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TRACTION DISTRIBUTION
POWER SUPPLY INSTALLATION
IN ELECTRIC TRACTION



भारतीय रेल
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PREFACE

The book on "Power Supply Installation in Electrical Traction" was brought out by Institution of Railway Electrical Engineers (IREE) long back. Since, lot of changes have taken place in the field of Power Supply Installation, it has become necessary to incorporate the changes in this volume. Few additions and modifications in the field of Power Supply Installations are included in this book.

For bringing out this book Shri M.K.Jain, Section Engineer(TRD) and Shri Suryawanshi M.A., Raj Bhasha Supdt. have made substantial efforts, under the guidance of Shri R.B.Bhargav, Professor (TRD).

I am delighted to note that lot of efforts have been undertaken in bringing out this book of "Power Supply Installations in Electrical Traction" in the present form. I am sure that this book will serve the needs of Electrical Engineers working in the field of Power Supply Installations in Electrical Traction.

Nasik Road
21st May, 2010

A handwritten signature in black ink, appearing to read 'A.K. Rawal', with a date '21/5/10' written below it.

A.K.RAWAL
DIRECTOR

POWER SUPPLY INSTALLATION IN ELECTRIC TRACTION

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1. GENERAL DESCRIPTION OF FIXED INSTALLATIONS

1.0 POWER SUPPLY ARRANGEMENTS AT SUB-STATIONS

1.0.1. Power Supply

25 kV, AC, 50 Hz single phase power supply for electric traction is derived from the grid of State Electricity Boards through traction sub-stations located along the route of the electrified sections at distance of 35 to 50 km apart. The distance between adjacent substations may however be even less depending on intensity of traffic and load of trains.

At present there are broadly four different arrangement in existence as under

1. The Supply Authorities supply power at 220/132/110/66 kV Extra High Voltage (EHV) at each traction substation which is owned, installed, operated and maintained by the Railways.
2. The Railway receives 3-phase power supply from the supply Authority at a single point near the grid substation from where the Railway runs its own transmission lines providing its own traction sub-stations.
3. All EHV and 25 kV equipment is owned, installed, operated and maintained by the Supply Authority except 25 kV feeder circuit breakers which are owned, installed, operated and maintained by the Railway.
4. All EHV and 25 kV equipment is owned, installed, operated and maintained by the Supply Authority but 25 kV feeder circuit breakers alone are operated on remote control by the Traction Power Controller (TPC).

1.0.2 Duplicate Supply

1. Fig 2.01 shows schematically the arrangement at a typical traction sub-station.
2. To ensure continuity of supply under all conditions, the high voltage feed to the traction substations is invariably arranged wither from two sources of power or by a double transmission line, so that if one source fails the other remains in service. Suitable protective equipment is installed at the substations to ensure rapid isolation of any fault in transmission lines and substation equipment, so that the power supply for electric traction is maintained under all conditions.
3. At each traction substation, normally two single phase transformers are installed, one which is in service and the other is 100% stand by. The present standard capacity is 21.6 MVA (ONAN)/30.2 MVA (ONAF).

However transformers of capacity 13.5 MVA (ONAN)/10.8 MVA (ONAN) have also been used at many of the substations. These transformers step down the grid voltage to 25 kV for feeding the traction overhead equipment (OHE). 25 kV feeders carry the power from the substations to feeding posts located near the tracks. Each feeder is controlled by a single pole circuit breaker equipped with protective devices.

1.0.3 Voltage Regulation

The permissible variation of the bus bar voltage on the busbars at the grid substations is +10% and -5% i.e. between 27,500 V and 23750 V. The tapplings on the transformers are on the secondary winding and set to ensure the voltage is maintained as high as possible but not exceeding 27.5 kV at the feeding post at any time.

1.0.4 25 kV Supply at Traction Substations

1. On the secondary side one transformer circuit breaker and one feeder circuit breaker are installed with associated double pole isolator the busbar connections being such that full flexibility of operation is assured.
2. The traction substation is designed for remote operation.
3. The facilities exist to change over from one feeder to the other by means of isolator/bus coupler.
4. One end of the secondary winding of the transformer is solidly earthed at the substation and is connected to track/return feeder through buried rail.

1.0.5 Feeding and Sectioning Arrangements

1. The generation and transmission systems of Supply Authorities are 3 phase systems. The single phase traction load causes unbalance in the supply system. The unbalance has undesirable effects on the generators of the supply Authorities and equipment of other consumers. If its value becomes excessive.
2. The permissible voltage unbalance at the point of common coupling on the grid supply system should not exceed the following limits:-

Voltage unbalance	(%)
Instantaneous	5
2 hours	3
Continuous	2

TYPICAL SCHEMATIC OF TRACTION POWER SUPPLY FEEDING ARRANGEMENT

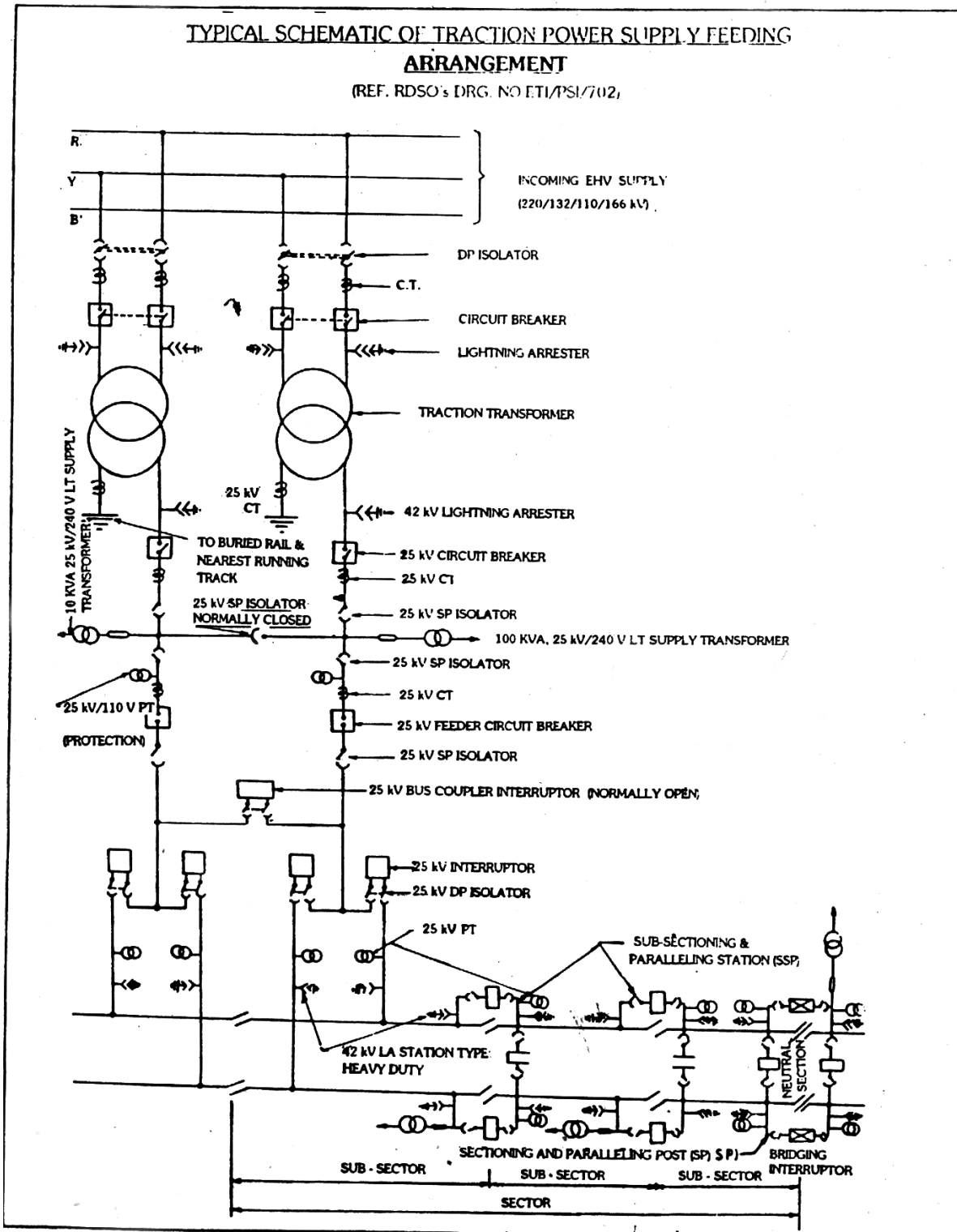


FIG 1.01

3. To keep the unbalance on the 3 phase grid system within the above limits, power for ac single phase traction is tapped off the grid system across the different phases at adjacent substations in cyclic order.
4. Thus it becomes necessary to separate electrically the overhead equipment systems fed by adjacent substations. This is done by providing a 'Neutral Section' between two substations on the overhead equipment to ensure that the two phases are not bridged by the pantographs of passing electric locomotives/EMUs.
5. To ensure rapid isolation of faults on the OHE and to facilitate maintenance work, the OHE is sectioned at intervals of 10 to 15 km along the route. At each such point a 'switching station interruptors, usually rated at 600 A are provided. The shortest section of the OHE which can be isolated by opening interruptors alone is called a 'sub-sectors'. Each sub-sector is further sub-divided into smaller 'elementary sections' by provision of off-load type manually operated isolator switches.
6. At some stations with large yards, alternate feeding arrangements are provided so that the power for feeding and yards may be drawn from alternate routes. Normally the switch is locked in one position, being changed to the other when required after taking necessary precautions.
7. To meet requirements at electric loco running sheds, isolators with an earthing device in the 'off' position is provided. At watering stations manually operated interruptors and isolators with earthing heels are provided to enable switching off of the power supply locally and earthing the OHE to enable working on roofs of rolling stock. There are several types of switching stations as detailed in the following paras.

1.0.5 Feeding Post (FP)

Each feeder supplies the OHE on one side of the feeding post through interruptors controlling supply to the individual lines. Thus, for a two track line, there will be four interruptors at each feeding post.

1.0.6 Sectioning and Paralleling Post (SP)

These posts are situated approximately midway between feeding posts marking the demarcating point of two zones fed from different phases from adjacent substations. At these posts, a neutral section is provided to make it impossible for the pantograph of an electric locomotive or EMU train to bridge the different phases of 25 kV supply while passing from the zone fed from one substation to the next one. Since the neutral section remains 'dead' warning boards are provided in advance to warn and remind the Driver of an approaching electric locomotive /EMU to open locomotive circuit breaker (DJ) before approaching 'neutral section'. to coast through it and then switch 'on' on the other side. Special care is taken in fixing the location of

neutral sections on level tangent tracks far away from signals level crossing gates etc to ensure that the train coasts through the neutral section at a sufficiently high speed to obviate the possibility of its stopping and getting stuck within the neutral section.

A paralleling interrupter is provided at each 'SP' to parallel the OHE of the up and down tracks of a double track section 'bridging interruptors' are also provided to permit one feeding post to feed beyond the sectioning post upto the next FP if its 25 kV supply is interrupted for some reasons These bridging interruptors are normally kept open and should only be closed after taking special precautions as detailed in these rules.

1.0.7 Sub-Sectioning and Paralleling Post (SSP)

One or more SSPs are provided between each FP and adjacent SP depending upon the distance between them. In a double track section. Normally three interruptors are provided at each SSP i.e. two connecting the adjacent sub-sectors of up and down tracks and one for paralling the up and down tracks.

1.0.8 Sub-Sectioning Post (SS)

These are provided only occasionally. These are similar to SSPs with provision for sectioning of the OHE but not paralleling.

1.0.9 Certain Equipment at Switching Stations

Certain equipments are installed at various points to protect the lines, to monitor the availability of power supply and provide other facilities. These are generally as under-

1. Lightning arresters are provided to protect every sub-station against voltage surges.
2. Auxiliary transformers are provided at all the posts and also at certain intermediate points to supply ac at 240 V, 50Hz required for signaling and operationally essential lighting installations. To ensure a fairly steady voltage. Automatic voltage regulators are also provided where required.
3. Potential transformers are provided at the various switching stations for monitoring supply to each sub-sector.
4. A small masonry cubicle is provided to accommodate remote control equipment, control panel, telephone and batteries and battery chargers required for the control of interruptors and other similar equipments.

1.2 POWER SUPPLY FOR SIGNALLING

1.2.1 Supply Arrangements

1. To ensure reliability of ac 240V, supply through 25 kV/240V auxiliary transformer by tapping 25 kV OHE is made available at following places:
 - (a) At each way side station for CLS.
 - (b) Level crossings located more than 2 km away from Railway Station.
 - (c) At IBH.
 - (d) At all the power supply installations.

2. In the event of power block being given on both the OHE sub sectors from which the signal supply is derived electric traffic would necessarily have to be suspended on the line. During such periods colour light signally will not also be in operation. Such cases are likely to arise very rarely at any station and the duration of the block is not likely to exceed one hour at a time. Therefore, no additional power supply arrangement need be made by the Electrical Department at wayside stations. However, to cater for this condition portable generating sets should be kept by the S&T Department to be operated until 25 kV supply is restored. At large stations with considerable shunting movements a stand by diesel generator set may be installed by the S&T Department to meet emergencies, if considered essential.

1.2.2 Voltage Regulators.

The fluctuating nature of the traction load causes perceptible fluctuation on the 240 V supply affecting operation of signalling equipment. To overcome this, static type voltage regulators are provided by S&T Department to limit voltage fluctuations to $\pm 5\%$. These voltage regulators are installed either in separate kiosks inside the remote control cubicles, inside the ASM's room, or inside the cabins depending upon the position of various load centers.

1.3. REMOTE CONTROL AND COMMUNICATION ARRANGEMENTS

1.3.1. Remote Control

The interrupters at the various switching stations as well as the feeder circuit breakers (and other switchgear owned and operated by the Railway) at the sub-stations are controlled from a Remote Control Centre (RCC) manned throughout the 24 hours of the day. During each shift there is one more number of Traction Power

Controller (TPC), depending upon the work load. All switching operations on the system are thus under the control of one single person, namely TPC, who is responsible for maintaining continuity of power supply on all section of the OHE. He also maintains continuous and close liaison with the Section Controllers in regard to train operations on electrified sections.

Further details regarding Remote Control are given in Vol II of this manual

1.3.2 Communication Facilities

All aerial telecommunication lines running by the side of the tracks are replaced with under-ground cables/microwave to overcome the interference caused by 25 kV single phase ac traction. The cables contain adequate number of pairs of conductors for the various types of Railway telecommunication circuits on ac traction. For technical details reference may be made to Indian Railways Telecommunication Manual.

In an electrified section it is essential, in the interest of efficiency to provide several independent telephone circuits to facilitate quick communication and to achieve co-ordination between different branches of the Railway. In an emergency several alternate telephone channels will be available for communication should one fail. The various telephone circuits provided in electrified sections are described below briefly :-

1. Train Control/Section Control:

This circuit is operated by the Section Controller and is used mainly for controlling train movements within his jurisdiction. It has connections with Signal Cabins, ASMs' Offices, Loco Sheds and Yard Masters' Offices.

2. Dy. Control Telephone:

This circuit is operated by the Deputy Controller and is used for directing traffic operations in general. It has connections with the important Station Masters' offices. Yard Masters' Offices, Loco Sheds and Signal Cabins.

3. Stock Control Telephone

This circuit is operated by the Stock Controller and is mainly used for keeping a continuous watch and to maintain control over the movements of wagons. It has connections with Yard Masters and important Station Masters office.

4. Traction Loco Control

This is a circuit provided for ac traction and is operated by the Traction Loco Controller who is responsible for movements of electric

locomotives and Electric Multiple Unit (EMU) stock. It has connections with Electric Loco Sheds, EMU Sheds, Important Station Masters, Yard, Divisional Officers such as Sr. DEE/DEE, AEE(RS), Sr. DEE/DEE/AEE(OP), Traffic Control Offices, Traction Foreman and important crew booking points.

5. Traction Power Control

This is a special circuit on ac traction and is used by TPC for all communications in connection with power supply switching operations and 'permit-to-work'. It has connections with Station masters' offices, cabin. Traction sub-stations, feeding posts, sectioning and sub-sectioning posts, traction maintenance depots, important Signal Cabins, Divisional Officers such as Sr. DEE(TrD), Sr. DEE/OP and Traffic Control Offices.

6. Emergency Control Circuit

This circuit is provided to facilitate the traction maintenance gangs and electric train crew to get in touch with TPC with the least possible delay in emergencies. It is also used by train crew in times of accidents for communication with the Control office. This circuit is operated by TPC and is located in the RCC.

Emergency telephones socket boxes are provided along the track at an interval of 0.75 to 1 km and also and near the signal cabins, sub-sectioning and sectioning posts, insulated overlaps and feeding posts etc. Portable emergency telephones are given to maintenance gangs, train crew and station Masters. By plugging the portable telephone into an emergency socket it is possible to communicate with the TPC.

7. Hot Line Communication

Hot line communication circuit should be provided between the HQ, divisional HQ traction loco controller and electric loco sheds. These would be provided in the HQ with CEE, CEE/Loco, Dy.CEE/RS, Sr.DEE/RS in the sheds and Sr.DEE/OP in the divisions.

8. Walkie Talkie sets :

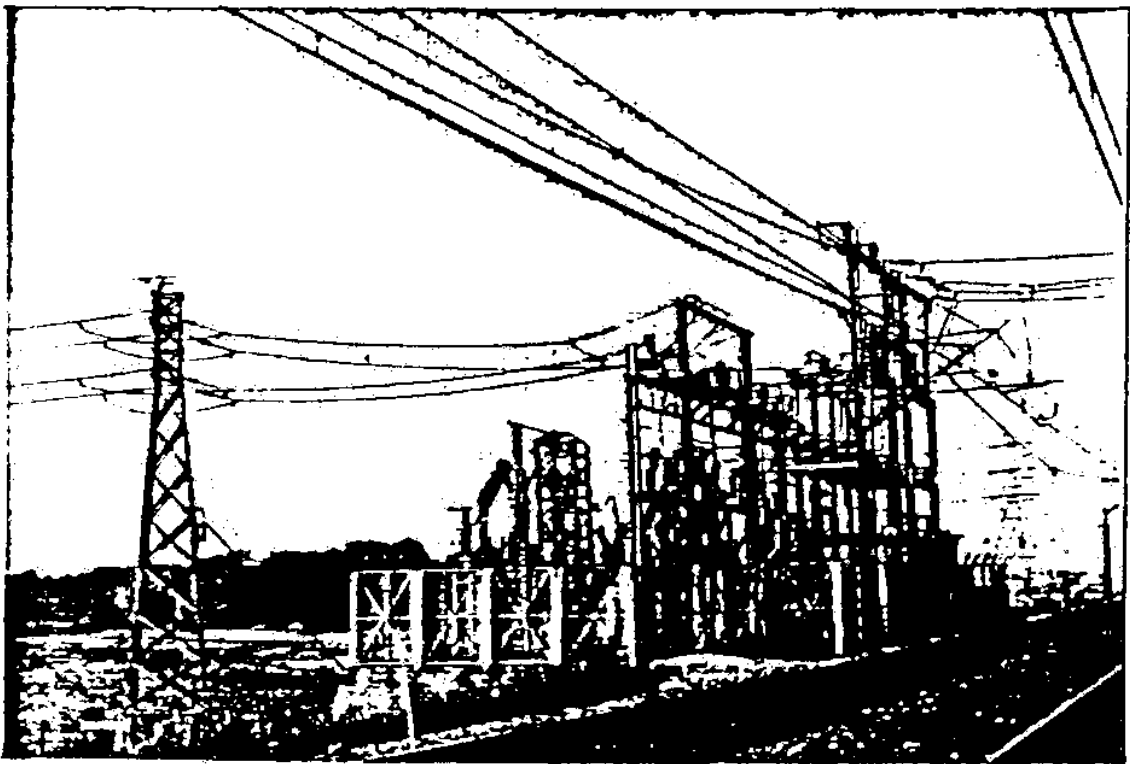
Every maintenance depots of OHE should have adequate numbers of walkie-talkie sets to be available with them during their normal maintenance work as well as break-downs so that not only effective communication is available at site but also to increase the efficiency and productivity of the work during power blocks. These walkie-talkie sets are to be used primarily for the following purposes:

- a) To communicate to the maintenance/breakdown gangs/parties that power block has been sanctioned.

- b) To direct and supervise work during the period power block is in force;
- c) Confirmation regarding cancellation of power block by each individual party and cancellation of power block.

9. Other Communication facilities:

An independent inter-communication circuit is also provided between the various Section Controllers and the Chief Controller for local communication between themselves. Facilities are also provided for the Chief Controller to talk to any station on train control, deputy control, stock control and traction loco control circuits. Similarly, facilities are provided to TPC to talk to any station on the train control and traction loco control in an emergency. However, it will not be possible for Chief Controller or TPC to ring independently any station on station on any control circuit as this ringing facility is only provided to the respective Controllers.



View of Traction Substation

2. POWER SUPPLY FOR TRACTION

2.0 Supply System

The single phase 50 Hz power for the electric traction is obtained from 220/132/110/66 kV Extra High Voltage 3 phase grid system through step down single phase transformers. For this purpose duplicate feeders comprising of only 2 phases are run from the nearest sub-station of the Supply Authority to the traction sub-station. The brief description of the system is given in Chapter 2 of Volume I. The 25 kV single phase conventional system as adopted on Indian Railways has been described in that chapter. A schematic diagram of the traction sub-station and feeding post indicating the general feeding arrangement is indicated at Fig 1.01.

2.1 Liaison with Power Supply Authorities

For ensuring continuity and reliability of power supply for traction it is important that effective liaison is maintained between the officials of Railway and Supply Authorities. Broadly action on the following lines be taken

- a) A system of periodic meetings at different levels at mutually agreed intervals needs to be evolved.
- b) Reliability of supply involves also the maintenance of traction voltage between 25 kV and 27.5kV at the feeding posts and frequency between 48.5 Hz and 51.5Hz. the serious repercussions on Railway traffic if the above limits are not adhered to should be constantly impressed upon the Supply Authorities.
- c) The traction load should be treated as essential load and should not be disconnected or reduced to meet supply system exigencies. This principle has been accepted by most Supply Authorities and where this has not been done, constant efforts should be made at the high level periodic meetings to get this principle accepted.
- d) Since the cumulative effect of frequency power supply interruptions, even though of short duration at a time, can be very serious to Railway working. A periodical review of 'such interruptions should be made at the Divisional level and the cause of each interruption ascertained as far as possible. The results as possible. The results of the review should be furnished to CEE to keep him fully informed of power supply position. This subject should also form an important item for discussion at the periodic meetings with the Supply Authorities.
- e) Power Supply for electric traction should be governed by a specific Agreement entered into by the Railway with the concerned Supply Authority before the supply is actually taken. Where this has not been done already, urgent action should be taken to have it finalized without delay.

- f) When grid supply to any traction sub-station fails and consequent emergency working has to be resorted to by extending the feed from adjacent sub-stations, the maximum demand at these sub-stations may go up. Most Supply Authorities have agreed to ignore such temporary increase in maximum demand for billing purpose. Where this has not yet agreed to, efforts should be continued to persuade the Supply Authorities to accept this principle.
- g) The present methodology of measuring maximum demand at each individual sub-stations for the purpose of billing has been reviewed by the Central Electricity Authority. It has been that Railways should be charged for traction power on the basis of simultaneous maximum demand recorded in contiguous sub-stations of the SEB serviced by the same grid transformers. Modalities to implement the decision would have to be mutually settled between SEB's and Railways, with cost of the equipment borne by Railways.

2.2 Tariff for Traction

- a) In Electric Traction the energy cost forms a substantial portion of the total operating and maintenance cost. The tariffs charged by various state Electricity Boards vary from a simple flat rate for the energy (charged by some states like MSEB & GEB) to a very complex tariff structure covering a variety of parameters (as indicated in the tariff charged by MPEB). The implications of the various parameters should be studied carefully to keep the energy cost to the minimum possible level.
- b) Contract Demand for each sub-station should be stipulated in relation to the expected actual Maximum Demand in such a manner that in fructuous payments by way of minimum guarantee on the one hand and penal charges for exceeding the contract demand on the other, are avoided. Notice period for altering Contract Demand should be kept as low as possible in the agreement. Preferably 4 to 6 weeks.
- c) In the tariff charged for electric traction, following are some of the parameters that should be given careful consideration with a view to keeping down the energy bill to the minimum:
 - i) Maximum demand charge Rs/kVA/month. Normally one feeder is 'ON' for feeding the traction load. If two sets of trivector meters are provided the higher of the two should be the MD to be charged. Caution may be excercised to ensure that addition of both is not taken as MD in billing.
 - ii) Energy charge Paisa/kWh.
 - iii) Fuel Adjustment Charge (FAC) accounting for the variations in cost of fuel and calorific value compared to stipulated basis

figures. This charge should be realistic and should be periodically verified with the Supply Authorities.

- iv) Penalty for low power factor. The penal charge is prescribed as an extra amount leviable in Rs/kVA of Maximum Demand if power factor falls below a specified value. SEBs usually insist on consumer providing PF correcting equipment and do not permit power factor lower than a prescribed value.
- v) Billing Demand is usually a certain percentage of contract demand or the actual MD whichever is higher.
- vi) Excess over Contract Demand and Corresponding units of energy are usually charged at higher tariff (excluding FAC). Even if the excess MD is for a short period of just 15 min. proportionate units for the entire month are charged at penal rate. One of the SEBs does computation of excess energy as under:

$$\text{Excess Energy} = \text{TU} (1 - \text{CD}/\text{MD})$$

$$\text{Where TU} = \text{Total Energy}$$

$$\text{MD} = \text{Maximum Demand}$$

$$\text{CD} = \text{Contract Demand}$$

The Contract demand therefore, has to be carefully determined and reviewed periodically and if necessary modified to avoid penal charges.

- vii) Minimum Guarantee

Usually, the agreement with SEB stipulate a percentage return of 15 to 20% on the capital cost invested by the SEB for giving the connection, as minimum guarantee. This is generally met by the pattern of energy consumption in traction. However, minimum guarantee in some case is specified in terms of guaranteed average load factor (say 30%). This ties up the Contract demand with the units consumed.

If a few heavy trains operate in a section raising the Maximum Demand high, the average load factors may not reach 30 % unless adequate frequency of passenger trains also forms part of the traffic pattern. Here, if contract demand is too high, 30% load factor is difficult to achieve while if contract demand is too low, exceeding it and attracting penal changes becomes a possibility. Careful balance between the two conflicting requirements is, therefore, to be struck.

viii) Harmonic Voltage Distortion

The consumer is required to carry Harmonic Analysis under full load conditions. It is stipulated that the individual harmonic distortion (Vn) and total harmonic voltage distortion (Vt) at the point of supply shall not exceed 1% and 3% respectively.

V - RMS value of fundamental voltage.

Vn - RMS value of harmonic voltage of order “n”, expressed as percentage of RMS value of fundamental and shall be calculated using the following expression.

$$V_t = \frac{\sqrt{(V_2^2 + V_3^2 + V_4^2 + \dots + V_n^2)}}{V} \times 100$$

- d) The tariff charged for traction should be reviewed periodically with the SEB. It should be ensured that the rates do not exceed those charged in EHV tariff of the SEB applicable to other consumers.

2.3 Monthly Meter Readings

- a) In earlier Railway Electrification installations, only one set of meters owned by the Supply Authority has been installed to meters the traction load. In later installations, a second set of meter is to be provided on the sub-station switchboard at Railways cost. Where only one set of meters belonging to the supply authority is installed yearly testing of the meter should be carried out. If its accuracy is the doubt at any point of time, the Railway is entitled to ask for testing and certification of the meter. Where a second set of meters has been provided at Railways cost, the figures for billing purpose should ordinarily be based on the average readings of the two sets of meters, unless specifically provided for otherwise the Agreement. The exact procedure covering these aspects should be embodied in the Agreement with the Supply Authorities.
- b) The monthly meter reading should be taken on an agreed date each month jointly by representatives of the Supply Authority and the Railway. The meter card as well as the printomaxigraph chart reading showing maximum demand for the month should be initiated by representatives of both parties. Only readings jointly recorded as above should be accepted for billing purposes.
- c) When visiting the grid sub-stations for taking meter readings, the supervisory official concerned will also obtain additional information such as daily maximum demand for traction, power factor, load factor, variation of voltage, changes in the system of interconnection, which

have a bearing on power supply for traction. Suggestions for suitable changes in the Supply Authority's network may be made at appropriate level and if necessary concrete proposals initiated for making power supply 100% reliable.

2.4 Scrutiny of Bills

- a) The Supply Authorities bills should be carefully scrutinized in the Divisional office with reference to the Agreement and the tariff. A time schedule should be laid down jointly with the Accounts Department for scrutiny and passing of the bill so as to take advantage of the rebate admissible, if any, for prompt payment. Penal charges levied, if any should be carefully scrutinized and appropriate remedial measures taken to prevent recurrence. If the minimum charge payable is in excess of the amount warranted by the actual energy consumption this fact should be promptly brought to the notice of CEE as well as the operating Department to take special steps to arrange for movement of additional traffic to the extent possible in the affected section, including diversion from other routes.
- b) Detailed instructions should be issued locally, jointly with the Accounts Department listing the items to be checked prior to passing the bills from the Supply Authorities. An illustrative list given below
 - i) Arithmetical accuracy.
 - ii) Meter readings shown on the bill tally with those received earlier from the subordinates.
 - iii) The tariff applied is in terms of the agreement.
 - iv) The method of computation of the maximum demand for billing purposes is in accordance with the agreement and that temporary increase in maximum demand on account of emergency feeding has not been taken into account where this principle has been accepted.
 - v) The time allowed for payment is in accordance with the agreement.
 - vi) There is no duplication in billing.
 - vii) The payee as provided for in the agreement is clearly indicated. The full particulars of the payee should be advised to the Accounts Branch to enable that Branch to issue cheques accordingly.
 - viii) Each new bill should be analysed and compared with earlier bill and the reasons for any significant departures investigated.

In case of any dispute/discrepancy, the payment be made "under protest".

2.5 Power Factor Improvement

- a) Provision of power factor improvement capacitors at 25 kV bus of traction sub-stations should be planned giving priority to sub-stations (i) which feed large marshalling yards and (ii) where penalty for low power factor and /or exceeding maximum demand has been stipulated in the tariff.
- b) The average monthly power factor is calculated as ratio of kWh and kVAh over a month. Care should be taken to make sure that it does not go 'leading' while P.F. correcting equipment is used and is kept near unity. Switched capacitor be used where load variations are wide.
- c) The Guidelines issued by RDSO in respect of selection of the kVAR rating should be kept in view at the time of planning.

2.6 Shut-Downs of traction Supply to be Pre-Planned

- a) At all grid sub-stations and traction sub-stations owned by the railways, duplicate EHV feeders are available. Most of the sub-stations also have two sets of traction power transformers and associated switchgear. Maintenance of equipment and transmission lines should not, therefore, necessitate total shut-down of EHV and 25 kV supply at a sub-station. It should be arranged with the Supply Authorities that on the rare occasions when shut-down becomes inescapable, notice should be given well in advance to Sr. DEE/DEE (TRD) stating the reasons for the shut-down and the anticipated duration. Such shut-downs should be arranged by Sr. DEE/DEE (TRD) in consultation with the Operating Department which may have to re-schedule trains and take other measures as necessary.
- b) A double circuit set of transmission lines from the Grid Sub-station are run to give supply to traction sub-station. Therefore, maintenance of the transmission line does not necessitate total shut-down of the system. However, all such shut-downs should be planned well in advance giving the reasons to the shut-down and anticipated duration.

2.7 Operating Instructions for Grid Sub-stations

Detailed operating instructions mutually agreed to between the Supply Authorities and the Railway should be made out for each sub-station as well as traction sub-station owned by the Railway and should be issued to TPC as well as operators at grid stations. These instructions should contain the following details:

- a) Procedure for carrying out switching operations at the sub-station.
- b) Procedure for interchange of message of pre-planned or emergency shut-downs.

- c) Procedure to be followed in case of failure of supply and information to be conveyed by grid sub-station operator regarding duration of failure and anticipated time of restoration to enable emergency works to be introduced.
- d) Records to be maintained by grid sub-station operators and TPC regarding emergency feed arrangements.
- e) List of office and residential telephone numbers of important grid and railway officials to be contacted in an emergency.
- f) Mutual assistance to be rendered for transmission of important messages in the event of telephone failures at the grid sub-stations or RCC.

2.8 Statistical Data regarding Energy Consumptions

In the divisional office, a register should be maintained to record month-wise the following particulars in regards to energy consumption at each supply point :-

- a) Energy consumption (kWh)
- b) Maximum demand (kVA)
- c) Average power factor (kWh/kVAh)
- d) Monthly average load factor (percent)
- e) Payment for energy.
- f) Payment for maximum demand
- g) Payment towards meter rent
- h) Payment of fuel surcharge, if any
- i) Payment for P.F. surcharge/penal charge
- j) Payment of covering the minimum guarantee load, if any
- k) Other payment, if any
- l) Total amount of bill under all heads.
- m) Average total cost per kWh

A consolidated statement giving the above details for all supply points should be furnished by Sr. DEE(TrD) to CEE each month by a stipulated date. CEE will in turn furnish a monthly statement in the prescribed proforma to the Railway Board and Research Design and Organisation (RDSO)

3. SUB-STATIONS AND SWITCHING STATIONS

3.0 Introduction

1. **This chapter is divided into 4 sections as under**

Section I Organization. A broad set up of the organization and duties of Senior Section Engineer (Power Supply Installations) are covered.

Section II Operation of sub-stations: The important points relating to operation of transformers and protective devices are covered.

Section III Guiding Notes on Maintenance: The important points to be borne in mind in the maintenance of power supply equipments are covered.

Section IV A recommended schedule of maintenance for power supply equipments is given.

2. The following documents have been incorporated as Appendices to this volume and are available in ACTM Volume II Part II.

2.1 “Code of Practice for Earthing of Power Supply Installations for 25 kV ac, 50 Hz Single Phase Traction System” issued by RDSO.

2.2. “Guidelines for Relay Setting at Traction Substations and Switching Posts” issued by RDSO.

2.3. “Guidelines for Provision of Maintenance Depots, Tools and Plants and Transport Facilities”.

2.4. “List of Specifications and Drawings for Equipments and Materials for Railway Electric Traction” issued by RDSO.

