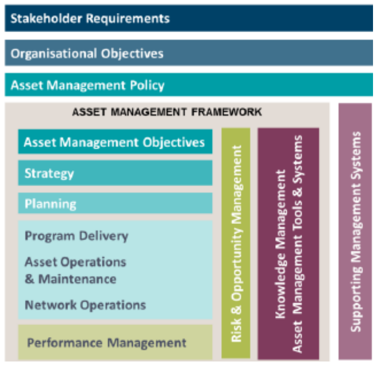
Substation HV Power Cables and Terminations

Design Standard



DOCUMENT HIERARCHY

This document resides within the Planning component of Western Power's Asset Management System (AMS).

DOCUMENT DATE

This document was last updated March 2026

IMPLEMENTATION DATE

This document came into service December 2023

DOCUMENT CONTROL

Record of endorsement and approval via Volt document control system.

RESPONSIBILITIES

Western Power's Engineering & Design Function is responsible for this document

CONTACT

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Contents

Revision Details

Version	Date	Summary of change
0	June 2025	First Issue in the Volt
1	March 2026	Addresses issues register items 15 to 25

1 Introduction

Power cables are used within substations to connect transformers, feeders, switchboards, capacitor banks station supply transformers, dynamic reactive compensation plant, and other primary equipment.

The purpose of this Design Standard (DS) is to assist engineers in designing substations.

1.1 Purpose and scope

This Design Standard outlines the design requirements for high voltage power cables and terminations, 33kV and below, within zone and terminal substations, including feeder cables within the substation boundary. It also applies to low voltage cables (0.6/1kV) with conductor cross sectional area greater than $70mm^2$. It covers design within green field and brown field sites.

This Design Standard also covers the general parameters of the cables used, the selection of cables and the layout and installation requirements relating to design. It includes the requirements for joints and terminations and earthing details. Information on the installation of the cables from a construction perspective is covered in the Technical Specification – Substation Electrical Construction.

Power cables for transmission voltages (≥ 66kV) are part of the transmission network and are procured by the Lines and Cables Design area as required.

1.2 Acronyms

Acronym	Definition

1.3 Definitions

Term	Definition
HDPE	High Density Polyethylene (sheathing for cables)
XLPE	Cross-Linked Polyethylene
PVC	Poly Vinyl Chloride (sheathing for cables)
LV	Low Voltage ≤ 1 kV AC
HV	High Voltage > 1 kV AC
FRP	Fibre Reinforced Plastic

1.4 References

References which support implementation of this document

Table 1-1 References

Reference No.	Title

2 Supporting Documentation

None

3 Compliance

This Design Standard complies with all higher-level Western Power technical documents and relevant Australian Standards.

This Design Standard should encompass all requirements of the relevant Australian Standards which are current at the time of issue. These relevant Australian Standards are listed in Table 3.2 below. A period will be set when the standard needs to be reviewed. If significant changes occur on an Australian Standard which affects safety, then an out of cycle review can be completed.

Table 3-1: Relevant Documentation

	Document Title
Western Power website	Network Standard – Transmission Substations Functional Requirements
VOLT-1381921126-6437	Construction Technical Specification – Electrical requirements for Substation Installation
EDM#64458144	Design Guideline - Switchboard Double Cable Terminations
ID05-1343104688-373264	Hazard Management Register – HV Cable and Terminations
ID-005-3caec6a000e4b23df5da53d05894cb9e	Western Power Cable and Conductors Technical Specification

The relevant Australian Standards are listed below in Table 3-2.

Table 3-2: Australian Standards

Standard Number	Standard Title
AS 1111.1	ISO metric hexagon bolts and screws – Product grade C - Bolts

Standard Number	Standard Title
AS 1111.2	ISO metric hexagon bolts and screws – Product grade C - Screws
AS/NZS 1125	Conductors in insulated electric cables and flexible cords
AS/NZS 1429.1	Electric cables – Polymeric insulated – For working voltages 1.9/3.3 (3.6) kV up to and including 19/33 (36) kV
AS 2067	Substations and high voltage installations exceeding 1kV a.c.
AS/NZS 2648.1	Underground marking tape – Non-detectable tape
AS/NZS 3000	Electrical installations
AS 3008.1.1	Electrical installations - Selection of cables - Cables for alternating voltages up to and including 0.6/1 kV - Typical Australian installation conditions
AS/NZ 3808	Insulating and sheathing materials for electric cables
AS 3865	Calculation of the effects of short-circuit currents
AS 4702	Polymeric cable protection covers
IEC 60287	Electric cables — Calculation of the current rating (all parts)
AS 62271.301	High voltage switchgear and control gear - Dimensional standardization of terminals

4 Functional Requirements

This Design Standard is intended to be used by Substation Engineering staff and by companies completing outsourced design work for Western Power, as it outlines the Western Power requirements.

5 Safety in Design

Safety in Design (SID) must be considered when completing all substation design work. SID focuses on making the design safer and easier to understand, with the aim to eliminate and mitigate potential hazards during the design phase of a project.

Some examples of Safety in Design in high voltage cable design include:

- Cable installation – can excavation near live cables be avoided?
- Potential trip hazards (in basements) – are cables being installed in a manner which allows personnel access?
- Cable sealing and support – Can we eliminate flooding of cable basements and improve conditions?

- Is there potential risk of damage to cables (e.g. close proximity to access roads etc.)?
- Magnetic induction – does the installation method create closed magnetic loops around single phase cables or groups of cables of the same phase?

All projects are required to have a SID Hazard Management Register to include evidence of all measures implemented to eliminate or reduce risks. The Hazard Management Register for this Design Standard is in the Volt.

6 Overview of the Main Design Elements

Standard cables must be used whenever possible. The standard cable layout (or part of) shall also be used whenever possible. Cable ratings shall be checked against the Western Power standard circuit ratings .

Cables shall be chosen to meet the required circuit rating, after applying any derating factors due to the installation parameters of the cable.

The requirements for cable joints, terminations, penetrations and earthing are outlined in this Design Standard.

7 Power Cable Types

Power cables are used within substations to connect transformers, feeders, switchboards, capacitor banks, reactors, station supply transformers and other primary equipment.

7.1 Cable Design Requirements

In general, all newly installed cables of voltages up to and including 33kV shall comply with the requirements of AS 1429.1. Low voltage cables shall comply with the requirements of AS 5000.1.

All cables shall meet the following requirements:

- All outer sheaths shall be UV resistant
- All cables shall be circular unless otherwise specified

Mineral insulated cable, lead and lead alloy sheath type cable are not acceptable cable types.

