

SECTION – II

AUXILIARY SYSTEMS

CHAPTER – 4

ELECTRICAL AUXILIARY SYSTEMS

4.1 Electrical Auxiliaries System Equipment - General Requirement

All components of the electrical items of Works of the auxiliary systems of electrical and mechanical installation should be of reliable design.

Ratings of main electrical works should generally include a safety margin of 10%. Short circuit calculations, de-rating factors, etc. should be carried out and taken into consideration for design.

Short-circuit calculations should be evaluated and every electrical component should withstand the maximum stresses under fault conditions, for fault levels and durations obtained under the worst conditions, e.g., upon failure of the corresponding main protection device and time delayed fault clearing by the back-up protection device.

The equipment should be suitable for the prevailing climatic conditions and insensitive to any signals emitted by wireless communication equipment.

Clearances: The layout of the equipment in the power house should provide ready access for operation and maintenance whilst the remaining sections of equipment are alive. Working clearance provided between isolated equipment and nearest live metal work should be as per Indian Electricity rules & Standards.

4.1.1 Electrical Supplies for Auxiliary Equipment: The electricity supplies available for various auxiliary equipments are:

- (i) High voltage (see Para 4.1.2)
- (ii) 415 V, $\pm 10\%$, 3-phase 50Hz, 4-wire for A.C. power supply,
- (iii) 230 V, $\pm 10\%$, single phase, 50 Hz for lighting, indication, and anti-condensation heaters,
- (iv) DC for essential indication, controls, protection, alarms and circuit breaker closing and tripping supplies
- (v) UPS system for computerized controls, SCADA and emergency lighting

Alternating Current Supply Practice: All mains supplies should be through Air/Moulded case/MCB circuit breaker of appropriate rating. Double-pole switches should be used to break single-phase A.C. mains supplies. For multi-phase supplies, each phase should be switched simultaneously and the neutral should preferably not be switched.

Direct Current Supply Practice: Power supply bus bars in cubicles should be carefully routed and each bus bar should be shrouded. It should not be possible to inadvertently short bus bars either between themselves or to earth. It should be possible to remove/replace cards from/to electronic equipment without damage and without interfering with the operation of the rest of the equipment or system.

4.1.2 High Voltage Switchgear

The high voltage switchgear in power station for 3.3, 6.6 and 11 kV is almost universally specified as air-break switchgear. High degree of safety of air-break switchgear, suitable performance characteristics and high degree of availability combine to make it so acceptable for the job. The firefighting equipment can therefore be reduced. Further absence of current chopping reduces the over voltages in the system and minimizes outages due to insulation failures. Withdrawable type, cubicle mounted, solenoid operated from the battery is usually specified to be provided. A total opening time of approx. 5-8 cycles is usually satisfactory for protection of equipment and for maintenance of system stability under fault conditions.

4.1.3 Electric Motors

General: The power station auxiliary motors range in size from fractional horse-power used for control of valves to several hundred horse-power for driving unwatering or unit cooling water pumps. The motors are generally of squirrel cage type with direction-on line starting for quick starting. Starting current for these motors has to be kept within reasonable limits. The motor should meet without difficulty a voltage variation of ± 5 percent and frequency variation of ± 4 percent. Besides reduction of wider voltage fluctuation (say 75 percent of nominal for 10 min.) and transient voltage dips of greater magnitude during system faults must not affect the operation of the motors.

All induction motors should conform to IS 325 induction motors with suitable eyebolts. AC motors should have squirrel cage type rotors. The insulation of all the motors should be of class F but temperature rise during operation should be limited to class B insulation. It should be suitable for operation in damp locations and for occasional contact with corrosive gases/vapors.

Ventilation and Type of Enclosure: All motors should be of the totally enclosed fan-cooled type, protection class IP 54 according to IEC Recommendation 144. Cable termination points should be of class IP55. Vertical motors should be provided with a top cover to prevent the ingress of dirt and droplets etc.

Terminal Boxes and Earthing: The terminals, terminal boxes and associated equipment should be suitable for terminating the power cables. The terminal boxes should be of ample size to enable connections to be made in a satisfactory manner. For earthing purposes, each motor should have adequately sized bolts with washers at the lower part of the frame. In addition, each terminal box should contain one earthing screw.

Motor Voltages and Power Ratings: The service voltages and corresponding power ratings for electric motors to be used should be as follows:

Motors up to 1 kW

- Service voltage : single-phase a.c. 240 V, 50 HZ
- Mode of starting : condenser

Motors above 1 kW and up to 160 kW

- Service voltage : 3-phase a.c. 415/240 V, 50 HZ
- Mode of starting : direct-on-line up

Motors intended to work on the D.C. System

- Service voltage : As per battery voltage
- Mode of starting : resistor

Rating: The rating of the motors should be adequate to meet the requirements of its associated driven equipment. The service factor, being the ratio of the installed motor output to the required power at the shaft of the driven machine at its expected maximum power demand, should be applied as follows:

Power Demand of Driven Machine Service Factor

Up to 5 kW	1.2
More than 5 kW	1.1

A.C. motors should be capable of operating continuously under rated output conditions at any frequency between 95% and 105% of the rated frequency and/or with any voltage variation between 90% and 110% of the nominal voltage. A transient over voltage of 130% of the nominal voltage should be sustained.

The motors should be capable of maintaining stable operation when running at 70% nominal voltage for a period of 10 seconds. The pullout torque for continuously loaded motors should be at least 160% of the rated torque and for intermittently loaded motors 200% of the rated torque.

D.C. motors should be capable of operating continuously under rated output conditions at any voltage between 90% and 110% of the nominal voltage with a fixed brush setting for all loads. The speed drop between no-load and full-load should not exceed 10% of no-load speed.

Starting: A.C. motors should be designed for direct on-line starting. They should be capable of being switched on without damage to an infinite busbar at 110% of the nominal voltage with an inherent residual voltage of 100% even in phase opposition. For starting the motors from the individual main and auxiliary busbars, a momentary voltage drop of 20% referred to nominal voltage should be taken into consideration. With 85% of the nominal voltage applied to the motor terminals, each motor should be capable of accelerating its associated load to full speed with a minimum accelerating torque of 5% of full load torque. The maximum starting currents (without any tolerance) should not exceed the following values:

- 5 times of rated current for L.V. motors rated up to 160 kW or above
- 2 times of rated current for D.C. motors (by means of starting resistors)

Generally, all motors should be able to withstand five cold starts per hour, equally spaced. Each motor should be capable of withstanding three successive starts under the same conditions or once every fifteen minutes without detrimental heating. Motors for frequent automatic starting should have an adequate rating.

Bearings: As far as possible, the motors should have sealed ball or roller bearings lubricated for life. All other motors with ratings of about 1 kW and above should be equipped with lubricators permitting greasing while the motor is running and preventing over-lubrication. Additionally, the bearings should be fitted with grease nipples permitting the use of a universal grease gun. Vertical motors should have approved thrust bearings.

Terminal Boxes and Earthing: The terminal leads, terminals, terminal boxes and associated equipment should be suitable for terminating the respective type of cables as specified in these General Technical Specifications and in the Particular Technical Specifications.

Noise-Level and Vibrations: Under all operating conditions, the noise level of motors should not exceed 75 dB (A) at any place 1.0 m away from operating equipment. All motors should be statically and dynamically balanced. The vibration amplitude should not exceed values specified in IS 4729.

Tests: Each motor should be factory tested and should undergo a test at site. The following tests should be performed under full responsibility of the Contractor.

Workshop Tests:

- Measurement of winding resistances
- No-load and short-circuit measurements
- Measurement of starting current and torque
- Efficiency measurement (type test)
- Heat test run
- Dielectric test
- Measurement of insulating resistance

4.1.4 Starters and Contactors

Motor starters and contactors should be equipped with short circuit protection and local disconnecting devices. The control circuit voltage should be obtained from a 415/240 V isolating transformer with primary circuit breaker and secondary fuse. The secondary winding of this transformer should be grounded. The operating coils of the contactor should be connected between the grounded side of the transformer and the control contacts.

Starters and contactors should comply with IEC 292.1 or National Electrical Manufacturer Association USA standard NEMA IC 1 and be suitable for direct on-line starting, uninterrupted electrical duty, and capable of 30 operations per hour. They should be installed in ventilated enclosures for indoor installation and weatherproof enclosures for outdoor installation. The enclosures should be complete with locks, cable sealing boxes, conduit entries, cable gland plates, bus bars, internal wiring, terminal boards, etc. as required by the duty of the starter.

Thermal type overload and phase failure relays should be supplied with starters for motors of 7.5 kW or greater. For motors of less than 7.5 kW, suitable rated 3-phase thermal overloads may be provided. Ammeters to read current in one phase should be provided for motors above 7.5 kW.

4.1.5 Moulded Case Circuit Breakers

All moulded case circuit breakers should be of 2 or 3-pole type as required, with requisite short time rating having thermal time delay and instantaneous trips with "On-Trip-Off", indicating/operating mechanism. Circuit breakers used in combination type motor starters or contactors should have the operating mechanisms interlocked with the starter or contactor cover so that the cover cannot be opened unless the circuit breaker is open. The breakers shall comply with applicable section of IEC 157/1 or equivalent standard.

4.1.6 Control Relays

Relays used as auxiliary control devices in conjunction with motor starters and magnetic contactors shall be of the type designed for machine tool application featuring contact convertibility. All contacts shall have a minimum thermal current rating of 10A over a range of 6 to 600 V AC.

4.1.7 Terminal Blocks

All terminal blocks should be mounted in an accessible position with the spacing between adjacent blocks not less than 100 mm and space between the bottom blocks and the cable gland plate being a minimum of 200 mm. Sufficient terminals should be provided to allow for the connection of all incoming and outgoing cables, including spare conductors and drain wires. In addition, 20 percent spare terminals should be provided. In enclosed cubicles, the terminal blocks should be inclined toward the door for facilitating terminations.

Terminals should be of the channel mounting type and should comprise a system of individual terminals so that terminal blocks can be formed for easy and convenient cabling consistent with the high reliability required of the circuits.

Terminal blocks should be provided with shorting links and paralleling links where applicable and mounting identification numbers and/or letters.

Terminal blocks should conform to the applicable standards. The smallest size to be used should be designated for 2.5-sq. mm wire and not more than two conductors should be connected under one terminal clamp.

Terminal identification should be provided corresponding to wire number of connected leads.

Circuit terminals for 415 V AC should be segregated from other terminals and should be equipped with non inflammable, transparent covers to prevent contact with live parts. Warning labels with red lettering shall be mounted thereon in a conspicuous position.

4.1.8 Equipment Wiring

All wiring connections should be readily accessible and removable for test or other purposes. Wiring between terminals of the various devices should be point to point.

Multi-conductor cables should be connected to the terminal blocks in such a manner as to minimise crossovers. Approved claw washers of crimp type connector should be used to terminate all small wiring. Each conductor should be individually identified at both ends through a system providing ready and permanent identification, utilising slip-on ferrules approved by the Engineer.

Markers may be typed individually or made up from sets of numbers and letters firmly held in place. Open markers should not be accepted.

Markers must withstand a tropical environment and high humidity and only fungus proof materials should be accepted. Ferrules of adhesive type are not acceptable.

All trip circuits should employ markers having a red background.

4.1.9 Cubicles and Control Panels

Cubicles and control panel enclosures should be of sheet steel vermin proof with minimum thickness of 1.5 mm, rigid self-supporting construction and supplied with channel bases. Cubicles should be fitted with close fitting gasketed and hinged doors capable of being opened through 180 deg. The doors of all cabinets/panels should be provided with integral lock and master key.

Cubicles and panels should be vermin proof. Removable gland plates should be supplied and located to provide adequate working clearance for the termination of cables. The cables and wiring should enter from bottom or top as approved or directed by the Engineer.

The cubicles and panels should be adequately ventilated, if required, by vents or louvers. All ventilating openings should be provided with corrosion-resistant metal screens or a suitable filter to prevent entrance of insects or vermin. Space heating elements with thermostatic control should be included in each panel.

Where cubicles are split between panels for shipping, terminal blocks should be provided on each side of the split with all necessary cable extensions across the splits. These cable extensions should be confined within the panels with suitable internal cable ducts.

Unless stated otherwise, all cubicles and panels should be provided with a ground bus with 40mm copper bar extending throughout the length. Each end of this bus shall be drilled and provided with lugs for connecting ground cables ranging from 70 to 120mm².

All instruments, control knobs and indicating lamps should be flush mounted on the panels. Relays and other devices sensitive to vibration should not be installed on doors or hinged panels, and no equipment should be installed on rear access doors.

The instrument and control wiring, including all electrical interlocks and all interconnecting wiring between sections, should be completely installed and connected to terminal blocks by the manufacturer.

The arrangement of control and protection devices on the panels and the exterior finish of the panels should be subject to the approval of the Engineer. The interior of all cubicles and panels should have a mat white finish unless specified otherwise.

Switched interior light and socket outlets should be provided for all cubicles and control panels.

All cubicles and control panels should be provided with nameplates, identifying the purpose of the panel and all of its components.

4.1.10 Earthing

Provision should be made for earthing all equipment intended for connection in an A.C. mains supply. All structural metal work and metal chassis should be connected to earth. Connection between circuits and metal work shall only be made for reasons of safety and/or reduction of interference. Where such connections are made, they should not be used as normal current-carrying earth returns.

Earthing conductors should be at least equal in cross-sectional area to the supply conductors and should be capable of carrying the fault current.

4.1.11 Labels and Plates

Labels and data plates should be provided in accordance with applicable standards and as detailed hereunder.

The proposed material of the labels, size, exact label lettering and proposals for the arrangement of the labels should be submitted to the Engineer (purchaser) for approval.

Labels written in the Contract language should be provided for all instruments, relays, control switches, push buttons, indication lights, breakers, etc. In case of instruments, instrument switches and control switches, where the function is indicated on the device, no label is required. The label should be fixed close to the devices in such a way that easy identification is possible.

Each separate construction unit (cubicle, panel, desk, box, etc.) should be identified. Cubicles and similar units should also bear this identification number on the rear side if rear access is possible. The overall designation of each unit should be given in the Contract language and - if required - also in a selected local language. These labels shall be made of anodised aluminium with black engraved inscriptions, arranged at the top section of the units. Manufacturer's trade labels should - if desired - appear in the bottom section of the units.

All Works inside cubicles, panels, boxes, etc., should be properly labelled with their item number. This number should be the same as indicated in the pertaining documents (wiring diagrams, Works list, etc.). Instruction plates in the Contract and selected local language, the sequence diagrams or instructions for maintenance should be fitted on the inside of the front door of the electrical switchboards.

4.1.12 Warning Labels

Warning labels should be made of synthetic resin with letters engraved in the Contract and selected local language, where required in particular cases.

For indoor circuit breakers, starters, etc., transparent plastic material with suitably contrasting colours and engraved lettering should be acceptable.

4.1.13 Labels for Cables

Each cable when completely installed should have permanently attached to each end and at intermediate positions as may be considered necessary by the Engineer, non-corrosive labels detailing identification number of the cable, voltage, and conductor size.

The cable identification numbers should comply with those of the cable list.

All cables in cable pits and at the entry to buildings should be labelled utilising the aforementioned type of label.

4.1.14 Single-Line Diagrams

Each switchgear room should be furnished with a copy of the final as-built single-line diagram detailing all electrical data and denominations, separate for each individual switchgear / distribution board / MCC, placed under glass and frame/wall mounted at an approved location.

The same applies to the Station Single-Line Diagram one copy of which should be arranged in the control room(s).

4.1.15 Key System for Electric Boards

Key interlocked switches should be provided with approved locks for locking in the neutral position. Similar locks should be provided for selector switches for locking the switches in any of the positions. The locks or padlocks should be co-ordinated for the different applications and should be supplied with three keys. The cabinet door keys should be similar and should be six (6) in number.

4.1.16 Instrumentation and Control Equipment

Design Criteria

All components should be uniform and inter-changeable as far as possible and pre assembled to the highest extent in the contactors or sub contactor's workshop. Shielded cables should be provided for the control and supervisory equipment where required.

All instrumentation and control functions should be shown on the piping and instrumentation diagrams. The symbols to be used should be in accordance with ISO standard. The identification system (tag numbers) should be in accordance with the Works identification system and subject to approval by the Engineer. All measurements and alarms should be listed in a measuring list of a standard form subject to Approval by the Engineer. For remote controls, a schedule of interlocks should be provided. The features of automatic controls should be shown in block diagrams.

Shielded cables should be provided for the control and supervisory equipment where required.

Sizes of Indicators, Recorders, Etc.

The meters, instruments and recorders should be of standard size, to be selected to guarantee unique appearance of switchgears, control panels, control desks, etc. The front glasses should be of the anti-glare type. The scales should be 90 degrees type for local control panels but must be 240 degrees type for control room instrumentation.

Tests

The single components and pre-erected assemblies should undergo functional and routine tests in the Contractor or Sub-Contractor's workshop. The ready mounted control and supervisory system should undergo functional tests on Site prior to commissioning of the power Works.

Calibration tests should be made on all-important pressure gauges and other instruments as required by the Engineer.

Measuring Systems: Electric measuring signals of 4-20 mA should be transmitted to the control room for essential or regulating circuits. Measuring signals for indicating purposes should be 4-20 mA. Measuring ranges of indicators, transducers, etc. should be selected in such a way that the rated value of the measured magnitude covers approx. 75% of the range.

All local instruments should, as far as practicable, be mounted vibration free to allow good reading. Wherever required, damping elements should be used. Corresponding systems should be grouped together in local panels.

Temperature Measurement: Resistance thermometers and thermocouples should be equipped with waterproof connection heads. The temperature sensors should be selected in such a way so as to minimise the number of different spare inserts.

Resistance thermometers should be used as far as possible and should generally be of type Pt 100.

The use of dial-type contact thermometers should be restricted to bearing metal and oil temperature measuring.

Pressure Measurements: Pressure gauges should be shock and vibration-proof (preferably by filling with glycerin) and the movement should completely be made of stainless steel. The casings should be dust and watertight and be made of stainless steel. The adjustment of the pointer should be possible by means of an adjustment device without removing the pointer from its axle.

Each gauge, pressure switch and transmitter for absolute or differential pressure should be equipped with a pressure gauge isolating valve including a test connection of the screwed type M20 x 1.5 mm so that such device can be removed without any disturbance of the plant operation. If the pressure is pulsating, the devices concerned should be connected via flexible tubes or other pulse-absorbing means.

The error for pressure transmitters should be limited to $\pm 0.5\%$.

Level Measurements: The liquid level measurements in reservoirs and tanks with atmospheric pressure should be made by means of displacement type transmitters, float disc transmitters or capacitance measurement type. The errors should not exceed $\pm 1.0\%$ of the total measuring range. Level switches should be of the externally mounted float or displacement operated type.

Electrical Measurements: All Electrical instruments should be of flush mounted design, dust and moisture-proof. A.C. ammeters and voltmeters should have digital type system of not less than 1.5 accuracy class for connection to the secondary side of instrument transformers. D.C. measuring instruments should have digital type systems of the same accuracy. Wattmeters/energy meters should have electro-dynamic measuring mechanisms if fed by transmitters. Wattmeters should be suitable for unbalanced systems and accuracy of energy meters should be of 0.2 % accuracy class.

All indicating instruments should generally withstand without damage a continuous overload of 20% referred to the rated output value of the corresponding instrument transformers. Ammeters should not be damaged by fault-currents within the rating and fault duration time of the associated switchgear via the primaries of their corresponding instrument transformers.

All instruments and apparatus should be capable of carrying their full load currents without undue heating. All instruments and apparatus should be rear connected, and the enclosures should be earthed. Means should be provided for zero adjustment of instruments without dismantling.

When more than one measured value is indicated on the same instrument, a measuring point selector switch should be provided next to the instrument and should be engraved with a legend specifying each selected measuring point.

Scales should be arranged in such a way that the normal working indication is between 50-75% of full scale reading permitting an accurate reading. CT connected Ammeters provided for indication of motor currents should be provided with suppressed overload scales of 2 times full scale. The dials of such ammeters should include a red mark to indicate the full load current of the motor.

All instruments mounted on the same panel should be of same style and appearance.

All metering circuits should be terminated in marked terminal blocks for remote metering purposes.

Position Measurements: Position transmitters for continuous position indication and measuring transducers should have an output current of 4-20 mA and aux. supply voltage (if required) 24/48 V D.C.

Limit Switches: Limit switches should be mounted suitable for easy adjustment and for rigidly locking in position after being adjusted. They should be of heavy-duty rating and have two changeover contacts suitable for D.C. operation.

Switch fixings should be positive and should be unaffected by vibration. At the same time they should be capable of easy adjustment to suit changing parameters of the associated plant.

Particular attention should be paid to potentially harmful environmental conditions, including water, oil, dust, dirt, temperature variations and differential expansions.

Contact Devices: Contacts of level switches, pressure switches, temperature switches, limit switches, and of all other devices should be of the snap action type (SPDT). Contact devices for interlocking systems should be separate, i.e., contact devices serving commonly for interlocking and other purposes should not be accepted.

Protection Systems: Electrical/Mechanical Protection and Interlocking Systems should be provided for all works components and individual systems to ensure a safe and reliable operation and to limit harm and damage to personnel and works to an utmost extent.

The primary functions of these facilities should be to disconnect selectively faulty sections of the systems prior to influence or damage to other works and to maintain operative systems as far as possible.

Moreover these devices should facilitate the duty of the operation staff and prevent mal-operation.

4.2 AUXILIARY POWER SUPPLY SYSTEM

Auxiliaries in a hydro-electric station consume very little power as compared to steam or nuclear station – say about 0.5-1.0 percent of the gross output. But it is the integrity of this power on which rests to a large degree the usefulness of the remaining power.

Electrical and mechanical unit and station auxiliaries integrity is important for successful operation of hydro station. Major considerations for selection and provision of auxiliaries in SHP station are: i) economic viability, ii) lack of skilled operators iii) unattended operation. Design consideration for the

supply of power to the auxiliaries are discussed with special reference to present-day trends. Provision and selection of auxiliaries are discussed as follows:

- a) Mega hydro power stations
- b) Selection of auxiliaries and system for large hydro station above 5 MW unit size
- c) Auxiliaries for Small Hydro (SHP) above 100 kW to 5 MW unit size
- d) Micro hydropower to 100 kW unit size

4.2.1 Auxiliary Electrical Equipment

The auxiliaries in usual power plant can be divided into two categories: (a) unit auxiliaries; (b) station service auxiliaries (c) Other Auxiliaries System.

(a) Unit auxiliaries may consist of the following:

- Governor oil pump motor
- Cooling water pump motor (if used)
- Turbine lubricating and drainage pump motors
- Generator space heater
- Generator rotor jacking pump motor
- Excitation Transformer
- Turbo-blower (if necessary in a variable head plant)
- Oil pump motors of oil coolers for unit transformers (if used)
- Electric drive for valve motors
- High pressure oil pumps
- De-humidifying in bulb type units

(b) Station service auxiliaries may consist of the following equipment. There may be several units of each type of equipment:

- Static charging sets for battery charging
- Air-compressor motor
- Unwatering pump motor
- Drainage pump motor]
- Ventilation fans
- Air-conditioning equipment
- Transformer oil handling pump motor
- Governor and lubricating oil handling pump motor
- Waste oil disposal pump motor
- Oil purifier centrifuge pump motor
- Machine shop equipment (for large hydro)
- Main power plant crane power supply
- Electrical laboratory power supply (for large hydro)
- Sewage disposal pump motor
- Treated water pump motor (if provided)
- Elevator motor generator supply (if provided)
- Switchyard power circuit
- Power outlet circuit
- Lighting power supply

(c) Other Auxiliaries System

- Dam/weir by pass etc. auxiliaries
- Lighting of the project and adjacent area
- Colony lighting (if required)
- Uninterrupted power supply

4.2.2 Requirement for Auxiliary Power Supply

The power requirements for the hydro power plant auxiliaries as enumerated above can be estimated at an early stage of design and form the fundamental parameters of the station.

Obviously, it is necessary to include a margin in rating of power station auxiliaries and consequently most auxiliary motors run at less than full load under normal condition. A load factor is thus obtained which reduces the actual maximum demand to approximately 60-70 percent of the running installed power for the auxiliary.

Main Considerations in designing the system for source of power is as follows, but ideal auxiliary system should remain a simple system:

Service should not be interrupted by **power system disturbances** as discussed below and Service continuity be maintained under all conditions.

- a) There are a number of circumstances that can lead to collapse of all of parts of a bulk power distribution system. Regardless of the circumstances, the triggering event generally leads to regional and sub-regional mismatch of loads and generation and “Islanding” (i.e., plants providing generation to isolated pockets of load). Separation of generation resources from remote loads and “islanding” can cause voltage or frequency changes that may result in the loss of other generation resources, particularly steam generation, which is more sensitive to frequency changes than hydroelectric turbine generators. Steam generation is also harder to return to service than hydro generation, so the burden of beginning system restoration is more likely to fall on hydro stations.
- b) When a transmission line is removed from service by protective relay action, the power it was carrying will either seek another transmission line route to its load, or be interrupted. If its power is shifted to other transmission lines, those lines can become overloaded and also be removed from service by protective relays. System failures are more likely to happen during heavy load periods, when failures cascade because of stress on the system. If the hydro units are running at or near full load when the plant is separated from the system, they will experience load rejections.
- c) Units subjected to a load rejection are designed to go to speed-no-load until their operating mode is changed by control action. Sometimes, however, they shut down completely, and if station service is being supplied by a unit that shuts down, that source will be lost. Units can’t be started, or kept on line, without governor oil pressure, and governor oil pressure can’t be maintained without a source of station service power for the governor oil pump.
- d) Assumptions made concerning plant condition when the transmission grid collapse, thus initiating the requirements and operating parameters which the station service design must meet. At least one emergency power source from an automatic start-engine-driven generator should be provided for operating governor oil pumps and re-establishing generation after losing normal station service power.

Black Start capability: “Back Start” capability is desirable at hydro plants since the plants can assist in re-establishing generation for the power system in an emergency. “Black Start” capability is defined as the ability of the plant, without an external source of power, to maintain itself internally, start generating units, and brings them up to speed-no-load conditions, close the generator breakers, energize transformers and transmission lines, perform line charging as required, and maintain units while the remainder of the grid is re-established. The plant must then be resynchronized to the grid.

Other Considerations: First cost, maintenance cost and operating cost should be low. Safety of personnel, simplicity of operation and ease of maintenance be ensured.

4.2.3 Auxiliary Power Supply Systems

Source of supply – Main sources of auxiliary power in a hydro-electric station may be:

- (a) Transformer connected to generator leads
- (b) Main station buses through house transformers
- (c) Direct supply from another station
- (d) House station service generators

A combination of the methods of supply is used and the auxiliary bus and switching arrangements may duplicate any of the arrangements for main electrical connection.

Unit Auxiliary Power Supply: The idea of unit power generation has been quite universally adopted especially for larger units. The unit auxiliaries system associated with unit generation is fed by two independent sources of power generation, one derived from the generating unit and the other may be from the station bus-bars, supplying station services as well as providing standby for the unit auxiliaries.

This method has been quite extensively adopted in the hydro-electric station in India. The rating of the unit transformer is based on the total connected capacity of running unit auxiliaries i.e. excluding standby drives. As such the transformer is operating at about 75 percent full load throughout most of its life. The unit supply by transformers connected directly to generator leads is a reliable and economical source of power and has been very extensively used in recent practice. This power supply is, however, susceptible to disturbances during severe faults in the main system, but system disturbances are somewhat cushioned by the impedance of the generator transformer. Application of modern high speed protection, coupled with the ability of modern motors to recover its speed after momentary voltage drop, has made this source of power supply all the more dependable.

The total loads of the auxiliaries in hydro-electric station being small (as compared to steam or nuclear stations) all the units in a large hydro-electric station may not be provided with unit transformer. Instead generator leads of only a few of the units may be tapped by transformers. The rating of these transformers is generally large enough so as to cater to the needs of running unit and station auxiliaries standby supply.

For unit type station a supply independent of the individual units is necessary and the station supply must be available when all units are shut down. As hydroelectric stations usually operate in interconnected system, this supply could be obtained from the main bus-bars through step-down transformers. An additional starting supply is necessary in case of the stations which are intended for operations on isolated systems. This supply may be a small diesel plant or a self-contained house set.

Normally one such station service transformer is enough unless the number of hydro-electric units is exceptionally large. This transformer should have a capacity large enough to meet the maximum demand of all the auxiliary load of the power house.

Selection of Voltage: The distribution voltage to be used should be selected on a cost basis. For most of the large station, a two-voltage system using 3.3 kV (or 6.6 kV) and 415 V. has been generally adopted. Fault level, current rating, voltage regulation and copper losses of the system are the main factors involved in comparing the costs.

The voltage drop on starting auxiliaries does not normally present any special problem except in the cooling water pumps (if used) in case of unit auxiliaries or large unwatering pumps in case of station auxiliaries. This can be improved upon by restricting starting current for these motors and by adjusting the size of the transformers feeding unit auxiliaries so that a large dip in supply voltage is avoided when the motor is switched on.

Sometimes if the unwatering pumps are of large capacities, it may be preferable to feed these motors on 3.3 kV and the motor obtained should have sufficient acceleration torque with voltage down to 80 percent of the normal value.

Some voltage adjustment at the transformer is useful and it is a usual practice to provide off-circuit tapping of 2.5 and 5 percent on unit and station service transformers.

Fault level: The voltage selected for an auxiliary system is closely associated with the fault level and both have to be considered in order to determine the most economical arrangement, the next higher standard voltage being adopted when the rating limit of available switchgear of a given voltage is reached. As previously stated, a two-voltage system keeps the fault level in big hydro-electric unit within proper limits. Insertions of reactors for limiting fault currents are liable to cause voltage regulation problems and should be avoided.

On the units boards, if paralleling of different sources of power is prevented by providing suitable interlocks, switchgear of a lower breaking capacity can be used. The induction motors contribute a fault current of short duration due to the effect of residual magnetism. This current approaches the motor,

starting current (5 times full load current) at full voltage and decays within a few cycles. It is therefore desirable to take this into account while calculating the fault level of the auxiliaries system.

Earthing: The practice and opinion on the type of grounding for the auxiliaries system varies. An ungrounded system may be operated with an accidental ground on one phase until alternative arrangements for supply can be made. But an ungrounded system is more prone to a ground fault, which is difficult to locate. A second ground fault on a different phase may occur before the first one is repaired and in the later event it is liable to cause lot of damage. On the other hand, a ground fault on an auxiliary system with solid or resistance earthing is quickly isolated by relays with no loss of service to unaffected portions of the system. With solid earthing the system voltage surges are the lowest, while with resistance earthing earth fault currents can be reduced to comparatively small values.

The present trend is to use solid earthing on transformer earthing. The extra cost of resistance earthing is not justifiable.

Earthing of the equipment is by connection to the combined station earthing system. Bare copper/steel wires or strips solidly connected to main earthing grounding mats have been used. In Indian practice, all earthing is being done by M.S. strip-all connections being welded.

4.2.4 Auxiliaries Control

The present-day trend in modern power plants is towards increased centralization of controls, aiming at more and more of automation. This is due to the fact that hydro plants can be started at very short intervals and are thus ideally suited for push button starting or closing. Automatic starting by drop of system frequency is being quite widely adopted in Russia, as a measure of enhancing static stability of the power system. In U.S.A. some large hydro-electric generating stations are being planned for remote control from a central computer control station so as to also provide for automatic loading, unloading and voltage control, besides of course automatic starting and stopping of the unit. The standby auxiliaries, i.e. governor oil pump, bearing forced lubrication pumps, unwatering and drainage pumps, etc., on which the safety of the plant depends are arranged for automatic start up, initiated electrically on failure of the main auxiliary or by an abnormal condition of pressure, water level, or temperature.

