Design & development of Protection scheme & Supervisory Control & Data Acquisition system (SCADA) of 25 kV ac traction system for Mumbai suburban section on Indian Railways (IR)

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Abstract

The paper is about the design, development & commissioning of protection & supervisory control and data acquisition (SCADA) system to meet special requirements of 25 kV ac traction system on Mumbai suburban section. The existing scenario of protection and SCADA systems on IR and improvements thereupon to develop the new system for Mumbai has been covered. The merits of integration of numerical relays with Remote Terminal Units (RTU) based on IEC 60870-5-103 protocol and other developments in the field of substation automation are also briefly discussed in the paper.

Keywords- SCADA, protection, RTU, numerical relays, traction, railway, OHE, control, monitoring, protocol, IEC.

1.0 Introduction

Electric traction in suburban areas of Mumbai started with 1500 Volts dc in year 1925; however during late nineties it was realised that dc traction system was grossly inadequate to cater for the ever increasing number of sub urban trains services and associated infrastructure. The decision was taken by the Ministry of Railways to convert existing 1500 V dc traction system to 25 kV ac.

Conversion of an existing 1500 V dc electric traction system to 25 kV ac had lots of constraints like minimum interruptions in train services, right of way i.e. space, clearances, fast developments in the field of protection and automation etc.

One of the important issues associated with the conversion work, was to economically design and develop a suitable protection scheme and SCADA system capable of controlling & monitoring large number of Circuit Breakers (CB) & Numerical relays provided at substation and switching posts in the Mumbai suburban area.

1.1 Brief description of 1500V dc and 25 kV ac systems

In old 1500 V dc system, the overhead equipment (OHE) power was being supplied at 1500 V from rectifier fed traction sub-stations (TSS) with normally no sectioning; i.e. the sub-stations were connected in parallel. In case of failure of one of the TSS, the supply was maintained from adjacent TSS. Total supply interruption for sub-urban trains (Electrical Multiple Units (EMU) and the dc locomotive hauled main line trains) was rare. Moreover, the motorman/driver of the EMU's were not required to negotiate any neutral sections (switching off/on of vehicle CB) thereby relieving them for better concentration on signals and driving.

In 25 kV ac system, power is drawn from two phases of the incoming EHV lines and stepped down to 25 kV. One of the secondary terminals of the transformer is earthed and other is connected to OHE to supply power.
Power is drawn from different phases at adjacent Traction Sub-stations (TSSs), cyclically, to balance the load on EHV transmission lines and hence the separation of phases is carried out on the OHE contact wire system by provision of "neutral sections", which do not draw power and provide mechanical continuity for passage of the pantograph of the motive power.

The drivers of trains are instructed to switch off the on-board 25 kV circuit breakers to prevent flashovers while the pantographs negotiate the neutral sections. Tripping of the feeder circuit breakers (CB) is associated with supply interruption over the entire feed zone.

1.2 Special Requirements of protection, control and monitoring systems

The single line diagram of the power supply arrangement at a TSS having details of protection relays for Mumbai suburban section and sectioning diagram for the conventional 25 kV ac traction system in use on IR are given in (Fig-1 & 2) for comparing the two systems. The special requirements of traction power supply system for the Mumbai suburban section are as under.

1.2.1 Traction supply at different traction substations in Mumbai area is taken at 110 kV and up to three adjacent traction substations are to be fed at same phases from one supply authority and thus the TSSs drawing power from the same phases are planned to be operated in parallel on the 25 kV sides of the traction transformers. *In service, the "neutral sections" separating the sectors, are to be kept live, there-by providing operational convenience under paralleled feeds on both sides, during exigencies, however, the neutral sections shall be capable of being* ***activated*** *by operating the specific switches/ interrupters/ CBs.*

1.2.2 OHE system in Mumbai area consists of 4 to 8 Railway lines (tracks) with 25kV bus type arrangement at Traction Substations/Sectioning/sub-sectioning & paralleling posts (TSS/ SP /SSP) is given in Fig-3 below. TSSs are planned at short distances of 6.5 to 20 kms as against 50-60 kms due to higher power requirements. In addition, some of the sub-sectors (sections between any two switching stations) are very short, about 1 km.

