Part of Energy Queensland

Substation Standard

Standard for Cables and Cable Installations

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If this standard is a printed version, to ensure compliance, reference must be made to the Energy Queensland internet site www.energyq.com.au to obtain the latest version.

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Abstract: The aim of this document is to establish a set of standard cables used in substations and to provide guidelines for cabling practices with the objective of providing safety to personnel and minimizing cable failures.

Keywords: Cables, cabling, screening, screen earthing, cable trays, cable ladders, fire stops

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1 Overview

1.1 Purpose

This document establishes a set of standard cables and provides guidelines for design of cable systems and cabling installation practices in Energy Queensland (EQ) substations with the objective of:

- Complying with WH&S legislation, policies and requirements
- Minimising cable failures and their consequences
- Maximise the reliability of supply, minimise potential outage costs
- Be economical without detrimental effects on cable life
- Reduce EMF level.

1.2 Scope

This document is intended to apply to internal cabling within transmission substations and zone substations.

This document covers types of cables used in substations including:

- HV power cables
- LV power cables
- Control and instrumentation cables

It also covers practices to be incorporated in the design of cable systems and preferred Installation methods

Communications cables and cabling are outside the scope of this document

Building wiring (light and power circuits) installed in accordance with AS/NZS 3000 are also excluded from the scope of this document.

2 References

2.1 Legislation, regulations, rules, and codes

Electrical Safety Act 2002, and associated Guides and Codes of Practice. Queensland Government

Electrical Safety Regulation 2013. Queensland Government

Work Health and Safety Act 2011. Queensland Government

Work Health and Safety Regulation 2011. Advisory Standards. Queensland Government

Building Code of Australia. (BCA)

2.2 Energy Queensland controlled documents

Standard for Climatic and Seismic Conditions – 3057510

Standard for Clearances in Air STNW3013 - 3054141

Standard for Substation Signage STNW3037 – 2941554

Standard for Electric and Magnetic Field Design STNW3042 – 3060782

Plant Rating Manual – 4179110

Substation Design Standards RED364 – 3062554

Panel Wiring, STNW3021 -2938164

2.3 Energy Queensland other documents

Energex Substation Design Standard, RED364

Energex Underground Distribution Construction Manual

Cable pulling tension calculator, Cable Pulling Tension Calculator Issue 2a - December 2022.xlsm (sharepoint.com)

TSD0027 – Application Details and Performance URD & Power Cables

Selection guide – substation control and multicore cables

TSD0171 – Guide to Passive Fire Protection in Bulk & Zone Substation Basements

TSD0188 - Guide to Cable Support and Fixing Requirements in Substations

Stds A611 - Where Insect Protected Cables Shall Be Used in the EQL North South Region

Standard Optical Fibre Cables, OFIBER-ARCH-012

2.4 Other sources

AS/NZS 1429.1:2006, Electric cables – Polymeric insulated. Part 1: For working voltages 1.9/3.3 (3.6) kV up to and including 19/33 (36) kV

AS/NZS 1429.2:2009, Electric cables – Polymeric insulated. Part 2: For working voltages above 19/33 (36) kV up to and including 87/150 (170) kV

AS 61386, (All parts) Conduits systems for cable management

AS 2067:2016, Substation and high voltage installations exceeding 1 kV a.c

AS/NZS 2373:2003, Electric cables – Twisted pair for control and protection circuits

AS/NZS 2967:2014, Optical fibre communication cabling system safety

AS/NZS 3000 : 2018. Amendment 1 – 2020, Amendment 2 - 2021, Wiring Rules

AS/NZS 3008:2017, (All parts) Electrical installations – Selection of cables

AS/NZS 5000.1:2005, Electric cables – Polymeric insulated. Part 1: For working voltages up to and including 0.6/1 (1.2) kV

AS/NZS 5000.3:2003, Electric cables – Polymeric insulated. Part 3: Multicore control cables

AS/NZS 60840:2020, Power cables with extruded insulation and their accessories for rated voltages above 30 kV (Um=36 kV) up to 150 kV (Um=170 kV) – Test methods and requirements

AS 62271.301:2022, High voltage switchgear and controlgear. Part 301: Dimensional standardisation of terminals

IEC 60287, (All parts) Electric cables – Calculation of the current rating

IEC 60502, (All parts) Power cables with extruded insulation and their accessories for rated voltages from 1 kV (Um=1.2 kV) up to 30 kV (Um=36 kV)

IEC 60853, (All parts) Calculation of the cyclic and emergency current rating of cables

IEC 60986:2008, Short circuit temperature limits of electric cables with rated voltages from 6 kV to 30 kV

IEC 61443:2008, Short circuit temperature limits of electric cables with rated voltages above 30 kV

IEC 61537:2007, Cable Management – Cable tray systems and Cable ladder systems

IEC/TR 62095:2003, Electric cables – Calculations for current ratings – Finite element method

IEC 62271-209, High-voltage switchgear and controlgear – Part 209: Cable connections for gas-insulated metal enclosed switchgear for rated voltages above 52kV.

ANSI/NFPA 70.2011, National Electrical Code

IEEE 525-2007, IEEE Guide for the Design and Installation of Cable Systems in Substations

NEMA VE 1-2017, Metal Cable Tray Systems

NEMA VE 2-2013, Cable Tray Installation Guidelines

EN 50180, Bushings above 1kV up to 52kV and from 250A to 3.15kA for Liquid Filled Transformers

EN 50181, Plug-in type bushings above 1kV up to 52kV and from 250A to 3.15kA for equipment other than liquid filled transformers

ENA (British) Engineering recommendation C55-4 2014, Insulated Sheath Power Cable Systems

CIGRE 005, Current ratings of cables for cyclic and emergency loads

CIGRE 124, Guide on EMC in Power Plants and Substations

Nexans, High Voltage Cables (catalogue)

Unistrut (Tyco), Electrical and mechanical support systems (catalogue)

3 Definitions and abbreviations

3.1 Definitions

For the purposes of this standard, the following definitions apply.

Accessibility	As applied to cabling/wiring method: Capable of being removed or exposed without damaging the building structure or finish or not permanently closed in by the structure or finish
Bonded (bonding)	Connected to establish electrical continuity and conductivity
Cable fire break	Material, devices, or an assembly of parts installed in a cable system, other than at a cable penetration of a fire resistive barrier, to prevent the spread of fire along the cable system
Cable screen/shield	A non-magnetic material applied over the insulation of the conductor or conductors to confine the electric field of the cable to the insulation of the conductor/conductors for reducing electrostatic coupling between the screened conductors and others
Cable penetration	An assembly or a group of assemblies for electrical conductors to enter and continue through a fire-rated structural wall, floor, or floor-ceiling assembly

Cable penetration fire stop	Material, devices or an assembly of parts providing cable penetrations through fire-rated walls, floors or floor-ceiling assemblies and maintaining their required fire rating
Cable tray system	A section or assembly of sections, and associated fittings, forming a mechanical system used to support cables and raceways
Common-mode noise (longitudinal)	The noise voltage that appears equally and in phase from each signal conductor to earth. Common-mode noise may be caused by one or more of the following: • Electrostatic induction. With equal capacitance between the signal wires and the surroundings, the noise voltage developed will be the same on both signal wires • Electromagnetic induction. With the magnetic field linking the signal wires equally, the noise voltage developed will be the same on both signal wires
Common-mode to normal-mode conversation	In addition to the common-mode voltages which are developed in the single conductors by the general environmental sources of electrostatic and electromagnetic fields, differences in voltage exists between different earth points in a facility due to the flow of the earth currents. These voltage differences are considered common-mode when connection is made to them either intentionally or accidentally, and the current they produce are common-mode. These common-mode current can develop normal-mode noise voltage across unequal circuit impedance
Conduit	Parts of a closed wiring system enclosing cables in an electrical installation, which allow the cable to be drawn in or replaced. Conduits may have a circular or non-circular cross-section
Control cable	A cable used for control, measuring and protection circuits
Coupling	The mode of propagation of disturbing energy from a power system to a telecommunication system. There are three forms of coupling between the two systems. Magnetic (inductive) coupling, electric (capacitive) coupling, and conductive (resistive) coupling. In addition, coupling by electromagnetic radiation exists and is associated with propagation of radiation fields, e.g. radio frequency interference (RFI), electromagnetic pulse (EMP), and corona
Double Brass Tape	Overlapped helically applied
Earthed (earthing)	Connected (connecting) to earth or to a conductive body that extends the earth connection
Earthed, solidly	Connected to earth without inserting any resistor or impedance device
Emergency cyclic capacity (EEC)/Long term emergency rating (LTER)	Of a transformer: The maximum permissible peak daily emergency loading for a given load cycle that a transformer can operate at for at least six months without exceeding acceptable thermal limits and loss of transformer life
Fire resistive barrier	A wall, floor or floor-ceiling assembly erected to prevent the spread of fire
Fitting, cable tray	A component that is used to change the size or direction of a cable tray system

Halogen-free conduits and fittings	Conduits and fittings which, on combustion, produce low levels of halogen halide-acid gas emission
HFI-90-TP	Halogen Free Thermoplastic Insulation, suitable up to 90 °C, having characteristics of reduced smoke emission and reduced flame propagation properties in fire conditions
HFS-90-TP	Halogen Free Thermoplastic Sheath, suitable up to 90 °C, having characteristics of reduced smoke emission and reduced flame propagation properties in fire conditions
High voltage power cable	A cable designed to supply power to substation utilization devices rated higher than 1000 V
Instrumentation cable	A cable used for Supervisory Controls and Data Acquisition (SCADA) systems or event recorders, and thermocouple and resistance temperature detector
Ladder cable tray	A fabricated structure consisting of two longitudinal side rails connecting by individual transverse members (rungs)
Low voltage power cable	A cable designed to supply power to substation utilization devices rated 1000 V or less
Noise voltage	Extraneous disturbing voltage signal due to coupling
Non-flame propagating conduits and fittings	Conduits and fittings which may or may not ignite as a result of an applied flame and which do not propagate the flame
Normal-mode noise (transverse or differential)	The noise voltage that appears differentially between two signal wires and acts on the signal sensing circuit in the same manner as the desired signal. Normal-mode noise may be caused by one or more of the following: • Electrostatic induction and difference in distributed capacitance between the signal wires and the surroundings, • Electromagnetic induction and magnetic fields linking unequally with the signal wires, • Junction of thermal voltages due to the use of dissimilar metals in the connection system, • Common-mode to normal-mode noise conversion
Redundant cable systems	Two or more systems of cables serving the same objective. (They may be systems where personnel safety is involved, such as fire pumps, or systems provided with redundancy because of system reliability such as primary and backup protection that may utilise redundant cable system.)
Safe working load (SWL)	Of a cable tray/ladder: Maximum load that can be applied safely in normal use
Screen/shield	A metallic sheath (usually Cu or Al) applied over the insulation of a conductor or conductors for the purpose of providing means for reducing electrostatic coupling between the conductors so shielded and others which may be susceptible to or which may be generating (unwanted noise) electrostatic field

3.2 Abbreviations

This list does not include well-known unambiguous abbreviations, or abbreviations defined at their first occurrence within the text.