The control and instrumentation of the hydro turbine and the hydro generator units are centralized to allow for overall supervision by one operator who can make any necessary adjustments without delay. In most of the large hydro-electric stations, it has also become a practice to centralize all controls of auxiliaries associated with starting, running and stopping of the entire unit on separate boards named unit control boards. These boards for each pair of units are located at or near the turbine floor level.

Automatic switching of selected standby and emergency auxiliaries is necessary to prevent dangerous conditions arising on failure of running auxiliaries. Automatic change-over of entire unit auxiliaries to the alternate source of supply is an unnecessary complication and is an avoidable additional expenditure for stations with large units, as failure of the main supply is usually the result of a major fault, which should be investigated.

4.2.5 Auxiliary Power Supply for Large/Mega Power Stations

The arrangement of auxiliaries system depends upon a variety of conditions, e.g. source of power supply, distribution system associated with a particular power station, etc. The arrangement as based upon these considerations is selected so as to give the best and most economic solution.

Figure 4. 1 and Figure 4.2 show the auxiliary systems for Bhakra power plants which contain 5 sets of 100 MVA each in power plant I on the left bank and 5 units of 135 MVA each on power plant II on the right bank. The main source of power supply is the station transformers connected to generator leads, while the standby supply is essentially from the station service transformer connected to the tertiary winding of the interlinking transformer connecting the main station buses at different voltages, in power plant I. Further, as can be seen from the diagram, voltages of 3.3 kV and 415 V. have been adopted. Fault level on 415 V. in power plant I was kept 25 MVA by specifying more than normal impedance for the 3.3 kV/415 V. transformers. In power plant II, the numbers of transformer were for the same reason increased to four and

higher than normal impedances adopted to keep down the fault level to 15,000 amps. and thus economize on much cheaper 415 V. switchgear and cables. In Dehar Power Plant (6 Units of 165 MW) unit system was adopted and fault level of 415 V switchgear reduced by providing low capacity (500 kVA) unit transformers.

Black start capability was originally proposed from a small hydro unit house set and from tertiary winding of 132 kV transformers. Small hydro set was replaced by a diesel generator set subsequently (Figure 4.3).

4.2.6 Auxiliary power supply for Medium Size Hydro Power Station above 5 MW

Unit Connected Generator: Multiple auxiliary power supply system is generally required for these power houses as the flexibility for restoring auxiliary ac supply is of prime importance if there are critical loads that must be energized quickly. Examples of such loads are sump pump, spillway gates, and head gate motors. The need for rapid restoration of station service power may justify a stand-by emergency source such as a small diesel engine generator or a separate feed from the utility.

A typical single line diagram on generator leads for unit connected generators is shown in Figure 4.4. A generator breaker is provided. Two normal sources of power are from the unit transformers. If the generator in Figure 4.4 is out of service, station service can be fed from the transmission line. If the main transformer is out of service, station service may be fed from the generator, with the isolating switch open, provided hydraulic conditions permit stable operation at low loads.

Black start capability is provided by auxiliary power supply source from a nearby grid sub-station or if necessary from an standby diesel generator set.

Unit Connected to Generator Bus: A typical single line diagram where units are connected at generator voltage and generator bus is available; station service transformers are provided from station bus section as shown is Figure 4.5.

In case any critical load are to be energized as discussed. A diesel generator can be provided for black start emergency.

4.2.7 Auxiliary power supply for Small Hydro Power Station below 5 MW

Auxiliary power supply sources may be unit connected, as in Sikasar Project Figure 4.6. Auxiliary power supply may be taken from the bus if the units are connected to a bus at generator voltage (Figure 4.7). These units are grid connected at 33 kV and power supply source may be 33 kV (Figure 4.8). SHP is interconnected at 33 kV with three other small hydro by double circuit 33 kV line. Emergency power supply for black start by 33 kV transformer was proposed.

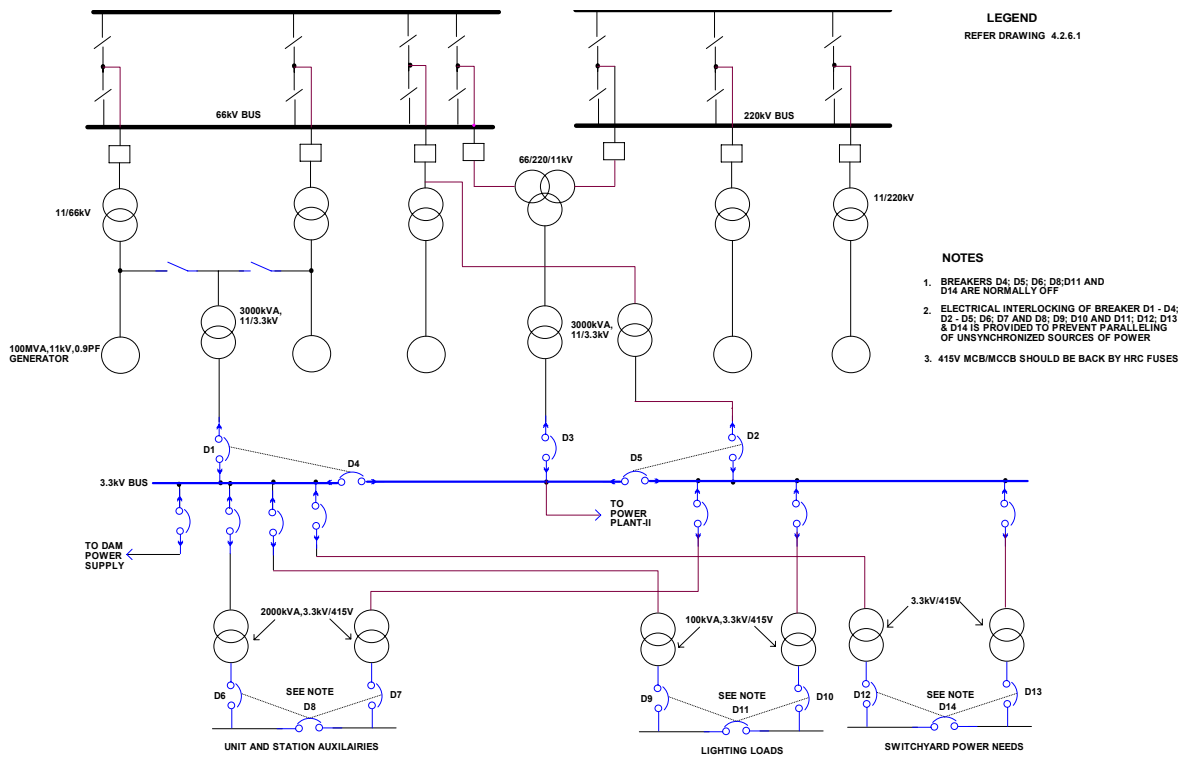


Figure 4.1: Auxiliary power Supply System - Basic Bhakra Power Plant I (5 units of 90 MW Each) (As Designed)

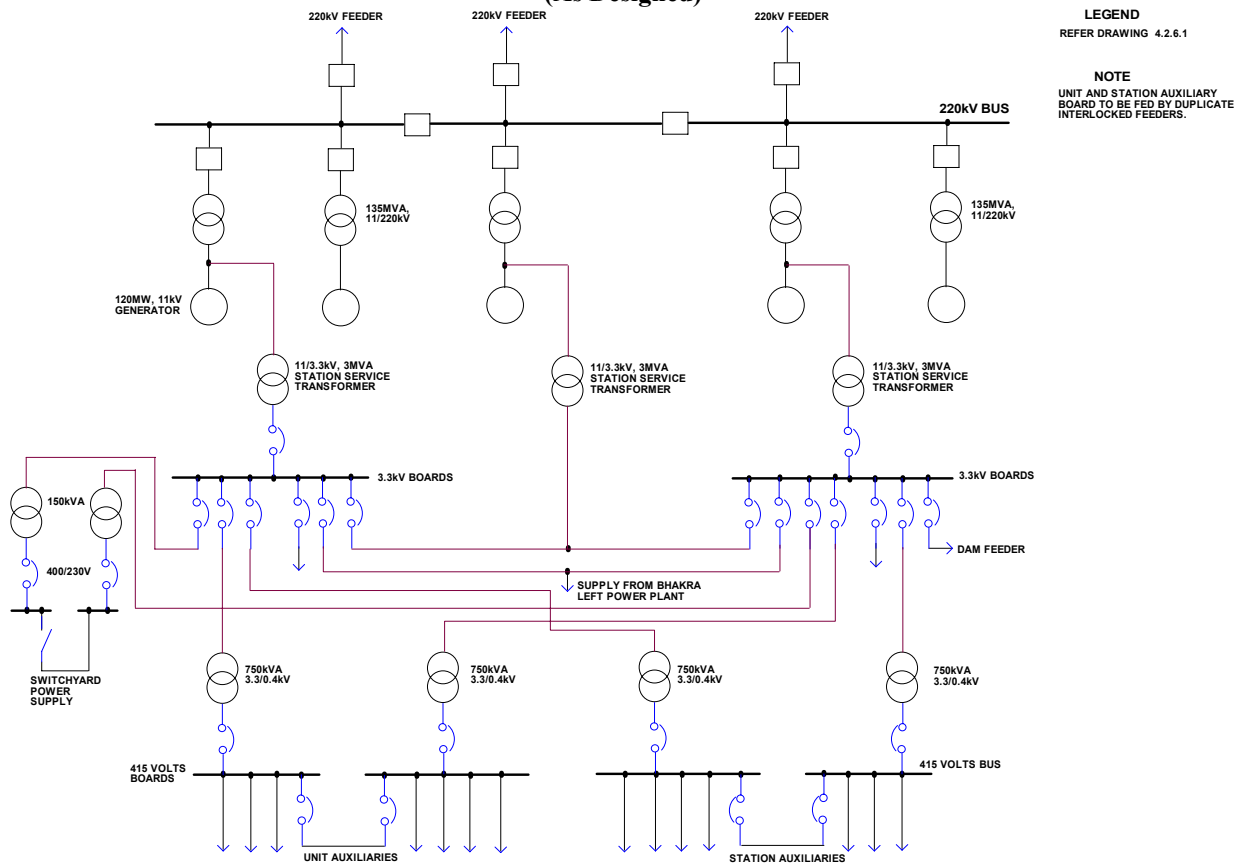


Figure 4.2: Auxiliary power Supply System-Basic Bhakra Power Plant II (5 units of 120 MW each) (As Designed)

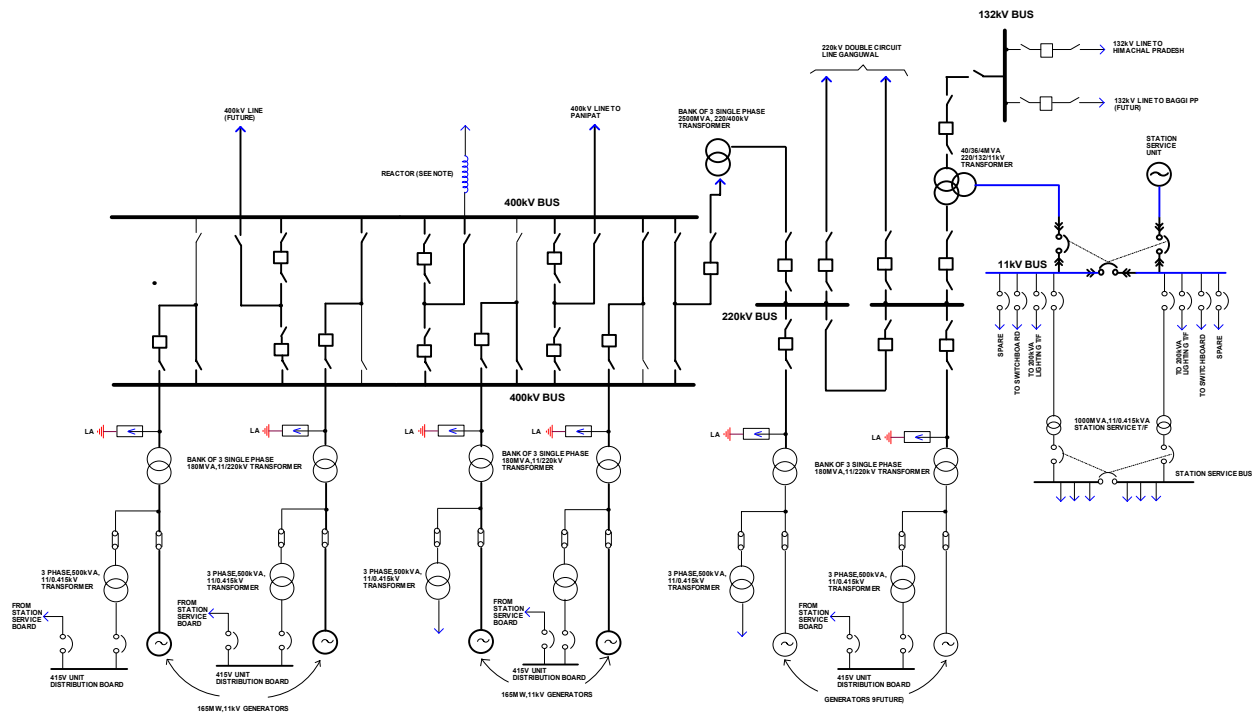


Figure 4.3: Dehar power Plant – Basic Auxiliary Power Single Line Diagram (As Designed)

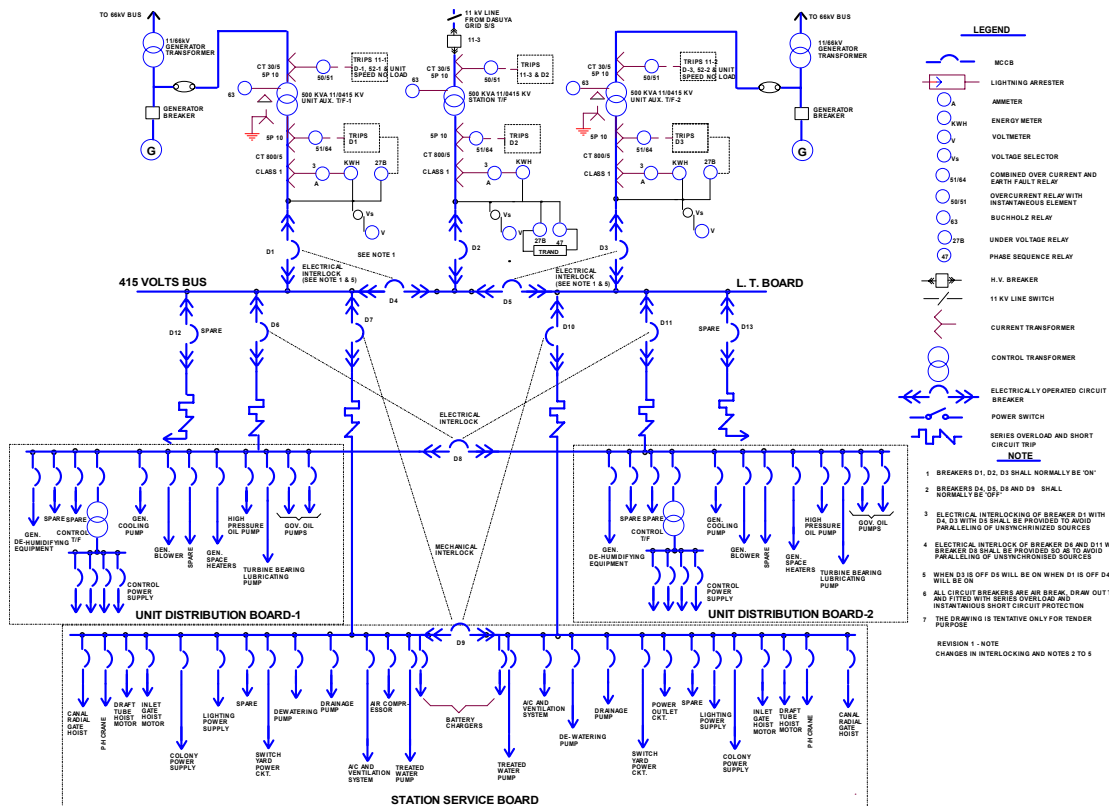


Figure 4.4: Typically Auxiliary Supply System (Mukerian 2 x 10 MW) – Proposed (AHEC Project – Specification drawing)

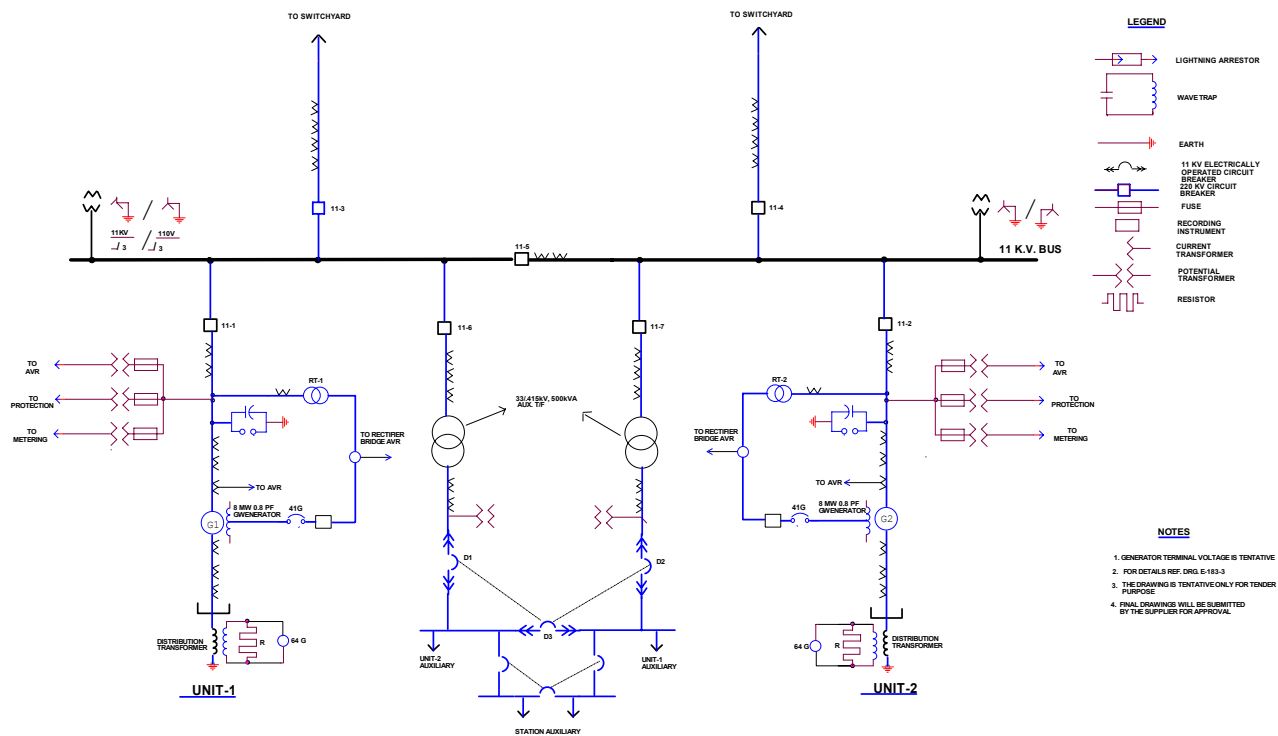


Figure 4.5: Auxiliary Power Supply System for Units Connected Generator Bus

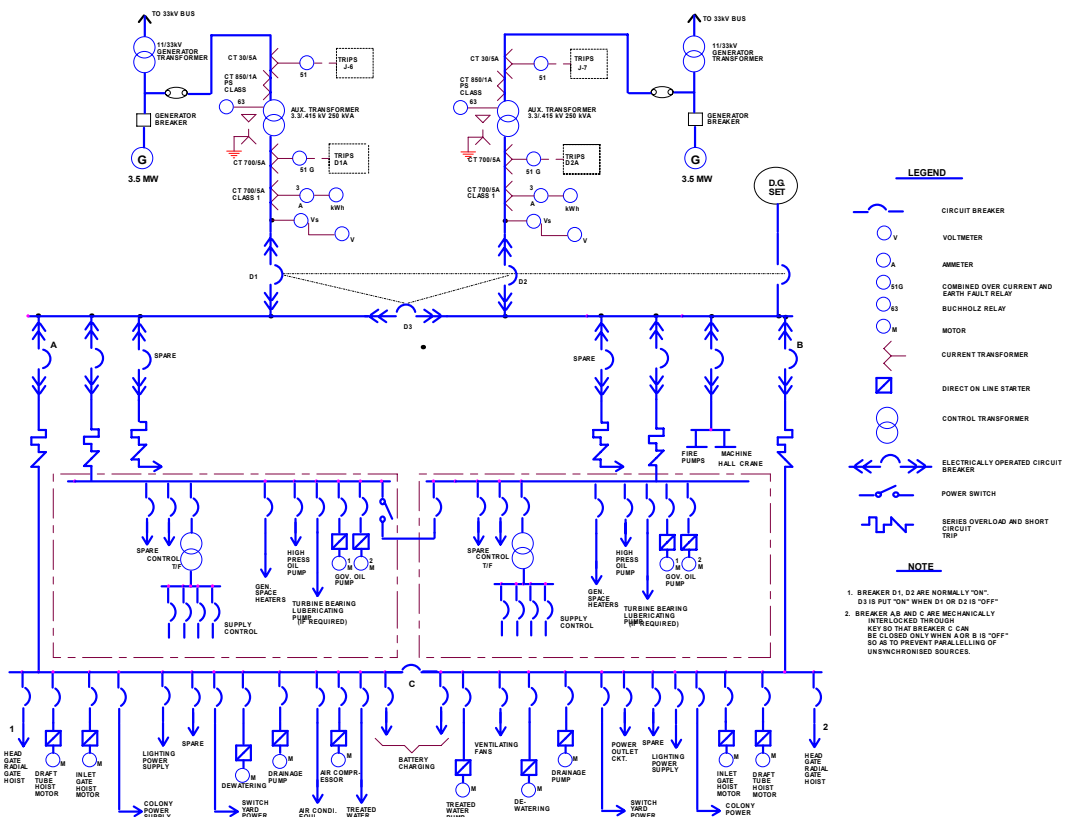


Figure 4.6: Unit Connected Auxiliary Transformer with D.G. Emergency Auxiliary Power Supply System for 2 x 3.5 MW Sikasar Project

4.2.8 Auxiliary Power Supply for Micro Hydro

Micro hydro are non critical plants whose loss of generation can be tolerated and would suffer no harm due to loss of auxiliary systems. Accordingly no special arrangement are normally made. The micro hydro are controlled by microprocessor based load controllers. Power supply for the microprocessor control is provided by manual start of the micro hydro up to speed no load position which supplies power for the micro processor as well as for station lighting etc. if required a 12 V UPS system can also be provided.

4.2.9 Auxiliary Transformers

In medium and large hydro station auxiliary transformer are generally from generator bus and located in the powerhouse due to economic reasons. Dry type transformers are now preferred as they do not require separate fire proof faults with elaborate fire protection systems (Bhakra Left Bank). In Bhakra Right Bank oil filled auxiliary transformers were located on transformer deck and were covered by water sprinkler system for fire protection of main transformers. Dry type transformers when located inside the powerhouse require separate ventilation system so that poisonous fumes (short circuit) do not mix with the powerhouse air supply system. In case of small hydros oil filled auxiliary transformers are used and located in adjoining switchyard.

Typical specifications for the dry auxiliary transformers are given below.

a. Technical Requirements (Typical)

Reference drawing 4.4.- Standards IS: 11171; IEC 35415

- i) Type and rating: Epoxy cast/resin encapsulated air cooled type, three phase unit, 11/0.415kV; 500kVA; DY 11, 50Hz.
- ii) Enclosure: Enclosure of a tested quality sheet steel of minimum thickness 2-3 mm shall also accommodate cable terminations. The housing door shall be interlocked such that it should be possible to open the door only when transformer is off. The enclosure shall be provided with lifting lugs and other hardware for floor mounting.
- iii) Core: High grade non-ageing cold rolled super grain oriented silicon steel laminations.
- iv) Winding conductor: Electrolytic grade copper. Windings shall be of class F insulation.
- v) Bushings: Solid porcelain/RIP, standard bushing as per relevant ISS.
- vi) Bushing CTs : As per IEC 185 of adequate rating for protection.
- vii) Fittings of auxiliary indoor transformers: All the required fittings of transformer shall be provided and will be subject to approved of the purchaser. However, the following fittings shall be specifically provided :
- viii) Tap changer: Off load tap changer should be provided on the transformer in steps of $\pm 2.5\%$.
- ix) Insulation level – As per IS/IEC
- x) Winding temperature indicator (WTI). Platinum resistance type temperature detector in each limb.
- xi) Thermistors embedded in each limb with alarm and trip contacts for remote annunciation.
Note: Alternatively digital temperature scanner to monitor winding temperature with RTD sensors with alarm & trip signals.

b. Operating Conditions

i) Loading Capability

Continuous operation at rated kVA on any tap with voltage variation of $\pm 10\%$ corresponding to the voltage of the tap as well as in accordance with IEC 35415.

ii) Flux density

Not to exceed 1.6 Wb/sq.m. at any tap position with $\pm 10\%$ voltage variation from voltage corresponding to the tap. Transformer shall also withstand following over fluxing conditions due combined voltage and frequency fluctuations.

- a) 110% for continuous rating
- b) 125% for a least one minute
- c) 140% for a least five seconds

4.3 DIRECT CURRENT (D.C.) AUXILIARY POWER SYSTEM

4.3.1 General

Direct current system in hydro generating stations and step up substation is provided for following usual functions.

- a) Supply to trip coils and closing coils of switchgear for switching operations.
- b) Indication: Indicating lamps, facia, semaphores, alarm and annunciation etc.
- c) For energizing the holding and operating coils in control and interlock schemes, and in protection schemes.
- d) For power supply to communication equipments (PLCC equipment) and supervisory control.
- e) Supervisory control and data acquisition system (SCADA)
- f) Emergency lighting including inverter.
- g) Generator exciter field flashing

The system should consist of a storage battery with its associated eliminator type chargers, providing the stored energy system required to ensure adequate and uninterruptible power for critical power plant equipment. The battery and battery circuits should be properly designed. Necessary safeguard maintained, and the emergency requirements should be carefully estimated to ensure adequate battery performance during emergencies.

4.3.2 D. C. Batteries

Type: Table 4.1 list commonly used battery types and their normal expected life, approximate number of full discharges, ampere-hour range, approximate cost range, frequency of use, advantages and disadvantages. Latest applicable Indian standard specification mentioned in the table 4.1 and be referred for confirmation.

Type of battery or batteries generally used in hydro generating stations are of the lead-acid type in vented cells or a sealed cell.

Following types of lead acid batteries are commonly used in power plants.

- Tubular positive plate with pasted negative plate: and
- Plant positive plate with pasted negative plate.

Plant positive plate batteries are costly and preferred for large hydro station above 5 MW as they have longer life and these cells are suited for applications requiring supply of large currents for short durations as required in unattended stations whereas the cells with tubular positive plates are suitable for the supply of smaller currents for medium to long durations. Use of glass containers is preferable over the other types as these facilitate checking up of sedimentation, electrolyte level, condition of plates, separators etc.

Standard

A. Lead Acid Storage Batteries

- | | | | |
|----|---|---|----------|
| a) | Pasted positive plate with pasted negative plates | - | IS: 6304 |
| b) | Plante Cells | - | IS: 1652 |
| c) | Tubular Cells | - | IS: 1651 |
| d) | General requirement and method of tests for lead acid storage batteries | - | IS: 8320 |

- e) Sealed Batteries - IEEE std. 1189 – Guide for selection of valve regulated lead acid (VRLA)

B. Ni Cd battery specification - IS: 13300 (for air craft batteries)

4.3.3 Battery Room

SHP Plant above 5 MW

A separate room with lockable doors provides adequate protection against accidental contact or malicious tampering. The room or area should be ventilated in such a manner that exhaust air from the room does not enter any other room in the plant. If necessary, heat should be provided to obtain full rated performance out of the cells. The cells should be mounted in rows on racks permitting viewing the edges of plates and the bottom of the cells from one side of the battery. The tops of all cells should preferably be of the same height above the floor. The height should be convenient for adding water to the cells. Tiered arrangements of cells should be avoided. Space should be provided permitting removal of a cell from its row onto a truck without reaching over any other cells. The lighting fixtures in the room should be of the vapor-proof type, with the local control switch mounted outside the entrance to the room. Battery charging equipment and controls should not be located in the battery room.

SHP Plant Up to 5 MW

At plants smaller than 5 MW, a ventilated battery room is not always required except for a flooded liquid electrolyte (lead acid) battery, because the small ampere-hour size means that the battery produces a minimal amount of hydrogen gas during charging. Furthermore, typically only qualified personnel (usually the operators) have access to the powerhouse. Therefore, a separate battery rooms is not required.

Owners of plants smaller than 5 MW should perform a “hydrogen produced” calculation to verify whether a ventilated battery room is necessary. Elements of this calculation are:

- i) Air volume in the powerhouse
- ii) Number of air changes per hour based upon the heating, ventilating, and air conditioning (HVAC) system design; and
- iii) Amount of hydrogen gas released during charging. (This amount is based upon the ampere hour size of the battery, the float charging voltage selected, and the type of battery to be charged)

This calculation should confirm that, in the worse case scenario, the hydrogen production of the batteries will be less than 1 percent of the total air volume in the powerhouse. Normally, a minimum of 3 percent hydrogen by volume is required before any explosive mixture is possible.

For Micro hydro SHP station unit AC supply is used for the microprocessor and for lighting etc. A 12V battery UPS system may supplement the supply. No separate room is provided.

4.3.4 Battery Voltage and Number of Cells

Rated voltage of the DC control supply for electrical installations can be selected out of the fairly standardized values of 220, 110, 48 and 24 volts. Higher voltage leads to more economical configurations as the total load of the DC system, lengths of circuits and number of DC cables increases.

Usually 220 V or 110 V turn out to be the optimum choice for medium and large hydro.

The voltage of a lead acid cell being approx. 2 volts per cell, the number of cells in the battery would be half of the rated DC voltage adopted.

Nickle Cadmium cells are 1.2 volts per cell. Accordingly no. of cells required will be 67 % more as comparative lead acid battery.

A separate battery for communication equipment is normally provided. The choice of communication battery, voltage has to be made according to voltage rating of the communication equipment already existing or that to be installed. In the absence of any precedent 48 volts is normally found to be optimum for most installations.

One or Two Battery System

Selection of a one-or two – battery system will depend not only on comparative costs of different battery sizes and combinations, including circuits and charging facilities, but consideration of maximum dependability, performance, and flexibility during periods of plant expansion.

Normally two battery system is adopted in hydro power station.

Table 4.1: Commonly Used Battery Types in Hydroelectric Plants

Sl No.	Type	Normal Expected Life Years (see note 1)	Approximate Number of full discharge	Ampere Hour capacity range in SHP	Relative Cost of battery	Advantages	Disadvantages	Remarks
Flooded Liquid Electrolytic								
1.	Lead Acid Flat pasted cells IS: 6304	Base (10 – 12 years)	1000 – 1200	6 - 4000	Base	Capable of providing a significant number of full discharges over the life	Frequent water addition, high hydrogen emission, needs monthly equalizing charge & separate well ventilated room	Only recommended for SHP below 5 MW in separate ventilated rooms
2.	Lead Acid Tubular IS: 1651	1.1 x base	50 – 100	6 - 4000	1.1 x base	Low water consumption, low hydrogen emission, no monthly equalizing charge		Smaller current for medium to long duration Recommended for attended hydro stations
3.	Lead Acid Plante IS: 1652	1.8 x base	1000 – 1200	6 - 4000	1.4 x base	Can function at room temperature higher than the standard 25°C		Suitable for application requiring large currents for small duration is generally used in hydro stations
4.	Nickel Cadmium Alkaline (NI-CAD) IS: 13300	3 x base	1200	2.5 – 1000 IS: 13300 covers only 24 V and up to 40 AH batteries	3 x base	Low maintenance; longer life, performs well in low temperatures, not damaged by freezing, low self-discharge rate, will not deteriorate in discharged condition, no release of corrosive fumes	Higher cost and at 1.2 volts per cell, requires a greater quantity of cells to attain a rating of DC battery. Little historic operation experience	Not in use Recommended for SHP at high altitudes and small unattended SHP
Sealed maintenance free batteries								

5.	Lead acid/special alloy Sealed maintenance free batteries	1.4 x base	300	200 – 4000	1.4 x base	Does not require water addition, no hydrogen emission	Cell plates or the electrolyte level cannot be seen as cells are in plastic container. Little historic experience in powerhouses	Used in Sikasar project May in use powerhouse below 5 MW when separate room is not made
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Note 1: Lifetime estimates can vary substantially depending on cell/plate construction, duty cycle and quality of maintenance

4.3.5 Battery Accessory is Generally as follows:

- i) Cell testing voltmeter
- ii) Hydrometer
- ii) Thermometer
- iii) Acid jugs for topping up of the cell
- iv) Rubber gloves
- v) Rubber apron
- vi) Tool box
- vii) Battery log books
- viii) Bridging clamps for cutting out individual cell in the event of defect
- ix) Protective goggles

4.3.6 Ampere Hour Capacity of DC Batteries

D.C. Loads Classification

Recommended procedure for determining battery rating is outlined in following standards/publications.