3.1 ORGANISATION

3.1.1 Organizational Setup

The Divisional setup of senior subordinates working under Sr.DEE/DEE (TrD) has been arranged on two types of patterns:

- a) Territorial basis
- b) Functional basis

In the territorial setup one Subordinate is responsible for all the activities of maintenance and operation over a predetermined section of electrified territory or a sub-division. The functional setup envisages separate Subordinate to be incharge of each activity viz, sub-station, OHE, Workshop, PSI etc. in a division sub-division. Duties, however, have been specified here in relation to particular function. For territorial setup the S.S.E. incharge will perform his duties keeping all functions in view, the next in command viz, SE being the functional incharge of the specific activity.

Remote control system or protective relay testing being a specialized activity. S.S.E. (RC) and S.S.E. (Test Room) usually have a functional jurisdiction over the entire division, with Head Quarters at the Remote Control Centre and Divisional Repair Shop respectively. The S.S.E.s in territorial charge, should keep a constant liaison between themselves since these aspects will have an element of dual control.

3.1.2 Duties of Senior Section Engineer, Power Supply Installations

He is the senior supervisor working under the control of DEE/AEE (TrD) and directly responsible for the safe and efficient operation and maintenance of traction power supply installations including sub-stations (when owned by the railway), switching stations, booster transformers and auxiliary transformers in his jurisdiction. He shall be thoroughly conversant with all technical details of the equipment under his charge including their rating, trend of power demand as also correct methods of their operation and maintenance in particular, he shall

1. Supervise the maintenance of installations under his charge in accordance with the prescribed schedules to keep them fully serviceable at all times and in a state of good repair.
2. Maintain proper co-ordination with the traction power controller, Senior Section Engineer, (OHE) supply authorities and render assistance when required to ensure reliability of power supply.
3. Keep his organization in constant readiness to deal promptly with any break-downs and failures of equipment.
4. Ensure that the programme of testing and maintenance of protective relays is adhered to and ensure that other safety equipment including bonding and earthing are functioning effectively.
5. Instruct, train and supervise staff under his control and ensure that they do not operate and maintain the equipment properly and in particular do actually observe all rules and regulations and safety precautions laid down.
6. Depute staff for refresher courses as prescribed, particularly for such staff as are found deficient in their working.
7. Ensure that special instruments and tools provided for maintenance operation and testing of all installations are properly cared for.

8. Keep a close watch on availability of spare parts and other stores required for maintenance and operation of the installations and initiate timely action to recoup stocks.
9. Ensure proper accountal and periodical verification of stores and tools in his charge.
10. Depute staff when required to man sub-stations and switching stations in the event of failure of remote control equipment.
11. Inspect all installations under his charge at least once a month, with particular attention to safety aspects.
12. Submit prescribed periodical returns after careful scrutiny to AEE (TrD) and Sr. DEE/DEE (TrD).
13. Keep his superior officers fully informed of all important developments and seek their guidance when required.
14. Carry out such other duties as may be allotted by superior officers from time to time.
15. Carry out inspections as indicated at Annexure 3.01.

3.2 OPERATION OF SUB-STATIONS

3.2.1 Introduction

Since the electric traction system depends upon continuous availability of power supply, sub-stations and switching stations have to be kept proper working condition at all the time. To ensure this, the transmission lines, the 25 kV feeder lines and traction transformers with associated switch gear and control and relay panels are duplicated so that if one unit fails the standby unit can be brought into service to continue power supply. All switching operations are also centralized and controlled by remote operation by a single authority namely Traction Power Controller.

3.2.2 Inspection Book and Log Book at Sub-stations.

An "Inspection Book" shall be maintained at every sub-station in which observations mad by supervisory officials visiting the sub-station for periodical inspections shall be recorded. In addition as log book should also be maintained to keep a record of the traction transformer oil temperature, ambient temperature as well as the currents and voltages as indicated on the control panel at a fixed time every morning. If there is any thing abnormal or unusual, S.S.E.(PSI) will investigate the cause thoroughly and take necessary remedial action.

3.2.3 Over load Capacity of Traction Transformers.

Traction transformers usually have the following overload capacity

1. Overload rating: (a) 50% overload for 15 min and (b) 100% overload for a period of 5 min, after the transformer has attained steady temperature on continuous operation at full load.
2. Over an ambient temperature of 45°C the maximum permissible temperature rise shall be as under:
 - (a) Winding = 50°C (by resistance method)
 - (b) Oil = 40°C (by thermometer)
 - (c) Current carrying parts = 35°C (by thermometer)
3. The hot-spot temperature after 50% overload for 15 min or 100% overload for 5 min shall not exceed 100°C for an ambient temperature of 45°C.
4. Interval of time permissible between two successive overloads (after continuous working at maximum ambient temperature of 45°C) is 3 hours for both 50% overload for 15 min and 100% overload for 5 min.

3.2.4 Tap Setting on Traction Transformers

Traction transformers are usually provided with off-load changers (operated locally or by remote control with taps from + 10% to (-) 15% in steps of 5%. To decide the correct tap setting a recording voltmeter should be connected at the traction sub-station to the secondary side of a potential transformer to ascertain the pattern of voltage variation throughout the 24 hours for at least 3 typical days. Based on the readings from the recording the tap position should be fixed so that the daily OHE voltage peaks at the traction sub-station lie just below 27.5 kV but does not touch 27.5 kV. This will ensure that the OHE voltage is well above the minimum of 19 kV at the farthest point on the system even when heavily loaded. Once a year 24-hour record of voltages available on the two sides of every neutral section should be taken to make sure that the voltage does not fall below 19 kV at any time.

Since any change in the inter-connections of the grid system would have repercussions on the voltage at the traction sub-station, the S.S.E.(PSI) should keep in touch with the supply authorities in regard to system changes so that he may arrange to take another set of 24-hour voltage readings if any change has taken place and to change the tap setting if required.

3.2.5 Tests in Transformer Oil

In order to improve the performance and to prolong the life of the transformers. EHV grade oil is used. The following two specifications, the first one for new oil and the second for oil in service are adopted

- (a) IS-335 Specification for New Insulating Oils.
- (b) IS-1866 Code of Practice for Maintenance and Supervision of Insulating Oil in Service.

A summary of tests for various characteristics, the requirements to be complied with and methods of tests as contained in the two specifications is at Annexure 3.03(A&B). The tests are wide ranging should be done once a year. However, some of the tests like Breakdown voltage (BDV) test, acidity tests, crackle test for moisture, may be carried out in PSI depots or sub-stations once in six months when samples are drawn for condition monitoring as per Para 20216 of ACTM. Procedures for these tests are indicated in IS-1866.

3.2.6 Purification of Transformer Oil

The object of oil purification is to remove all contaminants such as water, carbon deposits, dirt, sludge, dissolved moisture and gases. The most important quality to be preserved is the di-electric strength, which is affected by the presence of moisture.

The insulating materials used in the winding are hygroscopic by nature and therefore moisture is absorbed through defective breathers, gaskets and addition of untreated make-up oil. It is essential to remove these impurities by purifying the oil when the di-electric strength goes below the permissible limits.

3.2.7 Oil Purification Plant

For purifying the transformer oil, machines conforming to RDSO's Specification may be used. These are normally operated from 240 V single phase supply taken from the 100 kVA Station transformer provided at the sub-station. Supervisory officials in charge of maintenance of transformers should make themselves familiar with the supplier's instructions in regards to the operation and maintenance of the oil purifying equipment.

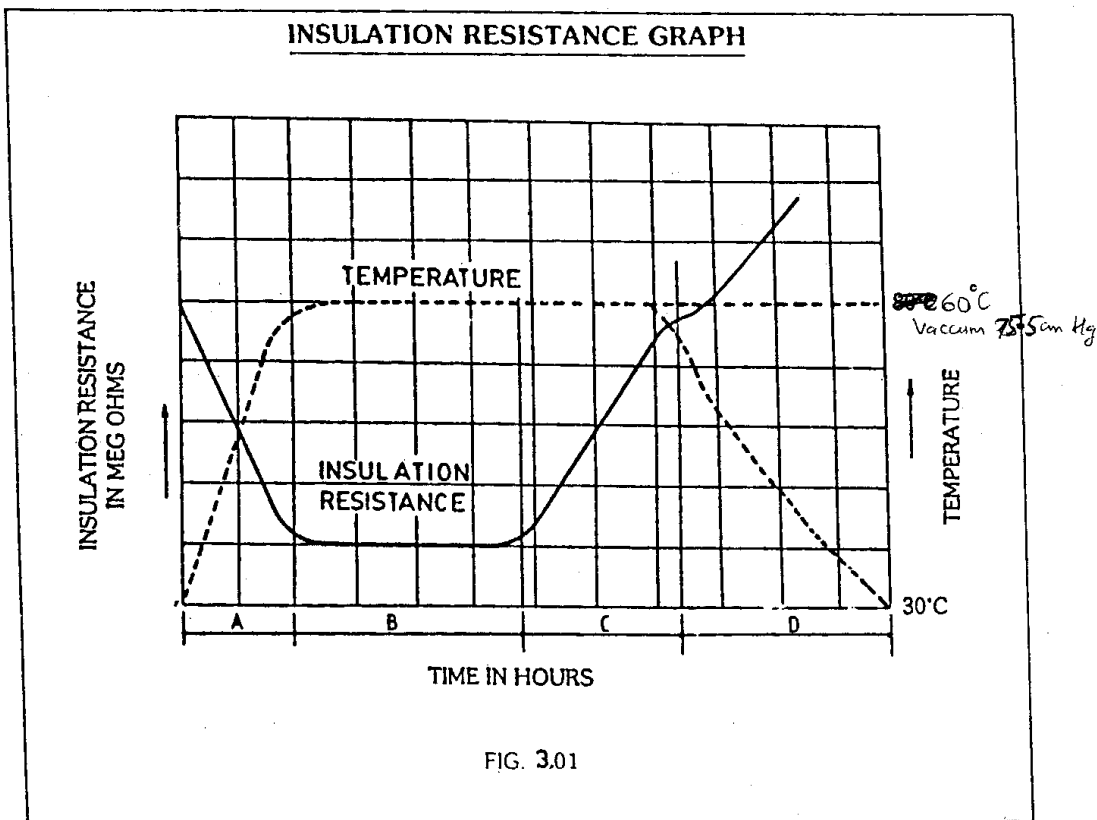
3.2.8 Insulation Resistance During Drying Out

Readings of temperature and insulation resistance should be recorded every two hours, from commencement until the full operation is completed. If the readings are plotted on graph, the appearance will be as shown in Fig. 3.01

It will be observed that there are four distinct stages:

- A. Initially the insulation resistance drops down to a low value because of rise in temperature of the oil upto about 75°C.

- B. Insulation resistance will continue to remain at a low level despite temperature being maintained at a high level until most of the moisture from the windings and oil has been driven out.
- C. The insulation resistance will thereafter rise gradually and level off, indicating that all moisture has been driven out and the drying out operation has been completed. At this point oil circulation should be discontinued.
- D. As the oil cools off, the insulation resistance will rise above the leveling off point at the end of stage (C). This is because the insulation resistance value doubles for a fall in temperature of about 10°C to 15°C.



3.2.9 Protective Devices

A number of protective devices are provided to ensure safe operation of traction transformers and other equipment (under normal and extended feed condition with appropriate adjustment of settings). Alarm and trip circuit operations are tele-signalled and indicated at the RCC. The TPC shall in every such case advise S.S.E., so that he could arrange for the inspection of the sub-station to investigate the cause and take necessary corrective action and submit a detailed report to Sr. DEE/DEE(TrD).

3.2.10. Operation of Temperature Alarm or Trip

Alarm and trip contacts are provided to operate should the temperature of transformer windings or transformer oil exceed pre-set limits. If alarm or the trip contacts have operated, both of which are indicated at the RCC, S.S.E. should personally inspect the installation. If the dial settings are correct, the reason for excessive temperature rise should be investigated. Normally instantaneous overloads of load 150% of full load are taken care of by overload relays, while sustained overload below 150% are cleared by thermal protection. It is advisable to connect a recording ammeter and get a 24 hour chart showing the current loading of the transformer in services. The shape of the load curve would give valuable clues as to corrective action to be taken.

If the alarm and trip circuits operate frequently during peak periods, attempt should be made with Operating Department to space out the trains more uniformly throughout the day so as to reduce the peak load. If, on the other hand, it is a suburban section and the peak load cannot obviously be brought down, the second standby transformer may have to be present into service for the duration of the peak load. Such parallel operation of traction transformers may sometimes also incidentally result in reduction of the total losses thereby effecting economy. Secondly, it will also result in higher OHE voltage, since traction transformer impedance is now halved as the transformers are identical.

If a sub-station is persistently overloaded and an adjacent sub-station is appreciably underloaded, the possibility of shifting the neutral section may be considered.

3.2.11. Operation of Differential Protection

Apart from operation on account of internal faults in the transformer, the differential relay could also operate either because of current inrush on account of magnetization of the core at the time of switching on or because of spill current caused by lack of perfect balance between secondaries of EHV and 25 kV current transformers. The causes for such mal-operation may be defective harmonic restraint filters or wrong CT ratios and should be eliminated.

3.2.12. Buchholz Relay

The Buchholz relay assembly is provided on transformers to detect evolution of gas caused due to internal faults. After first commissioning, the upper assembly of the relay may sometimes be found to operate causing the relay to trip. Analysis of the composition of gas collected will indicate the nature of fault. If it is mere air bubbles the transformer is sound. For details of tests manufacturers write up may be referred to. It is always a wise policy to get the dielectric strength of the oil tested, measure the insulation resistance and carry out ration test.

3.3. GUIDING NOTES ON MAINTENANCE

3.3.1. Introduction

1. For better utilization of traction assets, outage of any traction equipment from service should be minimum without compromising on safety of the equipment and personnel. Monitoring of condition of the equipment by reliable means is essential for following system of need based maintenance. However, till such time reliable condition monitoring techniques are introduced, the present system of preventive maintenance has to continue.
2. Recommendations of Original Equipment Manufacturer (OEM) and guidelines issued by RDSO, from time to time, shall be kept in view while defining the scope and periodicity of the schedules.
3. The tightening torque for fasteners of various sizes is given in Annexure 3.08.

3.3.2. Transformers

3.3.2.1. Condition Monitoring

In oil filled equipment like transformers, normal deterioration or ageing of insulators is caused by thermo-chemical reaction with participation of heat, moisture and oxygen. This results in formation of insoluble products which accumulate and deteriorate the properties of oil and cellulosic insulation. Whereas the oil can be reconditioned to restore functional properties, no such treatment is possible for the cellulosic insulation, which suffers from reduction of mechanical and di-electric strength. The condition of the insulation, therefore, needs to be checked by suitable method.

The thermal and electrical stresses caused during short circuits, overloads and over voltages in the system result in gas formation in appreciable amount and deterioration of di-electric properties and lowering of flash point of oil from 145°C to somewhere between 50°C to 80°C in extreme cases. In the case of incipient faults, the gases being soluble, are absorbed in oil. The Buchholz relay cannot respond during early stages of trouble and by the time these devices operate the damage is done.

Dissolved gas analysis (DGA) provides an important means in the art of condition monitoring of power transformers and other oil filled equipment. Of the various methods of gas analysis. Gas Chromatography (GC) is one of the most efficient and rapid method, eminently suited for detection of incipient faults and for monitoring of growing faults which are not always revealed by established routine tests etc. in order to timely detect the deterioration of insulation, oil sample shall be drawn annually and subjected to gas chromatography.

Guidelines for condition monitoring of traction transformers by Dissolved Gas Analysis technique are appended at Annexure 3.04

3.3.2.2. Overhaul Of Transformers

- a) Overhaul of a transformer is normally undertaken either if it is faulty or at the end of 7-10 years by way of periodic maintenance. This can be done in the Central Repair Shop which is a covered shop having full facilities including a core lifting bayu with a crane. Before commencing the work ensure that spare gaskets of proper quality are available. Drain out the oil, disconnect all leads, remove manhole covers where required. The EHV and 25kV bushings are then carefully removed out and stored well protected in a safe place. Then remove the core by means of the lifting hooks and place on shop floor over a trestle in a large receptacle into which oil can drain out.
- b) If the transformer has been opened up because of any internal fault, make a careful note of colour of transformer oil, arc-marks, carbon deposits, charring of insulation, condition of the windings, unusual odour and other abnormalities which would all help in ascertaining the cause of the failure. If a coil has been burnt out, the whole transformer will have to be completely dismantled and then the damaged coil replaced with a new coil. In the case of the traction transformers, the replacement of the damaged coil is best done in the Manufacture's works where necessary facilities and staff with the requisite skills are available.
- c) Arrange for the interior of the transformer tank to be thoroughly cleaned of all accumulated debris, sludge, etc and wash with fresh oil. Remove the drain plug, lightly polish the valve seat and renew the oil-tight gasket round the spindle so that when assembled the plug is fully oil tight; the same remarks apply to the oil sampling valve, if provided. Opportunity should also be taken to plug or weld up any small blow holes through which oil seepage was observed earlier. Finally paint the exterior of the tank if necessary after thoroughly cleaning it up of all paint work, rust and traces of oil and dirt.
- d) If the coil assembly is lifted up after 5, 10 or more years of service, considerable amount of sludge formation would have occurred on all parts of the transformer, i.e. at the bottom of the tanks, metal work of the transformers, windings and inter-spaces between windings. All these should be scrapped off carefully with a wooden or fibre wedge without causing any damage to the windings. Traces of the sludge left over in inaccessible places are best removed by directing a thin jet of transformer oil under pressure using small oil purifier. At the same time the old surface contamination should be brushed and washed down, until; the clear surface of the winding is exposed.
- e) Care should be taken to protect the windings against ingress of moisture particularly during inclement weather. Care should also be taken by wiping off body sweat with a towel. The windings should also be kept warm by surrounding the open windings by a number of infra-red lamps or by other means.

- f) Fully push home the wedges between the coils and take up the slackness of end-plates by tightening up the bolts and locking them. These are provided on traction transformers to hold the windings tightly together to withstand the high mechanical forces generated at the time of short circuits. Shrinkage and settlement usually take place within the first six months of the commissioning of a transformer. The coils are also liable to suffer displacement due to short circuit forces. If the coils are not held tightly in position, it will lead to repeated movement of the coils as well as layers and turns which will in turn cause abrasion and wear of insulation and ultimately failure. It is, therefore, sometimes recommended that the first available opportunity should be taken to have the wedges fully home and tighten up the pressure screws where they are provided.
- g) Finally put back the core assembly inside the tank, assemble the brushing check tightness of all internal connections, fit the top, provide new gaskets, fill oil and dry out as detailed in para 3.2.6 to 3.2.8. Experience has shown that tools like spanners are foreign objects like washers, pieces of cloth, etc are sometimes inadvertently left behind in the transformer, which present hazard of short circuits. It is, therefore, important that all tools, etc used in the overhaul work should be listed out at the beginning and accounted for at the end of the work.

When overhauled transformers are to be commissioned the same procedure as detailed for new transformer should be followed.

Each railway should plan, taking into consideration the resources available with to carry out the POH and repairs of the transformer and decide the agency to execute the work.

3.3.2.3. Investigation into causes of Failures of Transformers

In most cases the causes of the fault can be summarised by careful observation of the condition of the windings. e.g. displacement of the turns or coils, coil insulation (brittle or healthy), evidence of overheating, carbon deposit or flashing marks on the core, supports, the inner surface of the tank or cover. The following notes may be of help in identifying the cause:-

- a) Failure due to lightning discharge or over voltages – this is characterized by break-down of the end turns close to the line terminal. There may be a break in the turns or end lead and also flash marks on the end coil and earthed parts close to it, but the rest of the coil will be found to be healthy.
- b) Sustained overloads – the windings in one or all phases would show signs of overheating and charring, the insulation would be very brittle and would have lost all its elasticity.

- c) Inter-turn short, inter-layer short, or inter-coils short – the same signs as for indicated for sustained over load would be noticed, but only on affected coils, the rest of the coils being intact. This is likely if the differential relay or the Buchholz relay has operated.
- d) Dead short-circuit – this can be identified by the unmistakable, lateral or axial displacement of the coils. The coils may be loose on the core, some turns on the outermost layer may have burst outwards and broken as if under tension. If, in addition to these signs, the windings are also completely charred it is conclusive evidence that the short circuit has continued for an appreciable period, not having been cleared quickly by the protective relays.
- e) If the upper chamber of the Buchholz relay alone has tripped, check the insulation of core bolts, by applying a voltage of 230 V to 1000 V between the core and each bolt. If it fails, renew the insulating bush. Observe also all the joints, and tap-changer contacts, for over-heating and arcing.
- f) If the oil shows a low BDV, it does not necessarily mean that it has caused the breakdown. At high voltage ratings, excessive moisture content in the oil may result an internal flashover between the live parts and earth, which will leave corresponding tell-tale marks.

3.3.3. Circuit Breakers and Interrupters

The following types of circuit breakers and interrupters are now in use:

Circuit Breakers

- a) 220/132/110/66 kV, Double pole: -- SF₆ type
- b) 25 kV Single Pole -- SF₆ type
-- Vacuum type
- c) Interrupters -- SF₆
-- Vacuum type

Oil type circuit breakers/interrupters were used in earlier projects and require considerable attention for maintaining satisfactory condition of the oil. In case of minimum oil type equipments frequent replacement of oil is necessary on account of service conditions. To overcome these limitations, SF₆ type circuit breakers and interrupters are now standardized.

Manufacturer's detailed instructions may be referred to for installation commissioning, operation and maintenance for all types of breakers/interrupters. RDSO's additional instructions on maintenance and modifications to the circuit

breakers/interrupters should also be followed. Some tips for the maintenance of circuit breakers and interrupters, in general, are given in the succeeding paragraphs

3.3.4. Guidelines for Maintenance of Circuit Breakers and Interrupters

3.3.4.1 SF₆ Circuit Breakers

1. Gas System

the SF₆, gas in a pure state is inert, exhibits exceptional thermal stability and has excellent arc quenching properties as well as exceptional high insulating properties. Physical properties of SF₆, gases are indicated in the Annexure 3.05. There is very little decomposition of the gases after a long periods of arcing. Such decomposition has virtually no effect upon dielectric strength and interrupting capability. The solid arc product formed by arcing is metallic fluoride which appears in the form of a fine grey powder which has high dielectric strength under dry conditions as existing in the breaker. A good quality absorbent is used in the apparatus to remove decomposed gaseous by-product. During the maintenance record gas pressure and temperature. Supply the gas if pressure is less than the prescribed value. Check setting of gas pressure switches.

2. Interrupting Unit

Clean the surface of the porcelain and other parts. Contacts should be inspected and replaced if necessary. Renew the absorbent taking care that exposure of the absorbent to the atmosphere is minimal. The breaker should be evacuated as soon as possible.

3. Operating Mechanism

Check stroke from enclosed position to completely opened position and over stroke from completely opened position to stopped position. Check prescribed clearances. Relubricate moving parts. Check that pressure gauge is working correctly. Check pneumatic system for leakage.

The housing should be checked for water penetration and rust. Ensure that fasteners are not loosened. Check connections of control circuit wires for tightness.

3.3.4.2 Vacuum Circuit Breaker

Guidelines as indicated above in case of the other types of circuit breakers in respect of operating mechanism and its housing and other components are generally applicable in case of vacuum circuit breakers also except the interrupting chamber and pneumatic circuit. As regards interrupting chamber (vacuum bottle) no maintenance as such is required to be carried out.

3.3.5 Lead Acid Batteries

A battery is considered to be very vital equipment in the power supply installations and therefore its proper maintenance is imperative.

On electrified sections batteries and battery chargers are installed at the following locations:-

1. Traction Sub-stations –
110V, 200Ah lead acid cells for control, protection and indication circuits.
2. Switching Stations –
110V or 72V, 40Ah lead acid batteries for operation of circuit breakers and interrupters and motor-operated isolators.
3. Remote Control Equipment –
Batteries of suitable voltage and capacity are provided at remote control centre, traction sub-station and switching stations.

To reduce number of batteries at TSS/SS the remote control equipment is now being connected to the battery of TSS/SS.

In all cases mains operated battery chargers are provided with facilities for either trickle charge or boost charging. The rating of the battery charger should be related to the capacity of the battery.

3.3.6. Guidelines for maintenance of Batteries

3.3.6.1. As the entire system of protection at a sub-station depends upon a sound battery it should always be in proper condition. It should under no circumstances be disconnected when the sub-station is in operation

Batteries should be maintained keeping in view instructions of the manufacturer by a trained staff. The points to be observed during the inspections are summarized below

- a. General condition of the battery room and cells.
- b. Specific gravity of electrolyte in the cells.
- c. Charging current.
- d. Cell voltage.
- e. Condition of the plates and extent of deposits.
- f. Inter-cell connectors and main battery terminals

A detail history of every battery should be separately maintained in which all relevant information is periodically entered. Fortnightly specific gravity readings should be taken and recorded in appropriate forms.

Smoking or the use of open flames or tools which may generate sparks is strictly forbidden in the battery room. The battery room should be well ventilated and dust free and should have acid proofing done on the walls and flooring. It should be kept isolated from other electrical. Appropriate fuse protection for short circuit in the wiring between the battery and distribution switch board should be provided.

3.3.6.2 Specific Gravity

The specific gravity of the electrolyte should be maintained at about 1.210 at 27°C and when it drops to 1.150 the cells may be considered discharged. These values vary with the type of battery, temperature, age and working conditions.

Specific gravity is related to electrolyte temperature. For the purpose of test requirements, the fully charged specific gravity shall be 1.20 ± 0.005 corrected to 27°C. temperature correction hydrometer readings of specific gravity shall be made as follows (Ref. IS 1652):

- a) For each 1°C above 27°C, add 0.0007 to the observed reading and
- b) For 1°C below 27°C deduct 0.0007 from the observed reading.

When the battery is first commissioned the specific gravity of the all cells would be almost equal. Subsequently during periodical inspections, variations in specific gravity may be observed due to unequal rate of evaporation. This should be corrected by adding distilled water. In no circumstances should concentrated or diluted sulphuric acid be added to any cell except when acid is known to have spilled out. Distilled water alone should be used for topping up the level.

Hydrometer readings taken when a cell is gassing freely gives the specific gravity of a mixture of gas bubbles and electrolyte and not the specific gravity of the electrolyte. The readings should therefore be taken after allowing all bubbles to subside. Hydrometers of repeated make should only be used. Hydrometers of 300 mm length are necessary to give required accuracy. Two hydrometers should always be maintained in a station and they should be periodically checked to see that they read alike.

3.3.6.3 Pilot Cells

One of the cells in each row of the battery set should be selected and kept as the pilot cell. Readings should be taken on these cells with sufficient frequency to indicate its state of discharge and charge and serve as a guide to the condition of the other cells. The pilot cell which when once selected should not be changed unless the cell has to undergo special treatment or repairs in which case a note should be made immediately on record sheets. The height of the electrolyte in the pilot cell should invariably be kept at a fixed point (say 12 mm) above the top of plates by adding distilled water every fortnight, if necessary.

3.3.6.4. Trickle Charging

Lead acid batteries are very sensitive to overcharging as well over-discharging. If over charged, the positive plates will shed their active material quickly. If kept in discharged condition for long, the plates will suffer sulphation evidenced by appearance of whitish deposits on the plates. Prolonged charging at a very low rate after emptying the electrolyte and filling the cell with distilled water is sometimes useful if the sulphation is very light. However, there should be no occasion at all for any battery set in stationery traction installations to be sulphated, as a battery charger so that the terminal voltage of each cell is maintained close to 2.15V.

This can be achieved if the battery is kept on a very low rate of charge, say milli ampere per Ah capacity of the battery. The exact rate of charge should be fixed having regard to the normal and intermittent rates of discharge over a period of 24 hours so that the battery is always kept in fully charged condition and never overcharged or over-discharged.

When a battery is being properly float-charged very small gas bubbles (about the size of a pin head) rise slowly from the plate to the surface of the electrolyte. In batteries, that are being overcharged the bubbles are much larger and reach the surface at a higher rate.

3.3.6.5. Cell Voltage

The voltage of cell at the end of a charge is not a fixed value but will depending on the age of the battery, the temperature, specific gravity of the electrolyte and charging rate. The voltage of new cells at the end of a full charge will be about 2.5 to 2.75 V when it is receiving charge at the 10 hour rate. This gradually decreases as the age of the battery increases until it comes down to 2.4 V with normal temperature and charging rate.

No cell should ever be discharged below the point where the cell voltage reaches 1.85 V as measured when the cell is discharging at the normal 10 hour rate.

It should be noted that the voltage of a cell gives an approximate indication of its state of charge (or discharge) only when it is being discharged, say at the 10 hours rate, and not when the cell is an open circuit.

Sulphated plates, lug corrosion, partial circuit due to cracked separators and other defects of a lead-acid cell cause a noticeable drop in the terminal voltage with current flowing in the cell. This drop varies with the amount of current flowing and in order to get voltages that can be compared from month to month, the voltages should be taken with the same current flowing in the cell. The cell testing voltmeters in use should be periodically checked and recalibrated, if necessary, when not in use they should be kept in a safe place.

3.3.6.6. Condition of plates and Deposits

The active material in the positive plates in healthy cells in use for more than 12 months (when fully charged) should be chocolate in colour and negative plates

light or bluish grey according to age the chief indications of weak cells are badly coloured plates, irregularity in gassing or entire failure to gas and a fall in voltage and specific gravity below that of other cells.

In new batteries, flakes of brown scale will be seen getting detached from edge of positive plates. This information of scale is normal. Until all this scale is dispersed, the plate cannot be considered as stabilized. Sometimes pieces of this scale may lodge across adjacent negative plates and cause a partial short circuit. Such flaked pieces should be gently dislodged with a thin piece of wool and allowed to fall to the bottom of the cell. This scaling occurs only on the edges of the plates. The removal of the scales should be done very carefully so that the plates are not damaged.

Examine carefully the physical condition of the plates such as cracks, distortions, accumulation of whitish deposits etc.

The colour of the deposits gives a good indication of the state of health of the cells. Whitish deposits indicate undercharging leading to discharged condition. In healthy cells, the deposit is brown in colour but excessive shedding of active material from the positive plates indicates overcharging of the battery. If this is noticed, reduce the rate of charge immediately. If all the cells in a battery show whitish deposits immediate action should be taken to give boost charge at an appropriate rate and then to increase the trickle charging rate sufficiently to keep the battery in a healthy condition all the time. Weak cells should be immediately examined for any possible short circuit or metallic contact between positive and negative plates. The short circuit should be removed and the cell should then be given special additional charging by cutting it out and putting it back again when a healthy condition is regained, after it is attended to.

3.3.6.7. Inter-cell Connectors

The inter-cell connectors of the battery should be examined to ensure that they are clean and tight, making perfect contact with cell lugs and that no corrosion is taking place. Light Vaseline should be applied to prevent corrosion.

Inspection of copper inter-row connectors should be made for any signs of copper sulphate corrosion which should be cleaned up. Acid-proof paint or enamel should be applied to all exposed copper work in the battery room and any flaking of paint work given prompt attention.

3.3.7. Protective Relays

1. Each electrified division shall have specialist staff attached to the Central Repair Shop trained in the maintenance, overhauling, testing adjustment and calibration of protective relays as well as indicating, integrating and recording instruments. Such specialist staff should hold competency certificate No TR-7 as explained in Chapter XII.

2. The Central Repair Shop should be fully equipped with necessary apparatus, instruments, tools and equipment for overhauling, testing and calibration of relays.
3. Each Supervisor responsible for maintenance and testing of protective relays should maintain a register in which full details regarding each relay should be entered. The details to be recordable are-the type and serial number, PT and CT ratios, range of settings available, characteristics curves (where applicable), location where installed, schematic diagram of connections, normal setting \s and details of calculations for fixing the normal setting. Details of tests as well as repairs carried out should be entered in this register from time to time. These particulars should also be maintained in the office of Sr. DEE(TrD).
4. No alterations in the settings of protective relays should be carried out without the written authorization of Sr. DEE (TrD), who will submit proposals including detailed calculations for changes required, if any, for prior approval of CEE. Guidelines for setting of relays are given in the Chapter 5.
5. The procedure for commissioning of protective relays has been given in Chapter 5
6. The normal maintenance attention required for relays in service is generally as under
 - (a) It is essential to ensure that the cover gaskets are in good condition and the fixing screw quite tight so that the instrument is dust-tight.
 - (b) Manual operation to confirm that the relays do operate the trip circuits in the manner prescribed. These tests should be carried out by at least at the level of AEE once in a year for all relays. Simultaneously visual checks on relay connection, condition of the trip battery, trip and alarm circuits, and also the should be maintained showing the date time this is done.

On each occasion when the seal is broken subsequently the reasons should be recorded in the log book.
 - (c) Distance protection relay may be tested for calibration once in a year with primary injection set.
 - (d) Secondary injection tests: These should be done annually preferably before onset of busy season, making use of portable testing equipment and at the settings approved by the competent authority. Apart from testing the operation at the normal setting test should also be carried out at other settings to make sure that the relay has the required characteristic.

- (e) Overhaul, bench tests and calibration: these are necessary once in ten years or when a relay is not found functioning correctly. This work should invariably be carried out only in the Central Repair Shop by tightly skilled technicians fully conversant with all details of construction and adjustment.

The bench tests and final calibration should be carried out after overhaul of the moving parts and measurement of coil resistance and other data. Transport of the relays to and from the Central Repair Shop also requires utmost care including locking of the moving parts, and careful packing and handling. When laboratory tests are fully satisfactory, the relays should be sealed and date of overhaul painted on the outer cover of the relay.

3.3.8 Guidelines for Maintenance of Switching Stations

The maintenance required for equipment in switching stations is more or less similar to that for traction sub-station equipment, except that traction transformers, circuit breakers and current transformers are not present and area is much smaller. However, the only additional but important item which requires attention is condition of the return feeder connection to all the rails (at the feeding posts). These return feeder connections are liable to be damaged by Permanent Way gangs in their normal work of packing and maintaining the permanent way. Supervisory officials, therefore, should stress the importance of these from the electrical point of view to the PWIs so that they in turn may warn their maintenance gangs not to damage the connections. In addition, the supervisory officials shall, during their periodical inspections, make it a point to inspect the return feeder rail connections and ensure that they are in excellent condition.