2HEC	Two-hour emergency capacity
Al	Aluminium
Comms	Communications
Cu	Copper
DBT	Double brass tape
ECC	Emergency cyclic capacity, also earth continuity conductor
EQL	Energy Queensland (includes Energex & Ergon Energy)
EMC	Electromagnetic compatibility
EMF	Electromagnetic field
EMI	Electromagnetic interference
HDPE	High density polyethylene
HFI-90-TP	Halogen Free Thermoplastic Insulation, suitable up to 90°C
HFS-90-TP	Halogen Free Thermoplastic Sheath, suitable up to 90°C
LTER	Long term emergency rating
PVC	Polyvinyl chloride
SCADA	Supervisory controls and data acquisition
SST	Station service transformer
STP	Screened twisted pair
SWL	Safe working load

4 Operating Conditions

Standard service conditions shall be in accordance with STNW 3007 – Climate & Seismic Standard for Substations.

Factors that affect cable rating (ambient air temperature, soil temperature, thermal resistivity of materials) shall refer to the EQL Plant Rating Manual.

Insulation & fault current ratings for standard HV cables for substation use shall be in accordance with Table 1 below

Table 1: Substation cable parameters

Voltage (kV)	Cable voltage rating	Conductor Fault Level (kA/s)	Effectively Earthed System – Screen fault Level (kA/s)	Non-Effectively Earthed System – Screen fault Level (kA/s)
11	6.35/11 (12) [1]	25/1	10/1	6/1
22	12.7/22 (24)	25/1	10/1	-
33	19.1/33 (36)	31.5/1	13.7/1 or 25/1	5/3
66	38/66 (72.5)	25/1	25/1	-
110/132	76/132 (145)	40/0.5	40/0.5	-

Note

1. Where an 11kV supply is fed off a transformer delta stabilising winding with one corner of the delta earthed, 12.7/22 (24) kV cable to be used as a connection to a special purpose auxiliary transformer with 22kV rated insulation.

5 Cable Construction

5.1 HV Power Cables (> 1kV)

HV cables from 6.35/11 kV (12 kV) up to 19/33kV (36kV) shall comply with AS1429.1. HV cables from 38/66kV (72kV) to 76/132 kV (145 kV) shall comply with either AS/NZS 1429.2 or AS/NZS 60840.

Single core cables shall have the following construction:

- Stranded, circular, annealed, high conductivity copper or aluminium wire conductors up to 630mm^2
- Segmented (milliken) construction for cables 800mm^2 and above.
- Tree retardant TR-XLPE insulation for cables up to 36kV,
- Superclean XLPE for cables 72kV and above
- Semi conducting water blocking tapes above and below XLPE insulation layer
- Copper wire screen suitable for carrying expected earth fault current at 33kV and below. (Note that in some cases this construction may extend to 66kV)
- Corrugated metal (copper, aluminium, stainless steel) sheath 66kV and above.
- Composite flame propagation resistant black inner sheath with insect protection by a nylon (polyamide 12) jacket and flame propagation resistant black outer sheath. Chemical insectide shall not be accepted.
- For 33kV and 66kV cables with no full metal sheath, laminated aluminium tape (LAT) shall be installed during extrusion of outer jacket for additional moisture barrier.
- Printed meter marking and supplier details and cable type as per AS1429 Parts 1 &2..
- Marking as per Section 5.7.

- Distribution cables that exit the substation will be purchased to the distribution cable standard, and as such may not have flame propagation resistant sheath.
- Refer to Technical Instruction TSD0027 for a list of cables and their applications.

5.2 LV Power Cables (0.6/1 kV)

LV cables used on 230/400V circuits shall comply with AS5000.1, and have the following construction:

- Stranded, circular, annealed, high conductivity copper wire conductors.
- Flame propagation resistant, 0.6/1.0 kV insulation, XLPE or HFI insulation.
- Flame propagation resistant outer sheath (preferably orange for AC circuit, black for DC circuits).
- For AC power cables the phase insulation is identified by colours of red, white and blue, with black neutral and green-yellow earth. For DC power cables red and black.
- Marking as per Section 5.7.

Double brass tape (DBT) screen for outdoor runs of LV power cables to act as vermin protection and shielding. Where a metallic screen is required, it shall be a collective screen over all the cores, to provide 100% coverage of the conductors. Double Brass Tape (DBT) metallic screens shall consist of two layers of brass tape having a minimum thickness of 0.075 mm, applied helically over the bedding. A maximum gap of 30% may be used in each tape, provided the following tape is approximately positioned centrally over the gap in the underlying tape

Control building AC power and lighting circuits shall comply with AS/NZS 3000 and use XLPE or

HFI insulation where practicable

The standard cables are listed in Consolidated Plant Listing.

5.3 Control Cables

Control (multicore) cables shall be in accordance with AS5000.1, and have the following construction:

- Stranded, circular, annealed, high conductivity copper wire conductors,
- Flame propagation resistant, 0.6/1.0 kV insulation, XLPE or HFI insulation.
- Flame propagation resistant black outer sheath.
- Double brass tape (DBT) screen for outdoor runs of control cables to act as vermin protection and shielding. Where a metallic screen is required, it shall be a collective screen over all the cores, to provide 100% coverage of the conductors. Double Brass Tape (DBT) metallic screens shall consist of two layers of brass tape having a minimum thickness of 0.075 mm, applied helically over the bedding. A maximum gap of 30% may be used in each tape, provided the following tape is approximately positioned centrally over the gap in the underlying tape.
- Individual cores shall be identified with numbers printed (or embossed) in words and numerals at intervals of not greater than 100 mm. Identification shall be with black characters on white insulation.
- Marking as per Section 5.7.

The standard cables are listed in Consolidated Plant Listing.

5.4 Instrumentation Cables

Instrumentation and specialty cables are used for transmitting special analogue or digital signals.

Screened Twisted Pair (STP) instrumentation cables shall be in accordance with AS 2373 and preference should be given to cables with the following construction

- Plain annealed copper wire conductors,
- PE insulation
- PE collective insulation.
- Individually screened pairs, collective overall outer screen.
- Colour coded for each twisted pair,
- Flame propagation resistant HFS, 0.6/1.0 kV insulation,
- Consideration shall be made for suitable vermin and mechanical protection.

The standard cables are listed in Consolidated Plant Listing.

5.5 Communications Cables

OFIBER-ARCH-012 – Standard Optical Fibre Cables lists standard cables to be used within a substation. In addition, there are patch leads to connect from the fibre patch panels to equipment. Glass fibre patch leads are available in multimode and single mode variations.

5.6 DBT Requirements for LV, control and instrumentation cables.

In compliance with AS5000.1, Double Brass Tape is used to provide insect (vermin) protection as well as screening for induced voltages. Due to this, Double Brass Tape screened cables shall be used in all multicore and sensitive power cables leaving the substation building. Double Brass Tape screened cables are not required for cable runs within a substation building, or for power cabling to loads like yard lights, yard GPOs and heater circuits, air conditioning. Substation security panel and transformer compound AC circuits shall have DBT.

Where a metallic screen is required, it shall be a collective screen over all the cores, to provide 100% coverage of the conductors. Double Brass Tape (DBT) metallic screens shall consist of two layers of brass tape having a minimum thickness of 0.075 mm, applied helically over the bedding. A maximum gap of 30% may be used in each tape, provided the following tape is approximately positioned centrally over the gap in the underlying tape

5.7 Cable Markings

Markings must be provided on all cables and every packaging unit (cable drum) in accordance with Clause 16 of AS/NZS 5000.1.

This shall also include the following:

- Meter marking is required for all cables.
- The number of cores and size of the conductor(s) and the conductor material must be printed on all cables.
- Designation of insulation and sheath.

- Standard number, including Part number, i.e. AS/NZS 5000.1.

Due to the cable type and size, some requirements above may not be fully met; for example 1.5mm^2 single insulated cable.

6 Power Cable Ratings

The performance of a cable is largely determined by the cable's physical environment, system fault level, system voltage and earthing, method of installation and the number of conductors to be installed.

Cables shall meet the following requirements:

- Voltage rating,
- Continuous current rating,
- Short circuit current ratings,
- Voltage drop limits.

6.1 Environmental, System and Installation Conditions

Power cables shall be sized and accessories selected to operate under the conditions specified in Section 4 of this standard and the Energy Queensland Plant Rating Manual.:

Installation conditions to be assessed when determining ratings include:

- In air (shaded or unshaded),
- Direct burial,
- In ducts, conduits or trenches below ground, conduits above ground or in cable trays/ladders/basements.
- Burial depth,
- Screen earthing, the cable screen maybe single-point bonded or bonded at both ends, and transposed on long HV cable installations.
- Number of cables,
- Cable arrangement,
- Cable circuit grouping,
- Surge and overvoltage and voltage limiting devices.

System and load conditions to be assessed include

- System voltage,
- Loads,
- Voltage drop limits,
- System earthing and earth fault clearing time,
- System maximum three-phase fault level,
- System earth fault level (for determination of nominal short circuit duty of cable screen).

6.2 Voltage Rating

See Section 4 Operating Conditions.

6.3 Current Ratings

Current ratings of power cables can be determined from either

- calculations using software (e.g. Cymcap), or
- the manufacturer's given values with appropriate adjustment to meet Energy Queensland (EQL) environmental and installation conditions, or
- using AS 3008.1.1 given values (for LV cables) with adjustment, or
- hand calculation using formulae given in IEC 60287 and other IEC standards

Consideration should be given to cable terminations and the effect of cable screen bonding as part of this process.

See Annex B for examples of current rating calculations.

6.4 Required Ratings of HV Power Cables in Substations

6.4.1 Power Transformer Cables

Power transformer cables shall be capable of continuously carrying the Emergency Cyclic Capacity (ECC) also known as Long Term Emergency Rating (LTER) of the transformer, which is normally 125% of transformer rated current, and Short-Term Emergency Capacity or Two-Hour Emergency Capacity (2HEC), typically 150% of transformer rated current.

6.4.2 Distribution Feeder Cables

Cables for radial distribution feeders shall have a minimum continuous current rating of: 315 A, (6 MVA @ 11 kV and 12 MVA @ 22 kV).

6.4.3 Capacitor Banks

Cables connected to capacitor banks shall be capable of carrying at least 143% of the bank rated current continuously. This allows for harmonic currents and increased current at up to 1.1 p.u overvoltage

6.4.4 Local Supply Transformers

For HV cables to the local supply transformer, consider both the load and fault current rating in the selection of HV cables. Small sized cables shall only be used downstream of a HRC fuse at a zone substation, such that fuse total clearing time curves lie below conductor short time withstand curves.

6.4.5 Distribution Bus Ties

The continuous current of the cables should be sized to meet the load transfer requirements in emergency conditions. In the event of no further information use two thirds of the transformer rating on the bus as being the potential maximum load shift.