- a) CBI & P Technical Report No. 79 entitled specification for substation battery, charging equipment and DC switchgear.
- b) IEEE 485 – IEEE recommend practice for sizing lead acid batteries

These standards classify the system load into following categories.

- i) Momentary loads
- ii) Continuous load
- iii) Emergency light load: Duration of light load may be required for duration of 1 – 12 hours.

For hydro stations the following durations may be assumed for computation of battery capacity (as per CBI & P Manual) for attended stations.

	Where standby battery is provided	Where standby battery is not provided
Steady and continuous load	3 hours	6 hours
Emergency light loads	1 hours	2 hours

For unattended stations duration may be suitable increased.

Ampere Hour Capacity Calculations

Procedure for calculation battery size as per CBI & P manual is as follows:

- a) Classify all loads duration wise after converting them into amperes corresponding to 2 volts per cell applying a reasonable diversity factor to the indicating lamp load.

- b) Multiply the current due to each load and their respective duration to arrive at ampere hour capacities.
- c) Correct these capacities for rated electrolyte temperature of 27°C corresponding to the lowest actual site temperature by following equation.

$$\text{Capacity at } 27^{\circ}\text{C} = C_t + \frac{C_t \times R \times (27 - t)}{100}$$

Where,

C_t = observed capacity at $t^{\circ}\text{C}$

R = variation factor of 0.43% for 10 hours discharge

T = average electrolyte temperature, $^{\circ}\text{C}$

- d) Convert the AH capacities thus determined with the help of table 4.2 for Planted cells, into capacities referred to the standard 10-hour rate of discharge. Add those capacities to arrive at the total capacity referred to 10-hour rate of discharge.
- e) Determine the AH actually in each discharge duration and find out the residual capacity. Reduce the residual capacity left after first discharge duration from that determined for the next discharge duration and continue this process for all the discharge durations. Add the resulting capacity Figures to arrive at the total battery capacity.
- f) To account for ageing for battery multiply the load expected at end of its service life by 1.25. As the initial capacity of battery rises after some charge-discharge cycles or after some years of float operation, capacity of the battery need be 90 to 95 % of the capacity determined above.
- g) To account for unforeseen additions to the DC system and less than optimum operating conditions of the battery due to improper maintenance, the capacity determined above is further increased suitably, by 10-15 %.
- h) Capacity of the battery is fixed equal to that commercially available next higher size to the capacity calculated in (g).

Table 4.2
Capacities and Discharge Current at 27°C of
High Discharge Performance Cells at various rates of Discharge

Period of Discharge (hours)	AH capacities as Percentage of Standard Rating		Discharge Current as percentage of Standard Rating		Cell end Voltage (volts)
	8 and 25 AH Plates (percent)	10 AH Plates (Percent)	8 and 25 AH Plates (percent)	100 AH Plates (Percent)	
1.	2.	3.	4.	5.	6.
10	100.0	100.0	10.0	10.0	1.85
9	98.0	98.0	10.9	11.0	1.84
8	95.0	97.1	12.0	12.1	1.84
7	93.3	95.1	13.3	13.6	1.83
6	91.0	93.0	15.2	15.5	1.83
5	88.0	90.0	17.6	18.0	1.82
4	84.0	86.2	21.0	21.5	1.81
3	80.0	81.1	26.6	27.0	1.80
2	73.0	73.8	36.5	36.9	1.78
1	60.0	60.0	60.0	60.0	1.75

Note: Similar data for other type may be obtained from battery manufacturers.

Example of calculating battery size by the method given in CBI & P manual is given below for a typical power plant.

Data

- i) Power houses: - Unattended supervisory control
- ii) No. of Batteries: - Two – one being standby
- iii) Lowest Temperature: - Zero degrees centigrade

D.C. Loads

i) Continuous Load

Continuous load of indicating
Lamps, semaphore indicators,
Relays, discrepancy control switches
and spring charge (of CB) coil

- 431 watts (for 6 hours)

(ii) Intermittent Momentary Load

DC Power required for simultaneous
Tripping of motor operated breakers

- 1936 watts (for 1 minute)

Governor and exciter field flashing etc.

Misc. start stop contactors

(iii) Emergency lighting

- 1250 watts (for 2 hours)

Battery Capacity: Assuming 2 Nos. 110 volt batteries are to be provided. The battery capacity required is worked out in table 4.3. Batteries of 100 AH each are required.

Table 4.3

Load (Watts)	Current Amp. $I = \frac{(1)}{110}$	Duration (Hrs)	Capacity each Load AH		Capacity for individual load at 10 hrs. rate (AH) (table 4.3.6.1)	Capacity to add (AH) (6 – 10)	Total capacity for load (AH)	Capacity actually used (AH) (8) – (5)	Residual capacity (AH)
			0°C	27°C					
1.	2.	3.	4.	5.	6.	7.	8.	9.	10.
431	3.92	6	23.52	26.2	29.8	29.8	29.8	26.2	3.6
1250	11.30	2	22.60	25.2	39.8	36.2	39.8	25.2	14.6
1936	17.60	1/60	0.293	0.33	8.0	-	14.6	0.33	14.27
						66.0			

To account for aging, rise of battery capacity after charger, discharge cycle and possible future expansion capacity required = $66.0 \times 1.25 \times .9 \times 1.25 = 85.0$ AH say 100 AH.

Note: The factors are as per CBIP manual on substation chapter -1 entitled, 'Specifications for Battery charging equipment and DC switchgear'. The batteries each of 100 AH capacity is adequate for the power House.

Battery Capacity as per IEEE 485: Using the above load classes and durations and battery data (k factor) obtained from manufacturers literature, station battery duty cycle is determined (see IEEE 485). The battery

capacity required is determined as the sum of the requirements for each class duration of load comprising the duty cycle.

4.3.7 Battery Charging Equipment

Battery Chargers: Static charger sets are preferred for battery charging service. Two sets should be provided so one will always be available. The charger capacity should be sufficient for float operation as well as boost charging capability (equalizing mode).

Float Operation Term: This term applies to the method of operation in which battery remains connected to the load and the charger continuously. Voltage of charger is substantially constant and just higher than open circuit voltage of the battery. To keep the battery in a fully charged condition, the charger sends through the battery charging current of a few milli amperes at a voltage which is sufficient to compensate for local action and leakage losses. The magnitudes of the charging current and the voltage should be recommended by the battery suppliers. The charger also supplies the entire DC load under normal condition.

4.3.8 Switching from Float to Equalizing Mode

Switching from the float to equalizing mode can be done manually/ automatically. In manual mode, an operator switches the charger from the float mode to the equalize mode when the battery has been discharged. It is switched back to float mode once the battery is fully charged. However, this reliance on an operator's availability and/ or discretion will, over a period of time may result in charging errors that shorten the battery's life. If the errors are serious, such as leaving the charger in the equalizing mode for an extended period and consequently "bubbling off" a majority of the electrolyte, the battery's recharging capability will be seriously impaired.

Automatic switching of the charger commonly called automatic mode switching) uses voltage sensing to automatically switch the charger to the equalizing mode after the battery has been discharged. Once the battery cell potentials rise to approximately 90 to 95 % of their rated potential, the charger automatically switches to the float mode. Consequently, the equalizing charge is only applied to the batteries for the amount of time required to obtain 90 to 95 % of the rated cell potential. This approach minimizes hydrogen gas evolution and prolongs battery life.

4.3.9 Construction Features

Each battery should have a static battery charger, rated to fully recharge the battery from a completely discharged condition in not more than ten (10) hours in boost charging mode. Each battery charger should be capable of float charging the batteries while supplying at normal voltage. Voltage regulators shall have following facilities.

- (a) Manual selection facility for battery charging mode i.e. whether trickle or boost.
- (b) Automatic and manual control of output voltage and current. Selector switch should be provided for auto/manual selection. Auto to manual changeover should not result in any harmful surges.
- (c) Effective current limiting feature and filters on both input and output to minimise harmonics, RFT, EMT etc.
- (d) When on automatic control mode during trickle charging, the charger voltage should remain within 1% of set value for maximum permissible voltage, frequency and combined voltage and frequency variation on feeding system and dc load variation from zero to full load.
- (e) Degree of protection should be IP:42. For chargers located in air conditioned areas, same may be IP:31.
- (f) The rectifier shall utilise diode/thyristors and heat sinks rated to carry 200% of the load current continuously. Temperature of heat sink shall not be permitted to exceed 85 deg. C duly considering the maximum charger panel inside temperature.
- (g) Rectifier fuse and RC surge suppressor should be provided
- (h) Ripple content to be limited to 1% peak to peak.
- (i) All inter cell connectors and terminals should be fully insulated/shrouded.

4.3.10 DC System Design

DC scheme normally provides two feeds through diode sharing a critical consumers e.g. all protection panels/control all circuit breakers transformer and emergency lighting, switchgear panels, generator excitation system, generator oil seal system, etc.

Batteries and chargers are connected to dc distribution boards (DCDBs) through single core cables for each pole. The main HRC fuses on battery and charger output has alarm contacts. The battery fuse is located close to battery in the battery room.

The DC system is unearthed, and relays are provided for a sensitive earth fault detection and annunciation. The low/high voltage alarms, instruments for indication of charger current and voltage, dc voltage, battery current, etc. are provided.

Batteries having complete cell weight of 50 kg or more are arranged in single tier.

One set of variable metallic resistor and shunt suitable for carrying out discharge tests (5 hour discharge) on all batteries is recommended to be provided.

4.3.11 DC Switchgear

For reliability and flexibility, a dc distribution board with several outlets is preferable as this board provides connection of battery and charger to the various load circuits. Each circuit breaker is protected by a fuse and controlled by a switch or circuit breaker which should be suitable for making and breaking inductive loads at voltages up to the maximum floating voltage and not merely the rated voltage. Cartridge fuses are recommended to be used as back up even when circuit breakers with protective releases are installed. The breakers and fuses should be carefully chosen from the consideration of recovery voltage after interruption of faults. The fuses where used should be properly coordinated to ensure operation even for the farthest faults and each circuit should be properly segregated. The dc switchgear should have short circuit rating equal to about 10 times the maximum rated current if the associated equipment, without the current limiting feature on, and about 1.1 times, with the current timing feature 'on'. However, with the available standard dc switchgear usually having much higher short circuit ratings (4 kA), the above requirement poses no problem.

4.3.12 Battery testing

Acceptance tests should be as per relevant IS. Maintenance testing for replacement should be carried out as per IEEE 450.

4.3.13 DC Power Supply System

Hydro stations above 5 MW: A typical DC Single Line Diagram is at Figure 4.9 for medium size 2 unit hydro plant. For large plant unit DC cabinets may be supplied power by duplicate feeders one from each section of DC bus.

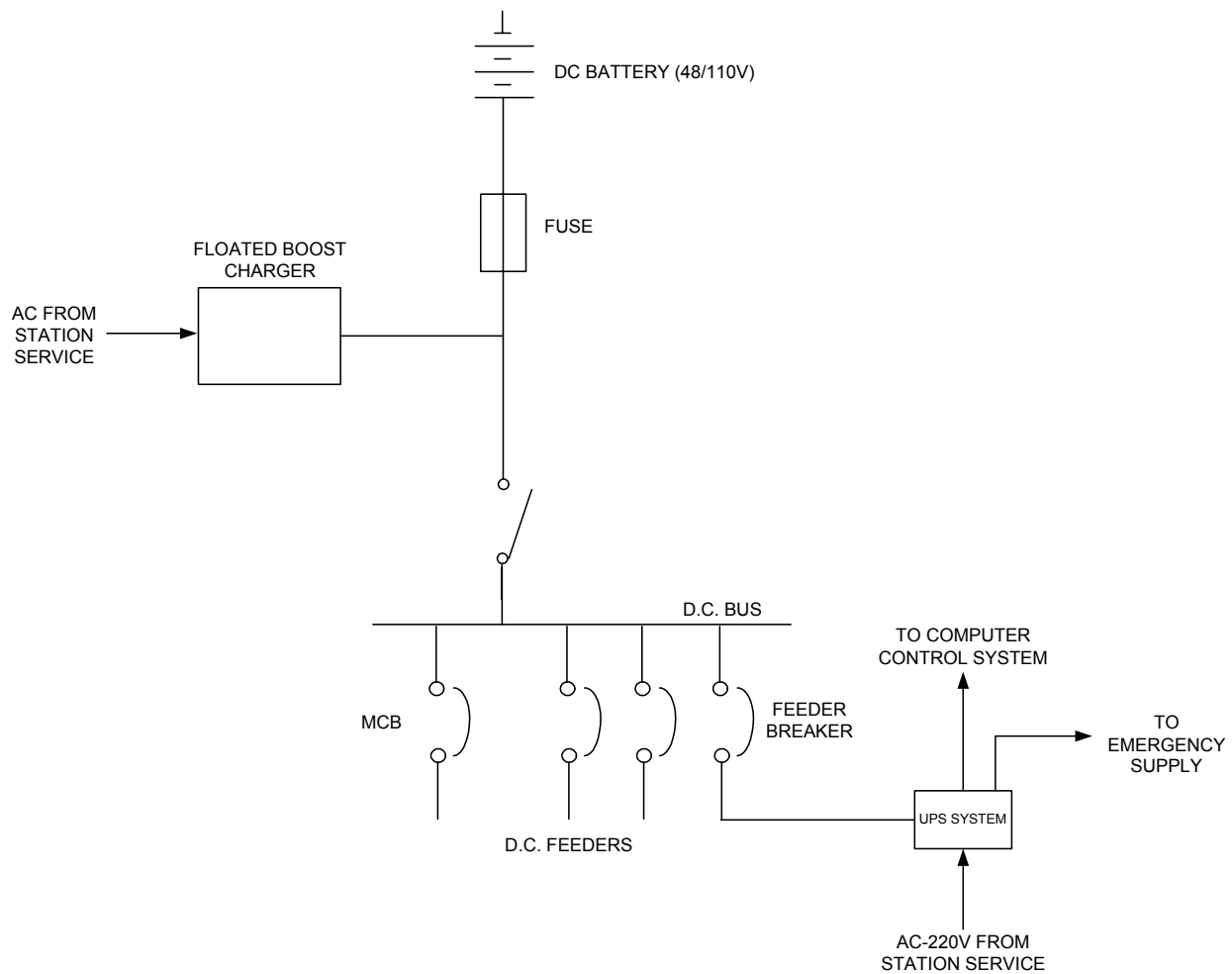


Figure 4.10(a): Typical DC and UPS system for SHP up to 3000 kW

Hydro stations below 5 MW: A typical single line diagram with single battery system is shown in Figure 4.9 which can be used on smaller unit. Fused disconnecting switch may be used instead of circuit breakers. For larger unit above 5 MW 2 batteries may be provided.

4.4 Uninterruptible Power Supply System (UPS)

Uninterruptible Power Supply System in Hydro Station are required to provide electricity for essential loads when normal power plant systems fail. These loads include plant computer, communications network, emergency lights etc. This may be provided as per IEEE: 944 – Recommended practice for application and testing of uninterruptible power supplies for power generating stations.

UPS system is defined as one designed to automatically provide power without delay or transient during any period when normal power supply is incapable of performing acceptably.

On line static (solid state) UPS system with sine wave output are required. An off line system take about 25 ms for transfer to DC which may impair critical control by computer system. Normal range of sizes for hydro plant up to 25 MW uninterruptible power supplies is given below:

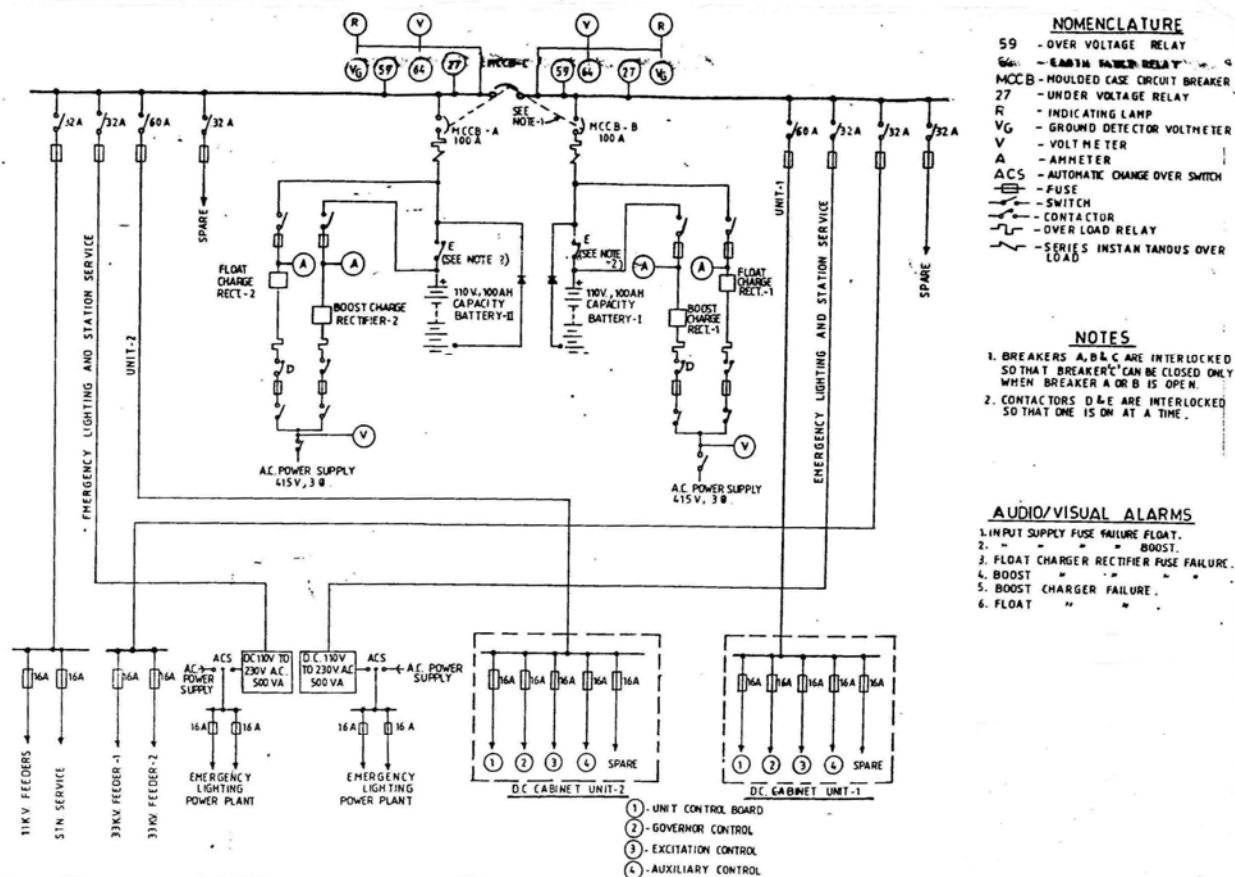


Figure 4.9: DC Auxiliary Power Single Line Diagram for a Medium Size Hydro Power Station (Typical)

Plat size (MW)	UPS size (kVA)	Remarks
5 - 25 MW	1 - 5 kVA	
0.1 to 5 MW	1 or less kVA	
Micro Hydro	i) Electronic load controller (ELC) may use its own converter and conditioned Dc supply system from UPS or otherwise ii) If remote controlled PC may be used with its own UPS	i) Use power line conditioner (power supply system) ii) May use standard single PC UPS

4.4.1 UPS System Design

UPS system is battery voltage (say 24/110 V DC) to 230 Volts AC static online reverse transfer system of appropriate capacity to meet the requirement. Rectifier inverter are solid state devices using thyristors. Manual Bypass Transfer Switch is maintenance bypass switch provided to bypass the entire UPS during maintenance period. (Figure 4.10(a) & (b))

Batteries – Sealed maintenance free batteries of appropriate capacity are generally provided and closely coordinated with the charger to avoid over or under charging the batteries.
Transformer – Adequately rated transformer is provided to avoid over heating at full load.

Provision for noise immunity, transient surge suppression and voltage stability are required to be provided.

4.5 LIGHTING SYSTEM

4.5.1 General Requirements

A comprehensive illumination system is provided in the entire project i.e. all areas within the plant boundary. The system includes lighting fixtures, distribution boards, lighting panels, junction boxes, lighting poles, receptacles, switchboards, cables and wires, conduits, poles and masts, etc. The system covers all interior and exterior lighting such as area lighting, yard lighting, street lighting, security lighting, etc.

4.5.2 Standards

IS : 3646 Code of Practice for interior illumination (illumination glare index)

IS : 694 Wires

IS : 732 Wiring installation conditions

IS : 9537

4.5.3 General Requirements

A comprehensive illumination system is provided in the entire project i.e. all areas within the plant boundary. The system should include lighting fixtures, distribution boards, lighting panels, junction boxes, lighting poles, receptacles, switchboards, cables and wires, conduits, poles and masts, etc. The system covers all interior and exterior lighting such as area lighting, yard lighting, street lighting, security lighting, etc.

4.5.3.1 Design Criteria

General

The illumination system is designed on basis of best engineering practice to facilitate normal operation and maintenance activities as per IS: 3646 part-II and should ensure uniform, reliable, aesthetically pleasing, glare free illumination. The design should prevent glare/luminous patch seen on VDU screens, when viewed from an angle.

Power supply is fed from 415/240 V normal ac power supply, station service board, and DC supply for emergency lighting. Lighting panels are located at different convenient locations for feeding various circuits. These panels are required to be robust in construction with lockable arrangements and MCB for different circuits.

Outdoor switchyard average illumination level is kept 50 lux on main equipment and 20 lux on balance area of switchyard. In the outdoor switchyard, the area covered by transformer/reactor should have 50 lux.

The lighting system of a particular area whether outdoor or indoor is designed in such a way that uniform illumination is achieved. As far as possible any dark spots are avoided. This requires careful placing of the luminaries, selection of proper mounting heights and provision of sockets in the marshalling kiosks and mechanism boxes of circuit breakers/disconnects switches for providing supplementary lighting wherever required. In outdoor switchyards, only the equipment/bus bar areas are illuminated. In outdoor area, luminaries are directed as far as possible towards transformers, circuit breakers/disconnect switches, their mechanism boxes etc., where some

The choice of lamps, i.e., CFL, *fluorescent*, mercury vapour, sodium vapour halogen etc., depends mainly on the nature of work, the number of hour of utilization annually, the cost of energy and the power available for illumination.

Flood light fittings are in essence, projectors with parabolic reflectors. There are two types of floodlights: the wide beam type and the narrow beam type. Wide beam type is suitable where accurate control is not necessary and the light is projected only over a short distance. The narrow beam type is used where light is required to be projected over longer distances.

The foremost criterion in the design of illumination system of indoor area such as control room, workshop, repair bay, offices, etc., is that illumination at the working height throughout the area should be as uniform as possible so as to avoid eye fatigue. In practice, complete uniformity of illumination is difficult to achieve and a ratio of the minimum intensity to the maximum equal to about 70 percent is usually considered acceptable.

Energy conservation requirement is kept in view while selecting type of lamp and type of fitting. While designing the lux level requirement Utilization coefficient factor may be considered to take care effect of dust, pollution etc. on reflectors used in the lighting fixtures.

The night time lighting of exterior areas is necessitated by operational requirement, security or decorative purposes or a combination of these. It is used for illuminating outdoor switchyards transformer yards, approach roads to substations, etc., Use of flood lights has been in practice for illumination of switchyards. However, floor lights generally cause glare, if not properly positioned and mounted at proper heights. As the lumen output of mercury/sodium vapour lamps

Table 4.4 : Typical Lamps & Fittings in Some Identified Areas

SI.	Particulars of area	Type of lamps	Type of fittings
1.	Unloading-cum-repair bay	Mercury vapour sodium	High bay
2.	Store rooms, workshops	Fluorescent	Industrial
3.	Control room, offices carrier room	Fluorescent	Decorative
4.	Battery room	Fluorescent	Acid proof, Industrial
5.	Compressor room etc.,	Fluorescent	Industrial
6.	External lighting on building	Mercury vapour sodium vapour	Water tight flood light
7.	Outdoor switchyard	Mercury vapour sodium vapour	Water tight flood light
8.	Fence lighting	Mercury vapour sodium vapour	Post type water tight, flood light
9.	Roads	Mercury vapour sodium vapour	Post type water tight street light fittings

Table 4.5: Recommended Illuminator Values

SI. No.	Particulars	Average illumination level 'Lux'	Limiting Glare Index
1.	Control rooms: Vertical control panels Rear of control panels Control desks Switch houses	200 to 300 150 300 150	19 19 19 25
2.	Generator Hall operating floor	200	-
3.	Switchgear room	200	-
4.	Turbine auxiliaries e.g. OPU etc. room	150	-
5.	Battery room	100	-
6.	Carrier room	300	-
7.	Offices and reception	300	19
8.	Cloak rooms	100	-
9.	Workshop/Repair bay	300	25
10	Test room and Lac	300-450	19
11	Outdoor switchyard	20	-
12	Stairs	100	-
13	Corridors	70	16
14	Approach roads	20	-
15	Pathways	20	-

16	Store room	100	-
17	Cable gallery/floor	70	-
18	AC plant/DG set room	150	-

is quite appreciable as compared to incandescent lamps, flood light units having mercury/sodium vapour lamps with medium and wide angle coverage, mounted at suitable heights are preferred. If the floor light is mounted at a height of 6 to 10m it would be away from the normal vision angle (8°) of a man approaching it and therefore, there would be no problem of glare. If the design of the flood lighting is followed in an orderly fashion, it is easy to obtain uniform illumination in the outdoor switchyard. The spillover light from flood lights provided in the switchyard is generally sufficient for fence lighting. Separate fence lighting is provided only in exceptional cases. Light fittings in the switchyards are mounted on substation structure/lighting masts. Typical lamps and fittings generally provided in some identified areas are given in Table 4.4.

Table 4.5 gives the recommended values of illumination level for different parts of power house and switchyard.

The purpose of street lighting in substations is to promote safety and convenience on the approach roads, service roads and side walls inside switchyard, etc., The aim is to provide conditions of visibility adequate for accurate, certain and comfortable seeing.

4.5.4 Emergency Supply

Power supply is fed from 415/240 V normal ac power supply, station service board, and UPS system for emergency lighting. Lighting panels should be located at different convenient locations for feeding various circuits. These panels are required to be robust in construction with lockable arrangements and MCB for different circuits.

Emergency lighting is provided in following areas:

- a) Generator room -20 lux
- b) Operating floors of turbine hall -20 lux
- c) Switchgear room - 15 lux (min. one lighting fixture between two rows of switchgear)
- d) Control and relay room -50 lux with one power 5 Amps
- e) Cable spreader room -at least 10% of illumination (min. one lighting fixture at convenient location.)
- f) Battery room -at least 10% of illumination
- g) Exit points and stair cases -One light fixture
- h) All other strategic locations for safe personnel movement during any emergency.

DC lighting comes on automatically on failure of normal ac supply. In off-site areas/buildings dc lighting is provided through self-contained 4-hour duration fixtures located strategically. It is required to be provided with Ni – Cd battery in SHP above 5 MW.

4.5.5 DC (Emergency Lighting) System Design

Lighting panels, fixtures, receptacles, poles, masts, distribution boards, switch boxes, conduits, junction boxes etc. are properly installed and earthed.

All outdoor fixtures are required to be weather proof type. Fluorescent fixtures, installed in other than control room areas are required to have electronic ballasts. For control rooms, the ballasts are copper wound inductive, heavy duty type, filled with thermo-setting insulating moisture repellent polyester.

All luminaries and their accessories and components are of the type which is readily replaceable by the available Indian makes. All fixtures and accessories are required to be of reputed make and non-corrosive type. Acrylic covers/louvres are of non-yellowing type.

The constructional features of lighting distribution boards are similar to AC/DC distribution boards. Outgoing circuits are required to be provided with MCBs of adequate ratings.

Wiring is by multi-stranded PVC insulated colour code cable laid in GI conduits. Wiring for lighting circuits of ac, and dc systems is run in separate conduits throughout. Minimum size of the wire is not be less than 1.5 sq.mm copper. Wire should conform to IS: 694 and wiring installation is as per IS: 732.

Conduits are of heavy duty type, hot dip galvanised steel conforming to IS:9537. In corrosive areas, conduits have additional suitable epoxy coating.

At least one 5/15A, 240 V universal socket outlet is provided in offices, stores, cabins, etc. 15A 240 V ac industrial type receptacles are provided strategically in all other areas. All the receptacles are 3 pin type and controlled with a switch. Suitable numbers of 63 A, 3 phase, 415 V ac industrial type receptacles with control switches are provided for the entire plant for welding purposes, particularly near all major equipment and at an average distance of 15 m. At least one 63 A receptacle is provided in each off-site building.

Suitable number of ceiling fans in areas not covered by air-conditioning and ventilation system should be provided.

Street lighting is provided with swaged/steeped tubular steel poles. The poles are coated with anti-corrosive treatment and paint.

Area lighting are with suitable lighting masts. Masts of adequate height have lattice structure with ladder, cage and top platform. Alternatively they have lantern carriage of raise/lower type with electrical winch provided inside the tubular mast.

All outdoor lighting systems in large power plants are normally automatically controlled by synchronous timer or photocell. Arrangements are provided in the panel to bypass the timer/photocell for manual control.

4.6 POWER AND CONTROL CABLES AND CABLING

4.6.1 Power and Control Cables

Standards

IEC: 60502	Extruded solid dielectric insulated power cables for rated voltages from 1.00 kV up to 30 kV.
IEC: 60331	Fire resisting characteristics of electric cables.
IEC-60189(P1 to P7)	Low frequency cables and wires with PVC insulation and PVC sheath
IEC-60227 (P1 to P7)	Polyvinyl Chloride insulated cables of rated voltages up to and including 450/750V
IEC-60228	Conductors of insulated cables
IEC-60230	Impulse tests on cables and their accessories
IEC-60287 (P1 to P3)	Calculation of the continuous current rating of cables (100% load factor)
IEC-60304	Standard colours for insulation for low-frequency cables and wires
IEC-60332 (P1 to P3)	Tests on electric cables under fire conditions
IS: 1554 (Part-1)	PVC insulated (heavy-duty) electric cables for working -1988 voltage up to and including 1100 V.
IS: 1554 (Part-11)	PVC insulated (heavy-duty) electric cables for working 1988 voltage from 3.3kV up to and including 11 kV.
IS: 7098(Part-11)	Cross-linked polyethylene insulated PVC sheathed cables 1985 for working voltages from 3.3 KV up to and including 33 kV.
IS: 3961	Recommended current ratings for cables.
IS: 8130 -1984	Conductors for insulated electric cables and flexible cords.
IS: 5831- 1984	PVC insulation and sheath of electric cables.