All conductors shall be manufactured from fully annealed, circular stranded copper or aluminium wires. Solid conductors shall not be used.

Cables shall have a minimum specified safe continuous operating temperature of 90°C for XLPE insulation for continuous operations. For emergency and short circuit operation ratings of HV cables refer to AS 1429.1, Table 1.2. For emergency and short circuit ratings of LV cables, refer to AS3008.1.1.

7.2 Standard Power Cable Types

The following table provides the recommended cable sizes used within a substation for varying circuits. Number of cables per phase is a guide only and must be confirmed with a cable rating study.

Refer to Cable and Conductors Technical Specification for details of cables below.

Table 7.7-1 Standard Power Cable Types

System Voltage Level	Equipment	Cable Type & Voltage See Note 2	Stock Codes See Note 2
11kV	33MVA transformer circuit	Single core 630mm^2 Cu, 3 cables per phase – 22kV	EC2180 - 1 core 630mm^2 Cu cable with no protection
11kV	Bus connection	Single core 630mm^2 Cu, 3 cables per phase – 22kV	EC2180 - 1 core 630mm^2 Cu cable with no protection
22kV	33MVA transformer circuit	Single core 500mm^2 Cu, 2 cables per phase – 22kV	EC1291 - 1 core 500mm^2 Cu cable with no protection
11kV or 22kV	Capacitors and Reactors	Single core 400mm^2 Al, 1 cable per phase – 22kV OR Single core 240mm^2 Cu, 1 cable per phase – 22kV	EC2181, EC2182, EC2183 – 1 core 400mm^2 Al with DBT (see Note 3) EC2198 – 3 x 1 core (triplex) 400mm^2 Al with DBT EC2175 – 1 core 240mm^2 Cu with DBT EC2195 – 3 x 1 core (triplex) 240mm^2 Cu with DBT
11kV or 22kV	Earthing compensators	Single core 185mm^2 Al, 1 cable per phase – 22kV	EC2193 – 3 x 1 core (triplex) 185mm^2 Al with Nylon
11kV or 22kV	315kVA station transformer	Single core 35mm^2 Al (**See Note 1**) – 22kV The maximum cable size based on the bushing types used by the transformer is 95mm^2.	EC2199 – 3 x 1 core (triplex) 95mm^2 Cu with Nylon EC2191 – 3 x 1 core (triplex) 35mm^2 Al with Nylon
22kV	Bus connection	Single core 500mm^2 Cu, 2 cables per phase – 22kV	EC1291 - 1 core 500mm^2 Cu cable without protection

System Voltage Level	Equipment	Cable Type & Voltage See Note 2	Stock Codes See Note 2
33kV	33MVA transformer circuit	Single core 240mm^2 Cu, 2 cables per phase – 33kV	EC2197 – 3 x 1 core (triplex) 240mm^2 Cu with DBT EC2178 – 1 core 240mm^2 Cu with DBT

Note 1: 35mm^2 Aluminium cable is only suitable if fed from a fuse (due to fuse fault limiting characteristics) and not suitable if fed from a circuit breaker. Use single core 95mm^2 Cu if station transformer is supplied from a circuit breaker and all new greenfield applications.

Note 2: Even when using the standard cables, the cable rating must be checked to ensure that it meets the required circuit rating, as part of the rating study.

Note 3: Phase cables are denoted by each stock code. Availability needs to be confirmed.

7.3 Insulation

HV single core cables shall generally have a semi-conductive conductor screen, XLPE insulation, semi-conductive insulation screen, heavy duty copper wire screen, and composite PVC and HDPE sheath. Longitudinal water blocking shall be provided for all cables in the form of a water blocking tape in accordance with AS 1429.1.

LV Single core cables of size greater than 70mm2 shall generally have XLPE insulation and PVC sheath in accordance with AS5000.1.

Oil filled cables shall not be used. Existing oil-filled cable boxes shall be converted to an air-insulated cable box prior to termination of new XLPE cables.

8 Power Cable Selection

It is compulsory for a cable rating study to be performed on all new cable installations. Parameters such as soil thermal resistivity, cable installation details and cable route are entered as site specific input criteria for the cable rating calculation.

The cable design is dependent on many factors, including:

- system nominal voltage;
- system fault level;
- voltage drop;
- conductor material;
- insulation and shielding material;
- type of installation (whether direct buried or in a trench);
- phase spacing;

- phase arrangement;
- number of conductors installed;
- presence of additional heat sources;
- method of shield grounding;
- earth thermal resistivity;
- ambient temperature;
- current loading;
- load cycling; and
- load factor

Three core cables are not recommended for new HV installations, but some installations may require joining onto existing 3 core cables (e.g. PILC) through transition joints (e.g. PILC to XLPE).

Three core cables may be used for new LV installations.

Cable sizing shall ensure that:

- Cables have sufficient ampacity - the installation that results in the highest insulation temperature should be used to determine the ampacity of a cable routed through several configurations.
- Cables can withstand maximum short circuit current, according to the capacity of both the conductor and the metallic sheath.

Refer to manufacturer data sheets for cable current capacity, short circuit fault withstand, impedance characteristics and derating values for various installation conditions.

8.1 Voltage Rating

For single phase HV cables, the voltage rating of cable insulation should be equal to or greater than the continuous phase-to-earth conductor voltage. For solidly grounded systems, the 110% insulation level of nominal voltage should be used but a higher insulation level may be selected where additional insulation thickness is required. Refer to AS1429.1, Table 1.1 for requirements.

For LV cables, the insulation level shall be 0.6/1kV as per AS5000.1.

8.2 Current Rating

Cables shall meet standard current rating requirements as per Network Standard - Transmission Network Configuration and Rating or as specified in the Works Planning Report (WPR). If the cable installation cannot meet standard current rating requirements, Grid Transformation shall be consulted to discuss revised current ratings. The new innovation and non-standard design flowchart must be followed.

8.3 Termite Protection

All HV cables in the Goldfields load area shall have termite protection. To standardise on the type of 33kV cable used, all 33kV cables should have termite protection. The designer must select an appropriate standard cable with embedded termite protection.

The current preferred methods of cable termite protection are a termicide impregnated outer sheath or double brass tape. Nylon jacket can also be used for termite protection, however consideration should be given to the increase in minimum cable bending radii when nylon is used.

8.4 Cable Connections

The points of connection for each cable must be considered during power cable selection. Number of cables per phase is not only determined by current rating, but also limited by physical space e.g. size of switchboard opening. If a cable is being connected to an existing switchboard, the cable box must be suited for the new cable type e.g. XLPE cannot be terminated into a PILC (oil-filled) cable box. In this case the cable box must be modified to suit XLPE, or a transition joint (XLPE to PILC) used prior to the substation boundary. However, cable joints within the substation can be installed when approved by the Principal Electrical Design Engineer.

