Part of Energy Queensland

Substation Standard

Standard for Busbar Conductor Selection

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Abstract: This standard provides guidance on the selection of busbar type and application.

Keywords: Busbar, Conductor, Connection, Support, Insulator, SS-1-3.2.

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1 Overview

1.1 Purpose

This standard provides methods for calculating current ratings and mechanical limits of outdoor, air insulated busbar conductors to be adopted within Energy Queensland. Specific ratings are provided for commonly used conductors and standard conditions. This standard should be used in conjunction with the STNW 3014 – Busbar Design Calculator.

2 References

2.1 Legislation, regulations, rules, and codes

National Electricity Rules Version, 2023 (AEMC)

Queensland Electricity Act, 1994 (Queensland Government)

Queensland Electricity Regulation, 2006 (Queensland Government)

Queensland Electrical Safety Regulation, 2013 (Queensland Government)

Queensland Work Health and Safety Act, 2011 (Queensland Government)

2.2 Energy Queensland controlled documents

Plant Rating Manual - 4179110

Standard for Clearances in Air - 3054141

2.3 Energy Queensland other documents

Busbar Design Calculator, STNW3014

2.4 Other sources

AS/NZS 1170.0, 2002, Structural design actions, Part 0: General principles

AS/NZS 1170.2, 2021, Structural design actions, Part 2: Wind actions

AS 1531, 1991, Conductors – Bare overhead – Aluminium and aluminium alloy

AS/NZS 1664.2, 1997, Aluminium Structures – Part 2: Allowable stress design

AS 1746, 1991, Conductors - Bare Overhead - Hard-drawn Copper

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

AS 4398.1, 1996, Insulators – Ceramic or glass – Station post for indoor and outdoor use – Voltage greater than 1000 V a.c

AS 62271.1, 2012, Common specifications for high voltage switchgear and controlgear standards

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

IEC 60287-1-1, 2014, Electric cables – calculation of current rating – Part 1-1: Current rating equations (100% load factor) and calculation of losses - General

IEC 60865-1 Ed.3.0, 2011, Short-circuit Currents - Calculation of Effects - Part 1: Definitions and Calculation Methods

IEC 60909-0, 2016, Short-circuit currents in three-phase a.c. systems - Part 0: Calculation of currents

IEEE 80, 2000, IEEE Guide for Safety in AC Substation Grounding

IEEE 605, 2008, IEEE Guide for Bus Design in Air Insulated Substations

TB601, 2014, Guide for thermal rating calculations of overhead lines

Morgan, Finlay, & Derrah, 2000, IEE Proceedings science, measurement and technology, 147 (4), 169-171. (New formula to calculate the skin effect in isolated tubular conductors at low frequencies)

3 Definitions and abbreviations

3.1 Definitions

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

Albedo	The incident solar radiation reflected from the ground. (TB601, 2014)
Cantilever	A long projection supported at only one end.
Fixed Support	Support which does not permit angular movement of the conductor at the supported point.
Emissivity	The ratio of power radiated by a material body to the power radiated by a blackbody at the same temperature. (IEEE 605, 2008)
Load	The value of a force appropriate to an action.
Shall	Indicates that a statement is mandatory.
Should	Indicates a recommendation advisable (non-mandatory).
Simple Support	Support which permits angular movement of the conductor.
Solar absorptivity	The ability of a conductor to absorb heat from solar radiation. (IEEE 605, 2008)

3.2 Abbreviations

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

AC	Alternating Current
AAC	All-Aluminium Conductor
AAAC	All-Aluminium Alloy Conductor
DC	Direct Current

4 General Procedure

The following criteria shall be considered when evaluating the suitability of a substation busbar conductor:

- Electrical criteria
    - Current carrying capacity of the conductor

- Short circuit capacity of the conductor
- Corona inception
- Mechanical criteria
  - Allowable deflection (rigid bus)
  - Wind and weight loading (rigid bus)
  - Vibration and resonance (rigid bus)

The STNW 3014 – Busbar Design Calculator evaluates the criteria listed above for a range of commonly used conductors and can be used to evaluate new conductors. The following sections of this standard describe the inputs required from the designer to obtain results.

Annex A and Annex B are included to provide detailed description of the calculations used in the evaluation.

5 Standard Design Inputs

The critical design inputs that can be amended to evaluate busbar conductors are listed in this section. Allowable range of inputs are provided where applicable. Parameters that are not included in this section either have negligible impact to the evaluation or should not be altered.

5.1 Substation Location and site conditions

Substation location data is required to determine standard site conditions based on the legacy region. Table 1 shows the standard parameters for each legacy region. The values in Table 1 will be applied in STNW 3014 – Busbar Design Calculator when legacy region is selected.

Table 1: Standard site conditions

Site Condition	**Value**	
Region	**N/S (Ergon)**	**SE (Energex)**
Summer noon (day 356) ambient temperature	40˚C	35˚C
Winter 6pm (day 172) ambient temperature	20˚C	15˚C
Busbar & connections continuous operating temperature	90˚C	90˚C
Busbar short time (fault) temperature	250˚C	250˚C
Wind speed (Plant Rating Manual, 2022)	1m/s	0.5m/s
Wind yaw angle to conductor axis (Plant Rating Manual, 2022)	45˚	90˚
Site latitude (Tropic of Capricorn, Brisbane CBD)	-23.5˚	-24.5˚
Site albedo (reflectance) of ground surface (Plant Rating Manual, 2022)	0.2 grass	0.2
Site height above sea level	1000m	1m
Clearness Ratio	1.0	1.0

Site Condition	Value	
Region	**N/S (Ergon)**	**SE (Energex)**
Conductor azimuth to the sun (degrees from north-south)	90˚	90˚

The parameters listed below are relevant to the substation location and can be overridden in STNW 3014 – Busbar Design Calculator to obtain more accurate evaluations.

5.1.1 Latitude and Distance from Coast

The designer should override the substation latitude and the distance from coast. This step is critical to obtaining the correct regional wind speeds for mechanical loading as per figure 3.1(A) of (Standards Australia, 2011), which is reproduced in this standard in Annex B. Note that all Queensland islands shall be selected as 0-50 km from coast.

5.1.2 Site ambient temperature

The default ambient temperature is based on Summer noon. This value can be set to the maximum expected ambient temperature for the day of the year and time of the day being evaluated.

5.1.3 Emissivity and absorptivity

Emissivity of a conductor is a ratio of how effectively it can radiate power with respect to a blackbody. Absorptivity of a conductor is a ratio of solar energy absorbed with respect to a blackbody. Although not strictly the same thing emissivity and absorptivity are generally set the same.

The values selected shall take into account the expected conductor weathering based on the site. The default values of 0.85 are a conservative selection and is a common value based on aged conductors in an industrial environment. For aluminium in rural areas 0.5 is an acceptable value for emissivity and absorptivity. Emissivity values less than 0.5 should be avoided.

Absorptivity should be set to 0 when evaluating current carrying capacity at night or indoor/fully shaded scenarios. Absorptivity can be reduced by a suitable margin for continuous partial shading of the conductors. In those examples the emissivity should still be set to a suitable value 0.5-0.85.

5.1.4 Site Albedo

Albedo is a measure of solar incident radiation reflected from the ground surface. The default value of 0.2 is based on grass/soil. Other typical albedo values are 0.1 for asphalt and 0.4 for concrete. Crushed rock as found in many substations is typically between 0.25-0.4, depending on the rock colour and aggregate size. Lighter colouring increases albedo and larger size aggregate decreases albedo.

5.1.5 Altitude above sea level

The site altitude can be set to actual to improve the accuracy of the current carrying capacity and corona inception of the conductor. As altitude increases current carrying capacity will decrease and corona onset will decrease.

5.1.6 Wind Speed (minimum/calm)

Wind speeds shall not be set to less than 0.5m/s. Even for indoor installations, natural convection will provide some power dissipation similar to forced convection at 0.5m/s.

Increasing the wind speed values should be undertaken with caution. However, if appropriate statistical weather studies are completed then wind speeds can be set to the minimum/calm conditions shown to be present at the time and day of interest for evaluation.

5.1.7 Day of the year and Time of the day

In STNW 3014 – Busbar Design Calculator, by default the day of the year is set to 365 to align with 31st December (Summer) and time of day is set to 12 for midday. These values can be changed to calculate current carrying capacity of conductors at differing times of year and day. This may be required if planning data forecasts maximum demand under conditions other than summer day and could result in more economical conductor selection.

