ANGLO AMERICAN	**CODE OF PRACTICE FOR EARTHING AND LIGHTNING PROTECTION IN COAL MINES**
AAC SPECIFICATION	

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1 SCOPE

This Code of Practice serves as a guideline for the installation and maintenance of earthing systems.

2 TECHNICAL REQUIREMENTS

Earthing installations shall comply with following recommended Practices and Specifications:

- IEEE 142-1972 - Recommended practice for grounding on industrial and commercial power system
- SABS 03-1985 - The protection of structures against lightning
- SABS 0199-1985 - The design and installation of earth electrode
- SABS 03A-1969 - The protection of dwelling houses against lightning

3 MINE HEALTH AND SAFETY ACT

All earthing systems shall comply with the latest revisions of the Mine Health and Safety Act.

4 DEFINITIONS

- Medium Voltage : System nominal voltage exceeding 1 000 volts but not exceeding 44 000 volts
- Low Voltage : System nominal voltage not exceeding 1 000 volts
- Solidly Earthed : Provision of a low impedance current path to the mass of the earth
- Grounding : Provision of low impedance interconnections and reference plane between objects
- Bonding : The connecting interface between an object and conductor or between conductors
- Unearthed : A system without an intentional connection to ground except through measuring device or other very high impedance device
- Effectively Earthed : A system earthed through an earth connection of sufficiently low impedance to ensure that earth faults that may occur cannot build up voltages in excess of limits established for the system

5 OBJECTIVES OF EARTHING

- The objective of "Earthing" is to ensure that at every part of the power distribution system an adequate earth connection point exists. Any conductor to this point is then prevented from attaining a voltage level dangerous to persons. Metal enclosures of switchgear and transformers are permanently earthed, and whenever work is to be carried out on e.g. busbars, they are temporarily earthed. Any earth connection must be capable of carrying the maximum current which will flow in it under any foreseeable conditions without sustaining damage.
- Although the earthing system is connected to the ground, earth fault current cannot just flow into the ground and disappear. It is necessary to provide a current path whereby such currents can return to the power supply system. In effect the earthing provides the required path, and the path is "Locked" to ground potential by connecting it at various points to the ground.
- If the earth fault current return path contains any significant resistance (e.g. a poor earth bond) at any point, then a potentially dangerous voltage could appear at that point under earth fault conditions. In addition, the current flowing could be greatly reduced. Since these currents are monitored and used to provide back-up tripping, a reduction in current could result in the back-up protection failing to "See" the fault. It is therefore essential that the integrity of all earthing system conductors and bonds is maintained at all times.

6 MEDIUM VOLTAGE DISTRIBUTION SYSTEMS ON SURFACE INSTALLATIONS

- The Mines or Works receives power from Eskom a supply configuration of 3 phase 3 wire 22 000 volts, 11 000 volts, 6 600 volts or 3 300 volts. The power supply normally originates from delta connected transformer without an earth conductor. To satisfy the objectives of this recommended practice the following items are necessary:
  - A reliable low impedance connection of less than 5 ohms to the general mass of earth.
  - A reliable earth fault current return path to the 3 wire system.
- A reliable electrical connection to the general mass of earth is achieved by an underground earth mat and / or electrode system.
- An earth fault current return path is provided by connecting a Neutral Earthing Compensator (NEC) between the 3 phases of the power system and earth system. This is done at the source of the supply.

  The NEC transformer winding has a "Zig-Zag" configuration with no secondary winding. The impedance of the winding is high when there is no fault on the system resulting in only a small magnetising current in the transformer windings. The "Zig-Zag" winding configuration results in a low impedance when an earth fault condition occurs. By inserting resistance the earth fault currents can be limited to any desired value.

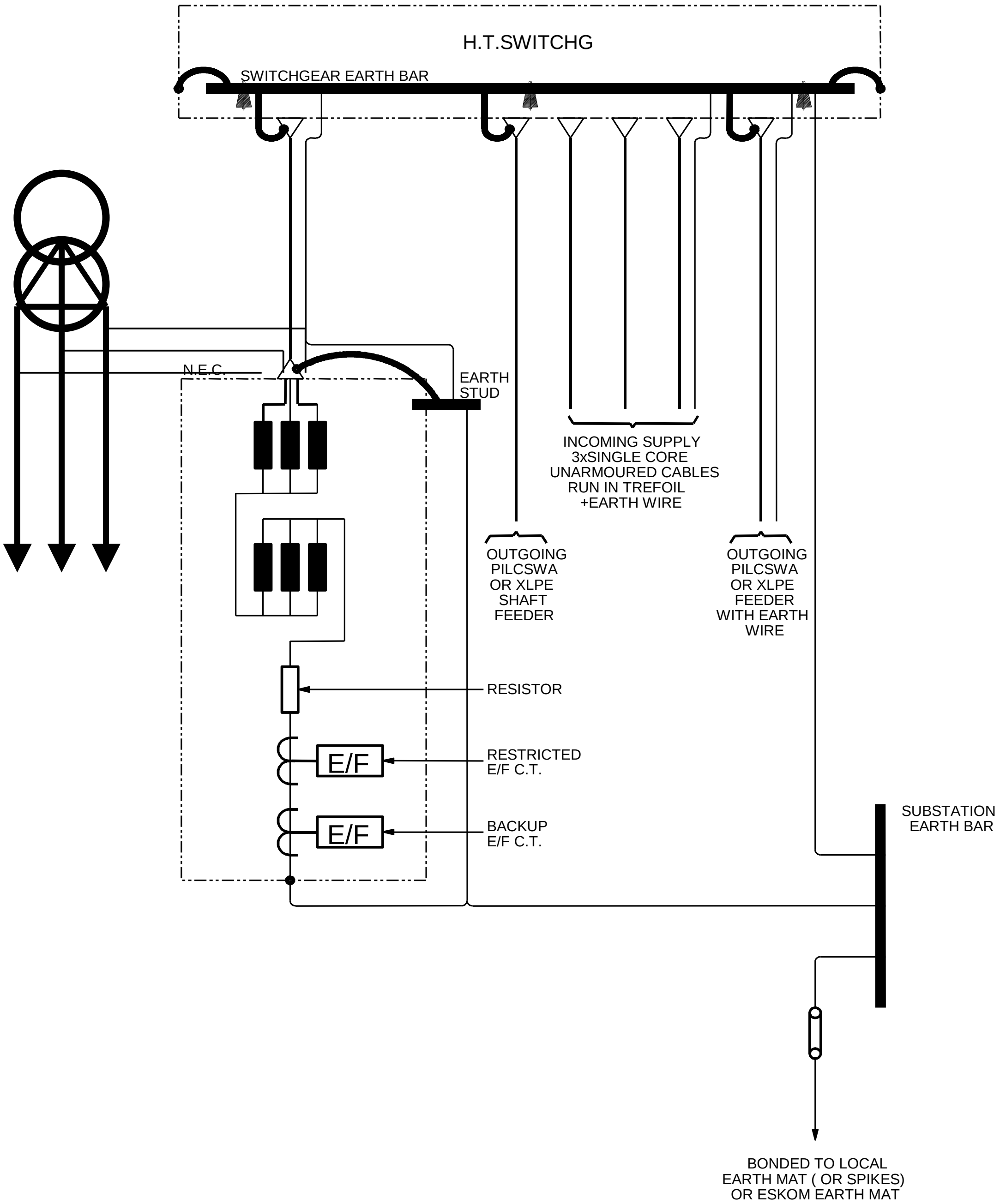
The resistance value and rating has been standardised to allow an earth fault current of 300 amp for 10 seconds, although some older installations may still operate at the old standard of 600 amps.

- A "Sustained" earth fault occurs when an earth fault in the power system is not cleared by its "Local" (i.e. next upstream circuit breaker). A CT at the NEC detects such currents and drives a protective relay, which trips the supply after a pre-set time.

