the systems provide the intelligence for the control of plant equipment, and information to optimize plant operation. Many power plants have been operating at realistic power generation levels as limited by the aging plant I&CS equipment. However, the plants are not operating at optimum levels with respect to the capabilities of the overall plant equipment. Lessons learned from recent I&CS replacements show that the advanced I&CS available today puts information in the hands of the plant staff to optimize plant operations and reduce plant operating costs. Therefore, some plants view the key to attaining longer term reduced plant operating costs as an integrated plant lifetime I&CS upgrade plan with implementation justified by strong cost benefit assessments. An integrated I&CS lifetime plan presents a methodical, integrated, process for replacing the plant's information systems, non-safety, and

[1] The unique terminology I&CS, with "I" meaning information—not the traditional instrumentation, is used to emphasize the authors' conviction that the traditional boundaries between instrumentation systems and information systems are eliminated by today's I&CS platforms. This fundamental aspect of today's I&CS has dramatic and far-reaching implications on the impact of advanced I&CS technology on plant profitability.

safety control systems. Entergy's ANO plants and Vattenfall's Ringhals plants are performing I&CS replacements based upon this integrated I&CS vision. At other plants, each specific I&CS upgrade project is evaluated for its own near term need. This latter approach for considering only near term needs can be used alone to justify major I&CS replacements as exemplified by the NSSS & BOP control system replacements recently conducted at ASCO® Units 1 & 2. With either a near term or integrated plan focus, plant O&M costs are reduced if the plan minimizes the number of I&CS platforms for the plant staff to understand, maintain, and operate. Crucial cost reductions for optimized plant I&CS staffing, training, and maintenance cost can then be added to the advantages of increased plant availability and reliability using advanced I&CS technology.

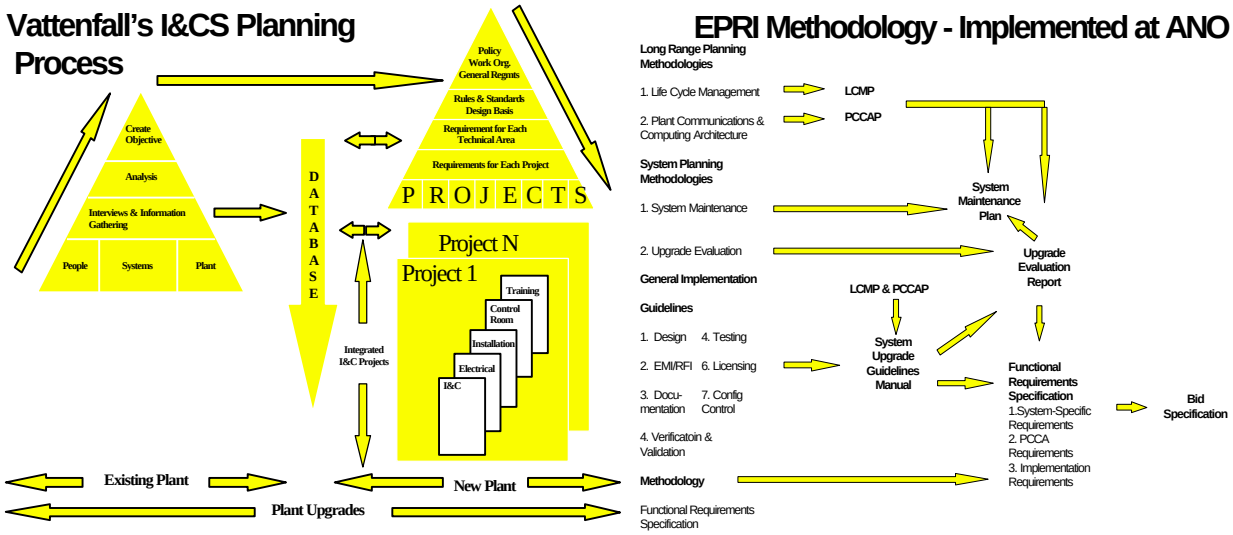


Figure 1A and 1B I&CS Replacement Address Plant Specific I&CS Objectives

I&CS REPLACMENT COST BENEFIT JUSTIFICATION

Successful cost benefit justification for a remaining plant lifetime I&CS replacement project should be based upon top-down goals integrating with bottom-up planning. Some basic methods to that tie these goals and plans into a common cost & benefit perspective are summarized below.

