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Design and Implementation of PLC and SCADA based Monitoring and Control System for Radiological Once through Ventilation System at BARC

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Abstract:- PLC and SCADA-based automation systems are the most widely used industrial automation systems today, owing to their numerous advantages. The specialized requirements and customization in various aspects of radiological once through ventilation system necessitate the requirement of efficient control and modernization in existing hardwired interlocked system. With the existing hardwired interlocking between the sub systems, there were certain operational challenges and unsafe operating conditions. The existing system lacked certain key features such as Working/Standby changeover and Mains/Standby selection for any sub system. Also, the manual regulation of control equipments in event of system changeover and during the normal operation manual throttling of damper actuators to achieve desired optimum performance, lead to inefficient control. This arose the requirement of sophisticated advanced automation system for simple and safe operation. The automation system with utilization of PLC and SCADA systems including the networking components represents the most efficient way to improve the radiological once through ventilation system. This paper elucidates the various design criteria & features, as well as the sizing and selection of various automation components, and the development activities performed for implementation of hot standby PLC and redundant SCADA based monitoring and control system for radiological once through ventilation systems catering to an important facility at BARC South Site Trombay.

Keywords:- *PLC, SCADA, HMI, DI, DO, AI, RS485, Ethernet, RTU PCC, MCC.*

I. INTRODUCTION

For functioning of any typical radiological laboratory, the uninterrupted availability of certain safety critical utility systems and engineering services is mandatory and therefore they are operated on round-the-clock throughout the year. There are various safety critical utility services but this paper covers only one of such services which is radioactive once through ventilation system. Ventilation is an important confinement barrier for radiological, biological, or toxicological hazards [1].

The once through ventilation system mainly provides dynamic confinement and maintain DAC level. In once through ventilation system, first the fresh conditioned air is supplied to all areas in the lab and exhausted through hot-cells, glove boxes, fume hoods and exhaust grills located in radioactive areas. This system mainly consists of four sub systems which are Supply air system (SB), general air exhaust system (EB), Glove Box exhaust system (GB) and Fume hood exhaust system (FH). The Fume hood (FH) and Glove box (GB) exhaust air systems are used for very high radioactive areas and hence there is only exhaust system with no direct supply air. Based on the nature of operations carried out and potential for the spread of radioactive contamination from the area four zones are defined which are Red, Amber, Green and White [2]. Sufficient inter-zone pressure difference is required to maintain to prevent back flow of air from higher radioactive zone to lower one. Certain amount of air changes is also necessary for each zone [2].

As per the standard guidelines (ASHRAE, 1993) Ventilation system for the radioactive area is so designed that glove boxes (*Red zone) are at slightly negative pressure with respect to the radiological laboratory and the radiological laboratory is at negative pressure with respect to adjoining area (*Green area: Inactive laboratories, inside offices/sitting rooms). The building is also maintained at slightly negative pressure with respect to outside environment. Thus, the facility ventilation is so tuned that no air from the operating area leaks out to the environment. As a safety requirement general air exhaust ventilation maintains desired plenum static pressure which in turn maintains constant volume air changes in the lab and lab are maintained the desired negative pressure. In addition, the exhaust air from radiological laboratory& glove boxes are passed through HEPA filter banks and radio logically monitored before being discharged through the common stack of Radiological Laboratories.

The above-mentioned sub systems are required to be hardwired interlocked in operation, and hence needs to be started in predefined sequence only. The standard operation starting sequence is that any one from the set of GB shall be started first, then any one from set of EB shall be started and then finally the SB shall be started. However, the standard stopping sequence is exactly opposite of starting sequence.

Each of these systems consists of set of redundant centrifugal blowers viz Mains & Standby blower, driven by star delta starter and has On/Off type suction dampers, modulating type discharge dampers. Motors of EB blowers are equipped with dual speed controls. Since these blowers operate in working standby mode, whenever operating blower trips/fails, the standby must be started automatically along the operation of respective dampers. For each of these sub systems certain process variables are required to be maintained continuously at a desired value by regulating the respective final control elements. Like the desired plenum static pressure at each SB, EB, GB & FH system by modulating the damper position, desired negative pressure inside lab/glove box/fume hood by regulating supply & exhaust grills position. The schematic block diagram of a general once through ventilation systems is as shown in Fig. 1.

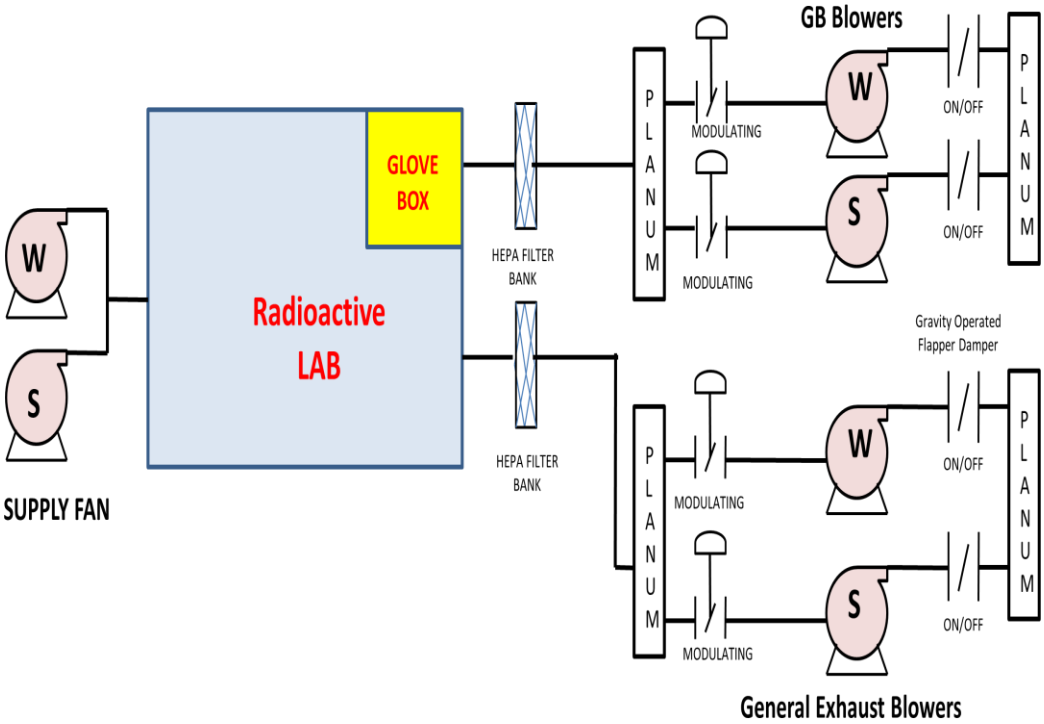

Fig. 1: Schematic of Once Through Ventilation System for radioactive lab

A. Operational Challenges in existing system:

Previously this system was monitored and controlled through manual surveillance. Plant operators had to physically monitor performance values and the quality of outputs to determine the best settings on which to run the process or various process equipments. Although system had the capability of manual as well as automatic operation through conventional hardwired interlocks in electrical starter panels, it was found to be tedious for operators during regular operations. For example, say in event of intended system changeover from working to standby, even if the blower changeover occurred automatically, switchover of damper had to be done manually. For this operator had to go near the damper (actuator) and manually adjust/throttle the damper position to achieve the desired pressure at plenum. Since the blower starter panels and dampers are located distant apart, the manual intervention adds significant time lag in operational switchover which generally results in operational inefficiency and sometimes unsafe operating conditions. Also, Plant parameters were manually noted down on regular intervals. It also lacked the data storage and history archival provision.

In addition, there were certain limitations hardwired starter panel-based controls such as Auto/Manual changeover provision for provided for individual blowers and not for system which comprises set of working/standby blowers, no Mains/Standby selection was possible, even for an intentional changeover of the system operator was required to follow certain special operating procedures. Also, since the blower operation was possible only in predefined sequence only, in case of changeover of only one sub system entire ventilation system had to be stopped once and restarted again as desired. This unnecessarily multiple time On/Off operations of large sized blowers were unhealthy for life of the motors. Also, even the hardwired interlock for system changeover was employed, it was solely depend on the On/Off feedback of running system. Because of which in event of loss of On/Off signal, the changeover could not be occurred. To avoid such situations certain additional interlocking conditions needs to be imposed ensuring the equipment safety. Additionally, since the process parameters instrument locations are geographically distributed at various locations, for data logging operator has to take a long round, which was quite tedious.

Hence to overcome these limitations, the PLC & SCADA based plant automation system was proposed with an intend to ensure the increased plant safety, less human error, increased accuracy, and repeatability. The automation system allows the real time online measurement, monitoring, and control of process parameters remotely from centralised control room. Also, the plant operating settings are then automatically adjusted to achieve the optimum performance. At the same time plant operators can manually override the process automation system whenever necessary under accidental situations. In addition to this there are other added advantages of PLC based automation system such as data logging, alarm and event management, trends of various process parameters, online system diagnostics are the added advantages of automation system.