4.6.2 Duty Requirements/Design Criteria

- A. The cables are specified to be suitable for the area where installation is required i.e. a tropical monsoon area having a hot humid climate etc. The reference ambient temperature specified depending upon the site i.e. 50°C on most canal fall schemes and plains.
- B. The derating factor for the various conditions of installation including the following is considered while choosing the conductor size:
- Maximum ambient air temperature.
 - Maximum ground temperature,
 - Depth of laying wherever applicable
 - Grouping of cables.
- C. The allowable voltage drop at terminals of the connected equipment is maximum 1.0% at full load for choosing the conductor size. In case of squirrel cage induction motors, the cable size is so chosen that the motor terminal voltage does not fall below 90% of the rated voltage, at the time of starting, if the motor is started with a D.O.L. (direct on line) starter.
- D. The maximum continuous conductor temperature and the maximum allowable conductor temperature during short circuit are taken as 70°C and 160°C respectively in case of PVC insulated cables and 90°C and 250°C respectively in case of XLPE insulated cables.
- E. The minimum size of all 11 kV grade power cables and 415 V power cables connected to circuit breakers are chosen taking into account the following factors.
- Fault level due to system contribution.
 - Fault contribution of running motors.
 - Expected time up to which motor contribution to fault current persists.
 - Maximum time for fault clearance (i.e. operating time of the backup protection relay plus the time of operation of the circuit breaker.)
 - Full load current of the circuit.
- F. The cables generally comply with the requirements of the latest revision of IS:7098 (part-11) for the 11 kV grade XLPE insulated cables and IS-1554 (part-1) for the L.T. PVC insulated power and control cables or the relevant IEC Standard. The design, manufacture, installation, testing and performance of the cables, are required to comply with the latest revisions of IS/IEC/NEMA/ASTM standard.
- G. For 11 kV cables, conductor screen and insulation screen are extruded semi-conducting compound and applied along with XLPE insulation in a single operation by triple extrusion process. Method of curing for 11 kV cables is "Dry curing/gas curing/steam curing". 11 kV cables are provided with copper metallic screen suitable for carrying earth fault current. For single core armoured cables, the armouring constitute the metallic part of screening. For 11 kV cables, insulation is XLPE, while for other cables it is PVC.
- H. Calculations are made for selection of cables showing type of cable and conductor size selected voltage drop, temperature rise, under rated load and short-circuit conditions, to meet the design requirement.
- I. Cable schedule showing the various interconnections and also the routing diagram giving details of various openings are requirement to be prepared.
- J. For the sake of reliability, it is required to use only copper conductor cables for the following services:

- Excitation systems (Single Core)
- Battery and battery chargers (Single Core)
- Inverters
- All control systems

K. As far as feasible, separate cables are provided for circuit of different plant and auxiliaries, for circuits of different voltages, and for circuits used separately. To the extent feasible Power, control and instrumentation circuits are taken through different routes, which are laid together on the same cable tray, otherwise necessary measures should be implemented to avoid the undesirable effects.

4.6.3 Range Of Cables

- Generator- Generator transformer/ Bus Bar connections (used in small hydro plants) are armoured power cables of copper conductors with unearthed grade EPR insulation Non PVC jacket HD – HOFR (high density, heat, oil and flame retardant or XLPE cables.
- 11KV system - Power cable
The cable are 11 kV grade, heavy duty, stranded, aluminium conductor, XLPE insulated, provided with conductor screening and insulation screening, galvanised steel wire/strip armoured, flame retardant low smoke (FRLS) extruded PVC of type ST 2 outer sheathed.
- 415 V System
The cable are 1.1 kV grade, heavy duty, stranded aluminium conductor, PVC type. An insulated galvanised steel wire/strip armoured, flame retardant low smoke (FRLS) extruded PVC of type ST1 outer sheathed. Cables may be either single or multi-core or both.
- Control cables
The cable are 1.1 kV grade, heavy duty, stranded copper conductor, PVC type-A insulated galvanised steel wire/strip armoured, flame retardant low smoke (FRLS) extruded PVC of type- ST1 outers, sheathed Cables may be multi-core; depending upon the circuit requirements or both.

Size of control cables normally not smaller then:

- Control circuits 1.5 mm² to 2.5 mm²
- PT circuits for energy measurement 1.5 mm² to 2.5 mm²
- CT circuits 1.5 mm² to 2.5 mm²

A summary of recommended cables used in hydro stations in given in table 4.6.

Table 4.6: cables used in Hydro Station

Particulars	Power cables		Control cables	Trailing cables
	XLPE	PVC		
a) Conductor				
i) Material	Stranded Aluminium wire complying latest edition of I.S. 8130 - 1976		Stranded plain annealed copper	Tinned copper of class 5 of IS:8130
ii) Size	As required Min. 6 sq.mm size		As required, but min. 1.5 sq.mm.	As required, but min. 1.5 sq.mm
iii) Shape	Circular/ Sector shaped circular only for 3.3 kV cables	Circular/Sector shaped.	Circular	Circular
b) Main Insulation				
i) Material	XLPE	PVC	PVC insulation shall be type I extended PVC 1.1 kV grade & free from voids	Heat resistant elastomeric compound based on ethylene propylene rubber (EPR)

ii)Continuous withstand temperature (deg.C)	90	70	70	90
iii)Short circuit withstand temp. (deg.C)	250	160	160	250
iv)Colour identification	As per relevant codes and standards			
c) Inner sheath	All armoured and multicore unarmored cables have distinct extruded inner sheath			
i) Material	PVC	PVC	PVC extended type 6 PVC	Heat resistant elastomeric compound
ii)Colour	Black	Black	Black	Black
d) Armour				
i)Material	Aluminium wire for single core cable and GS wire/flat for multicore cables as per Relevant IS. Minimum Coverage of 90%.		GS wire/flat as per relevant IS. Min. coverage of 90%	Nylon cord reinforcement
ii)Breaking load of joint	95% of normal armour	95% of normal armour		
e) Outer sheath				
i) Material (Polyethylene based halogen free material not acceptable)	PVC	PVC	PVC type 8 PVC with flame retardant low smoke properties. It should not stick to inner sheath & consistent in quality.	Heat & oil resistant & flame retardant heavy duty elastomeric compound
ii)Colour	Black	Black	Grey	Black
iii)Marking	-Cable size & voltage grade (by embossing) -marking "FRLS" @ 5 m (by embossing) -Sequential marking @ 1 m		Grey same as for power cables	Black same as for power cables
f) FRLS properties on outer sheath	Oxygen Index : Min. 29 (As per ASTM D 2863) Acid gas generation: Max. 20% (as per IEC 754-I) Smoke density rating : 60% (as per ASTM D 2843)			
g)Flammability	As per Swedish chimney test F3 as per 8EN 4241475. As per IEC 332 part-3(Category B).			

4.6.4 Co-Axial Cable

Coaxial cable is steel armoured and FRLS type. The cable is braided tinned copper conductor. The capacitance of the cable is required to be low so as to minimise attenuation in the carrier in the carrier frequency range.

The impedance of the cable is selected so as to match with the output impedance of the terminals and secondary impedance of the coupling units. The cable is required to be insulated to withstand a test voltage of 4 kV. Following type of H.F. cables are generally used.

1. Co-axial H.F. cable with 75 ohms impedance (unbalanced)

2. Test voltage in KV – 4 KV RMS for 1 minute
3. Size of conductor – 7 strands/0.4mm

The maximum attenuation at various frequencies is generally as follows

Frequency in KHZ	Attenuation in db/km
60	1.4
300	3.3
500	4.7

4.6.5 Cabling

Scope

The complete cable support system enable proper lying of all power, control, instrumentation and telephone cables, and provides necessary mechanical protection, ventilation and segregation for them. All hardware and anchoring arrangement is provided. All steel members should be hot dip galvanised.

Cabling from powerhouse to hydro-mechanical equipment e.g. intake and draft tube gates and gates for power & control from power house. Power and control panels to control panels of hydro mechanical equipment are properly provided.

Design

Detailed design and calculation are carried out.

General requirements

Sub zero level cable vault/trenches are provided below control building/switchgear rooms in main plant and switchyard areas.

Interplant cabling for main routes are laid along overhead trestles/duct banks/directly buried. However, for tap-offs, same can be through shallow trenches. Directly buried cable, if essential, should not have concentration of more than four (4) cables. Cables in switchyard area from main plant control room to switchyard are laid in cable tunnel duct bank/cable trenches. In switchyard area, cables are laid in RCC concrete trenches.

Cable entry from outdoor underground/cable routes to the buildings, if any are above the finished floor level inside the building. PCC flooring of built up trenches are sloped for effective drainage with sump pits and sump pumps.

Cable trays, support system and cable laying is summarised in table 4.7.

Table 4.7

a)	support system for cable trays	Prefabricated out of sheet steel and fully galvanised flexible type consisting of channels, cantilever arms and associated brackets & hardware, installed at site by bolting or clamping. These should be rigid enough to withstand max. possible loads during and after installation.
b)	Type of cable trays	Cable trap for power cables are perforated. Separate trays are provided for control instrumentation cables.
c)	Material of cable trays	Rolled mild steel, min. 2 mm thick for trays and 3 mm thick for coupler plate.
d)	Finish of cable trays	Hot tip galvanised.
e)	Duct banks (if provided)	Heavy duty GI pipes/heavy duty PE pipes (10% spare of each size, subject to min 1) with suitable water-proof manholes. For corrosive areas, pipes should have anti-corrosion coating both inside & outside.

f)	Pipe size	Suitable with 40% fill criteria
	Junction and Pull boxes	Hot dip galvanised sheet steel of 2 mm thickness.
	Cable glands	Nickelchromium plated brass, heavy duty, single compression type for unarmoured, and double compression type for armoured cables conforming to BS: 6121.
	Cable lugs	Solderless tinned copper crimping type. For HT cables, lugs should be as per DIN 46329/IS
	HT cable terminations and joints	Proven design and type tested as per VDE 0278. Elastimold or equivalent fully insulated moulded terminations are preferred.
Cable Laying		
a)	Identification tags for cables	To be provided at all terminations, on both sides of wall or floor crossing, on each conduit/duct/pipe entry/exit, and at every 20 m in cable trench/tray or buried run.
b)	Cable tray numbering	To be provided at every 10 m and at each end of cable way & branch connection.
c)	Joints	Joints for less than 250 m run of cable should not be permitted.
d)	Buried cable protection	With concrete slabs; Route markers at every 20 m along the route & at every bend.
e)	Road crossings	Cables to pass through buried RCC hume pipes.
f)	Transformer yard Handling area	RCC trenches to be filled with sand after cable laying
g)	Separation	At least 300 mm between HT power & LT power cables, LT power & LT control/instrumentation cables.
h)	Segregation	All cables associated with the unit are segregated from cables of other units. Interplant cables of station auxiliaries and unit critical drives are segregated in such a way that not more than half of the drives are lost in case of single incident of fire. Power and control cables for ac drives and corresponding emergency ac or dc drives are laid in segregated routes. Cable routes for one set of auxiliaries of same unit are segregated from the other set. Segregation means physical isolation to prevent fire jumping or minimum one hour fire rating. In switchyard, control cables of each bay are laid on separate racks/trays.
i)	Cable clamping	To be suitably clamped/tied to the tray; For cables in trefoil formation, trefoil clamps as provided required.
j)	Fire protection	Fire proof cable penetration seals rated for one hour when cable passes through walls and/or floors. This can be by suitable block system using individual blocks with suitable framework or by silicon RTV foaming system. In case foaming system is used, damming board, if used, are not considered for fire rating criteria. Any of the system used is to be of proven type as per BS: 476 (Part-8) or equivalent standard.

- A. Cables are laid on overhead cable trays and supports, pulled through conduits/GI pipes and on racks in built up cable trenches and vertical race ways and clamped with aluminium clamps on walls, ceiling and structures and may be directly buried in ground.
- B. Cable laying includes termination of power and control cables (i.e on both ends of the cables), at equipment terminals, switchgear, control panels etc. All electrical equipments after installation are completed with cable terminal boxes, cables glands, cable trays, lugs and terminal blocks.
- C. All power and control cables are provided with aluminium tag of an approved type, bearing cable reference. Cable routing is done in such way that cables are accessible for any maintenance and for easy identification. Power and control cables are laid in separate cable racks/trays, power cables being on upper most racks/trays. Asbestos sheets are laid beneath power cable where they are running over control cables

- D. The racks/trays, in general, are supported at a distance of 1500 mm on horizontal and vertical run.
- E. Straight through jointing of cables is avoided. Terminations are done by crimping. Termination kits for the 11kV XLPE insulated cables are heat shrinkable polymeric or tape type.
- F. Buried cables are avoided as far as possible but if necessary it is covered with alternate layer of bricks and sand for mechanical protection. Steel markers are provided at every 20 meters along the cable route.
- H. All cables laid on trays/racks are neatly dressed up and clamped/tied to the tray/rack. Suitable Trefoil clamps are provided for single core cables.

Galvanizing

All cable trays and their fittings are hot dip galvanized after fabrication according to IS: 2629 (1968) or relevant IEC. The galvanizing is required to be uniform, clean, smooth, continuous and free from acid spots.

Support and supporting structures

Angles, flats, channels, hangers, brackets clamps, nuts, bolts and other anchorage material used for the installation of cables, cable trays, race ways and conduits and all steel members are suitably treated and galvanized or painted with 2 coats of approved paint.

4.7 GROUNDING SYSTEM FOR GENERATING STATIONS AND STEP UP SUB STATIONS

4.7.1 Introduction

- a) Grounding system comprises interconnected ground facilities for hydro power stations including ground mat below the powerhouse, tailrace and step up substation, and grounding system network for equipment and safety. The guidelines pertain to design and installation of grounding system for hydro generating station and step up sub stations including earthmats and equipment grounding. System ground fault current and site soil resistivity are the primary basis for design of grounding system. Indian Electricity Rules and design codes for safety etc. are the basis of the design. The guidelines are divided into following three categories.
- b) Large and Mega Hydro stations connected to transmission system at 66 kV and above
- c) Hydro power station connected to sub-transmission system up to 33 kV – up to 5 MW.
- d) Hydro power stations connected to electrical distribution systems up to 11 kV - including Micro Hydro

4.7.2 Standards, Codes and Rules – (Latest Amended)

- a) Indian Electricity Rules
- b) National Electricity Code – ISI
- c) IS: 3043-2001 Code of Practice for Earthing
- d) IEEE std. 665 – 1995 – 2001 IEEE Guide for Generating Station Grounding
- e) IEEE std. 80 – 2000 IEEE Guide for Safety in AC substation Grounding
- f) Central Board of Irrigation and Power Publication no. 302-2007 - Manual on Earthing of AC Power Systems
- g) Rural Electrification Standards for grounding system

4.7.3 Design Objectives

Design objective in generating station grounding are as follows:

- a) Provide safety ground for protecting personal from injury.

- b) Equipment ground to trip faulted circuit for protection and alarm
- c) To limit potential difference across communication or control lines leaving the station during power system faults.
- d) Neutral ground to provide ground reference of electrical system
- e) Minimum noise interference in electronic control , instrumentation and protection system
- f) Lightning protection

4.7.4 Parameters to be considered for designing Earthing System

- i) Soil resistivity
- ii) Resistivity of the surface material
- iii) Magnitude of fault current
- iv) Duration of the fault current
- v) Material of the earth mat conductor
- vi) Earth mat geometry

4.7.4.1 Site Soil Resistivity Measurements and Installation: Site soil resistivity measurements should be carried out by 4 probe method to determine average resistivity as detailed in Annexure-4.7.1.

Resistivity of soil can vary within extremely wide limits. It depends on the type and nature of soil. Table 4.8 is indicative of the resistivity of various types of soils and other materials.

4.7.4.2 Effect of moisture, salts and Temperature: It may be noted that the resistivity of a rock is not unique to it and that there is considerable overlapping of resistivity ranges of several rock types, depending on clay content, water saturation, quality of water, salinity and porosity. Dry soil is generally very poor conductor of electricity. Also, if variation in soil resistivity during a year is considered, soil resistivity below water table is more constant than that above this level. The amount of water held in soil is dependent on weather conditions, time of the year and nature of subsoil. In hydro plants, power plant and tail race mat is under wet condition of soil. The soil resistivity may be designed accordingly. The switchyard mat may be designed for dry condition of soil, if necessary provision for pouring water into the earthing rod sumps every few days to keep the soil surrounding the earth pipe permanently moist be made as shown in Figure 4.12.

Table 4.8

S. No.	Type of Soil	Resistivity (ohm-m)	
		Average	Usual variation
1.	Surface soil (loam –clay and sand and decayed organic matter)	25	5 – 50
2.	Clay (stiff viscous earth chiefly aluminium silicate), black clay	30	8 – 100
3.	Sand and gravel	100	40 – 300
4.	Sand clay and gravel mixture	150	50 – 250
5.	Shale (fine grained sedimentary rock of mud and clay), sandstone wet (sedimentary rock chiefly quartz cemented together), slate, schist	-	5 – 500
6.	Sandstone dry		1000 - 10000
7.	Surface limestone (chiefly calcium carbonate)		100 – 10000
8.	Concrete, new or buried in earth	100	25 – 500
9.	Concrete dry	10000	200 - 1000000

Note: Table reference – extract from CBI & P Manual.

4.7.4.3 Magnitude of Fault Current: Magnitude of fault current is calculated from the fault level studies. The duration of fault is taken as 1 sec. for voltages above 33 kV and 3 sec for lower voltages.

4.7.4.4 Material and Size of Conductor: Electrical material does not affect initial earth resistance. Material resistant to corrosion in the type of soil at site is required. Mild steel electrodes with corrosion allowance are mostly used. It is cheaper and easily available.

Size of conductor for earth mat (steel) may be determined as follows as per IEEE-80-2000 based on thermal stability

$$A \text{ (for welded joint)} = 12.30 \times I \times \sqrt{t_c} \text{ mm}^2$$

$$A \text{ for bolted joint} = 15.13 \times I \times \sqrt{t_c} \text{ mm}^2$$

Where

A = Area of cross section of the conductor in mm value applicable for steel

I = Fault current rms in KA

t_c = Time of current flow (1 second for above 33 kV & 3 seconds below 33 kV)

4.7.5 Station Ground Resistance

4.7.5.1 Earthmat – Consisting of strip and ground rod electrodes

$$R_g = \frac{\rho}{4} \sqrt{\frac{\pi}{A}} + \frac{\rho}{L}$$

R_g = Station ground Resistance in ohms

ρ = average soil resistivity in ohm m.

A = Area under earthing mat in square meters.

L = Total Length of buried conductor in meters.

Note: In case of a grid rod combination, a combined length of horizontal conductors and ground rods is used.

4.7.5.2 Ground resistance of rod/pipe electrodes (Figure 4.12 (a))

$$R_g = \frac{100 \rho}{2\pi L} \log_e \frac{4L}{d} \text{ ohms}$$

Where

L = length of rod or pipe in cm, and

d = diameter of rod or pipe in cm.

Note: 25 mm steel or galvanized iron rods or pipes with 3 m depth of burial is recommended as optimum in National Electric Code (NEC)

4.7.5.3 For Plate Electrodes (Figure 4.12 (b))

$$R = \frac{\rho}{4} \sqrt{\frac{\pi}{A}} \text{ ohms}$$

A = Area of both sides of plates in square meters

4.7.5.4 Effect of Depth of Burial

To reduce the depth of burial without increasing the resistance, a number of rods or pipes are connected together in parallel (see Figure 4.11). The resistance in this case is practically proportional to the reciprocal of the number of electrodes used so long as each is situated outside the resistance area of the other. The distance between two electrodes in such a case is preferably kept not less than twice the length of the electrode.

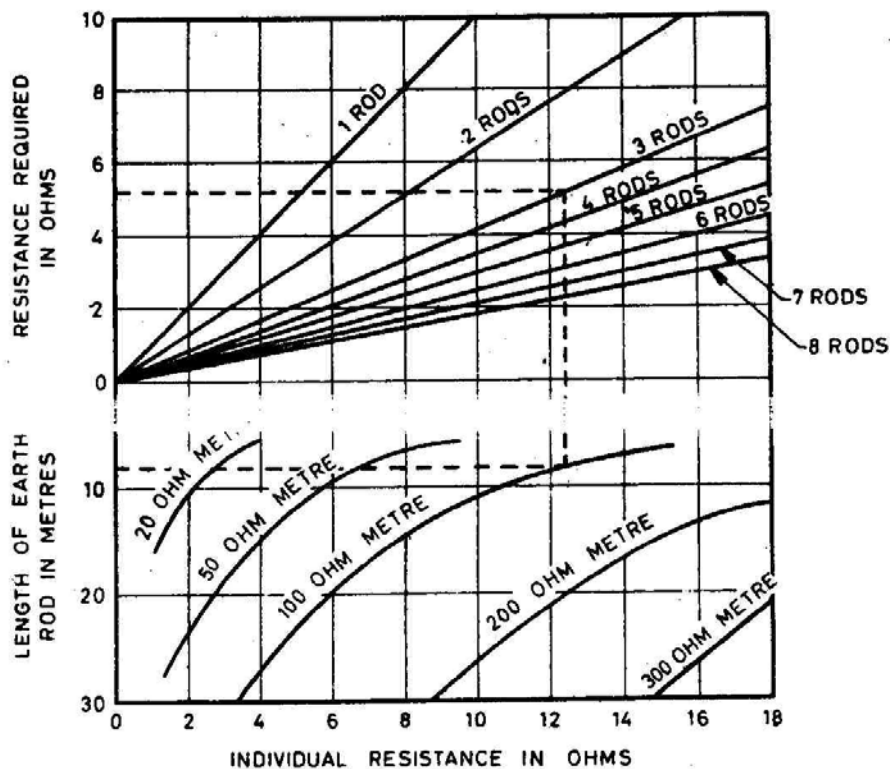


Figure 4.11: Resistance of Electrodes at Various Depths and Soil Resistivity (National Electrical Code)

4.7.6 Grounding System for powerhouse & Sub Station

General requirements of earthing system for generating station and sub station

The requirements as per Indian Electricity rules as follows:

- All medium voltage equipment shall be earthed by two separate and distinct connections with earth through earth electrode. In the case of high and extra high voltages the neutral points shall be earthed by not less than two separate and distinct connections with each having its own electrode at the generating station or substation and may be earthed at any other point provided no interference is caused by such earthing.
- Earth electrode shall be provided at generating stations, sub-stations and consumer premises in accordance with the requirements.
- Each earth system shall be devised so that the testing of individual earth electrode is possible. It is recommended that the value of any earth system resistance shall not be more than 5 ohms. In case common earth is used for systems of different voltages at a transformation point the combined resistance to earth should be 1 ohm or less for power station and large sub-station.

4.7.6.1 Current Carrying Capacity: Any conductor, electrode or connection used in a grounding system should be large enough to carry the following currents without excessive heating:

- Fault currents of magnitude and duration such as to produce maximum heating effect.
- The current caused by a direct lightning stroke, or induced by a lightning stroke may be relatively high but are usually of short duration and, therefore, generally present no problem for grounds that meet the other electrical and mechanical requirements.
- The current that may be expected to flow in the grounding system as a result of sustained neutral currents.

4.7.6.2 Control of Ground Potentials and Gradients: The grounding system should within reasonable limits, provide a low impedance path to ground for fault currents, neutral currents and lightning discharges, with uniform or near-uniform potentials of earth surfaces in the area under consideration. This result should be accomplished without the occurrence of hazardous potential differences between any surface on which a person may be standing and any surrounding structures or objects within his reach; and also without the imposition of dangerous difference of potential on equipment and circuits.

In situation where the impedance is such that potentials in the vicinity cannot be kept reasonably safe, special arrangements of grounding system should be devised.

Safe body current of an average Indian human being as per CBI & P Manual on earthing of AC Power System 2007.

$$I = \frac{0.116}{\sqrt{t}}$$

Where I is rms current through human body (50 kg wt) in amp., t is duration of shock in seconds (time)

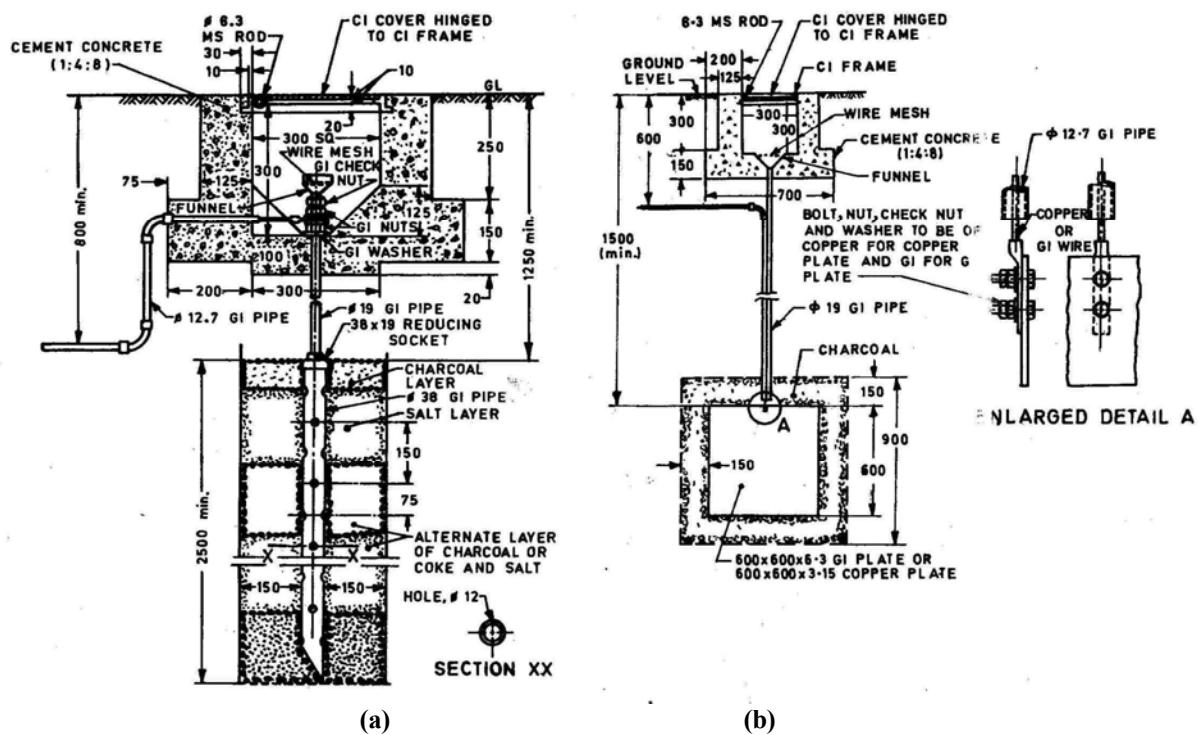


Figure 4.12: TYPICAL ILLUSTRATION OF PIPE AND PLATE EARTH ELECTRODE
(National Electrical Code)

Note: Three or four buckets of water to be poured into sump every few days to keep the soil surrounding the earth pipe/plate permanently moist

4.7.6.3 Maximum Touch and Step Potential

$$\text{Tolerance for sustained touch potential} = \frac{165 + 0.25\rho}{\sqrt{t}}$$

Where,

t = Duration of sustained shock contact in seconds (0.5 seconds as the fault is expected to be cleared much earlier)

ρ = Soil resistivity of top soil layer in ohms-meters.

Maximum safe step voltage is given by the following:

$$E_{\text{step}} = \frac{165 + \rho \text{ volts}}{\sqrt{t}}$$

4.7.6.4 Maximum Value of Station Voltage Rise (Transfer Potential) and Station Ground Resistance: The maximum voltage rise of the station ground bus over the potential of a remote point>equals the product $I_g \times R$ where I_g is the largest current expected to flow into the ground during power system fault through station ground resistance R . This voltage appears across communicating or control lines or metal pipes etc. leaving the station.

Maximum potential rise of the station ground bus is about 5000 volts (USBR & Bhakra Practice). Some utilities have adopted much higher values especially in high resistivity areas.

For a ground fault current of I_g and transfer potential of 5000 volts ground grid resistance (R_g) required is worked out as follows:

$$R_g = \frac{E_{\text{transfer}}}{I_g} \text{ ohm}$$

Where

R_g = Combined ground resistance
 E = maximum permissible transfer potential
 I_g = maximum ground fault current

In difficult conditions (high resistivity) and large currents the transfer potentials have been kept higher and up to 20000V have been used. In such cases due care is taken to insulate outgoing low voltage control or communication lines or pipes if any from the station property or avoided.

4.7.6.5 Ground Resistance of Powerhouse and Substation: Experience data of the resistance to ground of substation and powerhouse earthmats as per practice of some power utilities in India and abroad is given in table 4.9.

Table 4.9

Resistance to ground of power plant, tailrace and substation ground mats for hdro power Station and Step up Substations

Sub Station Voltage	IEEE Std.	CBI & P	Tamil Nadu	U.S. Army Corps	UPSEB
	(1)	(2)	(3)	(4)	(5)
11kV	1 – 5 ohm	5 ohms	Major substation 1.0 ohm	SHP up to 1500 kW – 1 ohm	5 ohm for 11 kV
33kV		-			2 ohm for 33 kV
66 kV	1 ohm and less than 1 ohm for EHV Substation with high fault levels		Small substation 2.0 ohm	SHP above 1500 kW – 0.5 ohm	-
132 kV					
220 kV					

- 1) IEEE std. 2000 – IEEE Guide for safety in AC substation grounding
- 2) CBI & P – Manual on substation layout pub. No. 290-2006
- 3) Power Engineer's Handbook – Tamil Nadu State Electricity Board
- 4) U.S. Army Corps of Engineer – Engineering and Design of Hydro-Electric Power Plants electrical Design June 1994
- 5) UPSEB substation construction manual – 1978

4.7.6.6 Maximum Ground Fault Current

Maximum ground fault current in SHP for 1 ohm ground resistance and 5000 volts transfer potential is worked out as follows:

$$I_g = \frac{5000}{1} = 5000 \text{ A i.e. 5 kA}$$

Ground fault current (grid current) in distribution sub-station (up to 33 kV) may not exceed 2500A and 66 kV and 132 kV may not exceed 5000A and may be assumed for design.

- 4.7.6.7 Mechanical Reliability:** The design and installation of conductors, electrodes and connections of a grounding system should be adequate to minimize the possibility of mechanical injury in order to maintain the reliability and continuity of the grounding system.
- 4.7.6.8 Electrical Reliability:** The design and installation of the grounding system should be such as to maintain permanently the performance requirements stated above. This point is of particular significance with regard to electrical connections.
- 4.7.6.9 Resistance to Corrosion:** The design and installation should be suitable for preventing deterioration from corrosion. For this purpose, the installation should be compatible with the surrounding soil, atmosphere and adjacent underground plants.
- 4.7.6.10 Low Impedance for System Operation:** The impedance of the grounding system should be sufficiently low to stabilize system potentials with respect to ground; to provide positive operation of over current devices; to improve voltage regulation and to restrict neutral potentials to suitably low values in those circuits where the grounding system is required to carry portion of the neutral current.
- 4.7.6.11 Provision for test and Inspection:** It is important that the condition of the grounding system at each installation may be known at any time. Therefore, the design of the grounding systems should be such as to permit adequate testing and inspection.
- 4.7.6.12 Grounding Material:** Steel grounding material is used due to cost considerations and easy availability with adequate sizes for earth fault currents, mechanical considerations and provision for corrosion etc. for duration of life of the civil structure.

Minimum size of steel earthmat conductors based on thermal stability for welded joints is given by following formula (CBI & P Manual).

$$A = I \times 12.30 \sqrt{tc}$$

Where,

- A = Cross sectional area in mm²
I = Current in kilo amperes
tc = Time of current flow in seconds (1 sec.)

The ground mat is laid below the power plant and substation structures. Taking the life of hydro power plant building as 100 years, table 4.10 gives the effective cross sectional area after 75 years of the ground conductors for some common sizes of MS flats in low resistivity areas.