9 Cable Installation

9.1 Cable Route

All cables shall be installed in accordance with AS/NZS 3000 and AS 2067. Cable routing in the substation should be practical and provide the shortest possible runs to minimise voltage drop and reduce the amount of cable required in the limited space. Crossing of cables shall be avoided where possible, and multiple layers of cables are not allowed unless it is a crossing or installed on cable ladder.

When determining cable routes for bus couplers connected to an ABB ZS1 switchboard with a cable connection isolation truck at one end, consideration needs to be given to the maximum allowable cable length to permit operation of the isolation truck.

The substation designer must also plan and specify proposed feeder cable routes within the substation boundary in consultation with the Distribution Design Area. Typically, a substation has a minimum of 2 feeder exit points per site, with 6 to 8 feeders allocated per exit.

The cable layout within the cable basement shall be planned to minimise the number of cables crossing the basement escape routes. Where the cables must cross the access/escape route (e.g. the transformer LV cables), they shall be spaced so that personnel can easily step between each cable/set of cables. Feeder exit cable routes shall be shown on drawings, both within the switchyard and within the switchroom basement.

9.2 Cable Derating Factors

The current capacity of cables is dependent on the cable installation parameters. Cable ampacity can be derated by factors such as:

- Installing cables in conduits
- Close proximity to other cables (especially when running in parallel)
- Backfill with higher values of thermal resistivity
- Deeper burial depth of cable installation

These derating factors should be avoided or reduced where possible along the entire cable route. Use CYMCAP software to model the cable installation and identify any limits and possible installation improvements.

9.3 Types of Installation

Cables shall generally be direct buried, in conduit or ducts, laid in culvert trenches, or installed on cable ladders. The installation type is determined in accordance with system conditions as part of a detailed cable rating study. Preference is for the cables to be direct buried as it is the most cost effective method and has the lowest derating factor.

Cables can also be installed along the ground surface in emergency conditions, but only for temporary periods. Cables must be supported and fixed if run along the ground or when laid in culvert trenches. Consideration shall also be given to the potential of cable theft. Exposed cables must be flagged to warn site visitors and routed in a manner to reduce traffic flow near the cables. Bridges across the cables shall be provided if personnel or vehicles are required to cross over the cables.

9.3.1 Direct Buried Cables

Designers shall check and confirm via existing cable layout/underground services drawings or on-site testing, that the proposed cable run will not interfere with existing cables, foundations, equipment or services.

The depth of cables shall be determined primarily by rating studies, taking into account measured soil thermal resistivity at the site. On Greenfield sites, or where site specific soil data is not available within the AMP TX, soil thermal resistivity tests shall be performed. For typical soil temperatures in the South West Interconnected System, refer to Appendix B.

Refer to drawing SSTZ1/3/9/1 for typical underground cable installations, spacing, soil thicknesses and mechanical protection requirements. Direct buried cables shall be protected by protective plastic covers installed at a depth of 50-75 mm above cables.

Directly buried cables installed in trefoil formation shall be restrained using heavy duty PVC cable ties to maintain the formation during the installation. Spacing between cable ties shall not exceed 2000mm.

Distribution feeder cables that are direct buried within the substation boundary should be installed as shown in drawing SSTZ1/3/9/1.

9.3.1.1 Thermal Backfill

Where backfill is required to improve cable ratings, compacted yellow brickies sand is the preferred medium. Required thickness of backfill around the cable on all sides shall be determined by the cable rating study. Due to studies completed in recent projects showing higher than default values, yellow brickies sand shall use a default thermal resistivity of 1.6°C M/W at a moisture content of 1%. Backfill shall be tested by a NATA accredited laboratory (sample-testing) to ensure that thermal resistivity values used in the cable rating study is accurate. The test shall be performed after oven drying to achieve a moisture content of 1%.

Where site conditions require further improvement to cable ratings that can't be achieved with yellow brickies sand alone, a sand/cement mixture of 20:1 or 14:1 may be used to surround the cables as necessary. The thermal resistivity of such backfill shall be tested by a NATA accredited laboratory.

9.3.1.2 Cable Protection

To minimise damage to direct buried underground cables during manual or mechanical excavation works, the presence of underground cables shall be marked by orange cable covers providing mechanical protection.

The orange cable covers shall be 150mm wide and shall be installed as indicated in drawing SSTZ1/3/9/1.

9.3.2 Conduits and Ducts

Generally cable conduits and ducts are not preferred due to the derating effect of the duct, but in some installations cables may need to be installed in PVC conduits. Feeder cables exiting the substation boundary are typically installed inside conduit to enter the switchroom. The effect of installation of cables in ducts/conduits must be considered during cable rating studies.

The benefit of using conduits and ducts for cable installation is staging of construction. Conduits and ducts can be installed prior to site resurfacing, roads and civil works, which allows cable hauling to be completed at a later stage of construction without major rework, saving project time and cost.

Switchroom basements shall use approved cable sealing systems to prevent water ingress and flooding from cable and conduit penetrations as mentioned before.

9.3.3 Culverts

Installation of cables in inverted culverts buried in the ground should be considered if cable rating cannot be achieved under direct buried installation. Culverts can also be utilised for construction staging (e.g. installation over existing cables to minimize outages) or for installation of temporary cables (e.g. RRST cables).

HV power cables, LV cables and instrumentation /control /communication cables laid in culverts shall be segregated as specified in this document.

Culvert dimensions and cable spacing shall be determined by a detailed cable rating study.

Culverts shall be covered by a lid with a non-slip top surface, such as concrete, FRP or steel floor plate, and continue across the complete run of the enclosure. Trafficable covers should be used when crossing roadways. Cable trench covers do not need to be earthed. An air gap should be left between each plate if additional cable cooling is required. Ideally, the duct should also be open at both ends to allow for natural convection and minimise derating of the cable. For a cable installed inside a culvert, a higher ambient temperature should be used to derate the cable. Cable derating can also be calculated using IEC 60287.

Suitable supports shall be provided to ensure trench lids cannot fall inside the culvert. Adequate drainage inside the culvert shall also be provided.

9.3.4 Cable Ladder

In certain circumstances where very high current ratings are required, such as LV cables connected to reactive compensation equipment (STATCOMs etc) or Battery Energy Storage System (BESS), the most practical and cost-effective installation method is to install the multiple cables per phase required on above ground, multi-level, shaded cable ladder.