1.2.3 All (SP/SSP) are provided with CB's in lieu of interrupters used in conventional 25kV ac traction system with protection relays and associated control and relay panels so that the smallest possible section can be isolated & faults localized automatically, with minimal intervention by the operators.

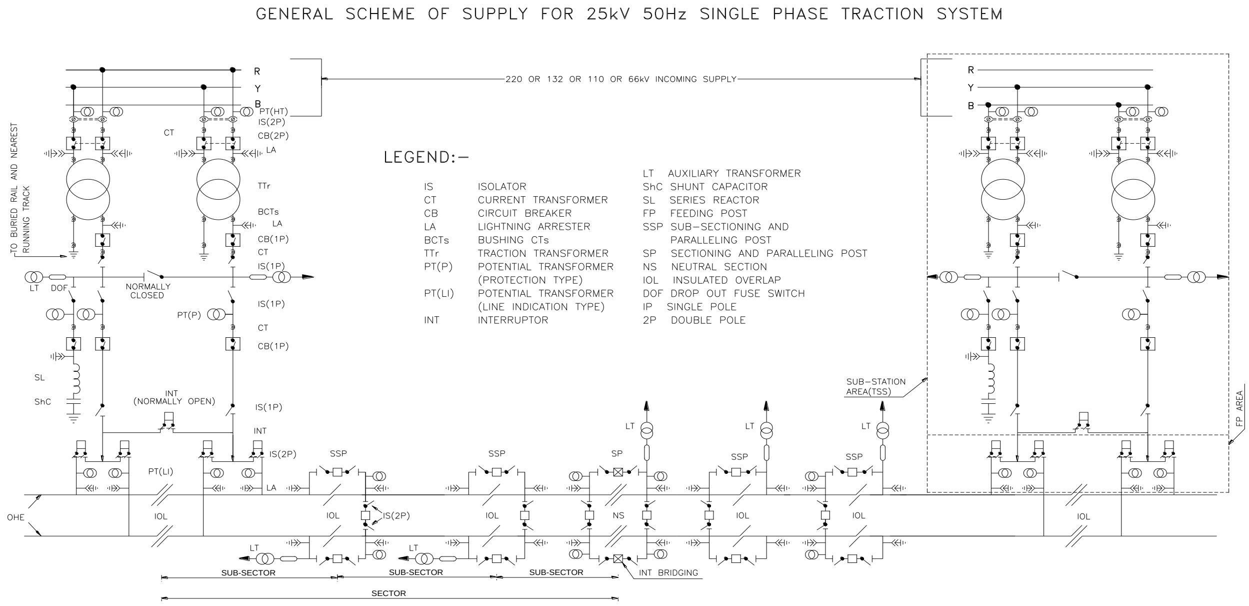


Fig-1

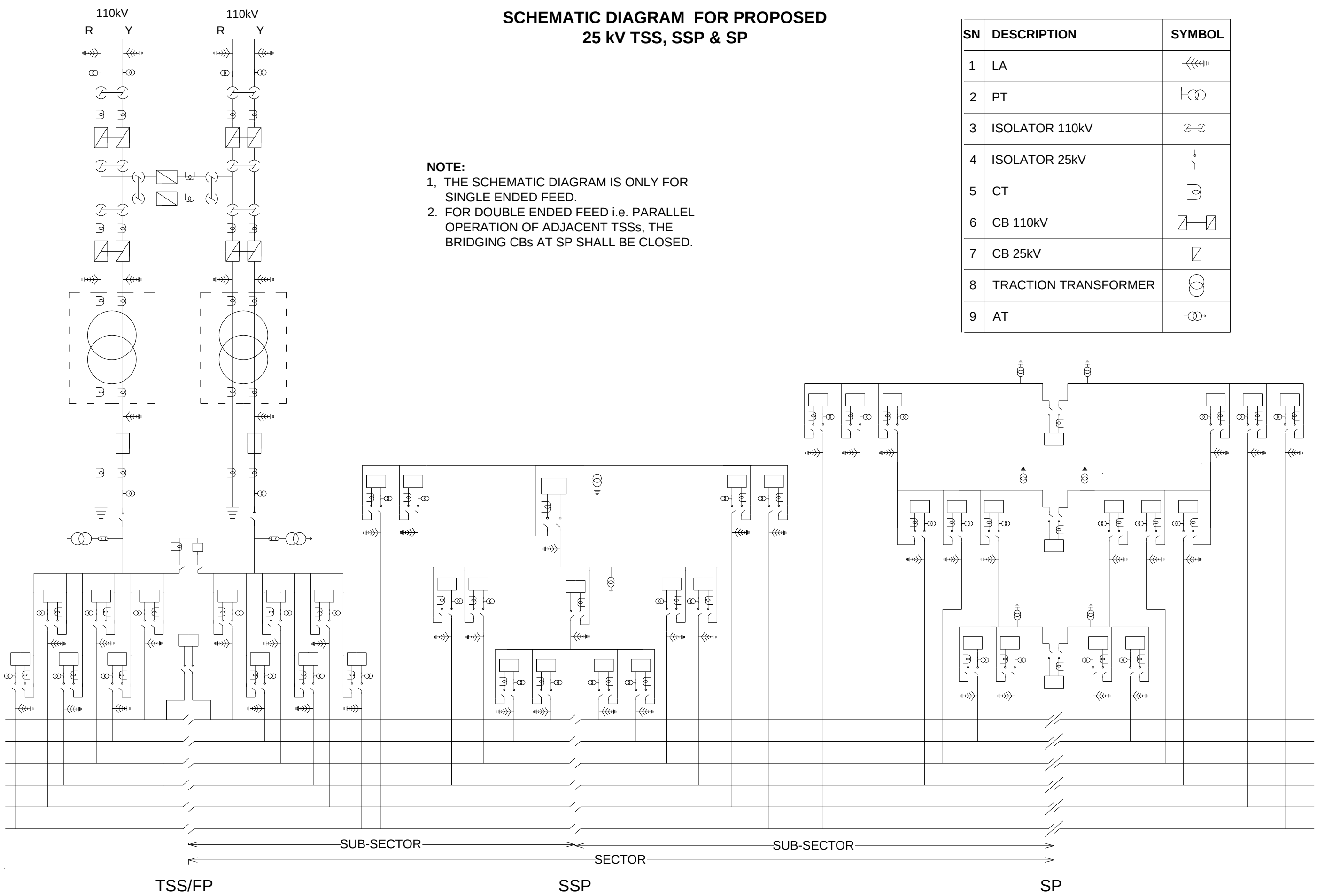
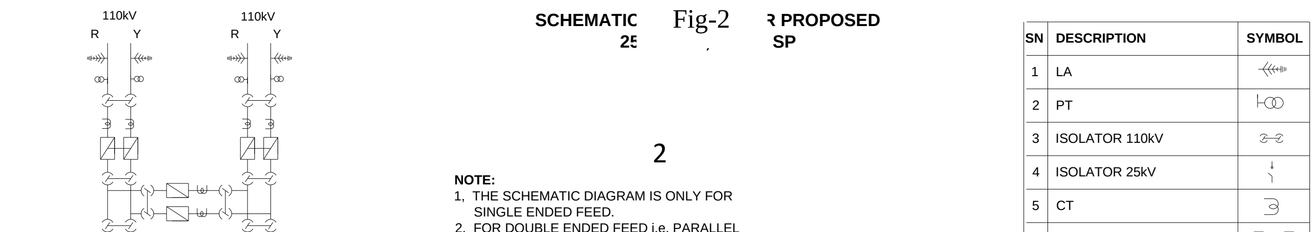


