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INSTRUMENTATION AND CONTROL IMPROVEMENTS AT EXPERIMENTAL BREEDER REACTOR II

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ABSTRACT

The purpose of this paper is to describe instrumentation and control (I&C) system improvements at Experimental Breeder Reactor II (EBR-II). The improvements are focused on three objectives; to keep the reactor and balance of plant (BOP) I&C systems at a high level of reliability, to provide diagnostic systems that can provide accurate information needed for analysis of fuel performance, and to provide systems that will be prototypic of I&C systems of the next generation of liquid metal reactor (LMR) plants.

INTRODUCTION

EBR-II was designed in the late fifties with criticality achieved in 1963. The design was based on technology available at that, time and included vacuum tube equipment, recorders, variacs and relays. Most of the controllers were on-off with a limited number of PID controllers. Operator action was frequent and mostly manual in adjusting setpoints, turning systems on or off, or adjusting variac settings.

EBR-II is now the focal point of the Integral Fast Reactor (IFR) Program. New IFR fuel will undergo steady state and transient testing in EBR-II and then be reprocessed in the Fuel Cycle Facility to prove the entire IFR concept. In addition to the IFR program, EBR-II supports a large number of tests and experiments in oxide fuel performance and in control system algorithm verification. Because of the importance of the IFR Program, it is important that the "health" of EBR-II be maintained at a high level. Major I&C modifications have been completed, several are presently being engineered, and others are in the planning stage to assure safe and reliable operation in the future. This paper will

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DISCLAIMER

address the I&C modification program at EBR-II, the design philosophy, major modifications, and problems in retrofitting an existing plant with advanced control systems.

The major modifications at EBR-II fall into four main areas. 1) The control room upgrade project which is in the initial design stage. This project covers the replacement of the reactor control console with color-graphic CRT based displays having ultra-high reliability by use of dual fail-over computer systems. 2) Control-system upgrades that install islands of computer-based control that will be available for supervisory control when the control room is upgraded. 3) Reactor shutdown system (RSS) upgrades that will replace the present system with state of the art modules having computerized verification of operability. and 4) The heavy electrical work that will replace all major motor control centers and switchgear.

DESIGN PHILOSOPHY

For the past ten years, I&C design philosophy has been geared to system improvement rather than replacement of like-for-like. The reactor core, non-replaceable components and major systems are always of prime importance followed by improved personnel safety, improved operator interface, reliability and maintainability of equipment. An I&C goal within the IFR Program is to make EBR-II appear prototypic of the next generation LMRs. To this end, modifications are screened to this goal and computer controlled systems installed if appropriate.

A design philosophy that is also followed is that the control system not be allowed to override the passively safe features of an LMR. For example; a loss of cooling would cause the core temperature to rise and the negative temperature coefficient would force power down. A computer controlled control-rod drive system must be designed to prevent addition of reactivity to maintain constant power.

CONTROL SYSTEM UPGRADES

With the advent of reliable micro-processor based controller and computer controlled systems, EBR-II moved to establish new I&C systems based upon these technologies[1]. As with any new technology, acceptance for installation was prolonged until adequate assurance of success was demonstrated. The first μP based controller (embedded system) was an on-off temperature controller that maintained the primary tank temperature by controlling the state of six 112kW heaters. The system is monitored and controlled via a switch and digital display panel. Each successive μP and computer-based control system was built on the knowledge base of the previous ones. Embedded systems operating in real time with hundreds of I/O, PID loops, color video displays and track ball operator interface are in operation.

For embedded systems, the STD bus was selected as the standard with the Z80 μP because of small board size, multi-vendor support resulting in low cost, and adequate computing power. The STD bus systems now control the primary tank temperature, the secondary pipe trace heating, the hydrogen meter leak detector temperature system, and is part of the cover gas clean-up system (CGCS)[2]. Two additional STD bus systems with Intel 80286 processors are being designed for the primary and secondary plugging temperature indicators.

The fuel performance programs and plant performance testing programs required manipulation of primary, secondary and BOP systems in a fashion that would have been difficult or impossible for the operator to achieve using standard control methods. A computer-based control system driving a pulse dc motor was installed on one reactor control rod and programmed to vary reactor power from steady state to ramps of 10%/s. The computer, programmed in Fortran, has also been programmed to vary power sinusoidally. One test series required the control rod to be varied by a pseudo-random-binary algorithm. A Bailey Network 90 system was installed to control the primary and secondary pumps and 10 BOP functions. These control systems have provided an outstanding control platform for conducting tests and experiments in EBR-II. These systems are used to test control algorithms developed by universities and Argonne and to determine the {feedback characteristics} of new reactor fuel.

The computer-based control system that replaced hundreds of individual control and indicator units in the CGCS[2,3,4] is the first system at EBR-II to use multiple computers in a supervisory control scheme with color CRT, fiber optics communications and a remote X-terminal. This system has improved CGCS reliability and operability to the point that operators have requested additional computer controlled systems that can be operated from the reactor control room.