Time of the day should only be adjusted to daylight hours, to calculate values for night time set absorptivity to 0 (see section 6.1.3).

5.1.8 Site exposure category

Site exposure category is defined in section 4.1.2 of (AS/NZS 1170.2, 2021). EQL default is 2, however the appropriate category shall be selected based on the descriptions in Table 2. Note if the site region is A0 the terrain category will be set to category 2 in the calculations.

Table 2: Terrain category descriptions as per Standards Australia Structural design actions Part 2: Wind actions (AS/NZS 1170.2, 2021)

Terrain Category	Description
Category 1	Very exposed open terrain with very few or no obstructions, and all water surfaces, e.g., flat, treeless, poorly grassed plains; open ocean, rivers, canals, bays and lakes.
Category 2	Open terrain, including grassland, with well-scattered obstructions having heights generally from 1.5m to 5m, with no more than two obstructions per hectare, e.g., farmland and cleared subdivisions with isolated trees and uncut grass.
Category 2.5	Terrain with some trees or isolated obstructions, terrain in developing outer urban areas with scattered houses, or large acreage developments with more than two and less than 10 buildings per hectare.
Category 3	Terrain with numerous closely spaced obstructions having heights generally from 3m to 10m. The minimum density of obstructions shall be at least the equivalent of a 10 house-size obstructions per hectare, e.g., suburban housing. light industrial estates or dense forests.
Category 4	Terrain with numerous large, high (10m to 30m tall) and closely spaced constructions, such as large city centres and well-developed industrial complexes.

5.2 Electrical parameters

5.2.1 Operating Voltage

The nominal phase to phase voltage of the busbar shall be used. The operating voltage is only used to evaluate corona onset.

5.2.2 Maximum load current

Maximum load current is used to provide a visual indication of the suitability of each standard conductor continuous current carrying rating when using STNW 3014 – Busbar Design Calculator.

5.2.3 Maximum short circuit current

Maximum short circuit current is used to provide a visual indication of the suitability of each standard conductor short circuit current rating. It is also utilised in the calculation of the short circuit mechanical load. Future substation and network arrangements should be considered when choosing a short circuit current magnitude value.

Short circuit current duration should be 1 second unless protection studies show normal clearance times for maximum short circuit conditions in excess of 1 second.

5.2.4 Real and Reactive impedance (R and X)

The site real and reactive impedance shall be obtained from the network planning fault level summary report. Positive sequence (R1 and X1) values shall be used.

The ratio of R/X affects the short circuit mechanical load calculation which is used in the determination of allowable rigid bus span lengths. It should be noted that there are other factors that affect mechanical loading and changing R and/or X values may not alter allowable span lengths.

5.3 Other parameters

5.3.1 Span lengths

Simple-simple, simple-fixed and cantilever design span lengths should be included to provide a visual indication of the suitability of each standard rigid conductor when using STNW 3014 – Busbar Design Calculator. After initial evaluation the span lengths should be updated if required for evaluation of the resonant vibration of the selected conductor.

If an anti-vibration damping conductor is required then this should be selected, see 9.2.4, and allowable span lengths re-evaluated.

5.3.2 Conductor operating and maximum allowable temperature

Allowable temperature rise above ambient is critical for current carrying of conductors. A continuous operating temperature of 90°C shall be used unless the calculation is for a defined emergency condition or the specified conductor has a different rating. Plant Rating manual (EQL, 2022) provides an acceptable emergency temperature of 100°C, this value should only be used in consultation with network planning and ratings and utilisation teams.

6 Evaluation of conductor size for current rating

Conductor continuous current rating calculations are based on the methods presented in Cigre Technical Brochure: Guide for thermal rating calculations of overhead lines (TB601, 2014). Conductor short time current rating calculations are based on the methods used in IEEE Guide of safety in AC substation grounding (IEEE 80, 2000). Detailed rating formulas and assumptions are presented in Annex A.

6.1 Conductor properties

6.1.1 Material properties for standard conductors

Table 3 shows the relevant conductor material properties used for the standard conductors included in STNW 3014 – Busbar Design Calculator.

Table 3: Standard conductor material electrical properties

Conductor	Thermal capacity (J/cm^3)	DC Resistance at 20^{0}C (Ω/m)	DC volume resistivity at 20^{0}C (Ωm)	Constant mass temperature coefficient of resistance at 20˚C (per ^{0}C)
Aluminium AAAC 6101-T6	2.6	Refer A.1.1.4	3.1347×10^{-8}	0.00363
Aluminium AAAC 6063-T6	2.6	Refer A.1.1.4	3.3114×10^{-8}	0.0035
Aluminium AAAC 1120	2.6	Refer 6.1.2	2.93×10^{-8}	0.0039
Aluminium AAC 1350	2.6	Refer 6.1.2	2.83×10^{-8}	0.00403
Copper (all)	3.42	Refer 6.1.2	1.7774×10^{-8}	0.00381

6.1.2 Standard stranded conductor properties

Table 4, Table 5 and Table 6 shows the relevant stranded conductor properties used for the standard conductors included in STNW 3014 – Busbar Design Calculator.

Table 4: AAAC 1120 stranded conductor properties (AS 1531, 1991)

Conductor Name	Nominal overall diameter (mm)	Diameter of outer layer strands (mm)	Cross sectional area (mm^2)	DC resistance at 20˚C (Ω/m)	Combined skin and proximity effect
Neon	18.8	3.75	210	14.2×10^{-5}	1.00
Oxygen	23.8	4.75	337	8.84×10^{-5}	1.00
Sulphur	33.8	3.75	673	4.44×10^{-5}	1.03
Twin Oxygen	47.6	4.75	674	4.42×10^{-5}	1.00
Twin Sulphur	67.6	3.75	1346	2.22×10^{-5}	1.04

Table 5: AAC stranded conductor properties (AS 1531, 1991)

Conductor Name	Nominal overall diameter (mm)	Diameter of outer layer strands (mm)	Cross sectional area (mm^2)	DC resistance at 20˚C (Ω/m)	Combined skin and proximity effect
Mars	11.3	3.75	77.3	37×10^{-5}	1.00
Saturn	21	3	262	11×10^{-5}	1.00
Triton	26.3	3.75	409	7.06×10^{-5}	1.01
Uranus	29.3	3.25	506	5.72×10^{-5}	1.02
Venus	33.8	3.75	673	4.29×10^{-5}	1.04

Table 6: Bare copper hard drawn stranded conductor properties (AS 1746, 1991)

Conductor	Nominal overall diameter (mm)	Diameter of outer layer strands (mm)	Cross sectional area (mm^2)	DC resistance at 20˚C (Ω/m)	Combined skin and proximity effect
19/2.14	10.5	2.14	68.3	27.5×10^{-5}	1.00
19/2.75	13.8	2.75	113	16×10^{-5}	1.00
37/2.50	17.5	2.5	182	9.96×10^{-5}	1.00
37/3.00	21	3	262	6.91×10^{-5}	1.01
61/2.75	24.8	2.75	362	5×10^{-5}	1.03

6.1.3 Skin effect

Skin effect coefficients have been calculated for all conductors listed in this standard in accordance with the methods used in IEC Electric cables – calculation of the current rating – Part 1-1: Current rating equations (100% load factor) and calculation of losses – General (IEC 60287-1-1, 2006) and (Morgan, Finlay, & Derrah, 2000). Skin effect is negligible for all tubular and stranded conductors listed within this standard with the exception of sulphur stranded conductor.

6.1.4 Proximity effect

Proximity effect coefficients have been calculated by the method used in IEC Electric cables – calculation of the current rating – Part 1-1: Current rating equations (100% load factor) and calculation of losses – General (IEC 60287-1-1, 2006). A proximity effect coefficient of 1.01 has been taken in the calculation of twin sulphur current rating. The spacing between twin conductors is assumed to be 114mm. For detailed calculation of proximity effect refer to Annex A.

7 Corona inception voltage

The conductor corona inception voltage evaluation is based on IEEE Guide for bus design in air insulated substations (IEEE 605, 2008). Designers shall ensure the conductor selected has a corona onset gradient that is greater than the conductor maximum surface voltage gradient as calculated.