7 Design Considerations

7.1 General Design Considerations

Unless otherwise specified, all cable runs shall be in conduits, cable trays, ladders or cable trenches. Underground (UG) cable runs shall be in conduits or trenches. The following should be considered in the design and installation of cable systems:

- Safety,
- Installation and maintenance,
- Accessibility,
- Earthing of circuits and equipment,
- Electrical segregation of cables for reducing electromagnetic interference (EMI),
- Physical separation distances,
- Screening/shielding,
- Screen/shield earthing,
- Protection of cables,
- Cable penetration fire stops and fire breaks,
- Bending radius,
- Pulling tension and stress limits,
- Supporting and securing.

7.1.1 Safety

All parts that must be examined or adjusted or tested during operation shall be arranged well away from internal arc fault vents on top of the switchboards

- Manual handling
- Electrical isolation
- Safe Tooling and procedures
- Confined spaces
- Public Safety
- Working at heights
- Environmental conditions

7.1.2 Installation and Maintenance Considerations

Location of UG cables shall be clearly indicated on substation cable records

- Clear drawings including cross sections as well as signage
- HV Cable termination and cable joint locations and details

7.1.3 Accessibility

All parts that must be examined or adjusted or tested during operation shall be arranged so as to be accessible to authorised persons by the provision of adequate working spaces, working facilities, clearances (exclusion zone), electrical switching, disconnection and reconnection.

7.1.4 Earthing of Circuits and Equipment

Conductive cable sheath/screen, equipment frames and cases, conductive material ducts/conduits/ guards that enclose power cables shall be earthed. Notes shall be provided on drawings to clearly indicate this.

7.2 HV Cables

The following considerations should be made when undertaking HV cable design within a substation.

7.2.1 Standard Cable Sizes

Standard cable sizes can be found in Technical Instruction TSD0027 available on the Asset Standards & Collaboration Sharepoint page, or from the Line Standards team.

7.2.2 Layout

- Maintain separation between cables as per design drawings to avoid mutual heating issues.
- When crossing cables within a substation maintain a minimum 300mm separation to reduce mutual heating effects. More detailed calculation on the effects of crossing cables can be found in IEC 60287-3-3 or from cable rating software programs.
- Conduits should be used where possible within substation to reduce future excavation when replacing.
- Foundations for sealing end structures to take account potential excavation when installing cables.
- Sealing end structures shall be sized to ensure bottom of termination (including bottom of shrinks for heatshrink and coldshrink terminations) are no lower than 2440mm above final ground level.
- Abandoned cables that can be readily removed should be removed. If the cables cannot be removed they should be capped at both ends with cores bonded to the sheath. One end should be accessible for future tracing and location. A note shall be provided on the drawings to indicate that all unterminated cables shall be clearly marked, sealed and capped to prevent moisture ingress.
- Cables shall be installed so that bending radius must never be less than that recommended by the manufacturer.
- HV power cable conduits entering the building and cable ramps shall be as per ZSS control building drawings and Energex LOSTD drawing standards.
- Conduits/ducts shall have a minimum 450 mm separation between groups in trefoil. Greater separation may be required after performing a cable rating study.
- Power conduits are to have their invert levels 50 mm maximum above the finished floor level of the basement and sealed.

7.2.3 Joints and Terminations

- Cable joints shall be adequately supported. They shall not be laid directly over a crossing cable. They should be adequately supported to avoid sagging.
- Cable terminations shall be of the following type:

Table 2: Termination types

Voltage	Location	Type
66-132kV	Air insulated	Self supporting, insulated base, polymer insulator
66-132kV	GIS	Plug/socket to IEC62271-209 (110/132kV) or EN 50181 (66kV)
33kV and below	Air insulated	Heatshrink or coldshrink, terminal palm to AS62271.301
33kV and below	GIS	Inner cone connector to EN 50181 to suit switchgear socket.
33kV and below	Air insulated cable box – DIN C2 bushing	Separable connector to suit DIN C2 profile
33kV and below	Air insulated cable box – terminal palm	Heatshrink or coldshrink, terminal palm to AS62271.301

- Onto a terminal palm – using approved heatshrink (preferred) or cold shrink terminations. Palms up to 630A 630mm^2 can be by single hole palm, with suitable load spreading washer. Palms at 800A and above shall have two hole palm with 50mm between hole centres.

Table 3: Bolted connections

Bolts per Joint	Bolt size	Flat Washers	Spring Washers	Torque applied to nut N.m	Cable Size
1	M12	2 x Type 1	1 x Spring	45	Up to 300mm^2
1	M12 SS	2 x Type 2	1 x Spring	55*	Above 300 mm^2 up to 630 mm^2
2	M12	4 x Type 1	2 x Spring	45*	Above 630 mm^2 up to 1000 mm^2

(* - torque wrench must be used)

The bolt threads and interface surfaces shall be lubricated with grease. Terminal lug size and material shall be suitable to for both the cable and equipment palm they connect to. Dissimilar metals should be avoided.

- Terminations shall be installed in accordance with the manufacturer instructions, and minimum clearances shall be adhered to. Air clearances shall comply with the minimum non-flashover distances in STNW3013 – Clearances in Air. Where these air clearances are not achievable, the use of insulating boots, shrouds and compounds can be applied.
- Ensure bay clearances for 66kV and above air insulated terminations take account of section clearances if scaffolding required to re-terminate cables.

Figure 1: Scaffolding around 110kV outdoor termination

7.2.4 Air Insulated Cable Boxes

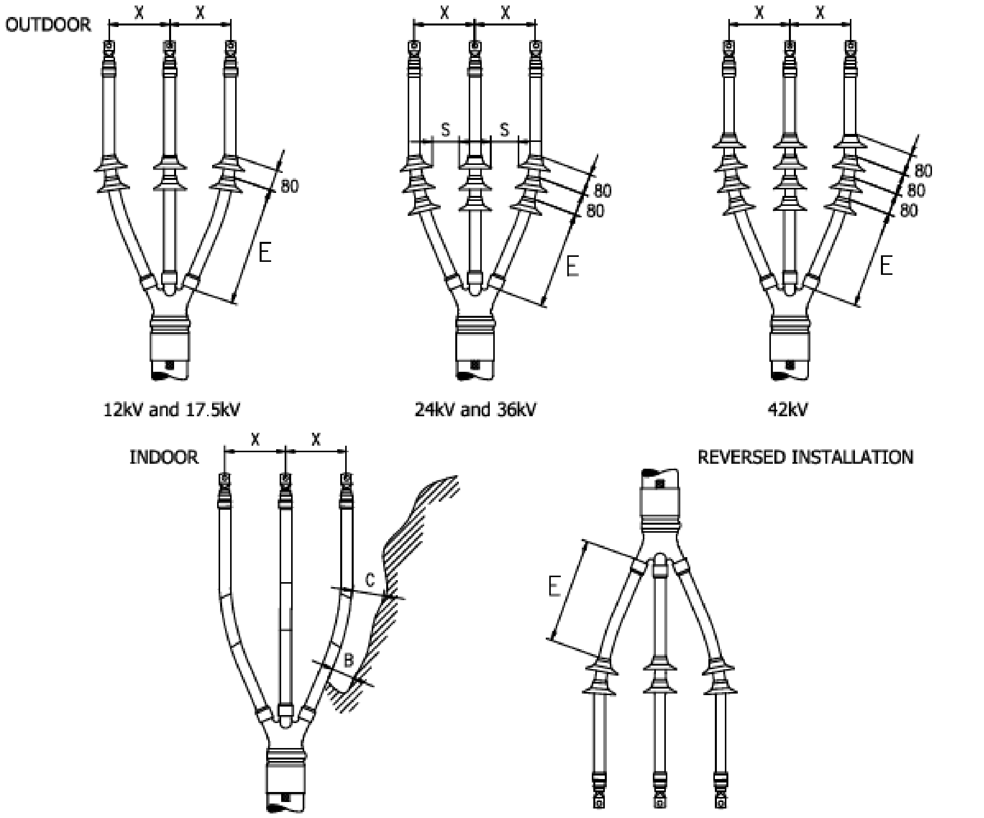
The majority of medium voltage cable connections into modern equipment are into unfilled air insulated cable boxes. Power transformers generally have larger air clearance between bushings that allow these connections to be left un-insulated. This makes it easier during transformer maintenance where cable connections need to be removed so winding resistance and ratio tests can be done.

Medium voltage switchgear is generally more compact, and as such does not have spacing between phases to allow these connections to be left un-insulated. Depending on the bushing type, the preferred option is discussed below.

Terminal palms

Air clearances shall be in accordance with STNW3013 between live terminals and terminals to earth. Where these clearances cannot be maintained, unscreened insulating boots may be used provided clearances can be maintained as per Figure 2 below

3. COMPLETION OF THE TERMINATION



TYPE	12TTG...	17TTG...	24TTG...	36TTG...	42TTG...
VOLTAGE Uo/U (kV)	6.3/11	8.7/15	12/20	19/33	20.8/36
N. SHEDS INDOOR TYPE	-	-	-	1	2
N. SHEDS OUTDOOR TYPE	2	2	3	3	4
E (mm)	300	300	440	780	780
OUTDOOR TYPE S min. (mm)	10	15	20	25	35
X (mm)	120	160	220	320	380
Y (mm)	40	60	90	160	220
B (mm)	10	15	25	35	45
C (mm)	15	20	40	50	60

X= min. distance between ph/ph in air
Y= min. distance between ph/ph with insulating boots

3.1 Slide and heatshrink the anti-tracking sheds one by one according to dimensions shown. Different numbers of shed available upon request.

Nexans

IM2020I	Sheet 7/8

Figure 2: Clearances for insulated and uninsulated connections (Ref- Nexans)

DIN Type C Bushings

The preferred bushing connections in MV switchgear are DIN Type C connections for connections up to 630 or 1250A. These are a bolted connection onto an epoxy bushing. For lower current carrying connections there is DIN Type A (250A) and DIN Type B (400A) that use a push in connection with a contact ring. These bushings all conform to a CENELEC EN 50180/50181 global standard.

