ADVANCED CONTROL ROOM DESIGN FOR NUCLEAR POWER PLANTS

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ABSTRACT

The power industry has seen a continuous growth of size and complexity of nuclear power plants. Accompanying these changes have been extensive regulatory requirements resulting in significant construction, operation and maintenance costs. In response to related concerns raised by industry members, Combustion Engineering developed the NUPLEX 80 Advanced Control Room.

The goal of NUPLEX 80^{TM} is to: reduce design and construction costs; increase plant safety and availability through improvements in the man-machine interface; and reduce maintenance costs.

This paper provides an overview of the NUPLEX 80 Advanced Control Room and explains how the stated goals are achieved.

INTRODUCTION

Commercial nuclear power generation began in the United States in the late 1950's. Since then, each succeeding generation of nuclear power plants has increased in size and complexity. Accordingly, concerns over plant safety have also increased, resulting in extensive regulatory changes. The most dramatic effect of this evolution in the nuclear industry has been a boundless increase in construction and operating costs.

C-E has developed the NUPLEX 80 Advanced Control Complex to reduce the design and construction costs associated with nuclear power plant instrumentation and control systems and to increase the utilities total return on investment by improving plant availability while maximizing plant safety. NUPLEX 80 represents a major milestone in C-E's continuing effort to make nuclear power generation a sound financial investment. This paper briefly describes the NUPLEX 80 Advanced Control Complex and most importantly emphasizes the benefits of NUPLEX 80 to the nuclear generating station owner. Cost savings achievable in both construction and operation are discussed along with features to better plant safety.

NUPLEX 80 DESCRIPTION

Overview

The NUPLEX 80 Advanced Control complex provides a completely integrated instrumentation and control design philosophy for both NSSS and BOP processes and systems. The design encompasses all aspects of power plant operation, monitoring, control and protection.

The advanced control complex design consists of four major interdependent systems: the Control Center Panels, the Data Processing System, the Solid State Plant Protection System and the Solid State Component Control System.

Utilizing a systems engineering approach, C-E has integrated all the necessary information available from the plant's instrumentation, protection and control systems to provide an optimized Man/Machine Interface for the control room operator.

C-E oversees the entire Control Center Complex I&C design thereby providing the utility a single source of responsibility to ensure an efficiently integrated end product.

Objectives

Increase the power plant's overall productivity and safety by significant improvements to the control room man/ machine interface beyond that currently available in existing power plants.

Reduce the information processing burden on the operator, so that his role can be more focused on meeting the plant's overall operational availability and safety goals.

Take advantage of currently available advanced computer technologies which provide: better reliability, flexibility for future

field changes, more compatibility for complex monitoring and control, improved on/off line diagnostics and self testing. Improved reliability is achieved through fault tolerant computer architectures and arrangements.

Reduce maintenance costs, design errors and operator errors through standardization of BOP/NSSS NUPLEX 80 equipment.

System Descriptions

The NUPLEX 80 Advanced Control Complex consists of five key elements:

Main Control Panels - The Main Control Panels are designed to provide an efficient and comprehensive operator interface. A rigorous human factors design process is performed which encompasses: (1) the panel arrangements and layouts, (2) the generation of color graphic CRT display pages, (3) the inclusion of an operators functional task analysis to ensure that process control and indications are available and properly integrated into the NUPLEX 80 design. The Main Control Panels are divide into the following three groups:

The Master Control Console (MCC) is a modularized compact design from which normal plant monitoring and control take place. It is designed to be operated by a single operator. From the panel, the operator has control of the Reactor, Reactor Coolant System, Main Steam and Feedwater systems and Turbine Generator. The MCC includes a section dedicated to overall monitoring of the plant's performance and system status.

The Auxiliary Control and Safety Center (ACSC) panels are the second group of panels provided to complement the MCC. These duplex bench board panels are designed to accommodate important infrequent operations which must be performed from the control room. The safety section includes control and status indications for the plant's Reactor Protection and Engineered Safety Feature systems. These panels are specifically designed to meet safety system design criteria with regard to physical/ electrical separation, as well as providing the operator with all indications and controls necessary to effectively cope with all postulated accident scenarios. The control section of the ACSC includes provisions for BOP auxiliary support systems such as condensate, feedwater, turbine, diesel generators, electric plant, component cooling water, HVAC, etc. The panels can be expanded to accommodate other BOP support system functions.

The third section of the Main Control Panel is the Supervisory Monitoring Console (SMC). This console is designed for a seated supervisor and includes a color CRT monitor and an alphanumeric keyboard. The alphanumeric keyboard provides communications with the Plant Monitoring and Display System. By keyboard entry, the supervisor is capable of displaying any page of information available for display at the MCC or ACSC. The supervisor utilizes these capabilities to monitor plant operations.