Refer to Annex A for the detailed formula and assumptions. Standard design parameters used in the corona calculations are provided in Table 7. Increasing either busbar height or phase spacing decreases the surface voltage gradient of the conductor. Generally, corona inception will be acceptable, but these values can be adjusted in the STNW 3014 – Busbar Design Calculator, 'Site & Conductor properties' worksheet if required.

Table 7: Busbar design parameters for Corona evaluation

Operating Voltage	Busbar height	Busbar Phase spacing
33kV	3700mm	1200mm
66kV	4000mm	1800mm
110kV	4700mm	2600mm
132kV	4700mm	2600mm
220kV	5500mm	3600mm

8 Rigid busbar mechanical design

This section provides an outline of the mechanical loads to consider in the design of a busbar. Refer to Annex B for methods of calculation. Mechanical design is based on allowable stress design in accordance with Standards Australia Aluminium structures Part 2: Allowable stress design (AS/NZS 1664.2, 1997).

8.1 Loads on rigid busbar and support insulators

The loads to consider in the mechanical busbar design are the permanent loads and exceptional loads. It should be noted that the loads and their intensity can vary according to substation location and application requirements. STNW 3014 – Busbar Design Calculator calculates the acceptable span lengths based on these loads and the user inputs.

8.1.1 Permanent loads

The permanent loads that shall be considered during design are:

- Dead loads: includes the weight of the structure, the weight of components and connections of the bus and the weight of an inserted anti-vibration conductor. When determining the portion of the busbar to be supported in a multiple support bus section the following has been applied to simplify calculations:
  - The inner insulators support half of the adjacent spans on either side.
  - The outer insulators support half of the adjacent span and the overhang portion.
- Tension loads from strained conductors.

- Thermal loads: if a section of busbar has two or more fixed supports, there will be a longitudinal load acting on the fixed supports due to thermal expansion of the busbar caused by short-circuit current. In calculating the thermal load, the insulator support posts/structure can be considered as having infinite stiffness. This conservative approach will provide some built-in safety factor for the insulators. To eliminate thermal load, common practice is use of only one fixed support in a busbar section, the remaining is of simple type.

8.1.2 Exceptional loads

The exceptional loads that shall be considered during design are:

- Wind loads: loads on busbars are considered as uniformly distributed acting horizontally. Loads on insulators are considered as concentrated acting horizontally at the middle.
- Electromagnetic loads (short-circuit loads): for flat configuration busbars this load is considered as uniformly distributed acting horizontally. The lateral deflection of the busbar creates an accompanying longitudinal deflection of the busbar support insulators. This longitudinal load will vary from a minimum at centre of the bus system to a maximum at the end support. This load could be minimised by using no more than one fixed support in a busbar section.

Other exceptional loads include earthquake and ice loads, in Energy Queensland's geographical area earthquakes and icing conditions seldom occur and therefore can be neglected.

Formulae for calculating various types of loads are given in Annex B.

8.2 Busbar mechanical data

8.2.1 Basic data

Evaluation of rigid busbar and insulator mechanical strength in STNW 3014 – Busbar Design Calculator is based on the following physical and mechanical properties presented in Table 8 and Table 9.

Tensile yield strength of copper conductors can typically vary from 70-240 MPa dependent on alloy composition and hardening treatment. Therefore, the tensile yield strength must be requested from the supplier/manufacturer if rigid copper busbar is being used.

: Aluminium conductor mechanical properties

Table 8: Aluminium conductor mechanical properties

Conductor property		Value
Specific gravity		2.703
Coefficient of linear expansion (1/°C)		23 x 10^{-6}
Tensile Ultimate strength MPa	6101-T6	207*
	6063-T6	207*
Tensile Yield strength MPa	6101-T6	172*
	6063-T6	172*
Tensile Yield strength for welded conductor MPa	6101-T6	76*
	6063-T6	76*
Modulus of Elasticity MPa		70,000

*These are minimum specified values as provided in AS/NZS 1664.2, 1997 and IEEE 605, 2008, typical values are slightly higher.

Table 9: Copper conductor mechanical properties

Conductor property	Value
Specific gravity	8.92
Coefficient of linear expansion (1/°C)	17 x 10^{-6}
Tensile Ultimate strength MPa	405*
Tensile Yield strength MPa	205*
Modulus of Elasticity MPa	124000

*These are typical values based on semi-hardened copper.

8.2.2 Busbar end supports

End supports for a busbar span range from simple to fixed. At least one simple end connection shall be installed on each span to ensure the effects of thermal expansion are minimised. If the end supports of the busbar are unknown, simple-simple end supports should be assumed as this is the most conservative in span calculation.

8.2.3 Support insulator mechanical strength

Bending moments on the support insulators should be evaluated for the vectorial sum of the worst case of load combination: busbar dead load + wind load on conductor and insulator + short-circuit load + thermal expansion load.

Dead weight, wind load on conductors, short-circuit load on the busbar and thermal expansion load if applicable will act at the union of the conductor and insulator as a concentrated load. Wind load on the insulator is considered as concentrated and acts at the middle.

Outermost insulators should be checked for torsional strength by performing calculations using the formula in Annex B.4.

Standard porcelain insulators are of designation C6-xxx of Standards Australia Insulators – ceramic or glass – station post for indoor and outdoor use – voltages greater than 1000Va.c Part 1: Characteristics (AS 4398.1, 1996). They shall have a cantilever strength of 8kN (or 8kN for 220kV), and a minimum torsional strength in accordance with Section 3 of AS 4938.1.

8.3 Evaluation of natural frequency

Natural frequency of each span should be calculated separately with the appropriate choice of end fixing supports. The formulae relating to natural frequency are given in Annex C.

The natural frequency of the busbar shall not be:

- Similar to the frequency of eddy shedding.
- Similar to the natural frequency of the insulator/post support unit as the busbar could be subjected to very high amplification of ground motion.
- Similar to the power frequency.

Wind induced vibration can be attenuated by placing a continuous length of stranded conductor loosely inside the tubular busbar. The stranded conductor shall be restrained at one end to prevent migration within the busbar. The damping cable used shall be between 10% and 33% of the bus conductor weight and be the made of the same material to prevent galvanic corrosion. Audible noise generated by the stranded damping cable inside the bus conductor should be taken into account during design.

STNW 3014 – Busbar Design Calculator calculates the natural frequency of the busbar and the wind induced eddy shedding frequencies for a wind velocity range between 8m/s for the lower magnitude and 20m/s for the upper magnitude. If the ratio of eddy shedding frequency to natural frequency sits outside a range of 0.5-1.414 the specified span length is deemed acceptable, otherwise a damping conductor should be added. The calculator assumes busbar end supports are simple-fixed or simple-simple. Fixed-fixed can be manually checked by referring to the 'Vibration and Resonance' worksheet of the calculator and comparing the fa/fbff values do not fall in the range of 0.5-1.414.

8.4 Maximum busbar span length based on allowable vertical deflection

Maximum busbar span lengths based on allowable vertical deflection of the busbar conductor are calculated in STNW 3014 – Busbar Design Calculator based on user inputs (refer section 6 and the following assumptions:

- Vertical deflection is limited to 30mm. The vertical deflection is measured from the busbar attachment point at the insulators to the mid span point. Note this value can be overwritten by the user to 1/150 of the span length if required.

If the evaluation of natural frequency suggests inclusion of damping conductor, then an inserted anti vibration conductor of 19/3.75 AAAC (Neon), or 19/4.75 AAAC (Oxygen) can be selected in the STNW 3014 – Busbar Design Calculator for this calculation. It is assumed that the conductor is inserted for the whole length of the busbar.

8.5 Maximum busbar span lengths based on conductor allowable fibre stress

Maximum busbar span lengths based on conductor allowable fibre stress are calculated in STNW 3014 – Busbar Design Calculator based on user inputs (refer section 6) and the following assumptions:

- Wind load, dead load and short-circuit load act simultaneously.
- Allowable stress is determined by design factor of safety of 1.65 (AS/NZS 1664.2, 1997). The safety factor is applied to the tensile yield strength of the conductor.
- Welded aluminium has a lower tensile yield strength, and therefore lower allowable stress. Welded and unwelded span lengths are provided in STNW 3014 – Busbar Design Calculator.
- Copper busbar will not be welded.