Fig-2



PROTECTION SCHEME FOR PROPOSED 25 kV TSS

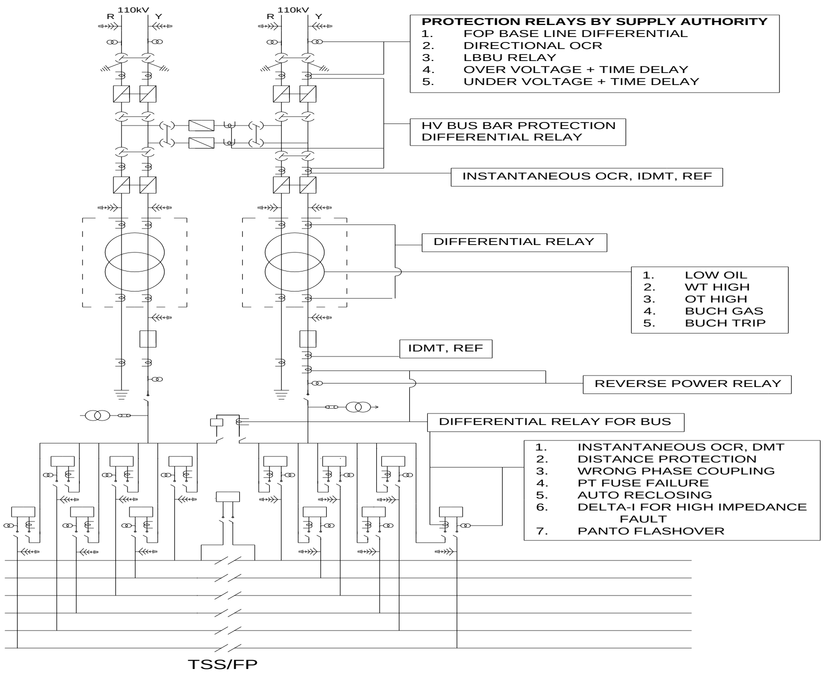


Fig-3

1.2.3.1 The comparative requirements of telemetering & controls for Mumbai sub urban section as compared to the conventional system are given below in Table-1.

Table-1

Typical requirements of Equipment, input & outputs	**Conventional Traction system on IR TSS /SSP or SP**	**Mumbai Suburban Section with 8 tracks TSS /SSP or SP**
No of Feeder CBs	2/nil	16/22
No. of Status / Alarms	96/28	600/600
Total No. of Controls	24/8	64/88
Parameters to be monitored	8/4	32/24

The hard wiring between RTU and panels for such large number of control points was not feasible due to space constraints (Fig 4).

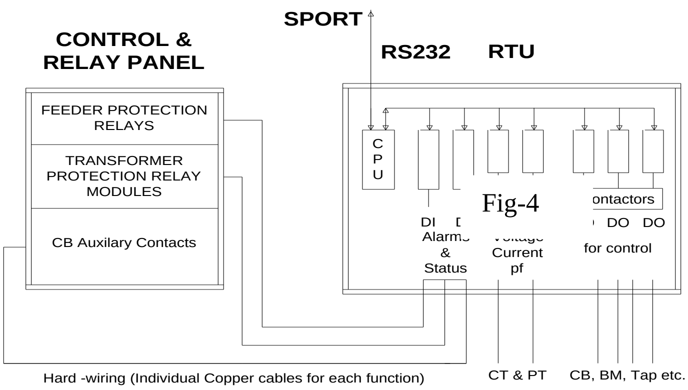


Fig-4

1.2.3.2 The size of the RTU designed to cater for the above requirement of control points through hard wiring should have been very large to accommodate all the cards, relays/contactors and associated wiring circuits. Moreover, with long loops of CT secondary wiring, the chances of failures are also high.

