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Development of Tele-Alarm and Fire Protection System using Remote Terminal Unit for Nuclear Power Plant

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***Abstract*—Tele-Alarm and Fire Protection systems are two important echelons of the defense-in-depth approach to achieve a degree of safety necessary in Nuclear Power Plant. Tele-Alarm systems are used to ensure that the operator in every shift performs area surveillance of all the equipment to check their healthiness and identify maintenance requirements. Similarly, Fire Protection Systems play a major role in alerting plant operator for implementation of emergency action and are used to actuate fire-extinguishing systems in the incipient stage so as to minimize the fire damage to structures, systems and components. In this paper we present design & development of Tele-Alarm and Fire Protection System using 8051 Micro-controller based Remote Terminal Unit (RTU) for real time monitoring of area surveillance keys, call buttons, detectors used for detection of water logging, oxygen deficiency & fire hazards and generating control outputs for fire extinguisher via commands received from remotely located control room operator in nuclear power plant like Prototype Fast Breeder Reactor (PFBR) being constructed at Kalpakkam.**

Keywords—Tele-Alarm System; Fire-Protection System; Remote Terminal Unit; Prototype Fast Breeder Reactor

I. INTRODUCTION

Tele-Alarm System (TAS) is used to ensure that the operator in every shift performs area surveillance of all the equipment to check their healthiness and identify maintenance requirements. During the surveillance, maintenance personnel operate area surveillance key that is provided at strategic locations such that no area in the plant is left unattended in every shift, as some of the equipment/buildings are unmanned normally. Water logging detectors are mounted near sumps, in pits, trenches/tunnels and other areas in the plant where water is likely to be accumulated and affect other systems. Call buttons are provided at different locations in the plant to enable the personnel to draw immediate attention of control room in case they need assistance in the event of some emergencies. Actuation of the button initiates soft alarm in Control Room. Argon is used as cover gas for sodium storage tank and there exists a potential danger of depleting oxygen from the atmosphere in the event of leak/hazard. Hence oxygen deficiency detectors are also play a major role for the safety of plant personnel. These sensors are installed at strategic locations in PFBR site based on their functional requirements. The signals from different sensors are terminated at nearest Tele-Alarm system for processing and generating soft alarms on display station in Control Room (CR).

Similarly, Fire Protection System (FPS) along with fire detector is deployed across the PFBR plant so that fire can be detected in its incipient stage that can be extinguished readily. Sensors like smoke detectors, flame detectors, beam masters, linear heat sensing cable, fire buttons, etc., are distributed throughout the plant and are connected to 8051 micro-controller based RTU located in the field. The main purpose of fire detection system is to automatically detect the presence of smoke/fire phenomena, then transmit this information to control room for operators action. They are used to actuate fire protection systems, to close fire doors and smoke dampers, shutdown power operated equipment and alarm personnel.

This paper describes development of tele-alarm and fire protection system using RTU, hardware design description, application software and graphic user interface (GUI) for operator’s interaction with widely networked RTU systems for PFBR.

II. SYSTEM IMPLEMENTATION USING RTU CARD

Signals from Fire Detectors (such as smoke, thermal and flame detectors), Area Surveillance Key (ASK), Call Button (PBN), Water Logging Detector (WLD) & Oxygen Detector (ADR) are terminated at the nearest signal processing cabinets to generate soft alarms in the form of data packets and sent to process computer through plant backbone. These signal processing cabinets are built using 8051 micro-controller based Remote Terminal Unit (RTU) designed to handle Digital Input (DI) and Relay Output (RO) card along with power supply, interface module, Ethernet switches with RJ45 connectors and two fiber ports all housed in a wall mounting panel. Field signals are connected to RTU cards via interface modules. All digital input channels connected to the DI card are scanned at periodic intervals and the values are sent to process computer for display on Display Station (DS). Similarly all digital output channels connected to RO card receive command from display station and generate potential free contact output for solenoid valve/actuator situated near the field to release either gas or

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water depending on type of fire. Status of each channel is displayed on Display Station in Control Room. The overall architecture of networked Fire Protection & Tele-Alarm systems in the plant is shown in Fig. 1. This system processes signals wired to it from various sensors as per processing logic and sends alarm status in the form of data packet to process computer through plant backbone for soft alarm display on display station. Similarly this system receives soft commands from display station to control valve opening/closing action in the field. Information pertaining to Fire Protection & Tele-Alarm System is stored in fault tolerant process computer with time stamp. The HMI running on Display Station at control room indicates the alarm condition of each channel and facilitates control action to be generated based on the operator's decision.