3.4. MAINTENANCE SCHEDULES

3.4.1. Schedules of Inspection

1. in order to achieve high reliability and ZERO DEFECT, and to ensure effective checks on the maintenance work minimum schedules of inspections to be carried out each month by the TrD officers and Senior Subordinates in charge of operation and maintenance of PSI equipments, are indicated at Annexure 2.01.

The schedule of inspections as indicated is the minimum quota to each official per month and should be independent of other tasks. They will not be of routine nature but shall be carried out in depth to identify:

- i) Deficiencies and short comings.
- II) Lack of skill amongst staff.
- III) Inadequate in maintenance facilities.
- IV) Constraints experienced.
- V) Conditions of environment which lead to poor quality of work if any.

2. The inspecting officials should adjust their inspections in such a manner as to cover all of the installations in their jurisdiction within the stipulated periods and stagger the inspections among themselves to avoid over inspection of the some installations repeatedly in a very short time and neglect of other installations. A check list in brief for various inspection is given in the Annexure 3.2
3. The items of attention listed here under at any particular periodicity are over and above those mentioned in the previous schedule. This should be kept in view while carrying out maintenance work.
4. The periodicity of the items of attention listed in the following paragraphs may be modified to suit local requirements with the approval of CEE
5. As regards new equipments, if schedules have not been drawn up tentative schedules may be evolved based on the original Equipment Manufacturer's guidelines and RDSO's recommendations, keeping in view the local conditions also and followed with the approval of CEE.
6. Schedules for maintenance of SF₆ type circuit breakers as recommended by one of the manufacturers are indicated in the Annexure 3.06 Schedules for maintenance of vacuum circuit breaker as recommended by one of the manufacturers are indicted in the Annexure 3.07. Schedules as indicted in the following paragraphs are for SF₆ circuit breakers.

3.4.2 General

1. No work of any kind shall be commenced on or in the vicinity of live equipment unless power supply to the particular part has been switched off and all other prescribed safety measures taken.
2. To guard against the possibility of unauthorized interference and pilferage from unattended sub-stations and switching station, all electrical department staff shall be vigilant and watch for any such activity when they are in the vicinity. Surprise checks coupled with periodical inspections will also act as deterrents
3. The TPC shall once a day check up communication to each of the grid sub-stations and obtain the maximum demand and energy consumption for the previous 24 hours and enter the figures in a register. Whenever inspection staff visit the sub-station or switching station, they shall contact the TPC on the telephone.

3.5. FORTNIGHTLY MAINTENANCE

3.5.1. General Inspection by a PSI Supervisor

1. Go round the whole area of the sub-station. Inspect for general cleanliness proper drainage, road and rail access. The surface of the roadway and pathways in the sub-station should be firm and sufficiently elevated to prevent water-logging. Remove any undergrowth of vegetation around the outer periphery. cut any tree braches likely to come in the vicinity of live lines.
2. If lubricating or transformer oil is stored, inspect for security and fire risk and see that no combustible material is in the vicinity.
3. Examine all “Caution” “Danger” “Shock Treatment” and other boards, whether they are clean and well secured. Inspect fire extinguishers, fire buckets and First Aid Boxes. If they are intact and serviceable.
4. Inspect structure and plant foundations for any sinking or cracking. Go round the structural work for checking tightness of various bolts and nuts.
5. Inspect all indication lamps on control panels for correct working.
6. Carry out inspections as indicated at Annexure 3.01

3.5.2. Battery

1. Check all cells generally in accordance with para 3.3.6
2. Take specific gravity and cell voltage of pilot cell and record in register. If any significant change is noticed specific gravity and voltage for all cells should be taken to identify any weak cells. Then top up with distilled water exactly to the correct level for every cell
3. Check operation of battery charger and note charging rate in register.

3.6 MONTHLY MAINTENANCE

3.6.1. Bonding and Earthing

Visually inspect all earth connections and see that they are in order and that every equipment has duplicate earths. Tighten connecting bolts and nuts as necessary. Where the sub-station and feeding post are close by ensure that sub-station structures are properly boned with the feeding post and the track by two independent connections.

3.6.2. Oil Level in Transformers, Circuit Breakers, CTs etc.

Check oil level in sight gauge glass and examine all joints, valves, plugs etc. for oil leakage in each equipment rectify leaky parts if found and restore the oil level.

3.6.3. Insulators

Clean all insulators with dry cloth and look for any flashover marks, cracks, chippings. Insulators which are badly chipped should be replaced. Minor chippings can be rendered impervious to moisture by a light coating of Araldite or similar epoxy resin.

3.6.4 Traction Transformers

1. Clean externally the tank, conservator, radiator, bushings, oil level indicator, gauges, etc. with dry cloth.
2. Make a note in the Register of the maximum temperature of transformer oil on dial indicator, reset indicator.
3. Check explosion vent diaphragm for any damage and presence of oil.
4. Check silica-gel breather. If turning pink in appearance, replace it with dry gel (blue colour) and recondition the old silica-gel. If the silica-gel is too wet, check dielectric strength of transformer oil.
5. Check for gas collection, if any. In Buchholz relay
6. Check for oil leakage on transformer body, conservator tank, oil drain valve and foundations. If leaking, take corrective action by tightening the bolts, replace gaskets, if necessary.
7. Check if heater in the marshalling box is functioning properly, and if all terminal connections are in order.

3.6.5. Operating Mechanism of Circuit Breakers and Interrupters

1. Open the cover of control box Examine the interior and remove the accumulated dust. If any part of the interior is badly rusted indicating entry of moisture, find out the cause, plug the holes and repaint the rusted part. Check in particular if the weather-proof gaskets are in good condition; if not, replace them to make the control box water-tight and dust-tight. Examine if the leading in pipe connections are properly bushed, sealed and water tight. Check if all pins and checkouts are in place. Check also tie-rod nuts for tightness.
2. Operate the mechanism at least twice manually. Have it operated on remote control from RCC; keeping the control door open, observe whether the mechanism functions smoothly without any rubbing or

obstruction and also if the shock absorber functions properly when circuit breaker is tripped.

3. Examine the commutator of the motor and clean with muslin cloth. Examine carbon brushes and replace if necessary.
4. Check breather and breather holes for clogging.
5. Check gear-oil level in the mechanism and replenish it, if required.
6. Check if heater is functioning properly.
7. Check interlocks of the equipment and associated isolators.
8. Check local position indicator and remote semaphore indicator for operation. Observe for the correct operation of recording counter.

After complete checking, close the cover and test the breaker for operation under remote, local and manual control.

3.6.6. Isolators

1. Manually operate isolator several times and observe if it operates smoothly and correctly. Check interlock and integral lock, lubricate moving parts as necessary with appropriate lubricant.
2. If isolator is motor-operated, check commutator of motor and clean with dry mull cloth, and check carbon brushes for proper bedding and wear. Check if motor is working smoothly, clean limit-switch and auxiliary switch contacts and check tightness of wiring connections. Examine contactor box and signal box; clean thoroughly and lubricate all gears, shafts, bearings, contacts etc.

3.6.7. Busbars, Clamps and Connectors

Immediately after switching off the power supply and earthing the lines, feel by hand all connectors and clamps on busbars and equipment terminals which carry heavy currents to see if they are too hot. If any connection is too hot, it indicates poor contact. Open up the connector carefully clean the contact surfaces, touch up the high spots on the contact surfaces so that the mating surfaces bed well together; apply a very light coat of vaseline, refit and tighten up. Wherever applicable, replace bi-metallic strip.

3.6.8. Control and Relay Panels

1. Make a note of flag indications, if any, then reset.
2. Check if all indicating and recording instruments are working normally and the pointers are not sticky.

3. Note and record in the Register the range of voltage and current variations during a 15 minute period at the time of the day when inspection was carried out. Abnormal voltage or current should be noted for corrective action.
4. Clean the panels externally.

3.7 QUARTERLY MAINTENANCE

3.7.1 Batteries and Battery Chargers

1. Take specific gravity and cell voltage of every individual cell and enter In the register.
2. If the battery is not in a fully charged condition, boost charge should be given as required and trickle charging rate increased to the extent required. This should only be done by a supervisory official after investigating the causes for excessive discharge.
3. Make a general examination of battery charger. Check earth connection to the body.

3.7.2. PTs and CTs

These should be maintained generally on lines similar to that of traction transformers except for items which do not obviously apply. In addition, for PT check the fuse holders on the LV side to see if they are in order.

3.7.3. Booster Transformers

- a) Replace or recondition silica-gel breather, if necessary
- b) Check earthing connections from bottom of structure to the earth electrodes or to the rails. Check the availability of duplicate earth strip and its proper connection.
- c) Check all caution boards, name plates and anti-climbing devices for proper condition.
- d) Check foundation for any sinking or cracking; Check all structure bolts and nuts for proper condition.

Annual maintenance and periodical overhaul are to be carried out, generally as indicated for the traction transformers.

3.7.4. Auxiliary Transformers

1. Measure insulation resistance of transformer winding and record values alongwith temperature.

2. Test a sample of oil for BDV.
3. Check that the 25 kV fuse-holder drops out freely on raising the spring latch. Check rod gap setting. Measure earth resistance of neutral conductor.

Annual maintenance and periodical overhaul are to be carried out, generally as indicated for the traction transformers.

3.8. HALF YEARLY MAINTENANCE

3.8.1. General

SSE (PSI) should visit the grid sub-station and ascertain whether any significant change in the EHV grid network has occurred during the past six months or are expected shortly.

3.8.2. Traction Transformers

1. Test oil sample from tank bottom for crackle test, acidity and BDV. If BDV is below the prescribed value, oil should be dried out.
2. Check whether the rod gap settings on bushings of transformers are in order, as per Maker's drawings.
3. Measure and record insulation resistance of all windings to earth and other windings with a 2500V. Megger alongwith temperature of windings and ambient temperature.
4. Check all alarm and Hip devices for proper functioning

3.8.3 Isolators

1. Observe for any signs of overheating and check the wipe of contact blades. Clean blade tips and fixed-contact fingers and lightly Vaseline the contact making surfaces.
2. Clean all articulated Joints, sliding and bearing surfaces thoroughly.
3. Check all split pins, lock nuts and check nuts for proper condition.
4. Check for correct setting and alignment of arcing horns.
5. Operate the isolator slowly, check for simultaneous operation of the blades on the poles and correct alignment of blade tips in the fixed contact jaws of the poles. Adjust if required to ensure that the blades are fully home between the contacts when handle is in closed position.
6. Check locking arrangements.

3.8.4 Control and Relay Panels

1. Check tightness of all connections, remove cobwebs and wipe off accumulated dust with dry cloth.
2. Check if tap and time settings of the relays are in order.
3. Examine fuses for signs of overheating or aging, springiness and cleanliness of contact making parts. Clean up and lightly Vaseline to ensure proper contact. ,

3.9. YEARLY MAINTENANCE

3.9.1 General

1. Inspect the fence all-round the sub-station and bending between metal fencing panels and to earth. Put a drop of oil in the hinges of all doors. Repaint any of the structural parts as necessary.
2. Open all the trench cover and clean them completely. Clean all culverts and remove cobwebs: check possibility of lizards or other insects gaining entry into enclosed control equipment, and make them insect-proof.
3. Arrange for painting of walls and metal-works as necessary.
4. Check all explosion vent diaphragms for any damage.
5. Check rod gap setting.

3.9.2 Lightning Arresters

1. Check earthing terminals and earth strips for proper condition. Check connection to the line.
2. Where lightning arrestors are provided with discharge counters, record the counter reading.

3.9.3 Bonding and Earthing

1. Check physically the soundness of bonding and earthing connections to every electrical equipment structural steel, lightning arrester etc. and inter-panel connections.
2. Record earth resistance to body of electrical equipment as well as to all parts of the fencing and structural steel work.

3. Check if the terminations of the overhead shield wire covering the whole sub-station are In good physical condition and properly bonded electrically to the structures.
4. Check and record resistance of each group of earth electrodes, after disconnecting it from common earth system. Improve, K necessary.
5. Check condition of connections to the burried rails.

3.9.4 Traction Transformers

1. Send samples to approved laboratory for all tests listed at Annex. 3.03B (IS 1866) including dissolved gas analysis.
2. Check oil level in bushings.
3. Inspect bushing gaskets for leaks and tighten bolts.
4. Move the tap-setting switch up and down the full range a few times so that by self-wiping action good contact is assured. Set the tap finally at the correct position making sure that tap-indication corresponds to position of main contacts.
5. Paint transformer tank on such parts as required.

3.9.5 Isolators

1. Smoother burrs, If any on the blade tips and fixed contact fingers with fine emery paper and smear Vaseline.
2. Measure clearance of blade in open position and record and adjust crank mechanism, if found necessary.
3. Check the adjustable stop set-screws for proper condition and correct positioning.
4. If the Isolator is motor-operated, measure and record insulation resistance of motor windings and contactor coils using a 500 V megger.

3.9.6. Bus Bars and Connectors

Measure with a 'Ductor' or other low resistance measuring Instrument the contact resistances of all connections which are carrying heavy currents.

3.9.7 Control and Relay Panels

1. Carry out maintenance on relays as detailed in para 3.3.7
2. Check and dean up control switches and push-button contacts for burnt or corroded marks; polish the surfaces. Check also if the contact springs have the correct springiness.

3.9.8. Batteries and Battery Chargers

If the battery is not in a healthy condition or if there is excessive accumulation of sediment, the whole battery should be replaced with a new set.

Battery Charger

Open out the covers of the battery charge and blowout all dust. Check tightness of all connections, bolts, nuts and screws. Measure and record the insulation resistance of the transformer windings of the batten,' charger with 500 V megger.

3.9.9. PTs and CTs

1. Test oil samples if possible.
2. Check rod gap setting, if provided.
3. Measure insulation resistance.
4. Check conditions of fuses of PTs and terminal connections for CTs.

3.9.10. Special maintenance Schedule for SF6 Circuit Breakers and Interrupters

Before starring maintenance of any switchgears ensure that the instruction manual of the equipment issued by the manufacturer have been fully studied and full knowledge of the working of switchgears is available with the maintenance personnel. Otherwise there may be adverse effect on the performance of switchgears and it may also endanger the safety of working personnel.

The periodicity of maintenance is:

- i) Fortnightly
- ii) Quarterly
- iii) Annually
- iv) Three yearly
- v) Eight yearly
- vi) Ten yearly

Fortnightly Schedule:

- a) Drain water from reservoir.
- b) Measure and record the gas pressure, air pressure and temperature. Gas pressure should not be less than 4.5 kg/cm²
- c) Check the position of indicator for correct position.
- d) Check the foundation bolt for its looseness.

Quarterly Schedule:

During Quarterly maintenance, following items shall be attended/ Checked over and above the fortnightly inspection items:

- a) Checking and cleaning of porcelain insulator surfaces.
- b) Check tightness of terminal connector fasteners Specified torque should be applied by torque wrench only.
- c) Check tightness of pole fasteners specified torque should be applied by torque wrench only.
- d) Check proper earth connection for supporting structure and operating mechanism.
- e) Remove dust and clean all internal wiring and components. Check proper functioning of following :
 - i) Local /Remote switch,
 - ii) ON/OFF switch,
 - iii) Anti-pumping device for CB only
 - iv) Interlock.
 - v) Setting of gas pressure switches as per relevant graph of individual make of switchgear.
- f) Check functioning of Operation Counter and note down the number of operation .
- g) Ensure proper functioning of following :
 - i) ON/OFF indicator.
 - ii) Spring charging indicator.

- iii) Limit switch of spring charging motor.
- iv) Auxiliary switch.
- h) Check connection of space heater and its healthy operation.
- i) Check all L.T. wiring connections for looseness tighten them if required.
- j) Check visually for any abnormality inside the operating mechanism, k) Checking of trip circuit for its healthiness.
- k) Checking the terminal voltage for control and motor circuit. If not within permissible limit of variation, check batteries and battery charger for its health.

Items to be checked for Pneumatic Opening and Spring Closing Operating Mechanism :

- a) Setting of pressure switches as per instruction manual.
- b) Normal, Max, Minimum, trip and lock out pressures.
- c) Operation of valves as per instruction manual of the manufacturer.
- d) Operation of drain valves of the air reservoir.
- e) Air Leakage from piping valves etc.
- f) Oil level in the crankcase of the compressor replace if required.
- g) Suction filter of the compressor if required, clean it with compressed air.

Annual Schedule :

During Annual maintenance, following items shall be attended/ Checked over and above the Quarterly maintenance :

- a) Check water seepage from pole joints of housing and from the top cover of operating mechanism.
- b) Check the door gasket for their intactness.
- c) Check resistance of trip and closing coils. Compare the values with design values indicated by the manufacturer in manual.

- d) Measure the IR between auxiliary control and motor circuit The value shall be min. 2 Mega Ohm with 500 V megger.
- e) Measure the IR between open contacts and earth The min . value shall be 1,000 M Ohm with 2.5 kV. megger.
- f) Check the charging time of compressor from 0 to 15 kg/cm² for pneumatic operating mechanism It should be less than 35 minutes.
- g) Check the gap of closing and trip coil assembly as per instruction manual.
- h) Check the oil leakage from shock absorber. If leaking replaces the same,
- i) Check free movement of various latches in operating mechanism,
- j) Check compressor oil condition and its level Change the oil in case it has turned yellow.
- k) Check V - belt for its tension and soundness.

Three Yearly Schedule :

During Three Yearly maintenance, following items shall be attended/ Checked over and above the items covered in Annual and Quarterly Maintenance:

- a) Measure the mechanical travels as per instruction manual and adjust if required.
- b) Replace the door gasket of the operating mechanism with new one.
- c) Measure the value of contact resistance of pole between upper terminal and lower terminal If value is more than 120% of the design value specified in maintenance manual. Approach the manufacturer for rectification.
- d) Check the movement of 'C' & 'D' rollers for its free movement If not free change the same (for M/s. CGL make CB)

Eight Yearly Schedule :

The following items shall be checked /attended (without dismantling the C.B./ Interrupter) if circuit breaker has completed 08 years of service or 2000 electrical switching operations or 5000 mechanical co-operations. In case of interrupter, following items shall be attended if it has completed 08 years of service or 5000 Electrical / Mechanical co-operation. This schedule can be categorized for its two parts separately, i.e. operating mechanism system and interrupting pole unit.

Overhauling of the switchgear :

Overhauling of the switchgear shall be taken up when anyone of the following conditions are met:

- a) The circuit breaker has completed 10 years of service .
- b) Number of electrical switching operation exceeds 3000.
- c) Number of Mechanical operation exceeds 6000.
- d) Breaker has completed 20 full short circuit tripping operations .

Trained persons as per Instruction Manual issued by the manufacturer shall carry out Overhauling of the switchgear.

3.9.11 Pre-Monsoon Checks

Before onset of monsoon season, it should be ensured that for every equipment no scheduled maintenance work is overdue. In the scheduled inspection just preceding the monsoon, special attention should be paid to the inerable points likely to permit ingress of moisture resulting in reduction in dielectric strength of the equipments and rusting of parts.

3.9.12 Overhaul Schedule for Equipment

- | | | |
|----|--|--|
| 1. | Transformers | In case of an internal fault or once in 7-10 years. |
| 2. | Operating mechanism of Circuit Breaker and Interrupters. | Once in 10 years or as and when any major part like springs have to be replaced or the mechanism is sluggish, and needs shop attention and overhaul. |

TRACTION DISTRIBUTION

Annexure .3.01

SCHEDULE OF MONTHLY INSPECTIONS

Sl. No	Nature of Inspection	Sr.DEE	DEE	AEE	SSE	SE	JEE	
1.	Traction Sub-stations		1	1	2	4	4	4
2.	Switching Stations		1	2	3	4	4	4
3.	PSI Depots		1	2	4	-		-
4.	Grid Sub-stations		2 in a year	1	2	1	1	1
5.	Office Inspection		1		1		-	

Notes:

1. These inspections are the minimum quantum per month.
2. In respect of Supervisory Staff, the inspections pertain to their respective jurisdiction.
3. Check lists of items to be broadly covered are indicated at Annexure. 3.02 The maintenance schedules prescribed should also be kept in view.
4. Quota of-inspections by HQ officers may be laid down by CEE.

CHECK UST FOR INSPECTIONS

1.0 PSI depots including Subordinate Offices

a) *OHE/PSI Depots.*

Check

- | | |
|------------------------------|--|
| 1. Staff grievance register. | 6. Stock position in Stores. |
| 2. Quarter register. | 7, Compliance of audit & account inspection notes. |
| 3. Attendance Register | 8. Test & Trial report. |
| 4. Cleanliness of Depot | 9. Availability of latest drawings and specifications. |
| 5. Upkeep of Stores | 10. Planning and progress of section works. |

b) *Subordinate office,-*

Check

1. Attendance register.
2. Compliance of audit & account inspection notes.
3. Compliance of Officer's inspection notes.
4. Test & Trial report,
5. Availability of Drgs. & specification.
6. Progress & planning of section works.

2.0 Inspection of Grid Substation

1. Be on look out for any modifications made / being made in the power supply arrangement.
2. Check up if there is any equipment under breakdown which is likely to increase risk of interruption in power supply to traction.
3. Note down meter readings and scrutini2e and record important data regarding power supply parameters including daily MD, variation in voltage, frequency and power factor

3.0 Inspection of Traction Sub-station

a) *Switch yard –*

Check

1. For vegetation growth and spreading of pebbles.
2. Painting of fencing and equipments.
3. Condition of cable trenches & trench covers.
4. Condition of approach road.

b) *Power Transformer:*

Check

1. O.T.I. and W.T.I, temperature - present and maximum loadings.
2. Oil level in conservation tank
3. Tap changer position of standby & service transformer.
4. For abnormal humming
5. Colour of silica gel.
6. For leakage of oil on transformer body, conservator tank, oil drain valve and radiator.

c) *Circuit breaker & interrupters.*

Check

1. Control box gaskets for water & dust tightness.
2. Operation by local & remote control.
3. Operating mechanism for smooth operation.
4. Oil level & leakages.
5. Closing time of interrupter.
6. Number of trippings since last replacement of oil in case of circuit breaker and counter reading of interrupter.

d) PT, CT, AT.

check

1. Leakage of oil.

e) *Isolator:*

Check –

1. Locking arrangements. .
2. For correct alignment of blade tip in the fixed contact jaws.
3. For correct matching & alignment of arcing horns.

f) Control Panel:

Check

1. Fuses for the correct size, overheating or aging signs.
2. For loose connections at terminal Boards.
3. Functioning of Alarms & visual indication on control panel,
4. Functioning of auxiliary relays.

g) Battery Charger & Batteries:

Check

1. Acid level
2. presence of sedimentation
3. Specific gravity & voltage of pilot cell
4. Presence of sulphation and tightness of inter cell connectors.
5. Size of fuses of Battery charger.
6. Voltmeter and ammeter readings, Energy meter check 1. Recorded maximum demand.

h) Condition of the seal.

i) Earthing check

1. Soundness of earth connection to each electrical equipment and structure.
2. Last recorded earth resistance readings.
3. Buried rail connection,

j) Remote control equipment check

1. General function of relays & selectors.
2. Wiring for loose connection if any.
3. For presence of dust & condition of cubicle gaskets.

k) General

Check

1. Availability of fire buckets, Respiration chart, First Aid Box, Tools & Plants.
2. Working of TPC Phones & emergency sockets. .
3. Inspection Register and remarks made therein.
4. History sheets of various equipments.

4.0 Switching Stations

- a) Switch Yard-check
 1. For vegetation and spreading of Pebbles.
 2. Painting of fencing & equipments.
 3. Condition of cable trenches & trench cabins.

 - b) Interrupters:
check
 1. Control box gaskets for water & dust tightness.
 2. Operation by local & remote control
 3. Operating mechanism for smooth operation.
 4. Oil level & leakages.
 5. Interlocking of Interrupters & undervoltage relay operation at SP.

 - c) PT & AT
check
 1. Leakage of oil *Isolator* check 1 Locking' arrangements.
 2. For correct alignment of blade tips, in the fixed contact jaws & alignment of arcing horns.

 - e) Battery charger & Batteries:
check
 1. Acid level
 2. Presence of sedimentation.
 3. Specific gravity & voltage of pilot cells.
 4. Presence of sulphation & tightness of inter-cell connectors.
 5. Size of fuses of batten, charger.
 6. Voltmeter & ammeter readings.

 - f) Earthing:
check
 1. Soundness of earth connection to each electrical equipment & structures.
 2. Last recorded earth resistance readings.

 - g) General
check
 1. Availability of fire buckets, respiration chart. First Aid box. Tools & Plants.
 2. Inspection Register and remarks made therein.
 3. History sheets of various equipments.
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**SOME IMPORTANT CHARACTERISTICS OF NEW OIL WHEN
TESTED AT THE MANUFACTURER'S WORKS**

(Ref. - IS 335)

Sl. No.	Characteristics	Test Method (Ref. to IS or Appendix)	Requirements
(1)	(2)	(3)	(4)
1.	Appearance	A representative sample in 100 mm thick layer	The oil shall be clear and transparent, free from suspended matter or sediments
2.	Electric strength (break down voltage)	IS:6792-1972	
	a) New Unfiltered Oil		Min. 30 kV (rms)
	b) After filtration		If the above value is not attained, the oil shall be filtered. 50 kV (rms)
3.	Resistivity at		Min.
	(a) 90° C	IS:6103-1971	35×10^{12} Ohm-cm
	(b) 27° C		1500×10^{12} Ohm-cm
4.	Dielectric dissipation factor (tan delta) at 90° C	IS:6262-1971	Max. 0.002
5.	Water content	Appendix E of IS:335-1983	Max. 50 ppm
6.	Interfacial tension at 27° C	IS:6104-1971	Min. 0.04 N/m
7.	Flash point	IS:1448	Min, 140° C
8.	Dissolved gas content		4-8%
9.	Neutralization value	IS: 1448	
	a) Total acidity		Max. 0.03 mg KOH/g
	b) Inorganic acidity/alkalinity	- do -	Nil

**APPLICATION AND INTERPRETATION OF TESTS ON
TRANSFORMER OIL IN SERVICE**

(Ref.: IS : 1866)

Sl. No	Tests	Value as per IS: 1866 Permissible limits	To be re-conditioned	To be replaced
1	2	3	4	5
1	Electric Strength (Breakdown voltage)	<i>Min</i>	Less than the value specified in Column 3	
	Below 72.5 kV	30 kV		
	72.5 kV and less than 145 kV	40 kV		
	145 kV.and above	50 kV		
2	Specific resistance (Resistivity) Ohm/cm at 27 °C	above 10×10^{12}	Between 1×10^{12} to 10×10^{12}	Below 1×10^{12}
3	Water content		Greater than the value, specified in Column 3	
	Below 145 kV	Max 35 ppm		
	Above 145 kV	25 ppm		
4	Dielectric dissipation factor, Tan delta at 90° C	0.01 or less	Above 0.1 to 0.1	Above 0.01
5	Neutralization value mg KOH/g of all	0.5 or less	Above 0.5	Above 1.0
6	Interfacial tension N/m at 27°C.	0.02 or more	0.015 and above but below 0.02	Below 0.015
7	Rash point In °C	140 or more	125 and above but below 140	Below 125
8	Sludge	Non-detectable	Sediment	Perceptible Sludge
9	Dissolved Gas Analysis (DGA)	Refer Annex. 2.04		

GUIDE-LINES FOR CONDITION MONITORING OF TRACTION POWER TRANSFORMER BY DISSOLVED GAS ANALYSIS (DGA) TECHNIQUE

(Reference : RDSO's Circular No. ETI/PSI/M/4 dated 5-2-91)

1.0 Introduction

- 1.1 Dissolved gas analysis (DGA) is a powerful diagnostic technique for monitoring the internal condition of transformer as it is capable of detecting faults in the incipient stage, before they develop into major faults and result in the outage of the transformer. The conventional BUCHHOU RELAY is universally used in transformers to protect against severe damages. However, its limitation is that enough gas must be generated first to saturate the oil fully and then to come out or there should be a gas surge to operate this relay. Moreover, Buchholz Relay is never meant to be a diagnostic device for preventive maintenance of transformers.
- 1.2 The DGA technique is very sensitive as it detects gas in parts per million (ppm) of the oil by use of the GAS CHROMATOGRAPH. It is possible to check whether a transformer under service is being subjected to a normal aging and heating or whether there are incipient defects such as Hot Spots, Arcing, Overheating or Partial discharges. Such Incipient faults otherwise remain undetected until they develop into a major failure.

2.0 Formation of Gases in Oil Filled Transformers

- 2.1 It is well known that Insulating oil in high voltage equipments can break down under the Influence of the thermal and electrical stresses to produce hydro-carbon gases, hydrogen and carbon oxides Gases may be formed in transformers and other high voltage oil filled equipment due to aging and to a greater extent as a result of faults. The accumulation of gases in transformer oil may be sudden due to a severe arcing fault or more gradual as in the case of slow deterioration of insulation. The principle mechanism of gas formation in a transformer tank can be classified as under:
 - a) Oxidation,
 - b) Vapourisation,
 - c) Insulation decomposition,
 - d) Oil break down,
 - e) Electrolytic action.

2.2 Oxidation

Carbondioxide is the gas predominantly liberated during the process of oxidation. The process begins when small quantities of oil combine chemically with the dissolved oxygen in the oil resulting in formation of trace-5 of organic acids. These acids react with the metal of the transformer, forming metal based soaps which dissolve In the oil and act as a catalyst to accelerate the process of oxidation.

2.3 Vapourisation

The vapourisation of oil occurs at about 280° C while that for water occurs at about 100 °C. The false alarm of a Buchholz relay may be attributed to the fact that the condensation of water vapour takes place when the excess moisture in the tank is vapourized by a heat source. False alarm can also occur, when hydro-carbons, the constituents of the insulating oil, vapourize.

2.4 Insulation Decomposition

The solid insulants in power transformers are mainly of cellulose or resinous type, viz. paper, press board, resins and varnishes. These substances contain in their molecular structure substantial amounts of oxygen, carton and hydrogen. In the temperature range of 150° C to 400° C, the insulation breakdown results in liberation of hydrogen, carbon dioxide and carbon monoxide. Above 400° C, the gases formed are relatively less.

2.5 Oil Break Down

The direct break down of oil by arcing results in cracking of the oil. The aromatic contents breakdown into simple and hydrogen. Acetylene and methane are the major constituents. Other hydro carbon gases may also be liberated due to cracking, if the necessary temperature is maintained for their stable formation.

2.6 Electrolytic action

Hydrogen and oxygen are liberated during electrolytic action. Presence of minute and small particles of fibres within the oil leads to electrolytic action. Light hydrocarbon gases may also be present, if solid insulation is involved.

3.0 Types of Fault Conditions

There are three main types of fault viz: overheating of windings, core and joints, partial discharges: and arcing.

3.1 *Overheating*

Overheating metallic parts heat up the surrounding regions such as paper insulating tapes and oil. This leads to thermal deterioration of these materials. Thermal degradation of paper produces carbon dioxide, carbon monoxide and water. The ratio of carbon dioxide to carbon monoxide is typically five: but if the ratio falls below three, there is indication of severe overheating of the paper, Oil degradation produces a number of hydro-carbon gases such as methane, ethane, ethylene. and acetylene. Methane and ethane are decomposition products that appear above 120^oC: ethylene appears above 150^oC while acetylene is a high temperature product, appearing at several hundred degrees centigrade Some hydrogen is also produced alongwith the hydro-carbons gases. The proportion of the various hydrocarbons varies with temperature. This is the basis of the well known Ratio Code introduced several years ago by Dorenberg and R.R. Rogers.

3.2 *Partial Discharge*

The second type of fault condition is partial discharge which occurs due to ionization of oil in highly stressed areas where gas/vapour filled voids are present or the insulation is containing moisture. The main product during partial discharge is hydrogen, though small amounts of methane and other gases would also be present depending upon thermal degradation. The disintegration of oil and cellulose due to partial discharge is characterized by the removal of the outer hydrogen atoms to form hydrogen gas. The remaining molecular framework polymerizes and long » chain products such as waxes are formed. Thermal degradation is a more predictable phenomenon which involves the break-up of chemical bonds. Cellulose decomposes ultimately to CO. CO₂ and water-, oil break up into lower molecular hydro-carbons.

3.3 *Arcing*

The third type of fault condition is arcing. Arcing can occur between leads, between lead and coil and between other highly stressed regions weakened by fault conditions. The high temperatures caused by arcing results in the production of acetylene and hydrogen.

3.4	Pattern of generation of gases in transformer is summarized below.										
	<table border="0"> <thead> <tr> <th style="text-align: left;"><i>FAULT/PATTERN</i></th> <th style="text-align: left;"><i>KEY GAS</i></th> </tr> </thead> <tbody> <tr> <td>Conductor Overheating</td> <td>CO/CO₂ (Carbon Oxides)</td> </tr> <tr> <td>Oil Overheating</td> <td>C₂H₄ (Ethylene)</td> </tr> <tr> <td>Partial Discharge</td> <td>H₂ (Hydrogen)</td> </tr> <tr> <td>Arcing .</td> <td>C₂H₂ (Acetylene)</td> </tr> </tbody> </table>	<i>FAULT/PATTERN</i>	<i>KEY GAS</i>	Conductor Overheating	CO/CO ₂ (Carbon Oxides)	Oil Overheating	C ₂ H ₄ (Ethylene)	Partial Discharge	H ₂ (Hydrogen)	Arcing .	C ₂ H ₂ (Acetylene)
<i>FAULT/PATTERN</i>	<i>KEY GAS</i>										
Conductor Overheating	CO/CO ₂ (Carbon Oxides)										
Oil Overheating	C ₂ H ₄ (Ethylene)										
Partial Discharge	H ₂ (Hydrogen)										
Arcing .	C ₂ H ₂ (Acetylene)										

4.0 Solubility of Gases

- 4.1 The solubility of gases in oil varies with temperature and pressure. While solubility of H₂, N₂, CO, O in oil increases with temperature and that of CO₂, C₂ H₂, C₂ H₄ and C₂ H₆, decreases with temperature, solubility of CH₄ remains essentially constant.

All the gases become more soluble in oil with increase in pressure. Solubility of gas is one of the factors contributing to the complexities in formulating permissible levels of gases on the basis of service life of a transformer. Table I shows solubility of different gases at 25° C and at 1 atm. The homogeneity of the gases in the oil is dependent on the rate of gas generation, access of the fault area to flowing oil, rate of oil mixing and presence of gas blanket.

