

Substation Design Instruction

Busbars and support insulators

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SUBSTATION DESIGN INSTRUCTION

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SDI 517 Busbars and support insulators

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1.0 PURPOSE

To set out in detail the minimum requirement for busbars, palm terminals, support insulators, stranded conductors and earthing points for use in indoor and outdoor open switchgear assemblies in transmission/zone substations and switching stations.

2.0 SCOPE

This instruction defines the minimum requirements for material to be used and design of busbars, palm terminals, support insulators, stranded conductors and earthing points used in both indoor and outdoor open switchgear assemblies in transmission/zone substations and switching stations.

3.0 REFERENCES

- Company Policy 9.2.5 - Network Asset Design
- Company Policy 9.2.10 – Network Asset Ratings
- ENA National Electricity Network Safety Code (Doc 01-2008)
- Network Management Plan December 2013 Review
- Earthing Design Instruction EDI 516 – Major substation earthing design, construct and commissioning
- Engineering Technical Specification ETS 0020 – Portable earthing equipment
- Substation Design Instruction SDI 501 - Network configuration
- SDI 505 - Minimum design and construction requirements for transmission and zone substations and switching stations
- SDI 507 - Voltages, insulation levels and fault ratings
- SDI 518 - Support structures
- SDI 520 - Lightning protection and insulation coordination
- SDI 527 - Clearances
- AS 1665:2004 - Welding of aluminium structures
- AS 1531:1991 - Conductors Bare overhead Aluminium and Aluminium Alloy
- AS 1824.2:1985 - Insulation coordination (phase to earth and phase to phase, above 1kV) application guide
- AS 1866:1997 - Aluminium and aluminium alloys - Extruded rod, bar, solid and hollow shapes
- AS 1874:2000 - Aluminium and aluminium alloys – Ingots and castings
- AS 2067:2008 - Substations and high voltage installations exceeding 1 kV a.c.
- AS 62271.1:2012 - High voltage switchgear and controlgear – Common specifications
- AS 62271.301:2005 - High voltage switchgear and controlgear, Part 301: Dimensional standardisation of terminals
- AS 7000:2010 - Overhead line design - Detailed procedures
- IEEE 605:2008 - Guide for Design of Substation Rigid-Bus structures
- Drawing no. 054170 - 127mm SQ Al. Busbar to 127mm SQ Al. Busbar on 132kV Post Insulator connection Detail
- Drawing no. 056365 - Earthing Stirrup to suit twin 19/4.75 AAC Detail and Assembly
- Drawing no. 064022 - Electrical Design General Instruction No. 1-G-3 Busbars current rating/temperature rise
- Drawing no. 064023 - Electrical Design General Instruction No. 1-G-4 Tubular Aluminium Busbar Main Busbar Design

4.0 DEFINITIONS AND ABBREVIATIONS

AAC ¹	all aluminum conductor
Ampacity ²	The rms value of the current that a device can carry within specified temperature limitations in a specified environment dependent upon: a) temperature rating; b) power loss; and, c) heat dissipation. Excessive conductor temperature may anneal the conductor, thereby reducing its strength, or may damage connected equipment by transfer of heat.
Black body	An object that absorbs all electromagnetic radiation that falls on it.
Busbar ²	A low impedance conductor to which several electrical circuits can be separately connected.
Corona ²	A luminous discharge due to ionization of the air surrounding a conductor caused by a voltage gradient exceeding a certain critical value.
Emissivity ²	The ratio of the radiation emitted by a surface to the radiation emitted by a black body at the same temperature. It is therefore a measure of a material's ability to emit radiant energy. Materials are assigned an emissivity value between 0 and 1.0.
Fault rating ³	The capability of equipment to carry or interrupt fault currents, which are specified as rated short-time withstand current or short circuit making/breaking capacity.
Open switchgear ⁴	Switchgear in which the live parts are not provided with protective covers.
Palm terminal	A rectangular conductor used to enable the connection of equipment.
Rated normal (continuous) current ⁵	The rms value of the current that switchgear and control gear carries continuously under specified condition of use and behaviour.
Rigid busbar ²	A substation busbar, which comprises metallic tubes, hollow square or solid bars, and is supported by insulators.
Stranded busbar ²	A substation busbar, which comprises flexible conductors.
Light pollution ⁶	Sites beyond 10km from the coast and without local pollution sources.
Heavy pollution ⁷	Sites 1-3km from the coast or within 0.3km of salt lakes or bays, near large chemical works, or exposed to severe dust deposits.

