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AUTOMATION OF CONVENTIONAL TRANSMISSION SUBSTATION USING SCADA

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Abstract *- This paper discusses implementation of the next generation solution for power system control and monitoring. Due to rapid development in automation system, the remote operation, control and monitoring can be performed easily by adopting it to the earlier conventional power systems. This can be achieved by integration of conventional systems and modern technology SCADA. This study is about the automation of substation by integrating the existing conventional substation devices with new networked infrastructure SCADA which can perform automatic industrial tasks such as data acquisition, device control, monitoring and event recording of the overall transmission system network. This combination of technologies empowers a highly reliable, self-healing (auto-restoration) power system that responds rapidly to real-time events with appropriate actions. Automation does not just replace manual procedures but permits the power system to operate in a most efficient and optimal way, based on accurate information provided in a timely manner to the decision-making applications and devices. The daily operation, load management and system faults are monitored by the SCADA which improves the performance of overall transmission systems.*

Keywords *– Conventional systems, SCADA, Control and Relay panel (C & R panel), Remote Terminal Unit (RTU), Very Small Aperture Terminal (VSAT), Master Control Centre (MCC).*

I. INTRODUCTION

Power demand in India is aggravating at an alarming rate with ever increasing population, industrialization and advancements in technology. With depletion of natural resources like coal, environmental restrictions, reduced right of way allocations, dearth of trained manpower in comparison to demand, and space crunch in metropolitan cities, we have only one option: to operate our existing system with utmost security and optimization, and as economically as possible. Power demand can be brought to stable state by automating the existing power system. This can be achieved by Power system automation through SCADA.

Power system automation is the process of automatically controlling the entire power system through automated processes via computers and intelligent devices. The different aspects of automation (like data acquisition, power system supervision and power system control) work together in a coordinated fashion to operate the system efficiently. SCADA system gives us the power of fine tuning operation of power systems to efficiently transmit electrical power with increased reliability and sophistication. It monitors more variables and provides detailed view of entire operation in real time.

Earlier electric infrastructure comprised of a complex system of power generation, transmission systems, and distribution systems which is called as the Conventional systems. The major components of this conventional system include power transformers, instrument transformers (current and voltage transformers), bus bars, isolators, relays, circuit breakers, battery chargers, capacitor banks, earthing equipments, rectifiers, transducers, lightning arrestors, etc. The main drawbacks of these systems are no real time monitoring, operational efficiency low, depends on the skill of the operator, no data logging, fault analysis and recovery would take long time, incorrect billing due to incorrect measurements and frequent grid failures. To overcome these drawbacks SCADA is implemented.

II. AUTOMATION USING SCADA

Supervisory control in electric utility systems evolved from the need to operate the equipment located in remote substations. In the past it was necessary to have personnel stationed at the remote site, or send a line crew out to operate equipment. The term SCADA for Supervisory Control and Data Acquisition Systems, came into use after the use of a computer based master station became common.

A formal definition of SCADA system, as recommended by IEEE, is “A collection of equipments that will provide an operator at a remote location with sufficient information to determine the status of particular equipment or a process and cause actions to take place regarding that equipment or process without being physically present”.

SCADA provides the mechanism for capturing real time data from field equipments, specifically controls, equipment status, system demands and alarms, transfer it to the central computer facility called as Master Control Centre and display the information to the operator graphically or textually, thereby allowing the operator to monitor or control an entire system from a central location in real time which significantly enhance operation efficiencies, better regulatory record keeping and reporting, remote trouble shooting to reduce downtime and increase repair efficiency, reduce time and travel labor cost and improved capability to instantly alert operators of alarms and undesirable events in remote substations. The control of any individual equipment, operation or task will be automatic or it can be performed by operator commands from MCC.

During normal condition, SCADA helps to operate the system optimally. It processes the incoming stream of data, detects abnormalities, alarms the operators through lights and buzzers, and takes rectifying actions as needed, thus relieving the operator of the burden of repetitious control and continuous monitoring. During extreme conditions, it helps to diagnose the source of alarms, guides the operator in decision-making and facilitates the operator in steering the system back to normal in the smallest possible time and with minimum damage to system resourced fashion to operate the system efficiently. The ability to perform operations at an unattended location from an attended station or operating center and to have a definite indication that the operations have been successfully carried out can provide significant cost saving in the operation of a system. This is exactly what is achieved through the SCADA system.