Enterprise Management for Intelligent Management Decisions

Figure 2B presents the detailed top-down driven Enterprise Management objectives for a typical plant to replace the plant I&CS system over a period of years. An Enterprise Management Financial Model is a top-down financial planning tool that allows what-if scenarios for the impact of I&CS paths on the plant's financial bottom line. From this tool, goals for cost reductions and capital investment can be selected to drive objectives for the I&CS staff. Therefore, this tool can quantify the I&CS staff's objectives and provide the basic guidelines for an I&CS lifetime plan that supports the plant's long term financial plan. The intent of this Enterprise Management plan is to make a meaningful contribution to the reduction of power generation costs by implementing I&CS upgrades that increase the plant capacity factor, reduce engineering costs, and reduce O&M cost much more favorably than the rate of capital additions for the I&CS upgrades. In this example, replacing I&CS systems requires the I&CS staff to implement a plan, not only reducing I&CS maintenance cost, but requiring an I&CS replacement plan leading to improvements to the current plant megawatt output and plant revenue.

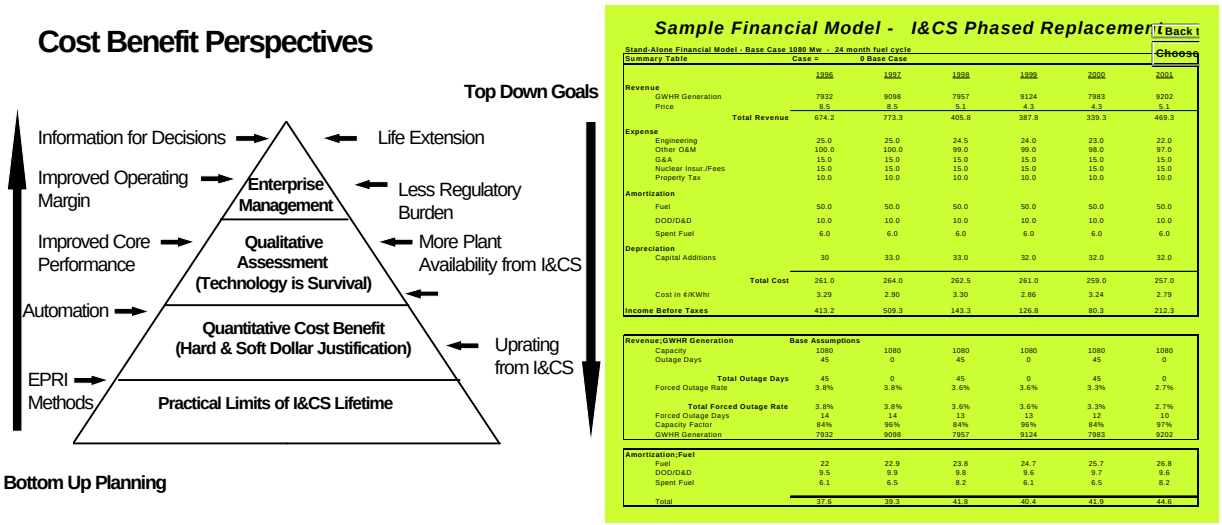


Figure 2A and 2B Cost Benefit Perspectives Integrate Enterprise Management and Near Term Operational Goals

