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Design of a SCADA Based Monitoring Platform for an Old Conventional Power Distribution Network

Manisankar Dhabal[1], Durgesh Lingampalle[2], O P Ullas[3]
[1,2,3]Hot Lab Utility & Engineering Services Section, NFG, Bhabha Atomic Research Centre

Abstract:- Supervisory Control and Data Acquisition System is widely used throughout the industry for better monitoring and control of any plant. However this requires a plant hardwires and sensor to be controllable and compatible for monitoring and control. The most convenient way to apply SCADA system is to use intelligent devices to connect to SCADA system. In a large plant consisting of components of very old technology application of SCADA system is not straight forward. When the plant is distributed in large geographical area with power system components located at scattered area it require special approach to convert the old technology based devices to bring into a common platform which is understood by the SCADA system. Hot Lab Utility & Engineering Services Section has designed a platform to monitor the power distribution system of a conventional Radiological facility in BARC to monitor its power system utilities for providing better services to the plant. The paper describes the design of a distributed SCADA system for monitoring power distribution system catered in Class I, II, III, IV categories.

I. INTRODUCTION

Electricity is a part and parcel of essential utility services. In modern society a day without electricity creates enough unrest situation. Hospitals needs high availability of power supply whereas industries loose lot of revenue if the power supply is not available during peak production time. The utility services needs to be sustainable and resilient. Electric power is received in three stages: generation, transmission and distribution. More than 90% of the disturbances arises from the distribution side[1]. This indicates that quality of power distribution network arrangement is not up to the mark. Voltage regulation, frequency regulation are not in hand of distribution network. But the availability of power to all equipment's is in hand of distribution network considering the power is always available from grid. Consider an industry which is spread over multiple building with lot of machineries and offices. Faults are attended when complaints are received from the respective operator or users. It takes a lot of time to attend the complaint by distribution side operator. There might be existing faults which are not rectified. Consider an earth fault current flowing within a limit to a particular panel however this is not attended as the current details are not available with the operator. Cumulative such fault current may trigger the main circuit breaker of the distribution network when there are multiple faults unattended. This will lead to a catastrophic blackout in the plant or industry. This may happen as there is lack of enough real time data to the distribution operator. If the distribution network is observable from a centralized location it will intensify the operator to take own decision making and help them to act with rapid response. Related works in this field are with smart appliances, intelligent electronic devices, automated substations, smart distribution panels. All these devices contribute to future smart grid. These works are based on IOT devices [2] used in the power system and the data is accumulated in RTU which sends the telemetry data to a SCADA system. IOT devices has now become universal. In SCADA individual devices as well as entire distribution network is shown in real time measurement parameters. These equipment are provided with several technologies in single equipment provided real time data, future data, diagnostics data , equipment health monitoring. The other related works employs self-healing type devices with capability to automatic closing, reclosing and can independently control the network to provide highest reliability in power. The trend is there to switch to smart devices but these devices are costly. Cost of smart panels, network, information technology, centralized SCADA system and their maintenance is quite a considerable amount. Now consider a plant which has lot of distribution panels which are fuse based with analog meters, analog protective devices in substation etc. These old panels need not be discarded suddenly and need not be replaced with the smart panels. But it is not possible to monitor most of the power distribution nodes of such system. The objective of this paper to describe a design and development of a SCADA system employed over conventional power distribution system consisting of such devices.

II. DESCRIPTION OF EXISTING CONVENTIONAL POWER SYSTEM

The power distribution network described in this paper is a part of Radiological services inside Bhabha Atomic Research Centre. As per safety classification of nuclear plant there are four classes of power supply system. [8[, [9]. Four classes have safety classification based on their use are given in Fig 1.

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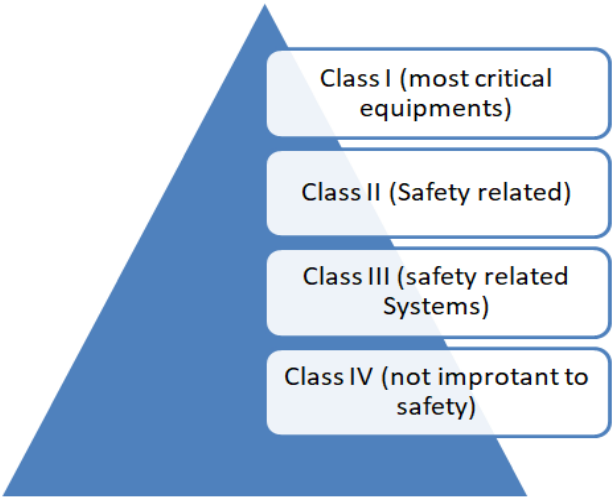

Fig 1 : Classification of different power supply system

The subject plant follows the similar convention as per local regulatory norms. The power system of the radiological facility is provided with Class IV (Grid Power), Class III Power (Station DG system with auto mains failure), Class III (station UPS) and Class I (Station Battery and charger) . The systems were installed and commissioned 15 years ago. Hence the power system components are very old but their basic performance is extremely good and as per the present market standards. Details of each distribution nodes are given below.

3.1 Conventional Switchgears System

The capacity of the plant is 1600 KVA. Out of this 1000 KVA is catered through a separate substation. Balance 600KVA is fed from nearby external substation. The substation equipment consists of 1600A Circuit breaker 3 nos (2 incomer and one bus coupler) and 8 distribution circuit breaker each of capacity 630A. Photographs of the substation is given in Fig 2. The circuit breakers are provided with local metering, indication, static relay based protection releases. The releases does not have any computer based communication features.