1.2.4 OHE used in Mumbai suburban area is of varying configuration in terms of size of contact & catenary wires (e.g. Catenary/contact wire cross sections of 65/107, 65/150 & 242/193 Sq mm) and therefore its line parameters like values of R and X are expected to be different for different sections. More over some of the sections are equipped with auxiliary catenary as third wire. This creates difficulties in fault current assessments and relay settings thereon.

1.2.5 There are number of foot & road over bridges (FOB/ROB's) wherein the minimum requisite clearance between OHE and the bridge for safe operation is not available and therefore innovative insulation schemes using paints & sheets are implemented.

In light of the above and considering very high traffic density in the sub-urban, the system design requirements were totally different from the conventional 25 kV ac traction system, therefore development of a protection system capable of isolating the shortest possible section in the fastest possible time and localize a fault with minimal human intervention and a state of the art SCADA system was essential.

2.0 Protection scheme adopted for Mumbai suburban section

The main features of the protection scheme adopted are as under.

2.1 All the protection relays developed for this purpose were of Numerical type having IEC 60870-5-103 compatibility for communication with RTU's.

2.2 Incorporation of all modern features in protection relay module like, multiple protection functions per module, events/data storage, graphical LCD display, communication ports and compatibility to EMC & EMI norms as stipulated in latest IEC standards like IEC 60255-5, 60255-22-1, 60255-21-1, 60255-22-2,3,4,5,7 & IEC 61000-4-5 etc.

2.3 Optimum level of selectivity, to achieve isolation of minimum possible subsector in case of faults on OHE.

2.4 Adequate provision of backup protection systems to avoid any catastrophic failures. Additional protection features like "synchro check relay" to take care of paralleling of 25 kV supply of three TSS. The relay also has a feature to permit CB closing without synchronism check for feed extension.

2.5 Numbers of auxiliary relay functions have been built in a single protection relay module for minimizing the control panel wiring, number of auxiliary relays and burden on CTs, PTs & aux. 110V dc supply.

2.6 All protection relays have a self monitoring feature and in case of failure of the relay, alarm and tripping of CB can be realized as per requirement.

2.7 The different protection functions implemented in the new scheme are as under.

2.7.1 **25 kV ac traction OHE feeder protection-**

- Three Zone parallelogram characteristic distance protection relay with independent setting of R & X values for forward, reverse and each zone

- Instantaneous and definite time over current, wrong phase coupling, PT fuse failure relays. Vectorial Δ I relays for high resistive faults protection as well as a backup protection to main feeder protection relays.

- Distance protection element have a automatic trip block feature by monitoring and analysing of second harmonic content of current to avoid unwanted tripping due to start-up of electric locomotives.

- Intelligent auto reclosure function has been inbuilt in the feeder protection module. The main feature of auto reclosure are:
- ✓ Single or double shot user selectable reclosing with settable time delay.
- ✓ Blocking of the reclosing of CB on high fault current.
- ✓ Two types of auto reclosing logics to avoid CB reclosing on the both ends of the faulty subsector in case of permanent fault.

- SOTF (switch-on-to fault) function has been provided for high-speed tripping when energizing traction supply, on to a short-circuit fault.
- Memory polarization is used to discriminate correctly between faults in forward and reverse directions in the event of voltage input falling down to 0 volt.

2.7.2 **Traction transformer protection-**

- Differential, Restricted Earth Fault (REF) and IDMT OCR protection along with three stage definite time OCR elements for both LV (25 kV) & HV (110 kV) sides.

2.7.3 LV and HV bus-bar differential protection

2.7.4 Protection scheme for 110 kV incoming transmission lines including reverse power flow relay at TSS to prevent reverse flow of power on transmission line through 25 kV Railway Feeder in case of parallel operation of TSS.

All the above listed protection relays are assembled on C&R panel toward the rear side, as shown in the fig-5 below.