Table 4.10

S. No.	Standard M. S. flat		Loss due to corrosion		Effective Gross Section Area After 75 years (col. 3 – col. 5)
	Size Maximum (mm)	Gross-sectional area mm ²	In weight grams	In sectional cross area mm ²	
1	2	3	4	5	6
1.	25 x 6	150	9.3	120	30
2.	35 x 6	210	12.3	160	50
3.	50 x 6	300	16.8	210	90
4.	50 x 8	400	17.4	220	180

Size of buried conductor (e.g. MS flat) for earthmat calculated as per Para 4.7.6.2 is increased in size to take care of corrosion depending upon soil. This increase is about 30% to 60% of the area.

Standard size of 50 x 6 ms flat as per IS: 1730-1989 and CBI & P Pub. 223 is generally provided as grounding buried conductor to take care of future expansion and corrosion in moderately corrosive soils.

Size of grounding conductors recommended for earthig system including equipment grounding is given in table 4.11 for uniformity.

Table 4.11

Equipment	Buried conductor	Conductor above ground & in trenches
Main station grid	25 mm dia. & 2.5 m long MS rod; 50 x 6 MS flat	50x6 mm GS flat
Switchgear/MCC	--	50x6 mm GS flat
415 V distribution boards	--	50x6 mm GS flat
HT motors	--	50x6 mm GS flat
LT motors above 125 kW	--	50x6 mm GS flat
LT motors - 25 to 125 kW	--	25x6 mm GS flat
LT motors - 1 to 25 kW	--	25x3 mm GS flat
Fractional HP LT motors	--	8 SWG GS wire
Control panel & control desk	--	25x3 mm GS flat
Push button stn. & Junction box	--	8 SWG GS wire
Cable trays, cols. & structures	--	50x6 mm GS flat
Bus duct enclosures	--	50x6 mm GS flat
Rails & other metal parts	--	25x6 mm GS flat
Eqpt. earthing for switchyard equipment	--	50x6 mm GS flat and 50x6 mm GS flat

4.7.7 Generating Station Grounding Design of Powerhouse and Substation

4.7.7.1 Design Procedure: Grounding system in the power plant generally consists of the following.

- a) Generating station ground mat
- b) Tailrace ground mat
- c) Substation ground mat

All the three mats are interconnected.

- ii) Practical design of grid should usually start with an inspection of the layout plan for equipment and structures.
- iii) A continuous grounding conductor should surround the grid parameter, to enclose as much ground area as practicable.
- iv) Within the grid; grounding conductors should be laid in parallel lines and preferably at reasonable uniform spacing of 3 m to 6 m.
- v) Depth of burial of grounding conductor may be fixed from 150 mm to 600 mm depending on the nature of the soil.
- vi) The preliminary design should be adjusted, so that the total length of the buried grounding conductor, including cross connection and rods, is at least equal to that computed in Para 4.7.6.3 & 4.7.6.4, in order to keep the local potential differences within acceptable limits.
- vii) A ground grid system in Generating station and substation ground design in a very high resistively soil, it might be desirable to drive the rods deeper, if soil resistivity permits.
- viii) If low station resistance is not otherwise obtained; one or more ground beds or wire mesh or rods or another loop at location of low soil resistivity away from the station area can be installed and interconnected.

Notes:

1. For having low station ground resistance, a simple loop encircling the largest area available, is the most economical design. Other consideration such as potential gradient control etc. may dictate a grid.
2. With dimensions or grid generally encountered, resistance of the grounding conductor, the cross sectional area; depth of burial and increase in the number of meshes within a grid, has very little affect on the total station grid resistance.
3. Selection of material and its dimensions are governed mainly by mechanical strength; corrosion; & current carrying capacity considerations.
4. Spacing; length; size and depth of burial of grounding conductor are governed mainly from potential gradient considerations. So far as internal gradients are concerned, these can be kept to any desired value by keeping the general mesh spacing throughout the station, reasonably uniform and sufficiently close, so that the mesh potentials, even at corners are within acceptable limits. Another alternative possibility is to use a somewhat wider mesh over most of the area and correcting the situation near the corners by using closer mesh.
5. To reduce touch voltage from outside, a perimeter earth conductor be laid outside the fence at the same depth as the conductor of grid earth conductor. This conductor is made part of earth electrode is electrically connected to the fence.
Generally rods cost less than deep grid for equal resistance and are preferable.

4.7.7.2 Generating Station Ground Grid Design: Difference between substation and generating station grounding grid design are as follows:

Persons inside the power house are not exposed to many of the step and touch voltage condition of substations. IEEE guide 665 and CBI & P Pub. No. 302 recommends that separate grid for step and touch voltage criteria is not required in generating station. Ground mat be laid as follows:-

- a) Outer grid conductor comprising the largest rectangle enclosing the power house should be provided at a distance of 1 m from building. Spacing of buried earth conductors should be about 3-4m.
- b) A similar earth mat be laid under the tailrace and interconnected with powerhouse mat.
- c) The sub-station ground mat should be interconnected to generating station grounding grid.
- d) Adequate number of risers a minimum of two should be taken from the earth conductors laid under the floor for safety grounding separate risers be taken for neutral grounding.
- e) Inside the powerhouse building an earthing be installed along outer wall of each floor of the building.

To meet the design objective given above, values of following item must be determined.

- a) Value of soil resistivity for surface layers and deeper layers at the station site area.
- b) Maximum and sustained values of ground fault current
- c) Maximum safe value of potential gradient (potential difference) and station voltage rise to avoid hazard to life and equipment (Para 4.7.6.3 & 4.7.6.4).
- d) Maximum acceptable value of ground grid resistance
- e) Material and size of grounding conductor (steel).

4.7.7.3 Site Soil Resistivity – Site soil resistivity measurement be made and Value of resistivity to be assumed for design are detailed in Annexure 4.7.7.1.

4.7.7.4 Ground fault Current: Single line to ground fault is considered for determining earth fault current. Symmetrical component of this current I_0 assuming zero fault resistance and neglecting resistance (positive, negative and zero sequence) which is negligible at the time of initiation.

$$I_G = \frac{E}{X_1 + X_2 + X_0}$$

Where,

E = Nominal phase to neutral voltage

X_1 , X_2 and X_0 are positive, negative and zero sequence reactance

I_f = symmetrical single phase to earth fault current

$$I_f = 3 I_G$$

Grid current I_G is the part of the current which is returned to local generators via neutral.

$$S_f = S_f I_f$$

Where S_f is fault current division factor. In case generator transformer are Δ/Y . Current fed to the fault from generator transformer does not return through earth as it cannot flow through Delta winding and

$$I_f = I_G$$

The single line to ground fault current can be calculated by sequence impedance network or by simulating the system network with digital computer software.

Value of grid current adopted for earth mat design should be increased by a factor of say 1.5 to take care of future change and use of decrement factors to determine effective current during a given time interval depending upon fault clearance time.

4.7.7.5 Magnitude of fault Currents and Grid Current at Hydro Station

Magnitude of fault Current calculated for 2 units rated 8 MW, 11 kV and 0.85 p. f. connected to 33 kV through 11 MVA 11/33 Δ/Y transformer by 12 km long lines (Figure-4.13). Example in CBI & P Pub. 302.

Maximum grid current = 1373A
For design of earth mat

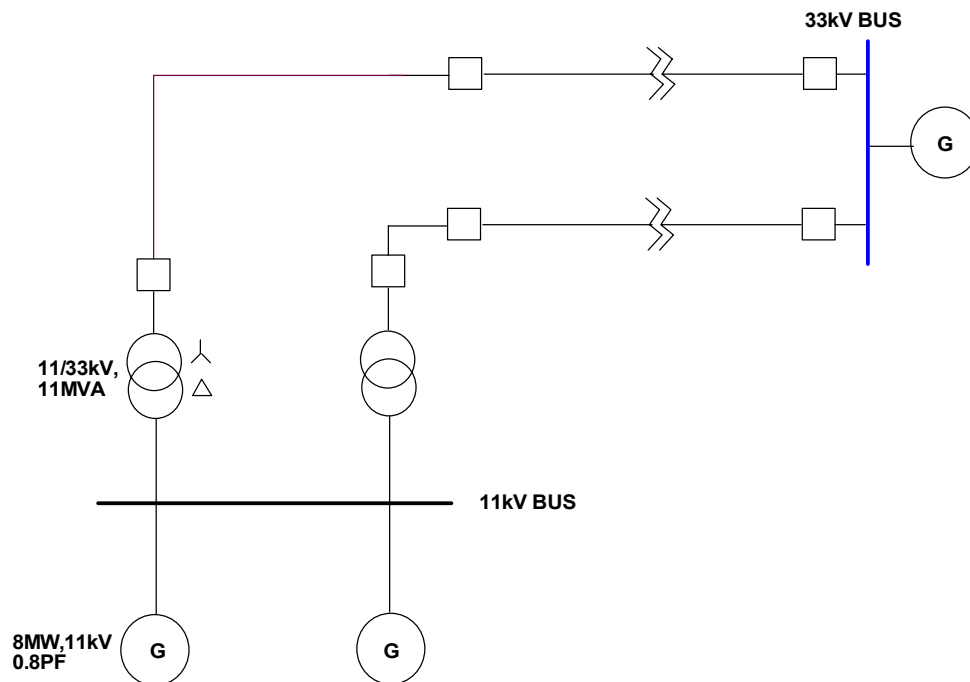


Figure 4.13 Single line to ground fault current , On 33 kV bus at SHP - 4485 A Grid current (I_G) - 1373 A **4.7.8 Design of Grounding Systems for Micro Hydro and Medium Voltage Station**

As per micro hydro standards issued by AHEC, earthing is to be provided as per REC (Rural Electrification Corporation) standards and Indian Electricity Rules.

Accordingly micro hydro station generating power at medium voltage 415 volts be earthed as shown in Figure 4.14. Neutral should be earthed by a separate earth.

In case an 11 kV pole mounted station is provided then it may be earthed as shown in Figure 4.15 & Figure 4.16. The neutral electrode should be at least on pole span away from the generator neutral.

As per Indian Standard (IS) Medium voltage (415 volts) generators require earthing by 2 separate and distinct connections with earth. Further neutral ground is to be provided for reference of electrical system.

Further step up substation if at 11 kV also requires three electrodes for earthing and lightning arrestor.

Substation earth mat be designed for safe mesh potential (safe touch and step potential).

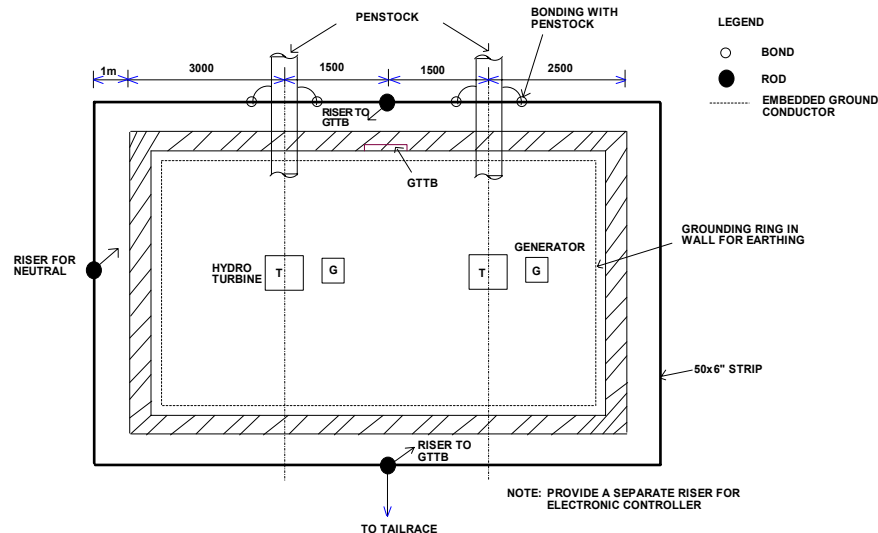
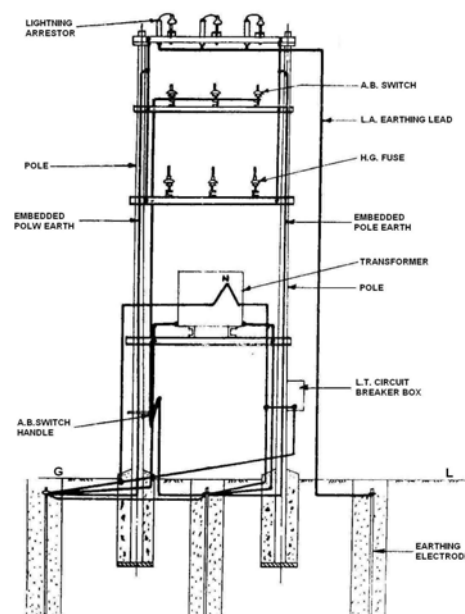


Figure 4.14: Micro Hydro and Medium Voltage Grounding System (Generating Station)

Distance between 2 electrodes (rod/pipe) should be more than twice the length (4.7.5.4) so as to be effective. Accordingly minimum distance between electrodes not more than two rod/pipe electrodes for 3 m long rod/pipe electrodes is required to be more than 6 m. Hence two rod/pipe electrodes may be used for economical and effective earth.



**Figure 4.15: Earthing Arrangement for Distribution Sub-Station (Pole Mounted)
(CBI & P Manual - Modern Practices in Sub Transmission)**

- Notes:** 1. Neutral electrode G should be one span away from powerhouse neutral
 2. Special arrangements below A. B. Switch handle (mesh on ground below feet) be made as per IS: 3043 in case earthing resistance is more than 5 ohms.

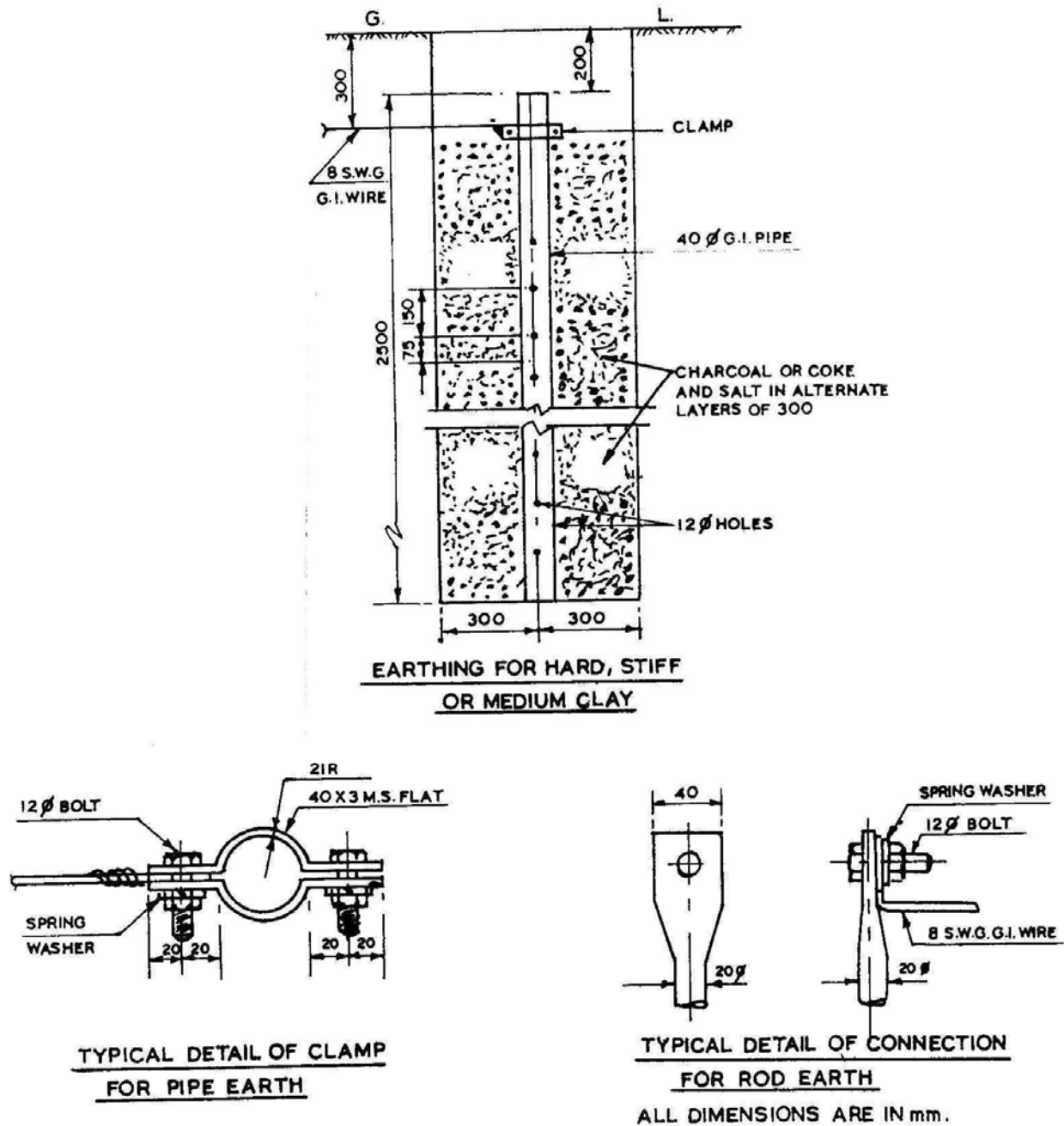


Figure 4.16: Micro HydroHydro – Earthing System

In higher resistivity areas chemical treatment of earth is more economical and pipe earth electrode may be used as also recommended in micro hydro standards issued by AHEC.

Ground Resistance for various values of earth resistivity (4.7.5.1)

$$R_g = \frac{\rho}{4} \sqrt{\frac{\pi}{A}} + \frac{\rho}{L}$$

Ground Resistance	Soil Resistivity (ρ) in ohm meter					Remarks
	10	25	50	100	200	
R _g	0.85	2.1	4.2	8.5	17	In case of high resistivity soil use pipe/earth electrode with chemical treatment of soil around pipe

Notes: Soil Resistivity should be taken in wet condition, which will be much lower

4.7.9 Grounding system design for SHP up to 5 MW and connected to grid at 33 kV and below and earth resistivity up to 100 ohm meter

General: Design is based on design practices for generating station and sub-station.

4.7.9.1 Earthing Practice of Sub Station

CBI & P Guidelines

CBI & P Guidelines for 11 kV substation earthing is shown Figure 4.17 and Figure 4.18. 33 kV substations earthing as per CBI & P Guidelines is shown Figure 4.19.

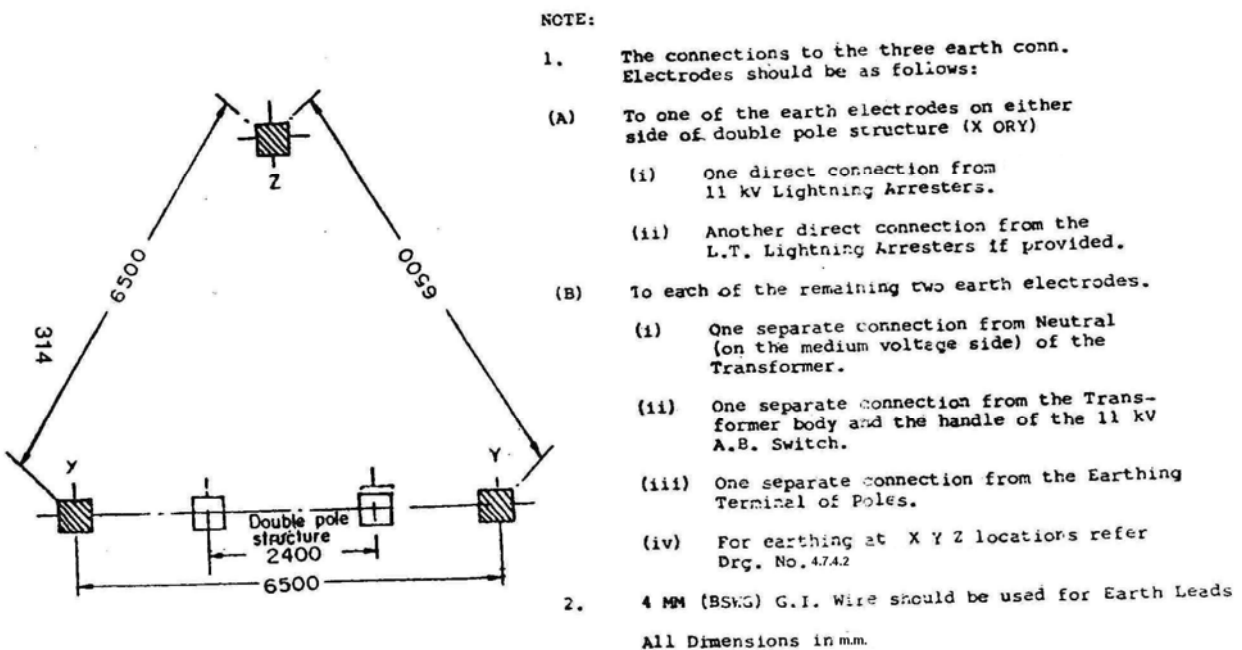


Figure 4.17: 11 kV/433-250 V, Distribution Sub Station Location of Earth pits and Connections (Modern Trends and Practices in Power Sub-Transmission and Distribution Systems)

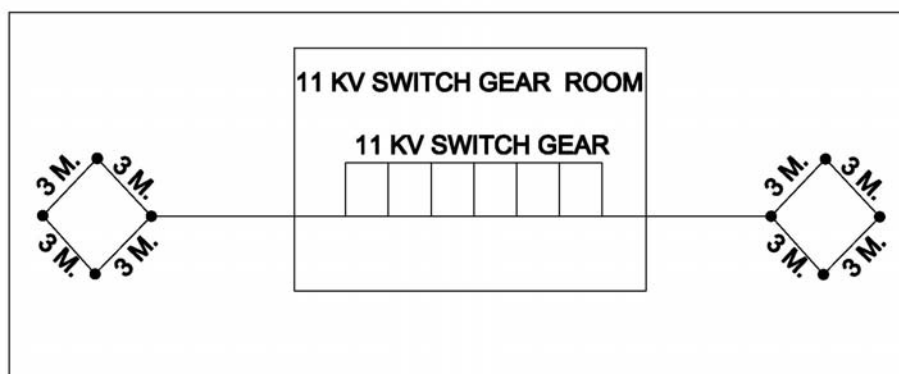
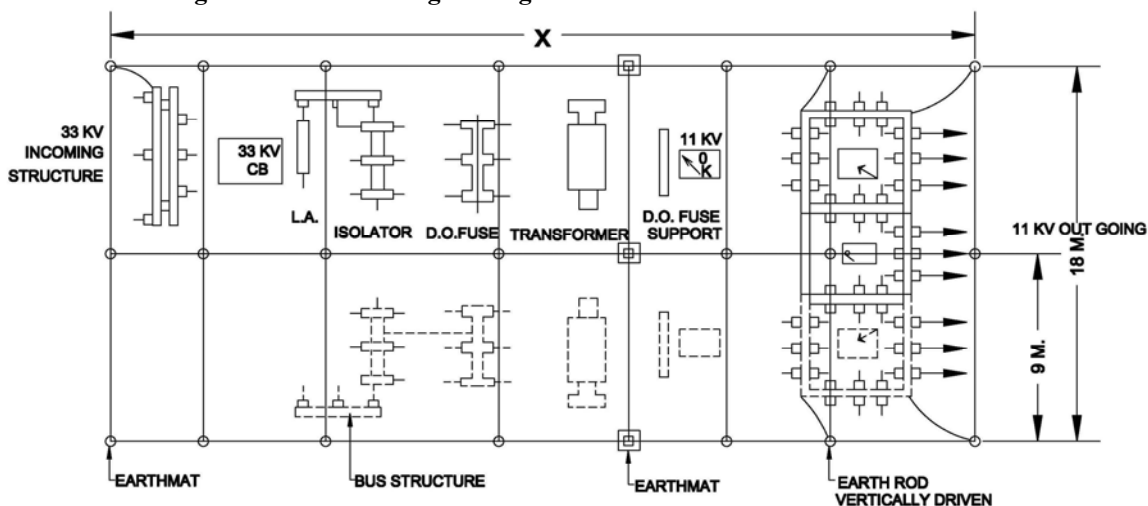


Figure 4.18: Grounding Arrangement for 11 kV Sub Station



1. EVERY STRUCTURE EQUIPMENT WILL BE CONNECTED EARTH WITH TWO CONNECTIONS.
2. M.S FLAT WILL ALSO BE USED FOR TRANSFORMER NEUTRAL CONNECTION TO EARTH.
3. ALL JOINTS SHALL BE WELDED.

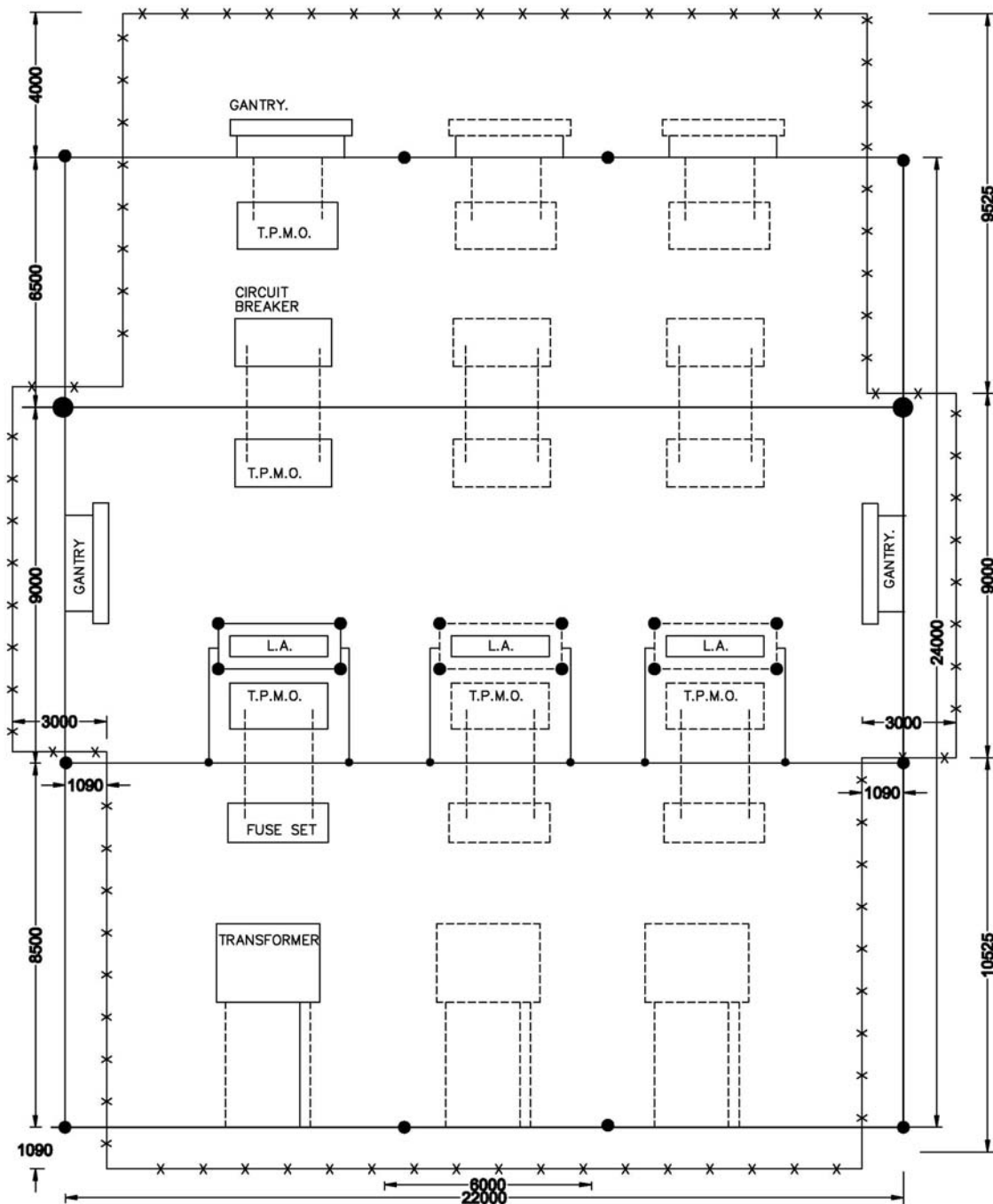
Figure 4.19: Earthing Arrangement in 33/11 kV Substation
(CBI & P -Construction Practices – Sub Station)

Sub-Station Earth Mat for 33 kV Sub Station (UPSEB Practice)

For 33 kV Substation having capacity up to 10 MVA the earth mat be designed as per drawings given below (UPSEB Guidelines):

Sl. No.	Soil resistivity	Size of Earth Mat	Drawing No.
1.	20 to 70 ohm-meters	22 M x 24 M	4.7.9.4
2.	- DO -	16 M X 32 M	4.7.9.5
3.	Up to 250 ohm-meters	21 M X 42 M	4.7.9.6

Except in the hill regions, the soil resistivity generally varies from 20 to 70 ohm-meters. Thus the actual resistance of sub-station earth mat will be even less than 2 ohms. At each substation soil resistivity should be measured by 4 electrodes method. Where it is within the range, the proposed earth mat may be laid. However, it is more than 70 ohm-meters the earthing system will have to be designed separately.