Fig 2: Photographs substation switchgears with circuit breakers

3.2 Power Distribution Panels

There are total 30 nos of power distribution panels. Few power distribution panels have motor control centre also. Switch fuse unit the switchgear of each of the incomer and outgoing feeder of these panels. In incomer and motor control outgoing feeders (large rating greater than 15 KW) current transformer and analog ammeters are provided. In most of the panel there is a bus coupler which is to provide a standby power from the nearest available other panel fed from separate bus section of the substation. These panels are part of Class IV, III and II power system of the facility.

Fig 3: Photograph of Old distribution panel

3.3 Power Distribution Boards

Single phase and three phase power to individual rooms and laboratories of the facility is provided through distribution boards (DB) installed near to those areas. There are total 100 nos of such distribution boards which are part of Class IV, III, and II power as per the design intent of the facility. The switchgear component used for the distribution boards are MCB, RCCB in incomer and MCB in outgoing. RCCB provides safety for earth leakage where as MCB provides short circuit and thermal overload safety. In Fig 3 a typical distribution board is shown where the bottom right most section is for the incomer MCB and RCCB. On left side of MCB and RCCB there is an auxiliary contact block fit .

Fig 4: Distribution Board with MCB, RCCB and auxiliary contacts

3.4 Intelligent devices UPS and Charger

Class II power source is UPS which is provided with the help of 60KVA UPS and 500AH battery bank. The UPS system is IOT based and is directly compatible with the SCADA system. Similarly Class I system source is Battery charger and 150AH battery bank. The charger is also IOT based and an upgraded one and hence is directly compatible with the SCADA system. Fig 5 show one set of existing Class I and Class II system.

Fig 5: Photographs of the UPS and Battery charger system along with VRLA battery banks

III. CONVERSION OF THE CONVENTIONAL SYSTEM COMPATIBLE WITH SCADA SYSTEM

3.1 Switchgear system for conversion

In conventional switchgear system the basic switching element is same as of current market. The element is circuit breaker which is in present case an Air circuit breaker. The circuit breaker has closing coil and tripping coil which is monitored via trip circuit supervision relay and latched and unlatched by lock out relay. Potential free additional contacts are generated in the switchgear panel for breaker ON status, trip circuit supervision (TCS) relay status, lock out relay (tripping relay), Local Remote Switch position (L/R SW), Breaker service position status. These status are taken into a digital input module of a modular rack based distributed IO module (Fig 6) .As this is remotely located it is often called as Remote IO module (RIO) and in all diagrams RIO name has been used. In order to get the controllability of the switchgear system a digital output module is used which has multiple channels. Each channel generates a potential free contact which goes to the closing and tripping circuit to give a close and trip command. There is analog meter fed from the current transformer of the bus bar chamber. The power information of the switchgear system is very important. Hence, voltage tapings are given from R, Y, B phase to a voltage transducer. Currents are given to a current transducer. Combined voltage and current transducers are available in market which on its own computes power, power factor and converts the voltage and current signals into a digital format. Voltage, current, power, factor in each phase is the key elements for monitoring the power system. These transducers are often called multifunction digital meter or multifunction meter or load manager. Or Voltage, Ampere Frequency meter (VAF). Options are available with industrial RS485 meters based multifunction meters. In the distributed Input output rack a RS485 module is taken which is able to connect 32 to 64 nos of Rs485 devices . In all the switchgear breaker panel already current transformer was available and analog meters were available. In the same cut out of 96x96 mm multifunction RS485 meters are installed by providing voltage signal as well. Now all the breaker power, voltage, current, power factor information are available to the distributed IO rack . Now the information available through digital input module, output module and RS485 module are available in a digital backplane of the system. In order to send the signal to the SCADA system another protocol is required which is understood by the SCADA system. SCADA being basically a computer it understand Ethernet in TCP/IP. Hence a Co-processor of TCP/IP module is taken in the same backplane the transmit the data to the SCADA server. The function of the co-processor will be explained later.

