DESIGN, DEVELOPMENT, MAINTENANCE, REFURBISHING, INSTALLATION & COMMISSIONING OF CONTROL & INSTRUMENTATION FOR RESEARCH REACTORS

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Abstract

The Control & Instrumentation (C&I) Systems in Research Reactors have to be designed, developed maintained & upgraded in a systematic, reliable & effective manner. The entire cycle involves conceptualization of various Control & Instrumentation systems, making system requirement specifications, detailing the concept, design, fabrication, creation of test facilities, testing, validation of system performance, preparation of various documents for the regulatory safety clearances, installation & commissioning of the systems after fine tuning the design for performance. Various C&I upgrades are required for enhancing safety, to mitigate obsolesces, simplification, improved O&M features & import substitute. Executing C&I upgrade projects in operating research reactor pose constraints of high safety requirements & limited time, that necessities long term planning & implementation strategies based on innovative ideas & careful use of the best available technology. This paper provides technical information on development & implementation of C&I systems for the research reactors with improved diagnostics, operator interface & O&M features and the commissioning experience.

Keywords: Research Reactors, C&I Systems, Dhruva, Critical Facility

Introduction

A Research Reactor is regarded as a fundamental prototype for functional evaluation of all aspects of nuclear science and technology. From validating a code design, evaluating nuclear performance of fuels, studying the thermal hydraulic aspects of energy removal, validating estimated flux profiles, etc. In addition there are various engineering & technology issues, pertaining to metallurgical study of in-core components, flow induced vibrations, performance evaluation of heat exchangers, instrumentation, control techniques, detector development, etc. Effectively all major branches of engineering and applied aspects of physical sciences are encompassed under one single unit — a research reactor.

Control & Instrumentation of Research Reactor consist of different systems, instruments and equipments required for monitoring different parameters, controlling of various processes and provide protection for the reactor. C&I facilitate the normal operation of the plant & provide the operator all the information required to take necessary action for an optimal, reliable & safe performance.

The C&I requirements of Research Reactors are far more complex and diverse in nature than those of a conventional plant. There are several reasons viz. higher safety, availability, non-accessibility of reactor areas during operation of the reactor, challenges arising due to technological advances & obsolesces etc. Considering all these, the design & deployment of C&I systems of
research reactors are based on the design philosophy of simplicity, redundancy, adherence to single failure criteria, fail safe philosophy, common mode failure criteria, facilities for in situ testing, use of proven systems, use of qualified systems (environmental, seismic and LOCA qualification for appropriate systems) and ease of operation and maintenance.

This paper provides comprehensive technical information on recent development & implementation of C&I systems for the research reactors located at BARC, Mumbai.

**Control & Instrumentation Systems for Critical Facility**

The Critical Facility is a low power research reactor with built in design features which allow arrangements of fuel rods, SORs and experimental assemblies in the variable lattice spacing to simulate different core configuration as per the requirements of various reactor physics experiments for AHWR and 500 MW PHWRs. Maximum power can be achieved is 500W and the core neutron flux is $10^9$nv. This is a manually controlled reactor where in reactor power is varied by varying the inventory of heavy water used as moderator in reactor vessel. Nitrogen is used as a cover gas for heavy water system.

The neutronic channels for monitoring nine decades of neutron flux from $10^0$nv (fresh core) to $10^9$nv (100% Full Power) independent source, intermediate and power range instrumentation with required overlaps have been developed. The important aspects, like safety, reliability, convenience of operation, ease of maintenance etc. are specifically taken care of in the design. A new type of nuclear channel Log-Linear channel with all the in-situ test facilities was designed for the use in regulation and protection system. An extensive testing of nuclear detectors and channels has been carried out. The details of the nuclear channels & detectors are as follows:

The Start Up Logic System (SULS) is provided for startup permissive for the reactor. The transition from the ‘reactor tripped’ state to desired power level is accomplished through a set of operation which is to be performed from the control console in a certain sequence. These operations will not be effective unless certain conditions which are validated by SULS.SULS permits the raising/lowering of SORs in a predetermined sequence & generates an ‘SOR out of sequence’ alarm whenever operations of raise/lower are done in out of sequence.SULS also generates few time-related trips and alarms, when demanded for, to indicate the performance of shut down devices.SOR Motor Drive Interlock & Phase Sequence Detection and SOR Out of Sequence Raise Facility (OOS) for in-pile testing of a selected SOR is also engineered & deployed.