Design is currently underway to totally replace the control systems associated with in-core and ex-core fuel handling. Fuel handling is an area where a system failure could lead to an extended reactor shutdown. For this reason, system reliability, safety and operability are paramount in the design. Presently these systems consist of original-plant design schemes centered around switches, relay logic and ageing analog equipment. A considerable amount of time is lost due to troubleshooting to find a failed component. The new design will use color graphic CRTs, dual redundant computer systems with fail over capability and high reliability actuators and sensors. The ladder logic type of control will have diagnostics to pin-point a failed component.

Software requirements, development, V&V, documentation and modification are all critical issues for software that is used in the EBR-II plant. Engineering department and quality assurance procedures assure high quality software. Software is thoroughly tested before it is installed in the plant.

The embedded systems and computer-based control systems discussed are islands of automatic control. Except for the CGCS and Bailey control systems, these systems are relatively small and control an individual process of the plant. These islands of computer-based control were designed such that minimal rework will be necessary to connect them into a supervisory control system where the operator has system control from the reactor control room.

CONTROL ROOM UPGRADE PROJECT

The control room upgrade project will be the culmination of previous I&C upgrades at EBR-II. The previous I&C upgrades have provided the necessary knowledge, hardware and software base to have a high level of confidence of success. The control room upgrade will be a team effort and have specialists from I&C engineering, analysis, control software, graphic software and human factors.

The upgrade will consist of total replacement of the existing reactor console that houses recorders, meters, status lights, annunciator panel and various control switches. The replacement console will consist of color graphic CRTs, track balls and initially some control switches. Some changes will also be made to the displays and annunciator panels on the vertical panels.

The replacement console will be very similar in size and shape to the present two-man U-shaped console. Initially, the control scheme will remain the same as present. The operational information provided to the operators will be on dedicated CRTs with other CRTs available for display of the rest of the plant data; some 1000 parameters. The screen displays will be developed by the graphics software specialist, human factors specialist and operators.

Diagnostics software will next be added to provide the operator with additional information on the status of plant systems and sensor validation. Smart alarms will be included to aide the operator in determining the initiating event in a group of alarms. Housekeeping software will be included to aide the shift supervisor in Technical Specification questions, operating limits, experimental procedure requirements, start-up requirements and a host of other items now performed by manual review of procedures and instructions.

The final upgrade will be to network the islands of computer control that exist throughout the EBR-II plant into a computer supervisory control scheme. This last change will also change the control hardware on the console from switches to track ball or touch screen to maneuver the plant.

Efforts are currently underway to start the ground work that will lead to the control room upgrade. Phase I covers specification, procurement and set-up of computer equipment. Phase I, on-going, will procure computer hardware required for plant-simulation code development, such as DSNP and SAS/SIS, that can run in real-time. This will allow Penn State, University of Arizona, Argonne and others to develop and test advanced control models and control schemes. This phase of work will be completed this year.

Phase II is a development, testing and training phase. Phase II networks the computer hardware with the EBR-II plant data acquisition system (DAS) via an Ethernet link. This will provide the code developers with real-time live plant data. Graphic displays will be developed and a mini version of the new reactor console fabricated. Simulations of plant tests will be run at the mini console to train the operators on how the plant will respond during normal operation, up-set conditions, and plant tests. It will also be a test bed for operator input to the screen development.

At the end of Phase II, all of the major unknowns and problems associated with a full scale control room upgrade will have been identified and solutions determined. The engineering will then continue to design a dual redundant DAS and dual-redundant fail-over computers that will drive the displays in the reactor console. The information input, transmission, analysis, display and control output must be extremely reliable. For this reason the system will be dual redundant and independent similar to that of a reactor safety system.

PLANT PROTECTIVE SYSTEM

The PPS consists of two major subsystems; namely, the Reactor Shutdown System (RSS) and the Engineered Safety Features (ESF). The ESF contains the Reactor Building Isolation System, the shutdown coolers and the siphon break system.

The original RSS had many parameters, [over 70 parameter and well over 100 relay contact], in it that would initiate a reactor trip (scram). Many of these scram parameters were anticipatory in nature; for example, loss of cooling water to the primary pump clutches. In the early 1970s, considerable analysis and experimental work was performed on the reactor fuel and core dynamics to upset conditions. The results of the studies was a task to reduce the number of trip parameters and to also improve the reliability of those trip systems that remained. At present a reactor trip is initiated only from the nuclear channels (two-of-three coincidence), subassembly outlet temperature (two-of-four), loss of flow (two-of-four) and loss of power to the primary pumps. Loss of power to the primary pumps is a single-sensor single-contact trip and is an anticipatory trip that provides additional protection of the fuel above the loss-of-flow trips. One external (natural) event trip is also provided; this is the trip due to a seismic disturbance (two-of-three). Presently 16 parameters will cause reactor scram.