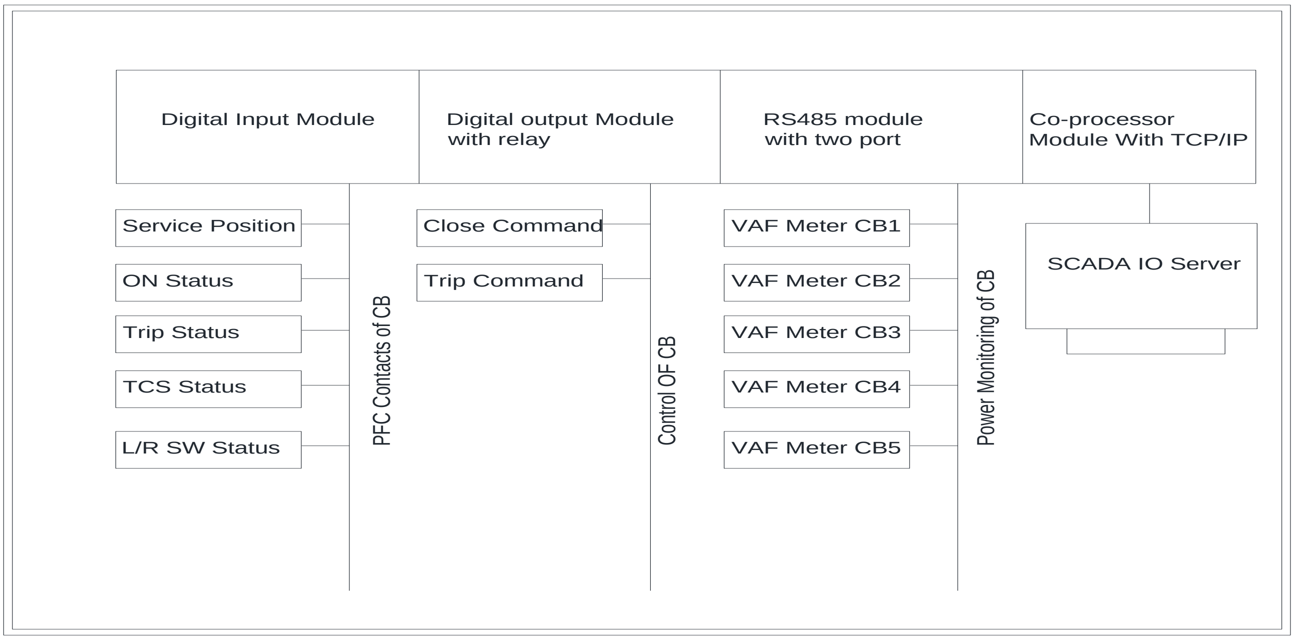

Fig 6:Remote Input Output Module Digital Input Output Module for Switchgear System

3.2Power Panels

As already explained the conventional power panels consist of mainly SFU unit which does not provide any potential free contact. However there are incomer feeder and few other important feeders where there is existing analog meter connected to a current transformer. The analog meter are replaced with digital voltage , current transducer in forms of RS485 based digital meters. Rs485 Receiver and transmitter lines are connected to a common bus and given to a local distribution IO module which consists of a Co-processor , RS485 module card and ethernet TCP/IP card. Now it has to ensure that all these RS485 devices have same baud rate, parity set in each devices otherwise they will conflict while transmitting data. There device addresses must be unique. More the no of devices less the speed of data transmission. Baud rate can be increased however very high baud rate will lead to limitation of length of RS485 wire . There is a TCP/IP card which communicates with the SCADA server. Fig 7 shows how various VAF meter of power panels are connected with RIO . In figure one RIO panel is shown which is connecting nearby 3 panels and their meters. Similarly all panels of the plants have been connected to many RIO panels.

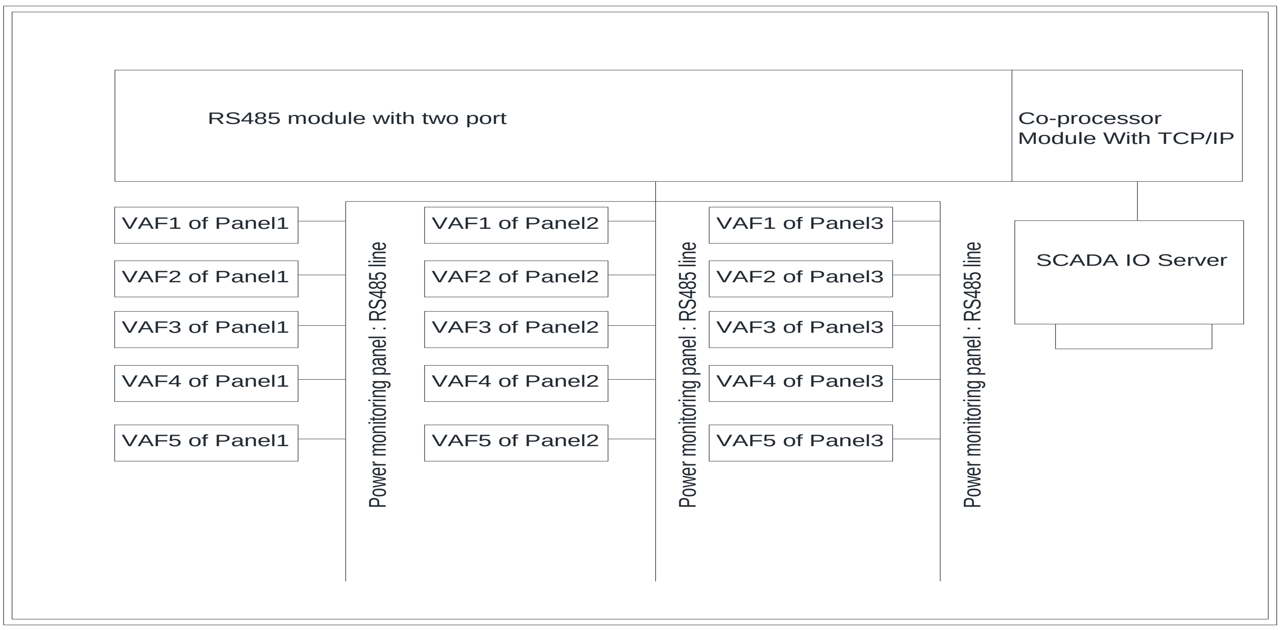

Fig 7: Remote Input Output panel for Power Monitoring of Conventional SFU based panels