5.0 ACTIONS

5.1 General

This instruction shall be read in conjunction with SDI 518.

¹ AS 1531:1991 - Conductors Bare overhead Aluminium and Aluminium Alloy

² IEEE 605:2008 - Guide for Bus Design in Air Insulated Substations

³ Company Policy 9.2.10 - Network Asset Ratings

⁴ AS 2067:2008 - Substations and high voltage installations exceeding 1 kV a.c.

⁵ AS 62271.1:2012 - High voltage switchgear and controlgear – Common specifications

⁶ AS 1824.2 Insulation coordination (phase to earth and phase to phase, above 1kV)

Busbars shall be supplied complete with all connectors (palm terminals), support insulators, support structures, clamps, earthing points and fittings. The materials used for the construction of busbars, connectors and fittings shall be selected to minimise the possibility of galvanic corrosion between dissimilar metals.

The busbar design shall cater for thermal expansion through the use of expansion joints.

When designing support structures and foundations for busbar conductors and support insulators, all gravitational, mechanical and electrical stresses/loading shall be considered, as set out in this Standard.

The busbar system shall be designed to avoid any corona discharge development. In order to avoid corona developing conditions, the busbar system shall be free of sharp edges throughout the conductor system. If this is not achievable, additional equipment, such as corona rings and stress-relieving cones, shall be incorporated into the busbar design, and mounted in the areas of high electric stress.

Similarly, the busbar system design shall consider the standard electrical clearances and confirm that the minimum conductor phase-to-phase and phase-to-earth clearance values are maintained (refer to SDI 527).

5.2 Design requirements

5.2.1 General

Use of both rigid and/or stranded busbar types is acceptable in transmission/zone substations and switching stations. These shall be designed in accordance with AS 2067.

In designing rigid and/or stranded busbars, the standard current rating of busbars shall be as set out in SDI 501 - Transmission network configuration. The busbar design shall also comply with the guidelines and parameters given in clauses 5.2.2, 5.3.1 and 5.3.3 of this Standard, and IEEE 605:2008.

5.2.2 Busbar design calculations⁷

When designing busbars, the ampacity⁸ of the bus conductor shall be determined by either the electrical system requirements or the ampacity of the connected equipment. In both cases, the emergency and continuous overload ratings of the connected equipment, which contribute to conductor operating temperatures shall be taken into consideration to arrive at the required current rating of the conductor.

The ampacity is limited by the conductor's maximum operating temperature (for the conductor's maximum operating temperature, refer to sections [g] and [h] below). The following factors shall be taken into consideration when calculating the ampacity of the bus conductor:

- Heat balance.
- Transverse wind speed.
- Solar radiation.
- Conductor emissivity.
- Solar absorption coefficient.
- Ambient temperature.
- Temperature rise.
- Maximum conductor temperature.

⁷ IEEE 605:2008 - Guide for Bus Design in Air Insulated Substations

(a) Heat balance

Under steady state conditions, the temperature of a conductor will be a function of the heat balance, which is the difference between the heat gain and heat loss.

For outdoor busbar installations, the heat generated due to I^2R losses and solar radiation equals the heat output due to convection, conduction and radiation. For the special case of indoor busbars, uninhibited natural convective wind flow conditions and zero solar radiation shall apply.