8.6 Maximum busbar span length based on insulator cantilever strength

Maximum busbar span lengths based on insulator cantilever strength are calculated in STNW 3014 – Busbar Design Calculator based on user inputs (refer section 6) and the following assumptions:

- Insulator cantilever strength is 8kN all voltages
- No torsional strength of the insulators is considered, however Appendix B4 includes formulae for calculation of torsional load for a fixed/simple beam.
- Insulator dimensions are to Standards Australia Insulators – ceramic or glass – station post for indoor and outdoor use – voltages greater than 1000Va.c Part 1: Characteristics (AS 4398.1, 1996). Surface area of an insulator exposed to wind pressure is taken at the produce of its given height and diameter.
- No thermal load and longitudinal load are taken into account.
- An allowable stress design strength reduction factor of 2 is used to allow for the effect of the dynamic nature of short-circuit load on the support insulator.

9 Documentation required

Documentation on the design of a busbar shall take the form of a design report and is to include, but not be limited to the following:

- Values for the critical design factors, the methods used, and assumptions made in ascertaining these values.
- Details on calculations used in the design process.
- A drawing or series of drawings detailing the layout of busbars.

Annex A

normative

Formulae and assumptions for calculation of conductor current ratings

A.1 Formulae Used

A1.1 Continuous current rating (I)

The formulae used for the calculation of continuous current carrying capacity are presented in Cigre Technical Brochure: Guide for thermal rating calculations of overhead lines (TB601, 2014). Conductor continuous current rating is calculated by the equation below:

$$I = \sqrt{\left[\frac{(PR + PC - PS)}{R}\right]}$$

Equation 1: Continuous current rating (I)

Where:

I = The continuous current rating of the conductor (A)

PR = Power dissipation due to radiation of 1 meter of conductor (W/m) refer A.1.1.1

PC = Power dissipation due to convection of 1 meter of conductor (W/m) refer A.1.1.2

PS = Power gained through sFreyolar radiation of 1 meter of conductor (W/m) refer A.1.1.3

R = AC Resistance of one meter of conductor (Ω) refer A.1.1.4

A.1.1.1 Power dissipation due to radiation of 1 meter of conductor (PR)

$$PR = \pi \cdot D \cdot \sigma_B \cdot \varepsilon_s \cdot [(T_s + 273)^4 - (T_a + 273)^4]$$

Where:

D = Diameter of the conductor (mm)

σ_B = Stefan-Boltzmann constant 5.67×10^{-8}

ε_s = Solar absorptivity of the conductor surface (0.5 new (less than 1 year old), 0.85 weathered (more than one year old))

T_s = Conductor operating temperature (˚C)

T_a = Site ambient Temperature (˚C)

A.1.1.2 Power dissipation due to convection of 1 meter of conductor (PC)

$$PC = \pi \cdot \lambda_f \cdot (T_s - T_a) Nu_\delta$$

T_s = Conductor operating temperature (˚C)

T_a = Site ambient temperature (˚C)

λ_f = Thermal conductivity of the air (W/k·m)

$$\lambda_f = 2.368 \cdot 10^{-2} + 7.23 \cdot 10^{-5} \cdot T_f - 2.763 \cdot 10^{-8} \cdot T_f^2$$

T_f = Temperature of the air film in contact with the conductor surface (˚C)

$$T_f = 0.5 \cdot (T_s + T_a)$$

Nu_δ = Nusselt number dependent upon wind direction (smooth conductors)

$$Nu_\delta = Nu_{90} \cdot (\sin(\delta)^2 + 0.0169 \cdot \cos(\delta)^2)^{0.225}$$

$Nu\delta$ = Nusselt number dependent upon wind direction (stranded conductors)

$$Nu_\delta = Nu_{90} \cdot (0.42 + 0.58 * (\sin(\delta))^{0.90}$$

δ = Wind angle of attack relative to the conductor (deg)

Nu_{90} = Nusselt number at 90˚ wind angle of attack relative to the conductor

$$Nu_{90} = B \cdot Re^n$$

B = constant dependent upon Re (see Table 10)

n = constant dependent upon Re (see Table 10)

Re = Reynolds number

$$Re = V \cdot \frac{D}{v_f}$$

V = Wind speed ($m \cdot s^{-1}$)

D = Diameter of the conductor (mm)

$v_{f =}$ Kinematic viscosity of the air film ($m^2 \cdot s^{-1}$)

$$v_f = \frac{\mu_f}{\gamma}$$

μ_f = Dynamic viscosity of air film ($kg \cdot m^{-1} \cdot s^{-1}$)

$$\mu_f = (17.239 + 4.635 \cdot 10^{-2} \cdot T_f - 2.03 \cdot 10^{-5} \cdot T_f^2) \cdot 10^{-6}$$

γ = Mass density of air film

$$\gamma = \frac{1.293 - 1.525 \cdot 10^{-4} \cdot y + 6.379 \cdot 10^{-9} \cdot y^2}{1 + 0.00367 \cdot T_f}$$

y = Site height above sea level (m)

Table 10: Coefficients dependant on the value of Re

Smooth Conductors			Stranded Conductors Rs ≤ 0.05			Stranded Conductors Rs > 0.05		
Re	**B**	**n**	**Re**	**B**	**n**	**Re**	**B**	**n**
35 – 5000	0.583	0.471	100 - 2650	0.641	0.471	100 – 2650	0.641	0.471
5000 - 50000	0.148	0.633	2650 - 50000	0.178	0.633	2650 - 50000	0.048	0.800
50000 - 200000	0.0208	0.814						

Where:

$$R_s = d/[2 \cdot (D - d)]$$

D = Conductor diameter (mm)

d = Diameter of wires in the outermost layer of the conductor (mm)

A.1.1.3 Power gained through solar radiation of 1 meter of conductor (PS)

$$PS = \alpha_s \cdot I_T \cdot D$$

Where:

α_s = Solar absorptivity of the conductor surface (0.5 new (less than one year old), 0.85 weathered (greater than one year old))

D = Conductor diameter (mm)

I_T = Global solar radiation ($W \cdot m^{-2}$)

$$I_T = I_{B(y)} \cdot \left(\sin(\eta) + \frac{\pi}{2} \cdot F \cdot \sin(H_s)\right) + I_d \cdot \left(1 + \frac{\pi}{2} \cdot F\right)$$

F = Albedo or ground reflectance (0.2 grass, 0.3 sand)

$I_{B(y)}$ = Direct solar radiation intensity adjusted to site height above sea level ($W \cdot m^{-2}$)

$$I_{B(y)} = I_{B(0)} \cdot \left[1 + 1.4 \cdot 10^{-4} \cdot y\left(\frac{1367}{I_{B(0)}} - 1\right)\right]$$

y = Site height above sea level (m)

$I_{B(0)}$ = Direct solar radiation intensity at sea level ($W \cdot m^{-2}$)

$$I_{B(0)} = N_s \cdot \frac{1280 \cdot \sin(H_s)}{\sin(H_s) + 0.314}$$

N_s = Atmosphere clearness ratio (1.0 for a standard atmosphere, < 0.5 for cloudy or overcast sky)

H_s = Solar altitude (deg)

$$H_s = \arcsin(\sin(\varphi) \cdot \sin(\delta_s) + \cos(\varphi) \cdot \cos(\delta_s) \cos(Z))$$

φ = Site latitude, negative for southern hemisphere (deg)

δ_s = Solar declination

$$\delta_s = 23.3 \cdot \sin\left[\frac{2 \cdot \pi \cdot (284 + N^*)}{365}\right]$$

N^* = Day of the year

Z = Hour angle of the sun (deg)

$$Z = 15 \cdot (12 - Time)$$

Time = Time of the day given in hours (0 – 24)

η = Angle of the solar beam with respect to the conductor axis (deg)

$$\eta = \arccos[\cos(H_s) \cdot \cos(\gamma_s - \gamma_c)]$$

γ_c = Azimuth of the conductor positive from south through west (deg)

γ_s = Azimuth of the sun positive from south through west (deg)

$$\gamma_s = \arcsin\left(\cos(\delta_s) \cdot \frac{\sin(Z)}{\cos(H_s)}\right)$$

I_d = Diffuse solar radiation intensity ($W \cdot m^{-2}$)

$$I_d = (430.5 - 0.3288 \cdot I_{B(y)}) \cdot \sin(H_s)$$

A.1.1.4 AC Resistance of 1 meter of conductor (R)

$$R = R_{dc(20)} \cdot \left(1 + \alpha_{20}(T_s - 20)\right) \cdot Sk$$

α_{20} = Conductor material constant mass temperature coefficient of resistance at 20˚C (specified by the conductor supplier)

T_s = Conductor operating temperature (˚C)

Sk = Combined skin and proximity effect refer Annex A.2.