When this method of installation is used, cables shall be installed in trefoil configuration on the ladder, with one cable of each phase making up each trefoil group. Non-ferrous cable clamps of suitable strength shall be installed at regular intervals along the ladder as determined by short circuit force calculations.

Where approaching terminal boxes of connected equipment, it is necessary to break the cables out of trefoil configuration for a distance approaching the terminal box to allow phases to reach the correct phase terminal within the box. Where this occurs, it is essential to ensure the cable support structure does not create closed magnetic loops around a cable or groups of cables of the same phase. Aluminium, stainless steel, or fibreglass support structures may be required if closed loops around the cables is unavoidable.

9.4 Spacing

All cables shall be laid neatly in single layer parallel runs in trefoil. A study shall be run for each installation to ensure that the design meets the required ratings outlined in the Network Standard – Transmission Substations Functional Requirements.

If possible, cables shall be installed at a distance from each other such that the cables are independent of each other. HV cables shall not be installed less than 300mm from an earth grid electrode.

9.5 Cable Supports

Galvanised angle supports shall be used to elevate and secure all cables inside culverts, in a building cable trench or basement. Single core cables installed in trefoil or flat formation are to be clamped to supports using Unistrut cable clamps or similar. Refer to drawings in Appendix A for typical installation details. Cable supports can be mounted to the sides of the culvert and multiple levels may be installed. Separation distance between the levels in the stack must be taken into account as part of the cable rating study.

For earthing requirements of cable support structures, refer to Substation Earthing Design Standard. Earthing cables must be coloured green/yellow for inside buildings and black for external use and within cable trenches.

All cables installed on cable supports shall be secured to the ladder with non-ferrous cleats or stainless steel cable ties. Cleats specified in Western Power approved equipment list shall be used. Refer to drawings in Appendix A for typical installations. When cleating triplex cable to cable supports, a cleat which permits any orientation of the trefoil group shall be used.

Cables must be supported by clamping close to the point of termination, to prevent stress on the bushing insulators caused by the weight of the cable. Certain switchboard manufacturers provide clamps within the cable compartment. If cable compartment clamping is not available, the cables must be clamped directly under the cable compartment. Cables must not be supported solely by the cable gland arrangement.

Cable ties are not to be used a substitute or cable clamps and cable supports.

9.6 Single Core Configuration

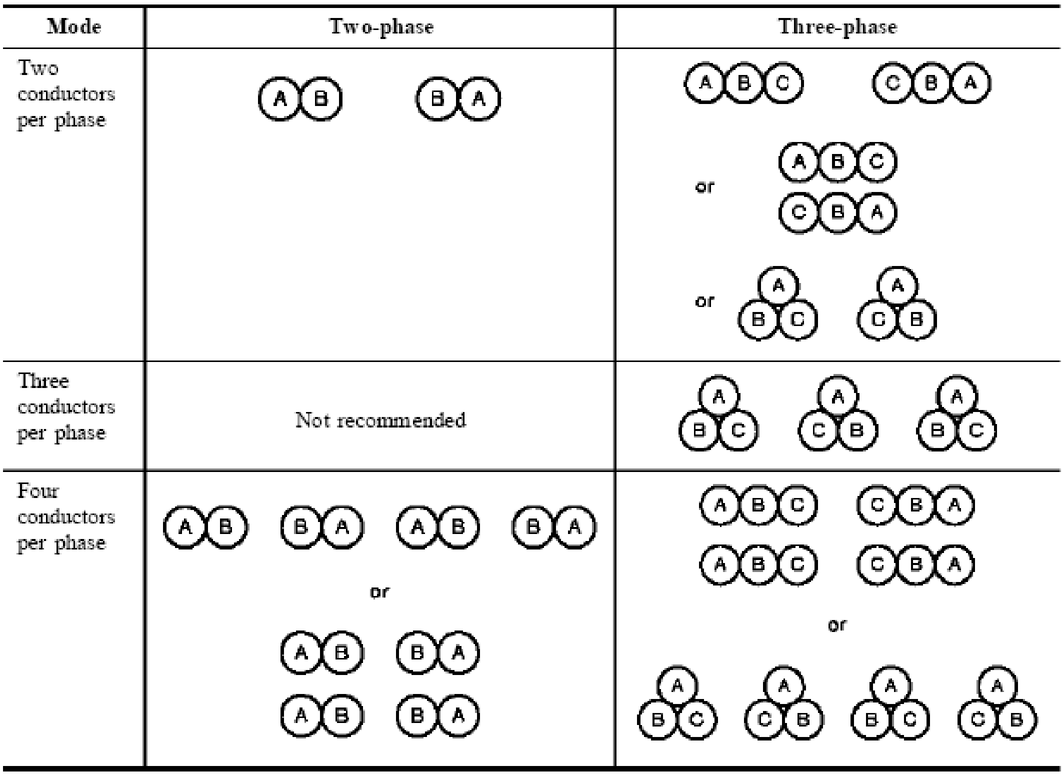
Single core cables carrying alternating current shall preferably be installed in close trefoil formation along the complete run of the cable and as close as possible to the termination points to minimise inductive reactance. If crossing of cables is required to maintain correct phasing, the crossing shall be located just prior to the appropriate termination.

Parallel runs of single core cables shall maintain trefoil formation, and spacing between trefoil groups shall be determined by the cable rating study. Multiple parallel circuits shall be arranged to minimise magnetic fields as indicated in Figure 9.1.

If an installation requires one single core cable per phase configuration or increased current rating, flat formation installation may be used where space is not an issue.

RECOMMENDED CIRCUIT CONFIGURATIONS FOR THE INSTALLATION OF SINGLE-CORE CABLES IN PARALLEL

(Informative)



NOTES:

1 Neutral conductors are to be located so as to not disturb the symmetry of the groups as illustrated.

2 Non-symmetrical configuration may cause unequal distribution of current between conductors. Provision should be made to maintain the recommended configurations to avoid these problems.

Figure 9.1: Recommended Circuit Configuration for the Installation of Single -Core Cables in Parallel (taken from AS/NZS 3008.1.1:1998)

A single core cable generates an alternating magnetic field around itself which can cause mutual heating and cable derating from hysteresis and eddy current losses when ferrous metal is allowed to encircle the cable. Hence individual single conductor cables carrying alternating current shall not pass through any closed ferrous circuit, and where three single phase cables pass through a steel bulkhead, all cables must pass through the same hole.

Under fault conditions, single core cables may be subjected to large electromechanical forces which tend to result in excessive cable movement, hence cables shall be adequately restrained. Cables installed on cable supports shall be adequately secured with non-ferrous cable cleats. Cleat spacing may need to be calculated (to AS 3865) for a specific installation but shall not exceed 1500 mm. The cleat manufacturer shall be consulted to determine the force withstand of the selected cleat.