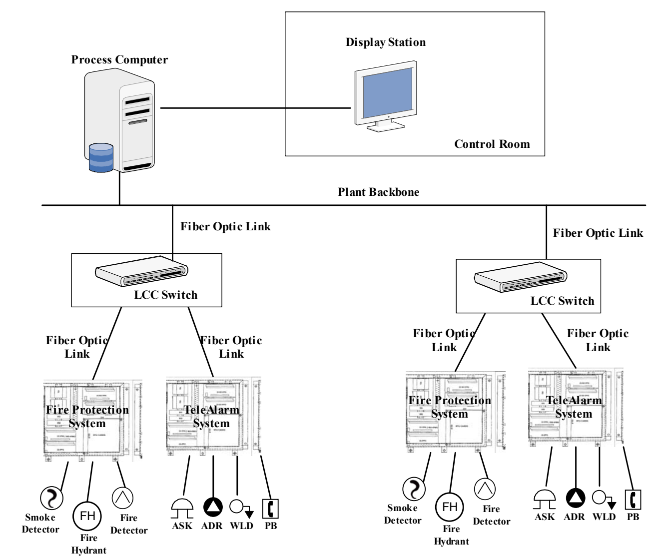

Fig. 1: Overall architecture of widely networked Tele-Alarm & Fire Protection System

There are 20 Tele-Alarm systems and 21 Fire Protection systems distributed geographically across the plant to scan 1272 digital input signals from various detectors and generate 123 digital output signals for control action [2][3]. All channel status are scanned at 1 second scan interval and data packets are sent over dual Ethernet to the Process Computer for data storage and retrieval by display station in CR. Control commands are received by field deployed RTU from control room via dual Ethernet communication to Open/Close valves of water sprinklers for extinguishing fire at incipient stage.

A. *Waterfall Model for System Development*

Waterfall model [1] as shown below in Fig. 2 is followed for the development of tele-alarm and fire protection system.

III. Hardware Design Description

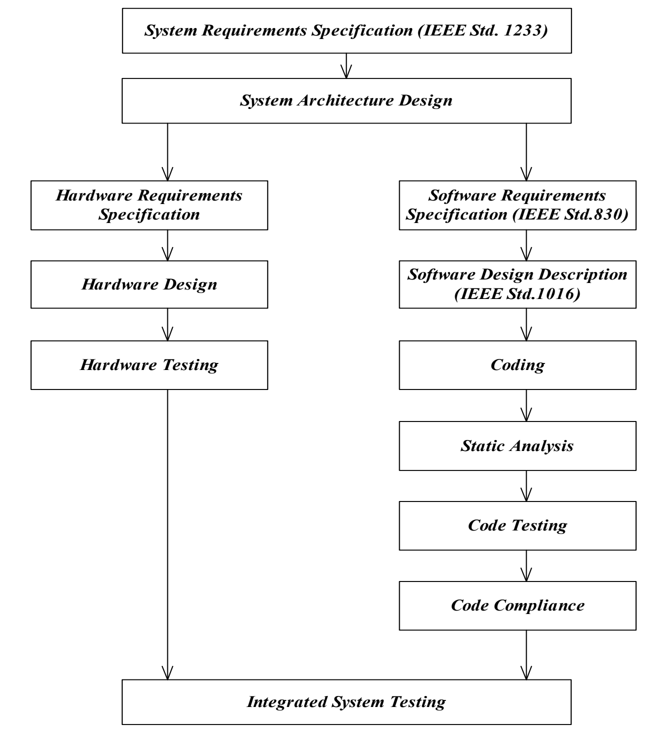

Fig. 2: Waterfall Model for System Development

Remote Terminal Unit is a general purpose 8051 micro-controller based single board data acquisition and control card which can be easily deployed in the field environment. It can sustain elevated ambient temperature, humidity and dust. It is based on Atmel 89C51RD2 flash micro-controller with following features:

