AUSTRALIAN RAIL TRACK CORPORATION LTD



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## Electrical

**Title**
# System Substation Earthing

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**Document Control**

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## About This Standard

The majority of System Substations in the ARTC network are traction locations with 1500 Vdc equipment and so require special precautions compared to standard transmission, sub-transmission or zone substations owned by Transgrid and the local Electricity Distributors. Those System Substations that do not contain 1500 Vdc equipment are interconnected to the ARTC traction network and so must still follow these requirements.

This document states the essential requirements for a safe earthing system at ARTC System Substations although the general methodology referred to in the document can also provide a general guidance to the design of earthing systems for System Substations.

## Document History

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**List of Amendments –**

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| 1.1 | 05/01/2005 | | Reformatted to ARTC Standard |
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## Contents

# 1 General

This document is written on the premise that a System Substation will use a combined earthing system and will therefore have only one earth grid. There will be rare occurrences at nontraction locations where a separate earthing system may be a better option resulting in the use of two separate earth grids for the high and low voltage earths. This situation is most likely to arise at a small AC switching station with transmission line feeders where it is not economical to meet all the requirements of a combined earthing system. In this situation the earthing design principles of Specification PDS 05 - "Distribution Substation Earthing" should be followed.

System substations in general tend to have:

- A high fault level
- A large earth grid that is walked over by substation staff
- A number of items of electrical equipment with electrical protection of various clearing times
- A number of aerial and/or cable feeders
- Fences with associated prospective touch voltages for people external to the substation
- Other services (eg water, communications) connected

## 1.1 Earthing System Design

Due to all the variations and high fault levels a full detailed design must be carried out for the earthing system of each individual System Substation. The design methodology set out in figure 2.1 of the ESAA Substation Earthing Guide can be used as a guide for the calculations to ensure safe prospective touch and step voltages.

**Note: The fault duration time applicable for calculating acceptable touch and step potentials, is that for the primary protection to operate, it being recognised that the number of occasions when the stated time limit may be exceeded due to unavoidable malfunction or combination of unlikely circumstances is negligibly small. Refer to section 4.4.3 of the ESAA Substation Earthing Guide.**

## 1.2 Equipment to be Earthed

Equipment to be connected to the combined high and low voltage earthing system includes:

- Earth grid.
- All accessible exposed metal parts containing or supporting high voltage conductors, including metal parts mechanically connected to the exposed metal parts.
- Metallic substation enclosures of all high voltage and low voltage equipment.

- Surge protection devices.
- Cable sheaths/screens/armouring.
- Exposed metal of all floor and wall reinforcing.
- Metallic fences, both internal and boundary.
- Fixed metal items within the substation building, eg door frames, metal roofs and down pipes.
- Metal pipes, eg waterpipes, within the substation boundary.
- Transformer low voltage neutrals.

The following equipment shall not to be connected to the combined high and low voltage earthing system:

- Any part of the 1500 V negative return path.
- Metal battery stands.
- Some existing 220 V auxiliary supplies (refer to section 4.1).
- Rectifier cubicles and dc circuit breaker frames. In most cases, and any future designs, this equipment shall be connected to earth through a frame leakage relay (refer to section 4.11).

# 2 Types of System Substations

## 2.1 Traction Substations

These locations are the supply points for the overhead wiring. All the sections in this document may be relevant.

## 2.2 Sectioning Huts

These locations are to sectionalise the overhead wiring for dc protection and voltage regulation. All the sections in this document may be relevant.

Note, if the Sectioning Hut includes any high voltage ac switching equipment, then the design shall be the same as for a Traction Substation.

## 2.3 AC Switching Stations

These locations are ac switching stations that have high voltage circuit breakers. There is no 1500 V equipment at these locations.

# 3 Earth grid

## 3.1 Electrodes

### 3.1.1 Standard Electrode

The standard electrode is a 3.6 m length of copper tube (14.29 mm outside

diameter, 11.03 mm inside diameter). Longer electrodes may be used if there is some difficulty obtaining the required resistance as the soil resistivity is usually found to be lower at a greater depth.

The current rating of the earthing electrode is 5 kA for 1 second when tested in free air in an ambient of 15°C to 25°C without exceeding a temperature rise of 350°C.

### 3.1.2 Electrode Spacing

The earthing system at a System Substation consists of a minimum of 4 earth electrodes installed around the inside perimeter of the substation and connected together with the earth mesh.