$R_{dc(20)}$ = The DC resistance of the conductor at 20˚C (specified by the supplier for stranded conductors) for tubular conductors see the following formula ($\Omega \cdot m^{-1}$)

$$R_{dc(20)} = \frac{4 \cdot \rho_{20}}{\pi \cdot (D^2 - D_1^2)}$$

ρ_{20} = Conductor material resistivity at 20˚C ($\Omega \cdot m$)

D = Conductor diameter (m)

D_1 = Tubular conductor inner diameter (m)

A.2 Combined proximity effect and skin effect

The formulae used in the calculation of conductor combined skin and proximity effect are presented in in IEC Electric cables – calculation of the current rating – Part 1-1: Current rating equations (100% load factor) and calculation of losses – General (IEC 60287-1-1, 2006) and (Morgan, Finlay, & Derrah, 2000). Combined skin and proximity effect for stranded conductor is calculated by the formulae below:

$$Sk = 1 + Y_s + Y_p$$

Where:

Sk = Combined skin and proximity effect

Y_s = Conductor skin effect factor

$$Y_s = \frac{x_s^4}{192 + 0.8 \cdot x_s^4}$$

x_s = Skin effect variable

$$x_s^2 = \frac{8 \cdot \pi \cdot f}{R_{dc}} \cdot 10^{-7} \cdot k_s$$

k_s = Skin effect coefficient equal to 1 for conductors listed in this standard

R_{dc} =Conductor DC resistance at operating temp ($\Omega \cdot m^{-1}$) refer A.1.1.4

f = Frequency (Hz)

Y_p = Conductor proximity effect factor

$$Y_p = \frac{x_p^4}{192 + 0.8 \cdot x_p^4} \cdot \left(\frac{d_c}{S}\right)^2 \cdot 2.9$$

d_c = Conductor diameter (mm)

S = Distance between conductor axis (mm)

x_p = Proximity effect variable

$$x_p^2 = \frac{8 \cdot \pi \cdot f}{R_{dc}} \cdot 10^{-7} \cdot k_p$$

k_p = Proximity effect coefficient equal to 1 for conductor listed in this standard

Skin effect factors for tubular conductor are calculated by the following formulae presented in (Morgan, Finlay, & Derrah, 2000):

$$Sk_{tubular} = 1 + 3.409 \cdot 10^{13} \cdot X^{2.078} \cdot Y^{3.92} - 3.32 \cdot 10^{-21} \cdot X^{4.55} \cdot Y^{Z}$$

Where:

$$X = \frac{t}{D_2}$$

$$Y = \sqrt{\frac{f}{R_{dc}}}$$

$$Z = 6.50 - 1.27 \cdot X^{3.33}$$

t = Conductor tube thickness (mm)

D_2 = Conductor diameter (mm)

f = Frequency (Hz)

R_{dc} =Conductor DC resistance ($\Omega \cdot m^{-1}$) refer A.1.1.4

A.3 Calculation of corona onset

The formulae for the calculation of conductor corona onset gradient and conductor maximum surface voltage gradient are presented in IEEE Guide for bus design in air insulated substations (IEEE 605, 2008). Designers shall ensure the conductor selected for application has a corona onset gradient that is greater than the conductor maximum surface voltage gradient as calculated below.

A3.1 Conductor corona onset gradient

$$E_c = mE_0 D_a (1 + \frac{C}{\sqrt{D_a r_c}})$$

Where:

E_c = Corona onset gradient ($kV \cdot cm^{-1}$)

E_0 = Empirical constant ($30 kV \cdot cm^{-1}$ peak value or $21.1 kV \cdot cm^{-1}$ rms value)

C = Empirical constant ($0.301 cm^{-1}$)

m = Conductor irregularity factor (0.7)

(0.2 for extreme irregularities or deposition to 0.85 clean, common range of 0.6 to 0.85)

r_c = Conductor outside radius (cm)

D_a = Relative air density

$$D_a = \left(\frac{273 + T_0}{273 + T}\right) \cdot PP_o$$

T = Site ambient temperature (40˚C)

T_0 = Reference temperature value (25˚C)

PP_0 =Reference pressure value

$$PP_o = 1 - \frac{A}{10}$$

A = Site altitude (1.0 km)

A3.2 Conductor maximum voltage gradient

A.3.2.1 Three phase single conductors

$$E_m = \frac{h_e}{h_e - d/2} \cdot E_a$$

Where:

E_m = Maximum voltage gradient at the surface of the conductor ($kV \cdot cm^{-1}$)

d = Conductor diameter (cm)

E_a = Average voltage gradient at the surface of the conductor ($kV \cdot cm^{-1}$)

$$E_a = \frac{V_1}{\frac{d}{2} \cdot In(\frac{4 \cdot h_e}{d})}$$

V_1 = 110% line to ground voltage (kV)

h_e = Equivalent distance from centre of the conductor to the ground plane for the three phases (cm)

$$h_e = \frac{h \cdot D}{\sqrt{4 \cdot h^2 + D^2}}$$

h = conductor centre distance from the ground (cm)

D = Phase to phase spacing for the three phases (cm)

A.3.2.2 Three phase bundle conductors

$$E_m = \frac{h_e}{h_e - r_e} \cdot E_a$$

E_m = Maximum voltage gradient at the surface of the conductor (kV·cm^{-1})

E_a = Average voltage gradient at the surface of the conductor (kV·cm^{-1})

$$E_a = \frac{V_1}{n \cdot r \cdot In\left(\frac{2 \cdot h_e}{r_e}\right)}$$

V_1 = 110% line to ground voltage (kV)

n = number of subconductors in bundle (2)

r = Conductor radius (cm)

h_e = Equivalent distance from centre of the conductor to the ground plane for the three phases (cm)

$$h_e = \frac{h \cdot D}{\sqrt{4 \cdot h^2 + D^2}}$$

r_e = Equivalent single-conductor radius of bundle subconductors

$$r_e = r \cdot (g \cdot \frac{s}{r})^{\frac{n-1}{n}}$$

s = Distance between subconductors (11.4 cm)

d = Conductor diameter (cm)

g = Bundle number constant (equal to 1 for bundles of 1, 2 and 3. And equal to 1.12 for bundles of 4)

A.4 Short time current rating

The conductor short time current ratings listed in Table 7 and Table 8 are calculated by the methods presented in IEEE Guide of safety in AC substation grounding (IEEE 80, 2000). The following formulae are used to calculate conductor short time current rating:

$$I = A_{mm^2} \cdot \sqrt{\left(\frac{TCAP \cdot 10^{-4}}{t_c \cdot \alpha_r \cdot \rho_r}\right) \cdot In\left(\frac{K_0 + T_m}{K_0 + T_c}\right)}$$

Equation 2: Short time current rating

Where:

I = RMS current (kA)

A_{mm^2} = Conductor cross sectional area (mm^2)

TCAP = Thermal capacity per unit volume (2.6 J/cm^3 for aluminium)

T_m = Conductor maximum allowable temperature (250˚C)

T_c = Conductor operating temperature (90˚C)

t_c = Duration of fault current (1 or 3 seconds)

α_r = Thermal coefficient of resistivity at the reference temperature 20˚C

ρ_r = Conductor resistivity at the reference temperature 20˚C (µΩ·cm)

K_0 = Variable

$$K_0 = \frac{1}{\alpha_r} - 20$$

Annex B

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Busbar mechanical strength and maximum span length calculations

B.1 Data used in calculation of maximum span lengths

The following tables list the data and factors used in the calculation of the loads applied to a rigid busbar structure

Table 11: Busbar wind load calculation data Standards Australia Structural design actions Part 2: Wind actions (AS/NZS 1170.2, 2021)

Region	**Region A (non-cyclonic)**			**Region B (non-cyclonic)**			**Region C (cyclonic)**		
Exposure & Terrain category	2	3	4	2	3	4	2	3	4
Regional wind speed V_R (m/s)	48	48	48	63	63	63	73	73	73
Wind direction multiplier (Md)	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0	1.0
Terrain/height multiplier (M_{zcat})	0.91	0.83	0.75	0.91	0.83	0.75	0.91	0.83	0.75
Design wind speed V_{des} (m/s)	43.7	39.8	36.0	57.3	52.3	47.3	66.4	60.6	54.7

Boundaries of regions A, B and C are indicated in Figure 1.