This paper elucidates the design and implementation of advanced PLC & SCADA based monitoring and control system deployed for once through ventilation system. The various sub systems of the automation system are Hot standby PLC, redundant SCADA IO server, redundant Communication network, PC based operator workstations also called as control clients and touch screen HMIs. Various design criteria & features, as well as the sizing and selection of these various automation components, and the development activities performed for implementation of hot standby PLC and redundant SCADA based monitoring and control system for radiological once through ventilation system is explained in following sections.

II. DESIGN METHODOLOGY FOR PROPOSED AUTOMATIC CONTROL SYSTEM

The primary objective of the design and development of a PLC & SCADA based automation system for a radiological once through ventilation system, is not only to serve the ease of operation by providing operator interface for remote monitoring from control room but also to provide increased safety with deploying additional interlocks in such a way that in event of failure of entire automation system, the existing hardwired philosophy shall remain intact. This paper attempts to explain each step involved in design and development PLC & SCADA based automation system for any type of large process systems, through an example of radiological once through ventilation system.

The online survey and literature study has been done on design of an automation platform with PLC and SCADA system. This guides in understanding various possible control scheme, configuration of various hardware components etc. The very basic information required for design of PLC based automation system is the number of Inputs/Outputs commonly referred as IO count. To finalise this, site survey of existing plant and in-depth knowledge of plant requirements is necessary. The IO count is finalised by referring to MCC interfacing scheme, list of equipments & sub-equipments, list of process instruments to be integrated. In addition to hard wired IO counts, soft IO counts which is basically soft data received form communicable devices is equally important. Once the requirement is finalized, then comes the design part. The step wise methodology followed, is explained here in further details.

Broadly there are three main steps involved in the design and development of automation systems. Then very first step involved is to collect the real time data from plant, for which the measurement system using field instrumentation is required. For designing this measurement and monitoring system, knowledge of sizing and selection of process instruments plays a very vital role. In addition to process field instruments, integration of other field devices such as MCC & PCC panels with PLC are required, which enable us to control the blower On/Off operations remotely. Whereas for controlling the process parameters at desired values controlling of valves & actuators is required. Then in the second step, these process transmitters and field devices are required to be connected to data acquisition system, through hard wired cables, for which proper C&I cable and cable tray laying is required to be designed and developed. Once these instruments are connected to data acquisition system, then finally comes the third and most crucial step, design of control system. In order to meet the operational requirements, providing increased safety interlocks, and most importantly uninterrupted highest availability of systems, various design criteria, factors and advanced features are needed to consider. The development of the control algorithms is most crucial step that determines the performance and effectiveness of the overall control system. Each of these steps are explained in further details in following sections.

A. Measurement System:

Various type of process parameters involved in ventilation systems are plenum static pressure, pressure drop across HEPA filters, gauge pressure, temperature, relative humidity, air flow, liquid level etc. The respective process field instruments or transmitters are geographically distributed across various locations inside the plant. Once the monitoring requirements are finalized, selection of appropriate instrument is a very essential step. Based on the type of instruments selected other provisions are required to considered in control system design such as power supply requirement based on whether the instrument is loop powered or separate power is required, configuration of instrument like 2-wire,3-wire or 4-wire, type of instrument output whether voltage or current signal etc. The instrument shall also be configured in desired measuring range and same Upper Range Limit (URL)&Lower Range Limit (LRL) values are used in scaling in PLC programming.

B. Signal and Control cabling:

For transmitting the output from field instrument to data acquisition system, C&I cables used are individual shielded, strip armoured, 0.5sq.mm, twisted pair, stranded class-II, copper as conductor material, PVC-FRLS as inner & outer sheath cables. Whereas that of used for interfacing field devices like MCC & PCC panels, solenoid valves, control equipments etc are multi-core, armoured,1.5sq.mm, copper as conductor material, overall shielded, PVC inner & outer sheath cables. Whereas for wet signals carrying 230V AC, 3-core 1.5sq.mm, PVC-FRLS insulated power cables are used.

C. PLC & SCADA based automation System

In modern times, for monitoring and control applications the PLC (Programmable Logic Controllers) and SCADA (Supervisory Control and Data Acquisition Systems) based control systems have become very much popular option for its varied advantages such as simplicity, modular construction, compatibility, fail-safe, highest system availability through redundancy at multiple levels, modular expandability, user friendliness (ease of programming& reprogramming) and exhaustive fault monitoring and diagnostic capability, rugged design to operate in industrial environment etc [4]. The subcomponents of PLC are central processing unit (CPU), memory, a rack or backplane into which various IO “cards” or "modules" are plugged. This various type of cards includes power supply module, different type of Input/Output module, communication modules, etc. The IO modules are generally hot swappable type, which means each card may be removed and a new one inserted without de-energizing power. The automatic control provided by the PLC ensures safe and efficient start-ups, shut downs, and handling of emergency events. The networking and data-logging capability of the PLC ensures remote monitoring of critical by plant operators. And for this, the interaction between process system and operators is prompted by SCADA through visual representation of process parameters [5].

The various type of IOs handled by PLC are Digital, analog and networked type. Digital Input (DI) devices such as the differential pressure switches, level switches, pressure switches, contacts, etc connect by wire to terminals on DI cards, while output devices such as lamps, solenoids, and motor contactor coils connect by wire to terminals on Digital Output (DO) cards. Analog Input (AI) devices includes various types of transmitters like pressure transmitters, temperature transmitters, relative humidity & temperature transmitters, electromagnetic flow meters, and ultrasonic level transmitters etc whereas Analog Output (AO) devices includes modulating damper actuators, I/P converters, control valves etc. And various network IOs includes soft communication data received from various communicable devices installed in starter panels, such as multifunction energy meters, microprocessor-based relay (µP), energy valves, UPS, battery charger etc can share data to a third-party system vide serial communication [6] over Modbus RS485 or TCP/IP protocol. Sometimes these devices are also available in the form of IoT devices [7].Also, certain control settings of these communicable devices are required to be changed remotely from SCADA.

After the hardware configuration of PLC part, then comes the software part where the control logic is written that decides the control action. The implementation of intended control philosophy can be further broken down into small sub steps. This covers first the identifications of the controlled variables (CV) and measured variables, also known as process variables (PV) in each sub systems or equipments. Then to establish the appropriate relation or algorithm between PV and controlled equipments. The various types of control algorithms such as PI, PID, Cascade, Override and split range controls are implemented for this control system. The proper selection and tuning of the respective closed loop control strategies are decided considering various factors such as desired speed of response, time constant, settling time, peak overshoot etc. This step of deciding the control algorithms has most significant impact on the overall system performance. Then comes the part if identifying the external factors that affects our closed loop. For example, say in event of changeover of exhaust fan from working to standby, the modulating damper corresponding to newly started blower shall be regulated and the damper of previously running blower shall be fully closed. Thus, considering such multiple constraints, the control algorithms needs to be further fine tuned.

a) Design of Control System Architecture

Since the field IOs are geographically distributed across the entire plant area, these are connected to nearest one or more localized Input/Output Modules, commonly referred to as Remote Input Output (RIO) panel. Such multiple RIOs are communicating with the centralized redundant PLC and centralized redundant SCADA system, through redundant Ethernet network media over Modbus TCP/IP protocol. This RIO based distributed architecture is preferred for its varied advantages such as reduced cabling cost, localized IOs make system easier to maintain and troubleshoot, etc. The RIO architecture is conceptually analogous to PLC itself deployed at multiple locations. However, only the logic part lies in main PLC and is located at a centralized location. The SCADA system is also kept in a centralized location. The control system architecture designed for the plant is shown in Fig. 2.However, the RIO-1,2,3 and 5 are used for once through ventilation system for one facility.