Data Processing System - The NUPLEX 80 Data Processing System (DPS) is designed to acquire large amounts of plant data and integrate the information for display in the control room and technical support centers. It also includes historical data storage and retrieval functions to assist in plant record keeping.

The DPS includes a Plant Data Acquisition System (PDAS) that makes extensive use of distributed multiplexors to reduce field wiring. The Plant Monitoring and Display System (PMDS) portion of the DPS processes the acquired data to provide integrated plant status, alarm and performance information to the operator via 16 CRT display monitors in the Main Control Room. The displays are easily accessed via a unique display hierarchy and are human engineered to provide concise, clear presentation of data.

High reliability and availability of the DPS is achieved through the use of fault tolerant hardware and software configurations. The design goal that a single failure within the DPS will not significantly impact normal plant operations is met through the judicious selection of inputs, the signal routing and the degree of hardware redundancy provided in the design.

Solid State Plant Protection System - The Solid State Plant Protection System (SSPPS) performs both Reactor Protection and Engineered Safety Feature initiation functions through the use of four redundant channels of equipment. The use of two-out-of-four coincidence logics allows the removal of one redundant channel for maintenance or testing while maintaining trip actuation and retaining the redundancy needed to prevent inadvertent trips. The design includes automatic test controllers for on-line testing of the SSPPS logic.

The hardware design permits each of the redundant SSPPS channel bays to be physically separated and located in different rooms to eliminate the possibility of a fire disabling all four redundant channels.

Solid State Component Control System - The Solid State Component Control System (SSCCS) is the NUPLEX 80 system that provides direct integrated control of standard plant components (valves, pumps, circuit breakers, etc.) through centralized logic cabinets. This system's

component control and status indication philosophy is an integral part of NUPLEX 80's human factors design concept.

The standard design includes six major subsystem assemblies capable of controlling a total of 1050 components.

The SSCCS's modern microprocessor based design includes standardized electrical interfaces for the Main Control Panels, Remote Shutdown Panel and actuated plant components. Being microprocessor based, its standard component control logics retain the flexibility for custom control logics while allowing the early shipment of system hardware.

The system includes an all solid state, 1E qualified Engineered Safety Feature Actuation logic and intelligent Diesel Loading Sequencers. The design is fully testable on-line. A Computer Aided Test (COMAT) program resident in the DPS is provided to aid the operator in performing and documenting ESF system tests.

The SSCCS design includes Master Transfer of Control from the Main Control Room to the Remote Shutdown Panel for Main Control Room evacuation events. Local controls are provided at the SSCCS logic cabinets to provide a centralized location of component control during a plant cold shutdown evolution with the control room evacuated. Fault isolation is provided to prevent damage in the MCR or RSP from propagating to the SSCCS logic.

Prefabricated Cabling - The centralization of monitoring and control functions through the implementation of the NUPLEX 80 SSCCS, SSPPS, and DPS designs will produce major economic, performance and reliability benefits that can be further improved through the use of prefabricated cabling. Prefabricated cabling is used between C-E supplied I&C systems, the Main Control Panels and the DPS to significantly reduce the cabling and wiring congestion found in today's power plants. The overall wiring effort and amount of errors in the field is minimized through the use of factory assembled cables which have been tested prior to shipment.

BENEFITS OF THE NUPLEX 80 - ADVANCED CONTROL COMPLEX

The NUPLEX 80 Advanced Control Complex design meets its objective to reduce construction costs, increase plant availability and improve plant safety by focusing on the following design goals.

Reduced Plant Construction Costs

A major cost contribution is the material and labor associated with plant field wiring. To reduce this cost, prefabricated cable, distributed multiplexors and standardized generic independent termination hardware are used extensively in the NUPLEX 80 complex.

A. In a typical nuclear power plant there are approximately 9500 signals interfaced between I&C cabinets and panels within the control complex. NUPLEX 80 utilizes multiconductor cables with connectors factory mounted at one end for these interfaces. The following table compares the NUPLEX 80 design to use of conventional field cabling techniques:

	Conventional	NUPLEX 80
Number of:		
Terminations	30,000	12,500
Cables	2,500	750
Cable Trays	250	100

Pre-Assembled cables offer the potential for clear reductions in hardware and labor costs which amount to greater than $2 million per plant. In addition, economic reductions can be realized in schedules due to reduced labor time and less rework previously resulting from termination errors.