  Protection against internal NEC faults is provided by "Restricted Earth Fault Protection". In this scheme the NEC HT switch and the earth conductor of the NEC are each provided with CT's which are connected so that through faults produce balanced secondary outputs. Internal faults in the NEC produce an unbalanced current which energises a trip relay.

  Whenever either the sustained or internal earth fault protection operates, the incoming power supply to the board must be tripped. (The NEC stays connected to the system). In some cases, this requires the provision of a trip signal to Eskom.

  A typical NEC connection at a Consumer sub-station is illustrated in Figure 1.



FIGUR

TYPICAL SUBSTATION

- At the newer consumer sub-station, it is the power utility's practice to supply the NEC, and connect it at their transformer output terminals. The earth terminal is then bonded to the the power utility's earth bar, along with the power utility's earth mats. To provide a current return path it is essential that this earth bar is interconnected with the consumer sub-station earth bar. At such Eskom sub-stations sustained earth faults cause the Eskom NEC protection to operate and trip out the transformer supply breaker (33 kV or 132 kV).
- Power is normally distributed via 3 core PILSWA or XLPE cables. To provide for a solid earth return path, a bare copper (normally 70 mm^2) conductor is installed in direct contact with the soil in a trench or cable racking in a surface installation.
- Where power is distributed via unarmoured single core cables, the sheath of such cable must be earthed at one end only to prevent circulating currents. A separate earth wire must be run in parallel with single core cables.

7 MEDIUM VOLTAGE DISTRIBUTION SYSTEMS FOR UNDERGROUND INSTALLATIONS

- The majority of the medium voltage systems are associated with primary distribution circuits and the earthing protection circuits will be similar as per the surface medium voltage distribution system.
- Where four or more shaft cables are installed, no additional earth conductor is required due to the number of parallel earth current return paths in the armouring and sheave of the shaft cables.
- Underground section feeders are not normally accompanied by separate earth conductors. It is vital that the electrical continuity of the sheath and armouring are maintained at every joint and termination.
- Earth fault current protection relays must be set to minimum values at all times to limit the touch potential experience on extended single cable systems operating in high humidity environments.
- Due to long distances involved, voltage drop along the return path can be high. To limit the touch potential, the sub-station earth bars shall be bonded to pipes, cable racks and general steelwork to reduce the impedance of the return path as indicated in Figure 2.

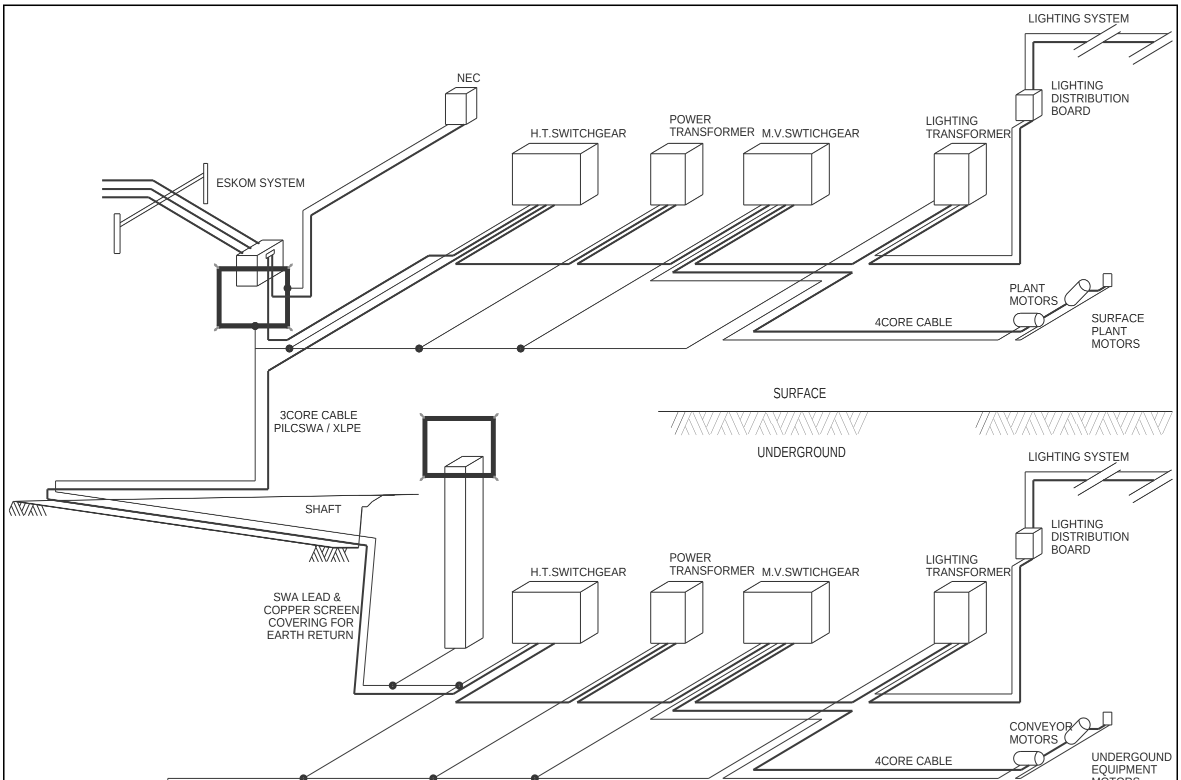


FIGURE 2

TYPICAL SHAFT DISTRIBUTION SYSTEM

8 LOW VOLTAGE DISTRIBUTION SYSTEMS ON SURFACE INSTALLATIONS

8.1 Power Transformers

Earth fault currents must return to the power system from which they originate, and cannot flow “Through” a power transformer. Each time a power transformer is installed in a system, a fresh return path to the LV side is required to return LV earth fault currents. This is achieved by using star connected LV windings and connecting the LV earth system to the star point. In 3 phase 550V/950V systems any current flowing through the star point connection is an earth fault current. Back-up earth fault tripping can therefore be operated by such currents. In 380 / 220V 3 phase, 4 wire systems, the star point of the transformer is connected to the neutral of the system and current will flow in the neutral of each 220V single phase circuit. It is important to separately connect the LV earth system to the star point of the transformer. This connection is passed through a CT, the output of which operates the back-up E/F protection.

8.2 Earth System Interconnections

All earth systems are to be connected together i.e. at a mini-sub, the HV and LV earth bars are interconnected, and at transformers both HV and LV earth systems are connected to the transformer earth stud.

8.3 550V / 950V Earthing System

Two methods are used to limit the magnitude of the earth fault return current to the star point of the transformers e.g.

- Inserting a 127 OHM for 550V (2.5Amp), 212 OHM for 950 V (2.5Amp) and 550 OHM for 950 V (1Amp) resistor between the star point of the transformer and earth.
- “ISOLOC” system inserting a high impedance between star point of the transformer and earth.

8.3.1 550V / 950V Transformer Earth-fault restriction

At 550V / 950V secondary transformer the earth fault current is limited by inserting a resistance in the return path, in the form of a resistor between the star point and earth. This limits the earth fault current to a maximum of 2.5 amp. If an earth fault occurs it should be cleared by the relevant circuits E/F protection. If this fails, back-up protection is provided by an ADIT relay driven by a CT in the return circuit to the transformer star point. This relay trips the HT switch supplying the transformer if the earth fault current persists for more than a certain (adjustable) time. (200ms to 500ms)

It should be noted that many old 550V systems do not have resistance earthing, or back-up ADIT relays. It is recommended that where danger to persons exists, the older system should be upgraded to include a 127 ohm resistor between the star point and earth.