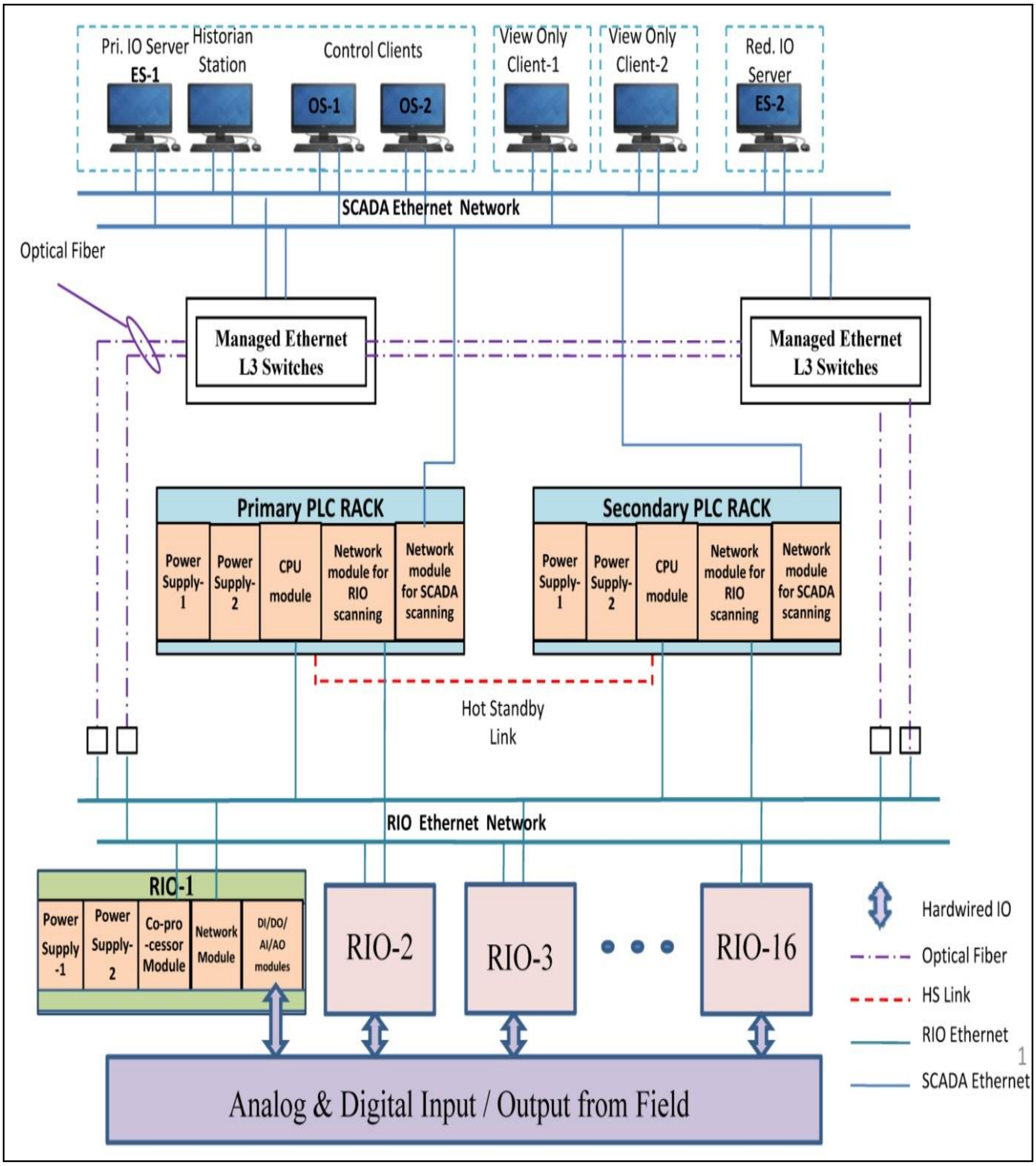

Fig. 2: Control System Architecture

All the TCP/IP ports of each RIO are connected to its nearby L2 Ethernet switch, referred as 'RIO Ethernet Network' in Fig. 2. Each network switch has Fibre Optic (FO) ports for uplink and multiple copper ports for Cat-6 devices. All the L2 Ethernet switches are networked through redundant managed L3 switch, through optical fibre media. In order to deploy the redundancy at network level, the RIO Ethernet Network is implemented such that each RIO rack has redundant communication module, which are Layer-2 (L2) physical networks. This L2 network is routed through redundant Layer-3 (L3) network switches, such that each L2 switch will have one FO uplink from both L3 switches. So, event of failure of one L3 switch, other one can keep the entire network intact and healthy. The conceptual diagram showing the interconnection between these L2 and L3 is as shown in Fig. 3.

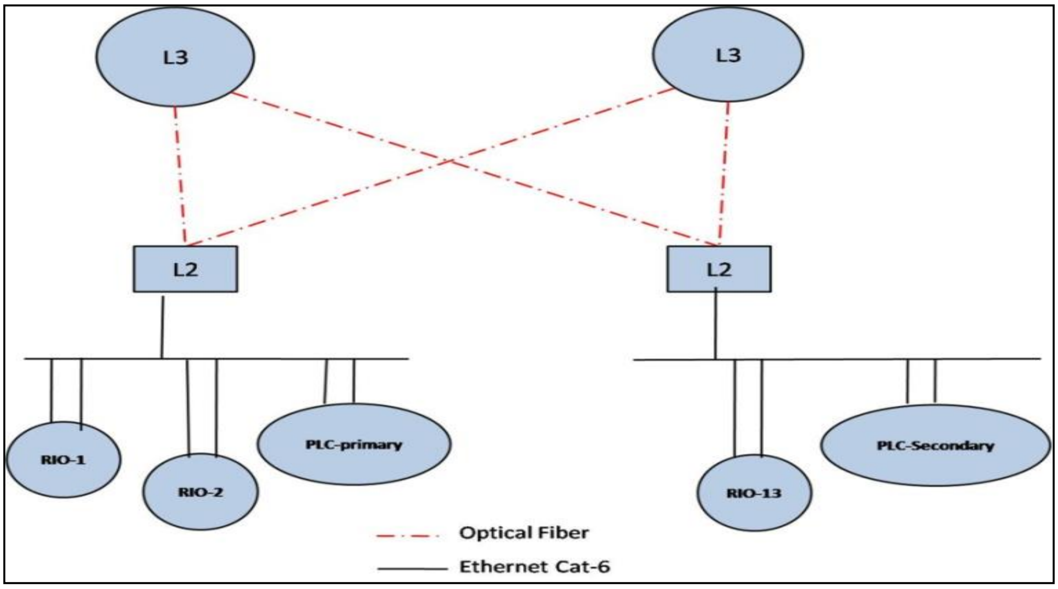

Fig. 3: Interconnection between TCP/IP devices and Network switches

b) Design features of control system:

Various design features implemented in PLC and SCADA based monitoring and control system are as follows:

- Highest availability of the system is provided through providing redundancy at various stages like power supply redundancy, controller redundancy, Backplane Redundancy, communication redundancy, etc
- Ease of operation from SCADA control stations, overview monitoring of all systems at a glance, mimics of process diagrams for better visualization, and operator guidance wherever required
- Functionalities like Mains/Standby selection, Auto-Manual changeover, Auto start/stop sequence, maintenance isolation, control key feature are provided
- Closed loop control is implemented using PLC-PID controller
- Continuous running hour and time duration since last start of all the blowers
- Multiple user access concurrently
- Data logging at periodic intervals, on operator request and automatically on occurrence of an event.
- Original hardwired interlocking is kept intact so that in event of PLC failure, the system will run in fail-safe mode.
- Alarm and event management
- Secured access control for various systems
- Report generation and history archival

c) Design, selection & sizing of components

The various type of field instruments (transmitters) and other field devices such as MCC, electrical panels, energy meters, smart control panels etc. are physically distributed at multiple locations. Field devices of a particular locations are monitored and controlled by employing local IO panels also known as Remote IO Panel (RIO) which will be communicating to Hot Standby PLC Panels using its co-processor over dedicated redundant Ethernet network, which is the most widely used communication platform [16].The redundant Ethernet communication module on main PLC backplane acts as an interface between main PLC (CPU) and these Ethernet IO drops (RIOs), SCADA computers and various third-party devices via Modbus TCP/IP communication protocol.

a. PLC System:

Hot Standby PLC system includes, two Hot Standby local racks, each containing a Hot Standby CPU with redundant Ethernet I/O scanner service. These two local CPU racks, called as Primary and Secondary are housed in separate enclosures and located at distinct locations in separate buildings. There is a dedicated Fibre optic hot standby (HSBY) link between primary and secondary PLC for synchronization. These two backplanes are configured with identical hardware and software. The primary and secondary state of these controllers are interchangeable. Both CPU panels are provided with redundant power supply taken from two separate sources. I/O modules are not supported on the local main rack.

Each RIO panel backplane is provided with hot standby dual in Rack power supplies, IO modules, communication processor modules, communication port extension modules etc. Entire plant field IOs are distributed across 16 nos of distributed RIO panels, located at different locations. The redundant communication between each RIO drop and Hot Standby PLC panels, is implemented in STAR network topology. Various Components and their mounting in an RIOs are as shown in Fig. 4 below:

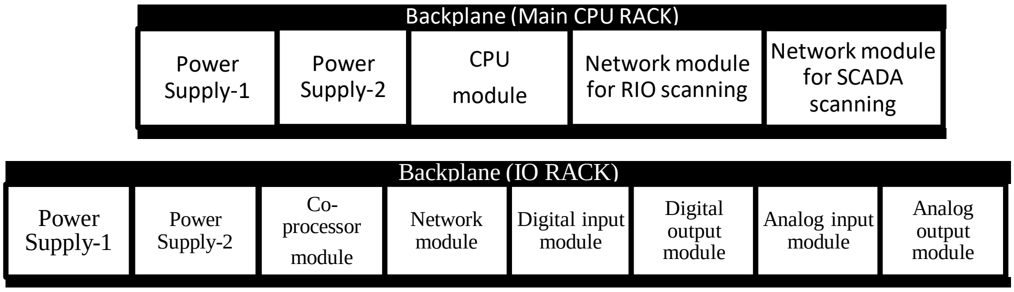

Fig. 4: Various type of modules mounted on Main CPU rack and IO rack

b. Power supply:
For all these panels, the incoming power supply voltage is 230V AC, 50Hzfed from two separate external source of power viz Class-II and Class-III. The field interrogation voltage is 24 V DC hence in each panel redundant SMPS with oring module is provided. All the IO modules mounted on rack will get power from backplane itself.