5. Dissolved Gas Analysis (DGA)

- 5.1 Dissolved gas analysis (DGA) of the oil of a transformer in operation is a specialized technique to assess the internal condition of the transformer. DGA is performed by Gas Chromatography. The gases extracted from the oil by a suitable apparatus are transferred to the Gas Chromatograph system for analysis.
- 5.2 The knowledge of solubility of Hydro-carbon and fixed gases at different temperatures, in insulating oils helps in interpretation of gas analysis. The permissible concentration of dissolved gases in the oil of healthy transformer is shown in Table II. The combinations of Gas levels for different types of faults are shown in Table III while Table IV shows the gas composition by volume under arcing fault with participation of various components of solid dielectrics in a transformer.
- 5.3 While the absolute concentration of fault gases gives an indication of status of insulation of transformer, whereas the relative concentration of these gases provides a clue to the type of fault. For fault diagnosis the method based on Rogers' Analysis is adopted.
- 5.4 *Roger's method:*

This method holds good for hydro-carbon gases. By evaluating the gas ratios, the type of fault is detected. Four ratios are used viz., Methane/Hydrogen, Ethane/Methane, Ethylene/Ethane and Acetylene/

/Ethylene. The value of ratios can be greater or smaller than unity. The ratio and type of fault represented by that ratio are given in Table V.

6.0 Data Collection and Analysis

- 6.1 It is recommended that DGA be performed regularly once a year on every transformer upto 4 years of service and thereafter twice a year upto 10 years and the frequency thereafter may be increased to thrice a year. .

Note: Wherever the Buchholz relay operates, the dissolved gas analysis be carried out immediately after operation of the relay to ascertain the cause of fault.

- 6.2 The results of the DGA for each transformer should be built into a data bank and based on the trend of the gas levels over a period of time as well as the faults, if any, that the transformer *had* suffered, an analysis may be done to establish the exact nature of the incipient fault that may be developing in the transformer.

TABLE - I

SOLUBILITY OF DIFFERENT GASES IN TRANSFORMER OIL AT 25 °C. 1 atm.

Gas	Volume % with reference to volume of oil
Hydrogen	7
Oxygen	16
Nitrogen	8.6
Argon	15
Carbon Monoxide	9
Carbon Dioxide	120
Methane	30
Ethane	280
Ethylene	280
Acetylene	400
Propylene	400
Propane	1900
Butane	4000

TABLE II

RANGE OF GAS LEVELS
(All concentrations are in PPM)

Gas	0-4 years	4-10 years	10 years
Methane	10-30	30-80	30-130
Ethane	10-30	30-50	30-110
Ethylene	10-30	30-50	50-150
Acetylene	10-16	10-30	10-40
Hydrogen	20-150	150-300	200-500
Carbon Monoxide	200-300	300-500	500-700
Carbon Dioxide	3000-4000	4000-5000	4000-10,000

TABLE - III

GAS LEVELS FOR DIFFERENT FAULT CONDITIONS
(All concentrations are In PPM)

Fault Gases	Hydrogen H ₂	Methane CH ₄	Ethane C ₂ H ₆	Ethylene C ₂ H ₄	Acetylene C ₂ H ₂	Carbon dioxide CO
Arcing	500-1000	20-130	10-30	10-30	40-100	3000-4000
Partial Discharge	500-1000	20-130	10-30	10-30	10-15	3000-4000
Hot Spot	20-150	10-30	10-30	150-200	10-15	3000-4000
Gradual Overheating	20-150	10-30	150-200	10-30	10-30	3000-4000

TABLE -IV

GAS COMPOSITION BY VOLUME (%) WITH REFERENCE TO VOLUME
OF OIL DUE TO ARCING FAULTS

Insulation	H ₂	CO	CO ₂	CH ₄	C ₂ H ₆	C ₂ H ₄	C ₂ H ₂	O ₂	H ₂
Oil only	60	0.1	0.1	3.3	0.05	2.1	2.1	2.4	6.3
Oil/Kraft paper	52	14	0.2	3.8	0.05	8	12	3	6.7
Oil/Press board Laminate	48	27	0.4	5	-	5	6	2	6.2
Oil, Alkyl paint	55	20	0.2	4	-	5	8	2.4	7
Oil/Polyurethane enamel	60	1	0.1	9	-	11	10	2	6
Oil/P.V. A enamel	61	5	0.1	6	-	14	5	2.5	6.5
Oil/Epoxy glass clothes.	57	2	0.1	14	-	10	8	2.5	6.5
Oil/Isophthalate Cotton tape.	55	11	4	8	-	8	5	-	-

TABLE V

ROGER'S METHOD OF DIAGNOSIS BY HYDRO-CARBON GAS RATIOS

Methane Hydrogen	Ethane Methane	Ethylene Ethane	Acetylene Ethylene	Diagnosis	% of transformers Sampled
0	0	0	0	If Methane/Hydrogen less than 0.1- partial discharge.	2.0
				Normal deterioration	34.2
1	1	0	0	Slight overheating below 150°C	11.8
1	1	0	0	Slight overheating 150°- 200°C	9.0
0	1	0	0	Slight overheating: 200°- 300°C	7.8
0	0	1	0	Normal conductor overheating	11.1
1	0	0	1	Circulating Currents and / or Overheated joints	9.0
0	0	0	1	Flashover without power	2.1
				Follow through	
0	1	0	1	Tap changer selector breaking Current.	1.1
0	0	1	1	Arc with power follow Through or persistent arcing	9.7

- CH₄ - Methane
- C₂H₆ - Ethane
- C₂H₄ - Ethylene
- C₂H₂ - Acetylene
- H₂ - Hydrogen

PHYSICAL PROPERTIES OF SF₆ GAS

1.	Molecular Weight	:	146.07
2.	Melting point	:	-50.7 °C
3.	Sublimation Temperature	:	-60.8 °C
4.	Critical Temperature	:	45.547 ± 0.003 °C
5.	Critical Pressure	:	38.55 kgf / cm ²
6.	Critical Density	:	0.730 g/cm ³
7.	Dielectric Constant at 25°C, 1 atm	:	1.002
8.	Thermal Conductivity at 30°C	:	3.36 X 10 ^s
9.	Density at 20°C	:	
	kgf/cm ² gm/lit.		
	at 0	:	6.25
	at 1	:	12.3
	at 5	:	38.2
	at 10	:	75.6
	at 15	:	119.0
11.	Solubility		
	in oil	:	0.297 cc/cc
	inH ₂ O	:	0.001 cc/cc
	of H ₂ O	:	0.35 ±0.01 gm/gm
	at 30°C		
12.	C _p	:	23.22 Cal / °C

MAINTENANCE OF SF₆ CIRCUIT BREAKERS

1.1 Schedules

The maintenance and check execution standard depends upon the working conditions of the CB. The checks to be carried out. Their frequency and scope are broadly as under:

Type of check	Frequency	Scope
Patrol Inspection	Every week	The patrol inspection is an external check of the circuit breaker in live conditions for irregularities.
Ordinary inspection	After every 1000 operations	The ordinary inspection is inspection Performed by turning off the circuit breaker for a relatively short time for simple inspection and servicing with emphasis on functional checks e.g. visual check of irregularities and cleaning of dust and dirt.
Detailed Inspection	After every 3000 operations	The detailed inspection is an inspection performed by turning off the circuit breaker for a relatively long time. To dismantle and inspect the mechanism for irregularities for the purpose of continuously maintaining the performance.
Incidental Inspection	_____	The incidental inspection is performed when inspection and repair are necessary due to the detection of an irregularity during patrol inspection.

1.2 General

Attention should be paid to the following points during ordinary and detailed inspection.

- a) Switch off control/compressor motor supply. Discharge all the air in the air receiver through the drain value.
- b) The circuit breaker is to be inspected in the open position unless otherwise specified in these Instructions. At the open position of the breaker the safety pins for preventing closing and opening must be inserted. On completion of the safety pins must be removed.
- c) Good quality grease should be used adequately.
- d) Circlips and split pins which are removed must be replace with new ones.
- e) Removed "O" rings must be replaced with new ones. While handling and placing "O" rings in their grooves. Care should be taken to avoid dust falling on them.

1.3 Inspection and Servicing Procedure

Point / Location	Item or Part/ Procedure	Patrol Inspection	Ordinary Inspection	Detailed Inspection
Appearance For damage	1.Check the porcelain	X	X	X
	2.Check the main terminal for discoloration			X
	3.Check the foundation Bolts for looseness	X	X	X
	4. Check the grounding pad for looseness		X	X
	5. Check the position indicator		X	X
	6.Drain water from air reservoir	X	X	X
	7.Record the number of circuit breaker operations	X	X	X
Interruption Unit	8.Inspection of contacts and renewal if necessary			X
	9.Renewal of absorbent			X
	10.Measurement of resistance of interrupting units.			X
Gas System	11.Record of gas pressure & Temperature	X	X	X
	12. Check the value B is open and value A is closed.		X	X
	13.Supply the gas, if the pressure is less than prescribed value	X	X	X
	14.Check setting of gas pressure switch		X	X
Operating mechanism housing	Pressure Gauge			
	1.Ensure that needle indicates rated operating pressure	X	X	X
	2.Ensure that needle indicates within tolerance (1.5% of full scale) when air is released thoroughly from air tank.	X	X	
	Air Leakage			
	1. Check pneumatic system such as valves and piping for air leak sound	X	X	X

Point / Location	Item or Part/ Procedure	Patrol Inspection	Ordinary Inspection	Detailed Inspection
	Space Heater:			
	1) Check for disconnection	X	X	X
	Operating Counter:			
	1) Check for disconnection.	X	X	X
	Draining:			
	1) Drain water from air tank water penetration & rust.	X		
	2) Check penetration of rain water and rust.		X	X
	Fastened Joints:			
	1) Ensure that bolts nuts. etc. are not loosened.		X	X
	Control Circuits:			
	2) Check connections of control circuit wiring for fastening.		X	X
Tripping Mechanism	Check the dimensions of tripping solenoid magnet:			
	1) Check the clearance "ST" (solenoid magnet stroke) Between armature and core		X	X
	2) Check the clearance "G _T " between plunger and trigger		X	X
	3) Check S _T - G _T Part replacement and relubrication (Grease) :		X	X
	4) Remove pin "B" and control value assembly then replace value seat with new one.			X
Tripping Mechanism	Roller Lever of Control Value Assy:			
	Close the breaker and fully drain out the air from air reservoir. Operate Control value by pushing down trip coil plunger with soft mallet. Rotate rollers (C) and (D) to check that they rotate freely Open the breaker by using Manual Jack Assembly		X	X

Point / Location	Item or Part/ Procedure	Patrol Inspection	Ordinary Inspection	Detailed Inspection
Closing Mechanism	Check the dimensions Of closing solenoid magnet : 1)Check the clearance "SC" (solenoid magnet stroke) between armature (27) and core (28)		X	X
	Check the pumping Prevention pin to latch distance. 1)Check the clearance "P" between anti-pumping pin and latch.		X	X
Main Piston Rod	Relubrication (Grease) : 1) Wipe contaminated grease off piston rod and apply new grease, in closed position.			X
Operating Mechanism	Operating Mechanism Stroke: 1) Check stroke "S" from completely opened position to stopped position.		X	X
	2)Check over-strokes "SO" from completely opened. Position to stopped position.		X	X
Testing	Manual Operation : 1)Remove closing and opening lock pins, and charge air up to 15 kg/cm ² . Operate closing solenoid magnet and opening solenoid magnet to check operation. Check of minimum operating pressure.		X	X
	1)Make sure that circuit breaker is opened at air pressure of 11 kg/ cm ²		X	X
	Air Pressure Switch: 2)Make sure that air pressure switch is properly set.		X	X

MAINTENANCE OF VACUUM CIRCUIT BREAKERS**1.0 General**

The maintenance and check execution standard depends upon the working conditions of VCB. Such as the environmental condition. Current switching frequency and others. The checks to be carried out. Their frequency and cope are broadly as under:

Type of check	Frequency	Scope
Patrol Check	Daily	Check VCB under daily operating condition
Ordinary check	Once every 3 Year or once every 1000 switching times	Check VCB after disconnection main supply and local Remote switch in LOCAL position.
Detailed check	Every 6 years	“
Provisional check	When a trouble occurs.	“

For the minimum number of operation without replacement of vacuum bottle Para 1.5 below may be referred.

1.1 Patrol Check

Patrol check shall be done visually. If any abnormality is found, stop the operation forthwith and examine.

Item No.	Check Items	Checking parts & key points.	Explanation
1.	General parts	a) Dust and moisture condensation and evidence of rain water in operating box. b) Unusal sound, small and decolouration. c) Condition of open-close indication d) Working condition of charge indicator	“On in red. closed condition. “off” in green open condition
2.	Temperature	Main circuit terminals and electrode pole assembly	Check carefully if the terminal section is discoloured and also, the air is waving with heat.
3.	Control voltage	Check if the operating voltage and control voltage are kept at the respective specified values.	

1.3 Ordinary Check

The standard checking items and servicing intervals (given by years or number of operation) are generally suggested in Table below. However, it is recommended that the checking intervals shall be determined according to the actual working conditions including the installed atmosphere and operating frequency of the circuit breakers.

Item No.	Classification	Checking & Servicing	Recommended Checking & Servicing procedure	Remarks Standard checking intervals.	
1.	General parts	Cleaning each part	Remove dust sticking to circuit breakers, especially the insulators	3 years	
		Tightened parts	Looseness in bolts and nuts, and also break & drop off of washers, snap rings, snap retainer etc.	3 years	
2.	Operating units	Operating mechanism & link mechanism	Check the movement Check the deformation & rust. Check limit switches for proper function	3 years	
			Condition of links and collars and damage in them	3 years	
			Leakage of oil in the terminations of wires.	3 years	
		Control Circuit	Looseness of the terminations of wires.	3 years	
		Counter	Number of operations	3 years	
		Open close indicator	Operating condition	3 years	
3.	Check of operation	Open-close Operation	Charge indicator	Operating condition	3 years
			Close and open several times each in manual and electrical operations. Spring charging operation	3 years	
4.	Measurement of insulation	Across main conductive parts and ground and across poles.	More than 500 M. ohms the general standard (by 1000 megger)	3 years	

1.5 Detailed Check

Checking shall be performed as per items in ordinary check and as per items listed below:

Item No.	Classification	Checking & Servicing	Recommended Servicing procedure	Checking & Remarks Standard checking intervals.
1.	VI	Vacuum check	Contract manufacture	6 years 3000 operations.
2.	Operating units	Operating mechanism	Lubrication to rotary part, sliding parts and pin engaging part (use low viscosity machine oil or equivalent.)	6 years
		Check of adjusting dimensions of each part	Gap between trip hook and roller followers and other adjusting dimensions Refer to clause 5-6	6 years
		Spring	Rust, damage and deformation	6 years
		Coils	Breaking of wires and others.	6 years
3.	Check of operating condition	Min. Operating voltage	Tripping voltage: Under 70% rated voltage Closing Voltage : under 85% rated voltage	6 years

1.6 25 KV Vacuum Interruptor

The minimum numbers of operations of Interrupter without replacement of vacuum book is as follows:

1. At a rated breaking current of 4 kA 4600 Nos.
2. At a breaking current of 2 kA 8000 Nos.
3. At a breaking current of 12 kA 10.000 Nos.
4. At a breaking current of 0.4 kA 10.000 Nos.
5. At a breaking current of 600 A 10.000 Nos.

Annexure 3.08

TORQUE FOR VARIOUS SIZES OF BOLTS IN kg.m

Bok Size	Nominal Stress	Steel	Stainless Steel
10	58	473	5.91
12	843	8.25	10.31
14	115	13.14	16.42
16	157	20.61	25.61
18	192	28.18	35.23
22	245	39.96	49.95

DESIGN ASPECTS OF TRACTION SUBSTATION

4.0 SPACING AND LOCATION

4.01 The sub-station spacings largely depends upon the permissible voltage drop at the farthest end, which in turn depends upon various factors such as the traffic to be moved, anticipated traffic in the future and gradients of the section to be electrified. The voltage drop at the farthest end is calculated both for normal and extended feed conditions on the basis of given combination of trains on UP & DOWN tracks, loads and specified speeds, track parameters of the section on the assumed length of the feed zone. The calculations are repeated for different assumed lengths of feed zone and it is ensured that the voltage at the farthest end is within the permissible limits.

4.02 Alternatively, the power requirement is calculated on the basis of average specific energy consumption of goods and passenger trains. Following figures of specific energy consumption are taken for level or lightly graded sections.

- (a) Goods train - 11 kwh. 1000 GTKM
- (b) Pass train - 19 kwh. 1000 GTKM

For Medium or heavily graded sections, the specific energy consumption figures have to be based on trials. The power requirement is calculated by the formula as given below :-

$$P = \frac{Q \times (2L_o) \times W}{1000} \times \frac{60}{H} \times \frac{1}{\cos\phi} \quad \text{KVA}$$

Where,

- 2 X Lo = Sub-Stn. covering area for double track line(km)
- W = Weight of a train in tones
- Q = Energy consumption rate (kwh/1000 GTKM)
- H = Headway in minutes during peak time (assumed)
- COS ϕ = P.F. (lagging)

Conversely, using the above formula 'Lo' can be calculated for a given rating of traction transformer. Typical calculation based on this formula is shown below -

SPECIFIC ENERGY CONSUMPTION

Considering a double track section and specific energy consumption 11 kWh / 1000 GTKM for Goods Train in the Loaded Directions and 19 kWh/1000 GTKM for passenger trains in the empty direction

$$W = (4570 + 2 \times 120) \text{ t For 4500t Loaded Train}$$

$$W = (1100 + 113) \text{ t For 22 Coaches Passenger Train}$$

$$H = 18 \text{ Minute Headway}$$

$$2L_o = 45 \text{ KM}$$

Hourly maximum output –

$$\begin{aligned} P &= \frac{Q \times (2L_o) \times W}{1000} \times \frac{60}{H} \times \frac{1}{\cos\phi} = \text{kVA} \\ &= \frac{11 \times 45 \times 4810 + 19 \times 45 \times 1213}{1000} \times \frac{60}{18} \times \frac{1}{0.8} \text{ kVA} \\ &= 14242 \text{ KVA} \end{aligned}$$

MAKING AN ALLOWANCE OF 25%
FOR EXTENDED FEED CONDITIONS
POWER REQUIREMENT

$$= 14242 \times 1.25 \text{ kVA}$$

$$= 17803 \text{ kVA.}$$

4.0.3 In Planning the requirement of traction sub-station and its location on any section for track electrification, the factor to be kept in mind may be summarised as given below :-

- Availability of adequate and reliable power supply lines. The transmission lines should be as close as possible to the Rly lines.
- Willingness of electric supply authorities to extend their HV transmission lines to feed the railway traction loads.
- Settlement of tariff rates.
- Traffic to be handled in the section.
- Gradients of the section.
- Anticipated traffic in the future.
- Single or double line section.

- Characteristics of the locomotive and speed etc.
- Allowable permissible voltage drop at the farthest end.
- Strength of the system to permit the voltage and current unbalance caused by the traction single phase loads.
- Suitability of standard equipments.
- The load is within the standard ratings of the transformer and other equipment under normal and extended feed conditions.
- Availability of reasonably good levelled land as near to Rly track as possible.
- Location should be away from the dumping yards.
- Location of sub-station should not be less than 3 km from the airport.
- Provision of siding track for loading and unloading of heavy equipments.
- Location should be close to main Rly. station where inspection staff can reach the spot in the shortest time

4.0.4 On an average the spacing between the successive sub-station as adopted in earlier electrification schemes was about 50 to 80 km, but with the interlocation of heavy haul trains and increased passenger and goods traffic the spacing has been reduced to 40 to 60 km. only. On high density routes it may reduce further by converting existing SP into TSS and SSP into SP.

4.1 TRACTION POWER SUPPLY SYSTEM

4.1.1 Before going into details of design aspects of various substation equipments, we may briefly discuss the power supply system adopted for feeding the traction substations.

4.1.2 Indian Rlys. purchase electric power from various state electricity boards and as well as from other electric utilities through their regional grids at different voltage, normally 220/132/110/66 kV. The incoming supply is stepped down to 25 kv. a.c. with the help of step down transformer. The primary winding of the transformer is connected across two phases of the three phase effectively earthed system and one terminal of the 25 kV. secondary winding is connected to the overhead equipment (OHE) and other terminal of the 25 kV. secondary winding is solidly earthed and connected to the running rails. The load current flows through the OHE to the locomotive and return through the rails and earth to the traction sub-station.

The substations are provided as close to the railway traction as possible at intervals varying from 40 to 60 km depending upon the traffic density and track conditions. In the initial stages of the AC electrification schemes, traction

substations were owned and maintained by electric supply authorities. But later on in the late sixties Indian Railways started purchasing bulk power at 220 or 132 or 110 or 66 kV. at a single point and run their own transmission lines and installed, operated and maintained their own substations.

4.1.3 In addition to two transformer circuit breakers, which are provided each on primary and secondary side of the traction transformer, the output from the transformer is fed to the overhead equipment on one side of the substation through a feeder circuit breakers and two interrupters provided at each line. The transformer breaker acts as a back up to the feeder breaker. The feeder breaker perform the usual duties of breaking the circuit under the normal and abnormal conditions according to situation. The interrupter is also a type of circuit breaker, but it is non-automatic i.e. it is not called upon to trip under fault conditions. It is capable to carry the normal rated current and through fault currents. It performs the duty of breaking the load current and is also called a load switch. All the breakers and interrupters are outdoor type and remote controlled from Central Control Room. generally situated at the Railways Divisional Headquarters.

4.1.4 Typical layout of traction substation is shown in figure 1.01

Each traction substation is provided with two transformers. Only one transformer feeds the traction over head equipment on either side of traction substation through the two feeder circuit breakers. For protection, in all six circuit breakers are provided at each traction substation out of which two are installed on the primary side and two on the secondary side of the transformer. These breakers are known as transformer breakers and act as back up protection to the feeder circuit breakers. Two feeder circuit breakers control the supply to the overhead equipment. In the event of any fault on the OHE, the feeder circuit breaker will trip and clear the fault. The interrupter, load switch controls supply for each track.

4.1.5 Approximately midway between two adjacent substations, a dead zone known as 'neutral section' or phase break is provided to separate two different phases. The section between the substation and the neutral section is called sector which is further subdivided into subsectors by a set of interrupters located at subsectioning posts situated at intervals of 10 to 15 km. To reduce the voltage drop along the line, both the lines in a double track section are paralleled at each subsectioning post and sectioning post with the help of a paralleling interruptor at each post. At each sectioning post, a bridging interruptor with an under voltage relay is provided at each line which enables the extension of feed from a substation to the section fed by an adjacent substation, in case of an emergency caused by failure of the adjacent substation.

4.2 LAYOUT OF SUB-STATION

Once the locations of the traction substation, is decided based on the

considerations enlisted in para 4.0.3 the next step to be followed is the design of the substation. The layout of the traction substation is influenced by the type and orientation of transmission lines with respect to tracks to be fed i.e. whether the feeding transmission lines are parallel to the track or at right angle to the track. Based on these various combinations of transmission lines and tracks, ten different types of substation layouts have been standardised by RDSO. These layout plans have been developed after giving due consideration to the following points.

- i) Physical and Electrical clearances between different equipments.
- ii) Phase to phase clearances.
- iii) Phase to ground clearances
- iv) Sectional Clearances.

A typical layout plan and cross sectional view of 220/132/110/66 kV. traction substation showing position of all the equipments is shown in the Fig. 1.01.

4.3 TRACTION POWER TRANSFORMER

4.3.1 Traction power transformer is the most important and costly equipment of the substation Therefore, utmost care is taken while designing and selecting the parameters of the traction power transformers In the initial stages of the electrification, the transformers used were of 7.3 and 10 MVA ratings, but later on transformers of 13.5 MVA were used in most of the electrification projects. The readings of the transformer are standardised on the basis of average spacing between the traction substations, loads to be hauled and gradients of the section to be electrified

4.3.2 With the introduction of heavy haul trains and increased passenger and goods traffic the transformer of 13.5 MVA rating are not adequate to meet the load requirements. Therefore in the ongoing electrification schemes transformers with 20 MVA are being used and on high traffic density routes transformers of 30 MVA rating are being tried.

4.3.3 The duties performed by the traction power transformers are very much different from the conventional distribution transformers. The traction transformers are subjected to peaky loads, rapid load variations and frequent short circuits. Therefore windings of these transformers are specially reinforced to withstand the high stresses developed due to the following service conditions.

- i) Repeated short circuits.
- ii) Frequent load variations.
- iii) Frequent variation in supply voltage.
- iv) Magnetizing inrush current due to repeated switching 'ON' of the

transformers from 'OFF' position.

- v) Overloading of the transformers as specified.

4.3.4 The traction transformers experience frequent short circuits due to various reasons such as bird dropping a wire across an insulator, insulator failure, flashover of insulators, switching surges, accidents, activities of miscreants i.e. theft of wires entering of loco in dead section, flashover of wire under overline structure where clearances are restricted and mechanical failure of OHE fittings etc. To limit the magnitude of fault current the percentage impedance for traction transformer has been specified as $(12 \pm 0.5)\%$. It shall not be less than 11.5% and not more than 12.5% at any tap position.

4.3.5 Technical particulars of 20 MVA, traction power transformer are as under :-

i)	Type	ONAN cooled, single phase step down power transformer, double limb wound core type for outdoor installation. The transformers are designed to keep provision of forced cooling at a future date without requiring any modification.
ii)	Windings	Concentric, Disc/interleaved for primary and secondary windings. Both windings are uniformly insulated.
iii)	Rated frequency	50Hz ($\pm 3\%$)
iv)	Rated primary voltage	220 kV, 132 kV, 110 kV, or 66 kV (As the case may be)
v)	Nominal secondary	25 kV Voltage
vi)	Rated current	Primary 151.5 A (for 132 KVØ Secondary 740.7A)
vii)	Percentage impedance	$(12 \pm 0.5)\%$ Voltage
viii)	Rated MVA at rated	20 MVA Secondary voltage
ix)	Overload capacity	50% for 15 minutes & 100% for 5 Minutes
x)	Tapping off-circuit	+10% to -15% on low voltage side in steps of 5%
xi)	No-load losses	12.5 kW

xii)	Load losses	135.0 kW
xiii)	Current density	Less than 2 Amp. per Sq.mm
xiv)	Temperature-rise limits	
	a) Windings	– 50°C (Temp. rise measured by resistance method)
	b) Insulation oil	– 40°C (Temp. rise measured by the thermometer method)
	c) For current carrying parts in air	– 35°C (Temp. rise measured by thermometer method)

4.4 CIRCUIT BREAKERS

4.4.1 Next to transformer, the other important equipment at any substation is the circuit breaker. Circuit breakers play an important role in the control and performance of a power supply system. From consideration of cost aspect also the circuit breakers constitute as a major item. Power circuit breakers are designed not only to carry the rated normal currents continuously but isolate the faulty section of the system under all normal and abnormal condition, and shall also be capable of interrupting load currents, capacitive and small inductive currents. They must be capable of clearing terminal and short line fault and shall also be capable to operate reliably under all ambient temperatures, under severe polluted conditions and at high attitudes. Voltages induced in the system due to switching operations shall be minimum.

4.4.2 Different types of circuit breakers use different types of quenching medium like oil, compressed air, SF6 gas and vaccum bottles. Till recently Indian Railways were using oil circuit breakers for control of traction power supply system.

In the initial stages of a.c. electrification these breakers were imported but later on these were procured from reputed indigenous manufacturers. The maintenance cost of oil circuit breakers particularly when used as feeder circuit breaker, various from Rs.3000/- to Rs.40,000/- per annum depending upon the number of trippings. Experience has shown that at some of the traction. substation oil

circuit breakers are just not able to meet the required duty due to very high cost of maintenance. Just to have a idea about the number of trippings a statement showing month wise number of trippings for the year 1985 for one of the traction substation (N Rly) are shown below :-

Statement showing monthwise No. of trippings for year 1985

Northern Railway (Chanakyapuri Substation)

Month	Feeder No. CB-61	Feeder No CB-62
January	67	95
February	44	12
March	59	20
April	71	27
May	99	41
June	139	53
July	108	56
August	81	48
September	86	45
October	104	29
November	96	32
December	84	48
Total :	1038	507

4.4.3 To minimise the rising maintenance cost and to keep the down time of the breaker to bare minimum, Indian Railways have adopted switchgear based on modern technology i.e. SF₆ gas and vaccum. In all future electrification schemes, so far as 25 kV feeder circuit breakers are concerned, will be either of SF₆ gas type or vacuum type.

4.4.4 Rated short circuit breaking current (for HV breakers)

Rated short circuit breaking current depends on the three phase short circuit level of the system. Short circuit levels at present for the different voltages varies between 1000 MVA to 10,000 MVA depending on the proximity of the generating station. Based on the short circuit levels the rated circuit breaking current values are as under.

item	Nominal System Voltage			
	66kV	110kV	132kV	220kV
Max fault MVA	3500MVA	5000MVA	5000MVA	10000MVA
Fault current	30.62kA	26.24kV	21.86kA	26.24kA
Rated short circuit breaking current as assigned to the breaker kA	31.5kA	31.5kA	25kA	31.5kA

The method of calculating the fault current both for primary and secondary side of the substation is shown below -

220 kV bus incoming (fault level - 10000 MVA)

For 20 MVA 220/25 kV power transformer

$$\text{FAULT CURRENT} = \frac{\text{FAULT MVA}}{3 \times \text{VOLT IN kV}} = \frac{10000}{3 \times 220} = 26.24 \text{ kA.}$$

on primary side

IN CASE OF SINGLE TRANSFORMER -

SYSTEM REACTANCE UPTO 220 kV BUSBAR (AT 100 MVA ASSUMED BASE)

$$X_s = \frac{\text{CHOSEN BASE IN MVA} \times 100}{\text{FALUT LEVEL}} = \frac{100 \times 100}{10000} = 1\%$$

THE CORRESPONDING PERCENTAGE REACTANCE OF TRANSFORMER AT 100 MVA BASE (Assuming short circuit Impedence of tranformer of 20 MVA to be 12%)

$$X_t = \frac{100 \times 12}{20} = 60\%$$

3	1%	220 kV BUS
3	60%	25 kV BUS

THEREFORE TOTAL REACTANCE = 1 % + 60 % = 61 %

FAULT LEVEL ON 25 kV BUS JUST OPPOSITE THE SUB-STATION(S/S)

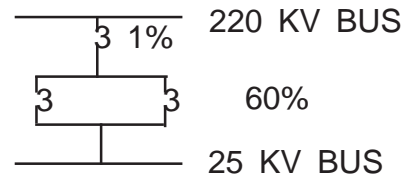
$$= \frac{100 \times 100}{61} = 163.93 \text{ MVA}$$

$$\text{FAULT CURRENT JUST OPPOSITE THE S/S} = \frac{163.93}{25} = 6.557 \text{ kA}$$

INCASE OF TWO TRANSFORMERS RUNNING IN PARALLEL -

TOTAL REACTANCE = 1% + 30% = 31%

$$\text{FAULT LEVEL} = \frac{100 \times 100}{31} = 322.58 \text{ MVA } 60\%$$



$$\text{FAULT CURRENT} = \frac{322.58}{25} = 12.90 \text{ KA.}$$

It will be seen from the above that though the fault current is less but rated short circuit braking current value assigned to the breaker is higher. This is because IEC, IS and BS specification have standardised the rated short circuit breaking current are as given below :-

6.0 kA, 8.0 kA, 12.5 kA, 16 kA, 20 kA, 25 kA, 31.5 kA, 40 kA, 50 kA, 63 kA, 80kA, and 100 kA.

Therefore, as a part of standardisation, the recommended values of rated short circuit breaking current have been adopted Recommended values of rated short circuit current and normal rated current are shown as under :-

CO-ORDINATION TABLE OF RATED VALUES FOR CIRCUIT BREAKERS

Rated Voltage (kV)	Rated Short circuit Breaking Current (kA)	Rated	Normal (Amps)	Current	
72.5	12.5	800	1250		
	16	800	1250		
	20		1250	1600	2000
	31.5	1250	1600	2000	
123	12.5	800	1250		
	20	1250	1600	2000	
	25	1250	1600	2000	
	40		1600	2000	
145	12.5	800	1250		
	20		1250	1600	2000
	25		1250	1600	2000
	31.5		1250	1600	2000
	40			1600	2000
	50				2000

	20	1250	1600	2000
245	31.5	1250	1600	2000
	40		1600	2000
	50		1600	2000

Value of rated short circuit braking current (kA) 6.0, 8.0, 10.0, 12.5, 16.0, 20.0, 25.0, 31.5, 40.0, 50.0, 63.0, 80.0 and 100 kA

Value of rated normal current (Amps) - 400, 630, 800, 1250, 1600, 2000, 2500, 3150 and 4000 Amps

4.4.5 Normal rated current

As indicated in para 4.3.5 the normal rated current of the primary winding of 20 MVA transformer is 151.5 Amps only for 132 kV system. Since these transformers are designed to deliver 100% overload for 5 minutes, therefore Primary current is likely to reach the value of 303 Amps. But the assigned value of normal rated current for HV circuit Breaker is 1250 Amps for 66 kV, 110 kV, 132 and 220 kV system.

This is again because IEC, IS and BS standards have standardised the normal rated current values to match the value of rated short circuit breaking current. The IEC and IE recommendations are as shown below :-

630A, 800A, 1250A, 1600A, 2000A, 2500A, 3150A & 4000A.

4.4.6 Thus it can be concluded that while deciding the ratings of the breakers used on the primary side, the rated short circuit breaking current is of importance and deciding factor and not the rated normal current which is generally much less. But for the breakers on the secondary side the situation is just the reverse while the deciding factor for the selection of the circuit breaker is the normal rated current and not the fault current.