The primary shutdown system consists of six shut-off-rods with cadmium absorber. During reactor operation they are parked out of core at a fixed elevation and held there by electromagnetic clutch in the shut-off-rod headgears. The protection action is through relay logic, wired in two independent groups for the trip parameters (Group-1 & Group -2) in order to provide two diverse chains of protection action. Each group is capable of independently tripping the reactor. The design also ensures reactor trip, due to one or more parameters in one group resulting in de-energisation of trip relays on the other group. The system is given 48 Volts class-I DC supply and the relays are kept energized during normal conditions. Moderator dumping is also incorporated in the protection system, as a backup protection action, whenever any one of the main group trip relays is in de-energized state. Based on earlier experience with plastic encapsulated relays where the contact resistance degrades due to dust entry, epoxy sealed relays have been used.Check Scram Facility for functional validation of all reactor trips through a test push button on control console which actuates respective relays in protection system is deployed.

Functional tests were carried out for all fabricated Nuclear Channels, Start Up Logic, Alarm Annunciation System, Digital Recording System etc. Climatic tests consisting of dry heat, dry cold and two cycles of damp heat tests are done for PCBs, control cables, electromagnetic relays. Endurance tests like drop, bump and vibration are done on relays to be used in protection system, as per relevant JEE standards. The control room panels and local panels are designed to meet applicable seismic requirements.
Functional tests were carried out on all the nuclear channels. These channels were subsequently kept ON for a continuous operation (burn-in test) to observe their performance. As for the DC channels, measurement accuracy at very low current signal is very important. It was confirmed that the developed DC channels can measure up to 2pA. Further the DC channels were tested at the maintenance laboratory at TAPS-3&4. Subsequently the channels along with the detectors were tested at a calibration facility at RSSD, BARC. Due consideration was given for integrated testing these channels considering gamma field that was estimated at detector location. To evaluate the sensitivities of the detectors and response of the nuclear channels, integrated testing at Apsara reactor was carried out. As the detectors used for the start up range are B-10 lined counters, to observe the effect of gamma field on its performance, the testing was carried out at RSSD. It was verified that there are no changes in the operating characteristics up to 100R/hr.

Finite Impulse Testing (FIT) System for Emergency Cooling System (ECS) in Dhruva

Finite Impulse Testing (FIT) system for Emergency Cooling System (ECS) is used to check healthiness of ECS logic circuits in an online mode. The ECS is an important safety system that ensures the cooling of reactor core during shutdown state of Main Coolant Pumps (MCPs), and hence FIT-ECS that monitors the health of ECS logic circuits in an online (real time) mode is an important part of it. Based on a Safety Related Unusual Occurrence in ECS system due to the malfunction of its earlier single channel FIT system, the new FIT-ECS system has been designed with new features and is commissioned.

The FIT-ECS system feeds the simulated input signals (fine impulses of nominal width 575μS) to the ECS logic circuits and read the outputs. These output (predicted) signals from ECS logic circuit are processed in the FIT-ECS system and in event of any discrepancy, the FIT-ECS system displays fault signature on local panel, detailed information of the fault on a PC based Operator Console (OC), and generates an alarm “ECS Logic Fail” in the control room. FIT-ECS also monitors the inputs and outputs of ECS logic circuit. All the information required is stored as a database that can be subsequently displayed in various formats.

ECS system is designated as Category I-A system and is a hardwired system & FIT-ECS monitors the healthiness of the logics of the ECS System is a computerized system. As per IEC 61226, FIT-ECS is categorized as Category I-B system.

The FIT-ECS system uses standard microcomputer board family designed by RCnD and manufactured by ECIL. Design philosophy was adapted for easy maintainability reduction in PCB cost and component availability. The FIT-ECS hardware was manufactured at ECIL. Climatic testing on the representative board of FIT-ECS system was carried out successfully at ECIL as per CSG: STD: 203 which is based on IS9000. Subsequent to the module testing and individual channel testing, three channels of FIT-ECS system were interconnected and integrated testing was carried out as per approved test plan with the help of ECS simulator. The three channels of FIT-ECS were integrated and tested along with the ECS simulator for more than 5000 hours, partly at RCnD and at RRMD after shifted to the site (Dhruva).

The final integrated test of all the three channels as per approved test plan was completed and detailed test report was submitted to safety committees. Subsequently after the review of FIT-ECS design, documents and test results safety committee recommended Commissioning of FIT-ECS channel-A as per procedure submitted. Based on the satisfactory performance of the channel-A for the period of two months Channel-B & Channel- were commissioned during monthly schedule shutdowns.