The value of current I , for a given conductor temperature rise may be resolved using the following heat balance equation:

$$I^2RF + q_s = q_c + q_r + q_{cond}$$

Therefore,

$$I = \sqrt{\frac{q_c + q_r + q_{cond} - q_s}{RF}}$$

Where:

I^2RF = Heat gained through current flow (W/m)

I = Current for the allowable temperature rise, (A)

R = DC resistance at the operating temperature

F = Skin-effect coefficient

q_s = Heat gained through solar radiation (W/m)

q_c = Heat lost through convection (forced outdoor or natural indoor) (W/m)

q_r = Heat lost through radiation (W/m)

q_{cond} = Heat lost through conduction (W/m)

Note: The product RF is the conductor effective resistance at a given temperature and frequency. Detailed formulae for calculating the above quantities of the heat balance equation can be obtained from IEEE 605: 2008 guideline.

(b) Transverse wind speed

Table 1: Standard values for transverse wind speed ⁸

Regional or location reference	Transverse wind speed (m/sec)
Inland	0.5
Coastal	1.0
Mountainous	1.0

(c) Solar radiation

The direct solar radiation shall be assumed to be 1,000W/m².

(d) Conductor emissivity

⁸ Company Policy 9.2.10 - Network Asset Ratings

Table 2: Standard values for conductor emissivity ⁹

Conductor surface*	Emissivity factor
Bright conductor	0.3
Grey conductor	0.8
Black conductor	1.0

* Physical appearance of the conductor outer surface from bright to black.

(e) Solar absorption coefficient

Table 3: Standard values for solar absorption coefficient ⁹

Conductor surface*	Solar absorptivity values
Bright conductor	0.6
Grey conductor	0.8
Black conductor	1.0

* Physical appearance of the conductor outer surface from bright to black.

(f) Ambient temperature

The ambient temperature values for outdoor and indoor switchgear are based on monthly temperature averages. The indoor busbar conductor rating applies to conductors that are sheltered from sun and wind and located so that natural convection is uninhibited (refer to Table 4 below).

Table 4: Standard values for ambient temperature ⁹

Ambient temperature	deg. C
Outdoors	40
Indoors	20

(g) Temperature rise

The temperature rise values of the busbar conductor shall be referred to the ambient temperature and allowable maximum conductor operating temperature.

(h) Maximum conductor operating temperature ⁹ = 90 deg. C

The maximum conductor operating temperature for aluminium or copper busbars of either stranded or tubular construction, generally, shall not exceed 90 deg. C. This is due to the limits on palm terminal operating temperatures (refer to AS 62271.301:2005, section B.2.2.1).

5.3 Busbar

5.3.1 Determination of busbar design

IEEE 605:2008 shall be used as a guide for determining forces on busbars due to gravity, wind, radio influence, vibration, maximum anticipated fault current, and current carrying capacity. A flowchart of the design process is provided as a guide in Annexure 2.

As a minimum, the following electrical, mechanical and structural loads shall be taken into consideration when satisfying the design conditions:

⁹ Company Policy 9.2.10 - Network Asset Ratings

- Short circuit loads.
- Wind loadings (wind speed and gust of wind, the conductor size and shape, the height and exposure of the conductor, and the radial thickness of ice).
- Thermal loads.
- Gravitational loads (weight of conductor, weight of the damping material, concentrated masses and mounting structure, and ice load).

5.3.2 Rigid busbar

Connections of rigid busbars shall be designed to reduce the effect of wind, natural frequency, thermal expansion/contraction and lateral harmonic vibrations to acceptable levels.

Tubular rigid bus conductors over 3m shall be damped to reduce aeolian vibration caused by wind. This shall be achieved by installing stranded bare cable inside the bus conductor to dissipate vibrational energy.

The cable should be of the same material as the bus conductor to prevent corrosion. The weight of the cable shall be 10% to 33% of the tubular bus conductor. The cable shall be installed so that only one end is connected to one end of the tubular bus and the other end of the cable is left floating inside the busbar. The weight of the cable shall be included in computing busbar gravitational forces.

Rigid busbar spans shall always be in continuous lengths between supports and fittings. Refer to Annexure 1 for rigid busbar maximum unsupported length.