Dimensions for DIN Type C bushings are as shown below:

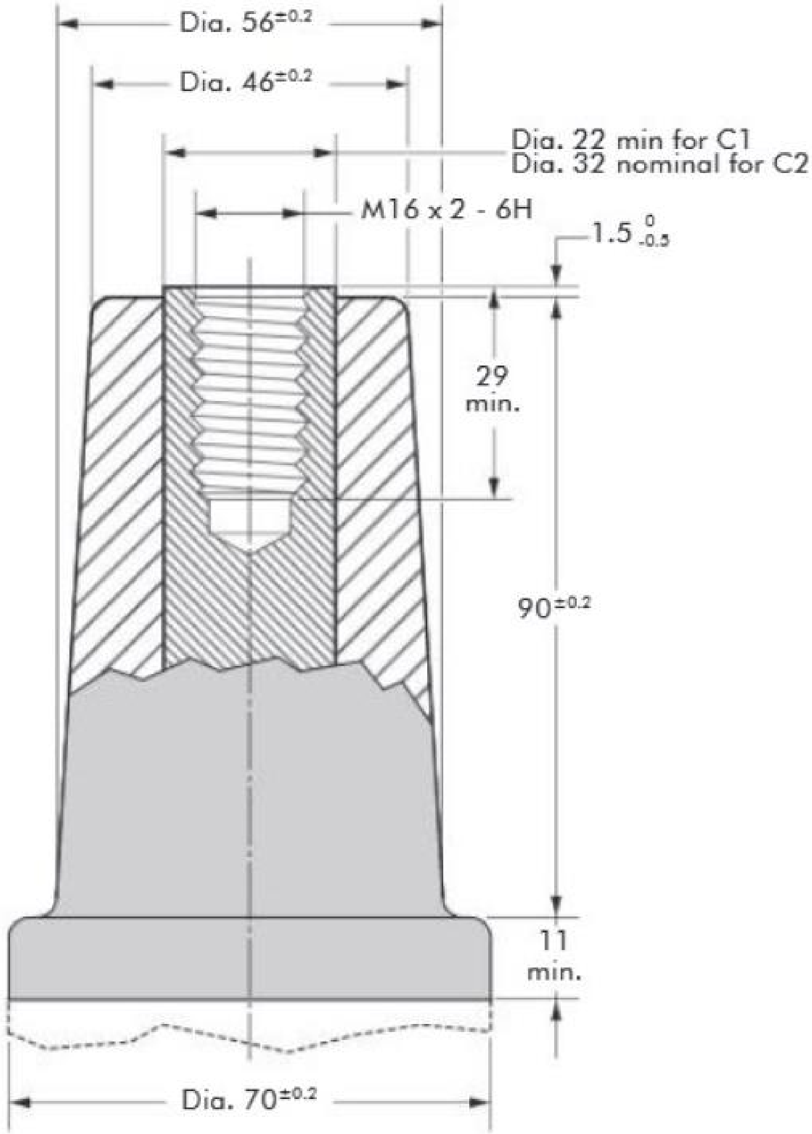


Figure 3: Dimensions for DIN C1 & C2 Bushing

Where these bushings are used, it is recommended that a fully screened separable connector is used.

Three core cables

Where three core cables are being installed into air insulated switchgear:

- There should be a minimum 700mm from bottom of the cable box to bushing to allow for transposition of phases.
- When transposing phases, ensure that unscreened sections of different phases are not touching and have separation.
- Preference is given to three phase kits with the stress control near the top of the termination rather than near the cable crutch.

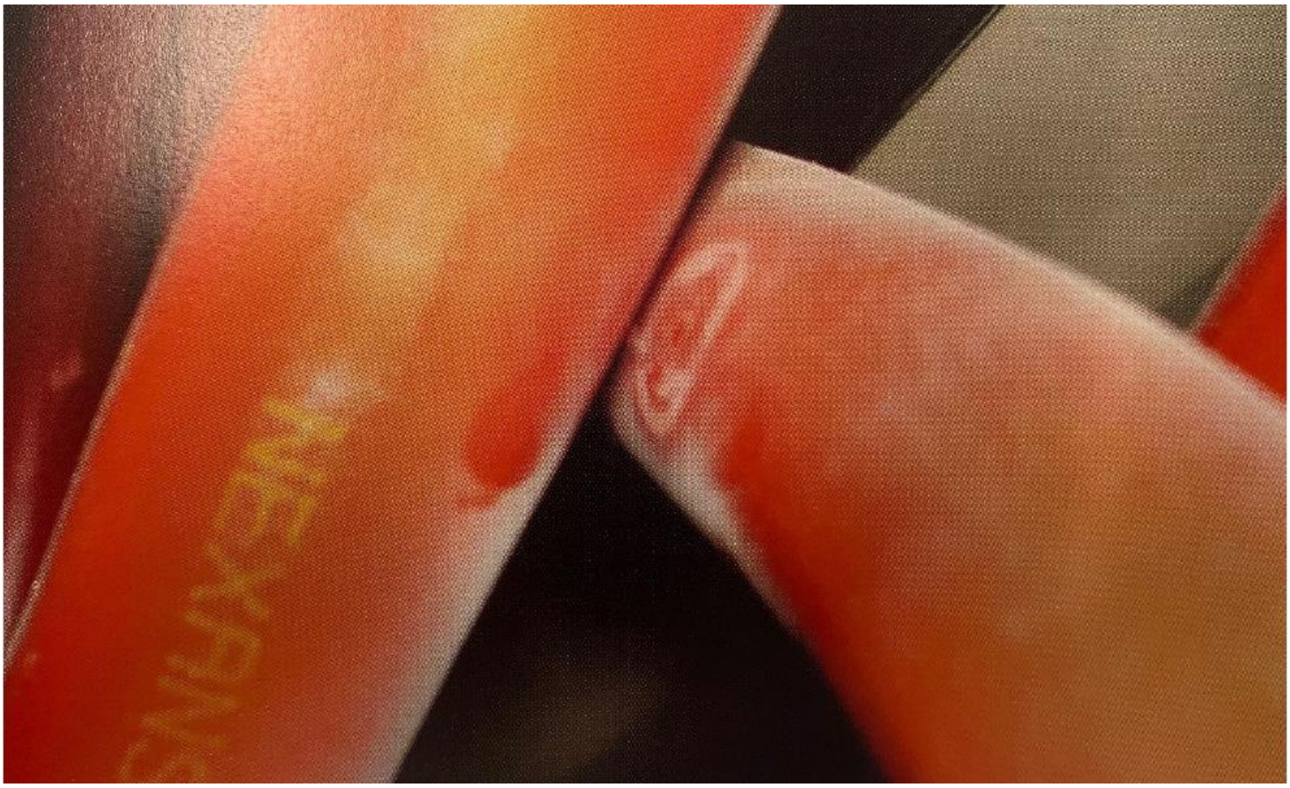


Figure 4: Discharge between different phases on a 3 core cable

7.2.5 Bitumen or Compound Filled Boxes

Where an existing bitumen or compound filled cable box is to be re-used, refer to TSD0217 - HV Cable Terminations & Joints Compound Selection for up to 33 kV. This document provides information on type of compound to be used for various cable types, and minimum phase-earth and phase-phase clearances.

7.2.6 EMF

- Refer STNW3042 – Electric & Magnetic Field Design for further information, particularly around cable configurations to minimise magnetic fields.
- Single core power cables shall be preferably run in trefoil to minimise EMF.
- High current cables such as transformer LV cables should be located away from fence lines to reduce magnetic fields at boundary.

7.2.7 **Earth Bonding**

In some instances for short cable runs, bonding of cable screens will be at one end only, to eliminate circulating currents and maximise cable rating. Refer to the underground transmission drawings. Ensure the screenwires at the unearthed end are insulated and sealed to prevent moisture ingress.

7.2.8 Cleating of Cables and Cable Glands

Cable movement can create stresses on equipment bushings that these cables are connected to. This movement can be as a result of:

- Thermo-mechanical movement as a result of changes to ambient temperature or high currents
- Electrical forces during through faults
- Settlement of direct buried cables in pits that are backfilled

As such, it is recommended:

- Cables transitioning to vertical that are backfilled shall be supported on the transition with stabilised sand bags.
- Transformer cables to have one end connected with flexible cables (usually at air insulated transformer cable box) to allow for expansion/contraction.
- Cables to be cleated as close to cable box base as possible to prevent stress onto equipment bushings
- Cables to be cleated in accordance with Technical Instruction TSD0188 - Guide to Cable Support and Fixing Requirements in Substations

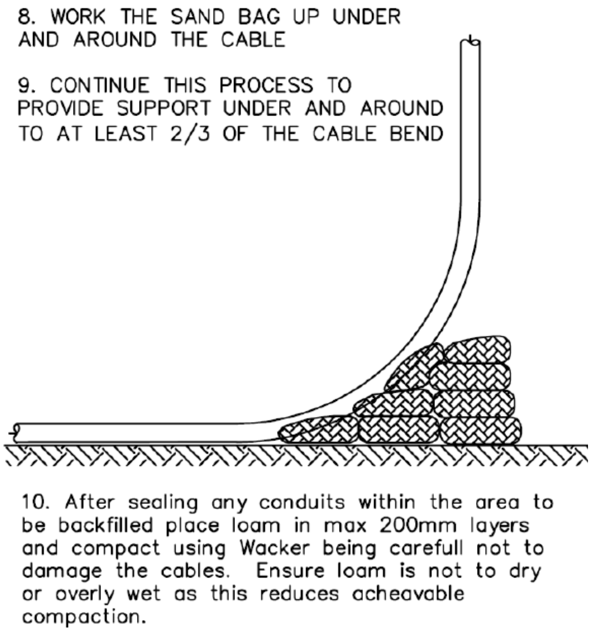


Figure 5: Supporting cables with stabilised sandbags

Figure 6: Flexible connectors to transformer

7.2.9 Conduit Sealing

Water that enters through power cable conduits creates a damp atmosphere that can promote partial discharge issues and rusting of supporting steelwork. Ensure all spare conduits are sealed with a plumber’s plug to prevent moisture ingress. All conduits with power cables shall be sealed after cable installation with an approved conduit seal. This can be a mechanical seal, gas filled sealing bags or a rubber mastic seal that is capable of withstanding at least 1m head of water. Expanding foam to seal cables in conduits is **not recommended**.

7.2.10 Fire Proofing Cables

Power cables with their plastic insulation and sheaths provide a high fuel source in a substation basement. Protection from fire is achieved by:

- Spacing cables well apart, avoiding cables and particularly joints resting on crossing cables
- Applying a fire retardant intumescent paint that ceramifies under heat and prevents propagation
- Installing a fire suppression system such as a sprinkler or inert gas system.

Where new penetrations are made in rooms that were sealed to provide a fire rating between rooms (e.g. between basement and switchgear room), then these penetrations shall be re-sealed after cable installation to the same performance standard.

Refer to Technical Instruction TSD0171 – Guide to Passive Fire Protection in Bulk & Zone Substation Basements for further information.

7.3 LV Cables

7.3.1 Standard Cable Sizes

Standard cable sizes, number of cores and construction can be found in the Substation Standard Consolidated Plant Listing under Cables.

7.3.2 Segregation

- LV AC power circuits shall be in a separate cable.
- CT and VT circuits shall be in separate cables.
- DC supplies do not require segregation from DC control circuitry.
- Cabling for duplicated systems shall be separated to ensure that no single event will prevent a required particular substation operation. The degree of separation required varies based on potential hazards.
- Segregation of LV AC power cables, control cables and instrumentation cables in the cable trench or cable tray/ladder system is necessary. Separation shall be 50 mm minimum.