MAIN ERATH STRIP
35 x 6 MM GS

BRANCH STRIP
25 x 6 MM GS

EARTH ELECTRODE
40 MM GS PIPE, 2.9 MM
THICK

**Figure 4.20 : Grounding Arrangement for 33 kV S/S with feeders
at Right Angle to Busbars (for layout of S/S)**

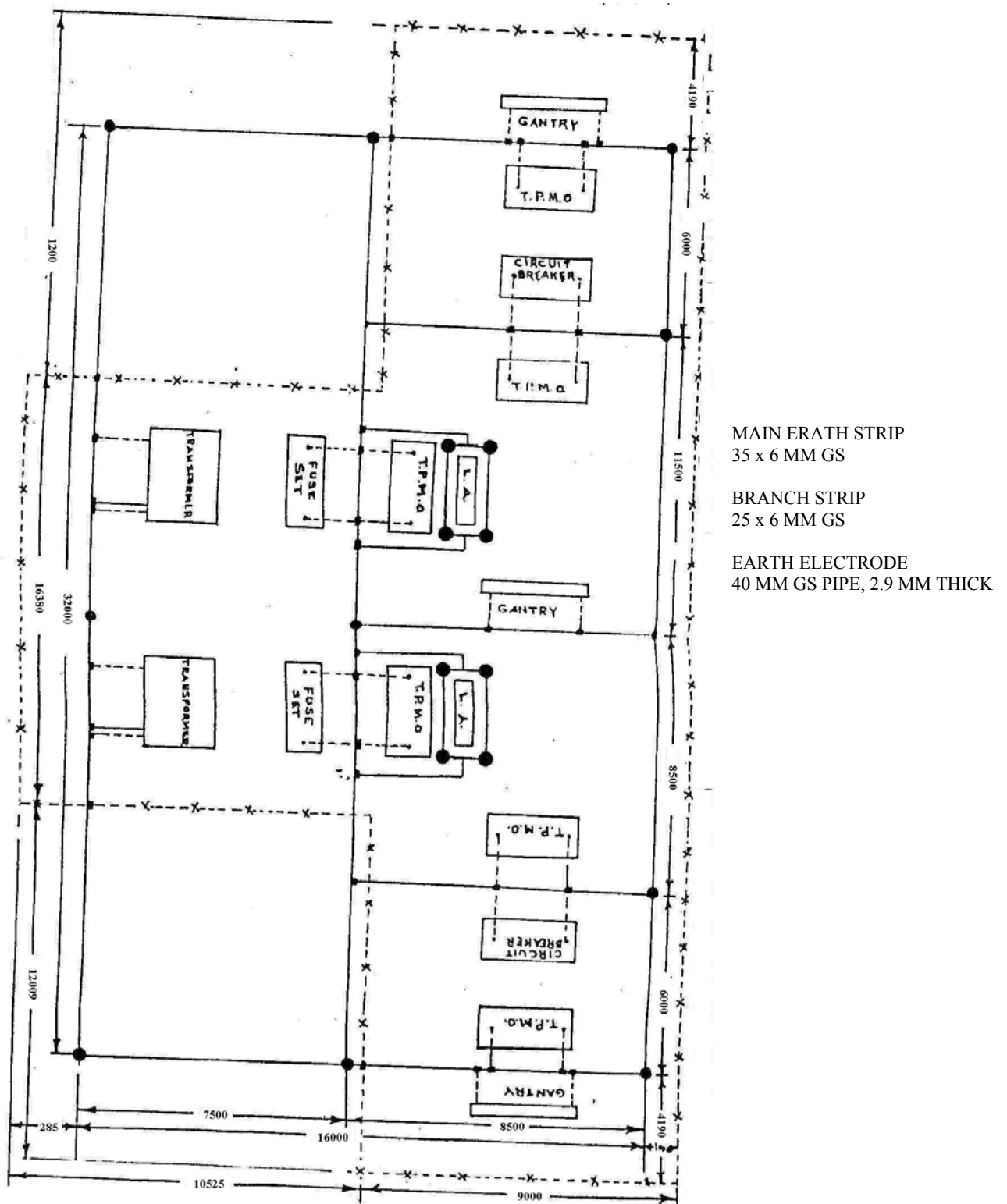


Figure 4.21: Grounding Arrangement of 33/11 kV Sub-Station with Two Feeders (Parallel to bus bar) in opposite Direction

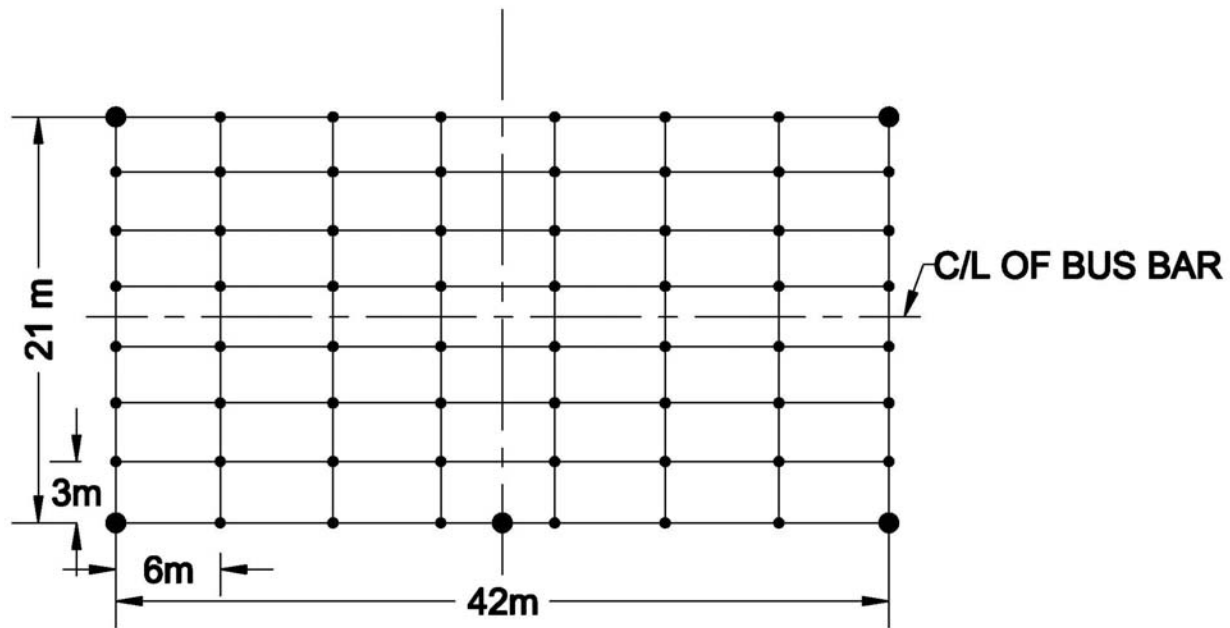


Figure 4.22: Grounding Arrangement for 33/11 kV S/S with Earth Resistivity 250 ohm-meter

4.7.9.2 Allowable values of resistance of grounding system: It is recommended that earth resistance of grounding system for 33 kV substations should not be more than 2 ohms and that for 11 kV sub stations and power house not more than 5 ohms.

Earthmat is laid under Generating Station, sub-station and tailrace and interconnected to each other so as to achieve overall earth resistance of not more than 2 ohms for 33 kV sub-station and 5 ohm for 11 kV sub-station.

4.7.9.3 Earthmat Under Generating Station: As per I.S. Medium voltage (415 volts) generators require earthing by 2 separate and distinct connections with earth. Further neutral ground is to be provided for reference of electrical system. Normally neutral is grounded through resistance and ground fault current is limited by the resistance. Therefore three electrodes are sufficient.

Further step up substation if at 11 kV also requires three electrodes for earthing and lightning arrestor.

For purpose of uniformity in design following be adopted for all generating stations.

- Provide an outer grid conductor comprising largest rectangle enclosing powerhouse. The conductor should be 1 m from outside well.
- Provide earth conductor in between at spacing of about 4 m.
- Provide interconnection with sub-station grounding system if required.

4.7.9.4 Typical Examples

- Belsar Power Plant (Figure 4.23)
- Pacha Power Plant (2 x 1.5 MW) interconnected with grid at 33 kV (Figure 4.24 (a) & Figure 4.24 (b))
- Jumgad Power plant (Figure 4.25)

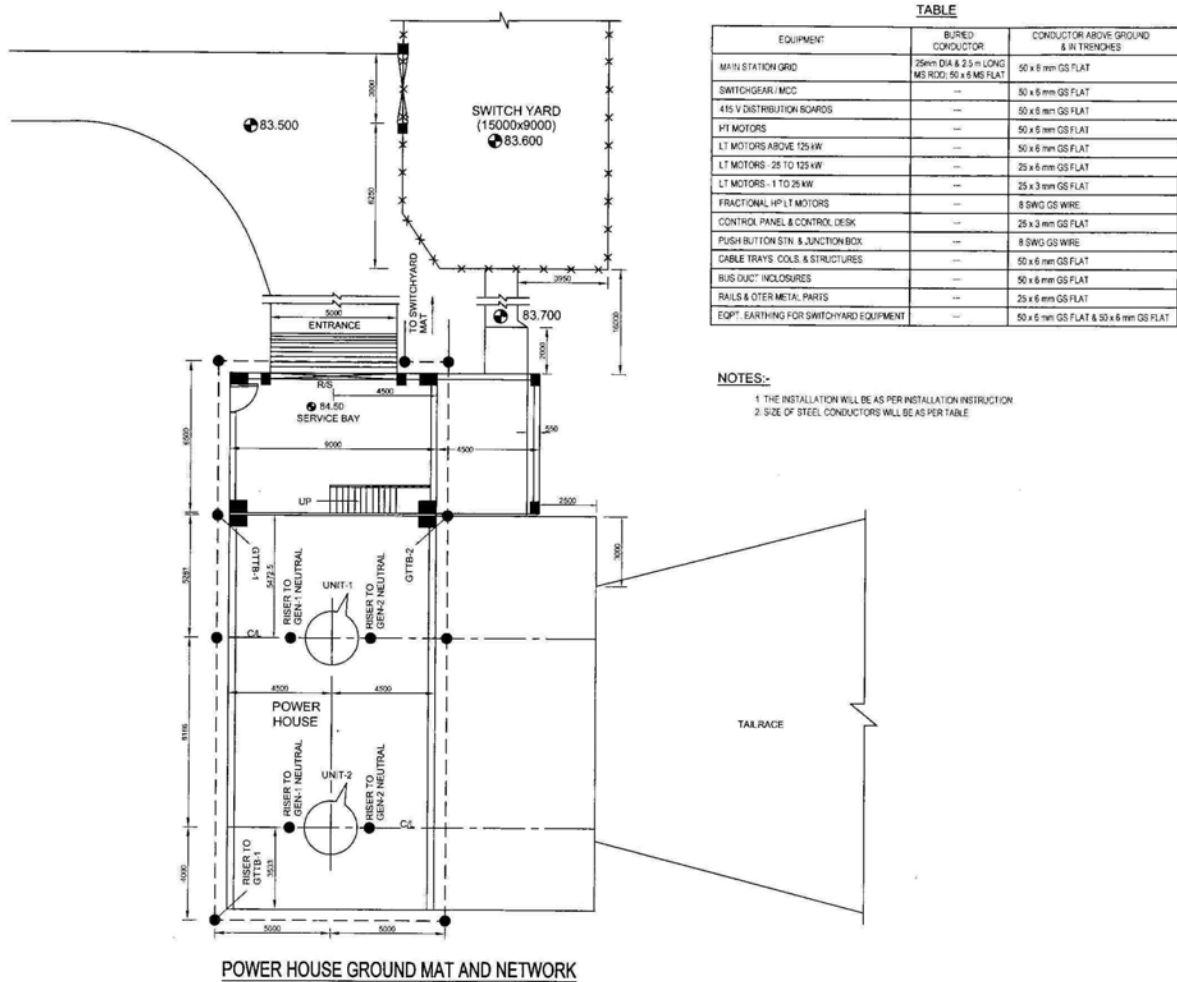


Figure 4.23: Belsar Power Plant Earthmat (AHEC Project)

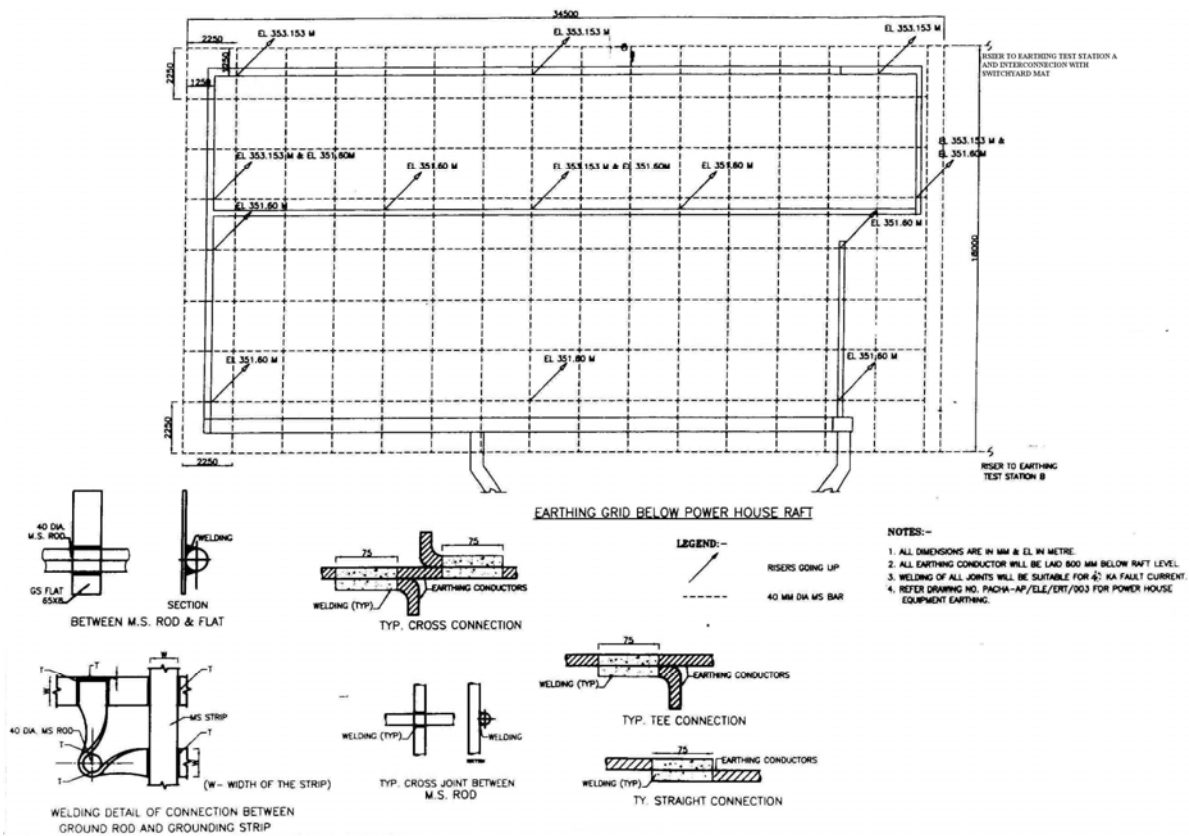


Figure 4.24(a): 2 x 1.5 MW PACHA PROJECT (Layout for Powerhouse Earth mat) (AHEC Project)

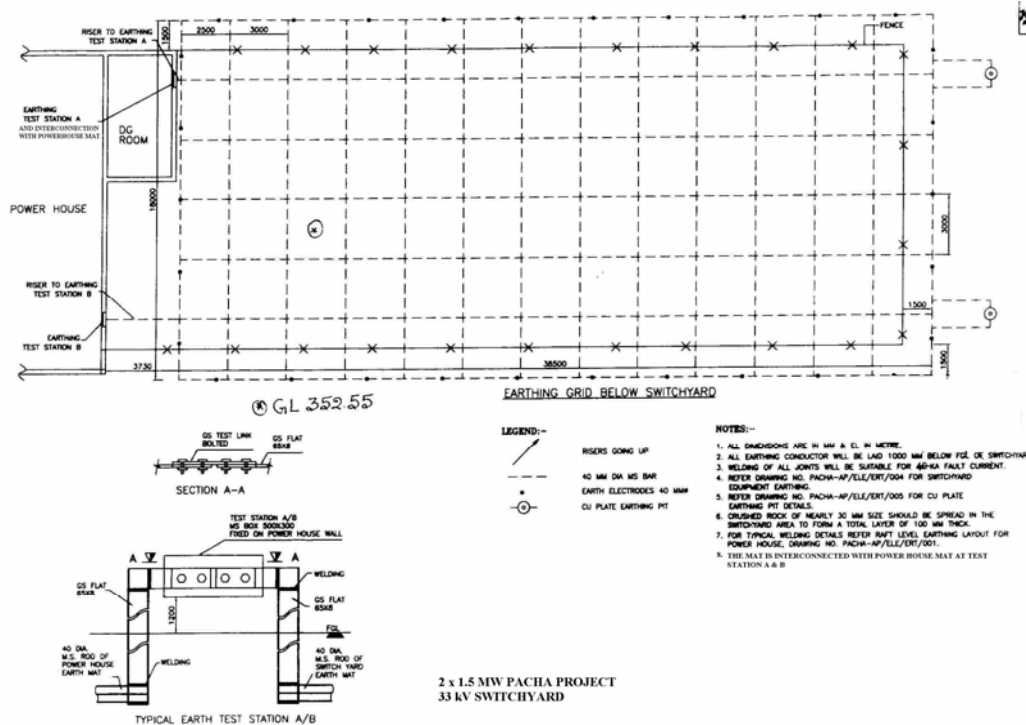


Figure 4.24 (b): 2 x 1.5 MW PACHA PROJECT (33 kV Switchyard) Earthmat (As Designed)

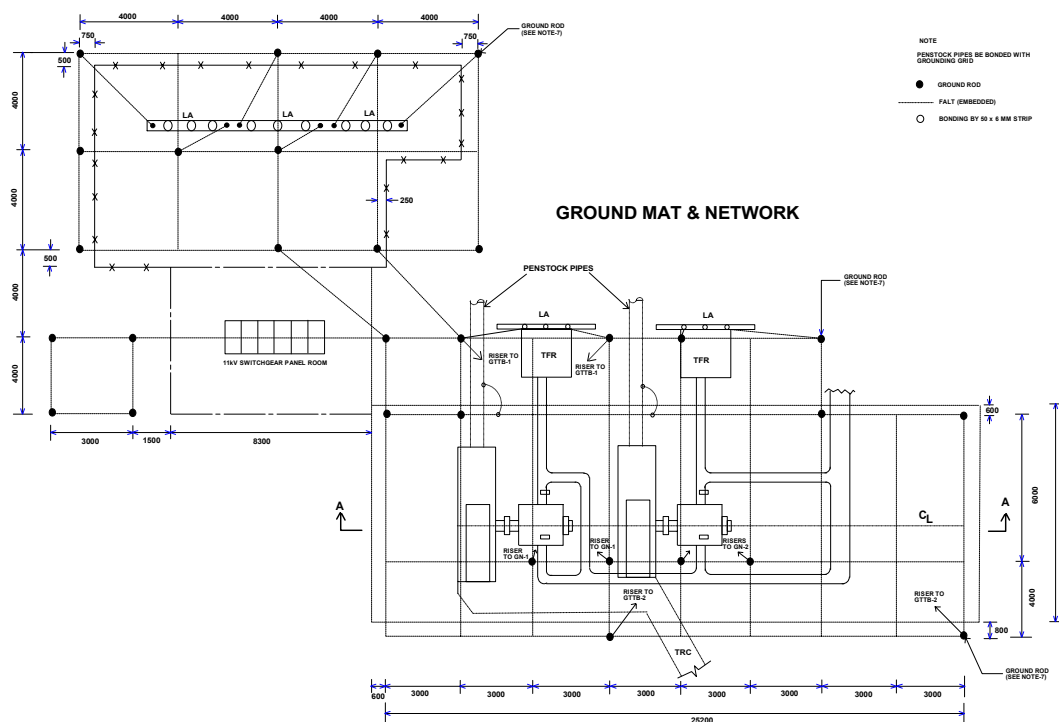


Figure 4.25: Jumgad Power Plant Earthmat (As Designed)

4.7.10 Grounding System SHP Above 5 MW or Interconnected with grid at 66 kV and above

Detailed design on the basis of earth fault current and soil resistivity measurements should be done. A ground mat should be laid under the powerhouse; sub-station and tailrace. The three mats should be interconnected.

Typical Examples

4.7.10.1 Mukerian SHP (2 x 9 MW): Single line to ground fault current for Mukerian Stage 3 (interconnected with grid at 66 kV shown in Figure 4.26) as calculated is as follows:

Single line to ground fault current = 31.5 kA (specified)
Grid current for earth mat design = 18.9 kA (calculated)

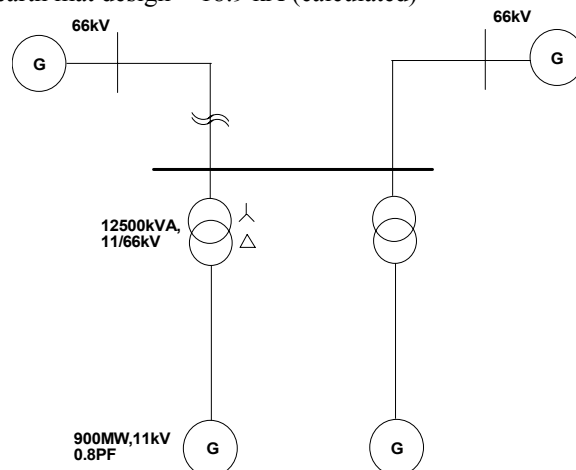
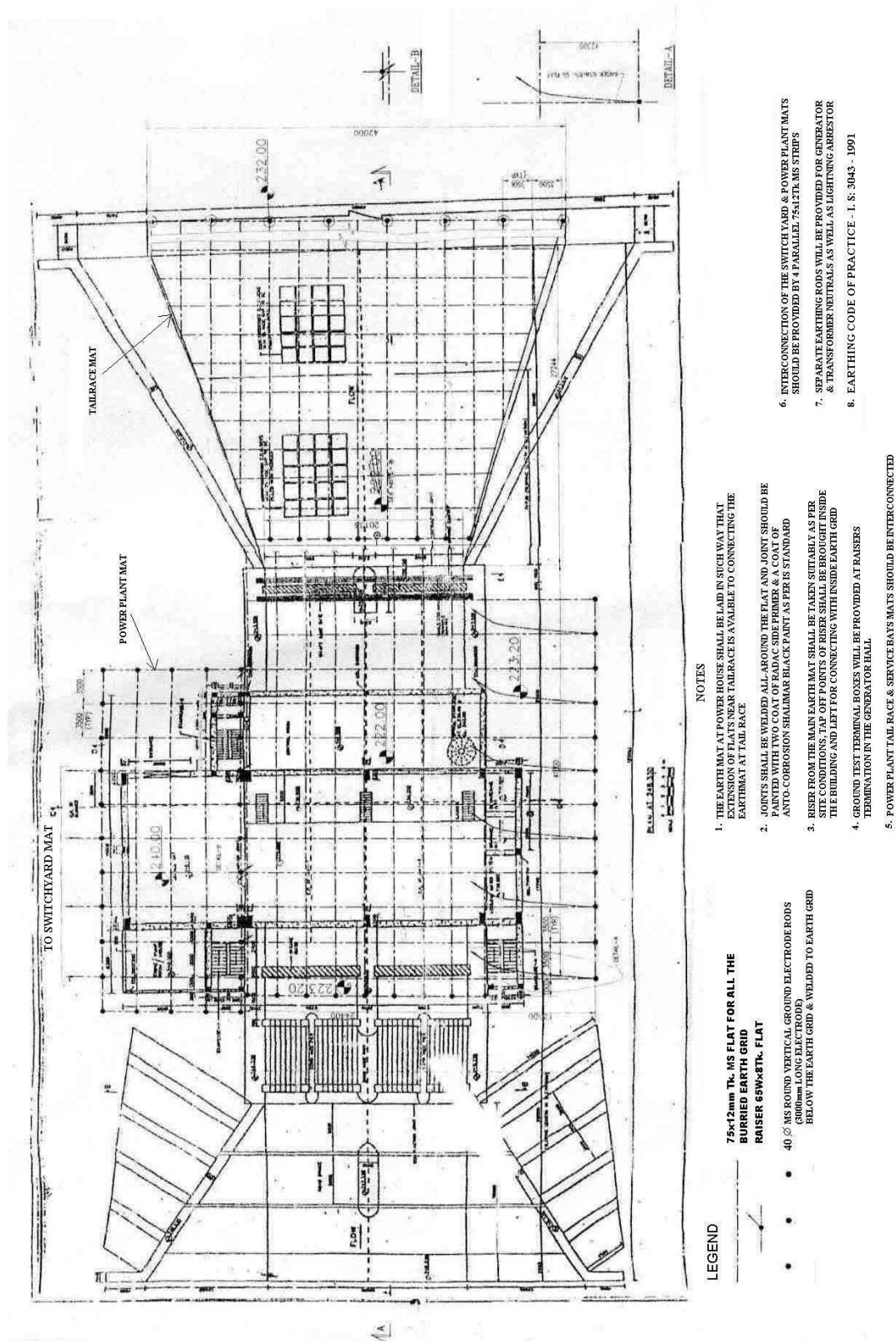


Figure 4.26: Mukerian Stage 3

Earthmat for the project is shown at Figure 4.27.



**Figure 4.27: EARTHMAT FOR 2 x 9 MW INTERCONNECTED WITH LARGE GRID (GRID CURRENT 18kA)
(AHEC Preproject)**

4.7.11 Earthing Electronic Equipment

Control and protection is being increasingly provided by digital/analogue electronics in hydro studies. Protective earthing for personnel safety and functional earthing for proper functioning of equipment against over voltages and noise interface is required. This may be provided as per CBI & P Pub. 302 and as per recommendations of supplier. Typical protective and functional earthing recommended in this publication for low operating frequencies (say below 30 kHz) by single point earthing is shown in Figure 4.28. The digital control equipment earthing proposed for a recent power unit is shown in Figure 4.29.

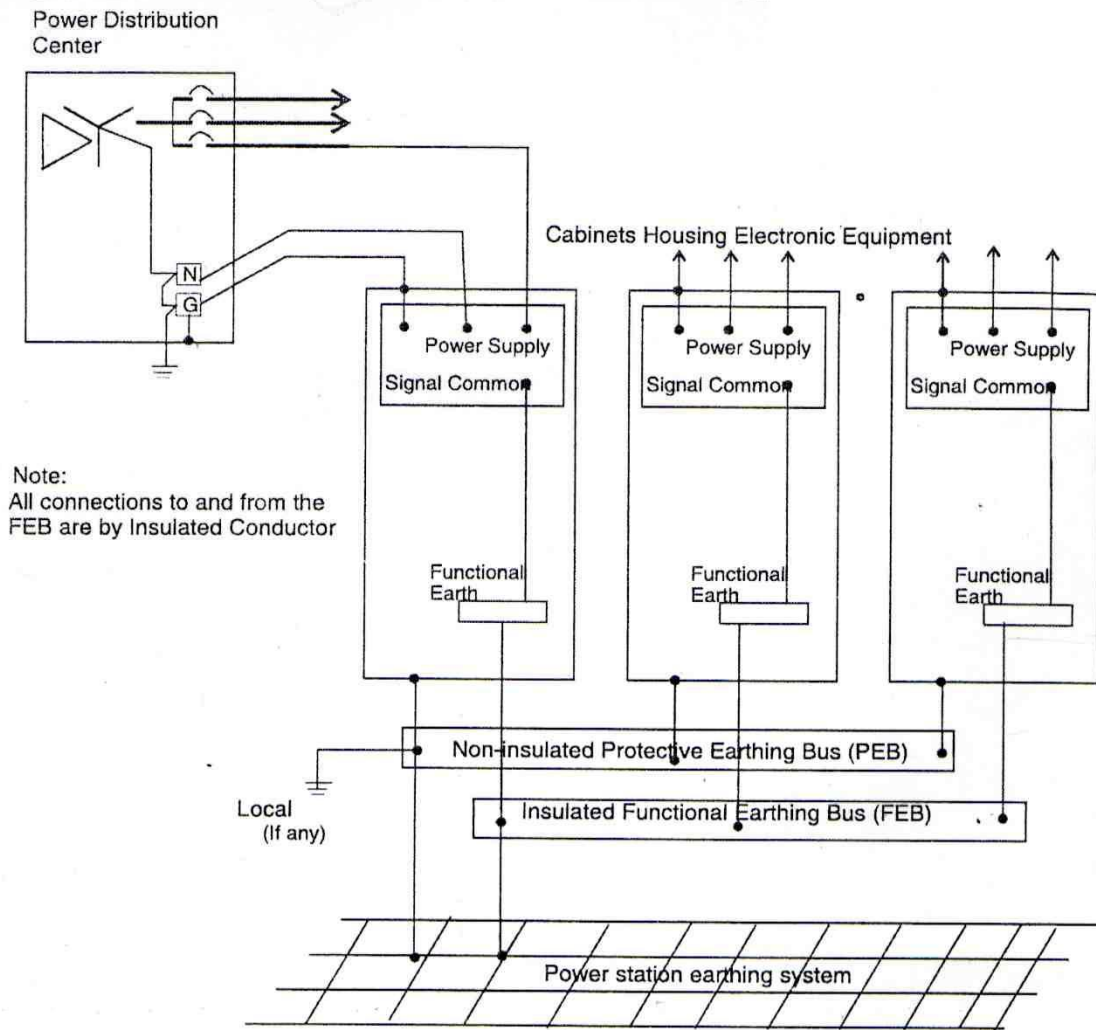


Figure 4.28: Electronic Equipment Single Point Earthing System with Cabinets in Close Proximity (CBI & P manual)

4.7.12 Installation

Detailed instruction for a installation of the Grounding system are enclosed at Annexure-4.7.12.1.

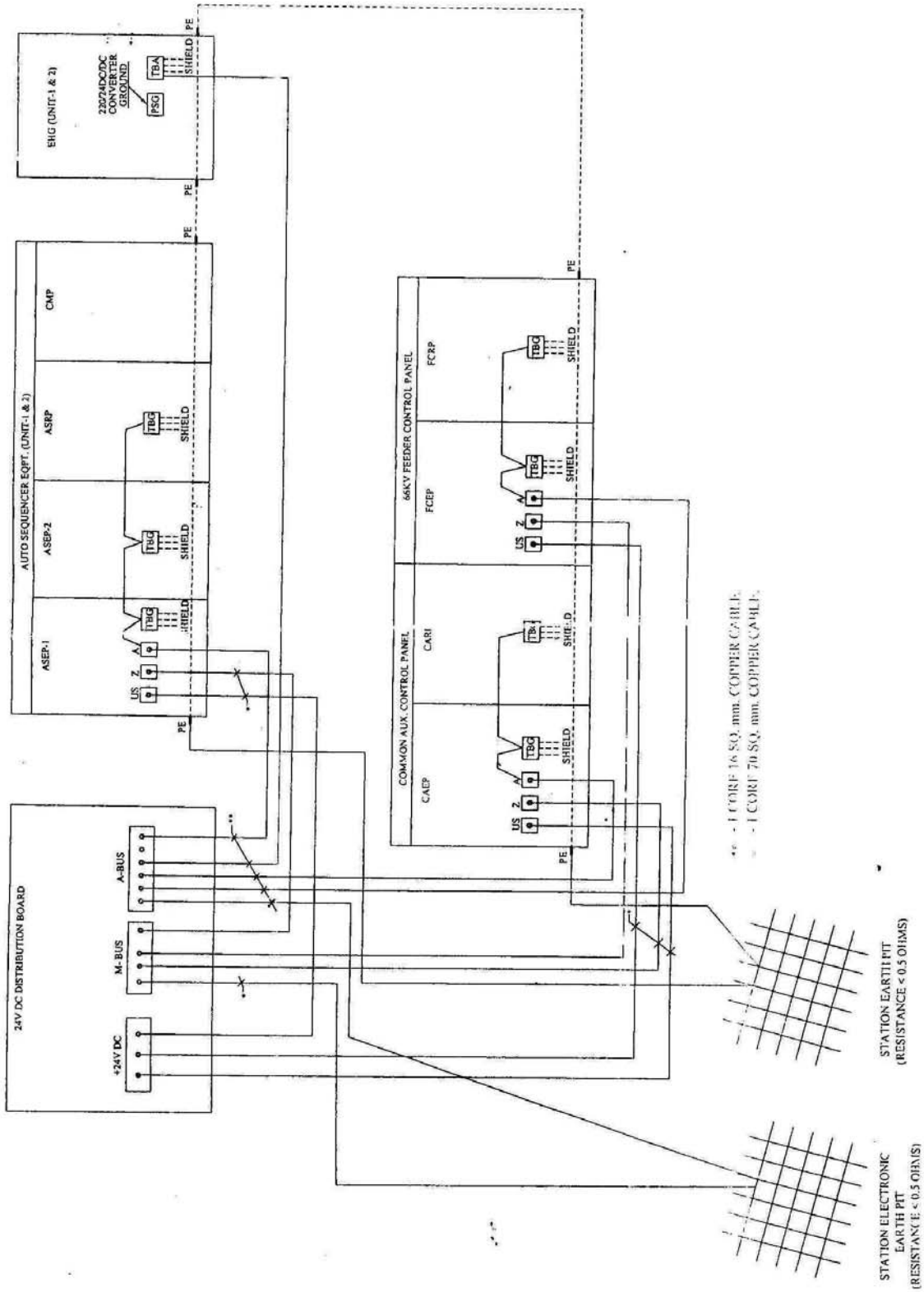


Figure 4.29: Earthing of Computerized Electronic Equipment for a Large Hydro Station

4.7.13 Typical Technical Specifications for Grounding System

Earthing system for each power house shall be designed as per IS: 3043 and IEEE: 80. Earthing system network/earthmat shall be interconnected mesh of mild steel flat and rods buried in ground in the plant. All off-site areas shall be interconnected together by minimum two parallel conductors. The contractor shall furnish the detailed design and calculations for Purchaser's approval. Contractor shall obtain all necessary statutory approvals for the system.

Soil resistivity data for the Project will be obtained by actual measurements at three sites. Installation of grounding system shall be as per Annexure – 4.7.2.

Enclosures of all electrical equipment as well as all cabinets/boxes/panels/etc. shall be earthed by two separate and distinct earth connections. Metallic pipes, conduits, cable tray section, etc. shall be bonded to ensure electrical continuity and earthed at regular intervals as well as at both ends. Metallic conduits, pipes, etc. shall not be used as earth continuity conductor. All hinged doors shall be earthed by flexible braids of adequate size.