B. Another significant cost benefit of NUPLEX 80 is the use of distributed multiplexing to eliminate cables. In the NUPLEX 80 design, all signals interfaced to the Data Processing System are multiplexed by one of three methods:

Field Multiplexors - These units are designed for distribution outside the I&C complex where hardwired cable runs would average greater than 250 meters.

Local Multiplexors - These units are distributed within the I&C complex to interface signals from analog and digital based I&C systems. Hardwired cable runs for these signals would average greater than 50 meters.

Data Link - Signals from computer based I&C systems are interfaced to the Data Processing System via Serial Data links. Hardwired cable runs for these signals would average greater than 50 meters.

In total there are approximately 10,000 signals interfaced to the Data Processing System, for which multiplexing saves approximately 250,000 meters of cable and associated cable trays and installation labor. This amounts to a capital savings of more than $10 million per plant. Similar to pre-fab cable, multiplexing will also reduce labor related plant construction schedules and costs.

C. Functional design independent hardware provides the advantage of schedule flex-

ibility and reduction. The use of standardized generic hardware permits installation of termination cabinets early in the construction schedule, even before all systems functional requirements have been finalized. Software based systems are shipped early with representative software to allow installation and preliminary checkout. Final software installation and functional testing is conducted at a more convenient point in the construction schedule. For hardware based systems, NUPLEX 80 uses termination cabinets that are separate from the electronics cabinets. The termination cabinets may be shipped at a time convenient for field cabling installation. Electronics cabinets are connected later with pre-assembled cables. This design philosophy can reduce plant construction schedules by as much as one year for many I&C systems. Since I&C requirements are not generally finalized until late in the plant's design schedule, this can make significant reductions in the time to complete I&C installation.

The NUPLEX 80 design achieves the goal of reducing plant construction costs over those encountered through conventional design techniques. Through the use of prefabricated cable, distributed multiplexors, and standardized generic (functional design independent) termination hardware, NUPLEX 80 decreases construction time. This presents an attractive capital cost reduction for plant construction.

Increased Plant Availability

The operating staff's understanding of how well the plant is performing is an essential ingredient for achieving plant operability. The plant operating staff must receive accurate, clearly presented and timely information to maximize plant operation. The objective of designing for the operator is based on the need for an operating and control environment which complements the operating staff's plant knowledge. To achieve this objective human engineering principles are an integral part of the overall design approach. Human engineering principles are applied early in the design process and the customer is involved in all phases of the design.

Since 1979, after the Three Mile Island event, considerable attention has been devoted to increasing plant operability through improving control room operator performance. A key ingredient in that improvement process is the use of human engineering design principles. The average number of reactor trips per reactor year has decreased from 7.7 in 1978 to 4.3 in 1985.

To date, incorporation of human factors based improvement has been on a backfit basis around existing construction and operating constraints. Operator and plant personnel error remain major causes for the 4.3 reactor trips in 1985; 24% and 20% relatively. The effectiveness of human factors principles is further increased in NUPLEX 80 because they are an integral part of the original design process.

A. The NUPLEX 80 operator interfaces are centralized largely in the main control room. Of these interfaces, CRTs present the majority of the display information and they are supplemented by hardwired displays for critical safety parameters. The NUPLEX 80 control room complex focuses on the control room operators information needs. The control complex presents the power plant performance information in an integrated, logical manner consistent with the operators cognitive understanding of the power plant and thereby reduces the probability of costly operator errors by as much as 65%.

B. Personnel errors are largely associated with maintenance and testing of plant systems. NUPLEX 80 incorporates automatic testing of the protection system and automatic testing and computer aided testing of all plant Engineered Safety Feature Actuation System components. In addition, modular designs and standardization of NSSS and BOP systems increases familiarization with plant equipment. These features can lead to a reduction of personnel errors by 50%.

The combined benefits of NUPLEX 80 in reducing operator and personnel errors can result in an availability improvement over 1985 levels of 28% which is equal to elimination of more than one reactor trip per year.

Improved Plant Safety

ESF actuations are another contributor to increased plant operating costs but more importantly a quantitative accounting of ESF actuations provides one measure of plant safety. In 1984, an average of 12.4 ESF actuations per unit occurred in the United States. Of these, 64% were false actuations and 36% were required actuations. NUPLEX 80 can reduce false actuations by as much as 80% due to 1) the four channel protection system which can accept a single failure without false initiation under all operating, maintenance and test conditions, 2) automatic testing of the SSPPS and ESF portion of the SSCCS which reduces personnel contact with the equipment, and 3) computer aided component testing (via the SSCCS and DPS) which reduces operator errors by guiding the operator through periodic test procedures. Required ESF actuations can be reduced by as much as 28% due to the same features that lead to elimination of plant trips previously discussed.