Also, the 24 V DC power for both DI/DO and AI/AO circuits are kept separate. For DI/DO modules, the electrical isolation between channel-to-channel and channel-to-ground is provided through Opto-isolators or opto-couplers made up of light emitting diode and photo transistor. Whereas that of for AI/AO modules, galvanic isolation is provided.

c. DI, DO, AI,AO Modules
The selection of various type of IO modules is done considering factors such as interrogation voltage, channel-to-channel isolation, channel-to-ground isolation, channel density so as to restrict the panel size, availability of prefabricated connectors between modules and terminal boards etc. In digital modules 32 channel both Digital Input and Digital module is used. Whereas in Analog Inputs 8 channel cards and in analog outputs 4 channel cards have been used. Since most of the field control circuits are 230V AC, for potential isolation from field and protection of the cards, relay boards have been used for digital output modules.

d. Data communication from third-party devices
Soft IOs are received from various communicable devices used in each starter feeder used for control supply for of all the safety support systems, such as multifunction energy meters, microprocessor-based relay (µP), UPS, battery charger etc can share data to a third-party system vide serial communication protocols like Modbus RS485 or Modbus TCP/IP. In general, the Modbus protocol interface is used to initiate intercommunication among one master and number of slave devices. The queries from master are responded by a particular addressed slave or groups who supply the requested data or follow the command. PLC controller or CPU acts as a master for all these slave devices.

e. SCADA system:
For remote monitoring and control, a set of dual hot redundant SCADA IO servers, 4 nos control clients, 2 nos view only clients and 10 nos web view only clients are provided. Communication to SCADA IO server and control clients is also redundant type. Real time field values and alarms/ events updates from the PLC shall be updated to both active/primary SCADA servers and standby SCADA server, to maintain database synchronization between SCADA servers. For remote monitoring and control two different control room are utilized, each containing 1nos IO server and 2 nos control clients. Two step user authentication or access control to both SCADA IO servers and control clients with the combination of passwords, biometric finger scanner and RFID card readers is provided. The card reader and biometric finger scanner is connected to IO server and control client PCs vide TCP/IP and UDP protocols respectively. Also, multi-level access such as Admin, Engineering, Maintenance Supervisor, Shift Operator, Shift In-charge is defined. For local monitoring and overall status at certain critical places, total 8 nos7" touch screen HMIs are also provided.

The SCADA hardware used are high configuration Server grade rack mountable PCs for Io servers & Historian, Touch screen IPC for control clients, and commercial grade PCs for view only clients.

For reporting of history data, Historian server is provided which stores data accurately for long-term reporting and gives an option for displaying and accessing the information via MS-SQL or equivalent server. Browsing of PLC soft tags for real time values as well as historical values is also possible whenever the analysis is required. Historian server generates the professional, state of the art reports with graphical representation, such as Shift wise Log report, Full day wise report (any start date to end date), overall report for very long-term analysis say 6 months. These reports can be generated manually as well as a feature is provided to automatically store the periodic reports at given location.

III. DEVELOPMENT OF PLC CONTROL LOGIC AND SCADA PROGRAMMING

The configuration tasks can be carried out online with PC connected to PLC-CPU and also in offline mode. As specified in IEC 61131-3, the configuration software supports the five IEC programming languages which are (i)Function block diagram (FBD), (ii) Ladder Diagram (LD), (iii) Sequential function chart (SFC), (iv) Instruction List (IL) and (v)Structured text (ST). For our system, majority of the program is developed using FBD which basically has the backend program developed in ladder logic only. The FBD programs uses the graphical blocks, which acts as a macros functional block or subroutine, also known as DFBs to make program crisp and helps in efficient program management to trace the error if any. With the use of DFBs, if any further modifications in programs occurs at later stage, it need not be changed in every section of the program, changing in one common DFB will itself reflect it at all places. typical

Various activities involved in PLC programming are defining and assigning variable tags, sequential IO address assignments, assigning memory locations for each variable, assigning data types, arithmetical & logical functions, sequential operations, configuration of timers, configuration of counters, configuration of PID controllers for closed loop controls etc. The programming of these PLCs involves use of timers, counters, various arithmetic & logical operation instructions/blocks, scaling blocks, comparison blocks, etc.

The PLC soft tags corresponding to each IO address, is so uniquely assigned such that it is not only non-repeated but also very user friendly so as to trace ay IO. The format of IO tags is 'LOC_EQUP_CC_STS' where the philosophy considered is first will talk about the location of the IO like RIO-1, then the details about the main equipment or system to which that IO belongs like say building-1 Exhaust Blower system, then about the details of the sub system like blower-1and then finally the IO description such as On/Off/Trip status, On/Off command etc. Thus, for the above example the entire IO address for ON status of blower-1 will be 'RIO1_B1_EB1_ SON'.

A. Development of control logic for Ventilation control:

The logic developed for once through ventilation system is explained herewith as an example. Once-through ventilation system includes building (general air), as well as glove box and fume hood exhaust ventilation system. This comprises of 2 nos Supply blowers (SB), 2 nos general air exhaust blowers (EB) and 2 nos Glove Box (GB) exhaust blowers, and 2 nos Fume hood (FH) exhaust blowers each in one working and one standby configuration. These above-mentioned systems are interlocked in operation and hence needs to be started in predefined sequence only. The start sequence is that first any one from the set of GB shall be started, then only from a set of EB and then finally from a set if SB. However, the standard sopping is exactly opposite of this i.e first SB then EB and then GB system. Along with the GB system only, FH system is also started. However, FH system is not used interlocked with any other system.

The common interlocks applicable for SB, EB, FH& GB system are as follows:

- Sequential start permissive interlock (i.e. to start EB system, first GB system must be running and similarly to start SB system, both EB & GB system shall be running,) whereas FH system can be started with GB system but is not interlocked with other sub systems.
- Only one blower from set of two shall be running at a time. Under any circumstances both blowers can not be running.
- Low Static pressure interlock
- Input power availability interlock (power in respective panel incomer)
- Maximum count for auto changeover is reached.
- Only One DG running condition interlock (EB can be started in SLOW speed only and SB can not be started)

B. Logic for Glove Box Exhaust system

There are two glove box air systems which can be put ON and OFF through individual star-delta starter panels. These two starters are part of EP1 and EP2 panel. The GB system is an uninterrupted service and hence cannot be stopped irrespective of the other ventilation system hence there is no starting interlock with EB or SB system. These blowers can be started/stopped from Local as well Remote (i.e. from SCADA) based on the selector switch position. In remote mode, it can either be started in Manual or Auto mode through selection from SCADA faceplate for respective blower/system. In Auto mode, whichever blower is selected as ‘Mains’ will start automatically whereas on tripping the working blower the standby blower will be started automatically. This changeover will work only up to a count of 6, in an hour and beyond that a pop-up message will be displayed and no further auto changeovers will take place.

a) Local/Remote Mode
Local remote (L/R) mode selection is done at site from local remote selector switch provided on respective MCC panel. Generally, L/R switch is in remote mode which will make the hardwire circuits controllable (start and stop both) from PLC system. In Local mode only stop command from SCADA will work. The L/R status is shown on the blower faceplate.

b) Auto/Manual Mode
Auto/Manual (A/M) mode can be changed from blower faceplate. The change of A/M mode is event stamped along with the username and time. A/M Mode of operation is applicable only for starting the system and Stop being a safety command it is irrespective of mode of operation. This A/M Changeover is available even when blower is running because there is no hardwired DO associated with it. This A/M changeover button, though shown on both blower faceplates, its selection is common for both. When 'A/M Mode change' is pressed the colour of the Auto/Manual changeover button changes to RED and text below the button changes to “Auto Mode”. In auto mode, the starter which is set as Mains will start automatically and then start button is disabled.

Standby starter is started automatically only if Mains starter is stopped by any of the following conditions:

- Stop button pressed from SCADA.
- Mains starter local stop button pressed in MCC panel.
- On Trip feedback or Loss of Run feedback.
- Static Pressure interlock.

c) Start Command:
Start Command in Manual mode is issued if

- Remote Selected from field
- And Manual Selected
- And Manual Start command given from SCADA and Remote selected

Start Command in Auto mode shall be issued if:

- Auto selected
- And Remote selected
- Auto start condition (permissive) is true, generated from logic

d) Stop Command
Stop command is generated whenever stop command is activated from SCADA mimic screen. It is irrespective of Local/Remote mode and Auto/Manual Mode.

e) Mains/Standby logic:
The GB blowers will operate in a working/standby mode. That means either of them will be designated as the working blower and hence other as standby. The operator must manually set the Mains/Standby status of the blower from SCADA mimic screen and by default it must be manually selected by the operator. Hence Mains/Standby selector switch is provided in faceplate of each blower.