All steel structures shall be duly earthed. Metallic sheaths and armour of all multicore cables shall also be earthed at both equipment and switchgear end.

Earthing conductor shall be buried at least 2000 mm outside the fence of electrical installations. Every alternate post of the fences and all gates shall be connected to earthing grid by one lead. Earthing conductor embedded in the concrete floor shall have at least 50 mm concrete cover.

Earthing connections with equipment earthing pads shall be bolted type with at least two bolts, and joint surfaces shall be galvanised. The connections shall be painted with anti-corrosive paint after testing and checking. Neutral of power transformers shall be directly connected to two rod electrodes in treated earth pits, which in turn shall be connected to station earthing grid.

The earthing terminal of surge arresters and voltage transformers, and lightning protection down conductors shall also be connected to station earthing grid through separate rod electrode.

Design Criteria

a.	Standard/Code	IEE-80, IS: 2309
b.	Earthing system life expectancy	40 years
c.	System fault level	20-40 kA for one second
d.	Soil resistivity	Contractor to measure at site at min. 6 locations approved by Owner as per Annex. 4.7.1.
e.	Min. steel corrosion rate	0.25 mm per year (depends on soil).
f.	Depth of burial of main earth	150 mm below grade level; where it crosses conductor trenches, pipes, ducts tunnels, rail tracks, etc., it shall be at least 300 mm below them.
g.	Conductor joints	By electric arc welding, with resistance of joint not less than that of the conductor. Welds to be treated with red lead for rust protection and then coated with bitumen compound for corrosion protection.

The minimum conductor size for earthing system shall be as per table 4.11.

SOIL RESISTIVITY MEASUREMENTS

1. Soil Resistivity Measurements

- 1.1 Period of Tests:** Estimates based on soil classification permits only a crude approximation of the resistivity. Therefore for obtaining an accurate data on the soil resistivity, field tests at the site are very essential. Further in order to know the effects of temperature and moisture content, the tests may be performed in the hottest month of June before rains; then sometime in the month of September and again in the coldest months of December/January.
- 1.2 Test Locations:** The area at the station site should be covered adequately by conducting resistivity measurements at several positions as shown in Figure 4.30; and with different probe spacings to get an indication of any important variations of resistivity with location or depth.

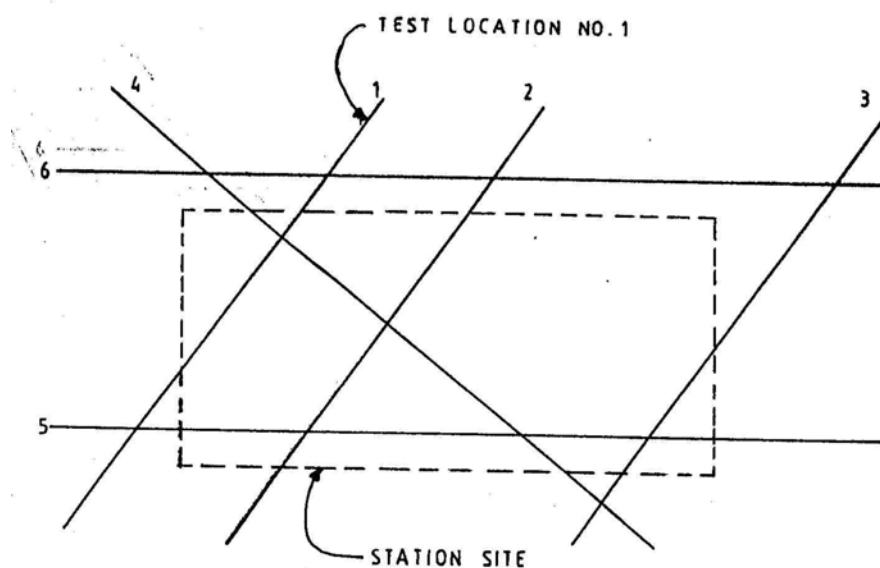


Figure 4.30 Resistivity Test Locations

- 1.3 Extent of Probe - Spacings:** It can be shown that the portion of the earth, which has an influence on the station ground resistance, extend down to a depth roughly equal to the station equivalent radius "r" (the radius of a circle, having the same area as the station grounding net-work). This means that to establish the nature of the soil at a given site for grounding design; the resistivity tests should be performed, as far as practicable, with probe spacings up to the station equivalent radius.
- 1.4 Formulae for equal probe spacing:** Resistivity measurements should be done by the conventional 4-probe method described by Dr. F. Wenner of the U.S. Bureau of Standards. This consists of driving two current probes and two intermediate potential probes into the earth at equal distance apart and in a straight line, to a depth, as shown in Figure 4.31. An earth tester circulates a current I between the outer two probes. Due to this current, a potential difference is established between the two potential electrodes equal to $I \times R$ where R is the resistance of the earth between the potential electrodes. The ratio IR/I i.e., the resistance of the portion of the earth between two inner electrodes is indicated directly on the earth tester. Using this value of the resistance, the resistivity of the soil is found out from the equation.

$$\rho = \frac{4\pi SR}{1 + \frac{1+2S}{\sqrt{S^2 + 4Z^2}} - \frac{2S}{\sqrt{4S^2 + 4Z^2}}} \quad (1)$$

Where,

ρ = resistivity of soil in ohm-meters.

R = resistance measured on the instrument in ohms.

S = Probe spacing in meters.

Z = depth to which probes are driven, in meters.

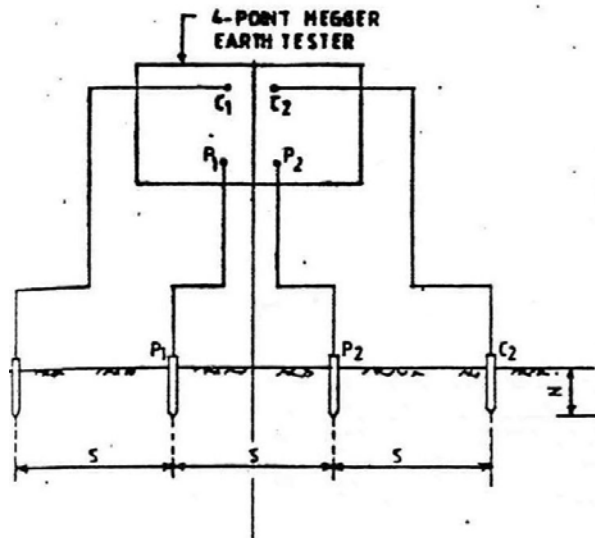


Figure 4.31 Measuring Earth Resistivity with Equal Probe Spacings

- (ii) When Z is less than $1/15^{\text{th}}$ of the probe spacing; the foregoing equation can be further simplified to

$$\rho = 2\pi SR$$

(2)

- (iii) For very large probe spacings equal to station radius “ R ”, which might easily be several hundred feet, 4-electrode method with equal probe spacings of that order is hardly practicable. Further, One short-coming of this method has been the rapid decrease in magnitude of potential between the two inner probes, when probe spacing is increased to relatively large values. This has often resulted in inadequate sensitivity and inability to obtain low resistivity readings at wide probe spacings because of the range of limitations of test instruments.

1.5 Formulae for unequal probe spacings

- (i) A method of expanding the range of measurement and thus improving sensitivity is by increasing the potential probe spacing as described by L.S. Palmer and A.L. Kinyon. The spacing is increased equally in each direction, keeping each potential probe a like distance from its adjacent, current probe as shown in Figure 4.32 and the resistivity is calculated from the formulae.

$$\rho = \pi R \frac{S^2 + S}{Q} \quad (3)$$

Where,

ρ = the measured resistivity of soil in ohm-meter

S = distance from C_1 to P_1 and C_2 to P_2 in meters

Q = distance from P₁ to P₂ in meters
R = instrument reading in ohms

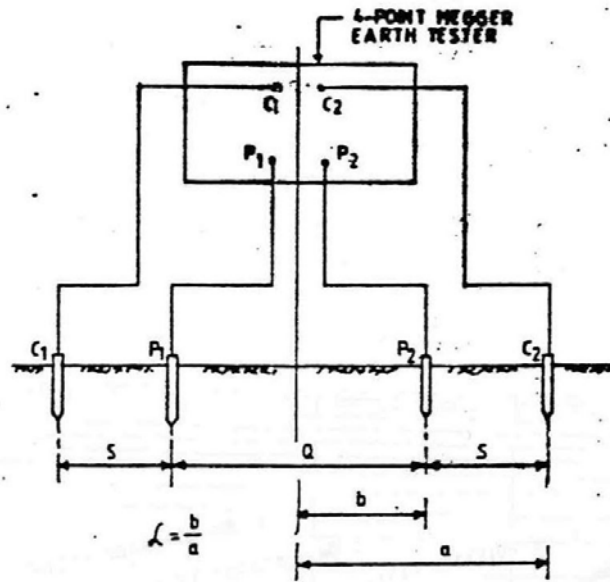


Figure 4.32 Measuring Earth Resistivity with Unequal Probe Spacing

(ii) The above equation can also be written in the following form.

$$\rho = \frac{1 - \alpha^2}{2\alpha} \cdot aR \quad (4)$$

Where,

α = ratio of distance between potential electrodes to that between current electrodes

A = one-half distance between current probes

1.6 Testing Kit

A soil resistivity testing “Kit” should consist of

- i) 4-terminal Megger Earth Tester range 0-2; 10;100;1000;10000 ohms 1 No.
- ii) Electrodes, about one meter long 10 Nos.

Note : The electrodes should have cross-bars welded near the top of the rod of facilitation their extraction from the ground.

- iii) Leads, P.M.C./ insulated; 2.5 mm² (1/1.80 Al.)
 - 150 meters reel 1 No.
 - 75 meters reel 2 Nos.
- iv) Short instrument leads.
- v) Sledge hammer, 5 to 8 lbs. 2 Nos.
- vi) Measuring tape 100 ft... 1 No.
- vii) Tools-pliers, wrenches, clips etc.

Note: For test connections; test procedure and correction factors if any; reference should always be made to the instruction booklet supplied with the instrument.

1.7 Earth Resistivity Curves

For a homogeneous soil, the value of resistivity thus obtained will be independent of the probe spacing. In actual fact, the ground is never homogeneous. There may be wide horizontal changes and significant vertical variations in the soil structure. However, as the lateral changes in the composition of soil are usually small and gradual, compared with vertical ones; the soil resistivity is normally considered as a function of depth only.

Further in a 4-probe method, the penetration of current and hence the resistance is roughly limited to a depth corresponding to the probe spacing. Thus more frequently than not, the resistivity as measured by the 4-probe method will vary with probe spacing. This variation usually indicates, a soil resistivity, which varies with depth. A plot of the measured resistivity should therefore be drawn against the probe spacing known as “Earth Resistivity Curve”. At a particular site, a number of such curves are drawn for different locations as shown in Figure 4.33 and an average curve is evolved. This average resistivity curve is then analysed.

Resistivity measurement records should include temperature data and information as to the dry; or moist condition of the soil at the time the resistivity is measured. Metallic objects (like rails, pipes, wires etc.) buried, or in contact with the soil can invalidate readings made by the method described above, if they are close enough to alter the test current flow pattern appreciably. All data available on buried conductors known or suspected to be in the area studied should therefore be recorded and tests should be done at such locations twice, with probes in two mutually perpendicular directions.

1.8 Uniform (Homogeneous) Soil

If the variation in the resistivity is less than 30%; the soil in the vicinity of test location can be considered homogeneous and an average value determined from the resistivity curve is adopted for design purposes. If the variation is more than 30%, the soil cannot be treated as uniform and the analysis of the curve is needed.

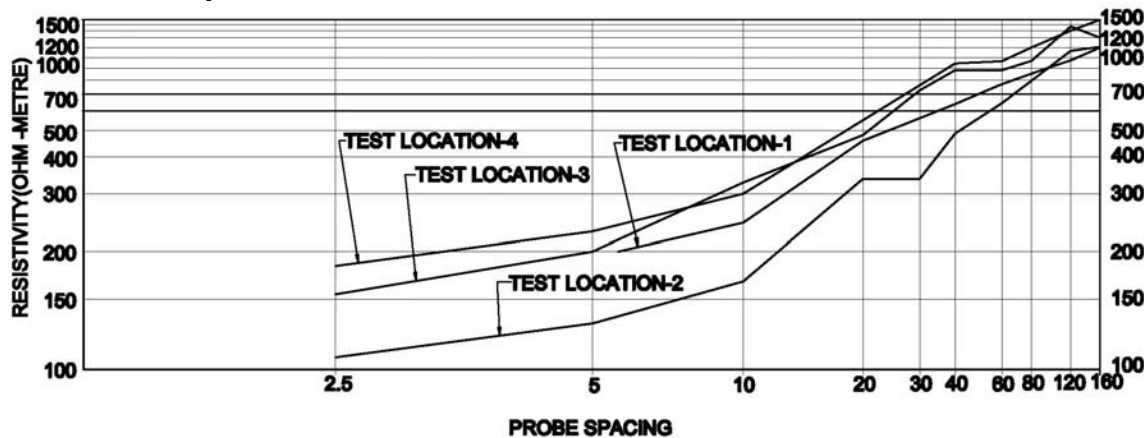


Figure 4.33 Resistivity test Curves for the Month of June

1.9 Non-Uniform Soil

In the non-uniform soil, where the soil resistivity varies markedly with probe spacing, a designer would like to know the value of apparent soil resistivity “ ρ_a ” that he should adopt for the design purposes; so that the calculated resistance of the grounding system approximately equals the measured resistance after the installation of the grounding system. This may be done in accordance with C.B.I.P. (Central Board of Irrigation Power) manual No. 302-2007.

Conductor for earthing mat and network steel flats with proper allowance for corrosion is used. – Standard sizes of conductor for earth mats as per IS 1730-1989 as follows:

- | | | | |
|------|-------------------------|------|------------------------|
| i) | 10 x 6 mm ² | ii) | 20 x 6 mm ² |
| iii) | 30 x 6 mm ² | iv) | 40 x 6 mm ² |
| v) | 50 x 6 mm ² | vi) | 60 x 6 mm ² |
| vii) | 50 x 8 mm ² | vii) | 65 x 8 mm ² |
| ix) | 75 x 12 mm ² | | |

INSTALLATION OF GROUNDING SYSTEM

General:

- i. Grounding conductors consist of mild steel strips for ground net-work and mild steel rounds for ground rods.
- ii. Grounding strips used for end connections to the equipment are galvanised.
- iii. Connectors like bolts, nuts, etc. used for grounding the equipment are galvanised.
- iv. Grounding is in accordance with Indian Electricity Rules

Ground Mats and Ground Test Terminal Boxes

- i. All grounding strips in the ground mats are laid in position as per typical methods shown in Figure 4.34, unless otherwise stated. When the grounding strips have been laid in trench, it shall be covered with excavated base material mixed with clay if possible and filled up to half the depth of the trench. The remaining half of the trench shall be filled with lean concrete so that the strip remains securely in position. A thick coat of bitumen may be applied over it if necessary so that it does not bond with the concrete which may be placed over it.

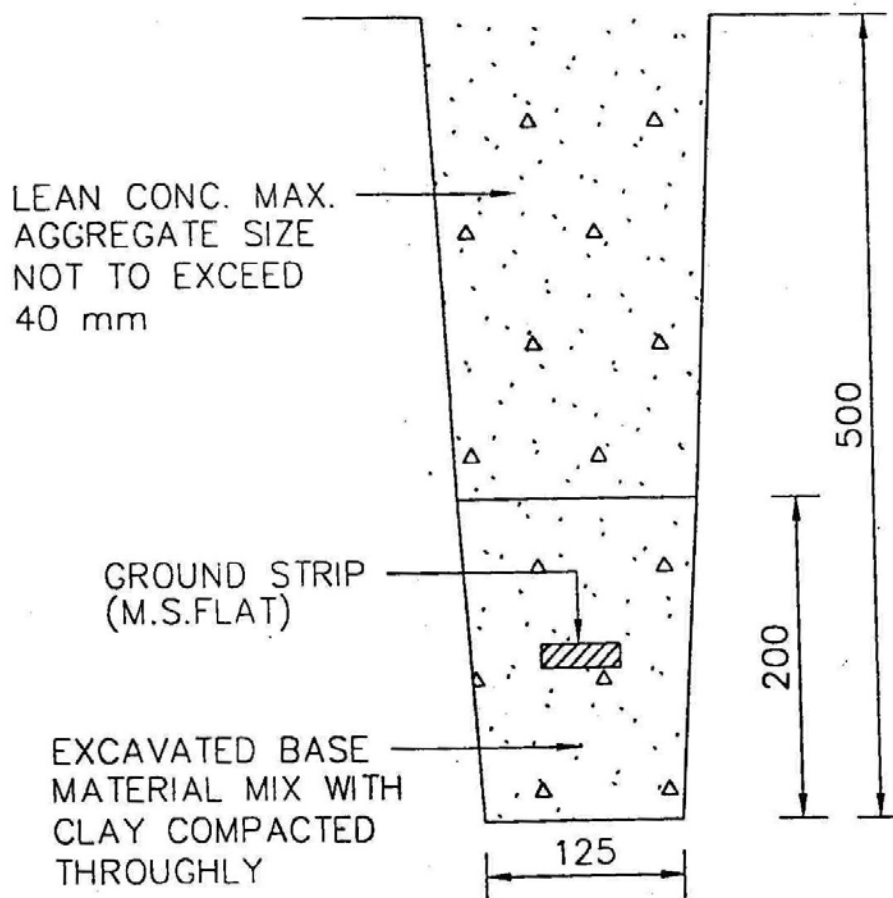


Figure 4.34– Installation of Ground Strip of Ground Mat

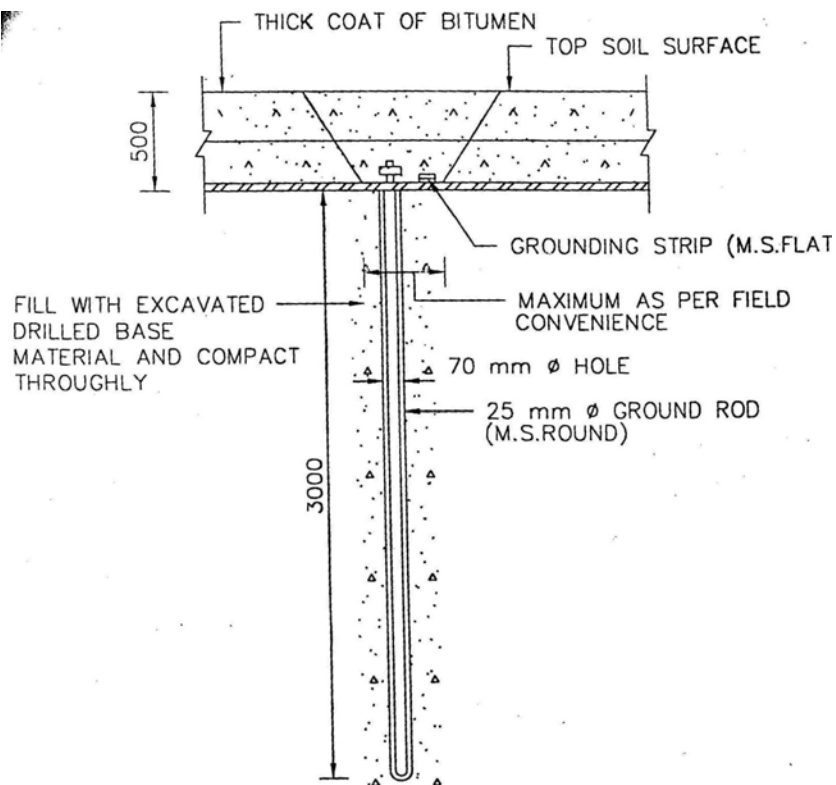


Figure 4.35 – Installation of ground Rod

- ii. The ground rod are fixed in position first by drilling a vertical hole of about 70 mm dia into the ground, then placing the rod centrally inside. Drilled base material mixed with clay, if available, are then poured into the hole all around little by little and compacted at short intervals by ramming with a suitable dia hollow C.I. pipe having a socket at the lower end. In locations where there is clay or soft soil, the ground rods can be driven in the ground by an augur (Figure 4.35).
- iii. In the installation of grounding strip the field authorities are in a better position than the designer to judge whether the mat is adequately anchored. They should feel free to add additional anchors but should never use less than those indicated on the drawings.
- iv. For rust protection, welded joints in the soil are thoroughly brushed, provided with a coat of shalimastic H.D. paint and wrapped with asphalt saturated cotton fabric tape/hessian cloth impregnated with shalimastic H.D. Paint followed by another coat of shalimastic H.D. paint. Alternatively welded joints may be protected by grouting concrete of not less than 40 mm thickness.

Ground Test Terminal Boxes (GTTB)

Ground test terminal box typical details and installation is shown in Figure 4.36 & Figure 4.37.

Grounding Net-Works

- i. Typical connection between ground rod and grounding strips is shown in Figure 4.38.
- ii. Installation of grounding strips are carried out in accordance with the grounding system network drawings, but field may deviate to clear possible obstructions keeping in view the technical requirements.
- iii. The route of embedded grounding strips between two connected points are by the shortest distance.

- iv. Main grounding strips inside the power plant building are laid surface embedded on the walls as per Figure 4.39 so that these can be tapped easily later on for connection to the individual equipment, which may or may not have been covered in the net work drawings.

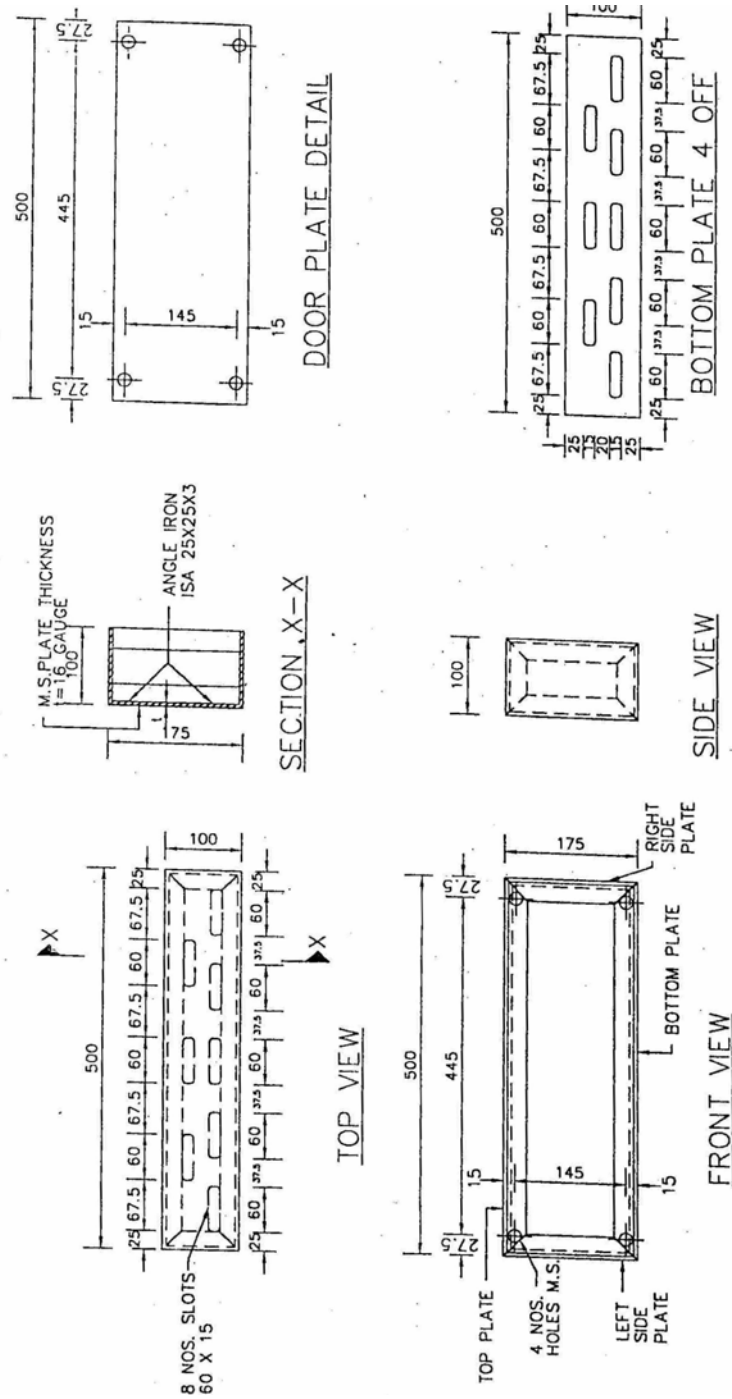
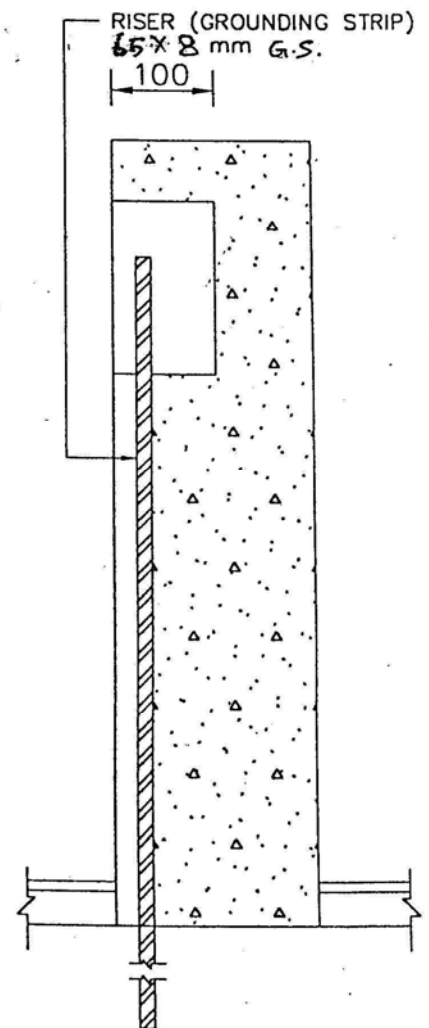
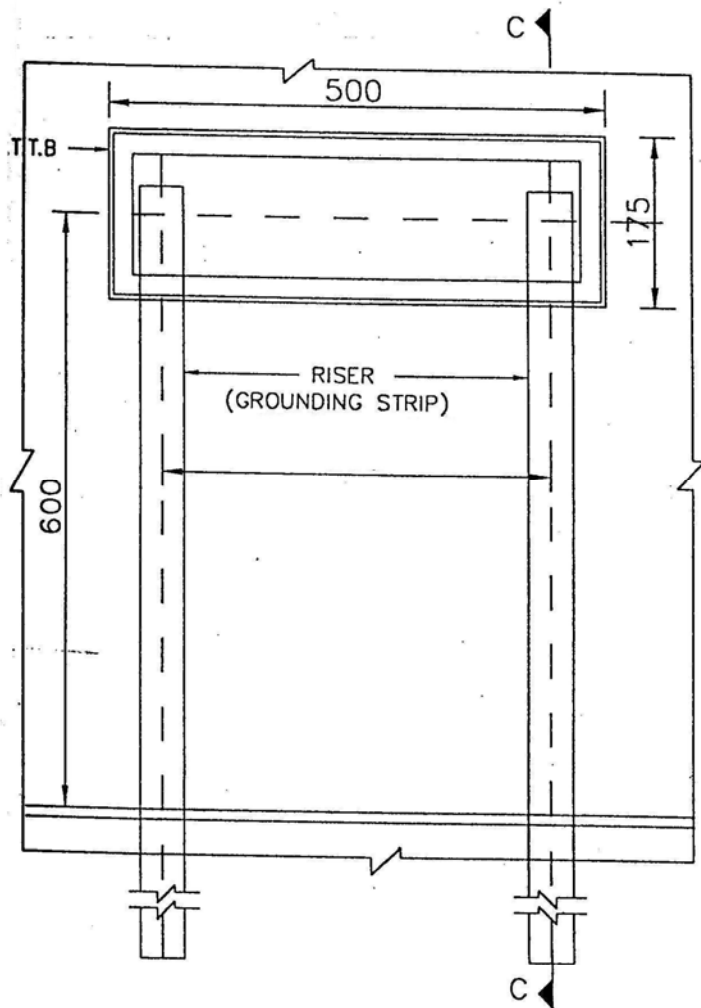
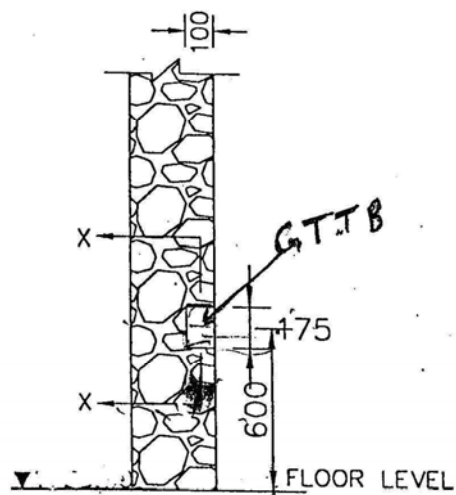


Figure 4.36 – Details of GTTB



SECTION C-C

FIG-1
 (SCALE 1:5)



DETAIL-A

(SCALE 1:20)

Figure 4.37

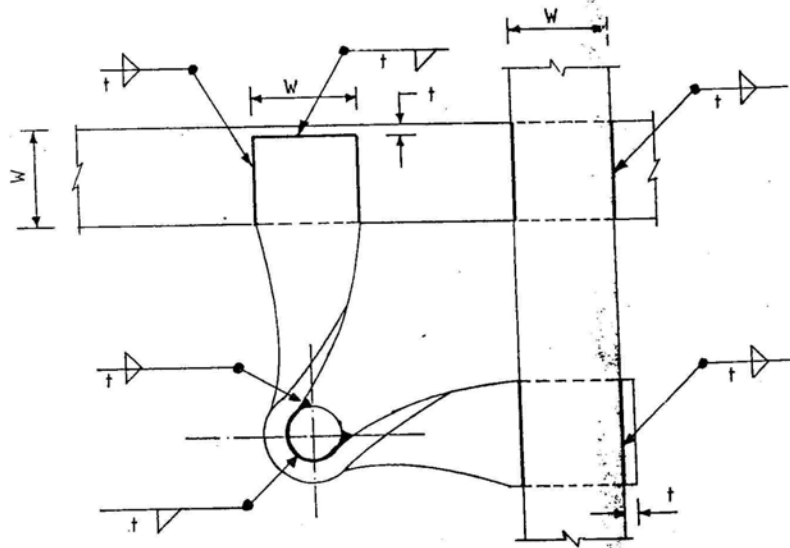


Figure 4.38 – Welding Detail of Connection Between Ground Rod and Grounding Strips (typical)

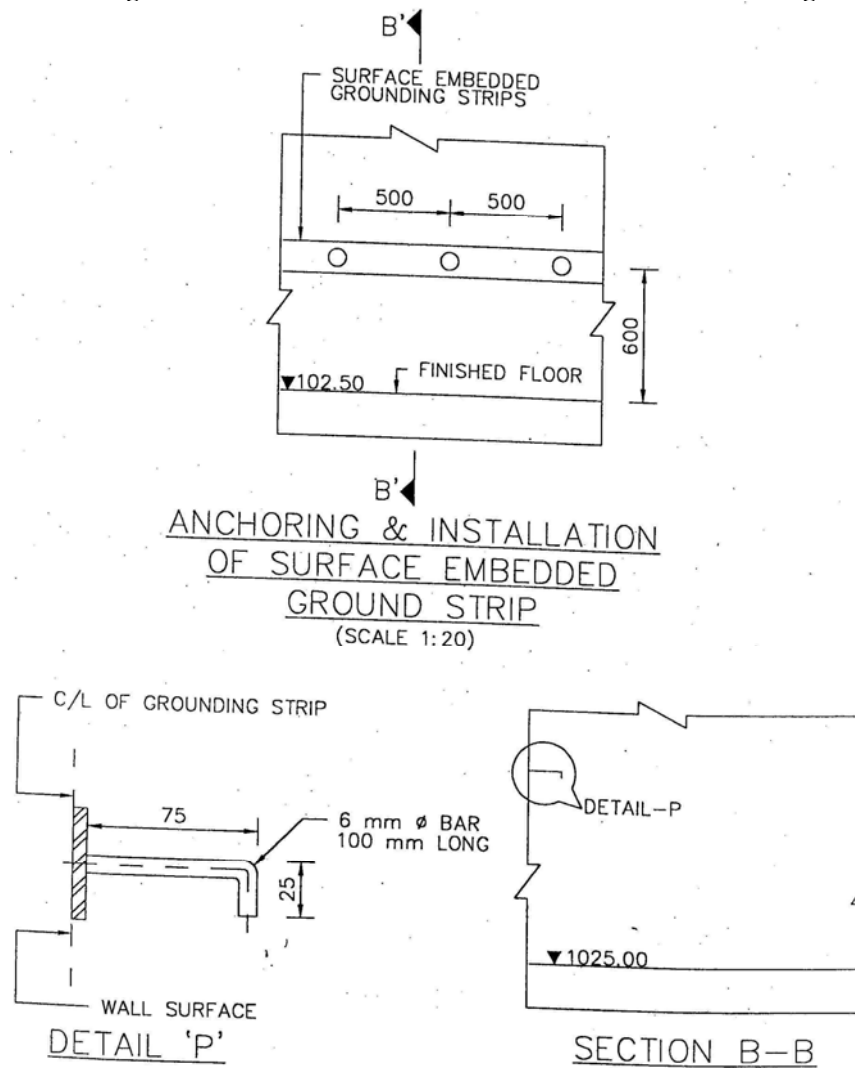


Figure4.39

- v. Embedded equipment such as frames for lighting distribution boards, power outlets, misc. recess etc., are grounded by electrical welding the grounding strip to such equipment. For all other equipment, which is to be installed at a later stage, grounding strip stub of at least 300 mm length is provided near such equipment for grounding. For equipment fixed on the wall, stubbing is from the wall and not from the floor or the tapping for this purpose is taken from the surface embedded grounding strip on the walls by an exposed grounding strip. It means that any tapping for grounding purpose is taken only from grounding ring laid surface embedded on the walls.
- vi. Cable racks on the walls and in cable trenches is welded directly to the grounding strips provided for the purpose. Cable racks installed on the floor and fixed under the ceiling are grounded at two points. (preferably entrance ends) and the different sections of the racks is bonded separately by a grounding .. to ground the entire cable rack effectively.