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3.3Distribution Boards

The distribution boards (DB) provides single phase and small rating three phase loads . These distribution boards are standard boards available in the market. It is necessary to check ensure that no tripping of the incomer has occurred. In incomer overload, short circuit and earth leakage protection is used . Overload and short circuit is provided by Miniature Circuit Breaker (MCB) and earth leakage protection is provided in Residual Current circuit breaker (RCCB). These two combination is common in single phase lighting and power distribution boards. These are two vital protecting devices however often causes spurious tripping due to faulty equipment connected in the distribution circuit. If any of these two incomer gets tripped all lights and power points fed by the distribution board will not get power. Hence an auxiliary contact has been attached with each of the MCB and RCCB of all the single phase distribution boards as has been shown in Fig 4. . There are similar 100 nos of distribution boards in the plant. . If they trips the auxiliary contact position will also get changed and it will provide a potential free contact. In existing distribution boards small cut outs have been made and these contacts have been fit. The potential free contacts are given to each digital input channel of a digital input module of local distribution module . In Fig 8,three lighting distribution boards and three single phase power distribution boards have been shown connecting their incomer status feedback to a digital input module. There are three phase distribution boards also which has incomer molded case circuit breaker (MCCB) . MCCB is combined with earth fault, overload, short circuit . Only one contacts is used for the MCCB to provide feedback of its status. In Fig 7 fivenos of distribution boards have been shown.

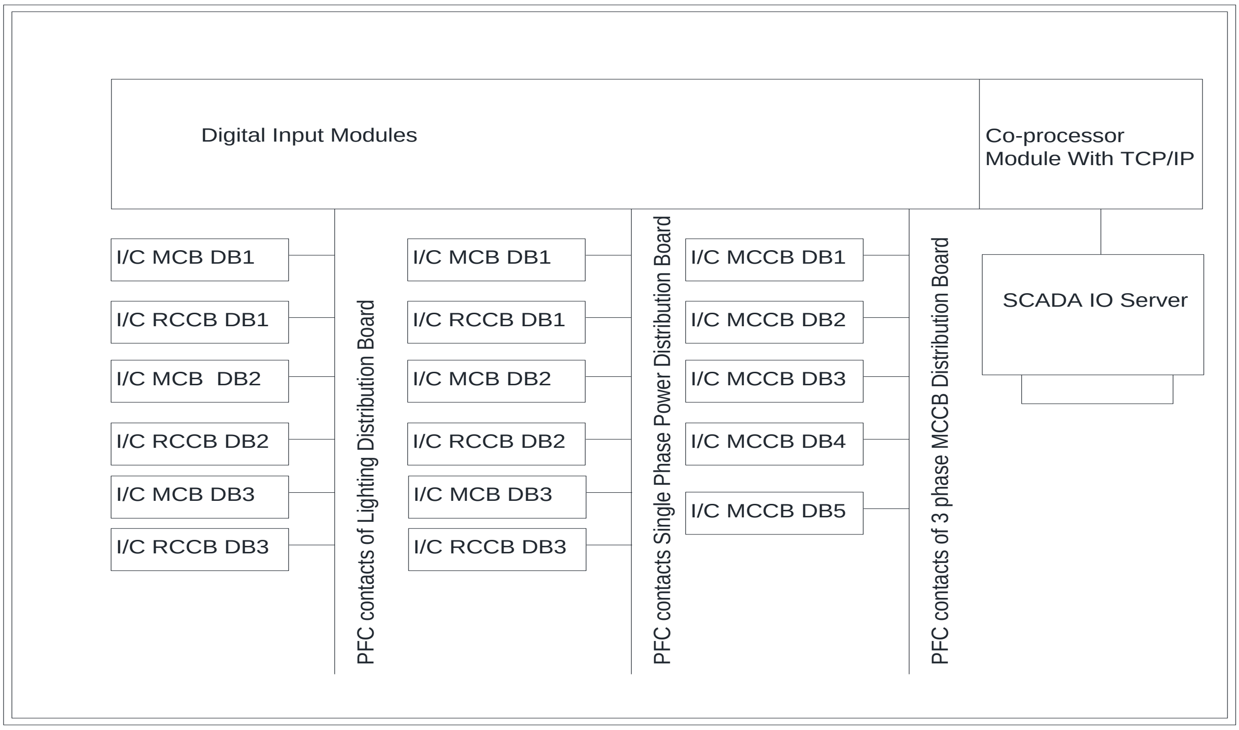

Fig 8: Remote Input Output Module for Distribution Boards Monitoring System

3.4Intelligent devices

There are two power system devices which is Uninterrupted Power Supply System (UPS) of Class II system and Battery Charger of Class I system which were upgraded one . These equipment provides monitoring data such as input voltage, current, output voltage, current, battery capacity, battery voltage etc in modbus TCP/IP in Ethernet media and hence these are directly compatible with the SCADA system. No special technique is required for them. Their register addresses are directly called in the SCADA program with appropriate scaling as provided by manufacturer. It gives all the data through single communication line.

IV. USE OF A CO-PROCESSOR

In fig 5 to 7 a co-processor has been used. The function of these co-processor is to configure the data available in each RS485 devices or digital input module in sequential manner. In commonly available RS485 meter there are more than 100 data . However most of them are computed data and to some extent repetitive data. Only essential data are addressed in co-processor and they are given an address which is shared with the SCADA tags. In SCADA system these tags can be directly used to show in graphical interface. The protocol of the meters are modbus over RS485. There are gateways available which also converts RS485 to TCP/IP interface however in those cases it will not be possible to generate a sequential addressing scheme in organized manner although it is slightly cheaper. If there is a power fail condition in any meter the modbus addresses will hold its last good communication values. In co-processor logic is written to detect the communication break and forcibly makes the corresponding meter related values to zero so that it is reflected aptly.