8.3.2 Modified Insulated Neutral System

Some areas are at present using a modified insulated neutral system having the trade name of ISOLOC (Figure 3). Here the transformer neutral is earthed through and impedance having a very high ohmic value in parallel with the normal insulation of the system conductors. Should the insulation resistance of the system fall below a preset value an alarm is sounded and it becomes necessary to locate the fault before resetting the system to normal. This system has two disadvantages, these being:-

- The necessity to switch out the system components in order find fault.
- Two earth faults on two alternative phases can develop into a phase to phase fault. To overcome this problem it is necessary to fit core balance earth leakage protection or indication on each individual circuit or group of circuits.

The advantages of the Isoloc are that insulation resistance can be monitored and repaired on a planned basis.

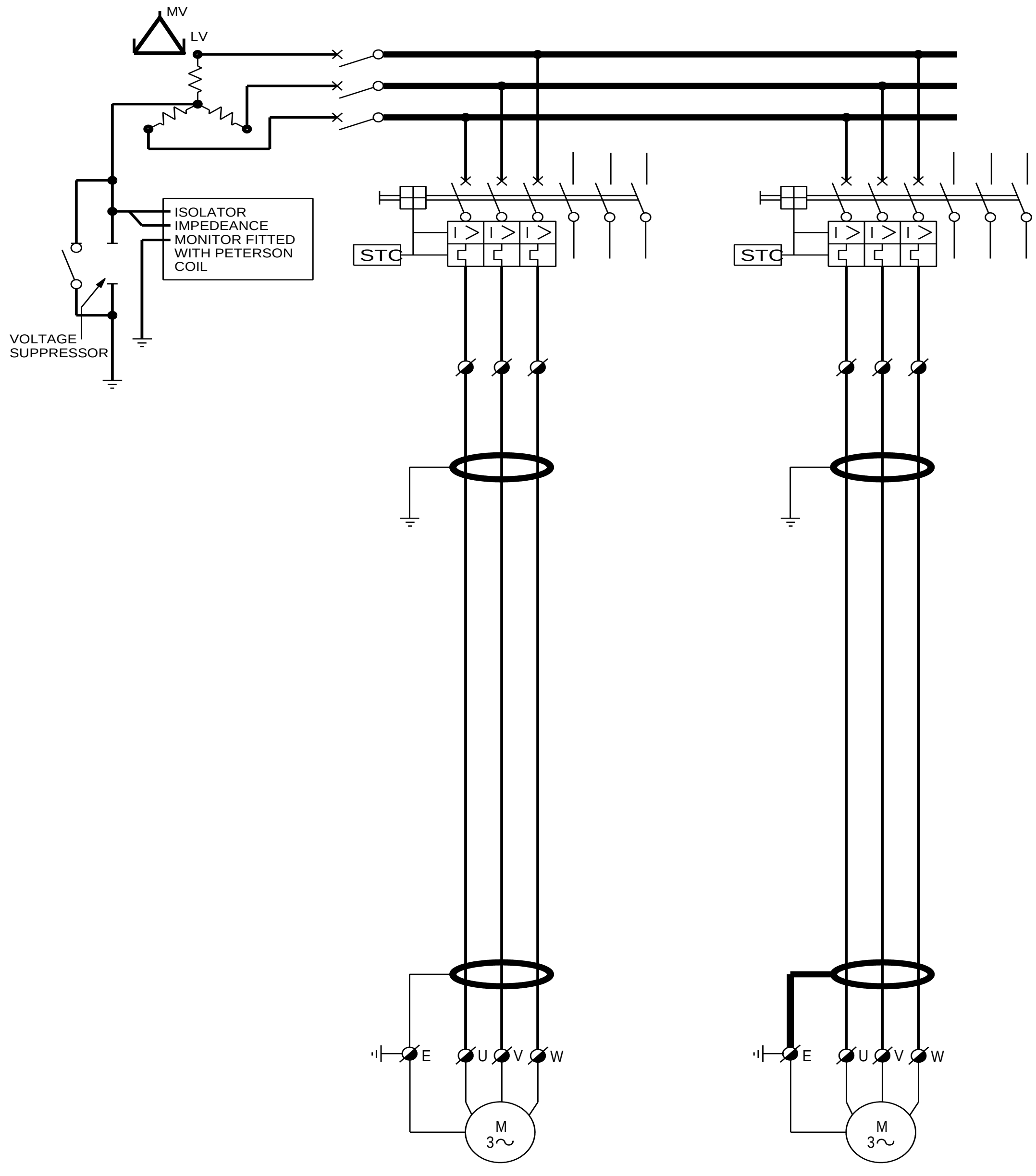


FIGURE 3

TYPICAL ISOLOC SYSTEM

8.4 Transformers Connected in Parallel

In the rare cases of transformers connected in parallel, only one transformer should be treated as discussed above. The star point of the other is not connected. This only applies while both transformers are connected in parallel.

8.5 550 Volt Systems

At 550 volts, power is distributed via 4 core PVC / PVC / SWA / PVC flame retardant cables, the fourth core used as an earth conductor. This is always the black core. At 550V transformers, this core is connected to the earth side of the neutral earthing resistor. The armouring of these cables is also used as an additional earth conductor, the connection being made via a mechanical cone type gland.

Figure 4 illustrates typical transformer connections.

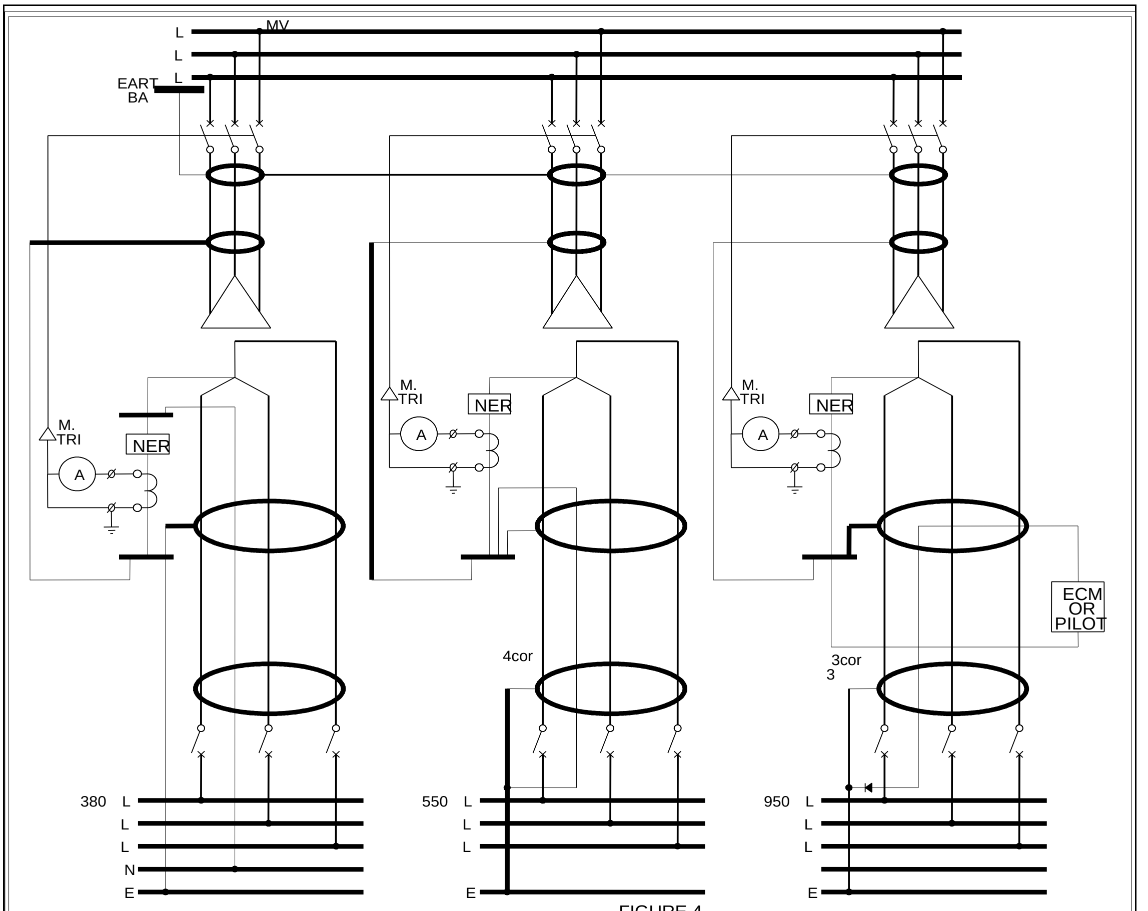


FIGURE 4
TYPICAL TRANSFORMER CONNECTION

8.6 Fourth Core of a Cable

Where the fourth core of a cable is used as an earth conductor, the fourth core must be properly terminated at each end and bolted to an earth terminal, stud or earth bar. (Not on to cover plate bolt or gland bolt).