5.3.3 Stranded busbars

As a minimum, all stranded busbars and their connections shall be designed considering the following criteria:

a. Conductor rating and size

The stranded busbar conductor size shall be the largest of the line conductors terminating at the substation gantry and capable of withstanding operational requirements and system faults without damage from overheating. These shall have adequate current rating based on the factors in section 5.2.2.

b. Conductor sag and tension

The stranded busbar conductor sag and tension shall be designed based on calculations given in AS 7000. The conductor sag shall be such that during any deflection or swing due to abnormal conditions, such as effect of wind, seismic or short circuit forces, the minimum conductor phase-to-phase or phase-to-earth clearance is maintained (refer to SDI 527 for minimum electrical clearances in air).

5.4 Material requirements

Busbars used in indoor switch rooms shall be manufactured from rigid conductors, and those used in outdoor switchyards shall be either rigid or stranded conductors.

Steel busbars are not acceptable as steel has a higher resistivity than aluminium and copper and, therefore, higher electrical losses.

5.4.1 Rigid busbars

Rigid busbars in indoor and outdoor open type switchgear may be fabricated from the following shapes and materials:

- Round or square aluminium hollow extrusions.
- Round solid aluminium bar.

- Round copper tube, round copper bar, or flat solid rectangular copper bar.

Busbars with round smooth tubular shape or hollow-square with bevelled edges are recommended for use in outdoor open switchgear.

The surface voltage gradient of a selected rigid busbar (hollow-square or tubular) shall not exceed the allowable surface voltage gradient. The allowable surface voltage gradient values shall be as set out in IEEE 605:2008¹⁰.

Tubular busbars shall be of high conductivity aluminium alloy in accordance with AS 1866. The recommended high conductivity aluminium alloy material to be used is 6101-T6¹¹.

Round copper tube, round copper bar, or flat copper bar are recommended for use in indoor open type switchgear. The open ends of tubular busbars should be plugged to prevent corrosion and bird nesting.

5.4.2 Rigid busbars - hollow-square and tubular

Typical conductor sizes, maximum unsupported length and material for hollow-square and tubular rigid busbars shall be as set out in Tables A and B in Annexure 1. The typical values selected will assist in establishing design calculations (refer to flow diagram in Annexure 2).

Round tubular rigid busbar is preferred because it has the following characteristics:

- Maintain equal rigidity in all directions, which is an inherent advantage for withstanding wind, short circuit and ice loading conditions.
- Bend easier than other shapes when forming bends or offsets.
- Minimise corona, audible noise and radio noise.
- Avoid large sags to provide a more pleasing appearance.

5.4.3 Stranded busbars

Stranded busbars shall be manufactured from aluminium or copper flexible conductors. A maximum of three (3) conductors shall be used for any one (1) phase conductor.

The maximum unsupported span of stranded conductor busbar shall be three (3) metres. Surge diverters shall not be used to support flexible busbar conductors and shall be connected to the main busbar by a separate flexible conductor.

All possible slack is to be removed from conductors and at least one (1) spacer is to be fitted in every span where more than one (1) conductor on each phase is used to stiffen the conductors.

Compression fittings shall be used for stranded conductor terminations. Bolted clamp terminations are not acceptable. Typical sizes, overall diameter, maximum unsupported length and material for stranded busbars conductors shall be as set out in Table C in Annexure 1.

5.5 Earthing points

Flexible and solid busbars shall be fitted with earthing stirrups at selected locations for connection of standard portable earthing and short-circuiting equipment as specified in ETS 0020. As a minimum, the stirrups shall be fitted on the following busbar locations:

- each side of a circuit breaker, HV side of a transformer and overhead mains connection to isolator (such as the line side of line isolator);

¹⁰ The round smooth shapes of busbars with permissible surface voltage gradient values generally perform at the highest corona-free operation, and are recommended for use

¹¹ AS 1866:1997 - Aluminium and aluminium alloys – Extruded rod, bar, solid and hollow shapes

- each section of the busbar or on an associated busbar connection (where a section of the busbar is 30m or more in length, provision shall be made for two (2) stirrups);
- on the line side of line earth switches; and,
- at the bottom of voltage transformer drop out fuse.