V. NETWORK BETWEEN RIOS

This may be noted that the power panels, distribution boards and substation switchgears are scattered around large geographical are of the plant as those are required to be kept near to the load equipment to save space and money of cabling. The SCADA system is kept ina centralized location. Hence it is essential to bring the information gathered in each RIO to the SCADA server desk. The distance from these RIOs to the SCADA desk in none of the cases are within 100 meter which is the permissible length for Ethernet network. Hence a network architecture is also required to establish between these RIOs to bring to the SCADA desk. This is done in following manner

- Information of all panels, distribution boards of a particular area is combined in a common RIO panel
- TCP/IP terminals of all the RIOs are brought to network switch which has a fibre optics port and multiple copper port to connect the devices through cat-6 cable
- SCADA server is connected to at least two different switches to provide a redundancy
- All the switches are networked in a managed switch which has multiple fibre optics port

The architecture is shown in Figure 9

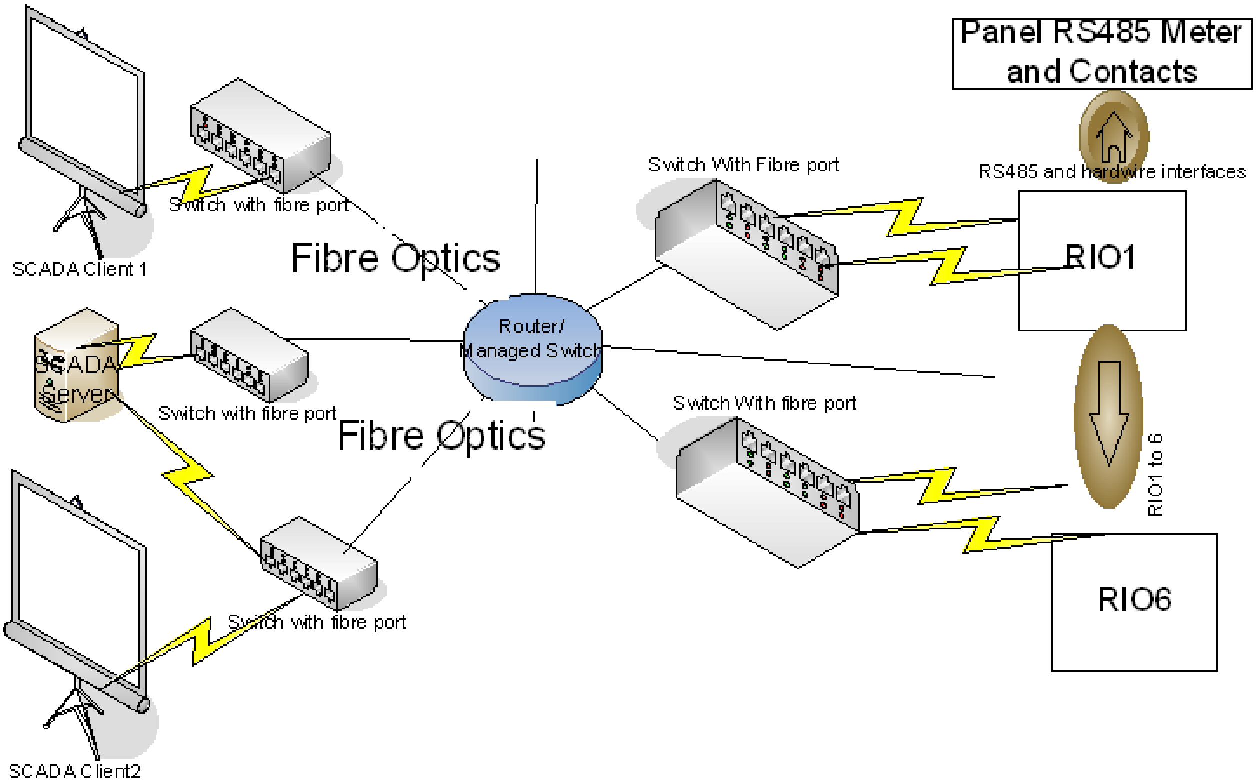

Fig 9: Network Architecture

VI. SCADA SYSTEM

In SCADA mimic of each panel has been developed. It may be noted that individual feeders information is not available from the conventional panel. However single line diagram is prepared in SCADA for the actual panel regardless whether the feeder is monitored or not. This is to provide a ready drawing to operating staff. The switchgear panel (circuit breaker panels) are completely monitored and controlled and hence mimic has been designed elaborately. The meter data is shown as a pop up which appears when clicked on particular feeder. Bus bar is given dynamic colour based on voltage availability.

VII. REDUNDANT POWER TO RIO

The scheme which ever discussed has a limitation. The RIOs, switches shown require power which is very small however those must be in power ON condition. However if the substation power is not available the RIOs will also not get power. Hence RIOs and switches have been given power from class II power which is backed up by battery bank and hence uninterrupted power is maintained. In order to make the system more reliable a secondary power has also been given from class IV power. These two power supply has been used in redundant configuration as per scheme shown in fig 10.