- 64 Kilobytes of In-System Programmable Flash Memory
- 256 bytes of RAM
- 1792 bytes of XRAM
- 9-sources 4-level Interrupts
- 16bit Programmable Counter Array with Three 16 bit Timer/Counters
- Programmable Enhanced UART Serial Channel
- SPI Serial Interface
- Programmable Watchdog Timer
- Operating frequency: 11.0592MHz

RTU card complements these features by providing:

- On-board 32KB NV SRAM with battery backup, RTC, Programmable WDT
- Both power ON and manual Reset
- One serial port and two 10/100 Ethernet ports
- 30 channel digital input with Opto-isolation and input signal de-bouncing
- 16 channel relay contact output with read-back facility
- Single operating voltage 5 VDC
- Board dimensions are 23.3 x 22.0 cm

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The flash micro-controller can be serially programmed in the field while in the target application circuit. This function of the flash micro-controller simplifies new program development and debugging. The functional block diagram of 30 channel digital input RTU & 16 channel relay output RTU are shown in Fig. 3 & 4. These boards were qualified for Environmental, EMI/EMC and Seismic requirements of PFBR.

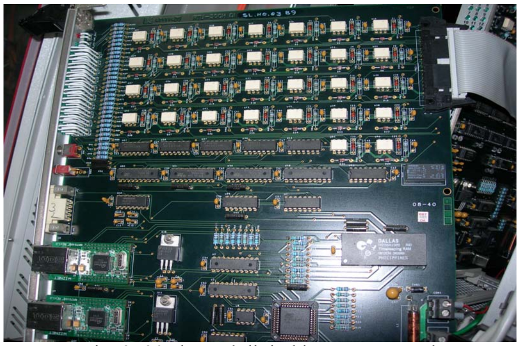

Fig. 3: 30 channel digital input RTU card

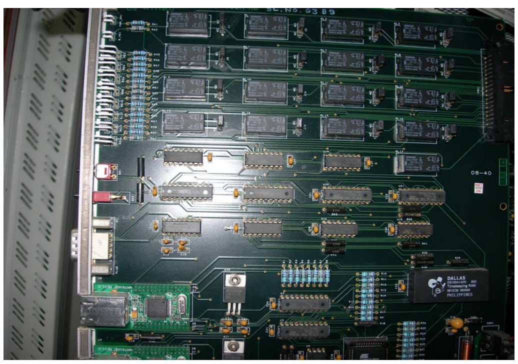

Fig. 4: 16 channel relay output RTU card

The system architecture using RTU card is shown in Fig.5 that houses following components inside the wall mountable enclosure as listed below:-

- RTU boards for Digital Input (DI) and Relay Output (RO) with mounting provision at four corners of the box
- Power supply unit for RTU board & Field Interrogation Voltage
- Media converter for UTP to Fiber Optic communication
- Fiber Patch Panel
- Terminal Block Assembly for receiving field I/O.

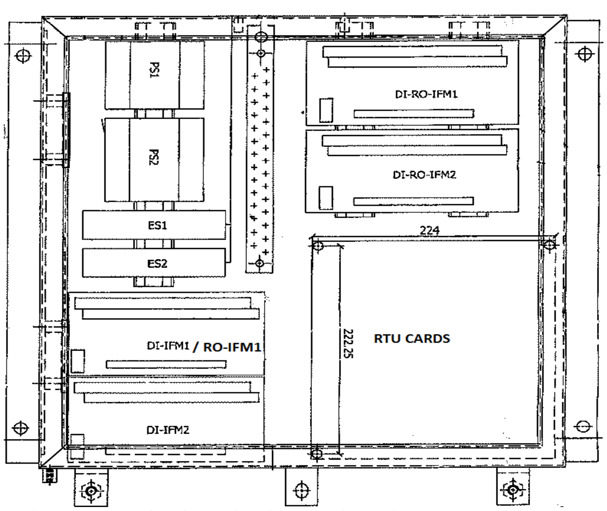

Fig. 5: System hardware implementation using RTU cards, Power supplies (PS1 & PS2), Ethernet switches (ES1 & ES2) and Interface Modules (IFM) for DI & DI-RO inside wall mounting box