On clicking this 'Main/Standby' button, the blower is set as Mains and colour of button changes to RED. The other starter will automatically go in Standby mode and GREEN colour. This button is toggle type; meaning if the user clicks this button again after setting as Mains, it goes in Standby mode and hence the other starter automatically becomes Mains.

f) Auto changeover to standby logic:

- **Working/standby interlock:** In Auto mode whenever a working blower trips, Suto changeover logic comes into picture. Before changeover to standby blower, logic will check the availability of power in standby blower, trough its panel incomer energy meter readings and one level preceding power panel incomer energy meter readings. Like for GB-1 blower power availability through EP-1 panel incomer mater and AMF panel-1 incomer meter is checked. However, in manual mode, if the running blower is tripped, then only TRIP alarm is generated to intimate operator to take necessary action.
- **Maximum Changeover Count Logic**: There is a counter initialized in PLC program whenever a changeover from the running to standby blower occurs, in Auto mode. This counter is reset to zero, on mode change from auto to manual. This counter is required to avoid frequent changeovers in Auto mode, in an hour. The logic is developed such that when the counter value reaches to 6 in an hour, no further changeover will take place and a pop-up message as 'MAXIMUM COUNTS REACHED' is displayed on mimic screen. And after reaching count value, the system is forcefully changed to manual mode on operator's acknowledgement to the pop up message.
- **Power availability check logic:** Whenever a running blower is tripped, before changeover to standby blower, the logic continuously checks for power availability alternatively in GB-1 and GB-2 till the power is available. During every changeover, program will check the availability of power. The power is said to be available only when there is a power in two upstream (preceding) power panels of that particular blower system. For example GB system is fed from two emergency panels EP-1 & EP-2, each having two incomers, Incomer-1 &2,one from Class-IV power panel (PCC-1/PCC-2) and other from DG (AMF-1/AMF-2)emergency power panel. There is a tie breaker between EP-1 &EP-2 as well as PCC-1&PCC-2, hence both incomer breakers can not be close at a time. Hence to check power availability for say GB-1 system, at least two phases out of 3 phase voltage shall be more than 200V for at least 2seconds, in GB-1 self feeder energy meters and in any one fromIncomer-1 from PCC-1 or Incomer-2 from DG AMF panel incomer. Based on this, a logic condition as 'GB-1 Power Available' or 'GB-2power available' is generated and used in further logic. A simplified flowchart for auto changeover logic of GB system in Auto mode is as shown in Fig. 6.

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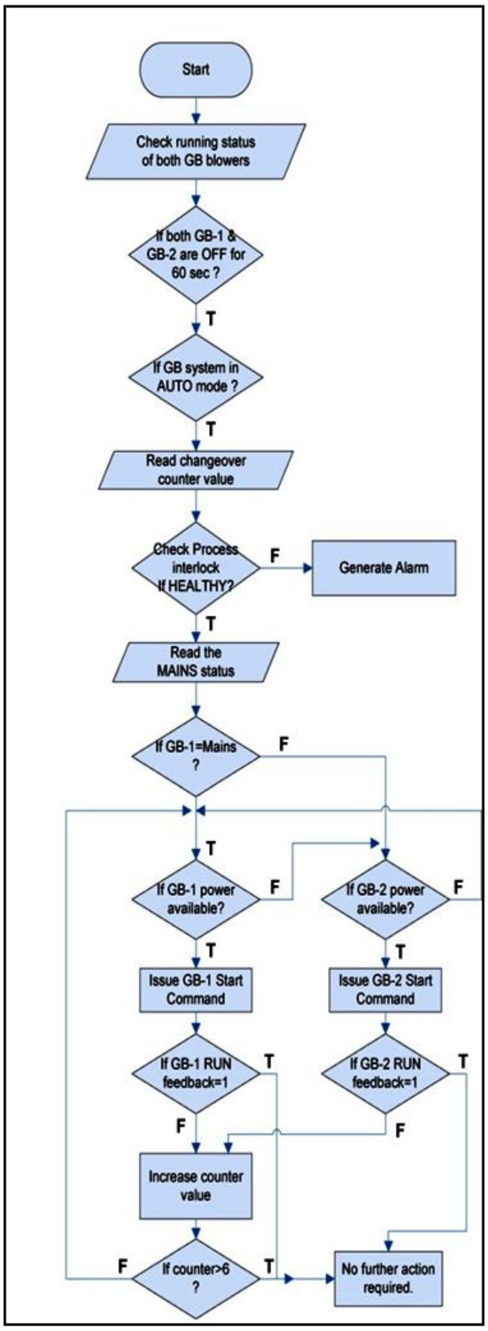

Fig. 5: Flow chart for Cold start logic of GB system

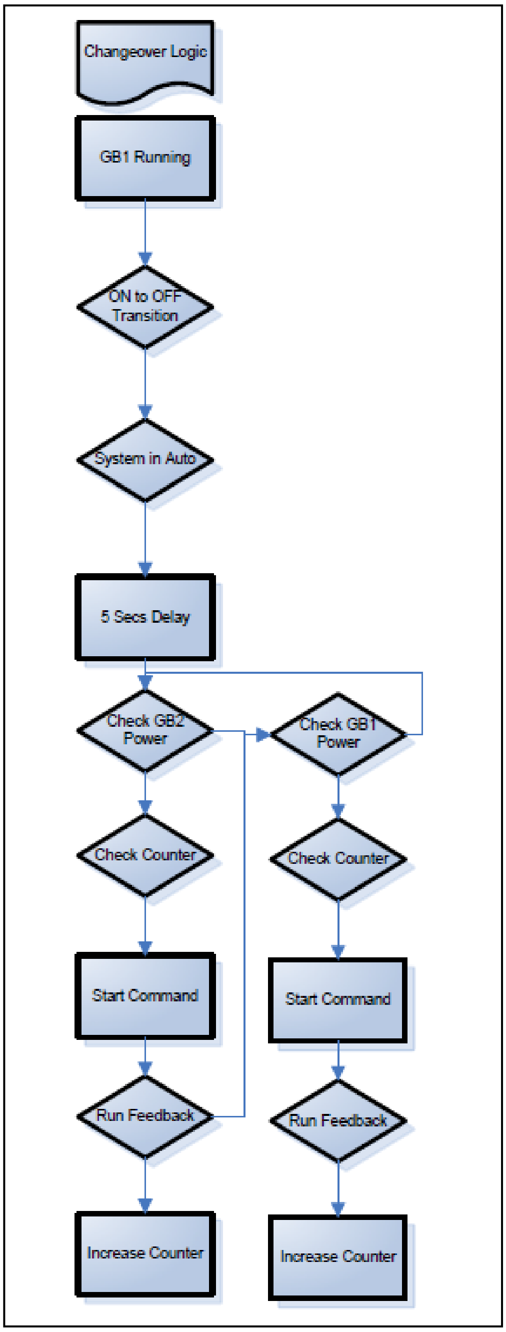

Fig. 6: Flow chart Auto changeover logic for GB system

g) Logic for Cold start of the system after power failure:
The logic developed for auto start of the ventilation system in event of power failure, is applicable only in Auto mode. The cold start condition is generated when entire plant power is not available and both the blowers from a set (e.g. both GB-1 and GB-1) are OFF for more than 60 sec. With this condition, a cold start logic is executed. It is developed such that first the changeover counter value is checked. If this value is more than 6, no further changeover to standby bowers are attempted in Auto. In addition, start permissive and process interlocks are checked for its healthiness. Then first it is identified which system was set as mains, just before the power failure. For example, say GB-1 was set as mains, then logic first checks for the power availability in GB-1, through energy meter values of GB-1 meter and EP-1 panel incomers meter. Power availability logic will work as per same logic explained above. If the power is found available, then immediately Auto start command is given to the GB-1 blower. After receiving the RUN feedback, changeover counter value is increased by 1. However, if 'Power is not available at GB-1', then logic will check similar power availability at GB-2 through respective energy meters. The simplified flow chart for Cold start logic of GB system is as shown in Fig. 5.

h) Interlock with Static Pressure (Process interlock):
The Logic is developed such that if the desired static plenum pressure is not developed, within say 5

minutes of blower running then working blower is automatically stopped and standby one started automatically started and low static pressure alarm is generated. This logic is developed to assess the accidental situation, motor is running but the fan is not running because of any reason such as belt connecting Motor with Fan is broken suddenly. In event of unavailability of the static pressure sensor, this process interlock can be bypassed from blower faceplate in SCADA mimic.

i) Damper On/Off Logic:
Both GB system and EB system has modulating type suction and On/Off type discharge dampers. The dampers corresponding to each working blower (applicable for both GB & EB blowers) will be operational automatically along with blower start operation, whereas that of standby blowers will be fully closed. The logic is developed such that the ON command to discharge dampers shall be sent immediately with respective blower ON command. Supply Blower have On/Off type discharge dampers only. Hence same logic is developed for Supply blower system so that ON command to the discharge damper is given automatically immediately with the ON command to respective blower. This damper On/Off logic developed for GB, EB and SB system is irrespective of its operating mode i.e. Auto or Manual. However, in case of GB & EB suction dampers, a PID controller-based logic is implemented and explained in following section.

j) Auto Static Pressure control PID logic
A common PID controller for dampers of both working and standby blowers are used so that in the event of power fluctuation, when working blower trips then along with automatic switchover to standby blower, the damper corresponding to previously working blower is required to be closed automatically and that of standby blower is required to be regulated to achieve the desired pressure at plenum. This PID controller has Plenum static pressure as process variable (PV), user defined standard Set point (SP) and for Output command, the logic is developed such that the PID controller corresponding to running blower only be operational. Thus, damper corresponding to running blower only, is regulated.

k) Pressure drop across HEPA filter banks:
Both the EB system and GB system has two HEPA filter banks viz Bank-1 & Bank-2, which are in working and standby mode. The operation of these HEPA filter banks is purely MANUAL and hence only the monitoring of pressure drop across filters is considered. However, for operator guidance there is a manual selection provided on SCADA screen, through a toggle type soft button animation with colour change. The running HEPA filter bank is shown as RED and standby as GREEN.