4.4.7 The salient technical particulars as adopted for 220 KV and 25 KV breakers are as indicated below :-

S.N.	Particulars	Nominal system Voltage	
		200 kV	25 kV
i)	No. of poles	2 or 3 as reqd.	1
ii)	Nominal system voltage	220 kV	25 kV
iii)	Highest system voltage	245 kV	52 kV class
iv)	Rated one minute power frequency withstand voltage	460 kV (rms)	105 kV
v)	Rated impulse (1.2/50 micro-second) withstand voltage	1050 kV (peak)	250kV (peak)
vi)	Rated normal current	1250 A	1600 A

vii)	Rated short circuit breaking current	31.5 kA	20 kA
viii)	Rated breaking capacity (Symmetrical)		
	a) Two Pole	7717.5 MVA	450 MVA
	b) Three pole	13366.7 MVA	
ix)	Rated making current	78.8 kA	50 kA
x)	Rated operating sequence	0-0.3 sec CO-3 sec. - CO	0-0.3 sec 30 sec -CO
xi)	Total breaking time	Not more than 80 ms.	Not more than 65 ms
xii)	Rated short time withstand current	31.5 kA for one second	20 kA for 3 seconds

4.5 25 KV INTERRUPTORS

4.5.1 The interruptors are non-automatic circuit breakers which are provided at feeding posts and switching stations. Interrupters are not required to clear the fault, except for the one which is provided at the sectioning post as bridging interruptor. This interruptor is called upon to clear the fault under extended feed conditions. The breaking capacity of the interruptor has been specified as 4000 Amps at a recovery voltage of 27.5 kV and a short time current with stand capacity of 4000 Amps. for 3 seconds. But now with the use of higher rating traction transformers, the breaking capacity and normal rated current has been increased to 8 kA and 800 Amps respectively in the RDSO's new specification.

4.6 ISOLATING SWITCHES

4.6.1 When carrying out inspection or repair on sub-station equipments, it is essential to disconnect reliably the unit or the section, on which the work is to be done, from all other live parts on the installation in order to ensure complete safety of the working staff to guard against mistakes, it is desirable that this should be done by an apparatus which makes a visible break in the circuit. Such an apparatus is called the isolating switch or isolator. Isolators are used to open or close the circuit either when negligible current is flowing or when no current is flowing through the circuit. These are also called as off load switches. The location of the isolating switch is decided in the sub-station on the basis of scheme of bus bar connections. Generally on either side of the circuit breakers, isolators are provided for attending to maintenance work etc.

4.6.2 Two types of isolating switches have been used in traction substation. On the primary side i.e. HV side. Isolators used are either of two pole or three pole according to number of poles. From constructional point of view these may be divided as.

- i) Three post, centre post rotating double break type and
- ii) Two post single break type.

These isolators are of horizontal break type on the secondary side i.e. 25 KV side, the isolators used are of vertical break type. The rated normal current of these isolators is fixed to match the rated current of circuit breakers and bus bars etc. The standard values of rated normal current as specified in the IEC and IS specifications are the same as shown in para 5.5 for breakers.

4.7 CURRENT & POTENTIAL TRANSFORMERS

4.7.1 Bushing type CTs have been provided on primary and secondary side of the traction transformers and are exclusively meant for differential protection. Separately mounted 132 KV and 25 KV CT and 25 KV PTs are of conventional type.

4.8 BUS BARS

4.8.1 Two types of bus bar have been used for traction substation viz. strung type bus bar on the HV side and rigid type bus bar on LV side i.e. 25 KV side. The strung bus used in the earlier electrification schemes was consisting of All Aluminium 'spider' conductor of size 19/3 99 mm. The capacity of this conductor is adequate only to meet the maximum fault current of above 17KA, but due to increase in the fault/level of grid system, the value of fault current has exceeded 25KA. Therefore, to meet the higher requirement of fault current in the system, use of 'Zebra' Acsr conductor has been adopted in the ongoing electrification schemes, (size 61/3.18, dia 28.62 mm). This conductor is capable to withstand fault currents of the order of 31.5 KA. The tension in the strung bus is kept between 500 to 900 kgf. To keep corona losses within limits, the minimum diameter of conductors (strung bus) and jumpers shall not be less than 28 mm in case of 220 KV system.

4.8.2 Similarly the rigid type bus used in earlier electrification schemes was of Aluminium Alloy of 36 mm O.D. (36/28 mm). This bus was capable to carry the normal rated current of 960 Amps. But with the use of 20 MVA, transformers the requirement of rated normal current has increased to 1500 Amps (for short duration). Therefore, the size of the rigid bus bar has also been increased to 50 mm O.D. (50/39 mm). This bus is capable to carry continuous current of 1530 Amps. The rigid type bus is supported on the support insulators provided at a distance not exceeding 3 m. The minimum height of the 25 KV bus bar has been kept as 3800 mm. Chances of failure of rigid bus are very remote, but its installation is costlier than the strung bus.

4.9 LIGHTNING ARRESTERS

4.9.1 Lightning arrestors are also called surge diverters. The primary purpose of a lightning arrester is to protect the system from getting damaged by the over-voltages caused due to lightning strokes and switching surges. Lightning arresters absorb the energy and reduce the over voltage in the system. The ideal arrester is one which draws negligible current at operating voltage by offering very high impedance and negligible impedance

during flow of current. The breakdown voltage of LA should be kept much lower than that of the other equipments in the substation, but should not be so low as to cause a power frequency flashover due to variation of the supply voltage or normal switching surges. While selecting a lightning arrester the following points are generally considered.

- i) Maximum line to line voltage
- ii) The rated discharge current
- iii) The power frequency flashover voltage
- iv) Impulse flashover voltage
- v) Residual discharge voltage

4.9.2 Types of lightning arresters

4.9.2.1 There are four general types of lightning arresters, namely :- The rod gap type, Expulsion type, Conventional valve type and Zinc oxide gapless lightning arresters. The rod gap and expulsion type lightning arrester do not provide the required level of protection. The conventional valve type LAs have become complicated due to use of large number of components forming ionising system, trigger systems grading net work, interrupting and are stretching system. Zinc oxide gapless lightning arresters are of new generation and these LA's have the following advantages over the types of LAs

- i) Matching and controlled protective level
- ii) Faster response due to elimination of series gap
- iii) Energy is absorbed and hence over voltages are reduced.
- iv) Light and rugged construction.
- v) Improved thermal characteristics.
- vi) Better performance under polluted conditions.
- vii) Better pressure relief performance.
- viii) Better sealing arrangement.

4.9.3 The Location of lightning arrester and precautions to be taken in its installation.

4.9.3.1 The lightning arrester shall be installed very close to the apparatus to be protected. A practical rule is that the distance should not be more than 10m. In case of big transformers LA is installed immediately after the busing. In case of the incoming Transmission line is more than 4 km. long then LA's shall also be provided at the entry of the S/S. The connections should be solid and direct. Earth connections should be of ample cross section to carry the rated discharge current & the earthing terminal of the arrester and that of the other electrical equipments shall be connected together to the main earthing bus.

4.10 CLEARANCES

To ensure satisfactory and reliable performance of any electrical net work, it is essential to provide adequate electrical clearances Electrical clearance is defined as the minimum distance required between live parts and earthed material (earth clearance) or

between live parts and different potentials (phase clearance) in order to prevent flashovers. Safety clearance also called as sectional clearance is defined as the minimum distance required between unscreened live conductor and the limits of a work section. Safety clearances are required for safety of personnel in inspection, operation and maintenance. Minimum electrical clearances for outdoor switchgear as stipulated in IS 3072.

Voltage rating	Impulse withstand level	Minimum clearance to earth	Minimum clearance between phases	Min clearance from any point where they may be required to stand to the nearest unscreened conductors air(section safety clearance)
kV (rms)	kV (Peak)	(mm)	(mm)	(mm)
72.5	325	630	750	3230
	<u>350</u>	<u>675</u>	<u>810</u>	<u>3270</u>
123	450	920	1065	3520
	<u>550</u>	<u>1150</u>	<u>1350</u>	<u>3750</u>
145	550	1150	1350	3750
	<u>650</u>	<u>1380</u>	<u>1600</u>	<u>3980</u>
245	875	1800	2000	4400
	900	1900	2300	4550
	<u>1050</u>	<u>2300</u>	<u>2700</u>	<u>4900</u>

Figures underlined have been adopted in RDSO's specifications.

4.11 EARTHING

4.11.1 Earthing system is of utmost importance for the purpose of protection in both electricity supply and utilisation. The primary need of earthing is that in the event of fault sufficient current shall flow through the fault path so as to operated the protective gear and preventing dangerous potential rise on parts of electrical equipments that are not alive. It is therefor, essential that earthing system shall have sufficient cross section and low resistance to provide a path for the traction current. Earthing also provide the return path for the traction current, ensures that non current carrying parts such as equipment frames, fencing and structures are always at ground potential even after the failure of the insulation. Earthing also helps to reduce the effect of induced voltage in adjacent communication circuits.

4.11.2 Types of earthings

There are two types of earthing namely

- i) Equipment earthing
- ii) System earthing

Equipment Earthing

Equipment earthing is for the safety of operating personnel, public and property. In this earthing all the non-current carrying metallic parts, such as frame of circuit breakers, interruptors, transformers, potential and current transformer, steel structures, fencing panels and uprights are connected to main earthing bus also known as earth grid by means of two separate and direct connectors. During an earth fault in the equipment heavy leakage current flows to earth resulting in potential rise almost that of live conductor and at that time if any person comes in contact with the frames or carrying maintenance will get severe shock which may prove to be fatal. Therefore, it is very essential to maintain a very low earth resistance value for all the metal parts so as to enable circuit breaking device to trip at pre-determined value.

4.11.3 System earthing

In system earthing one leg of the secondary bushing on 25KV side of each traction power transformer is solidly earthed by connecting it to the earthing ring by means of two 75mm X 8mm or 80mm X 12mm M.S. flats. Further the earthing ring shall be connected to a buried rail in the ground by the side of the track by means of four 75mm X 8mm M.S. flats (for two track section).

One of the designated terminals of the secondary of each potential, current and auxiliary supply transformers is also connected to the earthing ring by means of duplicate 50mm X 6mm MS flats.

4.11.4 Earth resistance

At each power supply installations, an earthing ring or bus comprising the required number of earth electrodes, also called earthing stations; inter connected by means of MS flat is provided. The combined resistance of system earth is not allowed to exceed the following limits.

Traction Sub-station	-	0.5 ohms
switching station	-	2.0 ohms
Booster Transformer Station	-	2.0 ohms
Auxiliary supply transformer station	-	10.0 ohms

4.11.5 Design of grounding system

4.11.5.1 The design of the grounding earthing system depends on the following considerations

- Magnitude of fault current
- Duration of fault current
- Thermal stability limits of material
- Mechanical strength
- Corrosivity

The short time current carrying capacity of a conductor can be determined from the following formula :-

$$A = (12.15 \times 10^{-3}) \times I \times \sqrt{t} \text{ for welded joints and}$$

$$A = (15.7 \times 10^{-3}) \times I \times \sqrt{t} \text{ for bolted joint where}$$

A is the cross-sectional area in mm² & I current in Amps and 't' is fault clearance time.

To compensate the loss due to corrosion, the main earthing ring size shall be increased by 100% and size of inner conductors by 50%.

4.11.5.2 The minimum number of pipe earth electrodes to be provided at traction substation depends upon the soil resistivity. However, the approximate number of electrodes can be determined from the following equation.

$$\text{Number of electrodes} = \frac{\text{Fault Current}}{500}$$

The distance between the two earth electrodes shall not be less than twice the length of the electrode. The earth electrode used at TSS is of 40 mm dia galvanised iron pipe of four meter length.

4.11.6 Shielding wire/earth screen

An overhead earth wire is provided in the switch yard of the sub-station connecting the principal gantry masts with 7/9 SWG or 19/2.5 G.I. wire for protection against direct lightning strokes. The shielding conductor is strung about 3.5 metres above the strung bus (for 132 KV's) so that all the conductors and equipments lies within the protection angle of

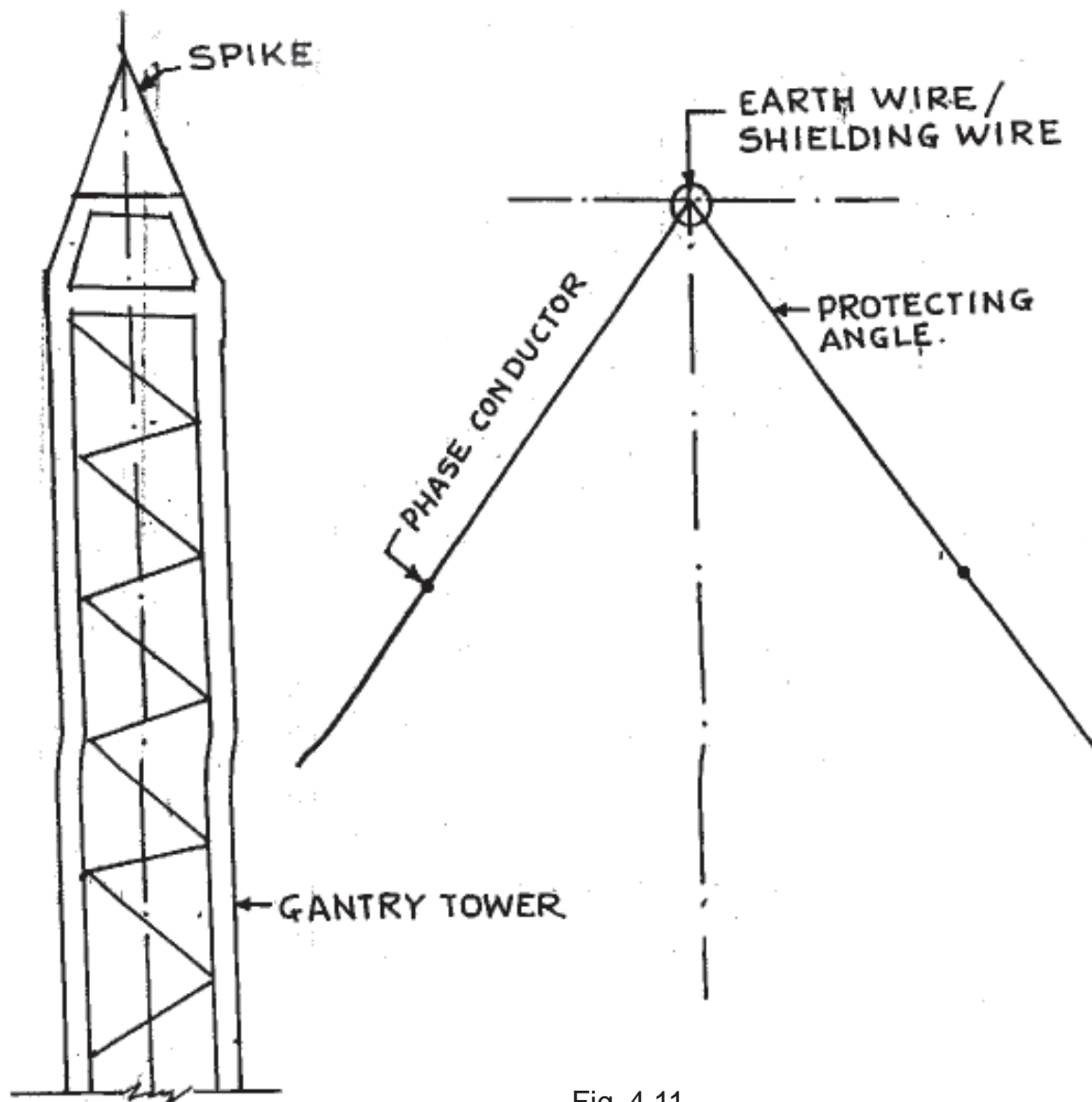


Fig 4.11

45° as shown in Fig 4.11. An angle of 60 deg. may be used where more than one wire is used.

Instead of shielding wire some of the electricity authorities are using spikes which serve the same purpose. These spikes are provided on the gantry towers/masts.

4.12 INSULATION CO-ORDINATION OF SUBSTATION EQUIPMENTS

4.12.1 For each system voltage basic impulse, insulation level has been fixed by most of the National and International standards. The major substation equipments, viz. transformers, and potential transformers are manufactured for the same insulation level. In general, four levels of insulation in a station are recognised, the bus section is the highest, the post insulators, breakers, switches etc. next lower, the transformers next lower and the lighting arrester is the lowest.

4.12.2 BIL of various equipments used in the Traction substation as adopted by Indian Railways are as given below

SN	Name of the equipment	One minute wet power frequency withstand voltage KV (rms)	1.250 micro second impulse withstand voltage test
1.	<u>Traction Power Transformer</u>		
	(a) 220 KV	---	
	(b) 132 KV	275	650
	(c) 25 KV	105	250
2.	<u>Circuit Breakers</u>		
	(a) 220 KV	460	1050
	(b) 132 KV	275	650
	(c) 25 KV	105	250
3.	Isolators		
	(a) 220 KV	460	1050
	(b) 132 KV	275	650
	(c) 25 KV	105	250
4.	132 KV CT275	650	
5.	25 KV CT	95	250
6.	25 KVPT	105	250
7.	25 KV interruptor	105	250
8.	Lightening arrestor		
	(a) 25 KV	Continued Op volt35 KV F/o 125 KVP max.	
	(b) 132 KV	-do-95 KV F/o 350 KVP max.	
	(c) 220 KV	-do-160 KV F/o 550 KVP max.	

4.13 SCHEME OF PROTECTION

4.13.1 The scheme of protection provided at each traction sub-station can be broadly divided into the following two categories.

- i) Protection of Traction Power Transformer.
- ii) Protection of the overhead equipment.

4.13.2 Protection of traction power transformer

The protection used for the transformer follows conventional methods and comprises the following :-

- (a) Protection against internal faults by means of high speed differential relay with necessary restraining features to prevent operation due to inrush magnetising current when the transformer is charged.
- (b) Back-up protection of internal earth faults by means of instantaneous restricted earth leakage relays provided separately on primary and the secondary sides.
- (c) Protection against over current by means of non-directional relays with inverse definite minimum time lag characteristics, provided on one of the phases on the primary side of the transformer and on the un-earthed leg on the secondary side of the transformer. The relay on the HV side is also provided with an instantaneous over current element.
- (d) Protection against internal faults by means of a buchholz relay
- (e) Protection against low oil level
- (f) Protection against high oil temperature
- (g) Protection against high winding temperature.
- (h) Protection against high voltage surges by means of LA.
- (i) Protection against direct lightning stroke by means of shielding wire and spikes.
- (j) Provision of adjustable arcing horns.

4.13.3 Protection for overhead equipment

The scheme of protection of the overhead equipment as adopted comprises the following relays :-

- (a) A 'Mho' relay for an impedance of 20-25 ohms and a phase angle of 75° for protection against the earth faults. This relay works on the principle of discrimination between the phase angle of the fault impedance and the working impedance of the system. This is used for protection against distance earth faults.
- (b) Instantaneous over current protection. This relay provides primary protection to the OHE on earth faults in the vicinity of the feeding post. The current setting of the relay may correspond to about 200% of the continuous current rating of the traction transformer.
- (c) Wrong phase coupling relay The 'Mho' relay with a maximum torque angle of 75° as not adequate for protection against wrong phase coupling of the two different phases at the neutral section or at the feeding post during extended feed condition. Therefore, an additional MHO relay with a maximum torque set at 125° is provided.

- (d) High speed inter tripping relay. In the event of failure of traction sub-station, 25 KV supply is extended from the adjacent sub-station by closing the bridging interruptor at sectoing post Under such emergency feed conditons, wrong phase coupling may be caused at the overlap oppostite the failed S. S. by the pantograph of the locomotive, rasulting in the tripping of 25 KV CB at any one of two S/S through wrong phase coupling relay (Mho). This may result in the formation of an arc at the overlap due to which the OHE may be damaged. The damage due to arc can be minimised by tripping the feeder circuit breaker at the other sub-station also. This is achieved by an inter tripping arrangement through the remote control equipment.
- (e) Auto reclosing of feeder circuit breakers single shot auto-reclosing scheme for 25 KV feeder circuit breakers at the traction sub-station has been adopted to facilitate reclosing of the 25 KV feeder circuit breaker authomatically once after a preset time delay after tripping of the circuit breaker on OHE fault. This feature will help in quick restoration of traction power supply to OHE if the fault is of transient nature. It will also help in checking the continuance of arc in the event of the pantograph of a moving locomotive passing the overlap opposite the feeding post.
- (f) Panto Flash Over protection relay : Panto Flash Over relay is provided for protection of OHE from flash over at insulated over lap in front of Traction sub - station, when pantograph passes from live OHE to dead OHE across the over lap. This relay opens the closed feeder circuit breaker to prevent melting down of OHE. Relay can be bypassed either locally or Remotely. One relay monitors one Line.

Principle and Operation :

When ever one of section of insulating over-lap (IOL) is tripped on intermittent fault, and electric train enters from live to dead section of the FP-IOL, there shall be a heavy flash over, particularly when the Panto leaves the IOL which may damage the Panto. The extent of damage is dependent upon the intensity of current drawn by locomotive. to indentify such situtation and trip the feeder circuit breaker connected to the live side of the overlap.

Refer Fig. PFRS the single line diagram of typical traction substration (TSS). One side of the insulated overlap, A or B can become dead while other section is live due to the tripping of respective feeder CB on fault or manual tripping. This

condition can take place on normal condition or at feed extended condition. The potential transformer PT1 to PT2 connected at either side of IOL indicates OHE healthiness. During dead connection the PT secondary voltage is considerably low. If voltage is appeared on PT secondary and respective feeder CBs is in open condition then this voltage is due to the bridging of Panto. The relay continuously monitor the status of both PTs, CB at TSS and SSP / SP and depend upon logic give trip command to respective CBs. The relay can by pass manually or either remotely from RC.

Logic Chart

Sr. No.	FCB1	SCB1	PCB1	PCB2	FCB2	SCB2	PCB3	PCB4	PT1	PT2	Trip1	Trip2
1	0	0	0	0	*	*	*	*	1	1	1	0
2	*	*	*	*	0	0	0	0	1	1	0	1

1-Breaker / Interruption Close / PT Normal

0 - Breaker / Interruption Close / PT no voltage

*- Don't care N - Normal Feed

Note : Same Logic shall hold good for other lines also with another Logic 2 Realy.

g) Delta - I protection Relay : Delta I protection Relay is provided for clearance of high resistance earth fault of OHE.

The protection functions include Vectorial Delta - I protection & Distrubance Recorder. The realy continuously monitoring the increments in the fundamental and the third harmonic currents.

Operation :

Digital Integrated Vectorial Delta - I Relay :

The Delta - I Relay continuously monitors the OHE Current and Voltage through CT and PT inputs. The high speed Micro - controller of the unit simultaneously samples these current and voltage signal using two separate A/D converter for zero phase difference error. The micro-controller performs a power full digital algorithm on the digitized current and voltage samples to find line Impedence (Z,R and X), the fundamental, second harmonic and third harmonic of the current, Vectorial values of current and voltage as required for the operation of the realy. The tuned band-pass characterstics provide stable and excellent filter response, rejecting noise signals.

The relay continuously monitors the vectorial ΔI , the moment ΔI current cross the set value, relay start Trip Time. During the Trip Time if X components of complex impedance is with in the set blinder limit then relay provides trip command.

The relay allows power transformer changing also starting of multiple locomotives (EMUs) on the same section without unwanted tripping. For this, the 2nd and 3rd harmonic components of the load current are monitored, and appropriate restraint of the Relay element is done. if 2nd harmonics component of current increases more than 15% then relay blocks the tripping operation. If a 3rd harmonics component increases more than 15% of fundamental then relay internally de-sensitized the - I setting by factor of 0% to 100% (programmable). The De-sensitized V. Delta - I can be claculated by following formula.

$$\text{De-sensitized V. Delta I setting} = \frac{(\text{V. Delta - I setting} * \text{De - sensitivity}) + \text{V. Dealta I setting}}{100}$$

The range of measured / computed parameters as well as internal digital flgas status are dynamically displayed on a pront panel dot - matrix 16 x 2 LCD display.

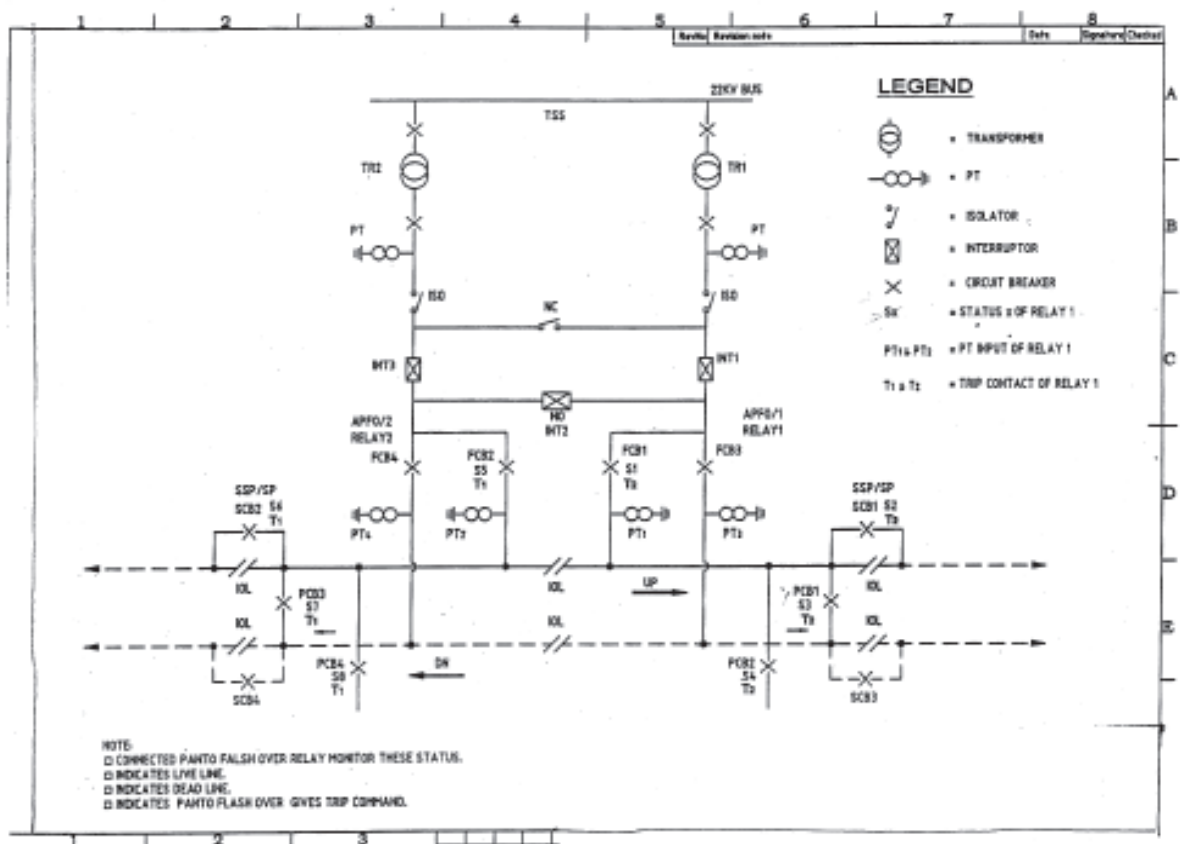


Fig. P.F.R.S.

4.14 INSULATORS

4.14.1 Provision of adequate insulation in a substation is of primary importance from the point of view of reliability of power supply system and safety of the working personnel. However, the substation design should be such that the quantity of insulators used is a minimum commensurate with the security of supply.

The creepage distance of the insulators to be used in the traction substation depends on the degree of pollution level. But as the pollution level, vary from place to place, therefore insulators to be used at the traction sustation have been provided with a creepage distance of 25 mm/ KV so that these insulators are able to withstand the service conditons even under heavily polluted condition including coastal areas.

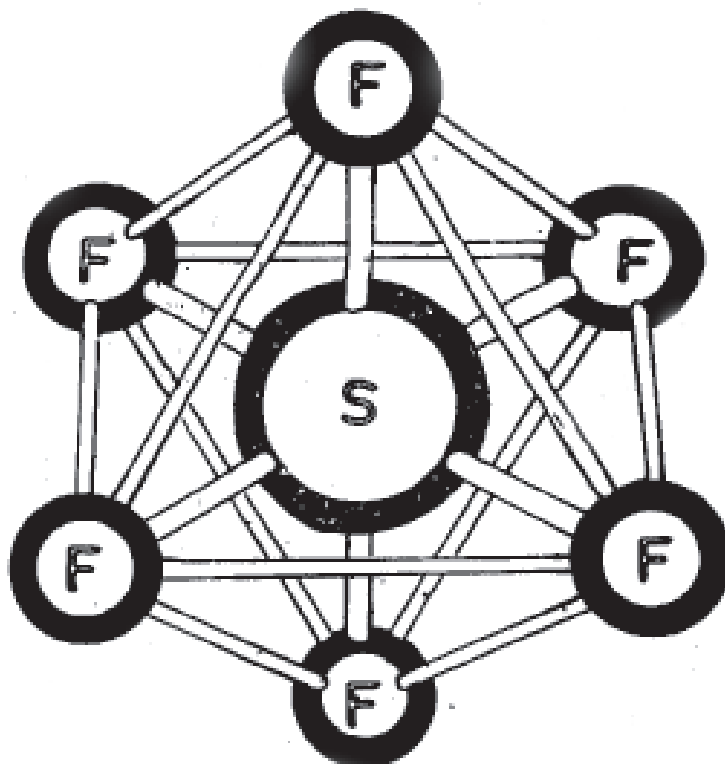
4.14.2 For strung bus, standard 10" disc insulators of 7000 Kgf. strength have been used for system voltage upto 132 KV and for 220 KV traction substation 11" disc insulators of higher strength have been specified. But for rigid bus, on the primary side of the transformer post type stack insulators have been used and for 25 KV side only solid core type insulators have been adopted for all applications. Due to development of solid core insulators even for higher system voltage and their added advantages over conventional post type stack insulators the same are being used now for all applications such as bus bar support insulators and isolators. Insulators used for the constructions of circuit breakers, interruptors, PTs, CTs and bushings of power transformer are of hollow porcelain housing.

SULFUR HEXAFLUORIDE(SF₆) GAS

The SF₆ Gas in a pure state is inert, exhibits exceptional thermal stability and has excellent arc quenching properties as well as exceptional high insulating properties. It is one of the most stable compounds. Inert, nonflammable, nontoxic and odourless. The SF₆ gas remains gas without liquification down to - 30 C at the maximum pressure of the puffer type breakers.

The density of SF₆ Gas is about five times that of air and heat dissipation in it is also much more than in the air. At the atmospheric pressure, the dielectric strength is about 2.4 times that of air and at about 3 kg/cm² it is same as that of oil. Table No.A gives physical properties. There is some decomposition of the gas after long periods of arcing however, such decomposition is very little and has no effect up on dielectric strength and interrupting capability. The solid arc-product formed by arcing is metallic fluoride which appears in the form of a fine grey powder. This arc generated powder had high dielectric strength under dry conditions as existing in the breaker. A good quality absorbent is used in the apparatus to remove most of gaseous decomposed by products. So the level of this gaseous By-product is kept very very low.

Certain impurities such as air result in the dilution of the SF₆ but it is not worth while bothering to measure the dilution of SF₆ Gas at the field as long as the process recommended is followed.



Physical Properties Of Sf6 Gas

1	Molecular Weight	146.07
2	Melting Pointing	-50.7C
3	Sublimation Temp	-63.8C
4	Critical Pressure	(45.547+0.003)C
5	Critical Pressure	38.55kgf/cm ²
6	Critical Density	0.730g/cm ³
7	Dielectric Constant at 25C 1atm	1.002
8	Thermal Conductivity at 30°C	3.36*10-5
9	Specific heat ratio	1.07
10	Density at 20°C at 0kg/cm2-g at 1 “ at 5 “ at10 “ at15 “	6.25gm/lit 12.3 38.2 75.6 119.0
11	Solubility in oil in H2O of H2O at 30°C	 0.297 cc/cc 0.001 cc/cc 0.0035+0.01gm/gm
12	Cp	23.22cal/mole°C

PROTECTION SCHEME OF TRACTION SUB STATION

(Extract of RDSO Specn No. ETL/PSL/65(8/84))

5.0 POWER SUPPLY SYSTEM

Power is received from the supply authorities grid network at 132KV or 110KV or 66 KV either at individual traction sub station(TSS) or at a single point of supply from where it is transmitted through railway's own 132/110/66KV transmission line to the various sub-station location, with line sectioning facilities provided as required 25KV power supply for traction is derived through 132 / 25 kv or 66 / 25 kv single phase transformer the primary winding being connected to any two (nominated) phases of the incoming three phase, two phase line and on the secondary side one terminal of the 25kv is connected to the traction overhead equipment (OHE), the second terminal being solidly earthed and connected to the running track rail each transformer has its associated breaker on the 132/110/66KV and 25KV sides , with a separate set of 25KV breaker called feeder breaker for feeding the traction overhead lines (OHE).Adjacent sub- station are fed from different phase of the three phase system in rotation and neutral section or dead section(SP) are provided on the 25KV OHE and for sectioning and fault location and maintenance of OHE.The OHE supply is switch ON or OFF through intrruptors (load switches) which do not open on fault but can be closed on fault.The fault is cleared by feeder circuit breakers.The 25KVtransformer beaker serves as back up protection

Normally power supply from a sub-station extend upto the neutral section on either side, but in case of an emergency, necessitating the total shut down of a sub-station, power supply from adjacent sub-station, on either side as extended upto the shut down sub-station by bridging the neutral section through intrruptor.

5.1 BOOSTER TRANSFORMERS

In order to reduce inductive interference in adjacent telecommunication circuit booster transformer on certain section of electrified track installed in series with the 25KV traction overhead equipment.The primary winding of the booster transformer is connected to the 25KV overhead equipmdent .The primary winding and the secondary winding as in series with the return conductor which is strung close to the 25KV overhead equipment .Booster transformer with a rating of 100KVA provide necessary voltage to force the traction return current from the rail and earth to flow through the return conductor .The booster transformer have a leakage impendence of about 0.15 ohm each and are spaced about 2.66Km apart.

5.2 PROTECTIVE RELAYS AT THE TRACTION SUB-STATION

For protection of transformer, sub-station and the feeder, the following relays are provided on control panel housed in the masonry cubicle at the traction sub-station(TSS)

i) FOR THE TRANSFORMER PROTECTION

- a) Differential relays
- b) IDMT overcurrent Relays for the primary (HV) as well as for the secondary (L.V) side, The IDMT relay on the (HV) side is also provided with an instantaneous overcurrent element
- c) Instantaneous Earth Leakage relays on the primary(HV) side as well as on the secondary (LV)side.
- d) High speed Inter tripping Relays
- e) Auxiliary relays for transformer fault i.e Buchholz Excessive Winding and Oil Temperature trip and alarm and Low oil level alarm

ii) FOR THE OVERHEAD EQUIPMENT PROTECTION

- a) Admittance type directional Distance Protection relays
- b) Admittance type relay for protection against Wrong phase coupling
- c) Instantaneous overcurrent Relays.
- d) Pantograph Relay
- e) Delta I relay for high resistance fault.