According to abbreviation of SCADA, Supervision, Control and Data Acquisition are the main tasks to be carried out at every substation.

- Supervision - of the incoming line, Feeders, Control and Relay Panels (C&R panel)
- Control - Switch gear
- Data Acquisition - such as Voltage (phase), current (phase), active and reactive power, frequency etc.

Supervision, Control and Data Acquisition is done by installing ABB's RTU 560A which consists of all facilities that is required for automation. In old substation there was need to acquire data from existing equipment. Renewing all equipment or replacing old equipment by new equipment will increase cost. Hence to automate the existing substation RTU560A is integrated.SCADA system comprises of

- Field instrumentations such as current transformer, potential transformer, transformers, circuit breakers, relays, Control and Relay panel, and Remote Terminal Unit.
- Communication infrastructure connecting the supervisory system to the RTUs through LAN and VSAT
- Control Centre – Master Control Centre and Area Load Dispatch Centre

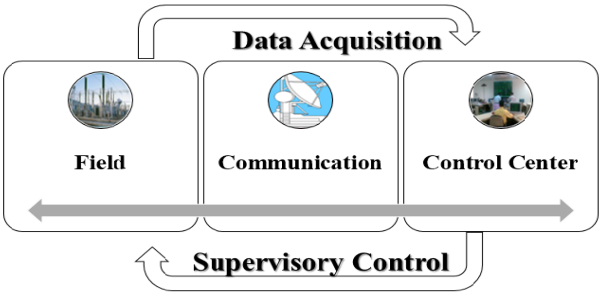

Figure 1. Components of SCADA system

As shown in the below block diagram, the C & R panels/switchgears housed in electrical sub-station send all the analog & digital data to remote terminal unit via cables and this in turn is processed by processors at RTU. These processed electrical data are transmitted to SCADA Control Centre through satellite communication, VSAT.

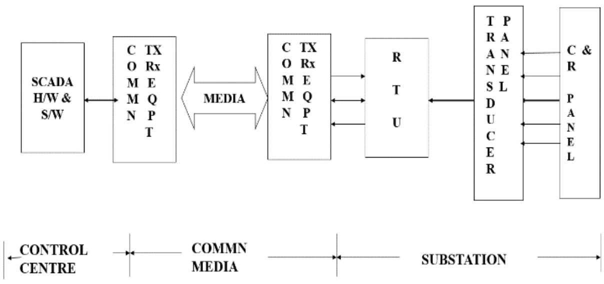

Figure 2. Block diagram of SCADA

The SCADA system is capable of collecting digital and analogue inputs (DI & AI) from field units and executing commands through digital outputs (DO) for which hard wiring is done between RTU and control & Relay panels. The central location or Master Control Centre (MCC) consists of server and workstation computers connected on a LAN and loaded with the SCADA application software for user interface and data interpretation, analysis & report generation.

III. CONTROL AND RELAY PANEL

Control and Relay Panel is one of the field instrumentation which belong to the conventional systems which is integrated with the RTU560A for automating the substation. Control and Relay Panel is mainly for metering, annunciation, mimic/indications and protection purposes.
Major Compartments / Components of Control Relay Panel:

3.1 Metering

The metering panel incorporate measuring instruments such as ammeter, voltmeter, KW meter / kVar meter, energy meter, frequency meter and power factor meter for current, voltage, energy, frequency or power factor.

3.2 Annunciation/Alarms

12 Window annunciators are provided in each control panel by means of visual and audible alarm to draw attention of the operator to the abnormal operation or operation of the protective devices or for specific fault indication.