Additionally there is Auto/Manual button provided on SCADA screen so that if when selected in Manual the above logic shall work. However, if selected in Auto mode, which will mean colour change animation will work automatically. If the pressure drop across any HEPA filter (AI value) remains near Zero for 10 minutes, means the filter bank is standby and hence the Colour is changed to GREEN automatically whereas any non-zero value (AI value >3mmWC) shall indicate the bank is running and shall be shown as RED.

l) Bypassing Working standby Interlock (Control Test button feature)
There is a working/standby interlock developed for each GB,EB & SB systems, which simply says that, at a time only one blower from a set can RUN. But there is special case when this interlock is required to be bypassed for very limited time for testing purpose, say one blower is running and other standby blower has had some maintenance to be carried out. So after completing the desired maintenance work, there is requirement to test this repaired blower for trail RUN, for limited period of time. In order to bypass this working/standby interlock a button is provided on blower faceplate, called as 'Control Test', which gives a DO command to energise a relay which will bypass the hardware interlock between GB and EB system and also interlock developed in PLC logic is bypassed. Thus, both blowers can be made RUN simultaneously for very limited time. There is a timer provided on faceplate to indicate the time since when the interlock between GB & EB is bypassed. Also it is ensured in logic that if in case operator forgets to remove bypassed interlock, automatically after 5 minutes the newly started blowers after interlock bypass will be stopped automatically and interlock will be put back in service.

m) Maintenance Isolation
A button is provided for each of the system to isolate the system. On pressing this button, a cross sign will appear on respective blower symbol and also energise stop command till the button is reset. However, additional pre-caution is always taken by operator to go at site and put OFF the isolator/MCCB.

n) Running hour computation
Running hour is computed for each system with following details. Continuous running time is the time since last start whereas Total running time is the total time run since its installation. It will be computed for mains and standby both systems separately. A provision is given for generating an warning if no of days for continuous running time exceeds a particular no of days. Default limit is 15 days.

Continuous Running time: Days: xx, Hour: xx, Time xx
Total Running time: Days: xx, Hour: xx, Time xx

C. Logic for Fume hood (FH)Exhaust system

The logic developed for FH system is exactly similar to GB system.

D. Logic for general air exhaust (EB) system

The Exhaust blower (EB) system can be started only when either one from a set of GB system is running. This safety condition is interlocked such that whenever GB fails, meaning both GB blowers are OFF for 10 seconds, the EB system (and also SB system) is made OFF immediately, irrespective of Auto/manual and local/remote mode.

Apart from this interlock, entire logic for EB is exactly identical to GB system, with certain modifications arose mainly because of the dual speed motor used for EB system. The EB in general will run in high speed only unless Class-IV power fails and emergency power comes up. Under emergency power condition, the pre-defined sequence for EB system start/stop operation are decided based on power availability conditions viz normal power and emergency power condition, etc and is as explained below:

- **Normal power condition:** The operation philosophy for EB system under normal condition is that EB system can be started in High-speed mode, only after GB is running. However, by mistake if someone manually turns down EB system from HIGH to LOW speed then Supply blower is stopped automatically and GB& FH system will run as it is.
- **Emergency power condition:** Under one DG power condition or both DG conditions, as usual first the GB system is started and then EB system is started in LOW-speed mode only. Under this condition Supply system can not be started hence will remain idle.

This above listed logic conditions is incorporated in PLC logic.

E. Logic for Supply blower (SB) system

Logic for SB system is also exactly similar to GB system with slight differences as listed below:

- SB system can be started only when either form a set of GB system and either one from a set of EB system is running.
- When both GB systems are OFF for more than 10 seconds, the immediately SB along with EB system is stopped, irrespective of auto/manual and local/remote.
- For SB system there is no suction damper and hence its logic is not applicable.
- SB static pressure is maintained through regulating SB discharge damper
- SB motor is alsoa conventional motor unlike dual speed for EB system and hence logic developed is exactly similar to GB system.

IV. SCADA PROGRAMMING AND MIMIC DEVELOPMENT

The basic function of SCADA in general is data acquisition from the PLCs, generation and management of real time database, Generation, and management of historic data for trending and archival. The various activities performed in SCADA programming are explained one by one.

A. SCADA mimic screen development:

Process P&ID of each system and sub systems are used to develop the mimic screens. IN addition to the graphical representation, there are certain buttons are provided for Start/Stop operation, auto/manual selection, main/standby selection, navigation through various systems, etc. Various activities performed in mimic screen development and associated programming involves following points:

- Configuration and programming of DI, DO, AI,AO dynamic values,
- Configuration of Alarm, Events, Trend graphs etc
- Process mimic screens for each & every system
- Electrical SLDs, and breaker operation
- Configuration of dynamic & static graphic objects with colour animation,
- Blower faceplates with buttons for Start/stop command, Auto/manual selection, mains/standby selection, maintenance isolation, control test key
- Displaying the real time status of running hour meter since previous start, cumulative running hour meter, Energy meter data, process variable value, changeover counter value etc. on each blower faceplate
- Animation of pump/blower run, line selection, breaker status, mode selection etc
- Scaling AI/AO, analog value animation in bar chart
- Multiple level user access control
- Diagnostic screen for all modules and components
- Control system architecture with each line status for diagnostics
- Faceplates for UPS, Battery charger, Multifunction energy meters, MCCB, etc.
- 6nos HMI screens for gross overview status of systems
- Fire alarm screens, emergency door status screen,
- Each RIO panel door limit switch and thermostat screen

a) Configuration of Events and Alarms

Alarms are very critical and vital features that not only guides the operator to monitor the abnormalities in operation, but also helps in its further diagnosis. Based on the alarms operator takes the necessary actions. On the other hand Events tells us about the normal operation and status changes of important systems. Both the alarms and events are recoded with date and time of occurrence. In addition features like time of acceptance of alarm (alarm acknowledgement) and time when the alarm got normalized are also provided so as to assess the operator's response on whether they are taking appropriate actions immediately or not. Appropriate colour animation is provided for each state of alarms i.e. occurrence, acknowledged, resolved.

b) Configuration of trends

The trends are provided to check the overall behaviour of the process parameters in chosen time intervals. This helps in understanding the system better, troubleshooting the faults and the failure analysis and diagnosis.

c) Secured access control and Login security

In order to provide the secured access to the SCADA system, in addition to password-based protection,

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RFID cards and biometric finger scanners are provided for each control clients. Through the RFID card readers, employees can use their ID cards for login into the system.

These users have been segregated with the categories as per terminology used in the division such as Operator, Shift In Charge, Maintenance In Charge/Manager, Engineer and Administrator. These users are allotted operating features or levels in increasing manner. Thus, 'Administrator' will have the highest level of access to system.

V. RESULTS AND DISCUSSION

During the commissioning of the entire system, both the demonstration of basic functionality of each system, sub-systems & equipments as well as the certain abnormality test are performed, and the system response is observed. The basic functionality test covers the On/Off operation of the equipment (or systems) in various possible modes like local/remote, auto/manual, mains/standby, maintenance isolation, interlock bypass etc.These further covers checking the sequential operations, tuning of all the closed loop controls to get the desired loop response, various interlocks check. Checking of SCADA systems covers colour changes, graphics animation, events & alarms generation and finally checking of various log formats etc.

A. PLC & SCADA abnormality testing- Validation of Redundancy:

In order to test the entire system under various abnormalities, for validation of various design criteria such as redundancy at multiple levels to avoid the complete system failure in event of common cause failure, fail safe logic (wiring), additional safety interlocks etc, certain abnormal scenarios are simulated, and the system response is observed. Such abnormality tests cover failure of PLC/RIO incoming power supply (either any one or both at a time), failure of PLC/RIO rack power supply, failure of communication modules, failure of communication link, failure of co-processors at RIO, failure of IO modules, failure of SMPS, etc. In case of SCADA, the abnormality test covers failure of IO servers, observing the trend data in event of server failure and Historian server failure etc. If historian server is failed because of any reason, then on resuming, the history data for missed out interval, will be automatically fetched data from SCADA trends. The results of above listed all the basic functionality tests as well as abnormality test are found satisfactory and in order with design basis criteria.

B. Actual Photographs and SCADA Mimic screens of system developed

Actual photograph of a internal arrangement of various components installed inside Main PLC panel and a typical RIO panel, typical, RIO rack/backplane, and main PLC rack/ backplane is as shown below from Fig. 7 to Fig. 10.