IV. Development of Application Software

Application software was developed as per standard practice of IEEE std. 830 in ‘C’ language using KEIL ‘C’ compiler. The specific requirements like initialization of micro-controller, memory & Ethernet for communication, loading watchdog timer for 10 second scan interval, reading digital input status, sending data packet via Ethernet ports, receiving data packets via Ethernet ports, latching output data and finally waiting for Watchdog timeout to happen before going to next scan cycle. The application code follows MISRA-C at the time of development and the hex code generated by the KEIL ‘C’ cross compiler are downloaded in to the Flash memory of RTU card using In-System Programming (ISP) facility. Separate IP & MAC addresses are assigned to each RTU card. Special features in tele-alarm system like auto reset of area surveillance status after completion of each shift was incorporated in the application software. With the help of RTC time keeper sitting on RTU board, software intelligence was included to count change in shift and accordingly area surveillance status was updated periodically pertaining to each shift. The flow chart for developing application code for tele-alarm and fire protection system is shown in Fig. 6 & 7.

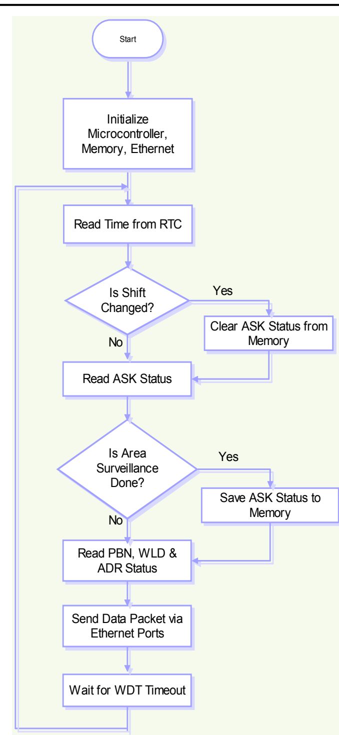

Fig. 6: Flow Chart for TAS

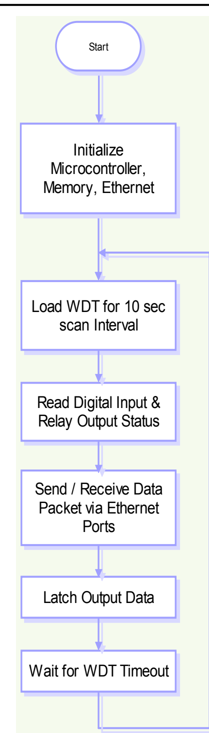

Fig. 7: Flow Chart for FPS

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A. Software Quality Metrics

The application software developed for FPS & TAS were subjected to software quality metrics using LDRA tool suite and various metrics like Clarity, Testability and Maintainability with respect to Executable ref. Lines, Total Comments, Comments in Headers, Comments in Declarations, Comments in Executable Code, Blank Lines, Total Comments/Executable Lines, Declaration Comments/Executable Lines, Code Comments/Executable Lines, Average Length of Basic Blocks, Unique Operands, Total LCSAJs, Depth of Loop Nesting and Expansion Factor, Knots, Cyclomatic Complexity, Executable reformatted Lines, Number of Basic Blocks, Total Operands, Number of Loops, Procedure Exit Points, Number of Procedures, Unreachable LCSAJs, Maximum LCSAJ Density, Unreachable Lines and Unreachable Branches were generated for independent verification and validation. The Kiviat Chart and Call Graph were obtained from LDRA tool suite as shown in Fig. 8 & 9. A traceability matrix was prepared to depict the chain from specification to implementation which helps in the complete traversal in software life-cycle. Reports were prepared and submitted to Verification & Validation committee.