12 Annunciations are:

- Distance protection operated
- Back up OCR protection operated
- Back up distance protection operated
- CB lockout SF6 protection low
- CB SF6 protection low
- CB TC1 circuit faulty
- Power swing block
- Conductor broken
- Weak end infeed
- VT fuse fail
- Distance relay healthy
- CB circuit faulty

3.3 Mimic diagram/indications

It is a Coloured graphic character presenting one line diagrams of electric circuits with dynamic representation of ON/OFF indication for circuit breakers, relative position of isolator switches etc. with LED position indicators at appropriate location.

Indications such as, Isolator open/close, circuit breaker auto trip, circuit breaker open/close, circuit breaker spring charged and earth switch open/close are located in the mimic one line diagram.

Non- discrepancy type T-N-C (Trip-Neutral-Close) switch is mounted for remote operation of circuit breaker. The switch shall be mounted in the mimic diagram such that the stay-put ('N') position will render the continuity of the mimic.

3.4 Protection relays

Over current relay, Earth fault relay, Distance protection relay, Differential relay, REF protection relay are equipped for fault protection of system operation. They are designed and applied to provide maximum discrimination between faulty and healthy circuits. System equipment will remain inoperative during transient phenomena which may arise during switching or other disturbance to the system.

3.5 Optocoupler

It is basically an interface between two circuits i.e. RTU and instruments in C & R Panel which operate at different voltage levels. This is necessary for the coupling between high voltage information gathering C & R Panel and low-voltage digital logic RTU. All the metering, annunciation, status indication data from 110V DC analog Control and Relay Panel is converted, voltage isolated and transmitted to 48V digital RTU.

Figure 3. Optocoupler

All the required circuits are connected to the 8 inputs of the Optocoupler and one output from Optocoupler is connected to RTU560A DI card. It only allows signal flow in one direction, responds to dc levels, and offer an extremely large resistance between the input and output circuits.

3.6 Terminal blocks (TBs)

Required number of disconnecting type TBs are used to terminate all the internal wiring to be connected to the external equipment. All TBs are arranged for easy identification of its usages such as CT circuits, PT circuits, analog inputs, status inputs, control outputs, auxiliary power supply circuits etc. All equipment on and inside the panels are mounted and completely wired to the terminal blocks ready for external connection.

All the data from Control and Relay Panel will be transferred to RTU via cables from TB.

IV REMOTE TERMINAL UNIT (RTU)

RTU 560A of make A.B.B. Private Limited is used in SCADA system to automate the conventional substations. It is a multi-processor architecture combined with the support of the full software functionality of the RTUtil560 provide the perfect solution for application in transmission substation. It is a high speed microprocessor controlled electronic device that are installed at remote sites such as primary/secondary substations that interfaces substation equipments with the SCADA system. It is a hardware of SCADA systems and acts as a standalone data acquisition and control unit which continuously transmits data derived from various field devices for any changes such as alarms, status of circuit breakers and isolators to the control center and controls the addressed device within the substation on the basis of commands received from Master control centre. So, it can be called as two-way communication device that keeps updating the status of the field equipment continuously and simultaneously executing the commands from the Master Control Center.

Engineering of the process signals and configuration of data for the RTU560 is managed by a tool called 'RTUtil 560' for all stations with RTU560A units. It generates all files requested to run the RTU560A units. It allows to download the files into the RTU560A in the stations via internet using web browser technology or via the communication line, when the protocol supports file transfer. RTUtil 560 enables the user to control the whole engineering process of an RTU based system. The RTU shall possess memory to permit storage of a minimum of 2000 events locally for subsequent transmission to the SCADA master station. The equipment will normally remain in continuous service to provide SCADA facilities. Failure can result in the interruption of the operation.RTU560A is mounted with 4 serial communication port for host communication with master station using IEC104 protocol, 32MB flash memory for event storage, 8 MB RAM, PC104 module with CPU 486/66MHz clock speed and has the capability to work with PLC.

There are two different types of Panels in RTU560A. One, housing a stack of racks called the “RTU Panel” and the other housing only the MFTS or Multifunction transducers, called the “MFT panel”. The RTU panel consists of a Basic Rack with CPU and communication ports, Extension Rack1 consists of 8 Digital Input cards (DI), 3 Analog Input cards (AI) and 1 Analog Output card (AO), Extension rack2 consists of 5 Digital Output cards (DO) and 1 MIC card, Annunciation panels for load alarm annunciation and AC/DC converter.