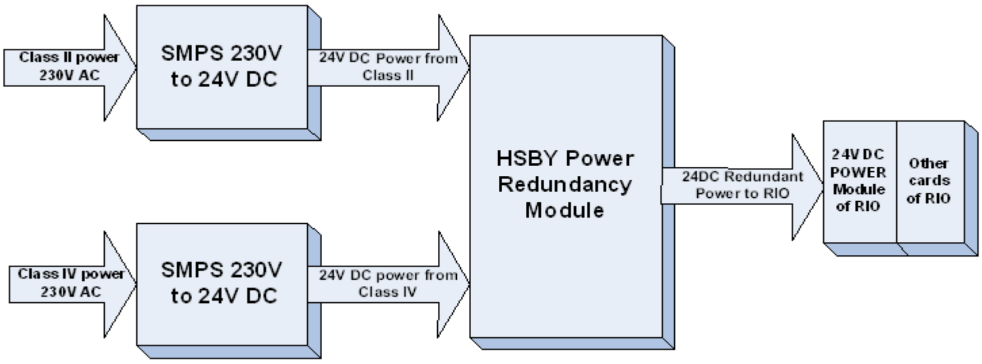

Fig 10: Redundant Power supply scheme for RIOs

The RIO co-processor is collecting the data from individual meters. If there is a power failure to the control supply of the meter or there is an error in the meters in communicating with the RIO through modbus RS485 the system will show the last good communication value. It will show wrong indication in the SCADA system . System bits are available in CO-processor which provides a bit whether the communication is healthy or not. With the help of this bit when there is no communication the whole meter data is reset and an error is massage is also given in SCADA screen. This will result in getting proper trend of the data stored and correct monitoring.

VIII. CALCULATION OF MAXIMUM DEMAND

It is essential to see maximum demand of the each panel, circuit breaker, main distribution feeder. It helps to check whether any further expansion can be done from each node to distribute power to more equipment. In such import feeders VAF meter are available. The voltage, current and power factor data is used to calculate the active power. Hence an algorithm has been developed to calculate maximum demand in KW. Active power data is stored in a variable. Whenever the active power is exceeded the old value is reset and the corresponding date is also stored. This data may conflict when there are equipment which draws very high current for certain small duration. Similar switching conditions have been eliminated while calculating maximum demand with the help of algorithm written in co-processor.

IX. RESULTS

Based on the data received through various RIO screens have been developed in SCADA system for each power system part. In Fig 11 the whole switchgear system consisting of 11 breaker (2 incomer, 1 bus coupler and 8 outgoing breaker) is shown . Each feeder ON status is shown in red colour and OFF status in green colour. The bus bar is charged and hence is in red colour. The VAF meter data are in pop up which appears when the meter symbol is clocked. The pop up screen developed are similar for all meters of the plant. A pop up is shown in Fig 12. Trends have been developed for voltage, current , power. A typical trend is shown in Fig 13. Similarly mimic screen has been developed for all panels and their meter data is shown in pop and trends have been made. There are 4 intelligent devices which are 2 nos of UPS and 2 nos of charger. One UPS mimic screen developed is shown in fig 14.