5.3 AUTO-RECLOSING OF FEEDER CIRCUIT BREAKERS

A single shot auto reclosing scheme for 25kV feeder circuit breakers(s) at AC traction sub-station has been adapted to facilitate reclosing of the 25kV feeder breaker automatically once after a pre-set time delay after tripping of the circuit breaker on OHE fault. This feature will help in quick restoration of traction power supply to OHE if the fault is of a transient nature. It will also help in checking/restricting the continuance of arc in the event of the pantograph of a moving locomotive passing the overlap opposite feeding post at such moment and thus protecting the OHE, catenary in particular, from consequent damages.

5.4 INTER-TRIPPING OF FEEDER CIRCUIT BREAKERS

In the event of failure of a traction sub-station, 25kV supply is extended from the adjacent sub-station by closing the bridging interruptors at SPs. Under such emergency feed condition, wrong phase coupling may be caused at the overlap opposite the failed sub-station by the pantograph of a passing locomotive, resulting in the tripping of 25kV Feeder Breaker at

any one of the two sub-station through Wrong phase Coupling (Mho) relay. This may result in the formation of an arc at the overlap due to which the OHE may be damaged. The damage due to the arc can be minimised by tripping the feeder circuit breaker at the other sub-station also. This is achieved by an intertripping arrangement through the Remote Control Equipment.

5.4.1 For the purpose of calculation, the values of loop impedance with earth return for the OHE are taken as under at 70° phase angle

- | | |
|----------------------------------|-------------|
| i) Single track OHE | 0.41 ohm/km |
| ii) Double track OHE | 0.24 ohm/km |
| iii) Single track OHE with
RC | 0.70 ohm/km |
| iv) Double track OHE with
RC | 0.43 ohm/km |

5.5 GOVERNING SPECIFICATIONS

The main component covered by this specification shall conform to the following standard specification (latest version) which shall be applied in the manner altered, amended or supplemented by this specification and Indian electricity Rule where applicable

- | | | | |
|---|------------|---|------|
| i) Electrical relays for power
system protection | IS:3231 | - | 1965 |
| ii) static protective relays | IS:8686 | - | 1977 |
| iii) Electrical indicating instrument | IS:1248 | - | 1968 |
| iv) Control cable | IS:694 | - | 1977 |
| v) Interposing current transformer | IS:2705(4) | | 1981 |

5.6 RELAYS

5.6.1 The relays shall be of the draw-out(plug-in)switch board type, back-connected and suitable for semi-flush mounting provided with dust-tight covers of dull black enamel finish.

5.6.2 The relays shall be provided with test plug or separate test blocks for secondary injection tests. The relays parts shall be easily accessible with the relays mounted on the panels. The terminal connections inside the relay's housing shall be such that when the relay is drawn-out the current terminal of the CT secondaries get shorted automatically. Since the sub-stations are normally unattended, the relay shall be of self-reset type except for the following which shall be of hand-reset type :

- i) Low oil level alarm.
- ii) Winding temperature indicator alarm and trip.

- iii) Oil temperature indicator alarm and trip
- iv) Buchholz alarm and trip
- v) Auxiliary unit in differential relays

5.6.3 In addition, wherever necessary for proper functioning of scheme hand reset contact in auxiliary relays shall also be provided. All the protective relays and all those associated auxiliary relays in the circuit of alarm and annunciations etc including inter trip relays shall have flag type operation indicators with manual reset service suitable for operation from the front of relay cases.

5.6.4 The current coil can be rated for the continuous current of 5A. The voltage coils shall be rated for 110Vdc. The contact of relays shall be silver plated. The current coil shall be capable of withstanding 20% overload for 8hrs.

5.6.5 The relays shall be test voltage class 2 as per clause 3.2 of IS 8686-1977

5.6.6 The auxiliary relay coils shall be designed for continuous service voltage of 110 V dc and shall be capable of satisfactory operation up to at least 20% fluctuation in voltage

5.6.7 The output of relays shall be capable of operating the armature attracted type auxiliary relay which shall have a burden of above 20VA at 110V dc.

5.6.8 the relays shall have name plates with rating data, serial number and manufacturer's name marked on them. The metal case shall be provided with separate earthing terminal.

5.6.9 The basic requirement of the scheme of protection are indicated in clause 20 to 23. The tender shall furnish full detail of the protective scheme offered together with the characteristics of relays and typical circuit diagram.

5.7 STATIC TYPE RELAYS

The Indian Railways have been using Electro Mechanical type relays manufactured by Ms English Electric co. of india ltd., (GEC-ALSTHOM) for 25KV Traction sub-station.

SN	Description	type design	Rating/setting range
A) TRANSFORMATION PROTECTION			
1.	Transformer percentage biased differential	DDT-12	Current setting 40-100% of 5A, 20%, 30% or 40% 5A Bias setting
2.	IDMT overcurrent relay combined with CAC-13 instantaneous high set overcurrent (132KV side)	CDG-26 CAG-13 CAG-14	CDG 16, 80-320% of 5A 400-1600% of 5A 10-40% Of 5A
3.	Restricted earth		

fault relay (132KV&25KV side)

- | | | | |
|----|--|--------|---------------|
| 4. | IDMT overcurrent relay
(25kv side) | CDG-16 | 80-320% Of 5A |
| 5. | Aux relays for buchholz
excessive winding and oil
tem tripping | VAA-33 | |

B) OHE PROTECTION

- | | | | |
|----|---|--------|--|
| 1 | MHO type directional
distance protection
relay(DPR)
gree | YCG-14 | 0.33 to 12 ohm extended
zone each upto 60 ohm
of 5A with MTA 75 de |
| 2 | MHO relay for protection
against wrong phase
coupling(WC) | YCG-14 | 0.33 to 12 ohm extended
zone reach upto 60 ohm
of 5A with MTA 125 de
gree with forward offset
of 11% |
| 3. | Instantaneous high set
over current relay on
25KVside(OC) | CAG-17 | 100-800%of 5A |

C) AUXILIARY RELAYS

- | | | | |
|------|---------------------------------------|--------|--|
| 1 | D.C Supervision | | |
| i) | Transformer HV CB
Trip supervision | VAA-11 | |
| ii) | Transformer LV CB | VAA-11 | |
| iii) | 25KV Feeder control | VAA-11 | |
| iv) | 25KV intrruptor control | VAA-11 | |
| v) | 5.DC fail alarm cancel | VAA-11 | |
| vi) | Alarm annunciation
control | VAA-11 | |

SN	Discription	Type design	Rating/setting range
2.	Auxiliary realy for contact multiplication of directiional distance protection relay(YCG-14)	VAA-11	
3.	Alarm bell realy	VAA-21	
4.	Flasher relay	VAA-21	
5.	Timer relay for single shot Auto-Reclosing	VAT-11	

	scheme	
6.	Auxiliary relay for Auto reclosing scheme	VAA-61
7.	High speed Master trip relay	VAJH-13
8.	High speed inter trip relay	VAJH-13
9.	Auxiliary relay for Buchholz oil temp/ winding temp/low oil alarm	VAA-43
10.	Alarm annunciation relay	VAA-121

5.8 SCHEME OF PROTECTION FOR 132/25 KV OR 110/25 KV OR 66/25 KV TRANSFORMER

5.8.1 Differential protection

Protection against internal fault shall be provided by means of a sensitive single-pole differential relays. The relays shall be of the high speed type and shall operate in less than two cycles. The relays shall incorporate the following feature

- i) There shall be no necessity for changing the setting of relays when the transformer tap is changed. The transformer is provided with tap from -15% to +10%.
- ii) Necessary harmonic restraining feature shall be incorporated to prevent operation due to inrush of magnetisation current when the transformer is charged either from the HV or the LV side.
- iii) The relays shall not operate for maximum through fault current.
- iv) The current setting of the relays shall be adjustable, preferably between range of 20% and 80%. The minimum current setting shall be as low as possible to obtain better sensitivity.
- v) Adjustable bias setting should also be provided. The bias at minimum operating current setting shall be 20%, 30% or 40% to suit the tapping range of the traction transformer and other designed considerations.

The relays shall be connected to bushing type current transformer provided in the bushings of 132/25 kV, 110/25kV transformer. However, interposing current transformers of suitable ratio and ratio with matching characteristics of knee point voltage, excitation current etc. shall be provided with the differential relays in order to boost up the bushing CTs secondary current, at full load, to a value equal to relays rated current. Magnetisation ratio error curves for the current transformers

will be supplied to the successful tenderer to enable him to match the characteristics of the relays and interposing CTs with those of the current transformer.

5.8.2 Earth Leakage Protection

Back up protection for internal earth fault within the transformer shall be provided by means of a sensitive, high speed, earth leakage. Such relays shall be provided separately for both the primary and secondary side the relays shall be connected to separately mounted current transformer. The relays shall be adjustable between 20% and 40% of 5Amps in equal step at 5%. The relays shall be of T-10 class with operating time not exceeding 10 ms.

5.8.3 Over current protection

Protection against over current in the transformer shall be provided by means of single-pole non directional overcurrent relays with inverse definite minimum time lag characteristics both on the primary and the secondary side of the transformer. Further an additional instantaneous over current relays shall be provided on the primary side. On the primary side the over current relays shall be connected to separately mounted current transformers. On the secondary side the over current relays shall be provided only on the live (unearthed) leg of the secondary terminal and shall be connected to a separately mounted current transformer. The overcurrent relay on the secondary side shall serve as back up protection against fault etc. The over current relays on the primary side shall serve as back up to the differential and earth leakage relays against heavy fault. Proper discrimination shall be maintained in the operation of these two sets of overcurrent relays. The setting on these relays shall be adjusted between

	Relay Position	current setting	Time multiplier setting
i)	IDMT overcurrent on primary side	80% to 320%	0 to 3 secs.
ii)	Instantaneous over current on primary side.	400% to 1600%	
iii)	IDMT overcurrent on secondary side.	80% to 320%	0 to 3secs.

The instantaneous relays shall be of T10 class with operating time not exceeding 10 ms at 5 times the current setting.

5.8.4 The differential relays and earth leakage relays both on the primary and secondary sides as also the over current relays on primary side shall cause inter-tripping of the 132/110/66KV and 25KV circuit breakers associated with the transformer. The inter-tripping of the associated transformer circuit breakers on HV and LV side shall also be effected due to other faults in the transformer, namely Buchholz trip. The IDMT over current relays on the secondary side shall, however, trip the respective circuit breaker on 25KV side only. The inter-tripping of associated transformer circuit breakers envisaged above shall be effected through a high speed tripping relay with 'hand reset contact. Such inter tripping relay shall lock out the closing of circuit breaker from all mode of closing commands viz. remote control, local at the panel and also at the circuit breaker mechanism, until the inter-trip relay or the lock out relay (if provided separately), is reset manually.

5.8.5 Other protective devices

The transformer as supplied by the purchaser will be fitted with following warning and protective devices.

- i) Low oil level alarm.
- ii) Buchholz relay with alarm and trip contact.
- iii) Oil temperature indicator with alarm and trip contact
- iv) Winding temperature indicator with alarm and trip contact

These contact shall be wired up to a weather proof terminal box mounted on the transformer by the transformer manufacturer .The connection shall be extended to the alarm and trip circuit as well as to annunciator provided on the control board.

5.9 SCHEME OF PROTECTION FOR 25KV OVERHEAD EQUIPMENT

5.9.1 The sub-station equipment as well as the over head equipment is protected against short circuit and over load by means of feeder circuit breakers .Normally the tracks on one side of the sub-station are fed through one feeder circuit breakers in case defect on one feeder,the other feeder circuit breaker is arranged to feed track on both side of the sub-station.To protection scheme shall full-fill the following function

- i) To detect all short circuit over the zone of overhead equipment fed by the feeder circuit breaker.
- ii) To operate with minimum delay in opening the circuit breakers.
- iii) To refrain from operation at the maximum working current i.e discriminate between the maximum load currents and short circuit current even though the magnitude of the former is at time more than the latter especially when the fault are remote from the sub-station
- iv) To detect and isolate fault on the OHE caused by accidental coupling of two different phase from adjacent sub-station
- v) To provide single shot auto-reclosing of the feeder circuit breaker after a present time interval adjustable between 0.5secs.to 30 secs.
- vi) To reclose the 25kv feeder circuit breaker through single shot automatic reclosing scheme in the event of feeder circuit breakers tripping on fault through any of the three relays viz.admittance(MHo)relay for wrong phase coupling and instantaneous over current relay.
- vii) To detect and isolate the flashover caused by pantograph on an overlap in front of Traction Substation when panto moves from live to dead section over the insulated over lap. This protection is provided by panto flasover Relay.
- viii) To detect and isolate a high resistance OHE ground fault. This fault can not be

detected by normal distance protection relay. Hence, a separate relay called Delta I relay is provided for the purpose.

5.9.2 The normal zone of a sub-station to neutral section varies from 25 to 40Km. Under emergency feed condition, however, the zone would extend upto the next sub-station by closing the bridging intrruptors at the neutral section and will be about double the zone of normal feed. It will be apparent from the impedance value given in para-4 that the fault current under such condition could be well below the traction load current. Over current or plain impedance relay which operate below a certain impedance level and which function independently of the phase angle between voltage and current, will be unable to discriminate of the argument of the impedance of given argument is required.

5.9.3 The protective system shall, therefore, comprise the following relays

- i) An admittance (MHo) relay to cover the zone of protection i.e. from the sub-station to the adjacent sub-station and operate for any earth fault on the overhead equipment in the zone. In order to allow for the additional impedance of booster transformers and return conductor, the relay shall have a reach of atleast 125km of single track OHE with an impedance of 0.52 ohm/km at 70 degree phase angle.
- ii) an admittance (MHo) relay for protection against wrong phase coupling due to phase to phase fault with 120 degree or 60 degree phase difference between two phases, with a maximum torque angle of 125 degree to 145 degree. The relay may preferably be provided with a forward offset to prevent it from operating on phase to earth faults.
- iii) An over current relay of instantaneous type which can clear faults between the sub-station and the section, with an adjustable current setting ranging from 200% to 800%. The instantaneous relays shall be of 10 class with operating time not exceeding 10 ms.
- iv) A single shot auto reclosing relays to work in conjunction with master trip relay shall be provided.
- v) Pantograph over relay for protection of OHE from flashover caused by movement of pantograph from live to dead OHE across the insulated overlap provided in front of traction sub station. If Neutral section is provided in front of TSS, then there is no need of panto flashover relay.
- vi) Delta I relay is provided for detection and clearance of high resistance earth fault of OHE (not detectable by Distance Protection Relay).

5.9.4 The relays (i), (ii), (iii), (v) & (vi) above shall trip the corresponding feeder circuit breaker in case of fault, through a high speed self reset type tripping relay to be designated as Master trip relay.

5.9.5 A single shot reclosing relay to work in conjunction with MasterTrip relay shall be provided. The auto-reclosing relay shall have an adjustable time setting between 0.5 sec. to 30 sec for the reclosure of the feeder circuit breaker. After single auto-reclose of the breaker it shall be possible to operate the same either manually or on remote control without any necessity for manual reset in auto-reclosing relay. This requirement is essential in view of the sub-station being unattended.

5.9.6 Suitable operation counter shall also be provided individually for distance protection admittance (Mho) relay, wrong phase coupling admittance (Mho) relay, instantaneous over current relays and also for the auto-reclosing scheme.

5.9.7 In addition to the above protection an instantaneous acting undervoltage relay is provided by the purchaser to trip the bridging interruptor at the neutral section in case of undervoltage during emergency feed condition.

5.9.8 The relays shall be suitable for operation from 25KV current transformer and 25KV potential transformer to the following particulars :

Rating	CT	PT
i) Rated system voltage	25KV rising upto 30KV	
ii) Rated transformation ratio	1000-500/5A	25KV/110V
iii) Rated burden	60VA	100VA
iv) Rated accuracy limit factor	15	--
iv) Accuracy class	5P as per IS:2705 (PTIII) 1981	1.0/3P as PER IS:3156 (pt.II & III) 1978

5.9.9 The relay shall conform to the accuracy class 15 as per IS 3231-1965

5.9.10 The operating time for the Mho relay shall be as small as possible and shall not exceed 20ms for a source to line impedance ratio of 1:1 in case of earth fault relays. The operating times for minimum and maximum setting of the relays in term of distance shall be furnished by the tenderer together with the variation in operating time for various fault positions expressed as percentage of relay settings.

5.9.11 The polarizing input for relays shall have a tuned memory circuit, so that it is possible to maintain a polarizing signal even after a fault occurs, for a sufficiently long time for the operation of relay to operate in case of a fault close to the sub-station, when the remaining voltage disappears.

5.9.12 The relays shall be insensitive to power swing, heavy overload and transient condition including magnetizing inrush current of locomotive to transformers and shall be suitably designed to compensate the effect of fault arc resistance.

Characteristics of the Track		LENGTH OF PARALLELISM IN Km.															
		0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000	1.100	1.200	1.300	1.400	1.500	2.600
Overhead	Conductor	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000	1.100	1.200	1.300	1.400	1.500	2.600
Return Circuit	Conductor																
Consisting of																	
all the 4 rolls	Cable	0.333	0.666	1.000	1.333	1.666	2.000	2.333	2.666	3.000	3.333	3.666	4.000	4.333	4.666	5.000	5.333
Overhead	Conductor	0.073	0.146	0.220	0.294	0.368	0.441	0.515	0.588	0.662	0.736	0.810	0.883	0.957	1.030	1.104	1.177
Return Circuit	Conductor																
Consisting of																	
2 rolls	Cable	0.243	0.487	0.733	0.980	1.236	1.480	1.716	1.960	2.206	2.453	2.693	2.943	3.169	3.434	3.660	3.925
Total Electromagnetically Induced Voltage (volts)																	
Mean distance of the conductor from the axis of the two track system in metres																	
6		5.51	11.03	16.53	22.00	27.50	33.01	38.50	44.10	49.60	55.10	60.60	66.00	72.00	77.00	83.00	88.00
10		5.32	10.64	16.00	21.30	26.60	32.00	37.30	42.60	47.90	53.20	58.50	64.00	69.00	74.00	80.00	85.00
12		5.14	10.28	15.42	20.60	25.70	30.80	35.00	41.00	46.30	51.60	56.50	62.00	67.00	72.00	77.00	82.00
14		4.77	9.54	14.31	19.00	23.30	28.60	33.40	38.00	43.00	47.70	52.50	57.00	62.00	67.00	72.00	76.00
16		4.55	9.11	13.65	18.20	22.70	27.30	31.90	36.40	41.00	45.50	50.00	54.50	59.00	64.00	68.00	73.00
18		4.41	8.22	13.33	17.60	22.00	26.50	30.90	35.30	39.70	44.10	48.50	53.00	57.30	62.00	66.00	70.00
20		4.23	8.44	12.66	18.90	21.15	25.80	29.50	33.90	38.00	42.20	46.40	50.50	55.00	59.00	63.00	67.00
25		4.04	8.08	12.12	16.10	20.20	24.10	29.30	33.30	33.40	40.40	44.40	48.60	52.50	55.50	61.00	65.00
30		3.67	7.34	11.00	14.70	18.40	22.00	25.70	29.40	33.00	36.70	40.40	44.40	47.70	51.40	55.00	59.00
40		3.30	6.60	9.00	13.30	16.50	19.10	23.10	26.40	29.70	33.00	36.30	39.60	43.00	46.00	49.50	53.00
50		2.94	5.88	8.82	11.80	14.70	17.60	20.50	23.50	26.50	29.40	32.30	35.30	38.20	41.00	44.00	47.00
75		3.43	4.84	7.26	9.70	12.10	14.60	17.00	19.40	21.80	24.20	26.60	29.00	31.50	33.90	36.30	38.70
100		2.05	4.11	6.15	8.20	10.30	12.30	14.40	16.40	18.50	20.50	22.50	24.60	26.60	28.70	31.00	32.80
150		1.61	3.22	4.83	6.44	8.00	9.70	11.30	12.90	14.50	16.10	17.70	19.30	20.90	22.50	24.00	25.80
200		1.33	2.66	3.99	5.28	6.65	7.90	9.20	10.50	11.90	13.20	14.50	15.90	17.20	18.50	19.80	21.10
250		1.10	2.20	3.30	4.40	5.50	6.60	7.70	8.80	9.90	11.00	12.10	13.20	14.30	15.40	16.50	17.60
300		0.68	1.75	2.64	3.52	4.40	5.30	6.20	7.00	8.00	8.80	9.70	10.60	11.40	12.30	13.20	14.00
400		0.59	1.18	1.77	2.35	3.00	3.50	4.10	4.70	5.30	5.90	6.50	7.10	7.70	8.30	9.00	9.50
500		0.40	0.80	1.20	1.60	2.00	2.40	2.80	3.20	3.60	4.00	4.40	4.80	5.20	5.60	6.00	6.40
600		0.29	0.58	0.87	1.16	1.45	1.74	2.00	3.30	2.50	2.90	3.20	3.50	3.80	4.00	4.30	4.60
700		0.22	0.44	0.66	0.88	1.10	1.32	1.54	1.78	2.00	2.20	2.40	2.64	2.86	3.10	3.30	3.50
800		0.12	0.24	0.36	0.48	0.60	0.72	0.90	1.08	1.26	1.44	1.62	1.80	2.00	2.16	2.34	2.50
900		0.13	0.26	0.38	0.52	0.65	0.78	0.91	1.04	1.17	1.30	1.43	1.56	1.70	1.82	1.95	2.10
1000		0.11	0.22	0.33	0.44	0.55	0.66	0.77	0.88	0.99	1.10	1.20	1.32	1.43	1.54	1.65	1.80

Table 9.2

Electro-static induction due to 25KV as traction

(The changed conductor is assumed to be at a height of 6m above rail level)

Length of parallelism of aerial conductor in km	0.100	0.200	0.300	0.400	0.500	0.600	0.700	0.800	0.900	1.000	1.500	2.000
Distance of the conductor from the catenary(m)	Discharge current in milli-ampere											
08	0.95	1.89	2.84	3.79	4.74	5.69	6.64	7.58	8.53	9.40	14.5	18.9
10	0.72	1.43	2.14	2.86	3.58	4.28	5.01	5.73	6.44	7.16	11.0	14.5
12	0.56	1.11	1.66	2.22	2.78	3.33	3.89	4.44	5.00	5.56	8.5	11.0
14	0.44	0.88	1.32	1.76	2.20	2.64	3.08	3.52	3.96	4.40	5.5	9.0
16	0.36	0.72	1.08	1.44	1.80	2.16	2.52	2.88	3.24	3.66	5.5	7.5
18	0.30	0.59	0.89	1.18	1.48	1.77	2.07	2.37	2.66	2.96	4.5	6.0
20	0.25	0.50	0.74	0.99	1.24	1.49	1.74	1.98	2.23	2.48	3.5	5.0

Length of parallelism of aerial conductor in Km	2.500	3.000	3.500	4.000	4.500	5.000	5.500	6.000	6.500	7.000	7.500
Distance of the conductor from the catenary(m)	Discharge current in milli-ampere										
08	23.7	28.5	33.0	38.0	42.5	47.5	52.5	57.0	62.0	66.5	71.0
10	18.0	21.5	25.5	28.0	32.0	36.0	40.0	43.0	46.5	50.5	53.5
12	14.0	16.5	19.5	22.0	25.0	28.0	30.5	33.5	36.0	39.0	41.5
14	11.0	13.5	15.5	17.5	20.0	22.0	24.0	26.0	28.5	31.0	33.0
16	9.0	11.0	12.5	14.5	16.0	18.0	20.0	21.6	23.5	25.0	27.0
18	7.5	9.0	10.5	12.0	13.5	15.0	16.5	18.0	19.0	21.0	22.0
20	6.5	7.5	8.5	10.0	11.0	12.5	13.5	15.0	16.0	17.5	18.5

REMOTE CONTROL EQUIPMENT

7.1 Introduction

A Remote Control Centre (RCC) is set up near the Traffic Control Office on each Division having electric traction, to work in close liaison with the traffic control. The RCC includes the main control room, equipment room Uninterrupted Power Supply (UPS) room. Remote Control Laboratory and Battery Room and is the nerve centre of the Traction Power Control

Types Of Equipment

The FMVFT equipment (stronger type equipment) was in use for all electrification schemes prior to 1980. Being mainly all relay system. the equipment has become outdated. Salient features of the system can be seen in earlier print of this book.

The SCADA equipment based on State of the art technology has come into use after 1980. Considering the fast growth and development of computer based equipment. newer types with enhanced capabilities and new makes are being introduced. Additional facilities at each new RCC is also natural as new features get incorporated.

7.2 SCADA - TRENDS

Supervisory Control is generally defined; “ as a form of remote control comprising an arrangement for selective control of remotely located units, by electrical means, over one or more common interconnecting channels”.

In the Electric Power industry, supervisory control may be used in as simple an application as controlling a single distribution feeder. In its most complex form, referred to as Supervisory Control and Data Acquisition (SCADA) system, it may control all generation, transmission and distribution over a wide geographical area, from one centralized location.

There were undoubtedly many methods of remote control invented by early pioneers in the supervisory control field, and long since forgotten. For sure, SCADA did not begin with electronic sensors and analog to digital converters; but with a person reading a measurement and taking some mechanical control action as a result of that measurement.

From 1900 to early 1920's many varieties of remote control and supervisory systems were developed. Most of these, however were of one class or the other i.e. either remote control or remote supervision. Perhaps one of the earliest forerunners of modern supervisory control was a system designed by John Harlow in 1921. This system automatically detected a change of status at a remote station and reported this change to a control centre. In 1923, John Bellamy and Rodney Richardson developed a remote control system employing an equivalent of our modern “Check-before-operation” technique to ensure the validity of a selected control point before actual control was initiated.

Perhaps the first logging system was designed in 1927. This system monitored information from a remote location and printed any change in the status of the equipment. together with the time and date when the change took place.

At this time, of course, there was a little choice in the type of components available, thus, all of these systems were electro-mechanical.

Just as the requirements of supervisory control system years ago were rather simple, so were many of the techniques employed. Naturally, as the scope of the supervisory control applications changed, so did many of the fundamentals of supervisory controls technology. Coding patterns were improved to provide higher security and more efficiency. Communication techniques were changed to permit higher speeds of transmission. The advent of solid state circuitry opened vast new possibilities in both operation and capabilities.

7.2.1 WHAT IS SUPERVISORY CONTROL?

Supervisory Control is a collection that will provide an operator, at a remote location, with enough information to determine the status of a substation or generating station and to cause actions or operations to take place at that station without being physically present. Although a supervisory control system may exist to perform control and data acquisition at one specific location, the normal arrangement is to have one central location receiving data and exercising control over many remote stations.

7.2.2 WHY INSTALL SUPERVISORY CONTROL?

The usual reason for installing supervisory control systems is to provide the system operators with sufficient information and control to operate the power system, or some part of it, in a safe, secure and economical manner. Before taking decision to install a SCADA system, certain factors are to be clearly defined. These factors are as follows :-

7.2.2.1 Who are users of data?

In a typical case, the user can be Operators for controlling the system, Maintenance department for maintaining the power supply equipment, Management for decision making and System Designer for designing a better system.

7.2.2.2 What data is available and/or necessary?

As theoretically it is possible to gather data pertaining to each and every event or activity on the power system, a judicious balance has to be kept between available finances as well as identification of all potential users and their requirements.

7.2.2.3 What are the user requirements?

As the SCADA is being designed for the use of power system operators, their needs have to be serviced first.

Firstly, the operator requires only that data, which will quickly and positively alert him to a problem and give him the means to take corrective action in a timely manner. So a sort of filter has to be built in the system to isolate and present the useful data only, to the operator. Then the data has to be in real time for the operator. Almost all other users have a need of the data for carrying out some postmortem operations. This imposes a time constraint on the system for collecting and reporting of data.

Second important need is organised presentation of the data, which should be made available for which the size of bulk memory has to be fixed.

Thirdly, means to get hard copy of data in a chronological order should be made available, for which the size of bulk memory has to be fixed.

And lastly, feature for getting summary of various events/records should be possible.

7.2.2.4 What is the type of display required?

Data displays are generally visual, recorded, or audible. In visual category would come VDUs, Mimic Diagram Board, strip chart recorders, lights and other forms of displays. The recorded format is generally some sort of hard copy obtained from the logger. Most common audible data output is in the form of a bell or hooter to call the attention of the operator.

7.2.2.5 Other factors

These can be regarding training of Operators, maintenance personnel and System designer for carrying out modification in the system, based on the requirement. There can also be cases where a new system is to be put along side and older system, thereby requiring special attention regarding power supply, cable route and related problems of working them in parallel.

7.2.3 CONSIDERATIONS IN APPLYING SUPERVISORY CONTROL AND DATA ACQUISITION SYSTEM TO ELECTRIC UTILITY STATIONS.

Supervisory control and telemetering installations have grown conceptually from simple, isolated, remote control facilities interconnecting to nearby stations and telemetering a few key system quantities to an operations centre to large scale, computerized, supervisory control and data acquisition (SCADA) systems. The data acquisition functions provide access to large portions of the power system, delivering real-time data and high quality input to planning data bases.

Control capabilities relieve demands for operating personnel and serve as primary tools for emergency switching and load shedding. In SCADA installations, both large and small, reliability, accuracy, dependability and security are qualities which must be designed into the power station (remote terminal) end from its inception to realise satisfactory performance.

An electric utility SCADA system depends on the interface between the power station and the SCADA Remote Terminal Unit (RTU) to provide and maintain the high level of confidence demanded for power system operation. Following is the description of typical functions provided in utility SCADA systems, and some important considerations in the interface between a power station and SCADA system.

7.2.3.1 Physical consideration the station environment

The implementation of a SCADA system in an electric utility requires the installation of remote terminal units (RTU's) in generation and switching stations to allow the master station to retrieve data and execute control commands. The RTU interfaces to control station equipment through interposing relays and to measuring circuits through transducers.

The environment of a power station or substation is less than ideal for electronic equipment like SCADA system remote terminal units and transducers. The temperature changes stress the stability of measuring components like analog to digital converters and transducers. Good temperature stability is an important feature of SCADA system equipment.

The use of hermetically sealed components, coated circuit boards and corrosion protected hardware should be a consideration selecting SCADA equipment for outdoor installation.

The electrical environment of a power station is more severe than its physical environment. Large amounts of electrical noise and transients can be generated by the operation of power equipment and their controls. These can be minimised through shielding and surge reduction practices. Ground potential during faults can also affect electronic equipment in station making a solid ground mass essential.

7.2.3.2 Analog data acquisition

Data Acquisition in an electric utility SCADA system concentrates on the power system performance quantities, line and transformer load currents, real and sometimes reactive power flow and bus voltage. Secondary quantities such as transformer temperature, transformer tap position, or other multiple position quantities are also transmitted in analog format.

The principal electrical quantities (volts, amps) are measured from power system instrument transformers with transducers. These are converted to DC voltages or currents which can be readily accepted by the SCADA system remote terminal unit.

The value received from SCADA system measurements is a function of the investment made in their measurement sub systems.

7.2.3.2.1 Measuring system performance

The overall accuracy of transmitted quantities is affected by a number of factors. These include instrument transformer errors, transducer performance, analog to digital conversion quantizing error, and offsets introduced in transducers and A/D converters.

7.2.3.2.2 Instrument Transformer Performance

Analog quantities can be no more accurate than the instrument transformers used for their measurement. When metering grade transformers are available they will provide the best accuracy.

7.2.3.2.3 Transducers

The measuring interface element between a SCADA system and a power system is the transducer. These provide scaled, low energy signal which represents a power system quantity that the RTU can easily accept. Transducers also isolate and buffer the RTU from the power system and station environments. Their outputs are usually D.C. voltages or currents which range upwards of a few tens of volts or milliamperes.

Transducers measuring power system electrical quantities are generally designed to be compatible with instrument transformer outputs. Potential inputs are based around 110 to 120 volts A.C. and current inputs accept 0-5 Amps. These are for the most part, long time steady state ratings. Input circuits are provided with short time, over range, capabilities so that they may survive power system disturbances which may produce abnormally high voltage or currents, many times higher than rated for short durations.

7.2.3.3 Status monitoring

Status indications are an important function of SCADA systems for electrical utility. Status monitoring is often provided for power circuit breakers, reclosures, interruptor, motor operated isolators, any variety of other ON-OFF functions in a power station. They may be provided with status change memory for between scan monitoring and in some cases, time tagging to provide sequence of events. These indications originate from contacts which are mechanically actuated by the monitored device and are input to the RTU, either directly or through an interposing relay. Interposing relay is required because there are seldom enough spare auxiliary switch contacts available, and the distance between the RTU and the monitored device is often great. The exposure of RTU status point wiring to the switch yard environment is also consideration.

7.2.3.4 Control functions

The supervisory control functions of electric utility SCADA system provide routine and emergency switching and operating capability for station equipment. SCADA control is most often provided for circuit breakers, reclosures, interruptors, and motor operated isolators. It is not uncommon to also include control for voltage regulators & tap changing transformers. All these control functions share a common thing that station control functions must be interfaced to the SCADA system remote terminal.

The RTU can not execute controls directly form its logic level, but must be interposed to the station control circuits. Also, RTUs generally provide momentary timed control output thus, latching type interposing is sometimes required.

The design of control interface for SCADA system deserves careful attention. The security of the equipment installed must ensure freedom from false operation, and the design of operating and testing procedure must recognise these risks and minimise them.

7.2.4 MASTER/REMOTE FUNCTIONAL DESIGN

7.2.4.1 Communication configuration, media and techniques

Communication configuration

The configuration of communication systems are dictated by the following :-

- * Number of RTUs
- * Number of points at RTUs and required update rates
- * Location of RTUs
- * Communication facilities availbale
- * Communication equipment and technique available

The configuration used in Railway SCADA system is party line one-on-a-few configuration. Here master station communicates with the RTUs via party line (shared) communication channel. In this case a unique address is required for each RTU on the channel.

This Configuration has the advantages of sharing the master station communication logic and the advantage of sharing the communication channel.