Reference shall be made to EDI 516, for location of brass earth studs on structures for connecting earth clamps of portable earthing devices.

5.5.1 Earthing stirrup details

The earthing stirrup shall be used to attach the phase clamp of portable earth sticks. The earthing stirrup shall have a cross-section of approximately 25mm diameter, with a connection area length a minimum of 75mm, and an internal height (for earth stick head) of minimum 100mm.

For aluminium conductors, the earthing stirrup shall be fabricated from high strength, high conductivity, aluminium alloy. The aluminium alloy earthing stirrup shall be supplied assembled by the manufacturer (refer to Drawing no. 056365).

For copper busbar conductors, the stirrup shall be made of either copper or tinned aluminium.

5.6 Finish on busbars

All busbars and conductors are to be left in their natural state. No painting of surfaces is to be carried out. In certain special cases, outdoor busbar conductors may be coated. This coating of the conductors shall be taken into account when estimating emissivity for use in calculations (refer to clause 5.2.2.d for different values of conductor emissivity).

5.7 Joints

For busbars and connections, the required joint depends upon the type of bus conductor selected. All joints shall be free from hot spots and corona development. The following joints shall be used with the corresponding bus conductor:

- Bolted, clamped or welded type joints for rigid conductors (also applies to indoor flat bar conductors).
- Compression joints for stranded conductors.

All bolted connections shall be designed in accordance with the AS 62271.301-2005. All copper joints shall be tinned.

The mixing of aluminium and copper at joints is to be avoided. If this is unavoidable, the aluminium section shall be placed above the copper section and the copper section has to be tinned.¹² Alminox or other suitable jointing compound shall be used on interfacing surfaces. Bimetallic connection joints are the best and most acceptable means of joining aluminium and copper conductors.

Note: Aluminium is installed above copper to prevent water-borne copper salts being deposited on the aluminium, possibly causing electrolytic corrosion.

Compression fittings shall be used for stranded conductor terminations. Bolted clamp type terminations are not acceptable.

Rigid aluminium bus hardware, including all connections to the buses, shall be welded.

Note: Welds in solid aluminium busbar shall be carried out using gas tungsten arc welding (GTAW) or gas metal arc welding (GMAW) processes (refer to AS 1665, or to information on welding procedures from the suppliers of the aluminium or the welding equipment).

¹² AS 62271.301 - High Voltage and switchgear and controlgear Part 301: Dimensional standardisation of terminals

The filler rod shall be aluminium alloy B4043.

5.7.1 Free joints

For rigid busbars, adequate provision shall be made for bus movement with temperature change by using slip or expansion bus supports, flexible taps and expansion terminals. Every length of rigid busbar conductor shall have at least one (1) free joint to allow for thermal expansion and contraction. Free joints shall have potential equalisation devices installed to reduce radio frequency interference.

5.7.2 Fixed joints

Fixed joints shall not be placed on any equipment bushing (transformer or circuit breaker). This is to ensure no additional loading is added to the equipment bushings.

5.8 Palm terminals

Palm terminals shall conform to AS 62271.301.

The standard sizes for palm terminals shall be used. Deviations from this standard may be allowed subject to Network Substations Manager approval.

Refer to Figure 1 for the standard palm terminal dimensions.