8.7 950V Distribution System

For the 950V system the earth current limiting resistor value inserted between the star point of the transformer LV windings and earth, should be 550 ohm (1 Amp) for explosion protected equipments and 220 ohm (2.5 Amp) for 950 V distribution systems

The power is distributed via PVC / PVC / SWA / PVC cables as specified in items 8.5 and 8.6 and trailing cables as specified in SABS 1520-1999.

9 LOW VOLTAGE DISTRIBUTION SYSTEMS IN UNDERGROUND INSTALLATION

9.1 Neutral Point of LV Transformers

The neutral point of the LV winding of the transformer or mini-sub supplying power to the underground 550V and 950V must be connected to the earth point via a 127 ohm and 550 ohm current limiting resistor respectively. (2.5 and 1 Amp)

9.2 Voltage Drop

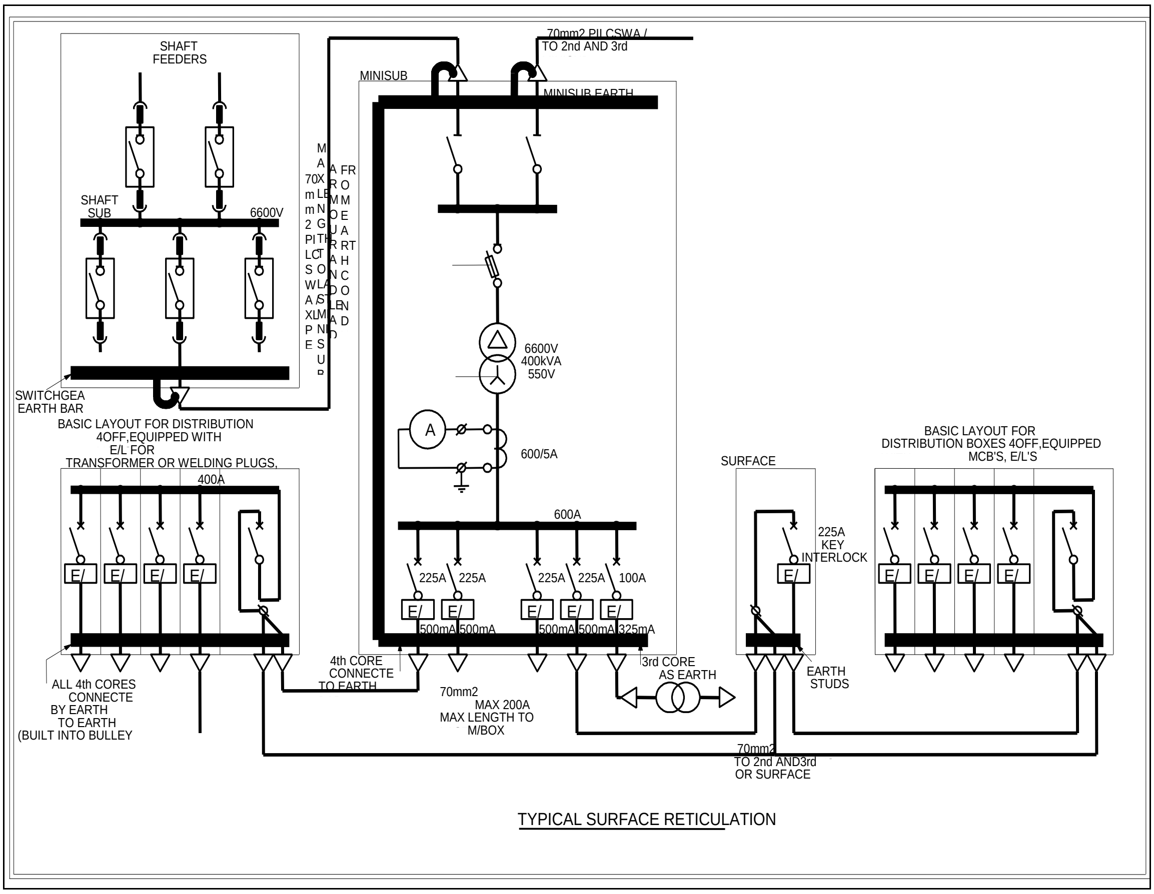
Due to long distances involved, voltage drop along the return path can be high. To limit the touch potential, the sub-station or mobile mini-sub earth bar should be bonded to pipes, cables, racks and general steelwork to reduce the impedance of the earth fault current return path.

9.3 Four core cable

The power is distributed via a 4 core non-halogen cable to AAC Specification 565/2. The fourth core of the cable is used as an earth conductor and connected to the earth side of neutral earthing resistor. The armouring of these cables is also used as an additional earth conductor.

Where a joint is made in the cable all the armouring must be connected through the joint by means of crimped ferrules.

A typical underground reticulation for a coal mine is as follows.



9.4 Earth continuity in Mechanised Mining

Present day practices in some coal mines is to solidly earth the neutral point of the LV winding of service transformers or mini-subs. This practice is not encouraged. Earthing should be through a neutral earthing resistor to limit the earth fault current to values between 0,75A and 2,5A.

To ensure end-to-end continuity exists, every trailing cable must be provided with a pilot conductor within the cable, and this conductor requires to be supplied with a Intrinsically safe pilot relay circuit installed in the gate-end box supplying the cable.

The purpose of the pilot relay as shown on Figure 5 is:-

- To monitor the continuity of the earthing system and trip the supply when earth continuity is disrupted.
- To ensure that the circuit will be tripped before an open flash occurs should any plug be pulled out its socket while the cable is alive.