4.1 Basic rack

Basic Rack or the Communication Sub Rack houses the brain of the RTU. It consists of a number of slots into which a set of “Cards” are mounted as shown in the figure. The Cards are the CPUs of the RTU. They help in coordinating the flow of data from and into the RTU.

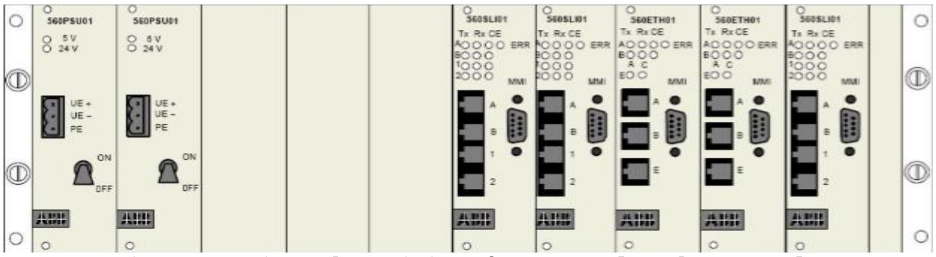

Figure 4. Basic Rack consisting of 3 CMU and 2 Ethernet cards

These CPUs are of two types: 3 no. of CMU (Communication unit) Card - 560SLI 01 or 560CMU 04 and 2 no. of ETH (Ethernet) Cards - 560ETH 01.

Communication unit (CMU) Card acts as an interface between the RTU and the IEDs (Intelligent Electronic Devices) like protection relays, multifunction meters and battery charger. It consecutively reads data in and out of the IEDs such as Numerical Relays present on the C&R Panel or MFTs placed on the MFT panel of the RTU. It communicates with the IEDs through four ports i.e. A, B, 1 and 2 which are RS485 type and RS232. Each CPU communication board has an additional serial interface for MMI to a PC which are RS232 type. The MMI is used for diagnostics, up and download of configuration files, etc.

The Ethernet card controls the process events and communications with the Control Centers. It continually reads the data from the Extension Racks, the CMU cards and sends it to the control center. The ETH card has a port marked by "E" used by the RTU to communicate to the Master control center. The ETH is connected to the Extension Rack through port A or B, called COM A and COM B. It also has an MMI port similar to the one present in the CMU card. The ETH and the CMU cards communicate with each other through a dedicated communication channel present on the back plane of the Basic Rack. It has the ability to manage and control the input/output boards through RS232/485 interfaces, reads process events from input boards, send commands to output boards and communicates with control centers via integrated serial line interface and Ethernet LAN interface.

4.2 Extension rack 1 and 2

It is a place, where Input/output Modules are placed. Similar to the structure of the Basic Rack, the Extension rack 1 has 12 slots into which 8 numbers of DI cards, 3 numbers of AI cards and 1 number of AO card are inserted. In Extension rack 2 only 5 numbers of DO cards and 1 MIC card are inserted. It communicates only with the ETH card of the Basic Rack. The communication port of both the extension racks are looped with the one succeeding it. As mentioned before, the extension rack is connected to the ETH Card through port A or B. The function of the input modules is to send the status of the equipment present in the station to the MCC. The function of the output modules is to control the status of the equipment from the MCC.

4.2.1 Digital input card (DI card): Status indication from control & relay panel are given to 8 binary input Digital card (DI) card - 23BE23 located in extension rack 1. Scanning and processing of the inputs are executed with the high time resolution of 1 ms. One DI card have 16 channels, which can be used for connecting the status of field devices as an indication to MCC. The board has sixteen light emitting diodes to indicate the signal-state, Each LED indicates ON/OFF status of an input connected to particular channel of the DI card. It has a buffer which allows the temporary storage of 50 time-stamped event messages in chronological order designated for transmission to the communication unit.