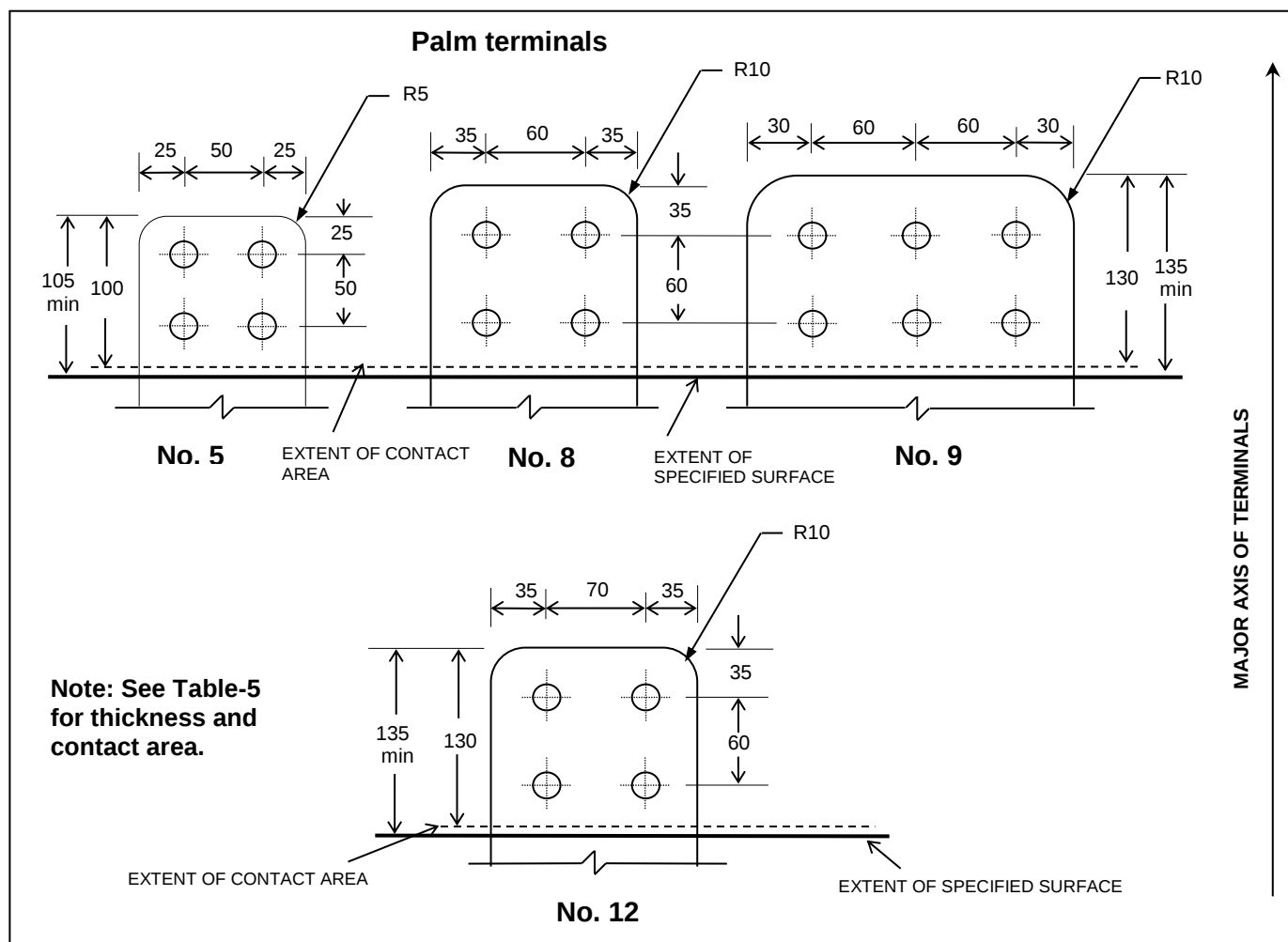
In any one installation, all main circuit palm terminals shall be of the same size to standardise connections. The standard palm terminals shall be as set out in Table 5 below.

Table 5: Standard palm terminals¹³

Terminal no.	Bolt hole diameter mm	Net contact area (mm ²)	Minimum thickness - aluminium (mm)	Assigned nominal current rating - aluminium (Amp)
5	14	9300	12	1250
8	18 or 22	15300	20	2000
9	18 or 22	21000	20	3150
12	18 or 22	16700	20	2500

¹³ AS 62271.301 - High Voltage and switchgear and controlgear Part 301: Dimensional standardisation of terminals

Figure 1: Dimensions of standard palm terminals



The bolt tightening torque, bolt load and joint contact pressure for palm terminals shall be as set out in Table 6 below.