7.2.4.2 Communication Media

Available communication media options are

- * Metallic cable pairs
- * Power line carrier (not used in Indian Railways)
- * Microwave
- * Leased circuits
- * Fiber optic cable
- * Satellites (not used in Indian Railways)

As on date only metallic cable pairs and fiber optic cable are of interest, only these options are discussed below :-

7.2.4.3 Metallic cable pairs

Cables have the advantage of involving little new technology and so it is easy to consider the use of cable pairs for data transmission, where typically, one such pair can be used for simplex or half duplex transmission at speeds upto 2400 bits per second.

Cables, as with S&T installations must typically be protected against induced voltage surges or lightning strikes by protective devices such as gas tube protectors and in addition if entering a high voltage substation, must be protected from huge difference in adjacent ground mat potential during substation fault current conditions through the use of additional devices such as neutralising transformers.

7.2.4.4 Fiber Optic Cable

Fiber optic cable systems that are used for communications are made of three basic components. The first component is a long fiber of very pure glass or plastic that permits light to travel from the transmitter to the third component i.e. receiver. The receiver converts the light signals back into electrical signals. The signals can be either analog or digital.

In addition to these three components, there are repeater where the light signals are converted to electrical signals amplified and converted back again. Splicing devices are also necessary in order for signals to travel from one fiber to the others with minimum attenuation.

The basic principle behind fiber optic is that when light reaches the boundary between the medium that it is in and another medium, it will be reflected back into its own medium, if the other medium has a lower index of refraction. Therefore, an optical fiber is constructed as a long cylindrical glass or plastic core surrounded by a concentric layer called the cladding which has lower index of refraction. Most light entering the core at one end will be reflected back forth all the way down the length of the fiber to the other end.

7.2.4.5 Advantages of Optical Fiber communication

- A prime advantage to electric power utilities is its total immunity to the electromagnetic interference.
- The band width available in the visible light region of the electromagnetic spectrum for communications via fiber optics is very wide as compared to metallic cable pairs.
- Cross talk between cables is impossible
- Unaffected by lightning and electrical storm
- Highly flexible and small physical size.
- As with a metallic cable, "Shorting" of a fiber optic cable cannot lead to invalid control signals or start a fire in hazardous environment.
- No trapping or waves dropping is possible without physically cutting the cable and coupling in.
- Long life expectancy.
- Very high speed of data transmission which is limited principally by the capability of the multiplexing equipment.

7.2.4.6 Disadvantages of optical fiber communication.

- High Cost.
- More no. of repeaters are required as compared to metallic cable pairs.
- Transmitters and receivers are required to convert electrical signals into light and back again. Thus, short run cables would not be cost effective, unless advantages, such as large band width capability, outweigh the cost of transmitter and receivers.
- Special connectors are needed to align fibers and require training to install.

7.2.5 COMMUNICATION TECHNIQUES.

7.2.5.1 In order to convey information from one point to another via a communication channel it is necessary to transmit a signal at one point which is recognised at the other point.

This may be accomplished by several methods :-

- * Change of signal amplitude (Amplitude Modulation)
- * Change of signal frequency (Frequency Shift Keying)
- * Change of signal phase (Phase Shift Keying)

At the receiving end of the communication channel, a demodulator detects the change in the signal and outputs the transmitted information. If the information is transmitted in one direction only this is known as Simplex transmission. If the information flow takes place in both directions, but not simultaneously then it is known as half-duplex transmission. However, if transmission takes place in both the directions simultaneously, then it is known as Full-duplex transmission. In Railway we use Half-duplex transmission. For Half & Full-duplex transmission, both a modulator and demodulator are required at both ends of the channel.

From view point of economy, a single communication channel is used for transmitting many pieces of information. This technique is known as Multiplexing. Two basic versions are :

- * Frequency Division Multiplexing, where each piece of information is transmitted over a dedicated part of the available communication channel. For a voice grade channel, upto 25 separate, sub channels 120 Hz. spacing per channel, can be utilised. Additional voice grade channels are required for each 25 pieces of information, therefore, large systems would require an impractical number of channels.

- * Time Division Multiplexing, where each piece of information is transmitted as part of a serial digital message over a separate span of time and demultiplexed by the receiver into the individual pieces of information.

The rate at which data is transmitted is measured in bits per second or baud. However, these two units are not always synonymous. Baud is defined as 1/length of shortest signaling element in seconds; if the shortest element is 0.833m.secs., then the signaling rate is 1200 baud (or changes per second). In order to determine bits per second, following formula is used :

$$\text{Bits/seconds} = \text{Baud} \times \text{bits/baud}$$

Where Baud = Signaling rate (changes per second)

$$\text{Bits per baud} = \text{Amount of information (bits per change)}$$

For transmitting information via a communication channel, two basic types of modems are used : Asynchronous and synchronous. The asynchronous type utilises separate timing sources such as crystals at each end of a data link to make the receiver to demodulate the data at approximately the same rate at which it was modulated by the transmitter. Due to this, the data message must

be frequently resynchronised by dividing the message into short blocks of characters, each with their own synchronisation bits. This is advantageous where short messages with quick synchronisation is desired. Thus, the efficiency is relatively high. The asynchronous modem is limited to 1800 bps in most applications and is usually of the FSK type. Cost is very low.

The synchronous modem on the other hand transmits a synchronising clock signal alongwith the data, so that the receiver is precisely synchronised with the transmitter. This permits very long message and high data rates without any problem of falling out of sync. Sync. modems are generally available from 2400 bps to 1 Mbps and are higher in cost.

7.2.5.2 Communication message formats

The transmission of information between master and remote using TDM techniques requires the use of serial digital messages. These message must be efficient, secure, flexible and easily implemented in hardware and software. Efficiency is defined as - Information bits transmitted/total bits transmitted.

Security is the ability to detect errors in the original information transmitted, caused by noise on the channel. Flexibility allows different amounts and types of information to be transmitted upon command by the master station. Implementation in hardware and software requires the minimum uncomplicated logic, memory, storage, and speed of operation.

7.2.5.3 All message are divided into three parts as follows

- * Message establishment, providing the signals for the receiver to select the message transmitted to it at the correct time, from hundreds of other possible messages and channel noise.
- * Information, which provides the data to be sent to the receiver, in coded form to allow the receiver to decode the information and properly utilise it.
- * Message termination, which provides the message security checks so that no errors in the message establishment of information fields are accepted by the receiver and provides a mean of denoting the end of the message. Message security checks consists of logical operations on the data which results in a pre-defined number of check bits transmitted with the message. At the receiver end the same operation are performed on the data and compared with the received check bits. If they are identical, the message is accepted; otherwise, a retransmission of the original message is requested.

A typical example of commonly used asynchronous message format is shown below :

2 bits 4 bits 8 bits 12 bits 5 bits 1 bit

8 msec pre Tx mark	S	M	RTU Address	Fund Code		BCH Sec Code	M	Add. Mess age
Synchronisation (Message Establishment)				(Information)		End of message (Message Termination)		

The Message Establishment field has three components :

- 8 msec min. pretransmission mark to condition modern receiver for syncbits.
- Synchronisation, which consists of two bits, a space followed by a mark.

RTU address, which allows a receiver to select the message addressed to it from the message to all the RTUs on a party-line.

The information field contains 20 bits, of which 8 bits are function code and 12 bits are used for data. For remote to master message, this represents the first message in the sequence; additional messages directly following the first message also transmit information in the RTU address and function code spaces, so that 24 of data are transmitted. These 24 bits may contain two 12 bit analog values or 24 bits 24 device status.

7.2.5.4 The message termination field contains

- BCH security code, which has 5 bits and allows the receiving logic to detect most message errors. If an error is detected, the message may then be retransmitted to obtain a correct message.
- End of message mark, which provides the last bit as a mark, so that another message can follow immediately after this message.

7.2.6 INFORMATION TRANSFER

7.2.6.1 Master to remote data transfer : Information transmitted from master to remote is for the purpose of device control, set point control, or batch data transfer. Due to the possible severe consequences of operating the wrong device or receiving a bad control message, additional security is required for control, this is provided in the form of a sequence of messages, commonly called select before operate sequence, as shown below :-

REMOTE - TO - MASTER CHECKBACK MESSAGE

FUNCTION CODE	CONTROL ADDRESS	SET POINT
---------------	-----------------	-----------

MASTER-TO-REMOTE EXECUTE MESSAGE

FUNCTION CODE	CONTROL ADDRESS
---------------	-----------------

REMOTE TO MASTER EXECUTE ACKNOWLEDGE MESSAGE

FUNCTION CODE	CONTROL ADDRESS
---------------	-----------------

NOTES :-

1. Message establishment and termination fields are not shown.
2. Function code specifies the operation to be preformed by the RTU.
3. Control address specifies the device or said point to be controlled.
4. SET point provides the value to be accepted by the RTU.
5. A remote to master check back message is driven from the RTU point selection hardware in order to verify that the RTU has acted correctly in interpreting the control selection.
6. A master to remote execute message is transmitted only upon receipt of proper check back message.
7. A master to remote execute acknowledge message is a positive indication the desired control action was initiated.

7.2.6.2The above sequence of message provides additional security by the check back and execute messages, since undetected errors must occur in the control. select, check back, and execute message in order to operate the wrong control device. Prior to transmission of the above sequence a control operator performs a similar select-verify-execute-acknowledge sequence via his control console.

Batch data transfers from master to remote include such data as parameters for report by exception and parameters for locally controlled devices. This type of transfer is accomplished by the sequence given below :-

MASTER - TO - REMOTE CONTROL MESSAGE

FUNCTION CODE	DATA ADDRESS
---------------	--------------

REMOTE TO MASTER ACK MESSAGE

FUNCTION CODE	DATA ADDRESS
---------------	--------------

MASTER-TO-REMOTE CONTROL BATCH DATA TRANSFER MESSAGE

FUNCTION CODE	DATA ADDRESS	DATA
---------------	--------------	------

REMOTE-TO-MASTER ACK MESSAGE

FUNCTION CODE	DATA ADDRESS
---------------	--------------

Notes :-

1. Message establishment and message termination fields are not shown.
2. Special security precautions are required if a party line communication channel is used, so that RTUs do not decode a batch data transfer message.

The purpose of first two messages is to prepare the RTU to receive the longer than normal message. The third message transmits the data and the fourth indicates that the data was correctly received at the RTU.

7.2.6.3 Remote to master data transfer

All remote to master data transfer is accomplished with one basic message sequence by using variations in the field definitions to accommodate different types of data. The basic sequence is shown below :-

MASTER-TO-REMOTE DATA REQUEST MESSAGE

FUNCTION CODE	DATA IDENTIFICATION
---------------	---------------------

REMOTE - TO - MASTER DATA MESSAGE

DATA UNIT 1	DATA UNIT 2	DATA UNIT
-------------	-------------	-----------

Notes :-

1. Message establishment and message termination fields are shown.
2. Function code specifies the types of data to be transferred by the RTU.
3. Data identification identifies the amount and type of requested by the master station.

On each message transmitted by the RTU (except for message containing only current data) it is necessary to retain the transmitted message in a RTU buffer, so that if the master station does not receive the message correctly, it can request a retransmission. Otherwise this information would be lost.

7.3 SCADA EQUIPMENT

7.3.1 General

The SCADA equipment at the RCC is called Master Station while that of the controlled station is referred to as Remote Terminal Unit (RTU).

7.3.2 Transmission Path

Underground telecommunication trunk cable is provided for transmitting the signals from and to the RCC and the controlled Remote Terminal Units (RTU). Three pairs of conductors (One pair for "Send", one pair for "receive" and the third as spare) from these cables are made available for remote control operation. These days optical fibre cables are used in most of the divisions instead of above mentioned copper cables. Sometimes, microwave communications is used.

7.3.3 Isolating Transformers

To limit the build up of longitudinal induced voltage on account of induction effects of 25 kV traction, isolating transformers are provided on the cable circuit at intervals of 10 to 15 km. The cable is tapped at the RCC and each controlled station and 3 pairs of conductors are terminated on a terminal board. Isolating transformer of impedance ratio 1120 : 1120 is provided at the point of tapping.

7.3.4 Repeater Stations

Voice frequency repeaters are provided at intervals of 40 to 50 km to boost the signal and make good the been attenuation. The amplifier gain at the repeater station is about 20 dB. with an equaliser incorporated to compensate upto 0.02 dB/kHz/km Depending upon the distance the repeater gain is state that the signal level at any point enroute is within certain prescribed limits.

If the lead is long suitable surge arrestors are provided inside the equipment room to ---- the ---- . The metallic sheath of the lead in cable shall also be kept insulated from the earth system of the switching station to prevent induction effect. the insulated conductor alone being led into control panels for the same reason switching station earthing. LT 240 V auxiliary transformer neutral earthing and earth of R C equipment are all kept separate and distinct and are NOT interconnected In addition the switching station structure should be solidly bonded to the track rails by two independent connections.

7.3.5 Microwave Communication

In some of the sections on Indian Railways dedicated Microwave channel at carrier frequency of 18 GHz has been provided for the purpose of communication.

7.3.6 Optical Fibre Cable

Optical fibre cable has also been introduced for communication in some sections of Indian Railways which is also used for RC equipment

Details of the interface between the latest communication systems and the RCC/RTU equipment may be seen in the relevant technical documents.

7.3.7 Master Station Equipment

Hardware Configuration: Dual main micro-computer/mini-computer system. one main and the other hot standby. is provided at the master-station. each system interfaces with its front end processors. If any, and modem for communication with RTUs and with the man-machine interface equipment to provide up-to-date network data and to accept commands. Each system has its own

system console and hard and floppy disks along with their drives. Watch dogs are provided for monitoring the health of the computer system. In case of failure of one computer system, the standby takes over automatically.

Two data-logging printers, one on-line and other as standby, are provided, both being connected to the same online computer system. In case of failure of one printer, the other printer automatically takes over.

Man-Machine-Interface : Work Stations

Two work-stations, one for each of the two operators each consisting of two semi-graphic colour Visual Display Units (VDUs) and a key-board are provided at the RCC. The key board contains both functional keys for operations that are repeated frequently and alpha-numeric key for input of numerical data and text.

Both workstations are connected to the same on-line computer and meet the following requirements:

- (i) Normally control pre-defined and physically demarcated sections.
- (ii) In case of complete outage of one workstation. all of its functions can be transferred to the healthy workstation, so that normal operations can continue.
- (iii) Normally one VDU is on line and the other acts as standby at each work station. However, if so needed, it is possible to have both VDUs of each work station on lines simultaneously, either of the two VDUs being used for viewing diagram for telecontrol purposes and the other for viewing alarm, on-demand trend curves, histograms or any other data.

7.3.8 Mimic Diagram Board (MDB)

A mimic diagram board and its associated mimic driver is provided at the RCC. The MDB depicts the traction power supply diagram, indicating the energize/de energize condition of the sub-sectors of the catenary. status of the interuptors and CBs at TSS & FP, SSP and SP

Unlike in the Conventional ! Mimic Diagram Board used in RCCs prior introduction of SCADA system (See para 20403) all control Operations are carried out from the key board(s) provided at the work stations(s) The Mimic Diagram Board's sole purpose is. therefore to give an overall view of the traction power supply, system to the operator Size of the MDB is therefore very much smaller. It is the intention to do away with the MDB altogether since the system can be viewed in the VDUs

7.3.9 Annunciations

Controlled Station

"Remote Station Defective" is annunciated by a LED

Master Station

The following annunciations by LEDs are provided on the MDB

- i) Main System "ON"
- ii) Standby System "ON"
- iii) Main System Defective.
- iv) Standby System Defective
- v) Main UPS Failed
- vi) Standby UPS Failed
- vii) UPS battery low (below 90% of nominal voltage)
- viii) 415 V, ac, 3 ph, supply to UPS failed

7.3.10 SCADA Software

The operating system used is suitable for multi-user, multi-tasking, net working and real time applications.

7.3.11 VDU Display

The application software supports a large number of versatile semi-graphic coloured displays for issuing telecommands, blocking/deblocking the controlled points. viewing alarm listing, event listing or for carrying out special functions. For details of these displays. manufacturers Operating Manual may be referred to. Calling any of the VDU displays is by simple keyboard operation, with pre-defined options available for the order and manner in which displays are called.

7.3.12 Transmission and Coding System

The master station equipment normally scans continuously all the RTUs in a pre-defined cyclic sequence to update the equipment status, alarms, events and measurands. Exchange of information between Master Station and RTUs takes place on interrogation by master followed by reply from RTU. The communication technique is based on Digital Address Time Division Multiplexing. Every data exchange is based on well defined transmission protocol. Each transmitted contains sufficient parity check bits to detect transmission errors.

7.3.13 Historical Data Storage

The SCADA system is designed to cater for historical data storage of traction power supply data for a period of one year. This includes.

- i) All alarms / events / -- of controlled stations and all system alarms
- ii) Day wise stronge of average feeder current and voltage dating the day maximum demand maximum and minimum feeder voltage in the 25 KV side. total number of operations of feeder protective relays viz OCR. DPR and WPC relays CB trippings and maximum and minimum OHE voltage on both sides of the neutral section A memory capacity of 40 MB is provided for this purpose in the hard disk with provision for further expansion of the memory as required.

7.3.14 UPS and Batteries at Rcc

Dual Stand alone UPS System of adequate capacity to supply 240 V and 50Hz single phase supply to the SCADA system at Master Station is provided.

Both the UPS work in parallel sharing the load. In case of failure of one. the entire load is automatically taken over by the healthy UPS without affecting the working of the system.

In case of both the UPS at the same time. the load of SCADA equipment is directly connected to input mains through a static switch without any break.

A single battery is provided with both the UPS with adequate Ah capacity to provide 2 h supply to various equipments in case of failure of input 415 V ac 50 Hz supply.

7.3.15 Remote Terminal Unit (RTU)

The RTU is microprocessor based and includes its associated digital input/output modules. alanninput modules. analog input modules. watchdog transducers. memery modules. interposting relays. summation. CTs power supply unit(s). surge arrestors and other items necessary for its proper working.

7.3.16 Storage of Events and Alarms

All changes (one or more) in the status of the CBs/interruptors / motor-operated isolators and alarms that may occur between consecutive polilngs are stores by RTU until they are reported to the master station. This is to eliminate any loss in reporting to the master station due to

intermittent failures of channel or any other reason. In other words, no event is lost without its being reported to master station.

7.3.17 SCADA Equipment Capacity

The SCADA equipment is generally designed for the following tele commands, tele signals and telemetered parameters for a typical TSS, SP & SSP of a double line section :

S. No	Controlled Station	Telecommand	Telesignal	Measurands
1.	TSS	24	64	8
2.	SP	8	12	4
3.	SSP	8	12	-

Number of controlled stations (TSS, SP, SSPs) to be controlled from an RCC will be as per the requirement of the section.

Speed of Transmission and Update Time

The communication between the master station and the RTUs is at a suitable transmission speed not exceeding 600 baud. Normal polling time for updating status, alarm and measureands for the designed capacity is not more than 4 sec for 20 controlled stations and not more than 6 sec for 30 controlled stations. The actual timings may slightly vary depending on communication protocol adopted and the system design.

The RCC should be in the middle of the electrified section if the number of controlled stations exceeds 30 so that scanning on either side is possible and update time kept to the minimum.

The RCC should be in the middle of the electrified section if the number of controlled stations exceeds 30 so that scanning on either side is possible and update time kept to the minimum.

7.3.18 Modems

- (i) The modems (modulator/demodulators) provided for communication between the master station and the RTUs utilize frequency shift keying (FSK) modulation and include send, receive and timing functions. The send and receive functions are independently programmed as required. The modern work satisfactorily upto an input signal level of -45 dBm
- (ii) The modern also incorporates necessary amplifier having a minimum gain of 30 db to compensate for any signal variation at different points in the system Suitable attenuation is provided within the amplifier to adjust the level through trimpot/rotary switch. It has an output signal level adjustable between 0 and -30 dbm in steps of 1 dbm

7.3.19 Special Features in SCADA Equipment

The following additional features are incorporated in the SCADA equipment

- (i) Tripping of bridging interrupters on under voltage at SP in extended feed condition
- (ii) Inter lock release request facility for circuit breakers/interruptors control at boundary post (for guidelines for these inter locks see RDSO's letter No ETI/PSI/RC/SPEC 19 dated 10.3.1989)
- (iii) Control of shunt capacitor bank and monitoring of power factor
- (iv) Automatic localization of fault on OHE and isolation of faulty sub sector

SCADA systems on Indian Railways are being supplied by various manufacturers Although the

systems are different, the basic features of the systems are similar. For details of operating instruction and maintenance the operating technical manuals of the makers should be referred to.

7.4 OPERATION AND MAINTENANCE OF RC EQUIPMENT

7.4.1 Duties of CTFO (RC)

He is the senior supervisor working under the control of DEE/AEE (TrD) and directly responsible for the proper operation and upkeep of the RC equipment. which are vital for the operation of the electric traction system. He shall be thoroughly conversant with all the technical details of the equipment under his control. In particular, he shall perform the following duties.

1. Maintain the RC equipment at the RCC and the controlled stations in accordance with the prescribed schedules.
2. Keep close liaison with the S&T department as to the sound condition of the cable pairs allotted for RC operation.
3. Measures periodically the levels of voice frequency signals at controlled stations and arrange with the S&T department for correction. when required at their repeater stations
4. Keep in constant touch with the TPC on shift duty and ensure prompt rectification of defects reported in the RC system
5. Ensure proper maintenance of UPS/battery sets for uninterrupted operation of the RC equipment and the stand by generating set in the RCC.
6. Inspect the RC equipment at every controlled post once in two months
7. Import necessary training to the staff under him in the special techniques of maintenance of R. C. Equipments as well as trouble shooting.
8. Ensure that the special instruments and tools provided for maintenance of the R. C. equipments are properly cared for.
9. Keep a watch on stocking of spare parts and other stores required for RC equipments and initiate timely action to recoup stocks.
10. Co-ordinate with SSE (PSI) and SSE (OHE) or territorial SSE for manning the controlled, posts in the events of persisting faults in the R. C. equipments.
11. Submit prescribed periodical returns on RC equipment to AEE (TrD) and Sr. DEE (TrD).
12. Keep his superior officers fully informed of all important developments and seek their guidance when required.
13. Carry out such other duties as may be allotted by his superior officers.
14. Carry out minimum monthly inspection as per manufacturers recommendations.

7.4.2 Operation of RC Equipment

The RCC is the nerve centre of the traction system from which full control over every switching operation on the entire electrified route is exercised. It should, therefore be kept in perfect operating condition at all times. No one other than an authorized official shall at any time operate the equipment. The TPC shall at every change of shift carry out a lamp test and once a day give a general check for all stations and thereby ensure that the indications on the mimic panel are in order. Any defects observed in operation shall be brought to the notice of AEE(TrD) Depending upon upon the nature of the defect TPC shall take adequate precautions against mal-operation until the defect

noticed is rectified.

Should Rc equipment of a switching station fail completely, the failure shall be reported to AEE(TRD) and Sr. Dee(TRD) and arrangements made to man the switching station with trained personnel to carry out the switching operations, observing the precautions prescribed in the Chapter VIII Breakdowns

TPC shall once a day contact on telephone the Operators of each Grid sub-station from which traction power supply is obtained and ensure that the communication facilities are intact.

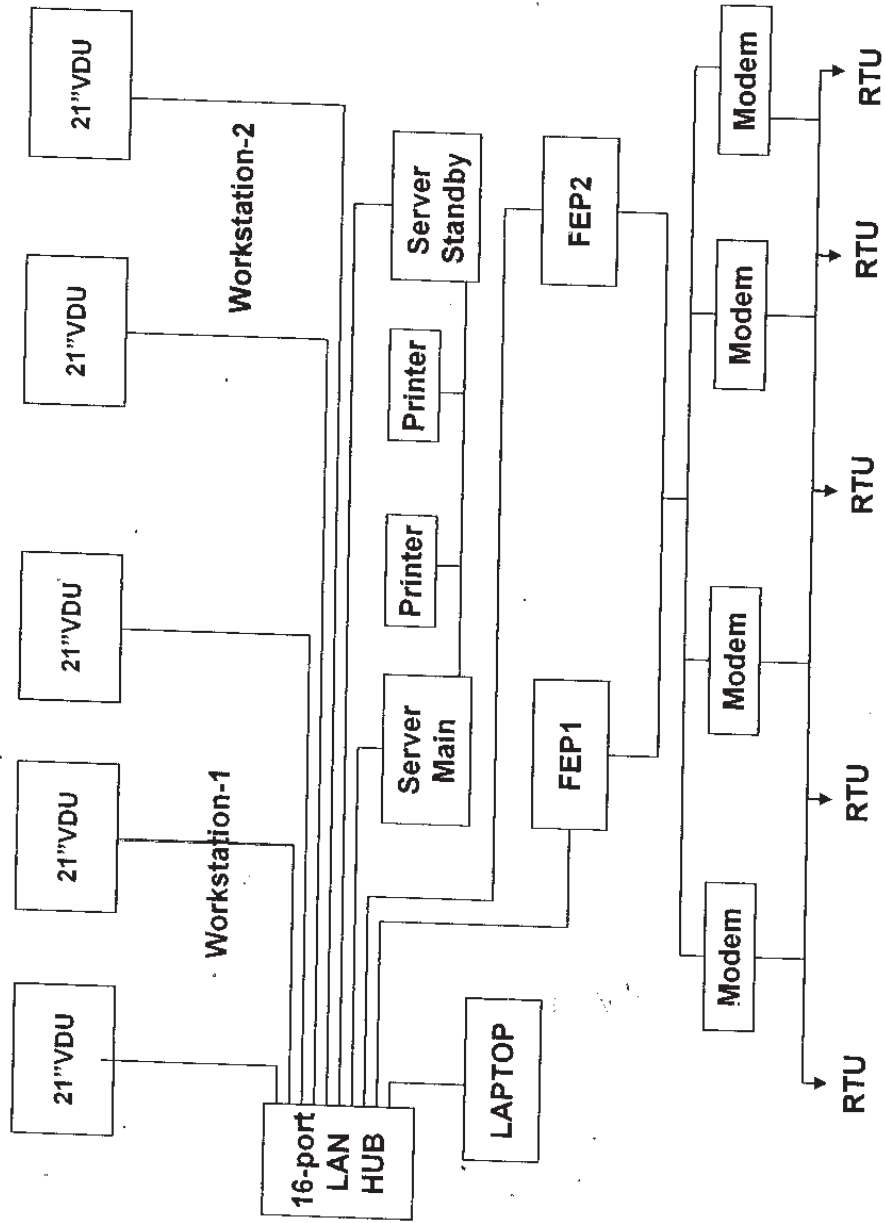
7.4.3 Investigation of Failures by SSE

As with any other equipment every failure of RC equipment should be separately registered. investigated and rectified. making a brief note in the failure report of the action taken as well as classifying and finally pin-pointing the exact cause of the failure. The failure should be analyzed every month and any special steps required taken to overcome the trouble and prevent recurrence should be taken. A history sheet showing the faults that have occurred on different items of equipment will assist in carrying out detailed investigation of recurring troubles in consultation with the Manufacturers of the equipment.

7.4.4 Maintenance Schedule

The specific maintenance instruction issued by the respective supplier of SRC/SCADA systems should be observed and changes to be made therein may be decided in consultation with the manufacturer For the batteries used in the remote control centre and the remote terminal units (RTUs) the instructions in Chapter II for fortnightly maintenance and quarterly maintenance shall be applicable.

BLOCK - DIAGRAM



INTERFERENCE PROBLEMS WITH 25 KV AC TRACTION

8.0 INTRODUCTION :

Interference to line-side cables from an adjacent ac traction system is a particular case of the more general problem of interference between power and telecommunication lines. This interference may arise either from the electric field or from the magnetic field. To appreciate how even with considerable separation between power lines and telecommunication lines i.e with very weak coupling between the circuits interference occurs, one has to realize the power used in the two systems.

Power used in transmission lines and telecommunications lines :

400 kV	10^9 W
132 kV lines	10^8 W
33 kV lines	5×10^6 W
11 kV lines	10^6 W
400/240 V mains	10^4 W
Telephone line	
- Sending end	10^{-3} W
- Receiving end	10^{-5} W

In a power system which transmits a kind of raw material i.e electric energy, the efficiency must be high but purity of wave form is not of primary importance. The telecom line transmits a finished product, a message concealed in a complicated wave form, therefore, the waveform must not get distorted, power losses in telecom line are not important. Additional or suppressed impulse in a telegram may falsify a letter and then the meaning of a message. Harmonics may reduce or destroy the intelligibility of the speech or distort music transmitted by land line for radio. The more perfect the transmission the more sensitive does it become to disturbance.

Power interference may thus manifest at very different power levels – as hardly perceptible noise or as grave disturbance of the service, as dangerous acoustic shock or even as over voltage endangering life or installations. Hence, a distinction is generally made between disturbance and danger. Normal operation of telecommunication system is possible if danger is non existent and disturbance is sufficiently low with normal operating conditions obtainable in the neighbouring power installations. During a fault of short duration in the power system the disturbance in a telephone system is usually tolerable. The question arises as to what should be the tolerable limit of danger.

To combat interference, co-ordinated action is called for from power and telephone engineers because both installations have to serve the same people who have to pay for the protective measures. Hence, technically and economically best remedies are to be adopted even when the two installations are under the control of separate administrations. General rules are laid down for all new installations so as to exclude the possibility of interference.

8.1 CCIT DIRECTIVES:

The International Telegraph and Telephone consultative committee has recommended the limits of permissible induced voltage under different conditions of operation.

8.1.1 Permissible Voltage Levels in the Case of Normal Operation of the Inducing Line.

To avoid danger, it is recommended that the permissible continuous induced voltage be limited to 60 volts rms. This applies to screened or unscreened cables or open wire line to which access is required for work operations by staff.

Under conditions of particular difficulty, the permissible voltage limit may be raised to 150 volts rms induced on conductors of a cable or an open wire line, provided special precautions are taken. These special precautions may include.

- The issue of special instructions to personnel likely to have access to circuits exposed to voltage in excess of 60 volts rms so that special work measures can be applied.
- The marking of accessible parts of the installations or equipment with warnings.

8.1.2 Permissible voltage levels in the case of a fault on the inducing line.

Except for the cases described in the following paragraphs of this section, it is recommended that the permissible voltage induced on cable conductors or open wire telecommunications lines be limited to :

- a) 430 volts rms during a fault on a nearby inducing line that is constructed to usually accepted technical standards.
- b) 650 volts rms during a fault on a nearby high-reliability power line.
- c) 1000 volts peak during a contact to earth of one wire of a nearby dc power or electrified railway line.

The permissible induced voltage may be increased for conductors in cables with earthed metallic sheath or screen and that are terminated in isolating transformers at both ends, or at one end with the other end connected through a low resistance to earth or, to a metallic cable sheath or screen, or if all the cable conductors are fitted with lightning protectors at their ends. In such cases, the permissible values are

- i) For cables tested for breakdown strength between conductors and sheath or screen after installation: an rms value equal to 60% of the test voltage if tested with dc or, 85% of the test voltage if tested with ac.

ii) For cables where the above tests are not made, an rms value equal to 60% of the lowest dc voltage to 85% of the lowest ac voltage used in factory tests to ensure the breakdown strength between conductors and sheath or screen unless there is reason to fear that the laying and jointing operations have caused any appreciable reduction in the breakdown point. In such cases, special studies should be made to select the method for determining the permissible limit.

Where only some of the cable pairs are terminated satisfying the above conditions, the voltage limit indicated in (i) or (ii) is permitted on such cable pairs provided that the dielectric strength from other parts in the cable is sufficient to avoid breakdown.

The isolating transformers and other line apparatus should have a dielectric strength equivalent to or greater than available on the cable conductors, unless lightning protectors are used.

Experience shows that dangerous levels of induced voltage are unlikely on cable conductors where the above conditions are met and where faults on medium voltage inducing lines are involved and where protective devices are used. Where the permissible induced voltage on cable conductors is increased above the permissible levels for open wire lines, it is desirable to consider safety precautions when work is carried out on these cables and to ensure that equipment connected to the line can withstand the resultant common mode voltages and currents.

Allowance may need to be made when considering permitted induced voltages induced into Cables carrying significant telecommunications voltages (e.g. power feeding systems).

8.1.3 Permissible capacitively – coupled current :

In cases of capacitive coupling, a resulting current through a contact between a conductor and earth of other metallic structure, upto 10 mA is permissible.

8.2 COUPLING BETWEEN CIRCUITS:

The coupling between two circuits may be conductive or alternately due to electric or the magnetic field. These are distinguished as conduction, electrostatic induction and electromagnetic induction. Even when all the three kinds of couplings occur simultaneously, usually one of them will usually prevail.

8.3 CONDUCTIVE COUPLING:

Conductive coupling is present when two circuits I and II have a common branch (See Fig.8.1). If the common branch is sufficiently well defined the distribution of the current and the effect produced in II may be calculated. If they are coupled by a common resistance “r”, the parasitic current I in circuit II is given by

$$I = \frac{Er}{RW + Rr + Wr}$$

Generally, $Wr \gg R \gg r$ because I is a power circuit and II a telecommunication circuit. It is approximately equal to $I = Fr/RW$. The effect in II is same as if a parasitic voltage

$e = Er / R$ were introduced in the voltage produced on r without the circuit II. This means that reaction produced on I by II is negligible.

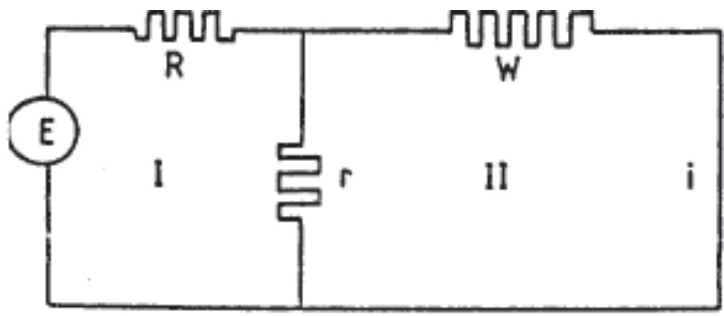


Fig. 8.1

Conductive coupling occurs often between two circuits, using to some extent, the earth as conductor. Very weak couplings of this kind exists, obviously between all circuits because of imperfect insulation. In practice, conductive coupling exists when electrified railways use rails as a return conductor. In telephony, coupling of this kind may arise in all circuits in which earth is used as an auxiliary or third conductor. Especially all circuits using common batteries. In all such cases disturbances may occur, if the earth connection of a telecommunication circuit is near enough to an earthing point on the power system.