Qualitative Cost Benefit Perspectives

Cost benefit justification for I&CS replacement can not be pursued on a purely quantitative, that is the traditional numerically analytical, bases. Supplementing the traditional quantitative evaluations, are qualitative perspectives on the value of the technology. I&CS replacements are viewed as being the technology to allow utilities to get actionable information in the hands of the plant staff in an efficient, and low staffing process. Actionable information means the technology provides information in a format that the plant staff can improve plant operations directly as a result of the information. More fundamentally, the rapidly advancing field of I&CS technology is the most important enabling technology for utilities to attain objectives for reduction of I&CS staff, reducing maintenance cost, and improving plant operations. Enabling technology means a new technology that allows attaining an objective that would not be reasonably attainable without the availability of the technology. Plant management must endorse this value perspective to pursue this visionary path, thus having a better chance of surviving the on-going re-structuring of our power generation industry.

Quantitative Cost Benefit Analyses

Quantitative cost benefit refers to the traditional numerical analysis of I&CS replacement pay back periods. The categories of hard & soft cost savings that can be attributed to an I&CS replacement are compared to the cost of the I&CS replacement plan. Quantitative cost benefit approaches are bottom-up tools focusing on today's cost and projecting cost reductions from current values. Typically, quantitative cost benefits are dominated by hard cost saving objectives for I&CS staff reduction, reduced equipment maintenance costs, and improvements in plant operations. Soft cost savings can be included in several areas depending upon the plant's integrated I&CS lifetime plan, if one exists.

Practical Limits of I&CS Lifetime

Replacement parts and original equipment manufacture (OEM) support for the current I&CS systems will not be available indefinitely. I&CS industry experiences on the steadily increasing cost of replacement parts, standard commercial OEM vendors' history of approximately one decade of installed base support, and the movement towards digital I&CS exemplify the practical limits of I&CS life.

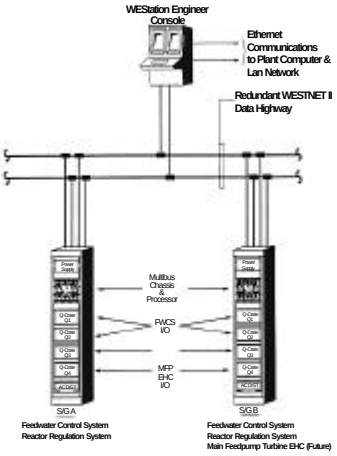
EXAMPLES OF THE IMPACT OF NEW I&CS TECHNOLOGIES

The following examples of recent I&CS technology show the cost benefit of I&CS standardization, improved system design, and I&CS automation.

Improved Control Algorithms to Increase Availability

Advanced control algorithms for the I&CS functional design of control and protection systems has proved to be effective through hundreds of plant years of operation. Several improvements have shown large positive impacts on plant operation, most notably advanced digital feed water control systems. See Figure 3A representing a recently successful project at Entergy's Arkansas Nuclear One - Unit 2 plant. Digital I&CS technology allows for more exact I&CS design algorithms and improved control system performance. As another example, improved steam dump control makes it possible to reduce the number of valves in the steam dump system, and minimize the impact on the plant when the steam dump valves are actuated. The financial impact of improved control system algorithms on plant operating costs can be very significant.

Arkansas Nuclear One - Unit 2 Advanced Feed Water Control System Architecture



Sample Impact of Improved Control System Algorithms on O&M Costs

Item	T/G DEH	Advanced Feed Water Control	Advanced Main Steam Control	Advanced NSSS/BOP Control
Plant Trips	$1000K	$1000K	$5000K	$2000K
O&M Reduction	$250KM	$250K	$250K	$500K
Plant Complexity				
Hardware	$500K	$500K	$500K	$1000K
Software	$250K	$250K	$250K	$500K
Total	$2000K	$2000K	$1500K	$4000K
Reference Plant(s)	Numerous	Ten Plants Including Diablo Canyon Units 1 & 2, Maguire Units 1 & 2, and ANO Unit 2	WH Studies	ASCO Units 1 & 2