Fig-5 Control and relay panel for TSS

3.0 **SCADA system on IR**

SCADA is one of the most critical system of electric traction network on IR as all the posts are unmanned. Since the inception of electric traction over IR in 1960's it started using SCADA based on electromechanical relays and mimic diagrams with switches. IR followed the developments in technology and gradually replaced its SCADA systems from electro mechanical to minicomputer based and to present PC based systems working on proprietary tailor made protocols like present SPORT protocol.

3.1 Conventional SCADA communication system working on IR

The schematic arrangement of conventional 25 kV ac traction SCADA system adopted over IR is depicted below in Fig 6

Slow speed V-23, FSK MODEMs, operating at 600/1200 bps are used on voice grade data channels over OFC and quad copper cable mediums in multi-drop, half duplex, unbalanced communication mode. 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 Remote Control Centre (RCC) 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.

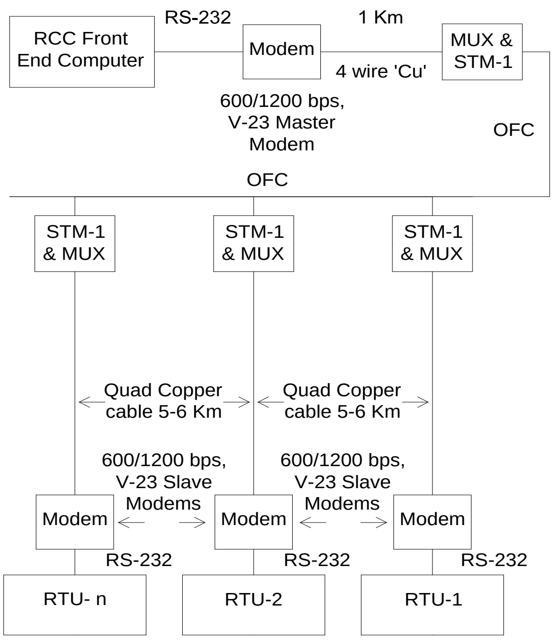


Fig-6

Indian Railways has adopted SPORT (standard protocol for railway traction) communication protocol which is a customized and cut down version of IEC 60870-5-101 companion standard. This helps in efficient operations of the system even with very slow data transfer rates of 600/1200 bps.

4.0 Overview of new SCADA system - IEC 60870-5-103 based Communication between numerical relays and RTU

4.1.1 IEC 60870-5-103 is a companion standard of IEC 60870-5 series standards and applies to protection equipment with coded bit serial data transmission for exchanging information with control systems. It also defines interoperability between protection equipment and devices of a control system in a substation.

4.1.2 This standard does not necessarily apply to equipment that combines protection and control functions in the same device, sharing a single communication port, however, in case of Mumbai suburban section the numerical protection relays have been utilized for implementation of the control of devices i.e. circuit breakers by interfacing all such relays with RTU on RS 485 for communication thereby saving in terms of RTU hardware. The RS 485 may be single or multiple channel but in Mumbai area, multiple channels are used to reduce the load of communicable data in relays and to ensure redundancy as well (Figure-8).

4.1.3 Either a fibre optic system or a copper-wire based transmission system may be used in this companion standard between the protection equipment and the control system. However copper wires are selected considering the cost and requirement levels. The RS-485 interface has been used for data communication between numerical relays and station controller units of the RTU.

4.1.4 The block diagram of the modified SCADA arrangement is given in Fig-7a. Most of the information in the form of DI, DO and AI, like status of CB's, voltage, current, phase and command execution (i.e. ON/OFF of CB's) is accomplished through numerical relays connected via communication channels (Fig-7b) thereby saving in terms of complicated hard wiring between RTU and control & relay panel. However, there is still some hard wiring because all the CB's, bus couplers etc. which are not controlled by any protection relays. The communication arrangement between RTU and RCC is same as depicted in the Fig-5.