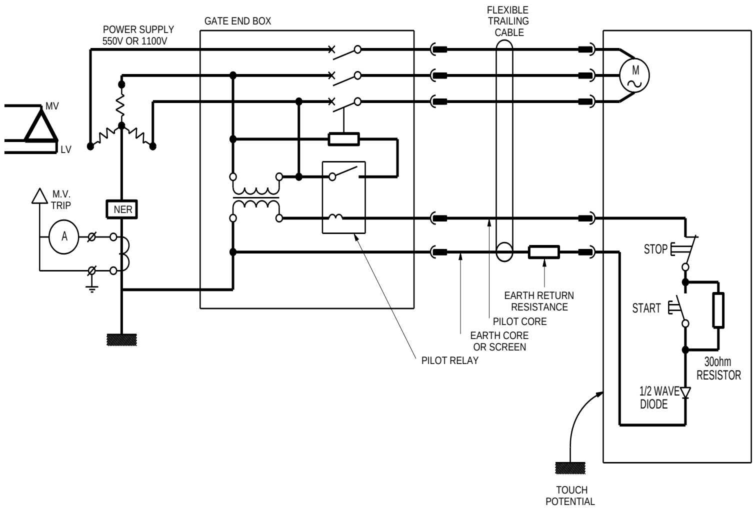


FIGURE 5

REMOTE CONTROL USING PILOT CIRCUIT

10 LIGHTING AND SMALL POWER DISTRIBUTION

- To provide power at 220 volts (for socket outlets, lights etc.), a 380 volt 4 wire system is used. This system has a phase to phase voltage of 380 volts and phase to neutral voltage of 220 volts. Each single phase 220V circuit makes use of one of this phase conductors and the neutral. It is therefore impossible to use the fourth core of a 4 core cable as an earth conductor. For that reason a separate earth wire is run from the 380 volt transformer to each distribution board, and from there to each circuit. The earth wire is to have an area determined according to Table 3 of SABS 0142. The armouring is again used as an additional earth conductor.
- At 380 volt transformers the normal neutral terminal is internally connected direct to the transformer star point. The neutral core of the 4 core cable is to be connected to this terminal. The earth system must be connected to the star point via a ring type CT. In some cases a second neutral terminal is available with an internal or external CT, and this terminal should be earthed to the transformer earth stud. Where this second neutral terminal is not available the normal neutral terminal must be earthed to the transformer earth stud via a CT. The earth wires accompanying the primary and secondary cables, and all cable armouring, are also to be connected to the transformer earth study, thereby earthing the transformer to sub-station earth bars, earth mats, etc. This is illustrated in Figure 4.
- On domestic type socket outlets, the SABS Wiring Regulations 0142 specifies that earth leakage protection of 30 mA sensitivity must be provided.

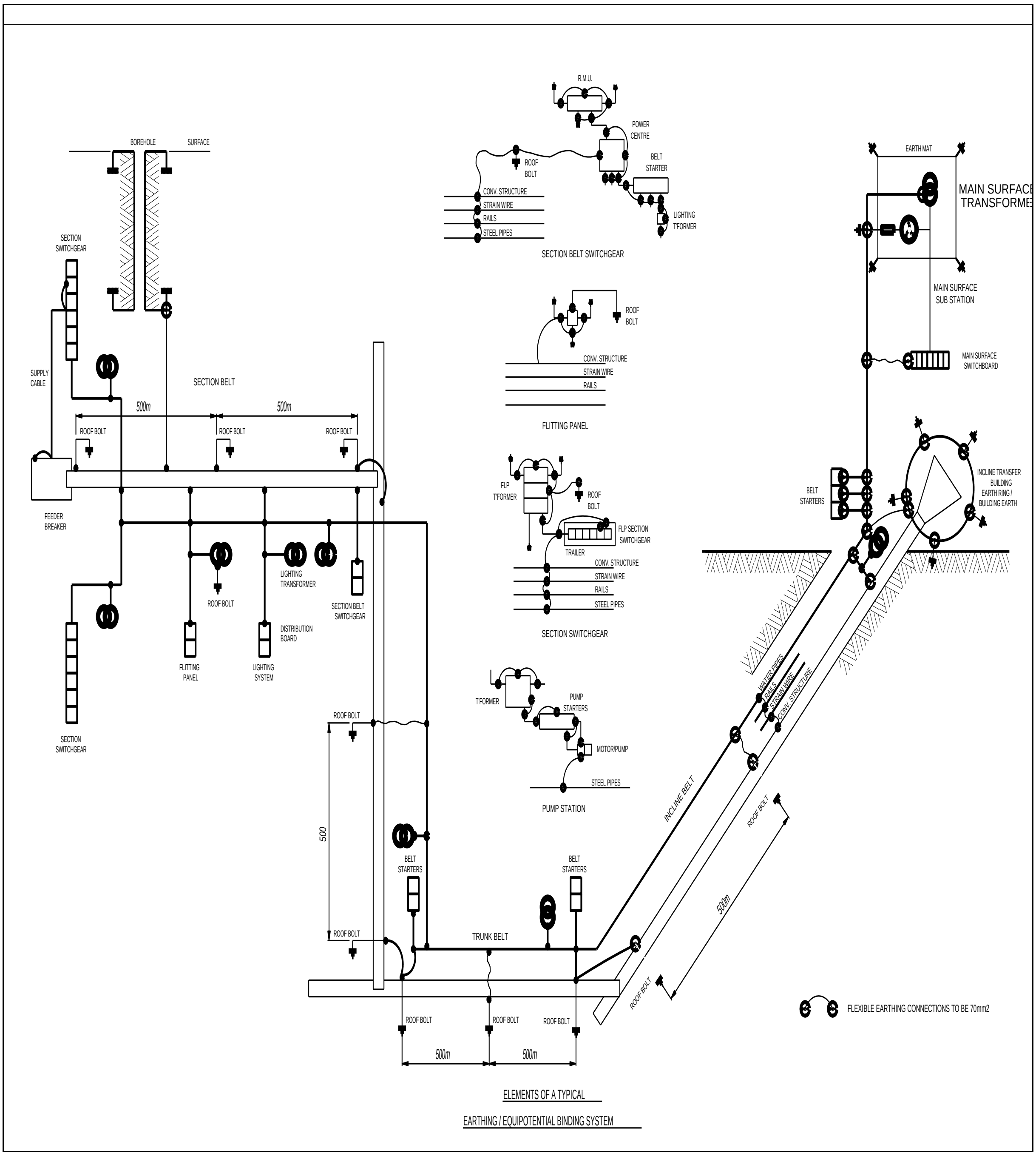
11 LIGHTNING PROTECTION OF EXPLOSIVE MAGAZINES

- The design of lightning protection of explosive magazines shall be in accordance with SABS 0142 and 086.
- The lightning protection system normally consists of free standing masts separated from the structure. It normally consists of two or more masts at suitable positions around the magazine to provide the appropriate shielding angle of 45° against lightning.
- The mesh used in the construction of floors, walls and roofs must be of a type in which wires are bonded in a permanent manner. The mesh aperture shall be 250mm or less.
- The roof must further have continuous metal roof with metal trusses or a reinforced concrete roof with continuous steel reinforcement or mesh.

  The roof must be bonded down to down conductors to a secondary building earth ring. Bonds to be thermo-welded.
- The building earth ring must be bonded to the primary earth ring which is grounding the masts together.
- The continuity of the earth ring must be tested annually by disconnecting the earth ring from all down conductors and masts. The resistance of any part of the earth system must not exceed 1 ohm. The results must be recorded in a log book and the inspectorate must be notified.