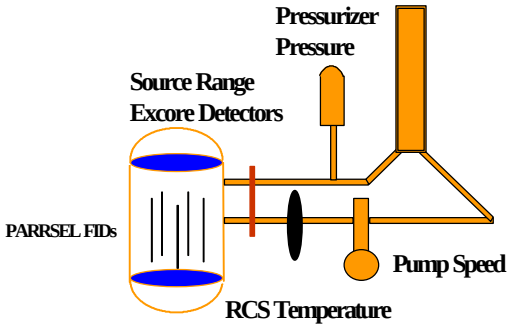
Figure 3A and 3B Improved I&CS Algorithms Have Been Successful Improving Operations at Several Plants

Representing the benefits that I&CS replacements produce on nuclear power plants, Asociacion Nuclear ASCO has performed a total nuclear steam supply system (NSSS) and balance of plant (BOP) digital control system upgrade, utilizing a distributed architecture approach, and incorporating functional improvement to the existing control systems:

- Provide fully automatic steam generator level control from 1 to 100% power via advanced digital feedwater control system (ADFCS) design,
- Eliminate the low feedwater flow trip function from the reactor protection system through the use of median signal selector, and
- Increase the reliability and fault-tolerance of the NSSS control system through the use of signal validation, functional separation, and hardware redundancy.

Advanced Protection System Design

Rethinking the system design basis by applying new technologies opens up possibilities for plant performance improvements resulting in both increased plant thermal output and reduced plant operating costs. At nuclear power generating plants, a prime area to look for improvement is in the area of nuclear fuel design where technology improvements can have large impacts on plant performance. Current fuel design methods, operating procedures, and plant technical specifications are based upon the operating plant data from the I&CS technologies gathering and processing the plant data.



Advanced Sensor Inputs for Sentinel™ Process Protection System

Safety System Control Architecture - Same Platform as Non-Safety Control System

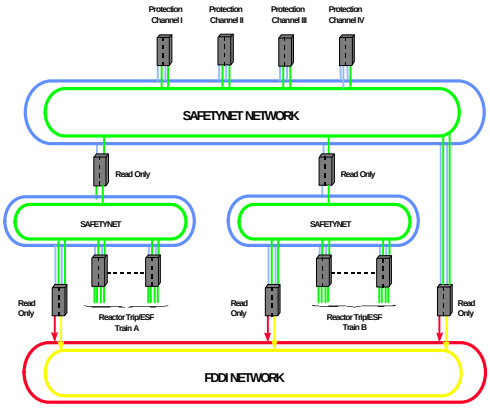


Figure 4A and 4B Sentinel™ Process Protection System Reduces Sensor Uncertainty and Allows More Plant Megawatts

Only incremental benefits are obtained unless the plant design basis itself is changed. Incore detector instrumentation is used to obtain fuel operating margins and its accuracy limits the reactor core performance as confined by technical specification compliance. Excore detector instrumentation is used in current reactor protection systems with I&CS logic to assure compliance with safety limits in the event of plant transients.

Impact of Advanced Process Protection System (Sentinel™)

	Operational Savings	Five Year Cost Savings or Profit Increase
Core Life Increase	**5%**	**$5,000K**
Relaxed Operating Margin (For example, reactor trips)	**50% to 100%**	**$3,000K**
Increased Plant Megawatts	**15%**	**$50,000K**

Detector and digital I&CS technology now exist to use fixed incore detectors as an online core thermal monitor, and improve core operating margin while improving safety margins. These improved operating margins can be used to improve core thermal performance through the use of higher core peaking factors, and relax operating procedures and technical specification requirements. This new design is referred to as

Sentinel™. Sentinel™ implementation is justified by its significant impact upon the plant's financial performance.