Table 6: Bolt tightening torque for palm terminal ¹⁴

Bolt nominal size/material	Torque applied to nut T (Nm)	Bolt load P (kN)	Contact pressure (MPa)
M12/steel (lubricated)	45	18	8
M12/aluminium alloy	38	13	6
M12/stainless steel (lubricated)	_*	18	_*
M12/galvanized commercial	_*	18	_*
M16/steel (lubricated)	90	28	7
M16/galvanized commercial	_*	18	_*
M20/steel (lubricated)	110	28	8
M20/galvanized commercial	_*	28	_*

* This information is not available in AS 62271.301. Use manufacturer's recommended values.

¹⁴ AS 62271.301 - High Voltage and switchgear and controlgear Part 301: Dimensional standardisation of terminals

5.9 Busbar support insulators

Busbar support insulators shall be selected using limit state methodology as defined in AS 7000, with the exception of insulator creepage length and minimum cantilever strength, which are set out in the sections below. Design criteria for insulator strength calculations are also covered in IEEE 605 guidelines.

5.9.1 Insulator creepage length

The insulator creepage distance shall be based on the standard pollution¹⁵ levels, as set out in Table 7 below.

Table 7 Insulator standard surface creepage length

Pollution level	Surface creepage length per kV rms phase-to-ground of system nominal voltage (mm/kV)
Light	25
Heavy	45

Underground to overhead termination insulators shall have 50mm/kV surface creepage length phase-to-ground of system nominal voltage.

5.9.2 Insulator cantilever strength

The minimum cantilever strength on all insulators shall be 10kN unless otherwise approved by the Substations Manager, Network Engineering.

6.0 AUTHORITIES AND RESPONSIBILITIES

General Manager Asset Management has the authority and responsibility for approving this instruction.

Manager Asset Standards & Design has the authority and responsibility for making recommendations to the **General Manager Asset Management** in respect of this instruction.

Network Substations Manager is responsible for keeping that the content of this instruction is kept up to date.

All **Endeavour Energy employees and/or contractors** are responsible for:

- Meeting the requirements of this instruction and SDI 505 are met.
- Working in accordance with local and statutory requirements.
- Maintaining public safety.
- Working in accordance with Endeavour Energy's Electrical Safety Rules.

All **Project Managers** are responsible for:

- Meeting the requirements of this instruction within their area of responsibility.
- Establishing that Endeavour Energy employee and/or contractors engaged to perform the work have appropriate qualifications.
- Determining that appropriate equipment details are entered into the Ellipse database as part of the work.

7.0 DOCUMENT CONTROL

Documentation content coordinator: Network Substations Manager
Documentation process coordinator: Branch Process Coordinator

¹⁵ AS 1824.2 Insulation coordination (phase to earth and phase to phase, above 1-kV) application guide and SDI 520.

Annexure 1: Busbar typical values tables

Table A: Typical values for rigid busbars (hollow-square)

Description	Maximum unsupported length	Recommended material
76mm square/6.35mm thick	6 metres	Alloy 6101 –T6
127mm square/6.35mm thick	9 metres	Alloy 6101 –T6