An important design consideration for the next LMR is to limit or eliminate scram parameters of an anticipatory nature. The RSS should include only those parameters needed to protect the fuel from damage. The control system should be the first level of protection and should provide ample alarms for out-of-bound conditions. As stated before, the control system should not override the passive safety features of the plant. One other consideration for the RSS is to provide four sensors for each scram condition. The reason for this is to allow the scram subsystem to be reconfigured, on-line, from a two-of-four trip logic to a two-of-three for maintenance on a failed channel.

Considerable resources were expended on bringing the RSS into compliance with the then accepted standard, RDT C16-1. Independence, redundancy and elimination of common mode or single event failures were designed into the RSS as far as practicable. There are few cases where retrofitting an existing plant would not allow total compliance with C16-1; for example, EBR-II only has two multi-coaxial reactor building penetrations and three were needed for the nuclear channels. A second scram string, made up of contacts from all of the trip parameters was added so that a single fault or wiring error could not negate the scram function.

Plans are now in place and modification work started on replacement of the aged equipment. The first modification is scheduled for installation this year and will replace the seismic trip detectors, relays and power supplies. The seismic trip system is key to completion of a reactor trip on the P-wave before the more damaging S-wave arrives. This key feature removes the requirement for the remaining RSS and ESF equipment to be seismically qualified. The seismic trip system is different than the other trip systems. There is no analog signal and associated readouts. The seismic system is a go/no-go system that normally has a zero input stimulus.

The design philosophy for the remaining trip systems is to install equipment that has the capability of being calibrated, setpoint verified, time response tested and operationally checked by a computer system. This is no longer a novel design idea but one that is finding acceptance with NRC. The next LMR will have advanced testing capability and EBR-II will take the lead in providing a pattern system.

At the present time, it is time consuming to perform all of the procedures on a scram channel. Also, there is a finite chance for human error involved with the many procedures. The computer system will provide repeatable tests and hardcopy documentation of each test. Software V&V will be a major design consideration.

Engineering is presently under way to replace the nuclear instrumentation channels that were bought in 1972. Vendors of nuclear instrumentation presently provide the testing capability required by EBR-II.

The replacement of the loss of flow and subassembly outlet temperature channels is in the planning and funding stage. It is expected that conceptual engineering will begin within the year on replacement of these channels.

Another area of the RSS that is being investigated for development is the replacement of the scram relays with a solid-state logic scram system. This would eliminate about 30 control power relays and a similar number of auxiliary relays. If the ESF is included in the upgrade, a similar number of relays would be eliminated. In addition to the replacement of electro-mechanical devices that have limited life times, the solid-state logic circuits would have on-line testing up to the final actuator while the reactor is at power. Maintenance, troubleshooting and response time testing would be reduced with the new scram logic.

INSTRUMENTATION IMPROVEMENTS

Throughout the EBR-II plant are meters, controllers, recorders and other instruments that are high maintenance units usually due to their age. Repair or replacement of these units is a maintenance task until it is flagged that spare parts are no longer available or that excessive maintenance is required to keep an instrument in operation. Engineering is then requested to evaluate and recommend a replacement which usually results in a plant change package being issued. Standardization of instrumentation is essential to reduce spare parts inventory and technician training. For these reasons, a thorough evaluation of possible replacement units is made and the top-rated units procured and tested. The selected unit is then designated as the replacement for all similar units in the plant.

The engineering evaluation also reviews the need for an instrument. Recently it was determined that 12 recorders (30 pens) could be eliminated because the information was being recorded on DAS. This had a substantial budget effect since the recorders eliminated provided spare parts for the remaining recorders.

ELECTRICAL SYSTEM IMPROVEMENTS

The motor control centers (MCC) and switchgear at EBR-II are the originally installed units. It has been determined that many of the component and breakers have reached end of life. A program was started three years ago to replace all of the 480V MCCs and switchgear. One or two units will be replaced each year during the annual reactor maintenance shutdown. The third MCC is scheduled for installation this year. The new equipment provides modern monitoring, diagnostic and display systems not available on the existing equipment.

When the 480V units have been replaced, then the plans are to replace the 2.4kV and the 13.8kV units.

For the most part the installation work has been accomplished without problem. Some power cables have been replaced since the old cables do not meet current requirements in the National Electrical Code.

CONCLUSIONS

EBR-II Engineering has set a course to improve the I&C and electrical systems throughout the EBR-II plant. This is in response to the needs of the IFR Program and experimenters. The I&C system improvements at EBR-II will require the assistance of several engineering and analysis sections. The work is on-going and expected to remain at a high level over the next several years.

A focus of many of the modifications is to demonstrate the feasibility of computer control systems that will be needed for the next LMR.

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