12 EARTHING SYSTEMS FOR SHAFT HEADGEAR

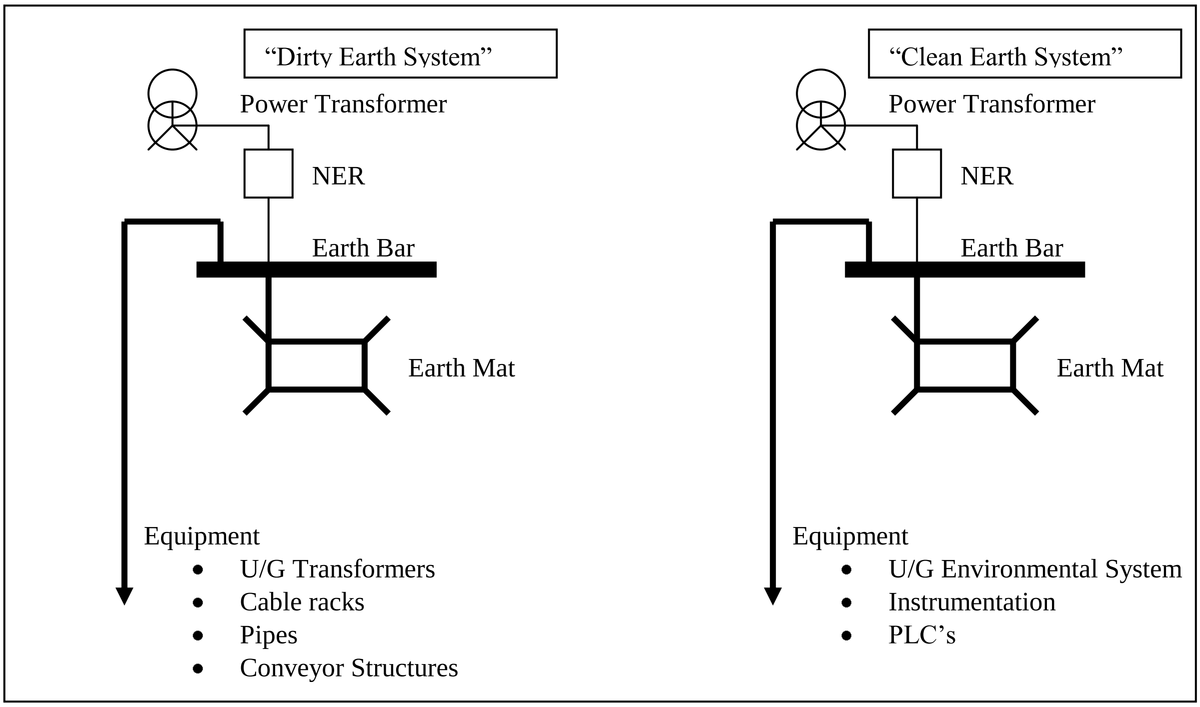
The earthing systems for headgears are fully described in Chamber of Mines Datasheet 1.6-1991 as indicated in the drawing.



13 EARTHING OF ELECTRONIC EQUIPMENT

- In practice, two separate grounding networks will normally be needed, namely:
  - A safety grounding system. ("Dirty") This consists of a common bus network for the grounding of electrical equipment such as equipment racks, cable trays, power panels, building structures, etc. This system serves to protect personnel and equipment against possible hazardous potentials resulting from faults involving the power mains from lightning.
  - A signal grounding system. ("Clean") This consists of an insulated low noise common bus network for the grounding of electronic equipment.

These systems should not be connected to each other due to high currents flowing in the "dirty" earth system caused by earth-faults and short circuits.



- The signal grounding system must provide a low impedance at the frequencies concerned and, in cases where the noise amplitude on the safety grounding system is very high, preferably install a separate earth rod system for the signal ground. Design and construct a grounding system for a new facility as follows:
  - Determine the probability of direct lightning stroke to the facility and provide measures to reduce the possibility of lightning discharge currents in signal ground conductors. For example, antennas can be protected by so extending the antenna mast above the antenna as to ensure that the antenna is located within the zone of protection of the mast, and by providing an adequate counter-poise earthing system for the mast.

   - By taking into account the frequencies and conductor lengths involved, determine whether single point, multiple point or hybrid grounding systems are required.
   - Use a type of conductor that will provide a low a.c. impedance at the relevant frequencies (e.g. flat copper strip).
   - If there is a possibility that the conductor will be required to conduct large lightning discharge currents, select a conductor having an adequate cross-sectional area.
   - Keep all grounding conductors as short as possible.
   - Take measures to prevent the coupling of noise and lightning energy into grounding conductors, as a consequence of surge-carrying conductors running parallel to the grounding conductors.
   - Ensure that all joints and bonding points are reliable and present low-impedance electrical connections. Preferably thermo-weld.
   - Where possible, avoid closed loops which may cause circulating noise currents. If this is not possible, keep the area of the loop as small as is practical.
   - To protect electronic equipment from surges on power and signal lines:
     - Provide isolation between signal line / power supply and equipment. (Often provided on equipment as standard).
     - Provide "Short Circuit" path from signal line / power supply to grounding system via combination of gas arrester, metal oxide varistor and silicon transient suppressor (transtorb) network designed to suit isolation provided and probability / amplitude study for the Geographic area concerned.
- In addition to the electrical requirements, ensure that the grounding system complies with the following general requirements:-
   - The system must be mechanically strong and reliable.
   - The system must be well documented so as to enable the average technician to understand and implement the design objectives.
   - Standard and readily available materials must be used.
   - Any alterations or additions to the system must be compatible with the original design aims.

14 EARTH LEAKAGE AND EARTH FAULT PROTECTION

14.1 950 Volt ,1000 Volt and 1100 Volt Explosion protected Equipment

Values of earth leakage relay trip sensitivities and clearance times for 1 Amp Explosion protected systems.

Equipment	Current	Time
Gate end box	80 - 125 ma	Instantaneous
Transformer Circuit breaker	200 ma	300 m secs
Transformer neutral, back up	200 ma	630 m secs

Note: There should be a minimum 5:1 ratio between the current trip sensitivity and the neutral earthing restriction. i.e. the maximum trip sensitivity with a 1 Amp restriction should be 200 ma

14.2 950 Volt and 1000 Volt Non-Explosion Protected Equipment

Values of earth leakage relay trip sensitivities and clearance times for 2,5 Amp systems utilising non flameproof power centres.

Equipment	Current	Time
Gate end boxes	80 - 125 ma	Instantaneous
Transformer circuit breaker	375 ma	Time delay
Transformer neutral, back up	500 ma	Time delay

Relays should not be used that can be set to greater than the 5:1 trip ratio.

14.3 550 Volt Distribution Systems

Values of earth leakage relay trip sensitivities and clearance times for 2,5 Amp systems utilising non flameproof power centres.

Equipment	Current	Time
Gate end boxes	250 ma	Instantaneous
Transformer circuit breaker	375 ma	Time delay
Transformer neutral, back up	500 ma	Time delay

Relays should not be used that can be set to greater than 5:1 trip ratio.

NOTE: The earth leakage total clearance time should not exceed the earth leakage relay operating time by more than 50 msecs.

15 STANDARD REQUIREMENTS FOR POWER DISTRIBUTION SYSTEMS

15.1 Earth Bar

15.1.1 Mini Sub-Stations

For both surface and underground mini-subs, AACT Specification 543/4 and 5 calls for the provision of an earth bar, common the MV and LV side.