7.3.3 Screening

Metallic screening of control cables can reduce induced transient voltages. The screen provides an equal voltage surface surrounding the sensitive circuit to prevent capacitive coupling to HV conductors and magnetic shielding to mitigate the effect of strong magnetic fields. EQ uses Double Brass Tape as the method of metallic screening.

LV power cables and control cables in the switchyard shall be screened / shielded from origins of transients in substation such as:

- High voltage switching,
- Capacitor switching,
- Transmission line switching,

- Capacitor voltage transformer (CVT) due to resonance between the capacitors of the CVT and circuit inductances of power system in the MHz range,
- Earth potential rise (EPR) during earth faults with respect to remote earth,
- Earth potential rise differences if the earth grid is large having sufficient inductance to cause high voltage differences due to electromagnetic coupling and conduction,
- Other transient sources such as fault occurring, fault clearing, load tap changing, arcing earth fault, lightning, etc.

7.3.4 Screen Earthing

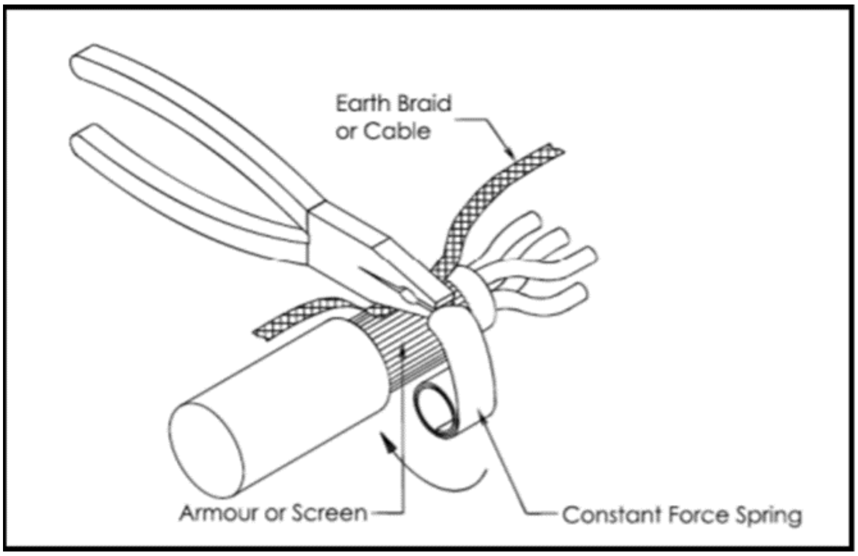


Figure 7: Use of roll spring for DBT earthing

- The screen of control cables should be earthed at one end. This will protect the connected equipment from induced voltages at the earthed end, whilst preventing circulating currents within the substation flowing through cable screens during earth faults.
- Where long runs of control cabling exist there is a chance for a large screen to earth voltage to develop at the non-earthed end. If this is the case then voltage limiters should be used to limit the maximum screen voltage to 25 V.
- To earth Double Brass Tape screens use constant force springs and 2.5mm^2 earth wire with green/yellow insulation. Stds A581 has the preferred method of application.

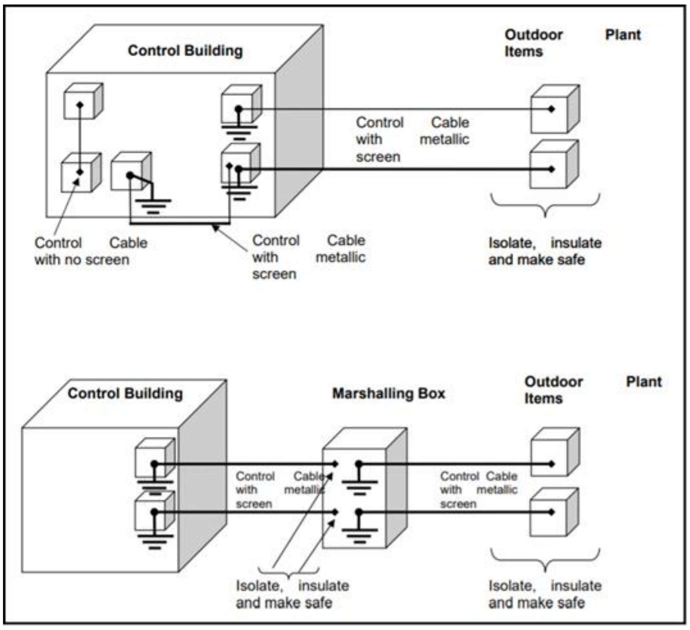


Figure 8: Earth bonding of DBT

7.3.5 Other Protective Measures

- Wherever possible, control cables should be routed perpendicular to HV buses. If unavoidable maximum separation distance must be maintained.
- Avoid routing of control cables through areas of potentially high earth grid current, e.g. power transformers, to avoid possible difference in EPR during earth faults.
- Wherever possible the control cables should be run below the main earth grid.
- All cables from the same equipment should be close together.
- Cables connected to equipment having comparable sensitivities should be grouped together and then the maximum separation should be maintained between groups.
- Control cables shall not be run beside HV power cables, in ducts or trenches.
- Radial arrangement of control circuitry will reduce transient voltages.
- Circuits should be designed with all common wiring contained in common cables connected to switchyard equipment.
- Avoid circuits routed from one piece of equipment to another in the switchyard with the return conductor in another cable.
- All supply and return conductors must be in a common cable to avoid possible large electromagnetic induction due to the very large flux linking loop that the loop arrangement provides.
- Where interference may be an issue, use an earthing conductor in parallel with control cables to eliminate possible voltage difference in the earth grid. This conductor also shields the control cables from transient/noise voltages. To be effective the conductor shall be as close as possible to the control cables.
- All secondary circuits from a capacitor voltage transformer (CVT) should be radial and contained within a screened cable to provide cancellation of the differences in earth grid

voltage. The secondary cables should follow the earth conductor as closely as possible.

- Cables in vertical run should be secured regularly to the cable tray or supports and shall minimise any force applied to terminals.

7.3.6 Conductor sizing

Information on conductor sizing can be found in:

- Ergon STNW 3021 – Standard for Panel Wiring
- Energex Substation Design Standard Part 5 Section 10 – Requirements for multicore and single core cables in substations

7.4 Instrumentation Cables

In this document instrumentation cables consist of cables for SCADA systems, serial port connection cables and resistance temperature detector (RTD) cables.

Instrumentation circuits are subject to the following noise voltages (refer to Definitions):

- Common mode noise (longitudinal),
- Common mode to normal mode conversion,
- Crosstalk,
- Normal mode noise (transverse or differential).

To minimise noise pickup all instrumentation cables shall be twisted pair type with screening..

7.4.1 Segregation

- Instrumentation cables shall be in separate cables.
- To reduce the effect of transients and interference, all instrumentation wiring runs shall be in cables separate from AC, DC and control cables.
- Analogue signal cables should be separate from all power and control cables.
- Digital input cables should be segregated from digital output cable where possible.
- Screened voice communications cable may be included in the trays with analogue signal cables.

7.4.2 Screening

Screens shall be earthed at one end only – same as LV cables (see Section 7.3.4)

7.5 Communications and fibre optic cables

Communications cables shall be designed and installed in accordance with EE's STMP004 - Standard for Communications Equipment Installation, and Energex drawings CCSTD-SC060 (all sheets).

8 Pipes & Conduits

8.1 Conduits in Substations

8.1.1 General

- The new foundations of switchyard equipment, where required, shall have conduits/ducts cast into the concrete. Cables shall be drawn through these conduits/ducts which shall connect to cable trenches.
- Conduit bends must have a minimum 1m from end of bend to the conductor connection on the cable, to ensure cables can be installed straight and without tension on the bushing. If this dimension can't be maintained then a pit should be used instead of conduit bends.
- Conduits and ducts are important consideration affecting the pulling operation. Selection of the appropriate conduit/duct should be based on the internal diameter to suit a cable size, and wall thickness to prevent deformation during installation.

8.1.2 Unplasticized Polyvinyl Chloride (UPVC)

For UPVC pipes, there is a full range of sizes, types and fittings available commercially. Solvent welded joints are used to create a permanent bond between the conduit spigot and the socket. As stated above, all solvent cements used shall comply with AS/NZS3879. Cast iron fittings are also available for use with UPVC conduits.

Generally, UPVC conduits used in substation civil works shall be orange coloured (except for telecoms applications, where white is used), UPVC to AS61836 - Conduits systems for cable management

Corflo conduit is not acceptable for any installation. Typical sizes for conduits are as shown in Table below:

Table 4: Conduit particulars

Application	Conduit diameter (mm NB)	Conduit & bends wall thickness	Conduit Bend Radius (mm)
Telecoms	80 (white)	Light Duty	600
Low voltage, control	125	Heavy duty	1830
11 – 33kV	125	Heavy duty	1830
110/132 kV up to 800mm^2	150	Heavy Duty	2000-3000
110/132 kV greater than 800mm^2	200	Heavy Duty	3000

Note: 33/110/132kV feeders require 2 x 80mm conduits for ECC/fibre optic cables for each feeder.

8.2 Installation Guidelines

8.2.1 Pipe Cover in Substations

The depth of cover of pipelines will vary to cater for design requirements ie to maintain flow in the pipeline.

8.2.2 Conduit Cover in Substations

The minimum cover for UPVC and FRC conduits shall be as follows:

66/110/132kV Power Cables	900mm
33kV Power Cables	750mm
22 & 11kV Power Cables	750mm
Earthing Grid Cables	500mm
Control Cables	350mm

Depth of cover shall be measured from F.S.L – depth of cover from substation gravel is not to be considered. Reduced depths shall only be used on the approval of the Civil Engineer.

8.2.3 Laying of Conduits

Conduits shall be laid true to levels, grades and alignment as shown on the civil conduit plans. When conduits are laid in two or more layers, the joints of each conduit in each layer shall be staggered with respect to the joints in the next layer of conduits.

Bell-mouths shall be installed for all conduit penetrations into basements and pits, and sealed with an approved product to prevent moisture seeping through the concrete interface.

Where separation between conduits is stipulated in designs, these separations are to be maintained, and the space between conduits shall be completely filled with compacted bedding sand. Where power cable conduits cross, there shall be suitable separation between the crossing conduits to ensure de-rating does not occur due to mutual heating. In general the following spacings should be maintained for crossing conduits (unless otherwise confirmed via cable ratings study):

- 11 and 33kV cables - 300mm separation
- 66/110/132kV cables - 500mm separation

All conduits are to be proven clear by a mandrel, and a draw rope included by the installer.

8.2.4 Backfill

An approved fill shall be solidly packed and hand rammed around conduits. This fill should reach a height of 300mm above the top layer of conduits. Approved filling and bedding material shall comprise stone free friable loam. Flowable fill is NOT to be installed within substation yards.