Jointing Of Grounding Strips

1. All joints between grounding strips and between grounding strips and ground rods are by electrical welding. At the time of welding, the jointing surface is cleaned by sand blasting or by other convenient means. The joint is clamped tightly to ensure that a good surface contact exists. For straight joints between ground strips an overlapping not less than twice the width of plate is made for welding typical angle joints and t-joints as shown in Figure-4.40 and Figure-4.39 respectively. Typical welded connection between ground rod and ground strip is shown in Figure-4.41. Typical details of welded joints are shown in FigureFigure 4.41 to Figure 4.45.

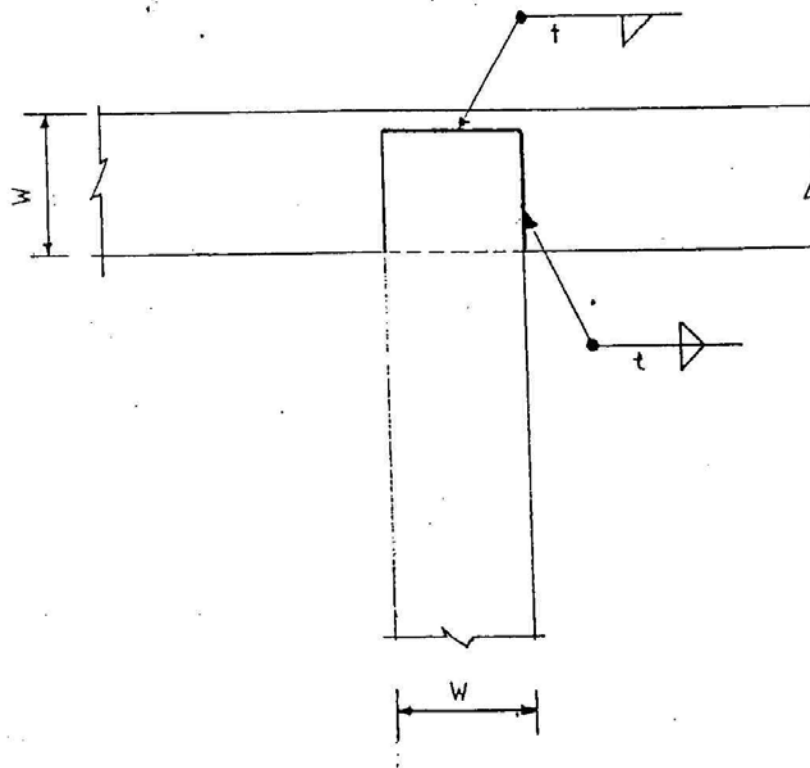


Figure 4.40 - Welding Detail of Tee Joint (Typical)

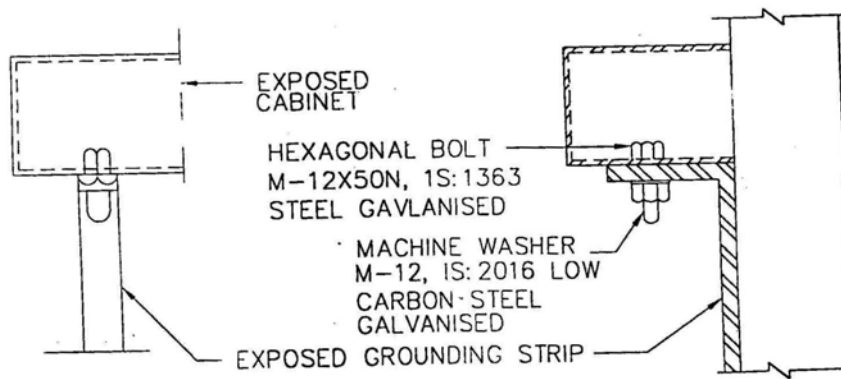


Figure 4.41 - Welding Connection to Exposed Cabinet

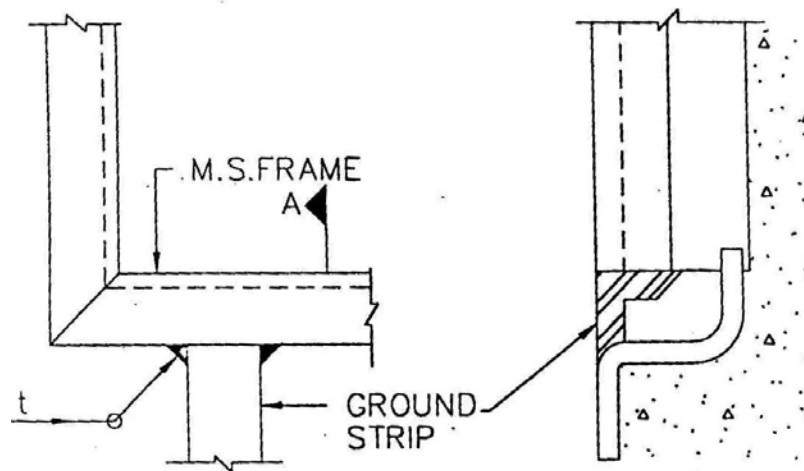


Figure 4.42 – Welded Connection to Recess Frame

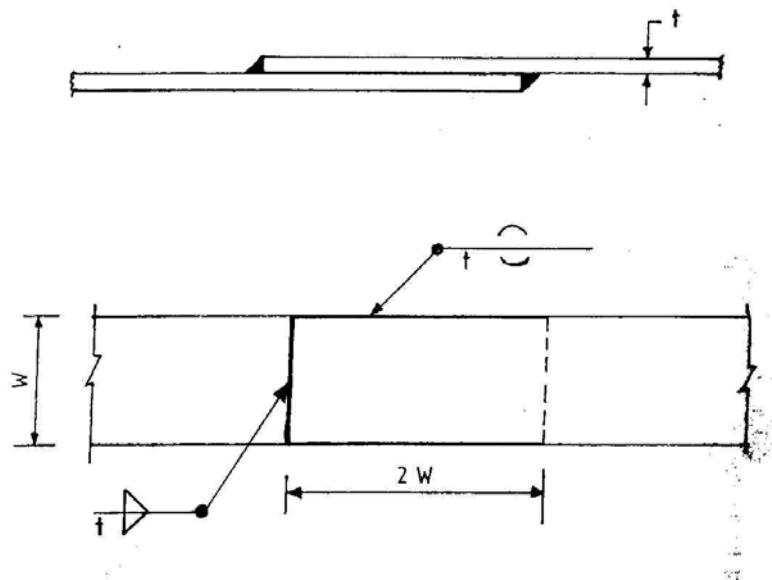


Figure 4.43 - Welding Detail of Straight Joint (Typical)

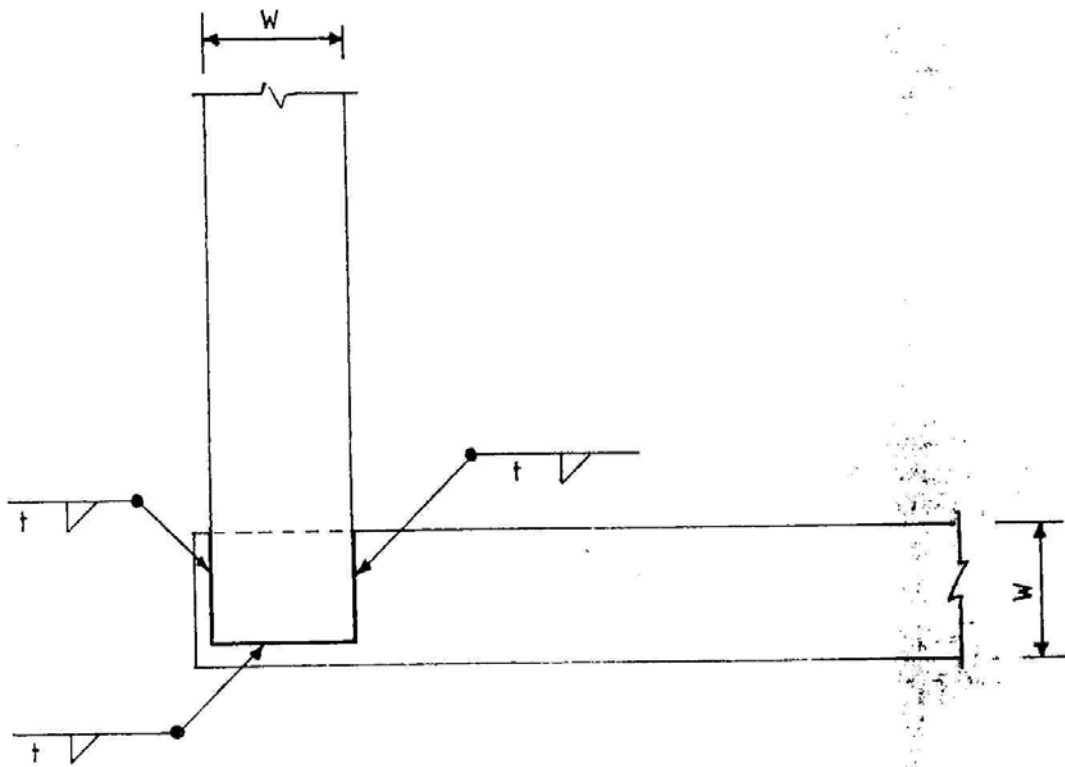


Figure 4.44 - Welding Detail of Angle Joint (Typical)

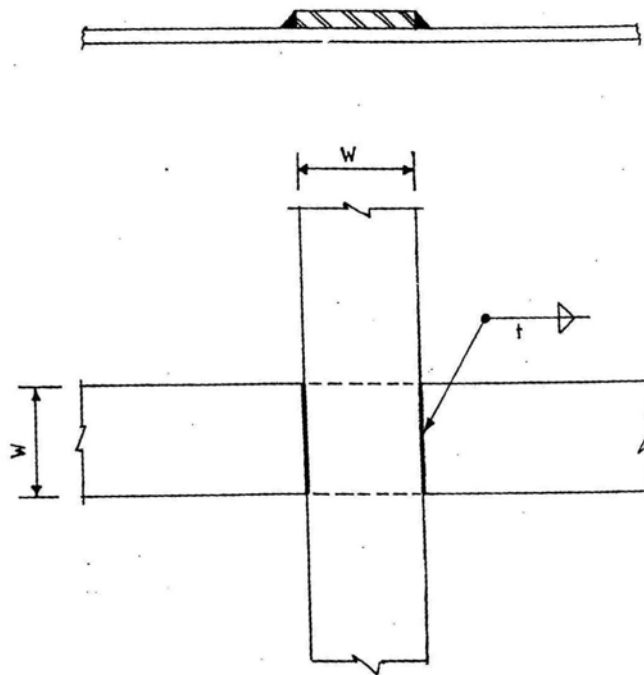


Figure 4.45 - Welding Detail of Cross Joint (Typical)

Connections to Equipment

Exposed surface of all electrical equipment must be grounded and non-electrical items like hand-rails, hatch cover frames. Cable rack support etc., should be grounding. In reinforced concrete structure most structural elements such as windows, frames, grills and louvers need not be grounded. Economy does not permit grounding of metal parts.

The frame of every generator, motor, circuit breaker and the metallic parts (not intended as conductors) of all transformers, and regulating or control apparatus connected with the supply are grounded by two separate and distinct connections.

The metal conduits, armour and/or sheath of a cable may be used as ground conductor and should be earthed at one point only (preferably at the source end) in the following cases: -

- a. Conduit, armour and/or lead sheath of single phase cable.
- b. In long runs, insulating sleeves are occasionally installed in the lead sheath, thus breaking up long sections and reducing sheath potentials. Each section of the lead sheath is grounded. Grounding the same lead sheath of a single phase cable at both ends intentionally or accidentally may over heat the cable and are avoided.

Three phase cables should have the lead sheaths grounded at both ends in all cases.

Metallic junction or pull boxes not containing protective equipment, and in which conduits are installed with a socket and metallic bush are not considered a break, when the voltage is below 240 volts to ground, but is so considered for higher voltages.

All junction and pull boxes in the runs of non-metallic conduits as well as these containing overload protective devices are individually grounded.

All paint, enamel, and scale is removed from the point of contact on metal surfaces before making ground connections.

In switchyard any items of equipment not covered by grounding system layout drawings and which are so located that there is some chance of a high-tension conductor flashing to or coming in contact with them must also be grounded with individual connections.

Where some arrangement for grounding is already provided on the equipment by manufacturers, that arrangement should be used for grounding if suitable for the size of grounding strips specified in the net-work drawing concerned. The mode of connection may not be the same as shown in typical equipment connections.

The bases of lightning arrestors are directly connected to the grounding test terminal box (G.T.T.B.) of system by grounding strips as short and straight as practicable to ensure minimum impedance.

For lightning arrestors mounted near the transformers, grounding strips are located clear of the cable and coolers in order to avoid possible leakage caused by arcing.

4.47. Typical grounding strips connections to various equipments are shown in Figure 4.46 and Figure

Main grounding strips ring inside the power plant building are laid surface embedded on the wall as shown in fig-6. So that these can be tapped easily later on for connection to individual equipments, which may or may not have been covered in the network drawing.

The frame of every generator, motor, control panels and the metallic parts of all transformer connected with the supply is grounded by two separate and distinct connections.

Any tapping for grounding purpose is taken only from grounding ring surface embedded on the walls.

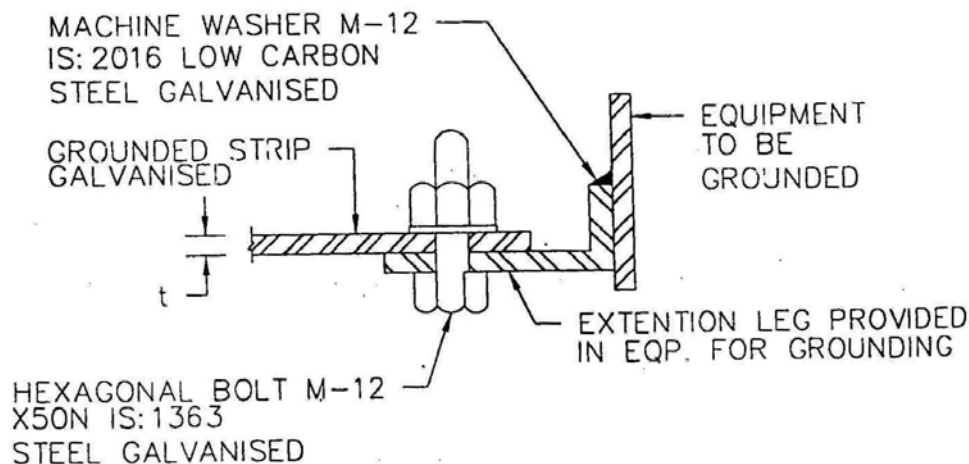


Figure 4.46 – Bolted Connection to Extension Leg

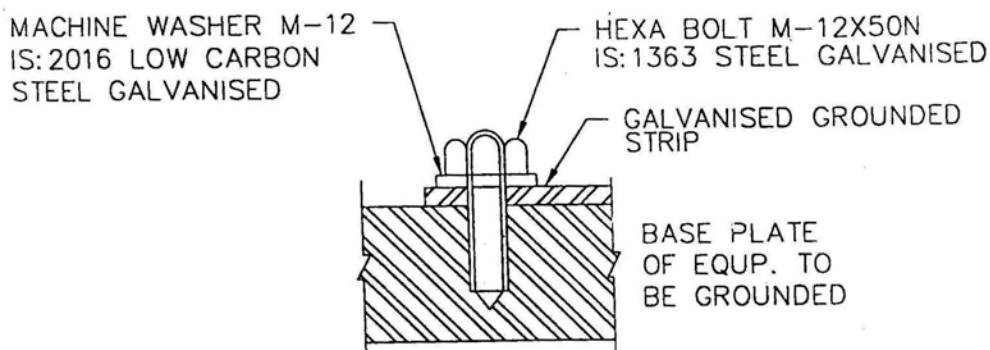


Figure 4.47 – Bolted Connection to Base Plate

Precautions

- i. Grounding strips should never be run through a steel conduit or through an opening in the floor or walls of magnetic material. It may be run in either fibre conduit or conduit of non-magnetic material.
- ii. Grounding strips should never be laid close to or parallel to generator single-phase main-leads or single core power leads and the distance or separation should not be less than 300 mm. This will be shown on the drawings concerned.
- iii. Current transformer secondary circuit should never be grounded at more than one point.

Ground Mat Resistance

After the grounding system is laid, actual measurement are taken and remedial measures if any required are devised by the field to bring down the resultant grounding resistance within safe limits.

4.8 COMMUNICATION SYSTEM

4.8.1 General

Reliable communication system is important for operation of every hydro power plant. Voice communication telephone system is provided in most hydro plants. Code call system for paging key personnel is provided in large/mega power stations. Dedicated communication system are required for SCADA system, telemetry, line protection relaying for interconnecting transmission lines.

Regulatory Requirements: Government Regulatory requirements are required to be met and sanctions for external communication system is required which is normally obtained by equipment supply contractor with the assistance of the purchaser.

4.8.2 Voice Communication System

Internal Telephone System: Normally internal telephone system is provided by an electronic exchange in powerhouses 3 MW and above. The distribution frame and switching equipment is installed in a location near the control room. So that it can be included in the air conditioned zone of the control room for the telephone equipment.

Telephone Locations: The telephone outlets are located at various vulnerable positions to facilitate the communication. Standard PVC cables are laid for these outlets. Some of the important locations for outlets are as follows.

- i) Control room
- ii) Switchgear room
- iii) Turbine pit
- iv) Machine hall
- v) Unloading/erection bay
- vi) Cable spreading room
- vii) Drainage/dewatering motor starter panel
- viii) Switchyard
- ix) Compressor room near switchyard.
- x) Fore Bay
- xi) Bye pass gates control room
- xii) Pump house
- xiii) Security gates
- xiv) Offices

4.8.3 Dedicated Communication System

Communication media for dedicated Communication Systems for telemetering, SCADA system, transmission lines, protective relays and communication to load dispatch centres and grid interconnected substations for power evacuation may be as follows.

- i) Power line carrier communication
- ii) Fibre optic cable
- iii) Microwave communication system
- iv) Radio communication system

4.8.3.1 Power line carrier communication

High frequency signal transmission along over head power lines has been mostly used in India for voice communication as well for pilot signal for transmission line protection because of following.

- i) for longer line lengths capital and running costs are lower;
- ii) transmission path is fully controlled by the operating authority;
- iii) the signaling channel is not affected by faults in electrically independent circuits;
- iv) the transmission medium is robust and therefore reliable.

A basic Power Line Carrier (PLC) system consists of three parts.

- a) The terminal assemblies, consisting of the transmitters, receivers, and associated components.
- b) The coupling and tuning equipment, which provides a means of connecting the PLCs terminals to the high voltage transmission lines.
- c) The high voltage transmission line, which provides the path for transmission of the carrier energy. High voltage coupling capacitors are used to couple the carrier energy to the transmission line, and simultaneously block 50 Hz power from the carrier equipment.

Most transmitter/receiver equipment is installed in cabinets located near the control room. Carrier frequency energy is conducted out of the plant by co-axial cable to the high voltage transmission line tuning and coupling equipment. PLC equipment power requirements are supplied from 48 V DC batteries.

Power line communication systems (PLC) are extensively used for relaying control and voice communication in India. PLC bandwidth is limited because of its operating frequencies and the transmission medium. Its transmission path is susceptible to noise from arcing faults, interruption by ground faults and other accidents to the line, and weather. It may therefore be advantageous to use other reliable communication means if available at reasonable cost.

Signal injection on the power line and extraction from it are achieved through high voltage capacitors used in conjunction with drainage coil, in order to provide isolation of the equipment from high voltage line. It is a practice to provide coupling capacitors and capacitor dividers with intermediate voltage terminal for an electromagnetic unit of coupling voltage transformers. The capacitor is rated at feeder voltage and is designed to pass through the carrier frequency for communication and provide low voltage for protection and metering. The coupling capacitors should comply with the provisions of IS 9348 – 1998. A high frequency barrier line trap is installed on the station side of the injection (or receiving) side of the transmission line to prevent dissipation of signal throughout the system. Figure 4.48 shows typical general arrangement of the terminal equipment when power line carrier facilities are used in the protection scheme. The protection relays are energized from voltage and/or current transformers depending on the type of the protection schemes.

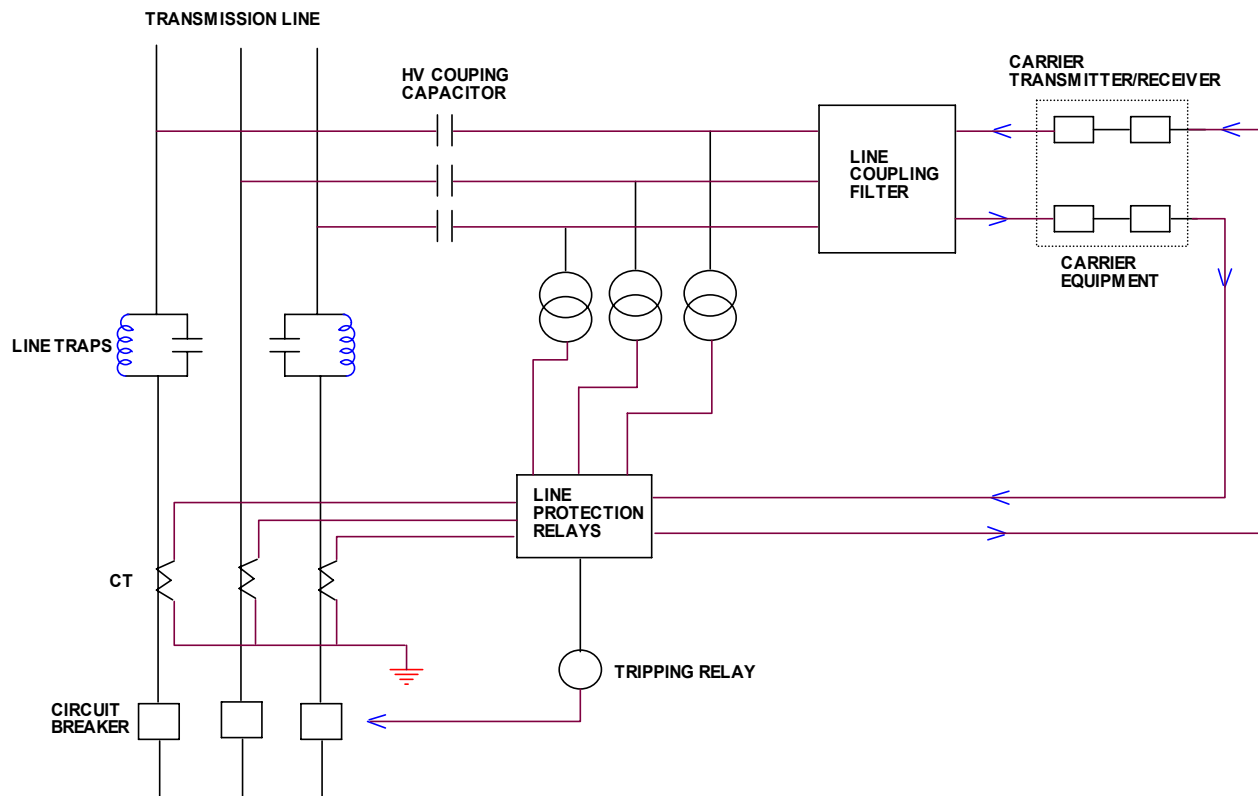


Figure 4.48: Line Protection Relay Scheme Using Power Line Carrier

4.8.3.2 Fibre optic cable

Traditional pilot wire using metallic pair has been used for short overhead lines and cables. The protection is based on current differential principle use metallic pilot wire. This is not generally used in India as the pilot security is exposed to external faults. Optical fibre using fibre interface system has been used in place of the metallic pair. Fibre optic cable system is not affected by ground potential and cost is reducing. Multiplexing allows optic fibre cable for other control, data acquisition and voice communication purposes and may be used in future as communication link for transmission line protection in addition to transmission line protection.

Fibre optic cable system consists of a terminal with multiplexing equipment, and a transmitter and receiver coupled to fibre-optic light conductors that are routed to the other terminal, which also has a receiver, transmitter, and multiplexing equipment. Because the transmission medium is nonmetallic, it offers the advantage of electrical isolation between terminals and immunity from electromagnetic interference.

Because of the frequency of the transmitting medium, (light) the fibre-optic system offers a bandwidth that can carry a great deal of data at very high speeds. The glass fibres are small and delicate, so are enclosed in a protecting sheath. For communication systems external to the plant, right-of-way acquisition may be a problem since the fibre optic cable requires routing. Fibre optic cable was proposed for supervisory control of Mukerian two Power project from a Mukerian 1 power project. The fibre optic cable was proposed to be laid along the canal bank.

It is possible to obtain high-voltage transmission line cable with fibre with fibre optic light conductors incorporated in its construction. Fibre optic light conductor can be under built on the transmission line to the plant. For long transmission distances, the fibre optic system requires repeaters.

The most important application for fibre optic technology is for a Local Area Network (LAN) within the plant and is being specified for most digital SCADA system.

4.8.3.3 Microwave communication system

A microwave pilot is used for relaying only when the relaying equipment can share the channel with enough other services; it is not economically justifiable for relaying alone if carrier current or wire pilot is applicable.

Microwave is suitable although it is not as reliable as carrier current for protective relaying purpose; this is partly because of the complex circuitry and the large number of tubes involved, and also because of the large number of services on the same microwave channel. When repeater stations are necessary, the complexity practically doubles with further loss of reliability. It may be realized that the requirements of protective relaying as to reliability are in certain respects more severe than the requirements of other services that use the microwave channel. Any lapse in the signal when a fault occurs is unacceptable.

Microwave has certain theoretical advantages because it is dissociated from the power line, but its only real advantages are in connection with remote tripping. Occasionally, microwave is useful where the attenuation would be too high for carrier current, such as on a power cable circuit, but even there microwave would probably not be selected unless there were many other uses in addition to protective relaying.

The same relaying equipments that are used with a carrier current pilot are also used with a microwave pilot. Therefore, the application considerations are the same so far as the relaying equipment is concerned.

4.8.3.4 Radio Communication System

Wireless radio communication system comprises wireless transceivers system at both places i.e. at the sending end power house and receiving end substation with repeaters as required (depending upon geographical constraints). This system is also not generally provided for hydro power station feeder protection and communication because of the problem of separator station security and foul weather disturbance.

4.8.4 Typical specifications

4.8.4.1 Communication Link

i) Scope

Design, supply, delivery, Site, erection, communication and training of personnel for communication links between the power house and off-site control station and communication between power house and grid substation (interlinking points) for voice communication.

ii) Code Standards

- ANSI/IEEE 1010 – 1987
- US Army of Engineers Engineering Manual
- Relevant National / International Standards

The contractor shall furnish detailed design and calculation for approval by purchaser.

iii) Regulatory Requirement

Govt. regulatory requirement and sanctions for the communication system shall be obtained by Contractor. Necessary assistance will be provided by Purchaser.

4.8.4.2 Dedicated Communication by Fiber Optic System Cable

Dedicated communication system for SCADA, voice communication and code call paging system from power house to offsite control at Power House shall be by Fiber optic cable. Code call facility shall be provided for paging key personnel.

4.8.4.3 Fiber optic cable

A fiber-optic cable system consisting of a terminal with multiplexing equipment, and a transmitter and receiver coupled to fiber-optic light conductors that are routed to the other terminal, which also has a receiver, transmitter, and multiplexing equipment shall be provided. Because the transmission medium is nonmetallic, it offers the advantage of electrical isolation between terminals and immunity from electromagnetic interference.

The Fiber optic cable may be laid (say along the canal bank) where no right of way problem is anticipated.

4.8.4.4 Repeaters

Repeaters if needed should be provided. Necessary equipment at sending and receiving and for Interfacing remote supervisory controller at offsite control Power House with SCADA. Centralized SCADA system to remote supervisory control in the control room should be provided by the dedicated Fiber optic cable. The design should conform to latest relevant standard.

4.8.4.5 Local area network (LAN)

Local area network inside the Power House for distributed control should also be connected by Fiber optic cable.

4.8.4.6 PLCC System

Two sets of PLCC system, line matching units and protective device are normally installed for communication and control with offsite control station and interlinking grid substation for voice communication. Coupling voltage transformer and Wave trap are covered in switchyard equipment.`12

The equipment to be supplied should have got the facility of transmission of speech and data simultaneously. Data transmission speed should be 9600 bps. To design the PLCC systems following line parameters are to be taken for a single circuit 66 kV line (may be worked out for other voltage i.e. 132, 245 & 420 kV etc.).

- | | | | |
|----|--|---|---|
| a) | Conductor | - | ACSR with a cross sectional area as 200 mm ² |
| b) | Line impedances | | |
| | i) L | = | 1.243 mh/km per phase |
| | ii) Inductive Reactive | = | 0.3905 ohm/km per phase |
| | iii) A.C. Resistance | = | 0.140 ohm/km at 20° C |
| c) | Transmission Voltage | | 66 kV |
| d) | Range of transmission | | 7 km |
| e) | Distance between switchyard and control room | | 20 meters |

- f) Input voltage to the system 48 V DC

Above parameters have been worked-out taking for configuration of a 66 kV line as right angled with Base = 3-5 m and perpendicular as 2.1 m. These parameters may also be verified by supplier of equipment.

PLCC is to be interfaced with supervisory controller with serial/parallel interfaces. Interconnection of outdoor equipment with PLCC should be done via shielded coaxial cable.

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