15.1.2 Fixed Sub-Station

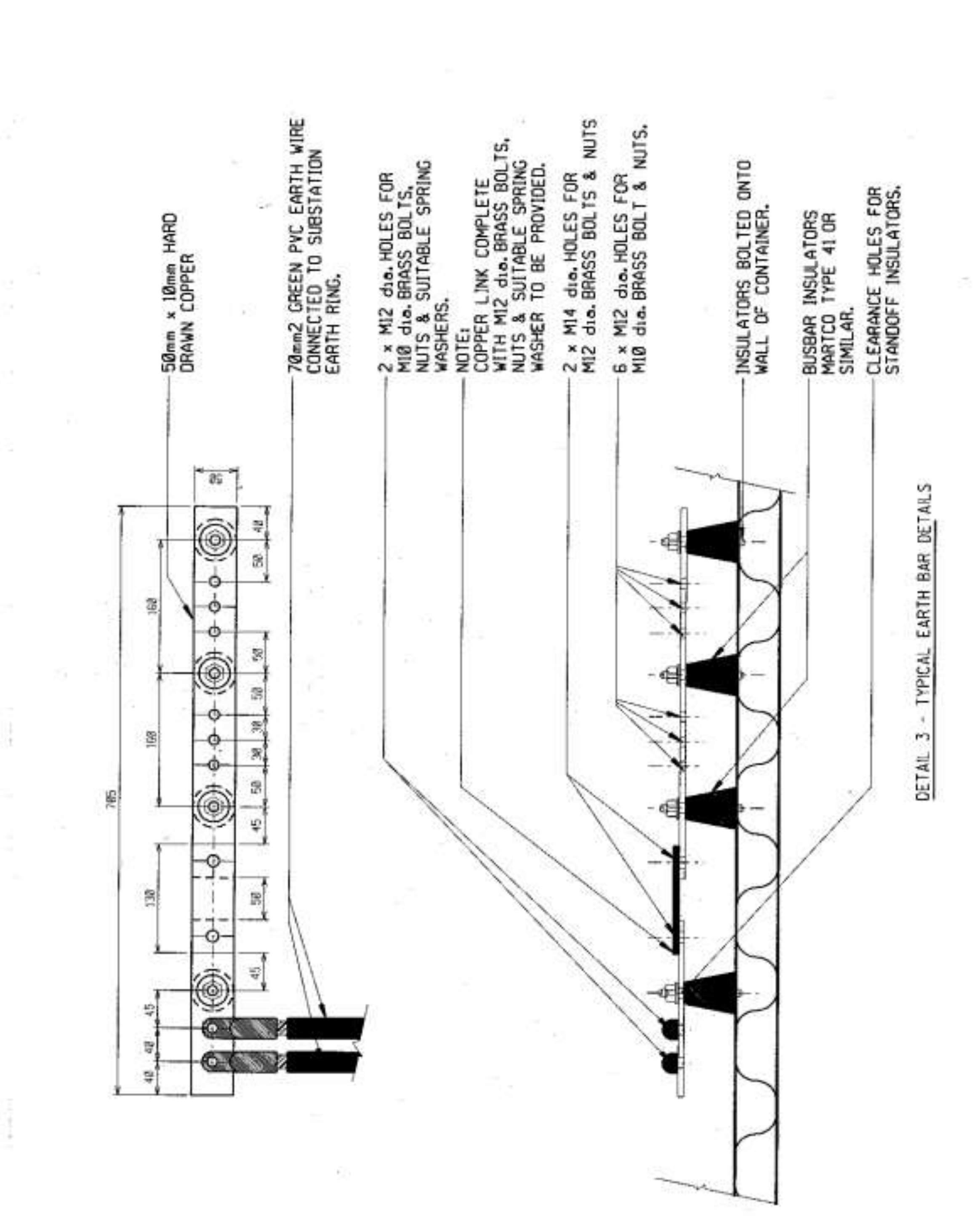
Each sub-station containing more than one switchboard shall be provided with an earth bar, as follows:-

- A solid copper bar of approximately 500 x 50 x 10mm dimensions mounted on the sub-station wall on stand-off insulators.
- 2 x 70 sq.mm or 1 x 95 sq.mm bare stranded conductors must be strained against the sidewall along the full length of the cable duct in the sub-station. No joints are permitted in these main conductors.

This is additional to the switchgear earth bar/s required by standard requirements.

15.2 Earth Bonding

- The conductor size for bonding of equipment is to be approximately 70 sq.mm stranded copper / stainless steel conductor.
- Branch tee-offs from the main earthing conductor mats are to be:

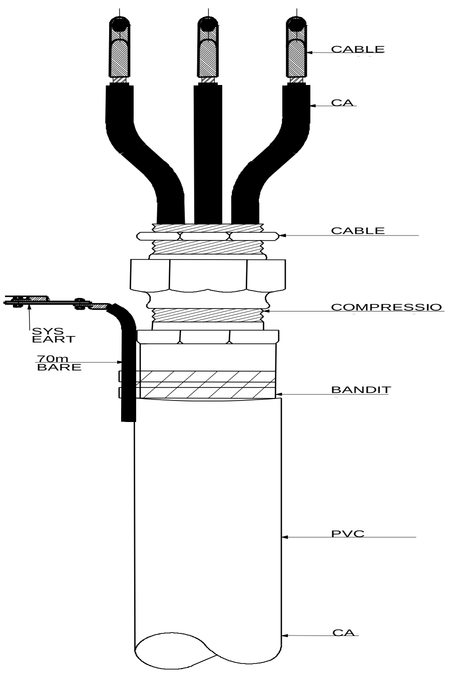


DETAIL 3 - TYPICAL EARTH BAR DETAILS

- Thermo-welded in the case of solid to solid conductor connections.
- A lug to be used in the case of stranded to solid conductor connections.

  - Wrapped and soldered in the case of stranded conductor connections.

- All metal cabinets, enclosures, cable trays, racking, conduit, trunking, sub-station screens and all other metal work connected with wiring (other that the current carrying parts) are to be bonded to earth.
- All cables terminating at switchgear are to have their earth conductors bolted to the switchgear earth bar. Where this connection is via a mechanical cone type gland the gland must make a good connection to the gland plate i.e. any non-conducting covering must be removed. In addition the gland plate must be bonded to the switchgear earth bar by a stranded copper conductor of at least half the area of the phase conductors. (Not applicable to single core cables).



FIGU
TYPICAL TYPE

- All cables terminating at transformers are to have their earth conductors connected to the transformer earth stud.
- All cables terminating at other equipment (motors, liquid starters, battery chargers, etc.) are to have their earth conductors connected to the housing or enclosure.
- At every sub-station all switchgear earth bars and any earthing mats or spikes are to be bonded to the sub-station earth bar by a 70 m^2 stranded copper earth wire.

16 EARTHING AND LIGHTNING PROTECTION OF PIT TRANSFORMER SKIDS

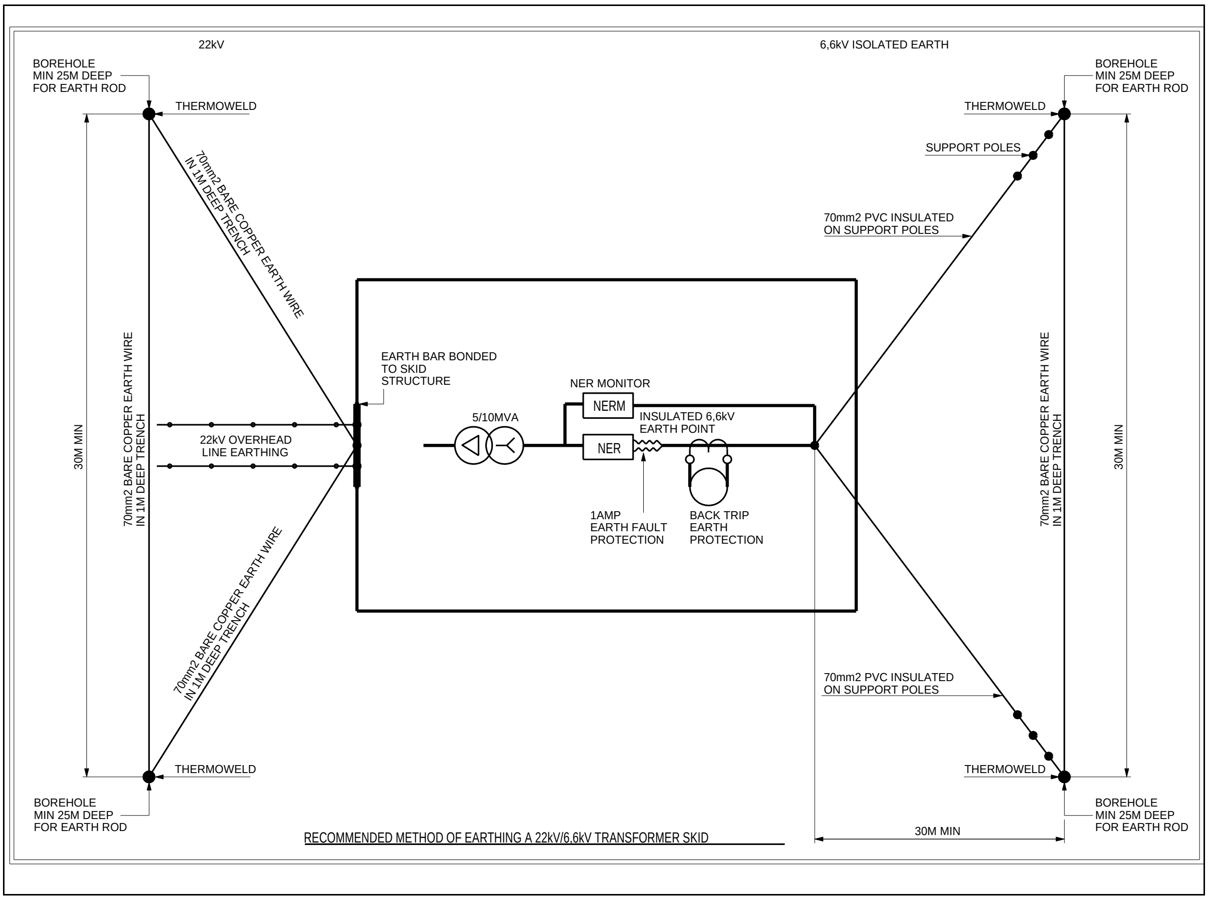
Each mine shall conduct an soil resistivity test to determine the soil resistance. Based on the outcome of the soil resistivity test, a skid mount Earthing arrangement shall be designed.