Up-gradation of Dhruva Main Control Room (MCR)

The MCR of Dhruva had been designed in the late seventies, where a predominance of pneumatic instrumentation in the field necessitated the usage of a large number of pneumatic recorders & indicators. The Main Control Room of Dhruva has a total of nine panels, A, B, C, D, E, F, G, H & I, of which the central three panels, D, E, F house the plant mimic. While, the
indicators & recorders of most of the process parameters are positioned on the first three panels, the indicators & recorders for channel temperature & other nuclear parameters are positioned in G, H, &I panels. Since there is a plan to progressively replace many of the pneumatic transmitters (pertaining to various process system instrumentation), to electronics, there would be need to replace many of the pneumatic indicators & strip-chart recorders, mounted on the panel fascia and replace the same with multi-input chartless recorders. In addition, as a consequence of the C&I upgrades, whereby the Operator Consoles (OCs) of the entire proposed computer based systems, need to be mounted on the MCR panels, some of the control room panels required changes.

For the upgrade of the Dhruva MCR panels, the preliminary design requirements for a control room, viz. functionality, ergonomics & aesthetics, had to be weighed against the constraints of a retrofit job along with the need to maintain operator familiarity. Considering this, the aim was to replace the panels A, B, C, G, H&I, housing the indicators & recorders, and retain the three mimic panels, D, E, & F. The upgrade design considered complete replacement of the A,B,C and G,H, I panels with chartless recorders & Operator Consoles (for the embedded systems) in panels A,B,H & I (for display & recording of the existing parameters) and large-size screens in panels C (for CC-TV) &G (for display of fuel channel matrix).

The replacement of all the six panels was completed in six campaigns (during monthly shutdowns) as per approved commissioning procedures. Provision of temporary instrumentation was made for monitoring important parameters and keeping the safety interlocks & critical alarms effective during each panel replacement.

Up-gradation of Dhruva Control & Instrumentation:

The existing C&I systems of Dhruva have been designed in the late seventies and are facing not only obsolescence but have limited diagnostic features. As upkeep of these systems with limited spares inventory, is becoming increasingly difficult and the expected life of C&I systems is typically twenty years, it has been considered to upgrade some of the important C&I systems in Dhruva, viz. Coolant Channel Flow Monitoring System & Trip Logic System (termed as the Reactor Trip Logic System (RTLS), Start-up Logic System (SULS), Alarm Annunciation System (AAS) & ECCS Instrumentation Logic (ECCS-IL) using newly developed VME bus-based family of microcomputer boards by RCnD. The full scale systems for RTLS, SULS, AAS & ECCS-IL were setup at RCnD and exhaustive testing was carried out at RCnD as per the System Validation Procedure. After successful testing and validation of the system at RCnD, RTLS & AAS have been shifted to Dhruva & one of the Channels of RTLS is commissioned for the performance feedback.

Upgradation of Dhruva Radiation Monitors:

Up-gradation in the instrumentation of Failed Fuel Detection System by enhancement of signal level from the detector by using a detector with higher sensitivity, changing the range of FFD-instrumentation from six

Up-gradation of Control & Instrumentation of Fuelling Machine-A of Dhruva:

Fuelling machine-A (FM-A), is used to handle heavy water cooled assemblies of Dhruva Reactor. Owing to obsolescence of various C&I components, increasing O&M and other related problems, for better operator interface, upgrade of the C&I of the FM-A was initiated & completed. Considering the functional requirements and human machine interface requirements, the control console has been upgraded / modified. The mimic panel, all the switches and push buttons, relays and timers are replaced. DC power supplies are replaced with dual redundant supply. A new microcontroller based Beetle Monitoring Unit, Alarm Annunciation System & Fire detectors are provided. A microcontroller based Extractor position indication system (ELIS) that senses extractor position using multi turn absolute encoder is developed along with CnID, & is commissioned.
decades to three decades for better resolution were completed. This is of paramount importance considering release of a very low order of fission products activity for detection in case of fuel failure. The development of a microcontroller based Neutron REM Monitor with diagnostic & customized features were initiated along with Electronics Division. The environmental, Seismic, EMI and source calibration test for these units have been carried out following which the units have been installed in research reactors.

Conclusion

The original reactor C&I system of Dhruva reactor was developed in the late seventies. Even if the original C&I system completely met the demands that were put on it, its technical design is becoming fast obsolete. There older technology presents difficulties with maintenance due to a lack of spare parts. Furthermore, to adhere to some new demands on quality and qualification it was decided to upgrade the existing C&I systems. Compared to the old system, the new C&I system provides better testability and maintainability and uses up-to-date technology in both the hardware and the software. The most important experience during the C&I upgrade & its implementation has been the significance of the complete, correct and unambiguous requirements and the thorough testing of safety and operational features of the upgraded safety system within real reactor conditions. Our experience & collective wisdom has shown that C&I modernization and refurbishment programmes for research reactors must be a continuous activity where small steps must be taken to improve the performance of the reactor with moderate budgets and shorter shutdown periods rather than very extensive refurbishment programmes that require large sums and long shutdown times. However, very well-planning and skilful management of the activities are the essential ingredients for successful implementation methodology.