The thermal properties for the backfill material will depend on the application being installed:

Material	Thermal Resistivity (oC-m/W)	Application
Standard	0.99-1.17	Control, LV
Blended	0.94-0.98	11, 33 kV
Premium	0.75-0.87	66/110/132kV, high capacity transformer cables

8.3 Conduit design

- Maximum conduit fill shall be as follows (NFPA 70.2011):

Table 5: Conduit fill factor

Number of conductors	% fill for all conductor types
1	53
2	31
Over 2	40

- Conduit and duct system design should consider the maximum pulling lengths of cable to be installed allowed by the cable manufacturer’s recommendations. The maximum pulling length is determined by pulling tension limits and side wall pressure. Pull point or manholes should be installed wherever calculations show the expected pulling tensions exceed the allowable tension limit or side wall pressure.
- Bending radius of the conduit shall not be less than the conductor allowable minimum bending radius.
- Conduit/duct runs shall be parallel or perpendicular to the foundations without diagonals.
- All conduit systems should have suitable pull points to avoid over-tensioning of the cable during installation.
- Conduits containing one phase of a three-phase power circuit or one leg of a single phase of a power circuit should not be supported by reinforcing steel or brackets of magnetic material forming closed loops around individual conduits.
- Reinforcing steel in the manhole wall should not form closed loops around individual non-metallic conduit entering the manhole. Non-metallic spacers should be used.
- Protection should be provided where non-metallic conduits emerge out of a floor.
- Concrete-encased duct banks should be adequately reinforced under roads and in areas where heavy equipment may be moved over the duct bank.
- Conduits in duct banks should be sloped downward toward manholes or drain points.
- End bells should be provided where conduits enter pits or building walls.
- Mechanical protection and marker tape shall be provided.
- Supports shall be provided for PVC rigid conduits as per the following table:

Table 6: Distance between supports for conduits

Conduit size (mm)	laximum distance between supports (m)
35 – 53	1.5
63 – 78	1.8
91 – 129	2.1
150 and over	2.5

Notes on protection of conduits/ducts shall be provided on detailed drawings.

9 Cable pits, trenches

Control and protection cables within the outdoor switchyard area shall generally be installed in conduits between equipment and the main trenches run up the centre of the yard. The trenches shall have removable covers.

9.1 Cable pits and trenches

- Cable pits and trenches shall be preferably precast from polymer concrete and shall be of box section with removable lids.
- Cable pits and trench shall be placed so that the top of the lid is 50mm above the finished switchyard level.
- Pits, trenches and conduits shall be excavated such that there is a fall from end to end so that rainwater can drain out in drainage lines provided.
- Heavy duty pit/trench covers, suitable for vehicle passage, shall only be located where vehicles are likely to cross the pits or trench.
- When design cable pits careful consideration should be given to the following:
  - Avoid confined space.
  - A minimum horizontal clear working space of 900 mm.
  - Pulling tension limit and maximum pulling length.
  - Direction of cable pulling when placing the cable pits. Pits should be oriented to minimise bends in the duct banks
  - Cable pulling facility.
  - Cable bending radii when sizing the pits. Cable pits and pit openings should be sized so that the cable manufacturer minimum allowable bending radii are not violated
  - Pit drainage. Pits should have a sump, if necessary, to facilitate the use of a pump
  - Exposed metals in pits should be earthed
  - Corrosion resistant fixed ladder should be provided.

10 Cable Trays, Ladders

Selection of material, size and shape of cable trays/ladders depends on the following criteria:

- Severity of electromagnetic (EM) environment along cableways, proximity to sources of conducted or radiated EM disturbance,
- Authorised level of conducted and radiated emission,
- Type of cables (shielded, twisted, optical),
- Electromagnetic interference (EMI) withstand capability of the connected equipment;

- Other environmental constraints (mechanical, fire, etc.),
- Future extension of the wiring system.

Information on pipe and cable supports and stock codes are available on the Consolidated Plant Listing

10.1 Standards

Metal cable trays/ladders shall comply with the requirements of NEMA VE 1-1984 or IEC 61537.

Typical dimensions of NEMA VE 1 cable trays and ladders are as follows:

Table 7: NEMA VE 1 Tray and ladder typical dimensions

Length (m)	Width (mm)[1]	Fill depth (mm)	Rung spacing (mm)	Inside radius (mm)	Arc for elbow (degree)
3 ± 5 mm	150 (6 in)	75	150 (6 in)	300 (12 in)	30
3.66 ± 5 mm	225 (9 in)	100	225 (9 in)	600 (24 in)	45
6 ± 9 mm	300 (12 in)	125	300 (12 in)	900 (36 in)	60
7.32 ± 9 mm	450 (18 in) 600 (24 in) 750 (30 in) 900 (39 in)	150			90

Designation of NEMA VE 1 trays/ladders (for USA) is, for example, 12B.

Where:	12 indicates the span in feet,
	B indicates the load of 75 lb/ft,
	Safety factor = 1.5

Table 8: Table of span / load designation (USA)

Load kg/m (lb/ft)	Span m (ft)				
	1.5 (5)	2.4 (8)	3.0 (10)	3.7 (12)	6.0 (20)
37 (25)	5AA	8AA	10AA	12AA	20AA
74 (50)	5A	8A	10A	12A	20A
112 (75)	-	8B	-	12B	20B
149 (100)	-	8C	-	12C	20C

10.2 Capacity

The size of the cable trays/ladders should cater for the design capacity of the installation Cable trays/ladders shall have

[1] Typical widths of wire mesh cable tray are: 50, 100, 150, 200, 300, 400, 450, 500 & 600 mm and channel cable trays 75, 100, 150 mm

- A minimum load capacity equivalent to NEMA Class 20B, i.e. the maximum safe load shall be 112 kg/m at 6.0 m support spacing with a factor of safety of 1.5.
- Minimum 300 mm width x 112 mm depth.

10.3 Galvanised steel cable tray/ladder

Cable tray/ladder shall be fabricated from steel with horizontal rungs at 300mm spacing welded to vertical side rails. Slots shall be provided in the horizontal rungs for cable fastening. All cable trays/ladders and fittings shall be hot dip galvanised after fabrication.

Aluminium cable tray/ladder can be used as an alternative – it also can be utilised for basement earthing conductor provided it has sufficient short time rated earth fault current carrying capacity.

“Side-rail out” is the preferred structure.

10.4 General requirements for installation design

- All cable trays/ladders shall be installed in accordance with NEMA VE 2 or as recommended by the manufacturer.
- All cable trays/ladders shall have a spare capacity of at least 25% of tray/ladder width after all cables are installed.
- Cable trays/ladder shall be wide enough to meet separation requirements.
- The route shall be designed to be clear of pipes and valves and shall not obstruct access to plant and equipment.
- The cable trays/ladders shall be designed for straight lines parallel or at a right angle to walls and floors.
- Where cable trays/ladders are installed one above the other the minimum spacing between each level of tray/ladder shall be 300 mm.
- In a stacked cable tray system the cables shall be arranged with power cables positioned above control and instrumentation cables.
- Where cable trays/ladders are installed in plant rooms or across walkways the minimum clear height from floor or ground level to underside of tray/ladder shall be 2.1 m.
- Bonding jumpers shall be used across expansion splice plates.
- Maximum resistance of spice or coupling between sections shall not be more than 0.33 mΩ.

10.5 Fittings

Factory fabricated bends, risers, tees and crosses shall be used for all connections and changes of direction. All fittings shall maintain the specified minimum bending radius for the largest cable to be installed on the tray/ladder run.

10.6 Brackets

Support brackets shall be installed at the required spacing to suit the load capacity of the cable tray/ladder and to limit mid span deflection to a maximum of 20 mm with all cables installed. Support brackets shall be provided at all connections or changes of direction in accordance with the recommendations of NEMA VE 1 (or IEC 61537). Support brackets shall be fabricated from Unistrut channel and accessories. Cable tray/ladder shall be firmly attached to each support bracket using hold-down clamps designed for the purpose. Wherever possible brackets shall be installed to support the cable tray/ladder from one side only, so as to leave the other side open for easier installation of cable, unless centre support brackets are utilised.

10.7 Covers

In areas exposed to direct sunlight or where cables would be vulnerable to damage from falling objects or build-up of spillage material continuous galvanised steel cable tray/ladder covers shall be fitted. Covers shall be peaked to give rigidity and shall allow air circulation to avoid additional de-rating of the cables. Covers shall be securely attached to the cable tray/ladder with clamps or hook bolts of an approved design and which allow easy removal and replacement.

10.8 Earthing

All cable tray/ladder runs shall be electrically continuous. A 70 mm^2 bare copper conductor / strap shall be run the entire length of the trays, regularly bonded to the trays and securely bonded to the main earthing system at both ends. For very long cable trays/ladders additional connections to the earthing system should be provided

11 Cable Penetration Fire Stops and Fire Breaks

11.1 General

The fire stops shall be used to prevent fire propagation along a cable system through a fire rated wall, floor, or floor-ceiling barrier while maintaining the integrity of the fire barrier through which the cable system penetrates.

- The fire stop shall have a fire rating equal to or greater than the wall, floor it penetrates.
- Modifications or additions of cables shall not compromise the integrity of the fire stop.
- Cable fire stop should be used when sleeve or tray penetrations are used beneath control panels or other panels.
- Cable fire stop shall be used to seal power cable entry from the basement to prevent spread of fire into the switchgear room at nominated sites with a large number of cables and higher fire risk. Refer to Energex Technical Instruction TSD0171 – Guide to passive fire protection in bulk supply and zone substation basements.

Refer also to Clause 3.9.9 of AS 3000-2007.

Details of fire stops and fire breaks and their requirements shall be shown on the detailed drawings.

In the absence of any BCA requirements, penetrations through internal building elements shall have a minimum FRL of -/120/120. A -/180/180 fire rating shall be provided through internal elements of indoor substations that form part of a larger building.

11.2 Design considerations

The following shall be considered in the design:

- Physical and chemical compatibility between the fire stop material and cable covering.
- Reduction of heat dissipation hence cable current rating.
- Thermal expansion which may crush cable insulation.

- Toxic or corrosive gas developed during installation or a fire.
- Ability to withstand pressure differential.
- Aging.
- Temperature rise during curing.
- Ease of installation.
- Provision for additional cables.
- Ability to withstand a hose stream test.

12 Installation design limits

12.1 Bending radius

The safe bending radius for a cable is limited by the flexibility of the insulation and sheathing material used. High elongation due to severe bending might impair the electrical performance and delaminate the semi-conductive screening. HDPE sheathing and nylon termite barriers both have to be treated with caution because, being hard and brittle materials, they are subject to damage if bent severely.

When installed in conduits the cables must be pulled around several curves in different directions and subject to dynamic stresses that could cause damage. Consequently, the bending radius around which a cable may be pulled is greater than that at which it can be set into its final position.

Fire retardant and halogen free sheathing materials, some being soft materials that could be damaged during the pulling operation. This should be taken into account in the design.

The following recommended minimum bending radii are expressed as a function of the cable diameter and refer to the inside of the curve, and a bending radius factor.