The above cable clamping requirements are also applicable to twisted cable.

9.7 Bending Radius

The safe bending radius for an electric cable is limited by the flexibility of its insulation and jacketing material. The pull in radius and set radius shall be greater than or equal to the manufacturer's specification during installation and after installation respectively.

Where there is no bending radius specified, the elongation of the conductor, insulation and sheath when bending a cable shall not exceed the elongation limits specified in AS/NZS 1125 for the conductor and AS/NZS 3808 for the insulation and sheath.

The pull in radius and set bending radius shall be shown on the cable layout (or other relevant) drawing to ensure the correct bending radius is met on site.

9.8 Segregation

Generally, power cables should be segregated from other cables and installed so that their voltage cannot be impressed on any lower voltage system. Two cables layouts are considered independent (i.e. no de-rating) if the two inner-most cables are minimum 2m apart.

Cables shall be segregated according to voltage and duty as follows:

- Low Voltage/ Control/Instrumentation/Communication cables
- High Voltage cables

Individual cable trenches with alternative routes shall be used for each cable category mentioned above.

If segregation is not possible (e.g. below a substation building), separation shall be provided. Separation shall be at least 300mm between HV and LV/control/instrumentation/communication cables.

In direct buried installation, such as capacitor banks, minimum separation shall be maintained between each category of cables as specified above.

All direct buried cables shall be spaced not less than 100 mm from other underground services.

9.9 Identification

Individual HV cables do not require cable identification labels. However, for identification of circuits, connected equipment shall be identified by marking equipment/switch numbers below the floor space.

Substation underground cable layout drawings shall show the route of cables. These layout drawings shall be revised if the cable route changes during installation.

10 Joints

Straight joints shall not be used on Greenfield sites. Straight joints shall not be used on Brownfield sites to join two existing transformer or bus coupler cables. The only exception is where the straight joint avoids breaking down a bitumen compound filled box or a box that cannot be modified to accommodate XLPE cable terminations. Substation Design shall be consulted prior to issuing designs involving a straight joint in Brownfield sites involving PILC cable.

The location of all cable joints shall be indicated and dimensioned on the cable layout design drawings.

Approved Western Power equipment shall be used when selecting the type of joint kit to be used for straight joints.

11 Terminations

The cores of all cables shall be terminated in accordance with the recommendations of the manufacturer of the installed equipment, cables and termination kits.

All bolts, nuts and stud screw threads shall comply with AS 1111 I.S.O., Metric Hexagon Commercial Bolts and Screws. Spring and flat washers shall be provided under all nuts, and flat washers under all bolt heads. Washers shall be the correct size for the bolt.

All cable terminations shall be selected to suit the cable size and type being terminated, the location, system voltage and termination type. Termination locations include the power transformer, switchboard, station transformer and earthing compensators.

All new transformers are fitted with C-type bushings for the use of elbow type terminations. It is the responsibility of the designer to select elbow type terminations appropriate for the size and type of cable being used and place it on the bill of materials.

Cable termination types at indoor switchgear varies depending on the type of indoor switchgear being used. Switchgear may be provided with an air box, bushings for elbow type connectors, or sockets for plug-in connex type connectors. It is the responsibility of the designer to select terminations appropriate for the size and type of cable being used and place it on the bill of materials.

Cable terminations on older type power transformers (brownfield), earthing transformers and switchboards were made within air insulated cable boxes. For type tested equipment, the minimum clearances stated in AS2067 need not be maintained because the ability to withstand the test voltage is established by a dielectric type test. Individual equipment not type tested shall maintain minimum clearances between phase-to-phase and phase-to-earth as stated in AS2067.

All cable terminations shall have sufficient means of cable support. Vibrational forces shall be taken into account when supporting and terminating cables.

Before each termination is made, it shall be ensured that the arrangement is such that the system phase rotation at the equipment is as per the system standard.

When terminating cables in an air insulated cable box, the designer must ensure the entire surface of the cable lug is in contact with the copper bar within the cable box to ensure the connection maintains the full current rating of the cable lug.

Plug-in terminations may be used where quick and easy connections and disconnections are required such as for the Rapid Response Spare Transformer (RRST), which is only installed on a temporary basis.

11.1 Outdoor Installations

For outdoor terminations, outdoor type cable terminations must be used. All outdoor cable terminations shall be fitted with the requisite number of insulator sheds depending on the voltage.

Surge arrestors shall be installed at all cable/aerial transitions.

11.2 Cable glands

All cables entering into equipment shall do so through approved weatherproof compression type cable glands. The correct gland shall be selected for each cable to the manufacturer's recommendations and confirmed by the on-site measurement of cable dimensions. Nickel plated brass is the preferred cable gland type for HV power cables, stainless steel may also be used. Plastic / PVC glands are acceptable for indoor MV switchboards only.

All glands shall be securely fixed to the gland plate. PVC shrouds shall be provided for outdoor cable glands.

Cable glands cannot be used to support the weight of the cable and suitable clamps need to be used.

Note that the plate at the bottom of some switchgear is not a gland plate but just a dust plate. Thus, cable clamping should be done inside the switchboard. See Figure 13.2.

11.3 Heat and Cold Shrink

Cable terminations, splicing and jointing shall be carried out using approved heat-shrink or cold-shrink kits appropriate for the type and voltage rating of the cable.

11.4 Lugs

Lug sizes shall comply with the cable manufacturer's recommendations and terminal dimensions. The size of lug shall be suited to the size of conductor terminated. Lugs on cables exposed to weather shall be sealed to prevent the ingress of moisture into the cable.

Single hole lugs shall not be used for transformer and bus cable connections (or circuits exceeding **400A** current rating). Twin hole lugs must be used for circuits exceeding 400A.

Mechanical shear-bolt lugs are preferred over crimp type lugs due to ease of installation on site.

Single hole lugs are suitable for use on cable screen terminations. Lug size to be chosen to suit size of conductor screen wire.

Refer to standard cable termination drawings for details of recommended cable lugs.

11.5 Dead-End Connections

Cables that are cut (to be made redundant or for construction staging), must be capped and earthed to the main earth grid at both ends. It is preferred that cables which are made redundant are excavated and removed from the substation, however if this in not practical, they may be left in-situ capped and earthed at both ends. Redundant feeder exit cables shall be physically removed from within the substation to prevent them creating an EPR transfer hazard. They can be capped and abandoned outside the boundary of the substation earth grid if required in accordance with Distribution Design Area Design Standards. Depending on cable type, cables shall be earthed according to the following assembly drawings:

- PILC cable - SS1/15/0/615/2
- XLPE cable - SS1/15/0/615/3

11.6 Double Feeder Cable Terminations

There are extra requirements when two feeder circuits are connected to a single circuit breaker, for both indoor and outdoor switchgear applications.