Table 12: Standard short-circuit site data

System nominal voltage (kV)	**66**	**110 & 132**
Short-circuit level (kA)	25	25
X/R ratio	5.5	5.5
Spacing between phases (m)	1.8	2.6

If the design requires higher short-circuit or X/R values refer to B.6

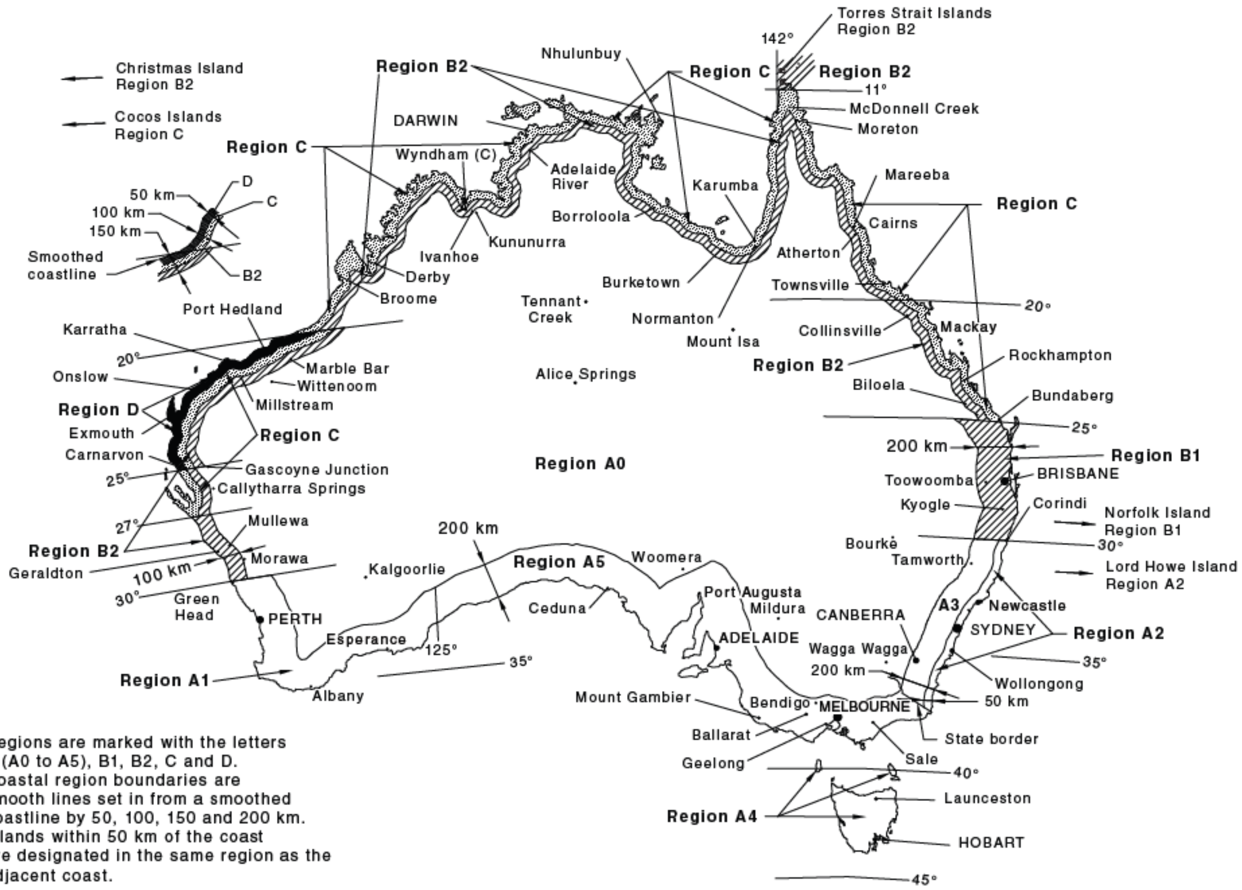

Figure 1: Wind regions

Standards Australia Structural design actions Part 2: Wind actions, fig 3.1(A) (AS/NZS 1170.2, 2021)

B.2 Maximum span length based on allowable deflection

The formulae used for the calculation of busbar maximum span based on allowable deflection are presented in IEEE Guide for bus design in air insulated substations (IEEE 605, 2008). Busbar maximum span based on allowable deflection is calculated by the equations below:

B2.1 Simple-simple end supports (Lvss)

$$L_{vss} = \left(\frac{384 \cdot Y \cdot J \cdot \delta_{max}}{5 \cdot (F_G + F_i)}\right)^{1/4}$$

Equation 3: Max span length based on allowable deflection – simple-simple

Where:

L_{vss} = The simple-simple busbar allowable span based on the vertical deflection limit (m)

Y = The Young's modulus of the conductor material (N/m^2) δ_{max} = The vertical deflection limit (m)

J = The bending moment of inertia of the conductor cross section (m^4)

$$J = \pi \frac{\left(D_o^4 - D_i^4\right)}{64}$$

D_o = The conductor outside diameter (m)

D_i = The condutor inside diameter (m)

F_G = The conductor gravitational weight by unit length (N/m)

$$F_G = \frac{(\pi \cdot w_c)}{4}\left(D_o^2 - D_i^2\right)$$

w_c = The specific weight of the conductor material (N/m^3)

F_i = The anti-vibration conductor gravitational weight by unit weight (N/m)

$$F_i = w_{ic} \cdot 9.81$$

w_{ic} = The anti-vibration conductor unit weight (kg/m)

B2.2 Simple-fixed end supports (Lvsf)

$$L_{vpf} = \left(\frac{185 \cdot Y \cdot J \cdot \delta_{max}}{(F_G + F_i)}\right)^{1/4}$$

Equation 4: Max span length based on allowable deflection – simple-fixed

Where:

Lvsf = The simple-fixed busbar allowable span based on the vertical deflection limit (m)

(For description and calculation of figures not listed see B2.1)

B2.3 Busbar maximum cantilever span based on allowable deflection (Lvc)

$$L_{vc} = \left(\frac{8 \cdot Y \cdot J \cdot \delta_{max}}{(F_G + F_i)}\right)^{1/4}$$

Equation 5: Max cantilever span length based on allowable deflection

Where:

L_{vsf} = The simple-fixed busbar allowable span based on the vertical deflection limit (m)

(For description and calculation of figures not listed see B2.1)

B.3 Maximum span length based on conductor allowable fibre stress

The formulae used for the calculation of busbar maximum span based on conductor allowable fibre stress are presented in IEEE Guide for bus design in air insulated substations (IEEE 605, 2008). Busbar maximum span based on conductor allowable fibre stress is calculated by the equations below:

B3.1 Simple-simple or simple-fixed end supports (LSs)

$$LS_s = \sqrt{\frac{16 \cdot J \cdot \sigma_{allowable}}{F_T \cdot D_o}}$$

Equation 6: Max span length based on conductor allowable fibre stress – simple-simple

Where:

LS_s = The allowable busbar span base on the conductor maximum fibre stress simple-simple or simple-fixed end supports (m)

$\sigma_{allowable}$ = The allowable stress of the conductor material (N/m^2)

$$\sigma_{allowable} = \frac{P_s}{SF}$$

P_s = The conductor material 0.2% proof stress (Mpa) refer 8.2.1

SF = The allowable stress design safety factor, equal to 1.65

D_o = The conductor outside diameter (m)

J = The bending moment of inertia of the conductor cross section (m^4)

$$J = \pi \frac{\left(D_o^4 - D_i^4\right)}{64}$$

D_i = The conductor inside diameter (m)

F_T = The total load acting on the conductor by unit length (N/m) refer B3.3

B3.2 Maximum busbar cantilever length based on allowable fibre stress

Maximum busbar cantilever length is calculated as half of the maximum allowable stress span length with simple-simple end supports refer B3.1.