In practice interference by conductive coupling between lines can be neglected. Conductive coupling is present if the interference can be suppressed by resting the earthing connections or by replacing the earth return by a metallic return conductor well away from the existing one. Electric or magnetic coupling is present if the interference can be suppressed by a displacement of the line well away from the inducing line without any alteration of the earthing connections.

8.4 ELECTROSTATIC INDUCTION :

Electric induction occurs due to capacitive coupling. Discussion hereunder is confined to the systems of lines which are long in relation to all dimensions perpendicular to the length (distance, diameter), the lines are assumed to be parallel with the surface of the earth and with each other.

Consider line I at voltage U_1 with the frequency f Line 4 is insulated (see fig. 8.2). The mutual capacitance K_{14} and the earth capacitance K_{40} are in the series. The voltage U_1 produces a charging current.

$$U_1 j\omega - \frac{K_{14} K_{40}}{K_{14} + K_{40}} = U_1 j\omega K_{14} \text{ as } K_{40} \gg K_{14}$$

$$\text{Voltage on line 4 is } U_4 = U_1 \frac{K_{14}}{K_{14} + K_{40}} = U_1 K_{14} / K_{40}$$

If line 4 is earthed the charging current from 1 to 4 and thence to earth is given by $U_{1jw} K_{14}$. This is proportional to the frequency and like K_{14} to the length of parallelism. Thus the voltage electrostatically induced in an insulated line does not depend on frequency and length of exposure whereas the current to earth from an earthed line is proportional both to frequency and length.

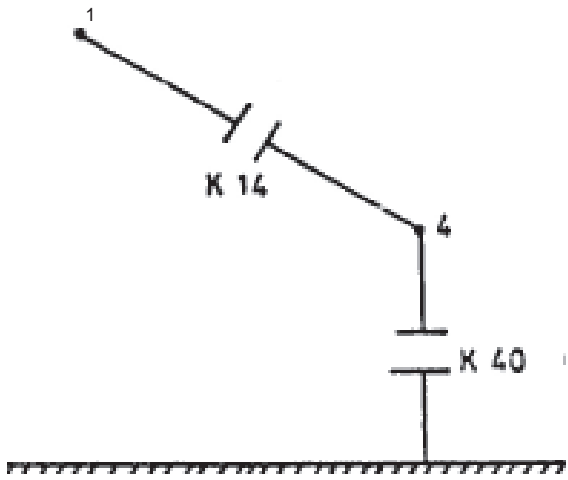


Fig. 8.2

The earth and mutual capacitance are calculated from the dimensions of the lines and the relations between voltage and charge of conductors established. The effect of earth is taken into account by means of Kelvins method of electrostatic images. The image of each conductor in the earth's surface has the same charge as the actual conductor but with opposite sign.

The induced voltage on overhead bare conductors running parallel to a 25 kV contact wire and insulated throughout can be calculated by the formula.

$$V = \frac{E}{4} \times \frac{bc}{a + b + c}$$

- where V = induced voltage to earth
- E = contact wire voltage i.e 25 kV.
- a = horizontal spacing between the contact wire and the overhead conductor.
- b = height of inducing line above ground.
- c = height of overhead conductor.

For the usual heights of contact wire and the overhead communication lines, the approximate induced voltages in the latter for different spacings are indicated below.

Separation (m) Induced voltage with 25 kV system

3	4600
6	2600
10	1440

It is seen that even if the lines are within 10 metre of contact wire they are subjected to induced voltages exceeding 1000. This would lead to a continuous discharge across the spark gaps with which telephone circuits are normally equipped and which have a nominal break down voltage of about 100V dc.

When such bare conductors situated in the electric field are earthed through a person's body the resulting discharge current is proportional to the inducing voltage and the capacitance or length of parallelism. If the parallelism reaches around 10 km the current could reach dangerous proportions. Hence, it is not possible to contemplate normal operation of circuits with bare overhead conductors over any significant length alongside an ac electrified railway.

Electrostatic effects decrease very rapidly when the separation between the inducing line and the line receiving induced emf is increased. If separation is increased to 40m the voltage in conductors placed parallel to 25 kV contact wire hardly exceeds 150V rms and the drawback of continuous discharge across the spark gaps is immediately removed.

The CCITT gives the following formula (which is more conservative than the one cited above) to arrive at the minimum separation between contact wire and the communication line to limit the induced voltage to 300 Volts. The minimum spacing is given by

$$a = 1/3 \sqrt{E}$$

Where E is the contact wire voltage. For 25 kV system this works out to 53 m.

In order to calculate electric induction due to an oblique exposure the distance a is replaced by the geometrical mean $\sqrt{a_1 a_2}$ between the distances at the ends in the formula.

The calculation takes into account ideal conditions i.e lines parallel to earth's surface and mostly to one another, free from additional capacitances and pure sinusoidal alternating current. In practice these conditions are never fulfilled. Line sags reduces average height and additional capacitances occur between wires and poles including capacitance of insulators. Further, roughness of earth's surface, vegetation, buildings, etc. result in reducing the effective height of conductors. The combined effect of all these is to increase capacitances to earth by 20% and mutual capacitances between conductors get reduced. Hence, measured values of electric induced open circuit voltages are usually smaller than the calculated values. However, high harmonics, even with a small amplitude may increase considerably, the electric induced short circuit current.

8.5 ELECTROMAGNETIC INDUCTION

The emf induced in an overhead line or a cable running parallel to an electrified railway is given by the formula :-

$$e = 2\pi f m L 1 K_r K_c K_m$$

where f = Supply frequency

M = Mutual inductance per unit length

L = Length of parallelism

I = Catenary current

K_r = a reduction factor which takes into account the presence of a current flow in the rails the effects of which partly compensate for those due to current flowing in the contact system.

K_c = a reduction factor when the line in which currents are induced is in a metal sheathed cable.

K_m = a reduction factor to take into account the existence near the railway or in the vicinity of the line receiving induced currents, earthed metallic pipework carrying an appreciable induced current.

It is seen that an appreciable reduction in interference is obtained from the screening effect of earthed conductors such as cable sheaths, metal pipes, earth wires and finally the rails themselves. These reduction factors are also known as screening factors.

The mutual inductance M per unit length is a complex factor which depends on the separation of the inducing and induced line (a) and the soil conductivity (s) and the frequencies of inducing current. The function M is in the form

$$M = f(a, s, f)$$

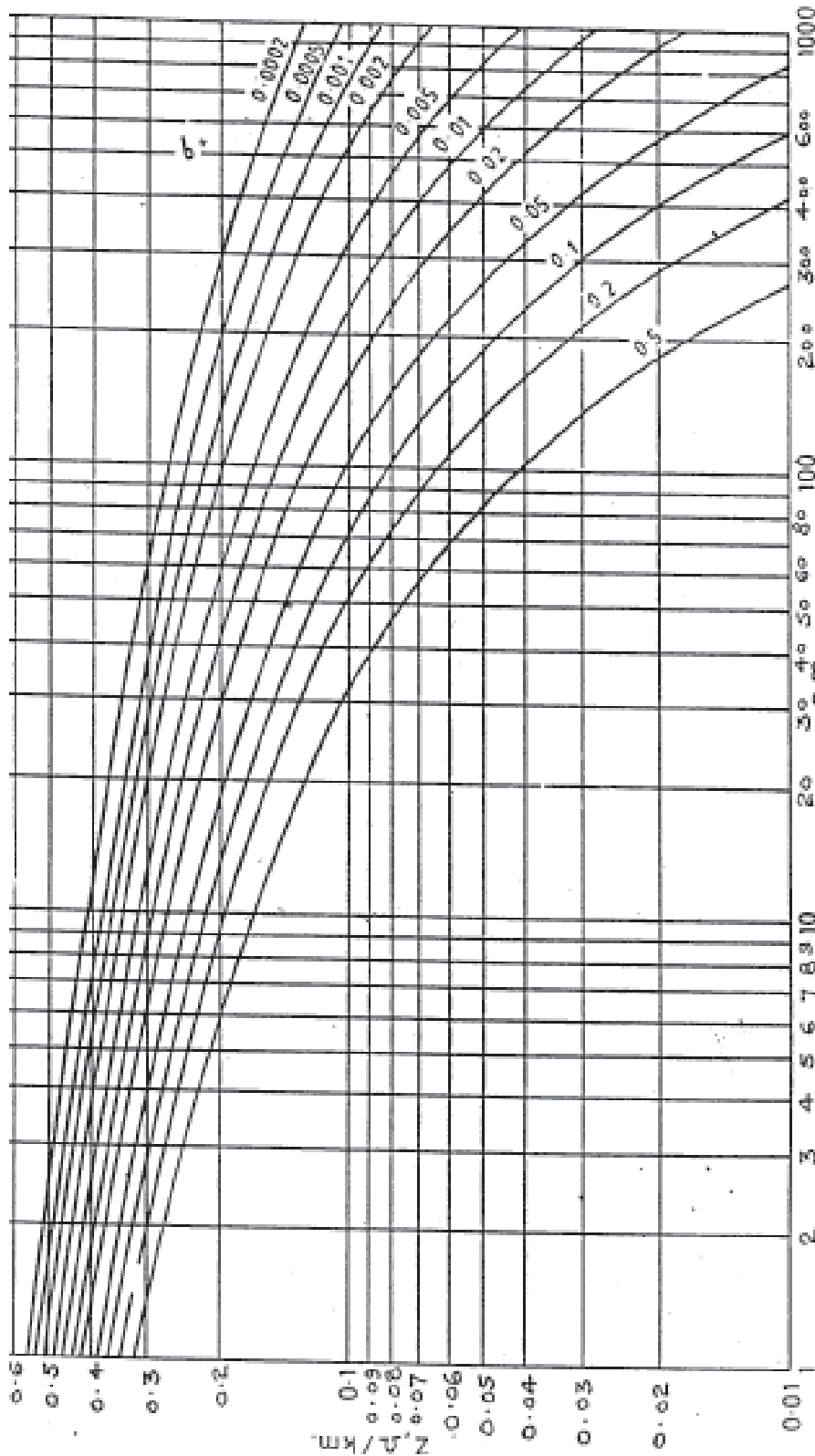


FIG 8.3
 MUTUAL IMPEDANCE AT 50 Hz BETWEEN TWO LINES WITH EARTH RETURN AS A
 FUNCTION OF THEIR SEPARATION a ; PARAMETER σ .

Fig. 8.3

Fig. 8.3 contains a family of curves, for the mutual impedance M per kilometer Vs distance of separation of the lines, for various values of parameter.

At a little distance from the track K_t can be approximated to $1 - I_t / I_c'$ where I_t is the total induced current flowing in the rails and I_c' the catenary current.

Reduction factor K_c represents the relationship of the emf developed between a cable conductor and its sheath to the emf which appears between an insulated conductor and earth in the absence of sheath. This reduction factor depends on character and dimensions of sheath and armoring and magnetic properties of the metal used for armoring. This improves as the frequency of the inducing current increases.

For cables located at a little distance from the track K_c is smaller under heavy inductive conditions like short circuits than under less severe conditions like normal operation.

Screening of cable sheaths can be improved by reducing the dc resistance of sheath and by increasing the mutual inductance between sheath and wires. Aluminium sheath has resistance of about $1/7^{\text{th}}$ of similar sized lead sheath. As against screening factor of 0.8 for lead sheathed cable for A1 sheathed cable it is 0.16. If the inductance is increased by steel tape armoring. Screening factor gets reduced to 0.025 and 0.2 respectively.

The presence of metal work electrically connected to earth near the track, or the circuit subjected to induction exerts a reducing effect, which may be considerable especially when several cables are buried in same trench as they shield each other to certain extent.

8.6 RAIL CURRENTS

The rails form a conductor with rather uncommon qualities. The resistance is very small and the leakage very large. The attenuation is so large that the return current is diverted completely to earth after about few kilometers and with higher frequencies even sooner. If the distance between feeding and loading points is large enough and if the track is homogenous, the rail current divides equally in both directions at both points without any preference for the 'inside' direction. Part of the current penetrates deep into the earth and some leaves the earth to find a path in cable sheaths, metal pipes and other similar conductor parallel to the track. Near the feeding point the whole of the current returns to the earthed end of the traction transformer winding through the rail/earth mat of the feeding point.

If the return current could be wholly retained in the rails the inducing effect on an adjacent telephone line would be that from a comparatively narrow loop formed by the overhead wires and rails and would be relatively small. In practice the load current rapidly leaves the rails for earth as shown in fig. 8.4 (b) which is applicable to an electrically long section where the rails continue for some distance on either side of the section.

The rails will however themselves be subjected to an induced voltage from the overhead wire which will cause a current to flow in the rails virtually in the opposite direction to the contact wire current as shown in fig. 8.4 (c).

In the centre of a long section the value of this current will be uniform and is equal to the induced voltage divided by the series impedance of the rails.

Typical Rail Current Distribution

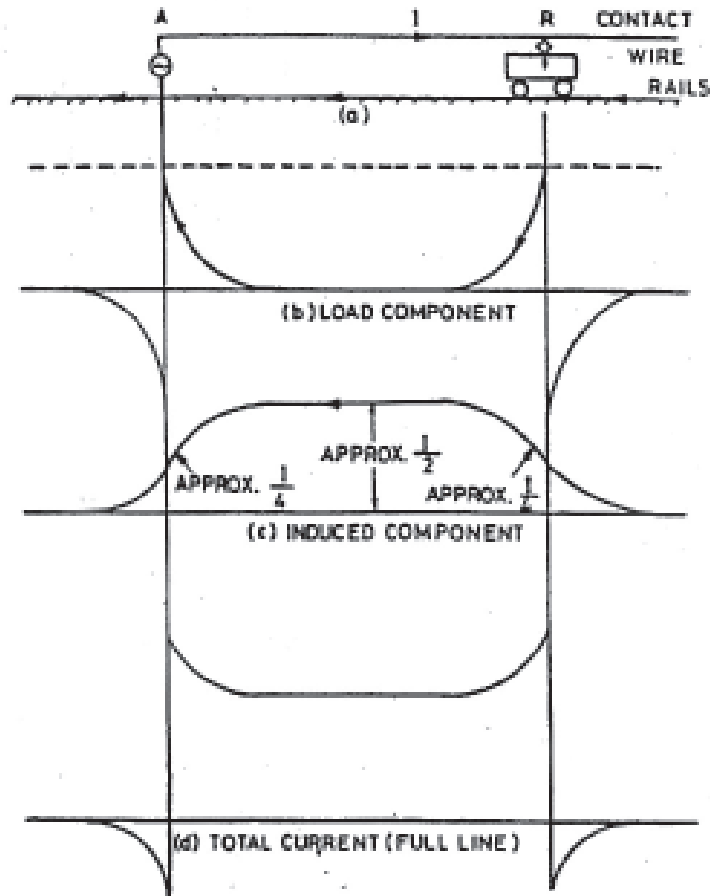


Fig. 8.4

It is usually about 0.4 to 0.7 of the overhead line current. Combining this induced current with the load current in rails, the total distribution of current in rails is shown in fig.8.4(d).

The resistivity of steel rails is rather high but the cross section is so large that the resistance mainly depends upon the resistance of the joints between rails. The dc resistance of welded rails is about 0.03 ohm/km. The screening factor becomes less than 0.6 if the track is well maintained. With imperfect fish plates there may be no screening at all at fundamental frequency even though certain amount of screening may exist even at this condition. Experience shows even bad fish plates are welded together by a coherer effect (high resistance at low voltages and negligible resistance at higher voltages) and thus the resistance across bad fish plates falls as soon as the induced voltages in rails becomes high enough. The screening factor then becomes dependent upon the primary current and may be good enough at short circuit currents even if bad at normal service current. This behaviour of the screening effect often makes special bonds unnecessary.

8.7 PROTECTIVE MEASURES:

Protective measures can be applied either in the low current communication circuits affected or at source (in the traction supply) or in both systems. Protective measures in telecommunication circuits consists of insertion of isolating transformers at intervals to limit the longitudinal build up of emf. balancing of the circuits and equipment and increasing the signal to noise ratio. Additional protective devices such as discharge tubes, drainage coils are also used.

The existing line side open – wire aerial communication lines will have to be abandoned because of intolerable induced voltages at fundamental frequency. The induced harmonic voltage is also dangerous as sophomoric voltages will be high. Hence, by use of cables the induced voltages can be reduced by the appropriate screening factors of different types of cables. A cable with a break down test voltage of 2000 volt should be able to withstand the voltages induced by a short circuit. All the ac circuits must be terminated by transformers. The terminating transformers only allow currents produced by differences of voltage (transverse voltage) to pass out to the external apparatus. As a result, in general the noise so produced is hardly noticeable and is not troublesome if the cable is only subjected to moderate induction and if there are not too many harmonics in the traction current.

Exchange and subscriber's equipment not separated by transformers from the line conductors must be protected by fuses and voltage arrestors or protectors against induced voltages.

DC circuits should be replaced by ac or impulse circuits. Special measures are required for the protection of the operators, the main precaution being to avoid any possibility of a simultaneous contact with the apparatus and with earth.

Anti induction measures include periodic transposition of the positions of conductors in a circuit at their supports, to produce compensation along the length of the line between the emf's induced between the conductor themselves. Even under favourable conditions (almost perfect parallelism between the inducing circuit and the circuits subjected to induction and regular spacing of the supports at which transpositions are made) and even if the distances between transposing points are small (less than 1 km) perfect compensation is not obtained.

In an overhead line at a short distance from the track the effects of electrostatic induction from the contact wire are added to the inductive effects due to traction current. Even if a bare overhead line is located at 300 m from a railway line with a parallelism of 4 to 5 km. it is likely to be affected by noise which creates difficulties for conversation.

Cabling the overhead communication circuits is an effective means of reducing interference. The screening is improved by reducing the resistance of cable sheath i.e by conductivity screening. This is achieved either by use of aluminium sheath or by addition of copper wires under the lead sheath. The cable sheath is also effectively earthed at intervals of about a km. Secondly, the magnetic coupling between sheath and conductors is increased by provision of steel tape armouring over the conducting sheath. The screening factor with such cables coupled with that provided by the rails and buried metal pipes, etc. can be around 0.06. Further improvement would be possible if the cable circuits are laid far away from the electrified sections.

8.8 SUPPRESSION OF INTERFERENCE AT SOURCE:

Though the above measures are generally adequate for protection of communication circuits, there might be special cases where highly sensitive long distance communication circuits or dense urban communication networks exist either parallel to the track or in its vicinity. When such a railway line is taken up for electrification, the above remedial measures might prove either too expensive or inadequate. In such cases suppression of interference at source may have to be resorted to.

Considerable reduction in the interference effects of electrified railways can be obtained by the use of booster transformers. These transformers have a 1:1 ratio with the primary winding connected in series with the contact wire and the secondary is connected either to the rails (as in Scandinavian countries) or to a return conductor as per general practice followed elsewhere. The return conductor arrangement is more favourable for reducing telephone interference.

8.9 RAIL CONNECTED BOOSTER TRANSFORMERS:

In this system the secondary winding is connected to the rails on either side of insulated rail joints and the current in the rails is thereby increased to an extent that for a booster transformer spacing of 2.66 km, only less than 5% of return current flows in the earth. The effective area of the inducing loop is much reduced and the interference effects are correspondingly reduced.

The screening effect of this system depends on the spacing of the booster transformers and the propagation coefficient of rail-earth return circuit which in turn depends on frequency and on the insulation of rails to earth. With a spacing of 2.66km the theoretical screening factor is taken as 0.05 at 50 Hz. As the rail screening factor without boosters would be 0.5, the improvement ratio due to the provision of boosters is 10:1. The reduction at higher frequencies is less.

The disadvantage of rail-connected booster system is that a considerable voltage can exist across the insulated rail joints, endangering the safety of maintenance personnel quite apart from the difficulty in proper maintenance of insulated joints. The screening factor for harmonic currents is lower than for fundamental current as the series impedance of rails is greater for harmonics than for fundamental and therefore larger proportion of harmonics escape into earth. Hence, this method is not satisfactory for the elimination of noise due to harmonics.

8.10 BOOSTER TRANSFORMERS WITH RETURN CONDUCTOR:

In this system the secondary windings are connected in series with a return conductor which is connected to the rails midway between booster transformers. The return current flows almost entirely in the return conductor and very little in the earth or rails except in section where the load current is being taken. The return conductor is erected on the overhead masts carrying the catenary and the inducing loop formed by the traction and return currents is therefore of small width.

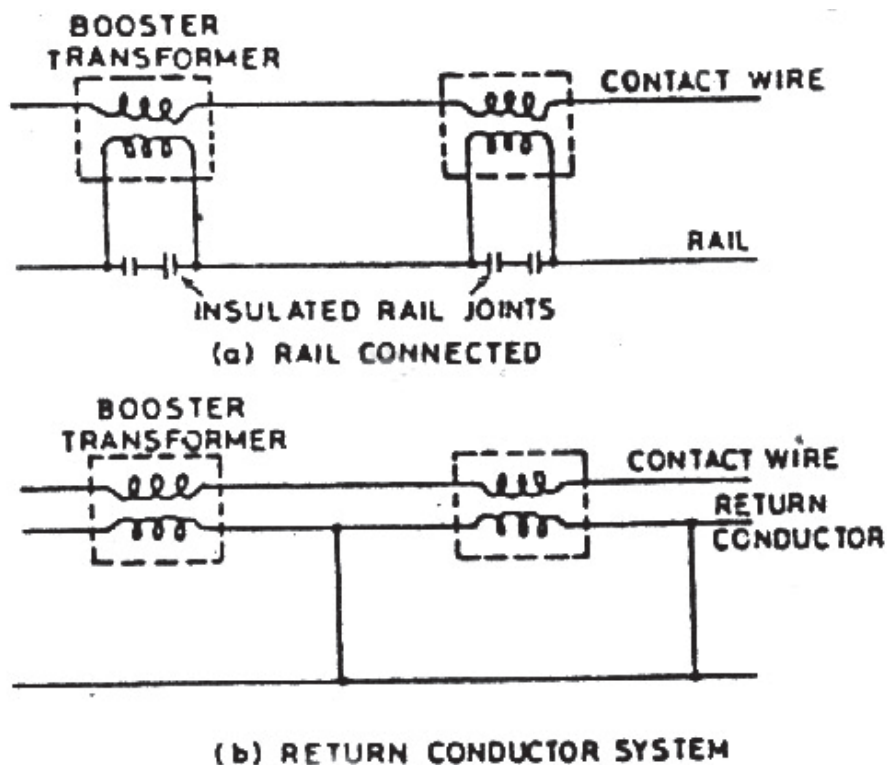


Fig. 8.5

With return conductor system two effects need to be considered. The first is induction from through currents i.e those currents taken by trains well beyond the parallelism and confined wholly to the contact wire and return conductor. The second is induction due to train in section effect i.e where the train is in a BT cell within the parallelism and the current is flowing along with the rails.

For telecommunication lines well removed from railways the first effect i.e direct induction from the contact wire return conductor loop (which are rarely equidistant from the cable) can be ignored. However, the rails are not and cannot be symmetrically disposed with respect to contact wire and return conductors and hence an induced current flows in rails which causes induction in telecom lines. Rail screening factor of remote cables would be about 0.025 and is independent of frequency. This represents an improvement of 20:1.

Considering the second effect, maximum induced voltage occurs when a train is close to a booster transformer in which case the length between the train and rail return conductor connection may be treated as being equivalent to a normal feeder section without booster transformer for which a screening factor of 0.5 at all frequencies would be appropriate provided the parallelism extends for about 3 km on either side of the equivalent section.

8.11 SALIENT FEATURES OF BOOSTER TRANSFORMER SYSTEM:

As the primaries of boosters are connected in series with the contact system with voltages of 336 V (for 100k VA boosters spaced at 2.66 km) they have to be designed to withstand 25kV. Since they are in series with the OHE they must be capable of withstanding the mechanical and thermal stresses caused by system short circuits.

Magnetizing current is required to flow in the primary to induce secondary voltage to enable secondary current to flow in the loop. This magnetizing current which flows in primary and (not in secondary) is superimposed on the load current. To limit the uncompensated current in the OHE to the minimum the exciting current has to be kept as low as possible. The harmonic current of the exciting current is to be minimum as this uncompensated current would create noise in telecommunication lines. To reduce the harmonic component of excitation current, the flux density in the core has to be kept low so that it lies on the linear portion of BH curve for the maximum voltage that may develop across the primary/secondary winding of the BT at 700 A (assumed maximum catenary current) Cold rolled grain oriented steel is used with maximum flux density of 0.7 T to contain the exciting current to 0.2 to 3% of full load current and the harmonics at 10 to 15% of the exciting current.

A high exciting impedance at harmonic frequencies is required to obtain compensation of harmonics induced voltages by currents in the return conductor. The exciting impedance at 800 Hz should not be less than 450 Ohms.

Since several booster transformers are in series and they tend to add to the OHE impedance, the leakage impedance of boosters is to be kept as low as possible.

8.12 LIMITATIONS OF BOOSTER TRANSFORMERS:

There is always a residual induced voltage in communication conductors due to proximity of other conductors including rails carrying induced currents etc. For a train in section only partial compensation is obtained. Whenever the booster primary is shorted by the pantograph of the locomotive while negotiating the BT overlap span, there will be no compensation in that cell even for through currents for that duration, though it is very small. During system short circuits due to saturation of core, compensation tends to be less than normal. Both even and odd harmonics are introduced in the exciting current flowing in the OHE.

8.13 DRAWBACKS OF BOOSTER TRANSFORMERS:

The initial cost of the system of booster transformers and return conductors is substantial. The impedance of the OHE is increased by more than 50% thereby increasing the voltage drop and decreasing the permissible loading of the section, necessitating closer spacing of substations. There will also be additional loss of energy due to additional impedance of the booster transformers and return conductors.

8.14 AT SYSTEM :

With increased system loading due to introduction of high speed passenger trains and heavy freight trains, the 2 x 25kV AT system has certain advantages over the conventional system apart from suppression of induction at source. BT system will be found wanting due to problems like heavy arcing at overlaps and higher voltage drops due to heavier currents. In the 2 x 25 kV AT system, electric power from traction sub station at single phase 50 kV is transmitted along the track between the OHE and a separate feeder wire supported on suitable insulators. At intervals of about 10 to 15kms along the track, centre tapped single phase auto-transformers are installed and connected between the OHE and the feeder wire, with the midpoint of these ATs being connected to the rails. Both the OHE and feeder wire will be at 25kV with respect to the rail but the actual voltage of transmission will be 50kV. The current from the substation flows between the OHE and the feeder wire to the two ATs on either side of the load.

These two ATs feed the current required for the load connected between the OHE and the rail. Due to equal and opposite currents flowing in the OHE and the feeder the magnetic fields produced will neutralize causing no interference except the AT cell effect. Voltage regulation on the traction system is also better with the AT system.

REGULATION FOR ELECTRICAL CROSSING OF RAILWAY TRACKS

9.0 Provision of the regulation for power line crossing of Railway Track, 1987 are given below.

9.0.1 Power line crossing up to and including 11kv require to be cabled and crossed underground

9.0.2 Power Line Crossings up to and including 33kv is recommended to be crossed through underground cables.

9.0.3 For overhead crossing of power lines, the minimum height above rail level to the lowest conductor including the guard wire shall be as given below.

Voltage(kv)	Minimum height above Rail level(m)
above 11 to 66	14.10
above 66 to 132	14.60
above 132 to 220	15.40
above 220 to 400	17.90
above 400 to 500	19.30
above 500 to 800	23.40

9.0.4 The angle of overhead crossing shall be perpendicular to the track. In exceptional cases it may be permitted with a skew, the angle of deviation not exceeding 30 degree. In case it is likely to be more than this value the case should be referred to the Electrical Inspector to the government (Chief Electrical Engineer of the open Line Railway).

9.0.5 In view of high cost of modifications to Power Line Crossing and also difficulty in getting shut down of important transmission line crossings of tracks contemplated to be electrified Electrical inspectors to Government may approve crossings with lower heights provided the clearance between lowest conductor of the power line to the highest traction conductor under most adverse ambient temperature condition is as indicated below.

Voltage(kv)	Minimum clearance(m)
0 to 66	4.44
above 66 to 110	4.75
above 110 to 132	5.05
220	6.58
400	9.71
500	11.45
800	16.67

If power line crossing has guard wire minimum clearance from the guard wire to the highest traction conductor should be 2 m

9.1 For other provision the Regulation should be referred to. Modification to Electrical overhead Distribution system at station and yards where 25kv ,ac 50Hz single phase traction is to be introduced.

9.1.1 It is essential for an electrical overhead distribution system that.

- a) There is adequate physical clearance to the 25 kv, system so that maintenance personel do not come within 2m of nearest point at a potential of 25kv.
- b) Elrctro-magnetically induced (EMI) voltage in the distribution system from adjacent 25kv traction current remains within safe limit, and
- c) Electro-statically induced discharge current due to Capacitive Coupling between 25 kv system and the power distribution is within safe limit.

9.1.2 If the above safety condition are not met with ,the overhead distribution system shall be modified to bring the value within safe limit.

9.1.3 The safe limit for :

- a) Electro-magnetically induced voltage are:
 - 1) For installations to which only trained and authorised personnel have access 60V
 - 2) For installation to which public or untrained staff have access 25v
- b) Electro-statically induced discharge current shall not exceed 8mA

9.1.4 Neutral of a 3 phase, 4 wire earthed system should be earthed at only one point,that is at the substation

9.1.5. In long metallic structures such as fencing or an overbridge,the electro-magnetically induced voltage shall not exceed 25 volts.

9.1.6. Formula adopted for Electro-magnetically induced voltage.

Electro-magnetically induced voltage 'E' is given by the expression:
 $E = 2\pi.Kr.Kc.M.I.L.$

where,

E is in volts

f is frequency of power supply=50Hz

kr is coefficient dependent upon type of return circuit and has been empirically established by SNCF the values are given below

Rails per track available for traction current	Value of Kr	
	Double track	Single track
2	0.39	0.56
1	0.53	0.69

K_c is cable screening factor and it is 1 for bare conductor and 0.8 for lead sheathed underground cable (figures adopted from SNCF)

M is mutual inductance in Henry and is a function of average distance between the conductors and the earth resistivity.

I is current in ampere in OHE

L is length of parallelism in metre

9.1.7. The length of parallelism of an overhead conductor is measured as projected on the alignment of the OHE. The separation distance, which determines the value of M for a given value of earth resistivity is the average of the length of offsets from the alignment of OHE to the overhead conductor.

9.1.8. Table 9.1 gives the voltage rise on an overhead distribution line due to induction from traction current. The table, obtained empirically by SNCF is adopted for use on Indian Railways. This table is applicable for following conditions :

- a) The Section is double track and all the four rails are available for traction current.
- b) The Current in OHE is 600 A
- c) The earth conductivity is 8×10^{-2} S/m. The value of earth conductivity generally encountered is expected to be higher than this value, as such the values in the table should be safe for majority of the conditions.

9.1.9. To obtain the voltage rise on an overhead conductor having different environment, the values given in the Table 9.1 requires to be modified. For example, to obtain the voltage rise on an overhead distribution line from an OHE on single track, with only one rail available for traction return current, the value obtained for the corresponding length of parallelism has to be modified to allow for :

- a) Single track section. This will have a maximum current of 300 A. The figure obtained should be divided by 2, i.e. 300/600.
- b) Only one rail is available for traction return current, hence the value of K_r adopted for double track, double rail section, being 0.39 is no longer applicable. The value K_r applicable for single track, single rail section is 0.69. The result obtained after modification as given in (a) above should be further modified by multiplying it with a factor of 0.69/0.39.
- c) When booster transformer and return conductors are used the value of voltage rise are reduced further. As a rough approximation the value obtained from the table in paragraph 8 above should be divided by 2.3 for a booster transformer spacing of 2.66 km and 1.7 for a transformer spacing of 4 km.

9.1.10. A Worked Example : See Fig.9.01 below giving the plan of an overhead line running along a double track section proposed to be electrified at 25 kV.

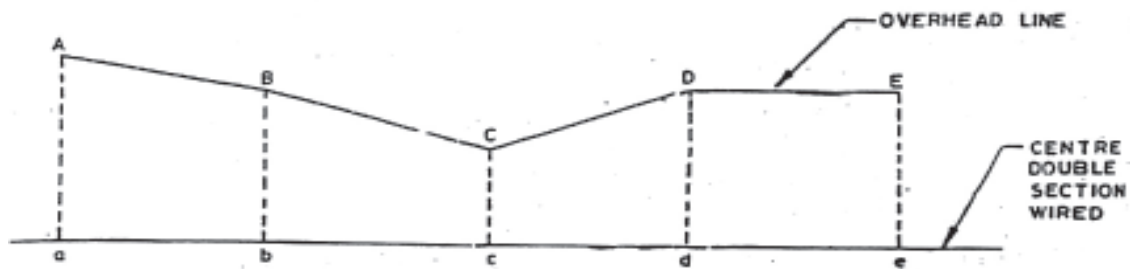


Fig 9.01

The considerations are :

- a) In the above diagram the project length of the overhead line A, B, C, D, E on electrified, route is a, b, c, d, e. a to e totals, say 0.8 km. Then this is the length of parallelism.
- b) From the diagram average of this offsets at a, b, c, d and e are taken. This is found to be, say 16 m. This is the mean distance between the two lines.
- c) Although there are four rails, if the section is near a station, there may be likelihood of track circuits being introduced in future. To be on the safe side only two rails are taken for return circuit.

On the above basis interpolating the readings of the table, the induced voltage comes to 50 V. If all four rails were available for traction currents the voltage rise expected would be 36 V. Both the values are within safe limits.

9.1.11. If it is found that the induced voltage due to electromagnetic induction is higher than the permissible limit, one or several of the means listed below may be adopted to bring the voltage down to safe limits

- a) Shift the point of feed from the end to the center of the line so as to reduce the parallelism
- b) Sectionalize the distribution line and feed short length separately.
- c) Provide separate 25 KV/240 auxiliary transformers for different areas with short distribution lines
- d) Sectionalize the line through isolating transformers
- e) Shift the distribution line farther away from the electrified track.
- f) Cable the overhead line in lead sheathed or aluminum sheathed cables.

9.1.12. To assess the electro-statically induced current Table 9.2 may be made use This table has been obtained from SNGF. In case the discharge current is found to be above safe limits, the separation distance may be increased so as to bring the value to a safe limit. It is generally found that the electrostatic induction presents little problem.