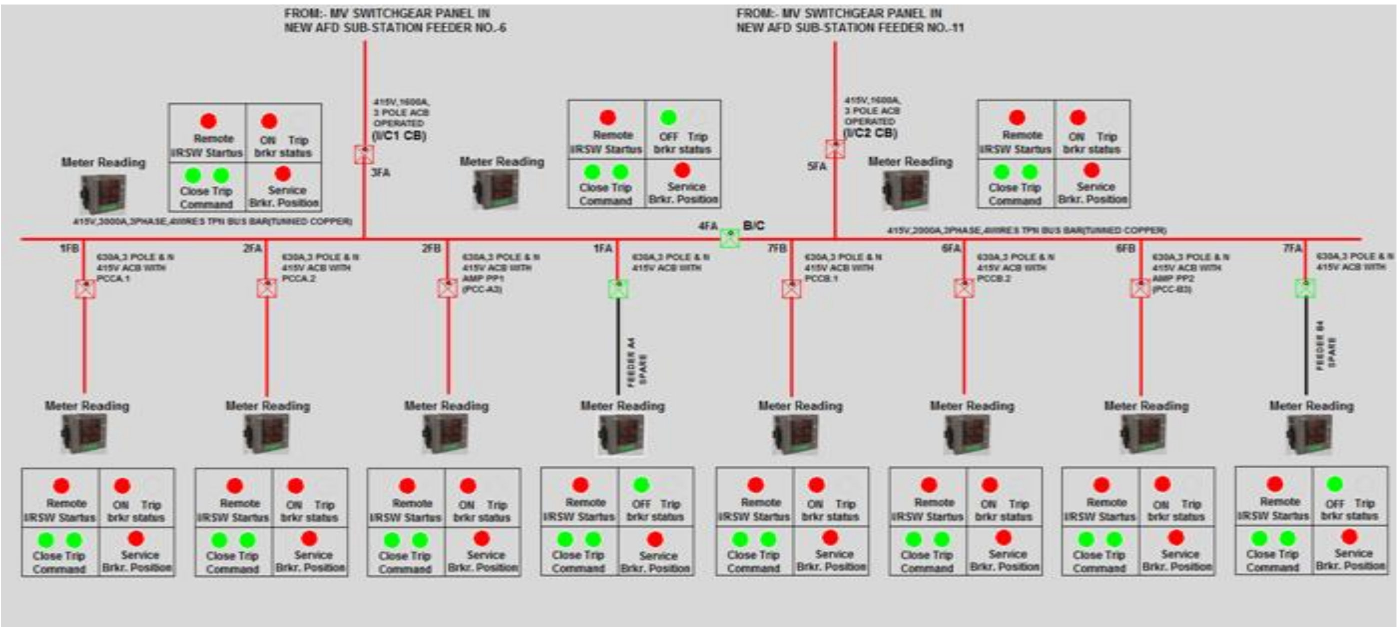

Fig 11 : Switchgear System SCADA screen monitored through a RIO

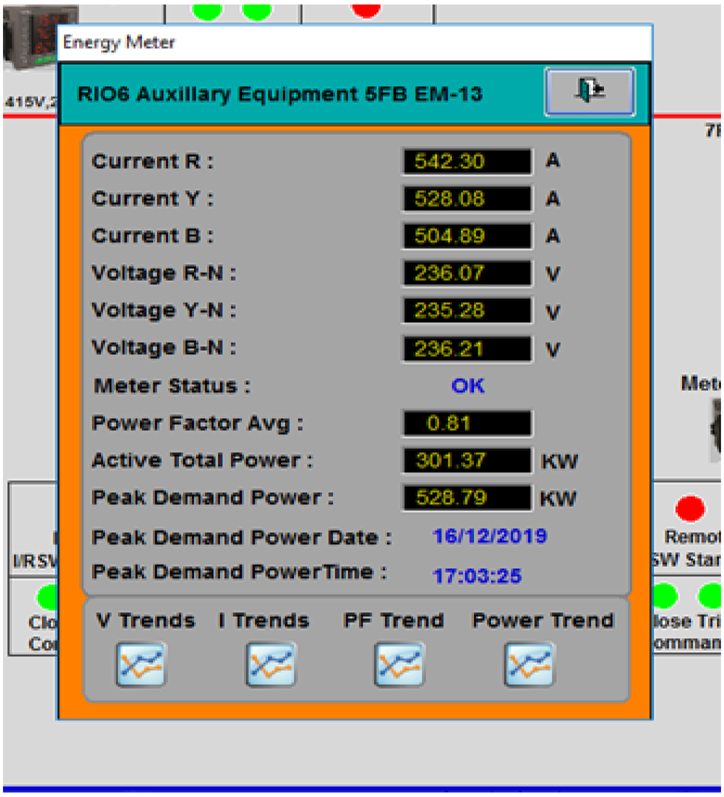

Fig 12 : POP up screen of the VAF meter

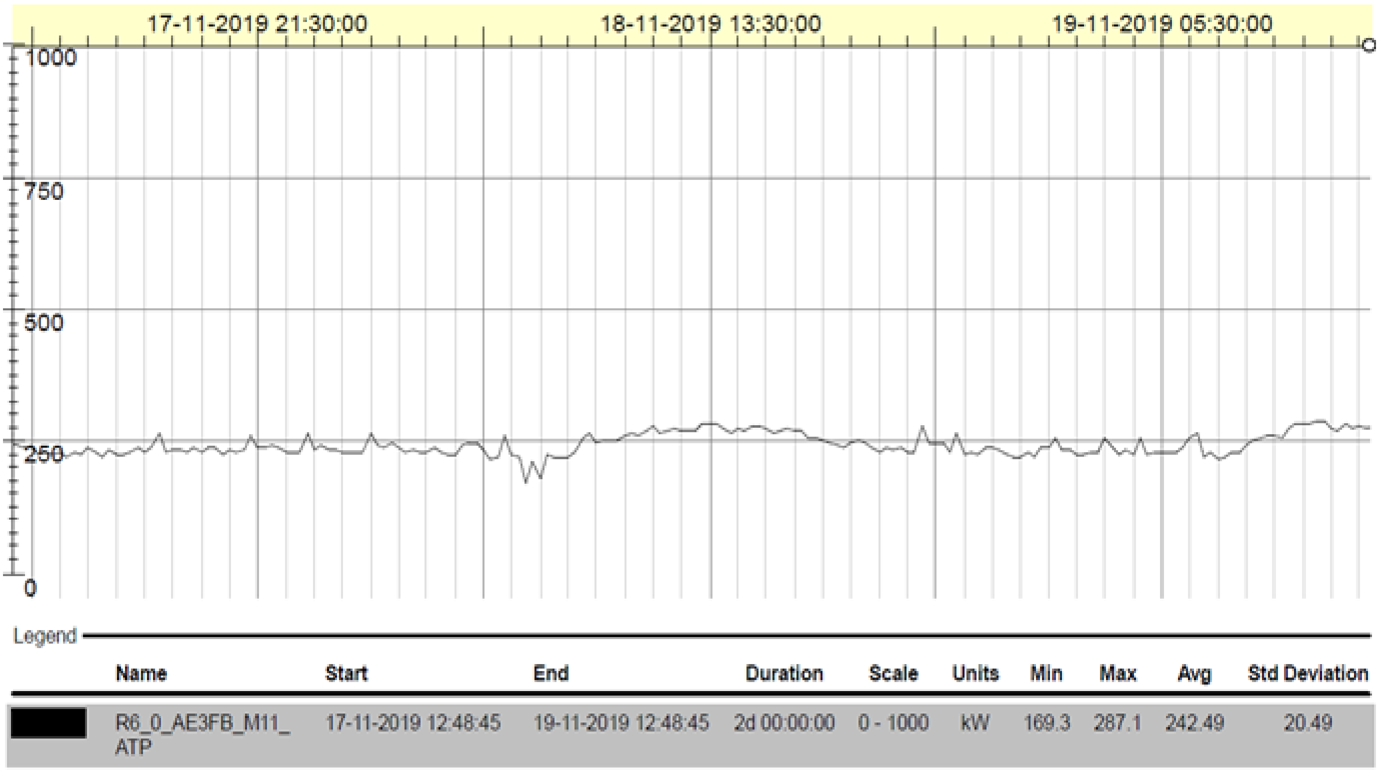

Fig 13: SCADA screen showing trend of Power

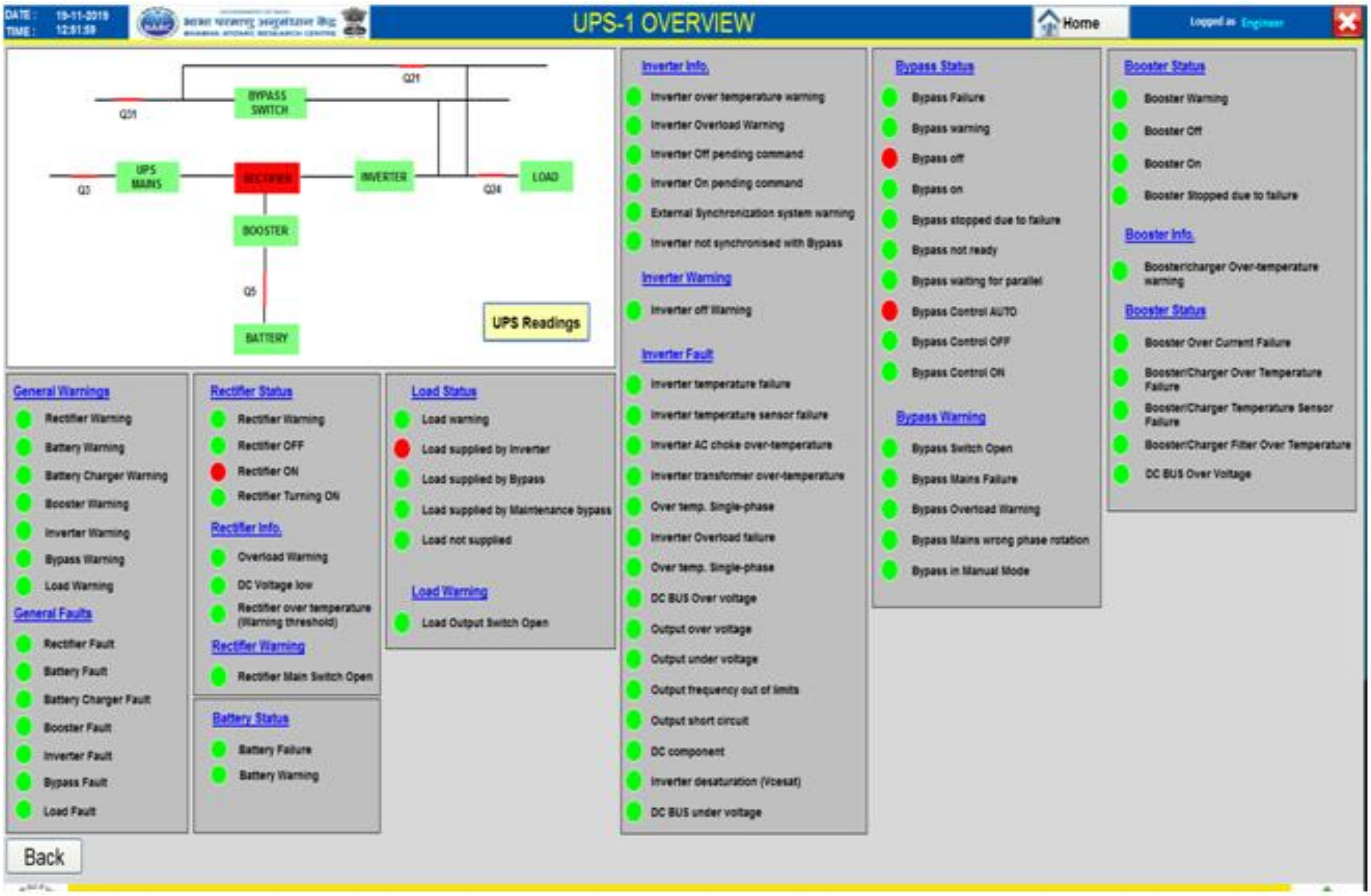

Fig 14: SCADA screen showing status of data of UPS

X. CONCLUSION

Common myth is that to employ a SCADA system old equipment needs to be discarded. However, with proper engineering and shortlisting the requirement it is possible to retain the same equipment and employ a very good monitoring system. The design covers all important equipment including single phase circuitry also. Unlike a smart grid the system developed does not monitor all power system details in depth. However the information covered are adequate to take up immediate action by an operator to restore the power distribution network on immediate basis. The system has helped to maintain the availability of all category power supply of the radiological facility more than 98% and it is possible to utilize make an efficient power system monitoring system for any distribution network.

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