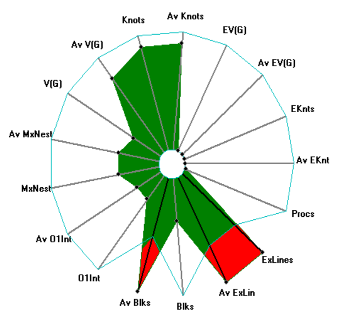

Fig. 8: Kiviat Chart generated for system application software

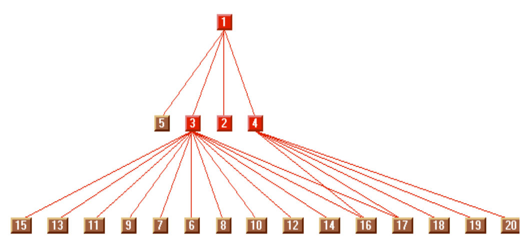

Fig. 9: Call Graph generated for system application software

V. Development of Graphic User Interface

A Graphic User Interface (GUI) was developed for using Visual Basic to get alarm status of each channel and send control command like open/close through soft button by selecting specific channel. Various features like auto reset of area surveillance status after change in each shift was developed and tested. System performance was observed and recorded for software bug fixing. The GUI for tele-alarm and fire protection system is shown in Fig. 10 & 11. Apart from status display in the form of soft alarm, it also indicates the healthiness of field deployed RTU cards based on the arrival of data packet on process computer at each scan interval. Open and Close commands are provided on the GUI for operators to take action based on alarm status on fire detection channels.

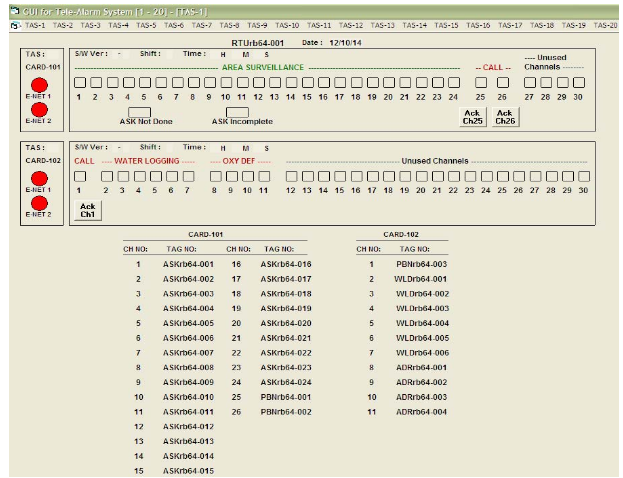

Fig. 10: GUI for Tele-Alarm System

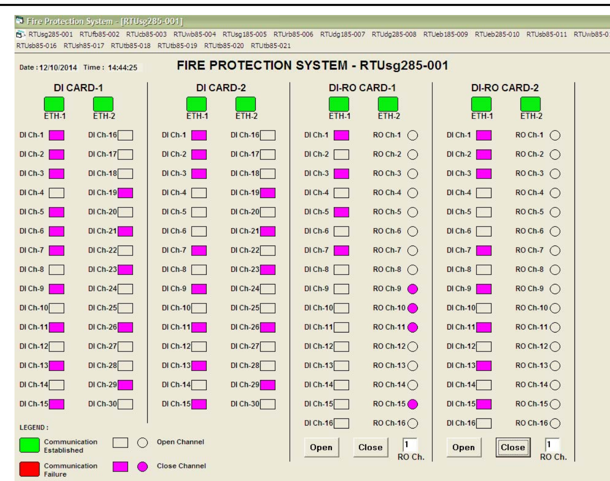

Fig. 11: GUI for Fire Protection System

VI. Conclusion

The micro-controller based Tele-Alarm and Fire Protection System with distributed architecture have been successfully designed, developed and tested for 500MWe Prototype Fast Breeder Reactor being constructed at Kalpakkam project site. The hardware has been qualified to meet the environmental condition, EMI/EMC and seismic guidelines for a nuclear reactor. The system application software has been developed according to AERB guidelines [4].

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