For details, refer to the Design Guideline “Switchboard Double Cable Terminations”

12 Building Penetrations

For new buildings, all penetrations for HV cables through the basement walls must be sealed with an approved cable sealing system. Approved systems include Hauff Technik, Roxtec and Filoseal or equivalent products. The sealing system manufacturer must be consulted when the seals are selected to ensure they will be appropriate for the cables used. The type of seal must be specified in the design drawings.

For existing buildings, any penetrations created by cable entries shall be sealed after completion of cable laying as shall any unused holes or conduits. All conduit and cable penetrations must be sealed with an approved water tight sealant or retrofitted cable sealing system. For cables passing between fire separated rooms of a building, the seal used must also be fire retardant. The sealing method used shall restore the integrity and degree of weatherproofing and fire rating if applicable of the original surface.

13 Earthing and Fault Indication

HV Cables shall contain a heavy duty copper wire screen to provide an earth fault return path. The screen shall be sized to withstand the prospective earth fault level.

The general earthing requirements for HV power cable screens are as follows:

a) A separate external earth bar, connected to the substation earth, shall be provided for cable earth screens.

b) Each phase cable shall be individually earthed to the earth bar.

c) The installation shall be such that screens can be tonged to measure circulating currents.

d) All earthing designs to be approved by the substation design engineer.

The specific earthing requirements for each type of cable circuit is as follows:

a) Power transformer and capacitor single core cable screens shall only be earthed at source end **(single point bonding**). This is to prevent the flow of currents that could de-rate the cable, due to induced voltages between metal sheaths and screens, which could occur if the cable was bonded and earthed at both ends (double point bonding).

b) Bus coupler cable screens earthed at only one end **(single-point bonding).**

c) Earthing transformer cable screens earthed at power transformer end only **(single-point bonding).**

d) Station transformer cable screens earthed at switchboard end only **(single-point bonding)**.

e) All three core cables terminated within the substation shall have the screen, sheath and armour bonded and earthed at both ends.

f) Typically, due to the balanced arrangements of three core cables, voltages induced into the screen will cancel each other out; therefore, circulating currents (and hence derating of the cable due to these) are minimal.

g) Distribution feeder cable screens should be earthed at the substation end with the remote end earthed according to Distribution Area Design Standards.

h) Switchboards with prime earth leakage protection shall **not** have their cable screens connected to the switchboard earth, but directly to the main substation earth.

13.1 Toroidal Current Transformers / Sensors and Fault Indicators

Note: The information below relating to toroidal current transformers applies also to current sensing devices installed around cables.

Toroidal current transformers (CT) can be installed around cables and used for protection and metering. Incorrect installation of toroidal CT's can lead to decreased fault sensitivity when used for protection purposes.

Where toroidal CTs are required around cables connected to indoor switchgear, consideration needs to be given the amount of space required in the switchgear cable box. If necessary, drop down boxes may need to be fitted to the indoor switchgear to ensure enough space is available to install toroidal CTs within the cable box. For an example electrical assembly for ABB switchgear, refer to drawing SS1/33/3/600/1.

When HV cables pass through toroidal CT's used for protection, it is important to ensure that these toroidal CT's only measure phase current. As the cable screen also passes through the toroidal CT, it is important to ensure any fault current in the screen does not affect the measurement accuracy.

To ensure that only phase current is measured, it is a requirement to pass the cable with screen through the toroidal CT and then return the screen back through the toroidal CT before it's connected to earth. See Figure 13.1 and standard drawing SS1/15/0/615/1 for a typical earthing arrangement.

For CTs used for metering purposes only, where it is physically impractical to route the cable screen earth in this manner, substation design should be consulted to determine if dispensation of this requirement can be granted for the specific case.

Fault indicators are also used in double feeder cable termination installations to allow fault discrimination between feeder cables. Each phase fault indicator shall be installed in the same manner as a toroidal CT. The earth fault indicator shall have the feeder cable earth sheaths (all 3 phases) passed through prior to bonding to earth. See standard drawing Figure 3 for a typical double feeder connection arrangement.

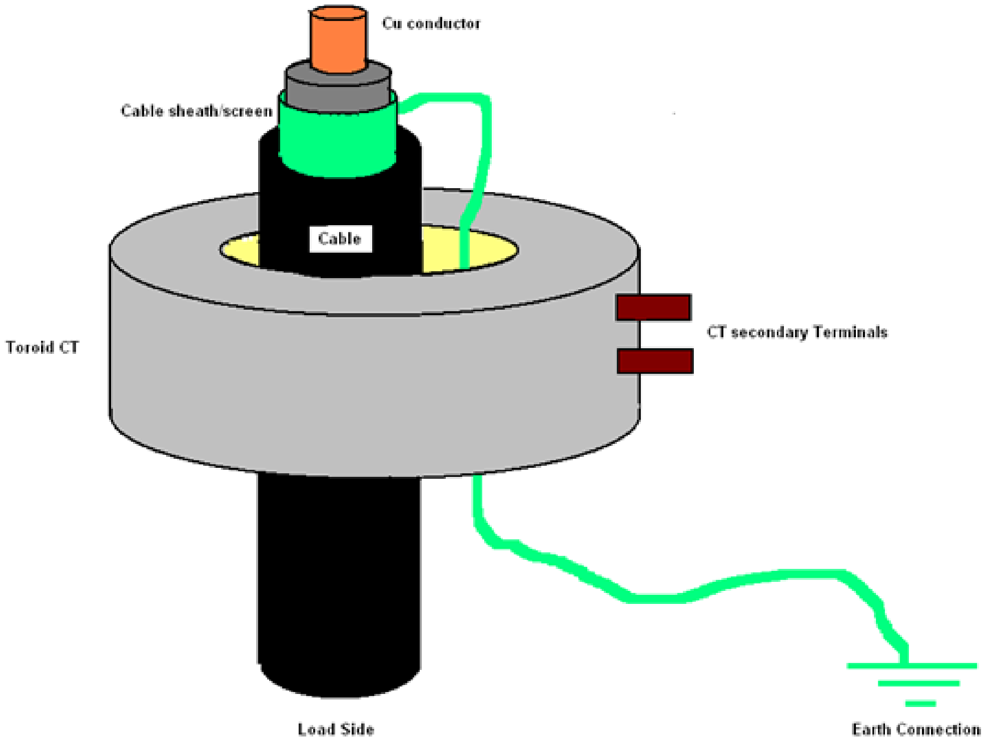


Figure 13.1: Toroidal CT Diagram (Sheath/Screen returned through Toroidal CT)