Table 9: Recommended bending radius factors for HV XPLE cables [57]

Cable type	Minimum bending radius factor (F)	
	During installation	**Set**
All cables (other than HDPE sheathed or nylon covered)	18	12
HDPE sheathed	25	15
Nylon covered	30	20

$$R = F \times D$$

Equation 1: Minimum bending radius (in mm)

Where:	**R =**	**Bending radius (mm)**
	F =	Bending radius factor
	D =	Cable diameter # (mm)

in the case of nylon covered cable D = Diameter over nylon

12.2 Pulling tension limits and stress limits

The maximum tension which may be used is limited by the tensile strength of the conductors or armour wires or by the gripping capability of the cable stocking, depending on the method used.

In the calculation of pulling tension, it is not usual to allow for the tensile strength of the insulating and sheathing materials, which can be considerable in the case of XLPE. Reliance on these materials, which have high elongation factors, may result in some elongation of the conductors and a consequent increase in conductor resistance.

Table 10: Maximum safe tensile stress, S of conductors and armour shall be as follows [57]

Material	Maximum safe tensile stress, S (N/mm^2)
Stranded copper conductor	70
Stranded aluminium conductor	50
Solid aluminium conductor	30
Galvanised steel armour	130
Hard drawn aluminium wire armour	60

Maximum pulling tensions are calculated using the value of S from Table . For pulling by conductor the maximum pulling tension, Tc shall be calculated as below:

$$T_c = N \times A_c \times S$$

Equation 2: Maximum Pulling Tension

Where:	T_c =	Maximum pulling tension (N)
	N =	Number of conductors
	A_c =	Cross-section area of one conductor (mm^2)
	S =	Maximum safe tensile stress (N/mm^2)

12.3 Sidewall Pressure

Sidewall pressure is the pressure applied at bends to the installation. Excessive sidewall pressure can cause deformation of the insulation and lead to premature failure.

Sidewall pressure is calculated as follows:

$$SWP = \frac{T}{r}$$

Equation 3: Sidewall Pressure

Where	SWP	Sidewall pressure (kN/m)
	T	Maximum pulling tension (kN)
	r	radius at bend (m)

Manufacturers will provide information specific to a cable's maximum pulling tension and maximum allowable sidewall pressure in their cable datasheets.

12.4 Jam ratio (multiple cables in a conduit)

Jamming is the wedging of cables in a conduit when three cables lie side by side in the same plane. Jam ratio is defined for three cables of equal diameter as the ratio of the conduit inside diameter (D) to the cable outside diameter (d). The jam ratio is a concern because jamming could cause damage to one or more cables. The possibility of jamming is greater when the cables change direction. Therefore, the inside diameter at the bend is used in determining the jam ratio.

Jamming cannot occur when $D/d > 3.0$.

Jamming is not likely when $D/d < 2.8$.

Jamming is probable when $2.8 \leq D/d \leq 3.0$.

12.5 Cable Pulling Tension Calculator

Lines Standards provide a calculator for calculating pulling tension of a number of power cables. The calculator can be accessed from Substation Standards Design Tools.

13 Documentation

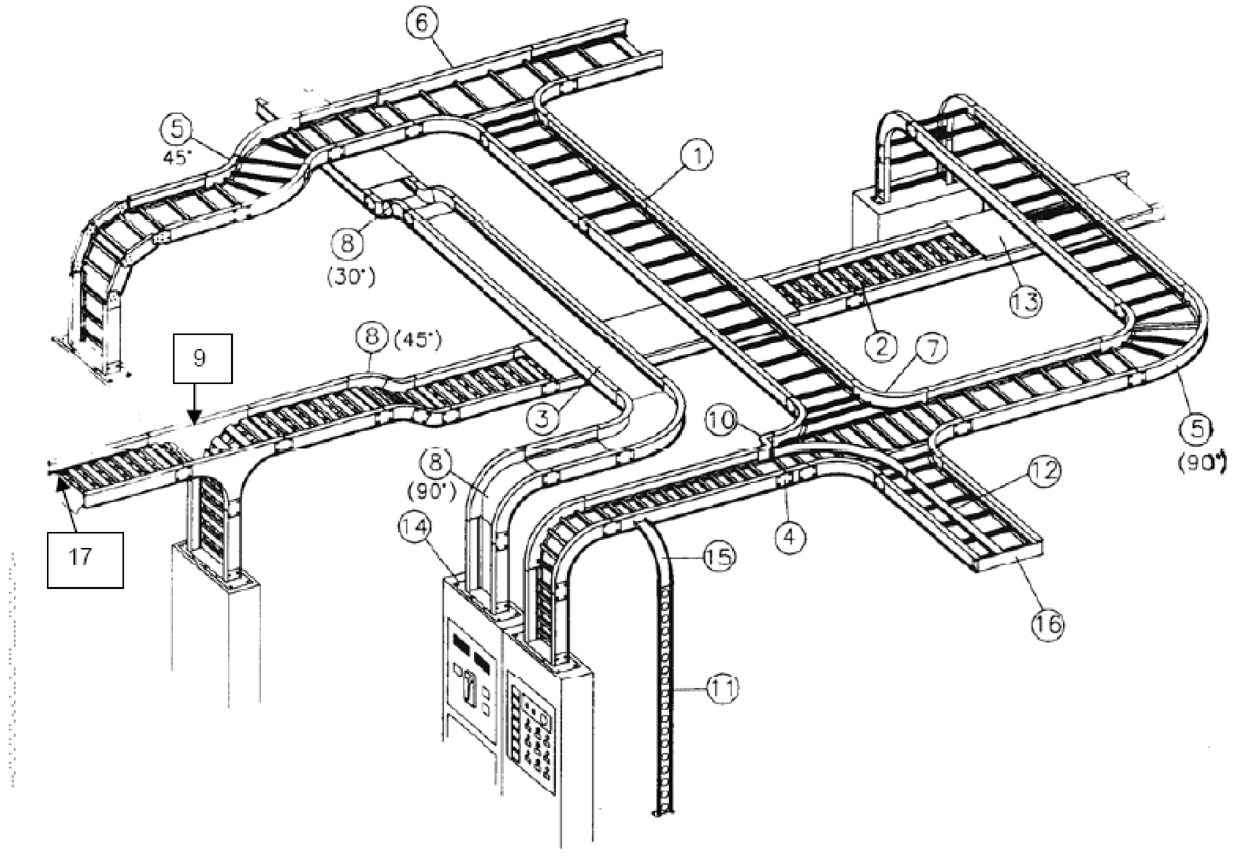
Documentation on the design of HV cable systems shall take the form of a design report to be submitted for approval and stored in the EDMS and is to include, but not be limited to the following:

- Values for the critical design factors, the initial temperature and maximum permissible final temperature, and the methods used and assumptions made in ascertaining these values.
- Details on how compliance is achieved with clause 6.1and .
- Methodology and determination of power cable ratings.
- Details of EMF reduction, EMC considerations, fire spreading prevention.
- Determination of pulling tension, cable fill.
- A drawing or a series of drawings showing the location of cable pits, trenches, conduits, ducts and underground services in the substation site.
- A series of drawings detailing cable schedule, cable routing, depth of burial, conduit/duct arrangement, cross sections of cable arrangement in trays/on ladders, separation between cable groups, separation between cable trays/ladders, protection against mechanical damage, required signage, cable tray/ladder installation, cable supports, cable restraints, cable terminations, cable screen earthing, tray/ladder earthing, resistance minimisation at tray/ladder joints, pit and trench details, fire barriers, notes for installation and construction, etc.

Annex A

Informative

Illustration of selected definitions of a cable tray system



Legend:

1 = Ladder cable tray
2 = Ventilated cable tray
3 = Solid-bottom cable tray
4 = Rigid connector
5 = Horizontal elbow
6 = Horizontal tee
7 = Horizontal cross
8 = Vertical elbow
9 = Vertical tee
10 = Reducer
11 = Channel cable tray
12 = Divider
13 = Cover
14 = Tray-to-box connector
15 = Channel vertical elbow
16 = Blind end
17 = Dropout

Figure 1
ILLUSTRATION OF SELECTED DEFINITIONS

Figure 9: NEMA VE 1

Annex B

Informative

Cable Rating Calculations – Examples

B.1 Manufacturer Standard Conditions

Generally, the nominal current ratings of XLPE cables given by manufacturers are calculated in accordance with IEC 60287 and based on the following standard conditions (these assumptions to be confirmed in the manufacturers catalogues:

Table 11: Standard cable laying conditions (typical)

Ambient air temperature	**40°C**
Ambient soil temperature	25°C
Soil thermal resistivity	1.2°K.m/W
Maximum conductor temperature	90°C for continuous current rating
Maximum conductor temperature	105°C for emergency rating
Burial depth	900 mm

Note that the 105°C emergency limit represents the following approximate percentage increase over the normal continuous ratings:

- Cables in air: +15%,
- Cables in ground (laid direct or in ducts): +11% (up to 13% in Energex area where ground temperatures are lower)

B.2 HV Power Cable Current Ratings

The preferred method for calculating current ratings of HV power cables shall be using software (Cymecap). Alternatively, current ratings may be determined from manufacturer data sheets with adjustments or hand calculation. Calculation software incorporates cyclic and emergency loads in the current rating determination, using manufacturer data sheets gives continuous current ratings only. For hand calculation that incorporates cyclic and emergency loads, reference should be made to CIGRE Technical Brochure 5 – Current ratings of cables for cyclic and emergency loads.

When using manufacturer data sheets, the current ratings must be adjusted for any deviations from the standard conditions by applying the following variation factors:

- Ambient temperature
- Ambient ground temperature
- Depth of burial
- Ground thermal resistivity (usually with various sizes and types of cables, single or three core and methods of laying, direct in ground or in duct),

- Screen bonding / earthing
- Grouping of cables derating

Example: Calculating current ratings utilising manufacturer data sheet:

A 3-phase circuit comprises of 2 single-core per phase XLPE, 6.35/11 kV, 630 mm^2, Cu, 10 kA screen cables laid in conduit buried at 1000 mm depth, in two horizontal touching trefoil groups, 0.60 m apart, solidly bonded screen, 1.5 K.m/W ground thermal resistivity. What are the circuit continuous and emergency current ratings with EQ regional summer and winter conditions?

Table 12: Manufacturer information

Single-core 6.35/11 kV, XLPE, 630 mm^2, Cu cable current rating in underground ducts in touching trefoil and standards conditions =	**625 A**
Ground temperature variation factor for 35^{o}C (Summer - regional) =	0.92
Ground temperature variation factor for 29^{o}C (Summer – ex Energex) =	0.97
Ground temperature variation factor for 20^{o}C (Winter) =	1.04
Depth of burial variation factor at 1000 mm =	0.98
Ground TR variation factor at 1.5 K.m/W for single core 630 mm^2 cables laid in single way conduits =	0.94
Derating factor for 2 groups of cables in touching trefoil single way conduits, horizontal formation at 0.60 m apart =	0.90

The summer continuous current rating of the circuit with EQ's conditions will be:

2 (groups)*625 A*0.92*0.98*0.94*0.9 = 953 A, say 955 A (regional).