An Enabling Technology—PARSEL

The PARSEL design is an alternative approach to traditional fixed incore detector designs because the devices are very reliable, accurate (incore) devices producing signals without time delay. PARSEL's prompt response is based upon using gamma sensitive platinum sensor elements and a co-resident vanadium element. The platinum sensor's elements allow the prompt response with core three dimensional signal distribution and the vanadium sensor element provide real-time cross-calibration between gamma flux, neutron flux, and reactor power generation. The use of real-time, three dimensional power distribution measurements provides a direct measurement of reactor power and eliminates the uncertainties associated with the traditional use of excore detector signals for the protection system. PARSEL is the enabling technology that makes the Sentinel™ system possible.

- Long lasting FID design—Proportional Axial Region Separation Extended Life (PARSEL)
- Design Incorporates Vertically Segmented Vanadium & Platinum Elements
- Vanadium Signal Proportional to Local Neutron Population
- Platinum Signal Proportional to Fission Rate
- Over Lapping, Sequentially Increasing Length Platinum Elements In Combination with Full Length Vanadium Element
- Very Accurate Axial Distribution Measurement
- Simple Reactor Physics Methods
- Signals Strong Enough for Standard Signal Processing Electronics
- Slow Decaying Elements Leads to Long Lasting Design

Plant Automation for Cost Reduction

Digital I&CS technology opens up the potential for plant automation because of its ability to gather and process plant wide information. Nuclear plant system operations are repeatedly performed over the plant life by plant personnel to a set of operating procedures. Automating these procedures is not a new idea, but because the process is difficult to implement with analog I&CS technology, the process has not been widely implemented at nuclear power plants. With digital I&CS technology, it is possible to automatically perform sequential supervisory control while allowing the operators to verify each step of the process. With information technology, the operators have available additional information to make plant operating decisions. The benefits are reduced plant personnel requirements for plant operation, improved operations reliability, and reduced operator action times. One example is automation of the plant heatup and cooldown processes for the nuclear steam supply system. These operations are governed by established plant heatup and cooldown curves in the plant technical specifications. Digital technology allows the plant to follow these heatup & cooldown curves more closely. With automation, the I&CS is designed to coordinate the numerous system actions; such as pump startup, valve open & close, equipment alignment, equipment isolation, control rod movement; to significantly reduce the burden on the plant operating staff.

Reductions in O&M Through Automation

Item	Estimated Five Year Savings
Administrative Costs	$1000K
Plant Performance Improvement	$1000K
Automated Testing	$500K
Availability Factor Increase	$1000K
Total	$3500K

Reference Westinghouse AP600 Design

Regulatory Burden Cost Reduction

Item	*Estimated Five Year Savings*
Reduced Surveillance Requirements	$1000K
Automated Regulatory Conformance Documentation	$1000K
Automated Plant Diagnostics & Monitoring	$3000K
Facilitated Plant Life Extension	$3000K

Reference: Westinghouse generic plant studies

Figure 5A and 5B Today's I&CS Technology Improves Cost Through Automation and Regulatory Burden Reduction

Reduced Regulatory Burden

Digital I&CS technology can be implemented to reduce the regulatory burden on the plant staff. Digital technology features of improved accuracy and reduced drift can be applied directly to optimize plant setpoints and reduce risk for technical specification compliance. In addition to these technology features, recent advancements in I&CS work process management and equipment condition diagnostics systems have been the enabling technology to significantly reduce regulatory burden. For example, new plants such as the Westinghouse AP600™, and the Temelin VVER power plants in the Czech Republic, have the ALLY™ system. This I&CS information system has a variety of monitoring and diagnostics subsystems for on-line continuous collection of critical information on the plants' systems and equipment. Over twenty equipment condition subsystems (leak detection, water chemistry, turbine/generator performance, erosion/corrosion, etc.) provide a baseline of information assuring optimum preservation of the plant's equipment through preventative & predictive maintenance guidance. ALLY™ uses an integrated I&CS structure providing actionable information on the plants' equipment diagnostic condition. ALLY™'s data base also provides automatic documentation of regulatory compliance, the basis for reduced equipment surveillance intervals, and a thorough data based for regulatory acceptance of equipment and plant life extension. The result is reduced cost for regulatory conformance. With the recent movements to a Maintenance Rule for nuclear power plants, the potential for I&CS technologies to address regulatory burden reduction is heightened.