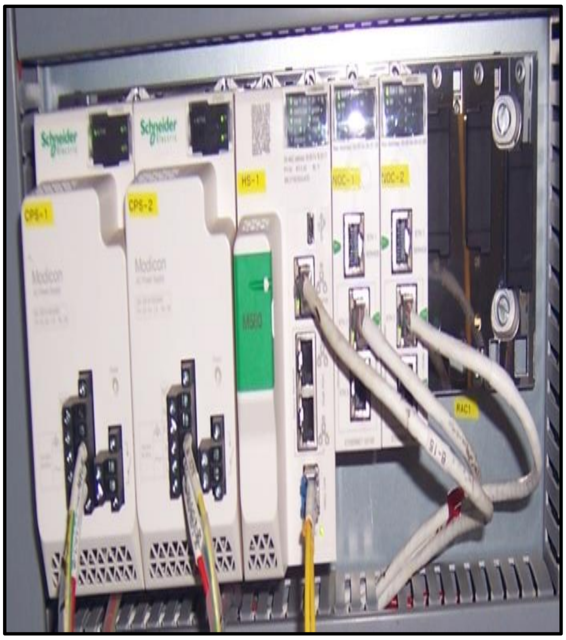

Fig. 7: Main PLC backplane

Fig. 8: Typical RIO backplane

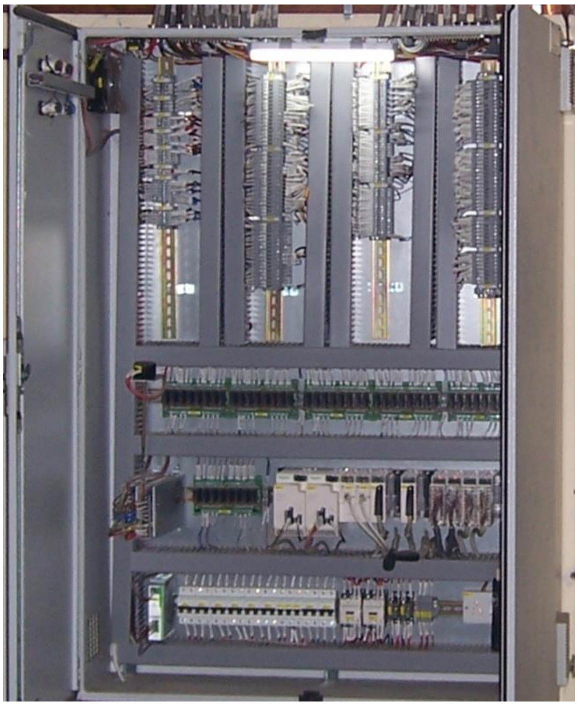

Fig. 9: Typical RIO panel internal arrangement

Fig. 10: Main PLC panel internal arrangement

C. Mimic screens and faceplates developed

The various mimic screens developed in SCADA for Once Through Ventilation system is shown in **Error! Reference source not found.**. The running blowers/pumps are indicated in RED colour with some animation whereas GREEN corresponds to standby blowers/pumps. Each dynamic text block with purple background indicates the real time process values. The sky-blue colour lines are static and indicate the air flow through duct.

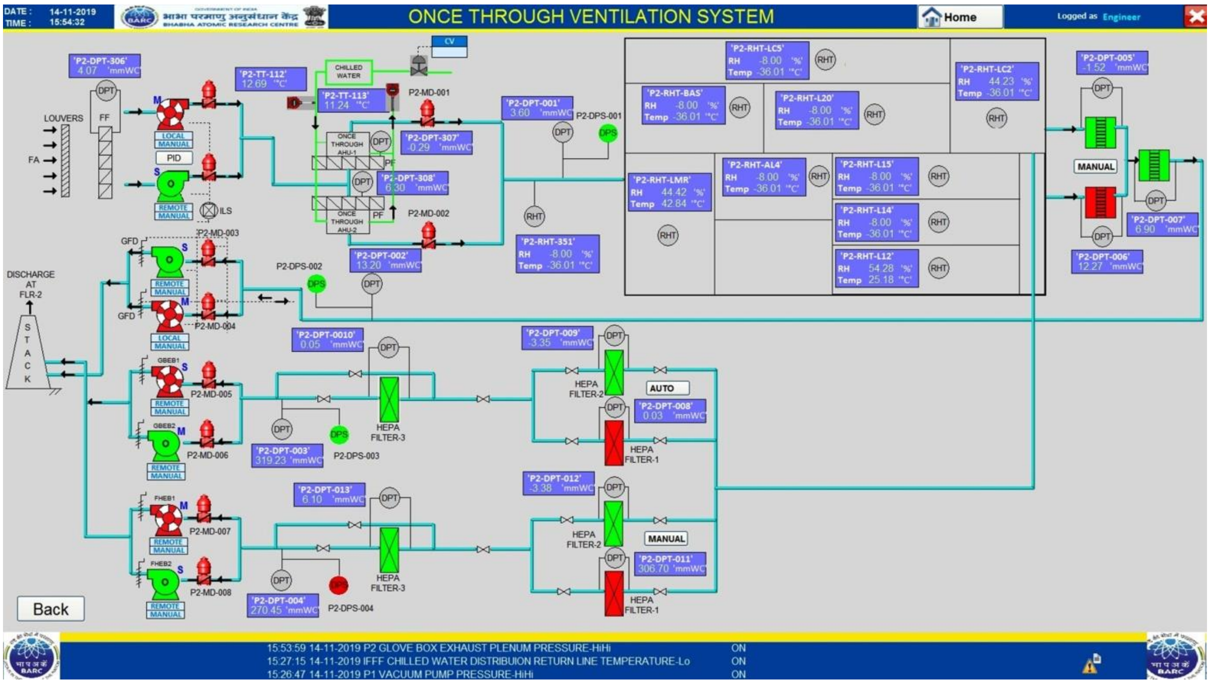

Fig. 11: SCADA mimic screen for Once Through Ventilation system

The faceplate developed for operation of Supply Blower is as shown in Fig. 12, which comprises various control buttons such as Mains/Standby selection, Auto/Manual selection, Start/Stop command, Maintenance isolation, control key to defeat main standby interlock for some small duration of time, and bypass static pressure interlock. It also displays the status of Local/Remote selection, Running/Trip/Stop status, running time since previous start and the total cumulative running time etc. The data received from multifunction energy meters is also displayed on this faceplate.

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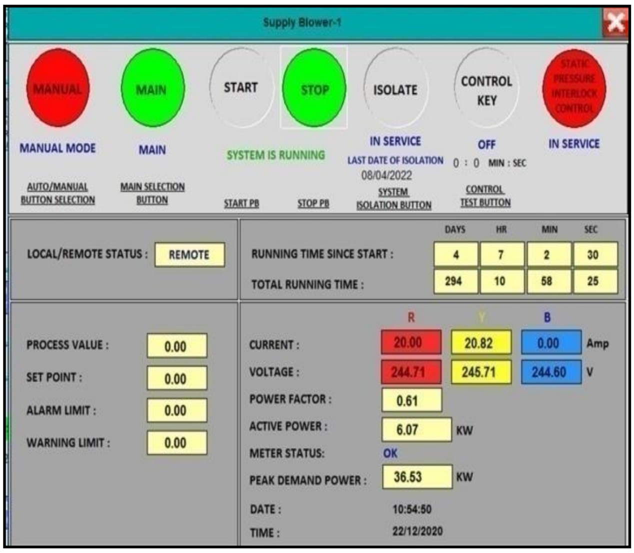

Fig. 12: Sample faceplate for SB system

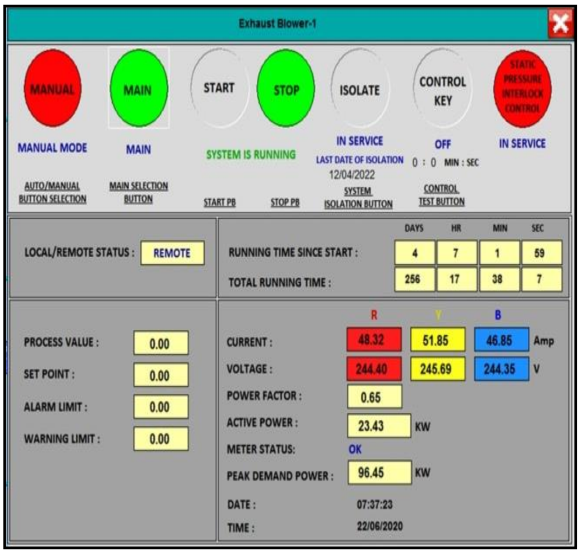

Fig. 13: Faceplate for EB system having dual speed motor

However, the faceplate developed for operation of EB system is as shown in Fig. 13. EB system has a dual speed motor and can be started either in high or low speed depending on requirement. Hence separate buttons for start operation in high and low speed are provided. Whereas a small faceplate for developed for each Analog input value (process variables) along with its trend graph is as shown in Fig. **14**. The faceplate for energy meter for showing the real time parameters such as R, Y,B voltage, R,Y,B current, power factor, active and reactive power, and meter communication system, etc is as shown in Fig. **15**. However, the peak demand power is derived using basic equations, through PLC logic. Also, the peak demand power date and time is displayed for operator information. In order to view the trends of R,Y,B voltages, R,Y,B current, power factor and power, a separate button for each is provided on the same energy meter faceplate.