B3.3 Total load acting on the busbar conductor (FT)

The formulae used for the calculation of total load acting on the busbar conductor are presented in IEEE Guide for bus design in air insulated substations (IEEE 605, 2008). Total load acting on the busbar conductor is calculated by the equations below:

$$F_T = \sqrt{(F_{Gtotal})^2 + (F_W + F_{SC})^2}$$

Where:

F_{Gtotal} = The combined busbar conductor and anti-vibration conductor gravitational weight by unit length (N/m) refer B.3.3.1

F_w = The wind load by unit length (N/m) refer B.3.3.2

F_{sc} = The short-circuit mechanical load by unit length (N/m) refer B.3.3.3

B.3.3.1 Combined busbar and anti-vibration conductor gravitational weight (FGtotal)

$$F_{Gtotal} = F_g + F_i$$

Where:

F_g = The busbar conductor gravitational weight by unit length (N/m)

$$F_G = \frac{(\pi \cdot w_c)}{4}\left(D_o^2 - D_i^2\right)$$

w_c =The specific conductor weight (N/m^3)

F_i = The anti-vibration conductor gravitational weight by unit length (N/m)

$$F_i = w_{ci} \cdot 9.81$$

W_{ci} = The anti-vibration conductor unit weight (kg/m)

Table 13: Typical anti-vibration conductor unit weight as per Olex 2015

Conductor	Unit weight (w_{ci})
Neon	0.576 kg/m
Oxygen	0.924 kg/m
Sulphur	1.86 kg/m

B.3.3.2 Wind load on busbar (Fw)

The formulae used for the calculation of wind load acting on the busbar conductor are presented in Standards Australia Structural design actions Part 2: Wind actions (AS/NZS 1170.2, 2021). Wind load is calculated by the equations below:

$$F_w = 0.5 \cdot A_p \cdot {V_{des}}^2 \cdot C_{fig} \cdot C_{dyn} \cdot D_o \cdot A_z$$

Where:

A_p = The density of air, taken as equal to 1.2 kg/m^3

C_{dyn} = The structure dynamic response factor, equal to 1

D_o = The outside diameter of the busbar conductor (m)

A_z = The reference area factor, equal to 0.8

V_{des} = The design wind speed (m/s), for standard values refer B.1

$$V_{des} = V_R \cdot M_d \cdot M_{zcat} \cdot M_s \cdot M_t$$

V_R = The site regional wind speed (m/s) refer B.1

M_d = The wind direction multiplier, equal to 1

M_s = The shielding multiplier, equal to 1

M_t = The topographic multiplier, equal to 1

M_{zcat} = The terrain/height multiplier, dependent upon site characteristics and location refer B.1

C_{fig} = The busbar conductor aero-dynamic shape factor

$$C_{fig} = K_{ar} \cdot K_i \cdot C_d$$

K_{ar} = The aspect ratio correction factor for individual member loads, equal to 1

K_i = The angle of inclination correction factor, equal to 1

C_d = The drag force coefficient for the busbar conductor

As per (AS.NZS 1170.2:2021 Table C.3)

B.3.3.3 Short-circuit mechanical load on busbar (Fsc)

The formulae used for the calculation of short-circuit mechanical load acting on the busbar conductor is presented in IEC Short-circuit Currents - Calculation of Effects - Part 1: Definitions and Calculation Methods (IEC 60865-1 Ed.3.0, 2011) and IEC Short-circuit currents in three-phase a.c. systems – Part 0: Calculation of currents (IEC 60909-0, 2016). Short-circuit mechanical load is calculated by the equations below:

$$F_{sc} = \frac{1.73 \cdot 10^{-7} \cdot (k \cdot \sqrt{2} \cdot I_{k3})^2}{D}$$

Where:

I_{k3} = The site maximum predicted r.m.s. 3-phase short-circuit current (A) refer B.1

D = The busbar phase spacing from conductor centres (m) refer (STNW3013, 2013)

k = The peak short-circuit constant

$$k = 1.02 + 0.98e^{-3 \cdot \frac{R}{X}}$$

R = The site real impedance (Ω) refer B.1

X = The site reactive impedance (Ω) refer B.1

B.4 Maximum span length based on end insulators torsional strength (Lb)

The formulae used for the calculation of busbar maximum span based on insulator torsional strength is presented by transforming the formulae for fixed - simple moment of a beam.

$$T = \frac{\omega L^2}{8}$$

Where:

$\omega = F_w + F_{sc}$ (N)

L = Length of Busbar (m)

T = Torque (Nm)

$$L_{b} = \sqrt{\frac{8T}{F_w + F_{sc}}}$$

Equation 7: Max span length based on end insulator torsional strength Lb

Where:

L_b = Maximum span length based on end insulators torsional strength (m)

T = maximum torsional strength of the insulator at the rated voltage (Nm)

F_w = Wind load on busbar (N)

F_{sc} = Short Circuit load on busbar (N)

B.5 Maximum span length based on insulator cantilever strength (Le)

The formulae used for the calculation of busbar maximum span based on insulator cantilever strength are presented in IEEE Guide for bus design in air insulated substations (IEEE 605, 2008). Busbar maximum span based on insulator cantilever strength is calculated by the equations below:

$$L_e = \frac{H_t \left[\dfrac{\frac{F_{is}}{SF} - \frac{F_{wci}}{2}}{\left[H_t + \frac{D_o}{2} \right]} \right]}{F_w + F_{sc}}$$

Equation 8: Maximum span length based on insulator cantilever strength (Le)

Where:

L_e = The maximum span length based on insulator cantilever strength (m)

H_t = The support insulator height (m)

F_{is} = The support insulator cantilever strength (N)

D_o = The conductor outside diameter (m)

F_w = The wind load acting on the busbar by unit length (N/m) refer B.3.3.2

F_{sc} = The short-circuit load acting on the busbar by unit length (N/m) refer B.3.3.3

SF = The insulator cantilever safety factor, equal to 2 due to the dynamic effect of short-circuit load

F_{wci} = The wind load acting on the support insulator by unit length (N/m)

$$F_{wci} = 0.5 \cdot A_p \cdot {V_{des}}^2 \cdot C_{figi} \cdot C_{dyn} \cdot D_{oi} \cdot H_t$$

Ap = The density of air, taken as equal to 1.2 kg/m3

Cdyn = The structure dynamic response factor, equal to 1

Doi = The outside diameter of the support insulator (m)

Vdes = The design wind speed (m/s), for standard values refer B.1

$$V_{des} = V_R \cdot M_d \cdot M_{zcat} \cdot M_s \cdot M_t$$

V_R = The site regional wind speed (m/s) refer B.1

M_d = The wind direction multiplier, equal to 1

M_s = The shielding multiplier, equal to 1

M_t = The topographic multiplier, equal to 1

M_{zcat} = The terrain/height multiplier, dependent upon site characteristics and location refer B.1

C_{figi} = The support insulator aero-dynamic shape factor

$$C_{figi} = K_{ar} \cdot K_i \cdot C_{di}$$

K_{ar} = The aspect ratio correction factor for individual member loads, equal to 1

K_i = The angle of inclination correction factor, taken as equal to 1

C_{di} = The drag force coefficient for the support insulator.

B.6 Thermal Expansion Load

Thermal expansion in the busbar and load exerted on outermost fixed support insulators due to thermal expansion can be calculated from the following formulae presented in (IEEE 605, 2008):

B6.1 Thermal Expansion (ΔL)

$$\Delta L = a \cdot L_i \cdot (T_f - T_i)$$

Where:

ΔL = The change in busbar span length due to thermal expansion (m)

α = The coefficient of linear expansion of the busbar conductor material (1/˚C)

L_i = The busbar span length at the initial temperature (m)

T_i = The initial installation temperature (˚C)

T_f = The final installation temperature (˚C)

B6.2 Load due to thermal expansion (FTE)

$$F_{TE} = S \cdot A_c$$

Where:

F_{TE} = The thermal expansion load at the conductor's ends (N)

A_c = The cross-sectional area of the busbar conductor (m^2)

S = The thermal stress (N/m^2)

$$S = E \cdot \varepsilon$$

E = The busbar conductor modulus of elasticity (N/m^2)

ε = The strain under thermal expansion

$$\varepsilon = \frac{\Delta L}{L_i}$$

Annex C

normative

Wind Induced Vibration and Resonance

C.1 General

Vibration of tubular busbar may be induced by steady light winds producing eddies, which are alternately shed from opposite sides of the tube. The frequency of eddy shedding (fa) is related to the wind velocity and tube diameter by the following formula presented in (IEEE 605, 2008):

$$f_a = \frac{C \cdot V}{D_o}$$

Where:

C = The Strouhal number, equal to 0.19 for cylinders

V = The wind velocity (m/s)

D_o = The conductor outside diameter (m)