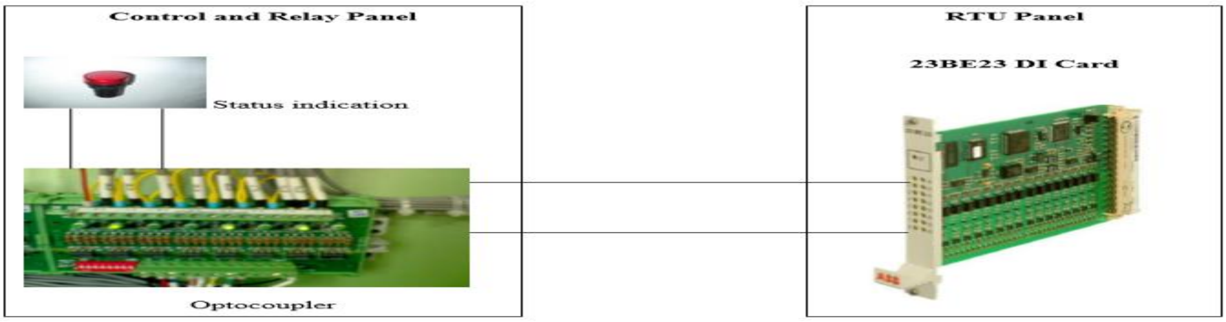

Figure 5: Connection of DI card to C&R Panel

The DI card shall accept two types of status inputs i.e. Single point status inputs and Double point status inputs. Single point status input will be from a normally-open (NO) or normally-closed (NC) contact which is represented by 1-bit in the protocol message. The Double point status input will be from two complementary contacts (one NO and one

NC) which is represented by 2-bits in the protocol message. A switching device status is valid only when one contact is closed and the other contact is open.

4.2.2 Analog input card (AI card): At substation 3 numbers of analog input card 23AE23 located in extension rack 1of RTU is interfaced to station battery and transformers tap positions of the field, to continuously monitor battery voltage and tap positions. The 23AE23 board records up to eight analog measured values. It gives the analog value of the signal.

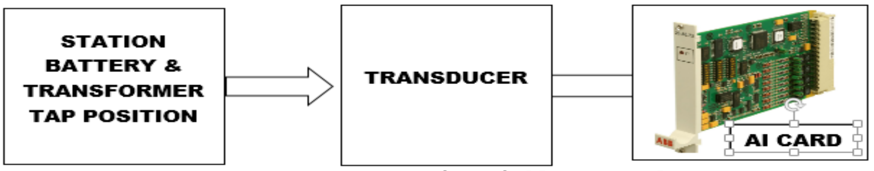

Figure 6: Connection from field to AI card

It has 8 channels on which eight signals can be configured. The input to a channel in the AI card is a 4-20ma dc current, which is a proportional output from DC Transducer required to measure DC voltages of station battery and status indications of transformer tap position in a RTCC panel, which in turn are sent to CMU cards for further processing.

4.2.3 Analog output card (AO card): Via the Analog output board 23AA21 of extension rack 1, analog control outputs for sequential or closed loop control, display instruments, measured recorders are connected to the RTU560Atohaveacontinuousplotof analog values. Each output has a digital to analog converter (DAC) which converts the digital value present in the output memory into an analog signal. A received output value is stored until a new value is received. At substation they are used for measurement of transformer temperature etc.

Figure 7: AI card 23AA21

AO card is an optional card, which is used during maintenance of field equipments to know the analog values of the equipment.

4.2.4 Digital output card (DI card): Connection from switch gear is connected to 5 binary output DO card - 23BA20 of extension rack 2 through relay contacts. Resistive loads of up to 60 W can be switched with output voltages between 24 and 60 V DC. The process relays to be switched have to be equipped with zero voltage diodes. Operating status and faults are displayed by light emitting diodes on the front panel of the 23BA20, ST: Common malfunction information of the board, PST: Command output fault condition display when the monitoring system responds, CO: Command output display during output time.