The exact spacing of the electrodes will be determined by the final design, which will be based on local conditions, resistivity of the area and space available for electrodes. The spacing between electrodes should be greater than the electrodes' length.

Although the earth mesh will often result in a low enough resistance without the use of electrodes, a minimum of 4 electrodes are still necessary to ensure the fault level capability ie 4 x 5 kA. Electrodes are also required in case of the drying out of the soil at the depth of the earth mesh in long dry spells. It should also be noted that the electrodes should be placed around the perimeter as it has been shown that any centre electrodes will not reduce the resistance of the earth grid significantly.

### 3.1.3 Installation of Electrodes

The electrodes shall not be driven. Use drilled holes (50 mm diameter) back filled with a conducting medium mixture, for example bentonite, gypsum and sodium sulphate (50%, 45% and 5% by weight respectively) mixed to AS 2239 - Cathodic Protection), or similar. The top of each electrode is to finish 200 mm below ground level.

Each earth electrode is to have a collar and lid.

### 3.1.4 Test Electrode

All new System Substations must have a test electrode installed. The test electrode is to be easily disconnected from the earth grid, without any effect on the grid, to allow resistance testing of the electrode and to check physical deterioration.

The test electrode must be placed where it is easily accessible and can be withdrawn without the need to remove supply from any item of live equipment. The test electrode shall be identified by painting the word "Test" on the lid.

### 3.1.5 Earth Mesh

Buried horizontal conductors are placed under the area of a substation to provide surface gradient control by reducing the values of prospective step voltages for persons working within the substation during a fault. The mesh configuration will also reduce the earth grid resistance.

The size and spacing of conductors must be calculated as part of the design process. For further advice refer to the Electricity Supply Association of Australia guide EG1(95) - Substation Earthing Guide.

### 3.2 Earthing Connections

All underground connections shall use an exothermic welding process such as a cad weld. This includes connections to electrodes. The exothermic weld is preferable to a clamp because of the high fault levels of System Substations and the electrolysis problems associated with Traction locations. C clamp connections may be used on above ground joints that are visible for inspection.
Typical connection diagrams are currently shown in drawing C/79930 which will be replaced by A3/90093 sheet 6.

### 3.3 High Voltage Earth Conductor Sizing

The size of the high voltage earthing conductors is determined by the earth fault level and shall be in accordance with AS 3000, clause 7.8.10.7.2, but in any case shall be not smaller than 70 $mm^2$ copper. This value is larger than the 35 $mm^2$ copper conductor specified in the standard, but is required due to the proximity of the traction system.

**Note 1: The fault duration time applicable for calculating the size of conductors (including cable screens), is the duration of the back-up clearance time, that is, assumes that one primary protection system fails to operate. The temperature rise will not exceed the maximum temperature for the selected conductor size when carrying the maximum earth-fault current for this fault duration time.**

**Note 2: The recommended inputs to the K factor referenced from AS 3008 are an initial temperature of 40°C and a final temperature of 160°C for PVC insulated conductors, or 250°C for bare or XLPE insulated conductors.**

## 4 Equipment Earthing

### 4.1 Auxiliary Supplies

The auxiliary services in a System Substation can include lighting, low voltage power, dc power supplies (not dc traction loads), ventilation and compressed air. The auxiliary services may be three phase 415 V or single phase 240 V, although a three phase 220 V system has been used in the past which is described at the end of this section. There is always a back-up auxiliary supply from a second source.

It is usual practice to supply the auxiliary services in a ARTC System Substation from a transformer (designated auxiliary transformer) whose primary winding is supplied from one of the secondary windings of the rectifier transformer. The case of the Auxiliary transformer shall be connected directly to the earth grid with a 70 $mm^2$ copper conductor.

In some situations the Auxiliary supply originates from a supply external to the substation, for example, a back-up emergency supply in a single rectifier substation. In these circumstances if the external supply is from the local distributor then the external supply must be connected via an isolating transformer. Refer to PDS 07 - “Low Voltage Distribution Earthing” for relevant guidelines.

Irrespective of the supply source, the neutral bar and the earth bar shall be connected together in the Auxiliary panel switchboard. This shall be the only neutral

earth connection in the System Substation auxiliary supply. The size of the connecting conductor shall be based on the size of the active conductors from the auxiliary transformer. The earth bar shall be connected directly to the Substation earth grid with 70 $mm^2$ copper conductor.