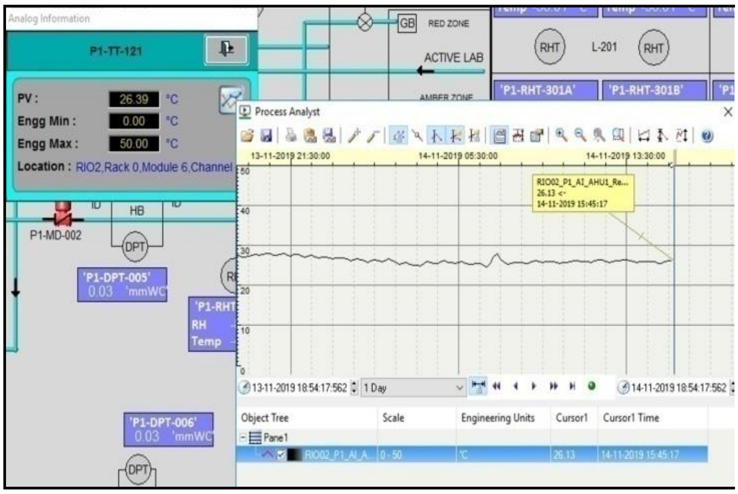

Fig. 14: Faceplate for analog value and its Trend graph

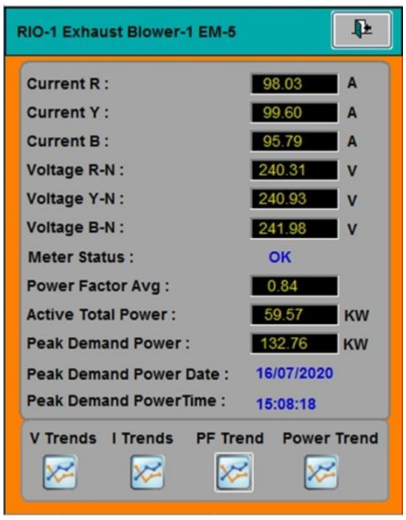

Fig. 15: Energy meter faceplate for exhaust blower power supply

A faceplate for the PID controller is as shown in Fig. 16. Whereas the sample report generated for 'Daily Log sheet' of ventilation system is as shown in **Error! Reference source not found.**. In the daily log report, in a 2 hours duration, the instantaneous value of a particular parameter is recorded at every 10 minutes and then the average of 12 sample in that 2 hours duration is logged in report. In addition for each parameter, minimum, maximum and average value of entire day is also calculated and logged for quick summary.

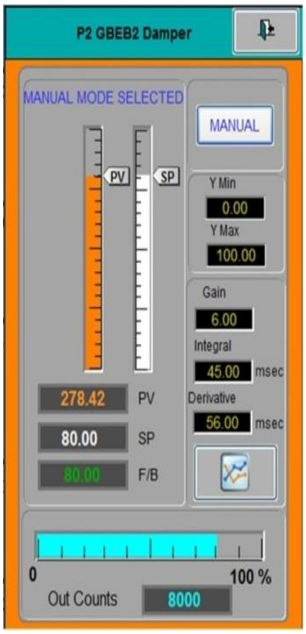

Fig. 16: Faceplate for PID controller

Location : Ground Floor Area (L-1)
Date From 01/02/2020 00:00:00
Date To 05/02/2020 00:00:00

Once Through Ventilation system Report
Daily Log Sheet

Date	Tag ID	Description	0:00-2:00	2:00-4:00	4:00-6:00	6:00-8:00	8:00-10:00	10:00-12:00	12:00-14:00	14:00-16:00	16:00-18:00	18:00-20:00	20:00-22:00	22:00-24:00	Min	Max	Daily	Units
01/02/2020	112	P2 OT AHU Pre-filter Pressure Drop-1	7.44	7.26	7.08	6.97	6.65	6.53	6.74	7.17	7.52	7.98	8.36	8.26	7.39	7.49	7.33	mmWC
	113	P2 OT AHU Pre-filter Pressure Drop-2	4.56	4.54	4.50	4.49	4.44	4.34	4.24	4.25	4.27	4.35	4.46	4.56	4.52	4.61	4.42	mmWC
	114	P2 OT AHU Pre-filter Pressure Drop-3	1.62	1.64	1.61	1.57	1.50	1.31	1.22	1.19	1.22	1.29	1.41	1.52	1.59	1.65	1.42	mmWC
	115	P2 Lab Exhaust HEPA filter bank-1 Pressure Drop	11.66	11.71	11.78	11.78	11.80	11.89	11.95	11.97	11.99	12.03	12.01	12.02	11.60	11.73	11.88	mmWC
	116	P2 Lab Exhaust HEPA filter bank-2 Pressure Drop	0.05	0.05	0.05	0.05	0.05	0.05	0.05	0.05					0.05	0.05	0.05	mmWC
	117	P2 Lab Exhaust HEPA filter bank-3 Pressure Drop	5.11	5.13	5.15	5.15	5.15	5.15	5.16	5.14	5.13	5.16	5.15	5.15	5.07	5.18	5.14	mmWC
	118	P2 Lab Exhaust Plenum Pressure Transmitter	18.73	18.43	18.46	18.58	18.79	18.81	18.91	18.66	18.69	18.58	18.60	18.65	18.26	19.10	18.66	mmWC
	119	P2 Fumehood Exhaust Plenum Pressure Transmitter	253.54	253.91	254.17	254.44	254.57	254.42	252.70	251.56	251.11	251.21	251.96	251.93	252.52	254.24	252.96	mmWC
	120	P2 Fumehood Exhaust HEPA filter bank-1 Pressure Drop	44.01	43.55	43.53	43.32	43.38	43.29	43.66	43.68	43.38	43.54	43.81	44.32	43.75	44.76	43.62	mmWC
	121	P2 Fumehood Exhaust HEPA filter bank-2 Pressure Drop	221.82	222.06	222.37	222.53	222.87	222.72	220.93	219.93	219.54	219.60	220.15	220.08	221.10	222.50	221.22	mmWC
	122	P2 Fumehood Exhaust HEPA filter bank-3 Pressure Drop	6.16	6.17	6.17	6.17	6.17	6.15	6.16	6.17	6.15	6.15	6.16	6.15	6.13	6.20	6.16	mmWC
	123	P2 Glove Box Exhaust Plenum Pressure Transmitter	303.51	303.12	303.39	303.55	304.06	304.24	303.69	302.83	302.40	302.64	303.15	303.18	302.86	305.27	303.31	mmWC
	124	P2 Glove Box Exhaust HEPA filter bank-1 Pressure Drop	-1.39	-1.40	-1.39	-1.37	-1.35	-1.32	-1.30	-1.29	-1.27	-1.30	-1.33	-1.37	-1.40	-1.38	-1.34	mmWC
	125	P2 Glove Box Exhaust HEPA filter bank-2 Pressure Drop	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.03	0.05	0.03	mmWC

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Fig. 17: Sample Report format

VI. CONCLUSION

The automatic control system using hot standby PLC and redundant SCADA, for real time remote monitoring and control of radiological safety critical utility services from operator workstation PCs, is designed, manufactured, installed, and commissioned successfully. The design of automation system successfully addressed all the operational safety issues associated with the installed once through ventilation system such as extensive operator dependency, inefficient control of process variables, lack of main/standby selection, Auto/Manual selection for each individual sub system and various other operational challenges. The automation system developed has achieved all its objectives such as to provide the highest availability, increased efficient control with minimum human intervention, and increased safety interlocks etc. This PLC and SCADA system provided a user-friendly interface to operators for simple and safe operation of all the utility systems.

The automation system comprised of advanced technology hot standby PLC with 16 nos remote IO (RIO) panels distributed geographically across various locations for monitoring and control of process parameters. These RIOs are communicating with main PLC through dedicated redundant Ethernet network over TCP/IP protocol. However, the SCADA system is comprised of a set of redundant IO servers, 4 nos control clients, 2 nos view only control clients. Redundancy is used at control, power supply and communication levels. The system is able to maintain all the closed loop controls such as plenum static pressure control at GB, FH, EB and SB systems, desired ventilation and directional airflow in lab areas, desired lab temperature, chilled water flow control, automatic control of emergency power system, etc.

The PLC logic developed is tested for its control operations and the consequent results are monitored. For deploying the secured access to SCADA system, in addition to conventional password-based protection, RFID & Biometric finger scanner is also implemented for two stage authorization. In addition to the hard wired IOs, certain soft IOs from various third-party equipment such as multifunction energy meters, microprocessor based MCCB release, energy valves, RFID card readers, biometric finger scanner etc are communicated with PLC over TCP/IP, and RS485 protocols.

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