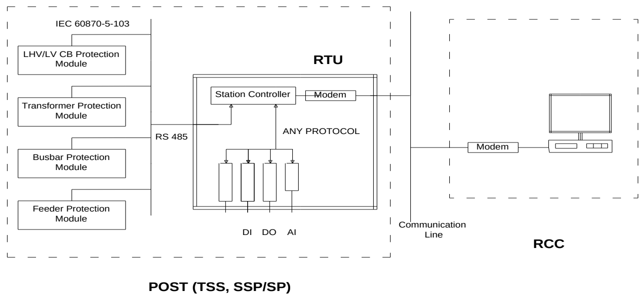


Fig-7a

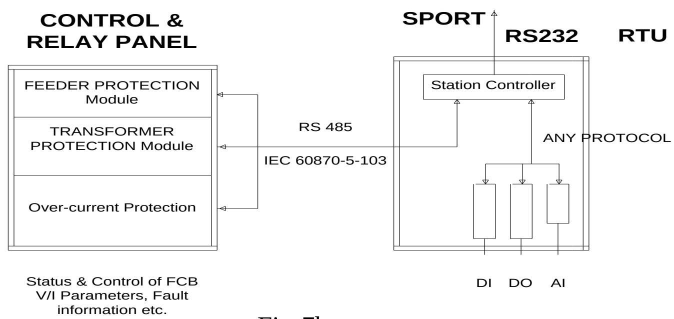


Fig-7b

For RCC to RTU the data transfer speed is adjustable from 600 bps to 19200 bps. For communication with relays it is settable to either 9600 or 19200 bps as per IEC60870-5-103 standard.

4.1.5 The local control operation of devices from the control and relay panel has been retained through the hard wiring between panel, relays and switch gear devices same as in conventional system.

5.0 Merits of modified SCADA system

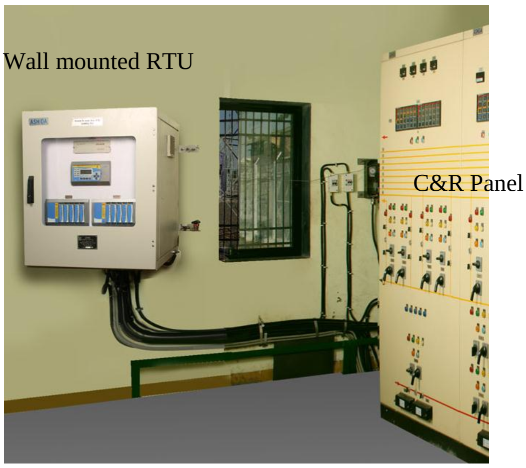
5.1 Reduced hard wiring due to status, Control & acquisition of parameters accomplished from numerical protection relays.

5.2 Compact wall mounted Aluminum RTU could be done to save considerable space.

5.3 The smaller size and lesser components make system more reliable and require less maintenance. (Fig 9)

5.4 The Station controller unit (SCU) of RTU is designed with multiple RS485 ports to reduce communication load on relays (Fig-8). The SC is having a local HMI with LCD display & push button switches for local setting of parameters like address, communication speed, etc.

5.5 Improvements has also been done in the Control centre computers, LAN and SCADA software in terms of optimization of layout of computers in Remote Control



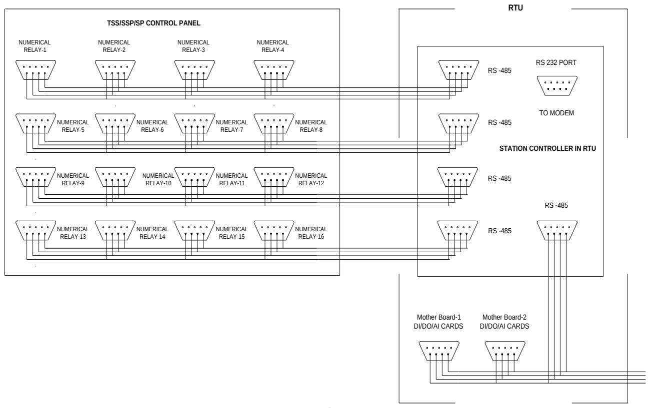


Fig-8

Centre (RCC). All server, modems, switches, etc. are mounted in a compact rack. In addition complete automatic change-over of main server to stand-by in case of failure has been ensured. Synchronization to satellite time using GPS timer server has also been incorporated so as to ensure same time stamping at RCC and RTU's.