In the past, several variations of the auxiliary supply design have been used. Some of these variations are still in existence, but they should not be used in any new designs. In one variant used in Traction Substations the earth-neutral connection is made at the auxiliary transformer. This is undesirable as it can result in circulating currents at two rectifier locations where there are two earth-neutral connections, one at each transformer. An older method used in Traction Substations and Sectioning Huts used a floating three phase 220 V system with C phase connected to earth via a spark gap and an earthed screen in the auxiliary transformers.

### 4.2 Low Voltage Final Subcircuits

Each low voltage final sub-circuit shall contain an earthing conductor in accordance with AS 3000.

### 4.3 Surge Arresters

The connection between the earth side of the high voltage arrester and the earth side of the equipment being protected must be as short as possible (the same applies to the live side of the surge arrester). The resistance connection to remote earth is not critical to the surge arrester operation but it is important to consider the touch potentials during the surge arrester operation.

### 4.4 Batteries

All System Substations require a set of batteries, and battery charger, to supply power for the control circuits of circuit breakers and SCADA equipment. The dc battery system shall not be earthed.

### 4.5 Cable Sheath and Armour

All high voltage and 1500 V positive screened cable sheaths and armouring must be connected directly to the earth grid.

### 4.6 Telecommunications Equipment

Refer to RailCorp publication EP90100003SP - “Co-ordination of Communication and Power Systems - Earth Potential Rise”.

### 4.7 Metallic Pipes

All underground metallic pipes (eg water or air) entering a System Substation shall be electrically isolated by the permanent installation of an approved isolating joint one metre outside the substation boundary, as shown on drawing D/89147. Isolation is to provide protection against electrolysis corrosion.

An approved sign, as also shown on drawing D/89147, is to be secured to the fence directly above the pipe.

Any metallic pipes within the substation boundary must be bonded to the substation earth grid by a 70 $mm^2$ copper conductor.

### 4.8 Neutral Resistors

Neutral resistors are employed at some System Substations to reduce the earth potential rise under fault conditions. The neutral resistor shall be connected to the System Substation earth through a neutral leakage relay.

### 4.9 1500 V Link Area (Voltmeter Rail)

A short length of rail shall be installed in the 1500 V link area to facilitate the connection of a voltmeter to test dead the feeders. The rail is to be connected to the track side of the negative reactor in a Traction Substation and to the negative of the REC in a Sectioning Hut. The rail should be placed 1 m clear of any other metalwork, if this is not possible a warning sign is to be erected on the fence of the link area opposite the voltmeter rail stating: WARNING VOLTMETER RAIL IS CONNECTED TO TRACTION NEGATIVE DO NOT BRIDGE TO EARTH.

### 4.10 Rail Earth Contactor

A rail earth contactor is to be installed at all Traction Substations and Sectioning Huts. This is a normally open latched contactor connected between rail and earth that is designed to close when its voltage sensing circuit detects a dangerous potential difference between rail and earth. It will remain closed until manually reset on-site. Refer to drawing D/82590 for Schematic Diagram, D/78180 for Connection Diagram and B/82194 for Panel Arrangement.

### 4.11 Frame Leakage Protection

The rectifier cubicles and dc circuit breaker frames in Traction Substations and the dc circuit breaker frames in Sectioning Huts shall be connected to earth through a frame leakage relay.

An earth conductor is connected from the DCCB frame leakage bar to each DCCB frame in turn. If a breakdown occurs between frame and earth on any one DCCB causing a current to flow, the frame leakage relay will open a set of contacts disconnecting supply for the 120 V controls to all DCCB's, as shown on drawing D/86513 sheet 1. In addition at a Traction Substation the rectifier, whose frame is sitting on a sheet of 3 mm Cadco (insulating material), has an auxiliary relay connected into the circuit as shown on drawing D/86513 sheet 2. This locks out the rectifier to prevent it feeding into the busbar and frame to earth. The rail earth contactor will also operate, refer to section 4.10.

## 5. Substation Metal Fences

### 5.1 Clearance to Other Earthed Equipment

A 2 m clearance shall be maintained between the substation boundary fence and any equipment connected to an external earthing system, such as an ARTC Distribution Substation or other local Electricity Distributor Substation. A clearance is required to reduce the risk of a prospective touch voltage. The distance of 2 m has been selected to ensure that a person cannot contact the substation fence, substation earth, and the other earthing system at the same time.