An Industry Standard I&CS

I&CS technology is advancing at a rapid pace. One example of advanced control system evolution is the I&CS replacements now being implemented at the South Texas Units 1 & 2 plants. New I&CS designs allow plant cost reduction because each level of the system designs are structured to make use by operations easier, and maintenance is standardized.

I&CS Structure

This platform is a modular and layered design that uses the most current I&CS technology while being

structured on industry standards allowing migration with technology… versus traditional vendor specific proprietary platforms. The I&CS platform has a higher level functionality including built in auxiliary power, automatic self documenting hardware & software configuration, on-line documentation, high levels of environmental qualification, and flexibility in data communication.

Sample Impact of I&CS Standardization on O&M Costs

Item	*Five Year Savings Assuming I&CS Replacement*
Implementation	$1000K
Training	$1000K
Inventory, Parts, & Service	$500K
Maintenance	$750K
Reference Plant(s)	Ringhals, Generic WH Studies

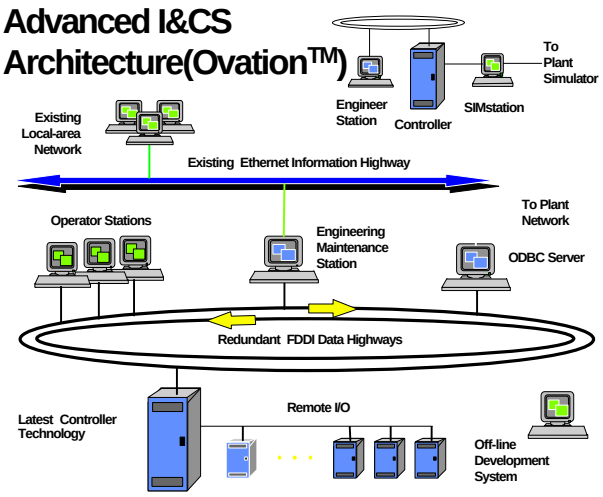


Figure 6A and 6B Current I&CS Technology—Standardization Reduces O&M Costs

Control Data Highway

First system built on non-proprietary network—the same network used for information systems…. versus traditional proprietary or vendor specific I&CS networks. Industry standard FDDI technology employing a synchronous (deterministic) mode used to guarantee transfer of vital read time data so that the plant control is assured even under the most demanding equipment control conditions. An asynchronous mode is used for non-periodic information such as file transfer protocol (FTP) or Internet protocol (IP) for access to network layers such as office LANS.

Controller

Commercially available PC platform…. versus traditional vendor-specific, proprietary hardware and operating system. Controllers are structured to easily change with the latest micro-processor design with surface mount technology, Pentium based processing units, DIN rail mounted hot swappable input/output, redundant hot-swap power supplies, and minimal internal cabinet wiring. Additional remote input/output can be added to the system, using the same hardware to reduce inventory and minimize maintenance training.

User Interface

Commercially available operating systems running platform-independent software…. versus traditional proprietary I&CS software running on non-proprietary platform. The user interfaces can be a UNIX based approach when the capacity is needed, or in less demanding applications, Windows NT based. Open Database Connectivity (ODBC) compliant SQL (Structure Query Language) interface is available via an Ethernet bridge to site LAN or other Ethernet networks to allow any network PC to operate as an ODBC client for access to static, live and historical (HSR) control system information. WSP WAVE (Java) compliant browser interface enables a wide range of users to view process diagrams, point reviews and trends of real-time plant data through Internet/Intranet applications.