Combining NUPLEX 80 error reductions in both required and false ESF actuations results in an overall reduction of 61%, which is equivalent to the elimination of 6.7 ESF actuations per year.

Total loss of safety system events represents another definite measure of plant safety. From 1981 to 1984, United States plants experienced .5 total loss of safety system actuations per unit each year. NUPLEX 80™ automatic testing and computer aided component testing will contribute to improved ESF actuation system operability, but the most important contributor is the ESF Status Monitoring System. This system is implemented through an integration of the Solid State Component Control System and the Data Processing System. It alerts the control room operator to ESF system inoperability. The features of NUPLEX 80 can improve ESF actuation system operability by as much as 80%; thereby, eliminating .4 total loss of safety system actuations per year.

Another important criteria in evaluating a plant's safety is its ability to safely shutdown during the presence of an exposure fire. Based on past operating history the US NRC predicts that nuclear power plants will experience "one fire (of a substantial reportable magnitude) per 10 reactor years. Thus, on the average a nuclear power plant may experience one or more fires of varying severity during its operating life."

NUPLEX 80 is uniquely designed to sustain exposure fires through three significant design features:

1. Safety channel equipment required for safe shutdown may be separated into independent plant fire zones such that the effects of an exposure fire are limited to only one channel.

2. Where all safe shutdown safety channels must be in close proximity (i.e., at the Main Control Panels and Remote Shutdown Panel) electrical isolation is provided such that faults at these locations (that may occur on all channels) will not propagate to the remotely located system electronics.

3. In addition to the remote shutdown panel, which provides a central location for control of hot shutdown equipment, the SSCCS provides centralized controls for all plant components which may be used to achieve cold shutdown.

The NUPLEX 80 design exceeds the current fire/safe shutdown related licensing requirements including draft R. G. 1.120 and Branch Technical Position CMEB 9.5-1.

Total Plant-wide Integration

The NUPLEX 80 Advanced Control Center provides many tangible benefits which have been quantified in measurements of construction savings, reduced plant transients and outages, and safety system operability. Somewhat less apparent is the benefit of single source responsibility offered by C-E for the complete integration of the plants instrumentation and control package.

Historically a plant's control complex is an assemblage of cabinets and panels supplied by both the NSSS vendor and the BOP supplier. Taken system by system it would be difficult to argue that all the requirements for the design were not met or that the design features are not necessary or desirable. However, in the aggregate, this position could be altered in that no comprehensive planned approach to plant-wide system integration is evident.

Of the cost for NUPLEX 80, more than 32% is for equipment that is normally within the scope of the BOP supplier. This equipment includes the Main Control Panels, Annunciation System, and Solid State Component Control System. These systems are offered in NUPLEX 80 to ensure a total integrated approach to the complete power plant control complex. The human factors design principles applied to the Data Processing System displays must also be applied to the Main Control Panel layouts and the component controls in the SSCCS, if any of these are to be effective individually.

Another extremely important result of single source responsibility is a plant with fewer system to system interface problems during start-up. When problems do arise there is one supplier to correct the problem and no conflicts to impede progress.

SUMMARY

The NUPLEX 80 generic design is based on C-E's Advanced Control Complex for the TVA Yellow Creek Nuclear Plants (YCNP). This control complex was produced by C-E in close cooperation with TVA who, as architect engineer, BOP supplier, constructor and end-user, brought extraordinary experience to the design process. Using NUPLEX 80 as the design foundation, that same team concept of C-E, working closely with the utility and BOP supplier, can generate an advanced control complex that is optimized on a plant specific basis.

In addition to C-E's experience with TVA, NUPLEX 80 technology established the foundation for C-E's Critical Functions Monitoring System (CFMS), full scope plant simulators and ongoing

plant computer upgrade efforts. C-E computer systems are installed at operating nuclear power plants throughout the US. In addition, a CFMS is under continuous evaluation at the Halden Reactor Project. Since these efforts have occurred after the design of YCNP, computer technology advances utilized in these systems have now been factored into the generic NUPLEX 80 design offered today.

The NUPLEX 80 Advanced Control Complex is a fully documented design offering technology developed by industry experts and proven through many years of plant operating experience. NUPLEX 80 meets the objectives of reducing construction costs, increasing plant availability and improving plant safety, through a totally integrated plant-wide I&C package that is provided from one supplier, Combustion Engineering, Inc.

References are listed to illustrate the design background and development of NUPLEX 80 and related technology. Additional copies of this Paper and References may be obtained by writing Combustion Engineering, Inc., Department 6435-0405, Windsor, Connecticut 06095.

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