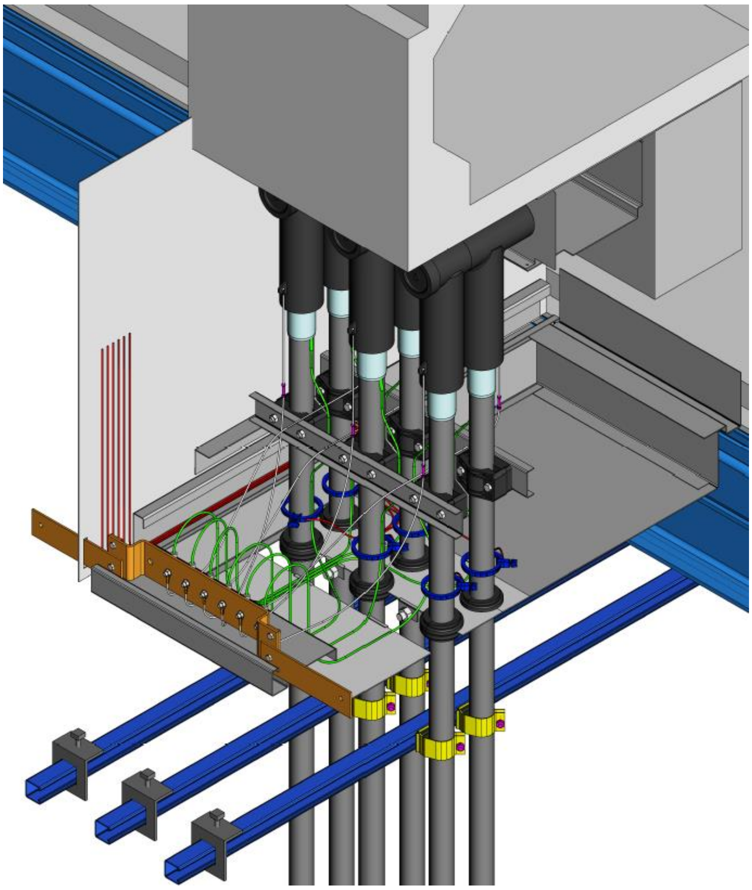


Figure 13.2: Current sensing devices for a typical feeder double cable termination arrangement

13.2 Switchboard Earth Frame Leakage

Special care should be taken on the earthing of sheaths/screens of cables connected to switchboards with Frame Leakage Protection in order to prevent incorrect operation under cable faults or any other condition causing current to flow in the cable sheaths/screens (e.g. unbalanced loads, induction etc.).

A main cause of maloperation of frame leakage protection is the incorrect earthing of cable screens/sheaths connected to switchboards.

Frame leakage protection requires the electrical segregation of feeder cable screens/sheaths earth paths from the switchboard earthing paths so that fast acting protection can be used to discriminate for switchboard earth faults only. This is accomplished by connecting feeder cable screen earths to a dedicated earth bar, connected to the substation earth, which is isolated from the switchboard frame as shown in Figure 13.3. Incorrect earthing such as connecting cable screen/sheath earths to the switchboard frame will compromise discrimination so that earth fault currents returning from feeder faults via the cable screen/sheath, can cause the frame leakage protection to operate. Any incorrectly earthed feeder cable on a switchboard can cause a maloperation for a fault on any of the other feeders being supplied from the same switchboard/transformer. This can also apply to incorrectly earthed secondary cables.

Western Power sites with frame leakage protection include Hay St, Milligan St, and Picadilly substations.

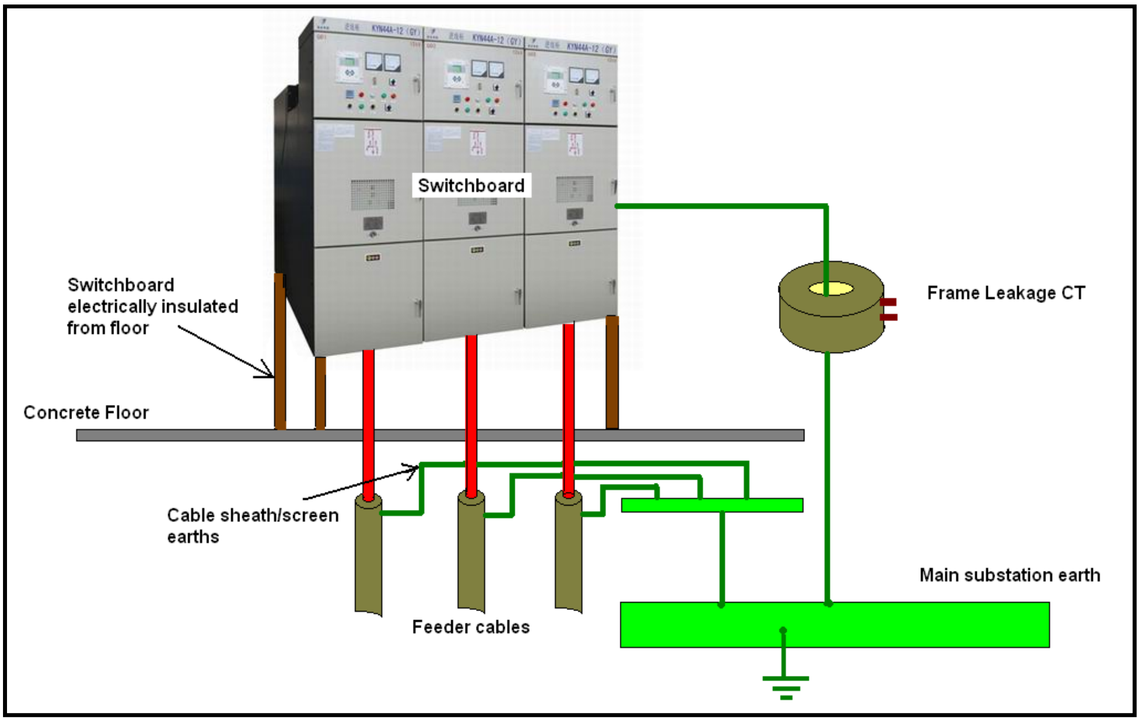


Figure 13.3. Cable Earthing with Frame Earth Leakage Protection diagram

13.3 Induced Voltage Limit for Long HV Cables Lengths

Long cable lengths (typically greater than 200m) should be avoided where possible in the cable design. However, if the design requires long cable routes, the induced voltage on the cable screens must be considered.