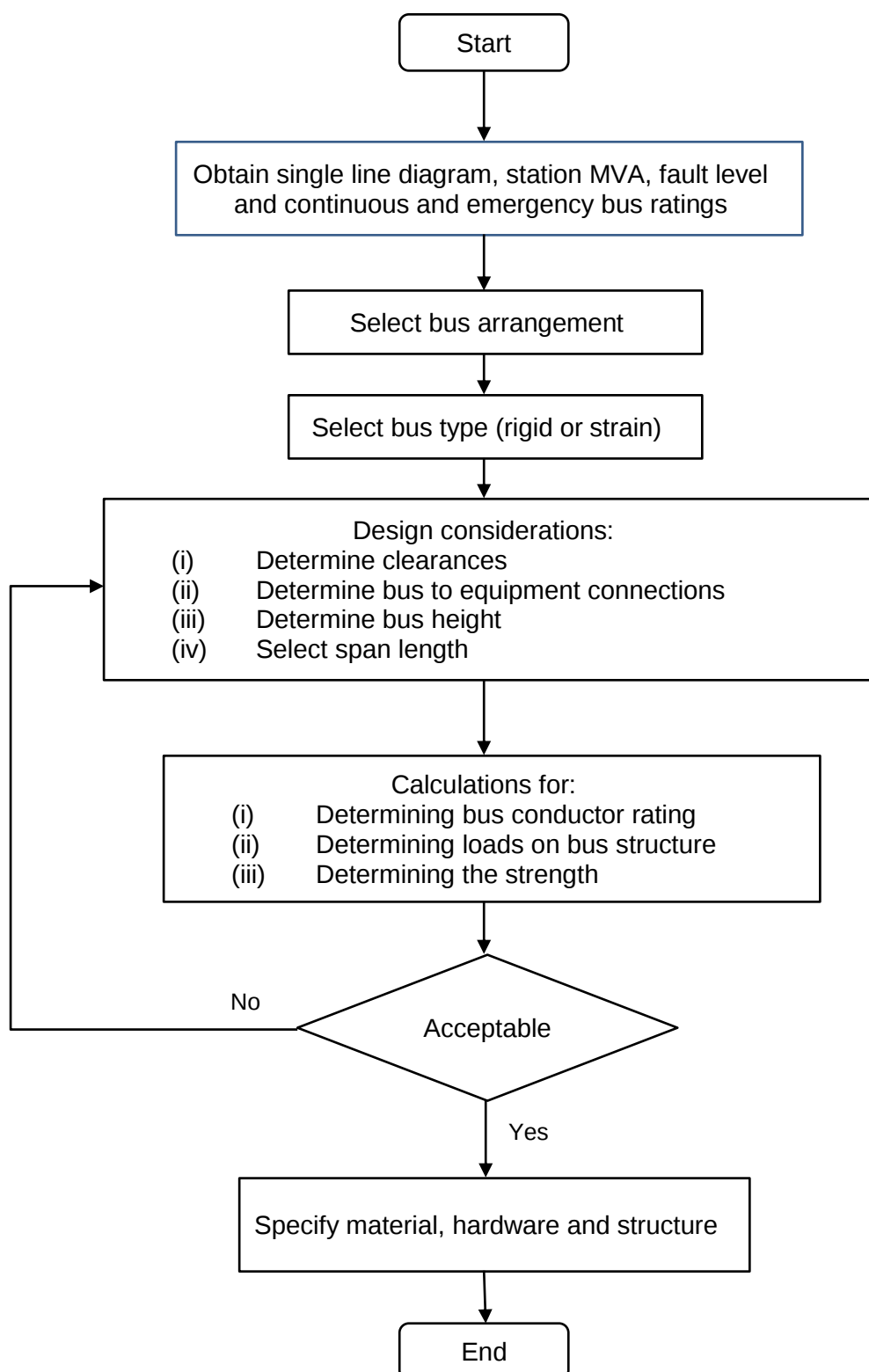
Table B: Typical values for rigid busbars (tubular)

Description Outer diameter. X wall thickness	Maximum unsupported length	Recommended material
80mm X 4mm	9 metres	Alloy 6101 –T6
100mm X 4mm	9 metres	
100mm X 8.7mm	6 metres	
100mm X 10mm	6 metres	
125mm x 6mm	10 metres	
140mm x 8mm	10 metres	

Table C: Typical values for stranded busbar conductors

Description	Overall Diameter	Maximum unsupported length	Material
61/3.25 stranded Al conductor	29.3 mm	3 metres	AAC
54/7/3.5 stranded Al conductor	31.5 mm	3 metres	ACSR
19/4.75 stranded Al conductor	23.8 mm	3 metres	AAC

Annexure 2: Bus design flow chart



Note: Detailed calculations and equations are available in IEEE 605:2008.