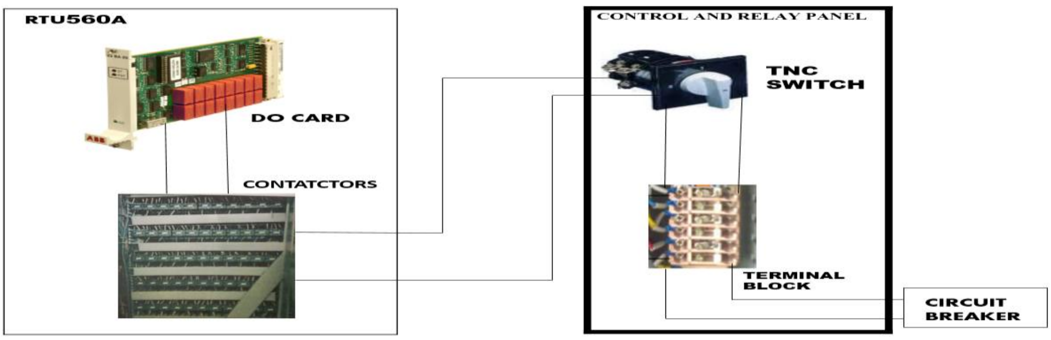

Figure 8: Connection from DO card to field equipments

DO card is used to execute commands that are sent from the MCC. As soon as the DO card gets a command, it sends a pulse of 48v dc to the exciting terminals of the relay contactor which in turn operates the TNC switch. The control points from TNC switch are terminated to circuit breaker or any field devices through disconnecting terminal blocks. These control outputs are used for close/trip operation of circuit breakers and isolator switches. Each control output consist of one set of potential free NO contact. The output contacts shall be rated for at least 0.2 Amp at 48V dc.

4.2.5 Meter interface card (MIC card): It is an add-on functional module, as a part of SCADA system that enables to fetch daily consumption of all interface points i.e. interEscom lines. These interface points meter data, of 15 minutes block are transmitted to Master Control Centre in real time. This data is primarily used for billing purposes. MIC are specifically used for collecting ABT information from Energy Meters over a RS485 multi drop network. MIC is just a flash memory. Following parameters are uploaded from meter for ABT: Voltage, Current, Frequency, Reactive energy in, Reactive energy out, Active energy in and Active energy out.

4.3 Annunciation Panel

If operator at MCC operates any of circuit breaker or any other equipment remotely, to indicate this information for local operator at substation SCADA Control Annunciator is provided in RTU 560A, which alarms operator regarding that particular operation.

4.4 AC-DC Converter

All racks of RTU560A consists of power supply unit 560PSU01 which require DC supply of 48V, thus AC-DC converter is used. This unit supplies required DC power to all racks of RTU panel.

4.5 Multifunction Transducer Panel (MFT)

It is an IED that can calculate real time analog values such as line voltage, phase current, frequency, active power, apparent power (MVA), reactive power (MVAr) and power factor when inputs from secondary of the CTs and PTs are given. It can measure 96 electrical parameters from single transducer. This output is transmitted in MODBUS or IEC104 protocol to RTU unit, which in turn processes and sends across to MCC.

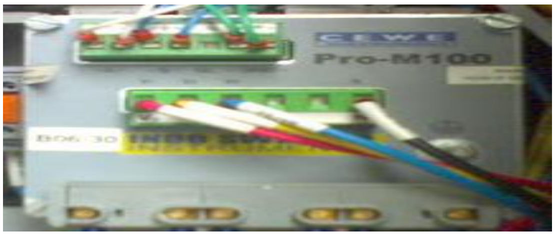

Figure 9: Multi Function Transducer (MFT)

There is a communication port available for each MFT with RS 485 connection scheme. The communication ports of 8 MFTs are looped through RS485 interface and assigned to the ports of CMU card through a cable.Baud rate of data transfer between MFTs and RTU is 19.2 Kbps.

V WIRELESS COMMUNICATION SYSTEM: VSAT

The conveying of data from RTU to MCC and vice-versa is done over a satellite communication system called VSAT-Very Small Aperture Terminal. A geostationary satellite INSAT3A maintained by ISRO with 17th transponder11.5MHz C band frequency bandwidth is used. VSAT refers to receive/transmit terminals installed at every dispersed remote substation housed with 1.8 Mtrs diameter antenna of parabolic reflector, connecting via satellite to a central hub MCC housed with 9 Mtrs diameter antenna.