Data Management

Control data available to business and financial systems via relational database…..versus traditional process where control data is stored in proprietary I&CS database structure. A fully integrated, master database, used for building and configuring a system, integrates with a set of programming tools for control building, point building, and graphics building. The control building implements a wide-view, AutoCad environment that simplifies the creation of control strategies, while providing automatic diagrams for tuning of the I&CS anytime in the configuration process. The point building feature provides an easy to use graphical interface for the creation of point information in the control system. Another tool, graphics building, provides the capability to build custom displays on the HMI.

I&CS Standardization Features

The same platform used for computer and control upgrades, and qualified for use in safety applications, allows standardization of safety and non-safety systems. In most operating nuclear power plants, the original I&CS had single, and distinct, platforms for process non-safety control, and safety control systems such as the process protection system. Over the past two decades as the systems became obsolete, utilities and vendors made decisions on the best technology for a given application. Minimization of plant I&CS platforms for both safety and non-safety control applications faced the regulatory issue of diversity and defense-in-depth. Unlike analog systems where system failures are classified as single random failures, digital I&CS software can have common mode failure aspects if the same software is used in redundant safety channels. To address regulatory issues with available I&CS technology, I&CS replacements were implemented with separate platforms for safety and non-safety control. Now, at least one system design has been able to overcome the issue of diversity and defense-in-depth in pursuit of the same I&CS platform for both safety (Class 1E) and non-safety applications. Class 1E and non-1E functions are performed by diverse software thereby limiting common mode failures to either control or protection but not both. Since the safety system software has previously been licensed in several applications, therefore regulatory concerns are reduced. This approach uses the same commercially available hardware platform used for non-safety control with an overall plant I&CS design to address diversity and defense-in-depth. A Utility Advisory Group is now working with the vendor to develop user requirements for this platform. In addition, the UAG and the vendor will imminently submit a topical report to the NRC for their review and approval of the process and platform.

Digital, Analog & Special Purpose Module Styles

Fast Input/Output Installation and Configuration

- **Single-point DIN rail mounting**
- **Built-in connectors eliminate power and communications wiring**
- **Software configurable -- no jumpers or thumb wheels**
- **Surge protection**
- **Fusing and signal conditioning through personality modules**

Figure 7A and 7B Latest I&CS Input & Output Design Makes Installation & Startup Easier

With this latest generation of I&CS architecture, the only significant component not entirely based upon common industry standards is the system's input/output modules. This is because industry standards for input/output modules are not established, and I&CS vendors traditionally have proprietary input/output designs. However, the input/output design does allow fast input/output installation and configuration.

SUMMARY

I&CS replacement with digital technology has benefits from improved plant efficiency, reduced I&CS maintenance costs, and increased plant megawatt output. Today's I&CS disciplines are the enabling technology to put actionable information in the hands of the plant staff. Actionable information that can dramatically improve the plant profitability. New I&CS architectures allow common, maintainable and open architectures for all the plant I&CS systems. Minimization of platforms; ideally one architecture for all I&CS safety, non-safety control, information, and plant computer systems; significantly reduces operation and maintenance costs. I&CS capabilities such as automatic plant heatup and cooldown, advanced non-safety control system features, and accurate safety system designs provide plant operating flexibility, and increased power generation benefits, not previously available. Qualitative, quantitative, and enterprise management cost & benefit perspectives can be used to prove the cost & benefit of replacing the a plant's current aging and obsolete systems.

Summary of I&CS Replacement Cost/Benefits (Five Years of Plant Operation)

I&CS Improvement	Cost Reduction, or Operating Profit Increase
Platform Standardization	**$3,250K**
Improved Control	**$4000K**
Improved Plant Safety Systems	**$3,000K to $50,000K**
Plant Automation	**$3,500K**
Regulatory Burden Reduction	**$6,000K**

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