2 (groups)*625 A*0.97*0.98*0.94*0.9 = 1005 A, say 1005 A (ex Energex).

The winter continuous current rating of the circuit with EQ's conditions will be:

2 (groups)*625 A*1.04*0.98*0.94*0.9 = 1077 A say 1075 A.

The summer emergency rating at 105°C limit with EQ's regional conditions is approx. ≈ 953*1.11 = 1058 A, say 1060 A, and with EQ's ex Energex area is approx. ≈ 1005*1.13 = 1135A

The winter emergency rating at 105°C limit with EQ's conditions is approx. ≈ 1077*1.11 = 1195 A.

B.3 LV Power Cable Current Ratings

Current ratings of LV power cables shall be determined either from using relevant tables in AS/NZS 3008-1.1 or manufacturer data sheets. Any deviations from the standard conditions given the current rating shall be adjusted by applying the appropriate correction factors as for HV power cables.

Example – Consider the supply to a 400V distribution board at a transformer bay with an anticipated load of 40kW.

Full load current $I = \frac{40\times10^3}{1.73\times400} = 57\text{A}$

Cable type Cu conductor, XLPE/PVC

Cable run Enclosed in conduit

Cable length 40m

Assume no other cables run in parallel – no other de-rating factors.

From AS3008 Table 8 Column 24 – closest cable = 6mm^2 Cu XLPE/PVC (60A)

Allow next size up (10mm^2) to allow for power factor, any other unknown de-rating factors and voltage drop issues (see below).

Short Circuit Rating

For short circuit current on the LV system the protective device must clear the maximum fault current before the maximum conductor temperature (250^{o}C for XLPE cables). The maximum fault clearance time of the upstream breaker is based on:

$$t = \frac{K^2 A^2}{Isc^2}$$

Equation 4: Short circuit rating

Where

t	Fault clearing time (s)
A	Cable cross section area (mm^2)
I_{sc}	Short circuit current at main board (say 3000A in this instance)
K	Constant for XLPE cables at 250oC (with initial temp = 90oC) = 143 (AS3008 Table 52)

$$t = \frac{143^2 10^2}{3000^2} = 0.227s$$

Protection by a 63A MCB Class B breaker to IEC 60947-2 the fault clearing time at this fault level will be 0.01s.

Voltage Drop

For a 10mm^2 XLPE cable Vd = 4.05 mV/A.m (AS3008 Table 41 Col 8)

Therefore at 57A and 40m cable run Vd = 4.05 x 55 x 40 /1000

= 8.91V = 2.2% (<5% so will be OK provided no significant voltage drop upstream)

Maximum Earth Loop Resistivity

The earth loop impedance needs to be low enough to allow sufficient fault current to flow with negligible fault impedance to operate protection in a specified time.

A rule of thumb formula given in Pirelli Technical guide is:

$$Lmax = \frac{0.8U_o SphSpe}{I\ \rho\ (Sph + Spe)}$$

Equation 5: Max Earth Loop Resistivity

Where

Lmax	Maximum length of cable run
Uo	Nominal volts ph-ground (230V)

Sph	Cross section area phase conductor (10mm^2)
Spe	Cross section are of protective earth conductor (10mm^2)
P	resistivity of copper = 22.5E-3 Ω mm^2/m
I	mean trip setting for instantaneous element.
	For Class B breaker approx. 4 x breaker rating = 4 x 63A = 252A

$$Lmax = \frac{0.8S \times 230 \times 10 \times 10}{252 \times 22.5 \times 10^{-3}\ (10+10)} = \ 162m\ > 40m$$

Therefore acceptable from an earth loop resistivity perspective.

B.4 Short Circuit Current Ratings

The short circuit rating is a symmetrical current which will cause the conductor temperature to rise from the normal operating value of 90°C to 250°C for XLPE and the copper screen from 80°C to 250°C in the time stated, usually 1 s, assuming adiabatic conditions, (no heat loss).

The short circuit current rating of a conductor and screen shall be calculated in accordance with IEC 60986 and IEC 61443, or given by the manufacturer. The maximum short circuit current Isc (under adiabatic conditions) can be calculated from the equations below:

$$I_{sc} = \frac{1}{1000} \times \sqrt{\frac{K^2 S^2}{t} \times \ln\frac{\theta_f + \beta}{\theta_i + \beta}}$$

Equation 6: Short circuit rating

Where

I_{sc} = short circuit current (kA)

K = constant for material

β = reciprocal of temp co-efficient of resistance at 0^{o}C

θ_f = permissible short-circuit temperature

θ_i = permissible temperature before short-circuit

S = cross section of sheath or screen in mm^2

t = rated short circuit duration (s)

Table 13: Material constants

Material	**K**	**β**
Copper	226	234.5
ead	41	230

Table 14: Temperature limits for insulation materials

Material 1)		Temperature °C
Paper:		
– MIND (mass-impregnated non-draining)	≤20 kV	170
	>20 kV	150
– oil/resin	≤20 kV	170
	>20 kV	150
– oil-filled		250
Polyvinyl chloride	(PVC/B)	
– conductor cross-section ≤300 mm²		160
– conductor cross-section >300 mm²		140
Cross-linked polyethylene	(XLPE)	250
Ethylene propylene rubber	(EPR and HEPR)	250
1) Materials and designations according to IEC 60055, IEC 60141 and IEC 60502-2.		

Table 15: Temperature limits for oversheath materials

Material 1)		Temperature 2), 3) °C
Polyvinyl chloride	(ST_1 and ST_2)	200
Polyethylene	(ST_3)	150
	(ST_7)	180
Polychloroprene, chlorosulphonated polyethylene or similar polymers	(SE_1)	200
Polyethylene bonded to aluminium or copper foil		150
Polyvinyl chloride bonded to aluminium or copper foil		160
1) Materials and designations according to IEC 60502-2. 2) Higher temperatures may be allowed, provided experimental data are available to demonstrate their use. 3) For cables in trefoil formation, these temperatures should be used with care due to possible high temperatures in the centre.		

Example

Consider a 33kV 630mm² XLPE/LY/MDPE cable with datasheet as follows:

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Construction	Type of material		Thickness(mm)			Diameter	Direc	Maximum	Unit	Weight
	Material	Size or code	Nom.	Min. avg.	Min.	(mm)	-tion	pitch (mm)		(Kg/Km)
Conductor	SCR	Φ8.0mm				3.9			61	5,735.9
Stranding	WOA	#61/3.9				30.5	S		1	
Binding(1)	Swellable tape ✓	0.4t	0.4	Overlap		31.3	Z		1	19.4
Binding(2)	Semi-con. tape ✓	0.13t	0.13	Overlap		31.7	S		1	14.2
Con. Screen	Semi-XLPE	SI-2	0.7		0.3	33.1			1	81.2
Insulation	X L P E	EI-1	8.2	8.0	7.1	49.5			1	979.6
Ins. Screen	Semi-XLPE	SO-2	0.8		0.6	51.1			1	146.6
W/B Layer	Swellable tape	0.4t	✓ 1.2	Overlap		53.5	S		3	97.1
Metallic sheath	Lead alloy	E alloy	2.0		1.8	57.5			1	3,939.8
Outer sheath	HDPE(Black)	ES-5C	2.9	2.8	2.04	63.3			1	522.7
Conducting layer	Graphite	CPA-83	0.01			63.3 ✓			1	2.1
									Total	11,538.7

*. Water Blocking tape

-. Conductor : Material should be semi-conducting swellable tape.

-. Under metallic sheath : Material should be semi-conducting swellable tape. (Min. 1 layer)

*. Cable Marking

-. Interval : Max. 500mm

-. Height of characters : Min. 9mm ~ Max. 13mm

*. Meter marking

Length shall be marked with number at one meter intervals on the sheath.

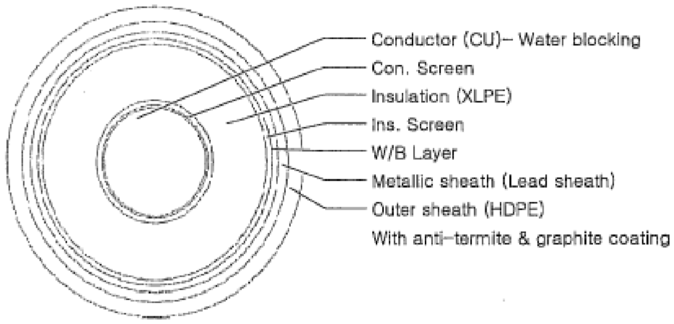

Figure 10: 33kV cable design table

K = 41

β = 230

θ_f = 250

θ_i = 80

S = ¶ x 55.5 x 2 = 349mm^2

t = 3

The rated 3 second short time current can be found from:

$$I_{sc} = \frac{1}{1000} \times \sqrt{\frac{41^2 349^2}{3} \times \ln \frac{250+230}{80+230}}$$

= 5.1 kA

Revision history

Revision date	Version number	Author	Description of change/revision
16/04/2010	1A	Q. Dinh	First draft
20/05/2011	1B	Q. Dinh	Major modifications to incorporate contributions, comments from stakeholders
08/07/2011	1C	Q. Dinh	Comments from SDOF, stakeholders incorporated. Revision log added. Clause 2.1 Underground construction Manual & pulling tension calculator added Clause 2.3 AS/ACIF S008 & S009 added Clauses 4.5 & 4.6 DBT requirement modified Clauses 6.1.1, 6.1.3 & 6.1.5 modified Clause 6.2.1 Last paragraph added Clause 6.2.4 new c) added Clause 6.2.5 e). added to incorporate feedback from SDOF. Clause 6.2.6. Last paragraph added Clause 6.2.7 modified. Clause 6.2.8 new Clause 7. Sub-headings modified and added Clause 8.1. Numbering added & modified. Clause 9.4 Heading modified. Clause 10.7 New Clause 11. Numbering changed
11/10/2011	2	Q. Dinh	Endorsed by SRC and approved
08/02/2012	2A	Q. Dinh	Clause 6.2.8 Sub-heading 6.2.8.1 added Sub heading 6.2.8.2 and text added
29/03/2012	2B	Q. Dinh	Front page. K. E title modified Clause 6.1.1 (new) Safety added. Clause 8.2.1 c) Last sentence added. Clause 8.2.2 c) modified to S. McGuiness' comment

29/09/2022	STNW3018 Ver 1.0	J.Lansley	Update with new STNW no. Section 2 – added Energex references Cl 4.4 – added requirements 66/132kV cables. Cl 4.4-4.6 – removed reference to cypermethrin as termite repellent Cl 5.1 – added max ground temperature requirements SE Qld Cl 5.4 – added calculation for short circuit rating Cl 6.1.5 – updated table on vertical cable supports Cl 6.2.6 – termination requirements updated Cl 6.2.7 – update to allow nylon glands Cl 6.3 – update for screening in Energex area, include DBT as alternative Cl 7 – fire stop penetration details updated Cl 8 – sealing of conduits in basement updated