Figure 10: VSAT communication

Components of VSAT are antenna, Indoor unit-modem (IDU) and Outdoor Unit (ODU). To avoid communication problem separate SCADA phones (Voice Over Internet Protocol) are provided at each substation. 8 port switch is used for separate connection for MIC, IDU, Voice Over Internet Protocol (VOIP), CMU etc.

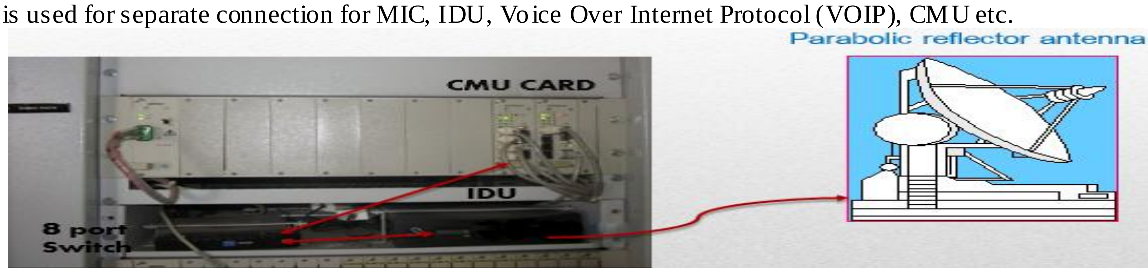

Figure 11: VSAT Components and connections

CMU card and IDU are connected to the 8port-switch using LAN cable.Finally IDU is connected to VSAT antenna using RF cable.

The entire data acquisition uses Multi Frequency Time Division Multiple Axis technology (MFTDMA) on IEC 104 communication protocol which manage the data traffic over the network and allows understanding between two communicating devices. Star topology is used so that data can be received individually from every substation and unhealthiness of one node (station) does not affect the data transmission of another node (station).VSAT networks offer value-added satellite-based services capable of supporting the Internet, data, LAN, voice/fax communications and provides powerful, dependable private and public network communications solutions.

VI MASTER CONTROL CENTER (MCC)

Master Control Centre is a centralized hub consisting of large computer consoles that serve as the central processor for the SCADA system where real time data from all substations are acquired securely through VSAT communication for storage, scrutinizing, control and alarming purpose. The main strategy of MCC is to balance the generation and demand load, monitor flow and observe system limits, coordinating maintenance limits and protecting equipment from various kinds of damage. It performs centralized monitoring and control for field remote sites over long-distance communications networks, including monitoring alarms and processing status data. Based on information received from remote stations, automated or operator-driven supervisory commands are pushed to remote station control device RTU which in turn operates a particular equipment. Operator can access real time data such as Feeder ON OFF indication, Circuit Breaker status, tap change of transformer, station load, station battery voltage, current, frequency, active & reactive load, isolator status, faults events, alarms etc. Basically, electrical operators in SCADA master station can be able to remotely monitor and control electrical substation/switchgears.

VII CONCLUSION

By combining the electronic, telecommunication and signal processing technology, SCADA automation has upgraded and optimized the conventional substation. By interfacing SCADA to the conventional systems, it has helped automating the substation by performing automatic remote monitoring and controlling of field equipments, automatic real time data acquisition, data sharing and data analysis, automatic protection of field equipments, smart load demand management and reduced man power is achieved. Combining the benefits with the ability to extract information automatically leads to the monitoring and controlling capabilities that are faster and more robust. From this study it can be said that in order to improve the overall system performance, reliability, stability and security it is necessary to implement the SCADA system for controlling the whole electricity network. The combination of Automation and SCADA has not just replaced manual procedures but also permitted the power system to operate in a most efficient and optimal way, based on accurate information provided in a timely manner to the decision-making applications and devices. With the introduction of the SCADA technology, a true redundancy is possible at reasonable cost for all functions of the substation. Thus, SCADA has delivered the next generation solution in the field of automation and power system monitoring and controlling. Hence SCADA is the back bone of effective Load management and is assuming greater importance in the Power Sector and Automation.

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