The following general arrangements shall be included for skid mounted transformer substations fed from overhead lines:-

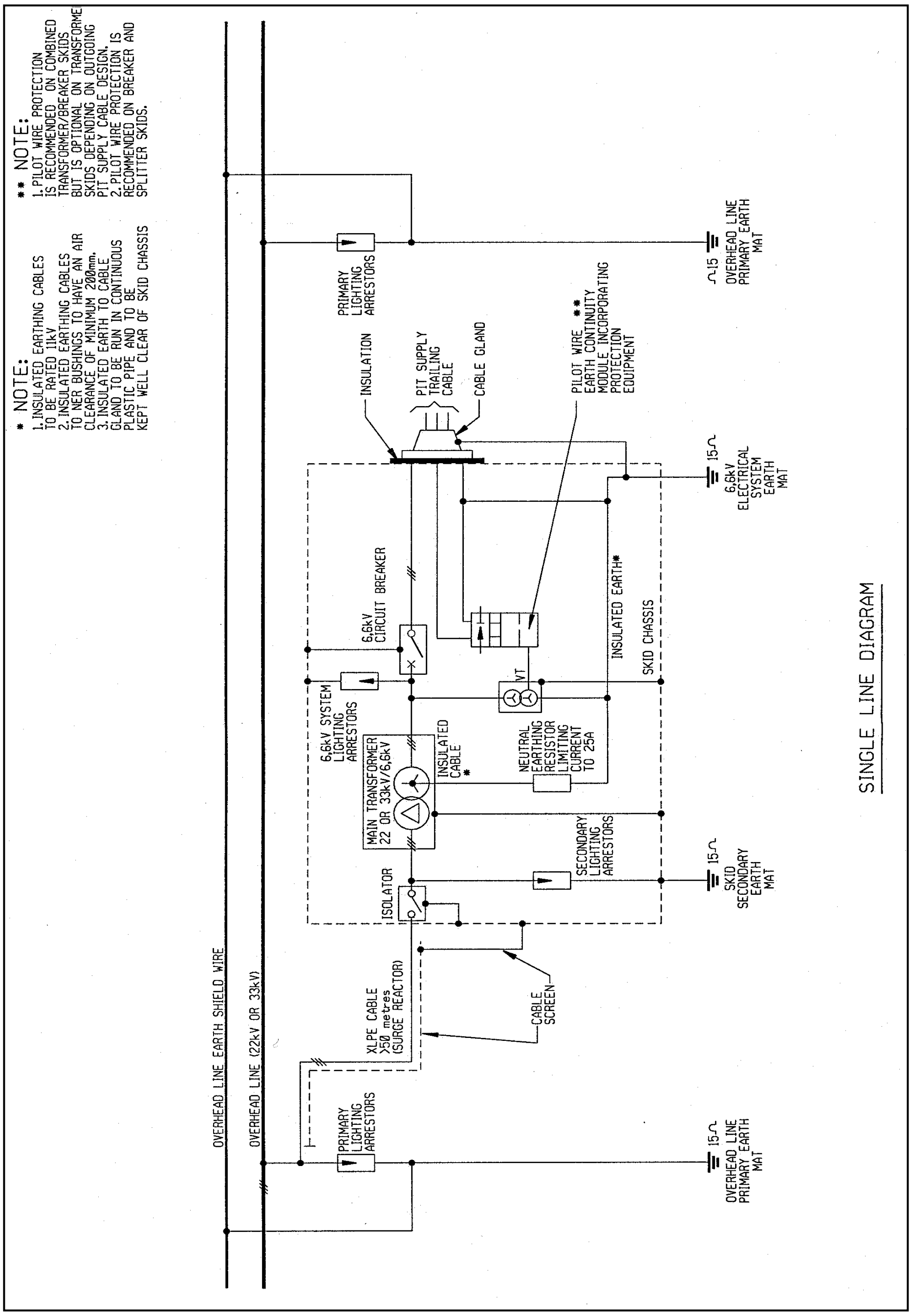
- Earth mats for
  - Overhead line primary
  - skid secondary and
  - 6.6kV electrical system must be established.

  The resistance of these earth mats is required to be approximately 15 Ω each but if this is not achievable, readings up to 30 Ω are acceptable.
  An earthing survey will need to be conducted on site to determine the actual earthing requirements.
  It has been found on coal mines that satisfactory results can be achieved using two rods in parallel installed 30 m apart in 20 m deep drilled holes filled with conductive slurry (eg. metronite).

- The earth mats are to be 30 m apart from each other and from the skid.



- The skid is to be installed below the power lines and will thus be protected from direct lightning strikes by the overhead line earth shield wire which is connected to the primary earth mats. The overhead line shall be protected from lightning by means of the overhead earth shield wire and lightning arrestors connected to the primary earth mats.
- The equipment on the skid is protected by the secondary lightning arrestors on the 22 or 33kV side and on the 6.6kV side which are both connected to the skid secondary earth mat.
- The skid isolator is to be connected to the overhead line through XLPE cable, at least 50 m long (coiled if necessary), to provide a surge reactor to reduce the lightning surges induced on the overhead lines from damaging the equipment. The conductor screens of the cable are to be earthed only at the skid, to the skid earth, and not at the overhead line end.
- The 6.6 kV transformer secondary star point is to be earthed through a neutral earthing resistor to limit the maximum earth fault to 25 or 1 Amp. The resistor shall be of a good quality robust design having a low inductance and be suitable for carrying the current continuously. The connection to the 6.6 kV electrical system earth mat shall be by means of an 11 kV XLPE cable suspended on insulating poles.
- The skid shall be fitted with notices warning personnel to stay clear and not to touch the skid in the event of lightning activity in the area. All personnel should be trained in this way.
- Metallic entrance gates, staircases and hand rails are to be insulated to avoid personnel making contact with the surrounding ground and the metal of the skid. It shall be arranged such that personnel move from the ground to an insulated section and then to the metallic skid.
- If a metallic fence is installed around the skid it shall be solidly bonded to the skid and shall be treated as part of the metallic skid.
- All lightning arrestors shall be 10 kA station class arrestors.



- If a metallic fence is installed around the skid it shall be solidly bonded to the skid and shall be treated as part of the metallic skid.
- All lightning arrestors shall be 10 kA station class arrestors.
- The outgoing 6.6 kV trailing cable earthing screens and the cable gland shall be bonded to the 6.6 kV electrical earth mat and shall be insulated from the skid.

- The pilot wire earth continuity module shall be protected from pilot to phase faults by means of an in line filter and sacrificial crow bar protection unit. This protection equipment is generally part of the pilot wire module.