Under steady state and fault conditions, long cable lengths can have a cable screen voltage that exceed safe limits. This safe limit is defined such that if a person touches or steps on the screen it does not pose a hazard. The typical safe limit for screen induced voltage used in the industry is 65V.

If the screen voltage exceeds the safe voltage limit, Sheath Voltage Limiters and/or double end bonding should be considered where both ends of the cable screen are connected to the system earth. With the double end bonding method, no standing voltages occur at the cable ends; however, circulating currents may flow in the screen as the loop between the two earthing points is closed through the ground, resulting in the generation of heat. These circulating currents are proportional to the conductor currents and therefore reduce the cable ampacity. This cable derating due to circulating currents must also be considered when performing the cable sizing calculation.

14 Testing

HV cables shall be installed to allow testing to be easily performed. Required testing includes sheath integrity testing and insulation VLF testing.

All cables shall be connected only after the completion of all tests. All cable screens shall be checked to ensure they are continuous and properly earthed.

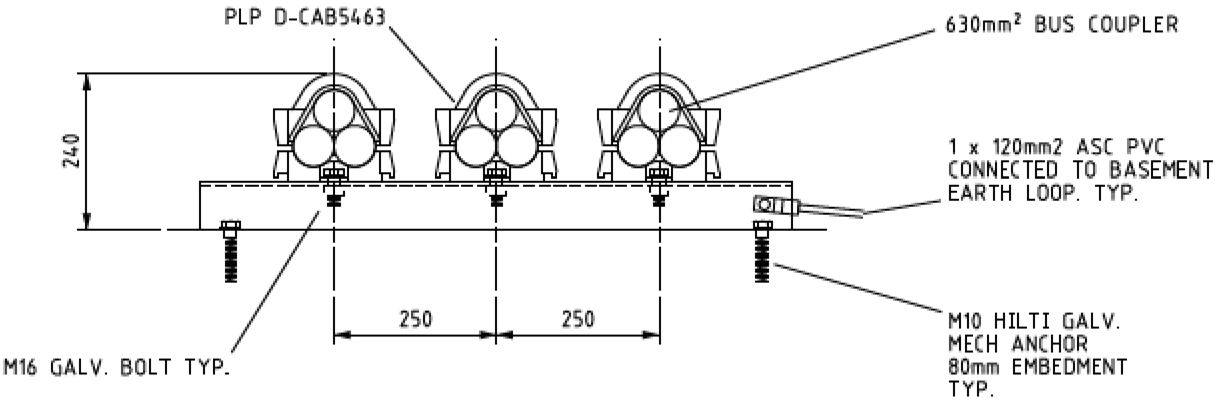
15 Standard Drawings

Table 15-1 Standard Drawings

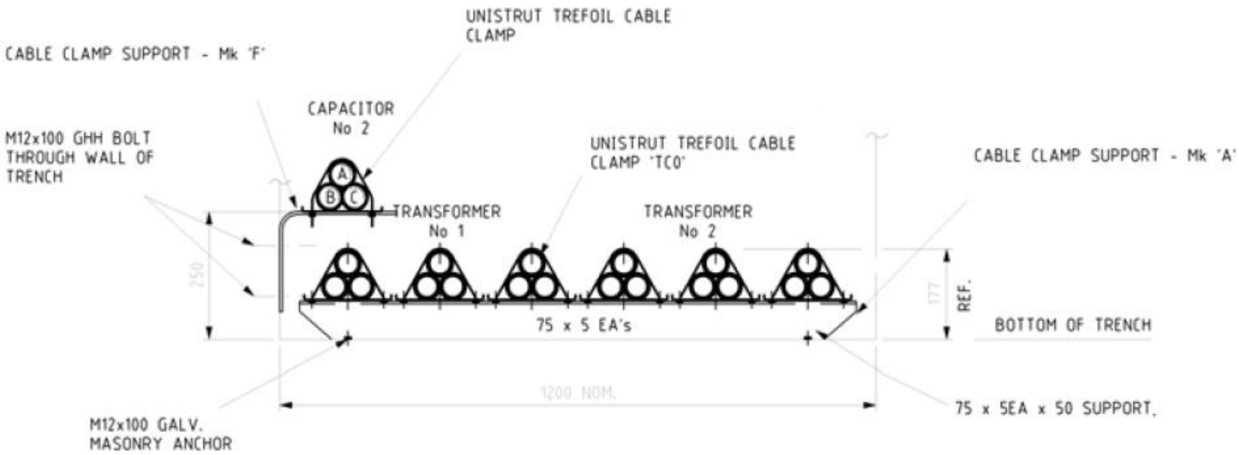
Drawing Number	Drawing Title
SSTZ1/3/9/1	TEMPLATE Substation 132/22kV – Switchyard – Arrangement – Underground Services – Cable Entry
SSTZ1/3/9/2	TEMPLATE Substation 132/22kV – Switchyard – Arrangement – Underground Services – Aerial Entry
SS1/15/0/615/1	Earthing Assembly – XLPE Cable Sheath to Switchboard
SS1/15/0/615/2	Earthing Assembly – 800sqmm PILC Cable Dead End Connection
SS1/15/0/615/3	Earthing Assembly – 240sqmm XLPE Cable Dead End Connection
SS1/15/0/614/12	Earthing Arrangement – Cable Screen Earthing to Cable Box Enclosure
SS1/33/3/600/1	Switchboard Assembly – 11kV Feeder Switchboard with Drop Down Box
SS1/33/3/601/1	Switchboard Assembly – 11kV Incomer Switchboard Power Cable Installation
SS156/3/A/33/1	Switchroom 2 Cable Basement Details (sample)
SS156/3/A/34/1	Switchroom 4 Cable Basement Details (sample)
SS156/3/A/37/1	Unistrut Cable Support Detail (sample)

Appendix A: Typical cable support installation of single core cables

Cable support details (on unistrut)



Culvert trench details



Appendix B: Soil Ambient Temperatures

Table B-1 Soil Ambient Temperatures

Depth (mm)	Summer Temperature
100	44.00 C°
150	40.00 C°
200	36.00 C°
250	35.33 C°
300	34.67 C°
350	34.00 C°
400	33.33 C°
450	32.67 C°
500	32.00 C°
550	31.70 C°
600	31.40 C°
650	31.10 C°
700	30.80 C°
750	30.50 C°
800	30.20 C°
850	29.90 C°
900	29.60 C°
950	29.30 C°
1000	29.00 C°
1000+	28.00 C°