5.6 The design of controlling operations and status monitoring of devices (mainly CB's) through numerical relays has resulted in to large savings in terms of wiring, relays and contactors (for DO's).

5.7 There are no requirements of separate transducers for acquisition of analogue parameters like Voltage, current, power factor etc. as the information is provided by the relays..

5.8 The data which could not be read from the relays (as tabulated in table No.-2 below) was wired to separate Digital In, Digital Out & Analog In modules. These modules along-with associated contactors/relays were housed within the RTU.

For DI **For DO**

Description	Description
25 kV Bridging Interrupters	25 kV Bus coupler
25 kV Bus coupler	HV Bus coupler
Transformer	25 kV Bridging Interrupters
Tap position	All HC CB
AC Fail	LV CB
DC Low	Tap Raise
DC Fail	Tap Lower
Any other annunciation circuit or 110 V dc failures.	

Table-2

5.9 The closing of circuit breakers through the feeder protection relays was achieved by using auto-reclosure function available in the feeder protection relays. A simple built in logic in the relay distinguishes the operation of breaker due to the operation of some protection element or by the controller at RCC.

6.0 Future developments and emerging technologies for substation automation

There are rapid developments taking place in the field of protection, control, monitoring & integration of devices and substation automation technologies. The recent developments in this field are as under.

6.1 **Development of numerical technology for protection**

Numerical protection relays are capable of implementing multiple protections, control and monitoring functions per hardware device, using a well crafted software platform. The devices are also capable of extensively using optical interface serial communication facilities.

With the use of these devices it is now possible to combine protection and control functions and it is now possible to transfer the useful data available in the form of sequence of events, disturbance reports, fault waveforms and even system parameters.

6.2 **Standardization of communication protocols**

The fast development of numerical technology necessitated standardisation of communication protocols and to some extent, of the substation bays, layouts and protection functions. The serial communication was standardised by IEC in its 60870-5 series of standards. The IEC 60870-5-101/104 companion standards defined the communication between substation and remote control centre, while IEC 60870-5-103 for communication with protection equipment. The standard protocols like DNP3, Modbus etc. are also being utilized extensively by electrical utilities.

6.3 **Complete substation automation & integration of all IED's**

The latest development has been the evolution of IEC 61850 standard, which comprehensively covers all communication issues within the substation, assures interoperability between the functions existing inside the substation and is virtually considered to be future proof. It uses 100 Mbps Ethernet substation LAN & switches, object oriented data model having logical nodes under client server architecture for non time critical data transmission and Generic Object Oriented Substation Event (GOOSE) for exchange of time critical data between same bay or horizontal communication.

The IEC 61850 was not considered for the Mumbai project because there were limited suppliers & developers of Numerical Relays, IED's and other IEC 61850 compliant field devices. The cost of the devices complying with the above standard is high and the complexity, voltage levels, number of bays and configurations of the Railways TSS and switching posts as compared to the HV/EHV Grid Substations was much less therefore it was not selected for Mumbai traction system.

In addition to above, other aspects like complexities involved in implementation of the IEC 61850, limited technical expertise available at grass root level and availability of brief past experience of such systems in India were also the deterring factors.

7.0 Summary:

Indian railways has taken a leap ahead by adopting a new technology for 25 Kv ac traction protection and SCADA application at Mumbai suburban section to meet the special requirements of the area like 6-8 lines, space constraints, parallel operation of 2 to 3 TSS, small subsectors etc. New designs of numerical relays and control and relay panels were developed and provided. The results have been encouraging and the system comprising of 7 posts and nearly 30 km section between Borivali and Virar stations has already been commissioned and is working satisfactorily as per the new protection scheme and SCADA system.

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