### 5.2 Other Clearances

A 2 m clearance shall be maintained between the substation boundary fence and

any continuous metal structure, such as a fence, pipe or signal troughing, that can be connected to a remote earth. Where the 2 m clearance cannot be obtained, a suitable approved method such as installing two isolating breaks 2 m apart in the continuous metal structure shall used. Alternatively the situation can be proved safe by calculation and testing for dangerous touch voltages in accordance with the ESAA Substation Earthing Guide.

### 5.3 Bonding of Gates

Bonding conductors must be used where there are any breaks in continuity in the fence, such as for gates. The size of this conductor is dependent on the fault level at the substation, but in any case shall be a minimum of 70 $mm^2$ copper.

### 5.4 Grading Ring

Grading conductors, where required, are to be placed around the fence to reduce prospective touch potentials, usually one bare 70 $mm^2$ copper conductor is installed 1 m outside the fence and at a depth of not more than 0.5 m. The grading conductor is to be regularly bonded to the fence at intervals not greater than calculated in Appendix C3 of AS 2067. This grading ring is included as part of the overall earth grid design and included in the resistance calculations.

## 6. Supplies to Nearby Loads

Low voltage supplies are not to be provided to nearby loads, such as depots, camps or private consumers, external to the System Substation unless a detailed design is carried out. The connection of a load external to the substation will transfer the substation earth potential which, under a high voltage fault, will result in high prospective touch voltages at the remote site. Note, a 33 kV fault can result in voltages over 10 kV but a standard 240/240 V isolating transformer has a design withstand voltage of only 5 kV.

Where an isolating transformer is used in a System Substation the case of the transformer must be connected to the Substation earth. This requirement is based on the necessity to earth all metalwork in a substation. (refer to section 1). It is not an electrical requirement with regard to isolation.

The screen of the isolating transformer must also be connected to the Substation earth grid. The connection is to be sized to carry the maximum fault currents that may flow for the time required for the back-up protective device to operate. Refer to section 3.3, except that the minimum size shall be 16 $mm^2$ copper.

## 7. Sectioning Hut Supplied from Distribution Substation

A Sectioning Hut is usually supplied from a dedicated ARTC Distribution Substation located outside of the Sectioning Hut boundary. In this situation the relevant section of the Specification PDS 05 - “Distribution Substation Earthing” in Volume 2 shall be used for the high voltage earthing only. The secondary of the transformer shall not be earthed at the Distribution Substation, the only low voltage earth system will be the Sectioning Hut earth grid. The transformer mains active and neutral conductors must be double insulated all the way into the supply main switchboard of the Sectioning Hut. The Sectioning Hut supply main switchboard shall have the neutral bar and the earth bar connected together; this shall be the only earth-neutral connection for the Sectioning Hut supply. The earth bar of the switchboard shall be directly connected to the Sectioning Hut’s earth grid.

In the situation where a Sectioning Hut is not supplied from a dedicated Distribution Substation, that is, other loads are connected to the same Distribution Substation as the Sectioning Hut then the Sectioning Hut must be supplied through an isolating transformer located within the boundary of the Sectioning Hut. If the high voltage supply to the Distribution Substation is greater than 11 kV then a detailed design shall be carried out to ensure the withstand voltage of the isolating transformer is rated for all possible fault conditions. The screen of the isolating transformer must also be connected to the Sectioning Hut earth grid. The connection is to be sized to carry the maximum fault currents that may flow for the time required for the back-up protective device to operate. Refer to section 3.3, except that the minimum size shall be 16 $mm^2$ copper.

If the supplying Distribution Substation is owned by a Local Distributor, refer to Specification PDS 07 - “Low Voltage Distribution Earthing” for additional guidelines.

Due to the relatively low ac fault levels at Sectioning Huts and the fact that the 1500 Vdc system is unearthed, the earth grid resistance can be based on the size of the transformer of the Distribution Substation supplying the Sectioning Hut. Refer to Specification PDS 05 - “Distribution Substation Earthing”.

This policy is based on EC 5 - Guide to Protective Earthing - Electricity Council of N.S.W. - 1992 which recommends a maximum touch voltage of 4000 V when a fault duration of 0.2 seconds can be achieved at ‘frequented locations’ with an operating voltage less than or equal to 66 kV. The dc circuit breakers and rail-earth contactor operate well under this time, therefore, a 1500 V fault will not cause any dangerous touch and step voltages The Sectioning Hut can then be treated as a Distribution Substation for calculation of earth grid resistance, although all other aspects should be based on this document, including minimum numbers of electrodes.