When the frequency of the eddy shedding coincides with the natural frequency of the conductor, wind induced vibration of the conductor may occur. To ensure there is an allowance for installation variations the ratio of the eddy shedding frequency to the conductor natural frequency is outside the range of 0.5 to √2 as below:

$$\frac{1}{2} \leq \frac{f_a}{f_b} \leq \sqrt{2}$$

Where:

f_a = The frequency of eddy shedding (Hz)

f_b = The natural frequency of the conductor (Hz)

The natural frequency of a conductor span is dependent on the manner in which the ends are supported and on the conductor's length, mass, and stiffness. The natural frequency of a conductor span (fb) is calculated as follows:

$$f_b = \frac{\pi \cdot K^2}{2 \cdot L^2} \cdot \sqrt{\frac{E \cdot J}{m}}$$

Where:

L = The conductor span length (m)

E = The modulus of elasticity of the conductor material (N/m^2)

m = The mass per unit length of the conductor (kg/m)

K = The dimensionless constant accounting for the type of the conductor end support:

K = 1.00 for simple-simple

K = 1.25 for simple-fixed

K = 1.51 for fixed-fixed

J = The moment of inertia of the conductor cross sectional area (m^4)

$$J = \pi \frac{\left(D_o^4 - D_i^4\right)}{64}$$

D_o = The conductor outside diameter (m)

D_i = The conductor inside diameter (m)

Annex D

informative

Standard palm terminal sizes and current rating

D.1 Overview

D1.1 Purpose

This standard defines the materials, dimensions and hole patterns for terminal palms to be used with outdoor substation equipment, busbars and conductors to ensure suitable current carrying capacity.

D1.2 Scope

This document defines terminal palms to be used for various outdoor substation equipment, busbar and conductor fittings. The terminal palms used shall comply with the requirements of AS 62271.301 “High voltage switchgear and controlgear Part 301: Dimensional standardization of terminals”.

D.2 References

D2.1 Legislation, regulations, rules, and codes

Electrical Safety Code of Practice – Works, 2020 (Queensland Government)

Environmental Protection Act, 1994 (Queensland Government)

Queensland Electricity Act, 1994 (Queensland Government)

Queensland Electricity Regulation, 2006 (Queensland Government)

Queensland Electrical Safety Act, 2002 (Queensland Government)

Queensland Electrical Safety Regulation, 2013 (Queensland Government)

Queensland Work Health and Safety Act, 2011 (Queensland Government)

Queensland Work Health and Safety Regulation, 2011 (Queensland Government)

D2.2 Energy Queensland controlled documents

D2.3 Energy Queensland other documents

STNW3015 - Standard for HV Equipment Ratings

D2.4 Other sources

AS 1154.1-2009	Insulator and conductor fittings for overhead power lines
AS 1856:2004	Electroplated Coatings - Silver
AS 1865:1997	Aluminum and Aluminum Alloys – Drawn wire, rod, bar and strip
AS 1874:2000	Aluminum and Aluminum Alloys – Ingots and castings
AS/NZS 1567:2023	Copper and copper alloys - Wrought rods, bars and sections
AS 4169:2004	Electroplated coatings – Tin and tin alloys
AS 62271.301:2022	High-voltage switchgear and controlgear

	Part 301: Dimensional standardization of terminals
AS 2067:2016	Substations and high voltage installations exceeding 1 kV a.c

D.3 Definitions and abbreviations

D3.1 Definitions

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

Terminal palm	The bolted connector plate on substation plant, busbar fittings and conductors.

D.4 General Requirements

D4.1 Palm Terminals

All terminals shall comply with the details and dimensions shown in Figure1, Figure 2 and Table 1 of AS 62271.301. Palm 13 terminals may be used on equipment in lieu of Palm 9 terminals to allow greater clearance between centres to accommodate lug widths on larger conductors.

The sizes of terminal palms are generally to be selected based on the current rating. In certain circumstances for shunt connected devices that don’t draw significant current other materials can be used.

Where connections are made to plates with surface areas greater than the palm face areas specified in AS 62271.301, materials and finish apply to the area of the plate used for the connection.

D4.2 Copper

Terminal palms are to be machined or cast with high conductivity copper to AS/NZS 1567. Contact surface to be tinned or silver electroplated to accept other copper or aluminium connectors. Minimum thickness of tin plating is 100 microns, and for silver 20 microns.

D4.3 Aluminium

Terminal palms are to be machined or cast with aluminium material alloy 6101-T6, 6061-T5 or 6060-T5 to AS1865 (drawn wire, rod, bar and strip) and AS 1874 (castings).

D4.4 Other materials

Stainless steel may be used for terminal palms on shunt connected devices where there is typically little/no current (eg surge arresters).

D4.5 Current Ratings

Current ratings are based off AS62271.301. Current ratings are calculated for a maximum allowable temperature rise of 50^0C based on a 40^0C ambient.

Table 14 - Terminal palm dimensions and ratings

Terminal Number	Bolt Hole diameter mm	Net contact area mm^2	Minimum thickness mm		Assigned current rating A	
			Copper	Aluminium	Copper	Aluminium
1	14	780	4	6	200	80
2	14	1430	4	6	400	200
3	14	3670	6.3	12	800	630
4	14	4670	10	12	1250	800
5	14	9300	16	12	2500	1250
6	14	4270	10	12	1250	630
7	18 or 22	7730	16	20	2500	1250
8	18 or 22	15300	16	20	3150	2000
9	18 or 22	2100	-	20	-	3150
10	18 or 22	28100	-	20	-	4000
11	18 or 22	6430	-	20	-	1000
12	18 or 22	-	-	20	-	2500
13	18 or 22	-	-	20	-	3150(3750)
14	18 or 22	-	-	20	-	5000

D4.6 Circuit Breakers, Disconnectors and Current Transformers

For equipment in the path of the current circuit, terminal palms shall match the current rating of the bay. Suppliers are generally supplying aluminium palms due to lower weight and cost. Typical sizes for aluminium palms are:

- Size 5 (1250A)
- Size 8 (2000A)
- Size 9 or Size 13 (3150A)

Some equipment from overseas may be fitted with an adaptor plate to convert from NEMA hole patterns to AS62271.301 patterns.

D4.7 Voltage Transformers and Surge Arresters

These devices are shunt devices not generally in the current carrying path. Typical sizes are Size 4 with 2 x 14mm diameter holes at 50mm spacing.

In the case of surge arresters that are not generally carrying current, stainless steel has been used as a connection palm to provide increased corrosion protection.

D4.8 Busbars and Conductors

Terminal palms for stranded conductors shall be crimped terminal lugs, manufactured to AS1154.

Terminal palms for solid busbars shall be clamped with a minimum of 4 x stainless steel bolts.

D4.9 Bolted Connections

Stainless steel bolts shall be used. All bolted connections to have stainless steel flat and spring washers and one nut. To reduce scatter in bolt tensions caused by application of a given torque, the bolt threads as well as the nut/washer bearing face shall be coated with jointing compound/grease. This will also allow for easier disassembly.

Suitable compounds that are stable and provide environmental protection to the contact interfaces shall be used. Typical compounds are:

- Pfisterer grease
- Kopr Kote
- Dulmison Alvan R3

D4.10 Joint Preparation

Prior to making the connection, check the “flatness” of the faces with a straight edge. Dome shaped palms caused from punching the holes in palms may increase the connection resistance.

Contact faces for tinned and copper surfaces shall be flat and cleaned, but need not be highly polished or machined.

If aluminium palms are used, additional care is required. Aluminium, when exposed to air, forms a thin oxide film that has high electrical resistance. This film shall be removed before making connections by cleaning with a solvent, coating with jointing compound and scratch brushing.

After jointing is completed, visually check that there are no gaps between the contact faces, and the two faces are parallel after being fully tightened.

All terminals shall comply with the details and dimensions shown in Table 29 and Figure 2, Figure 3, Figure 4 and Figure 5 which are adapted from Standards Australia: High voltage switchgear and control gear Part 301: Dimensional standardization of terminals (AS 62271.301, 2022). Cross hatched areas in Figure 2, Figure 3, Figure 4 and Figure 5 represent the minimum connection contact surface area.

All palm terminals except numbers 6 and 11 may be used either as equipment palm terminals or as conductor terminals. Terminal number 7 is intended for use as conductor palm terminal with equipment palm terminal numbers 12, 13 and 14. Terminals 6 and 11 are intended for use as conductor palm terminals.

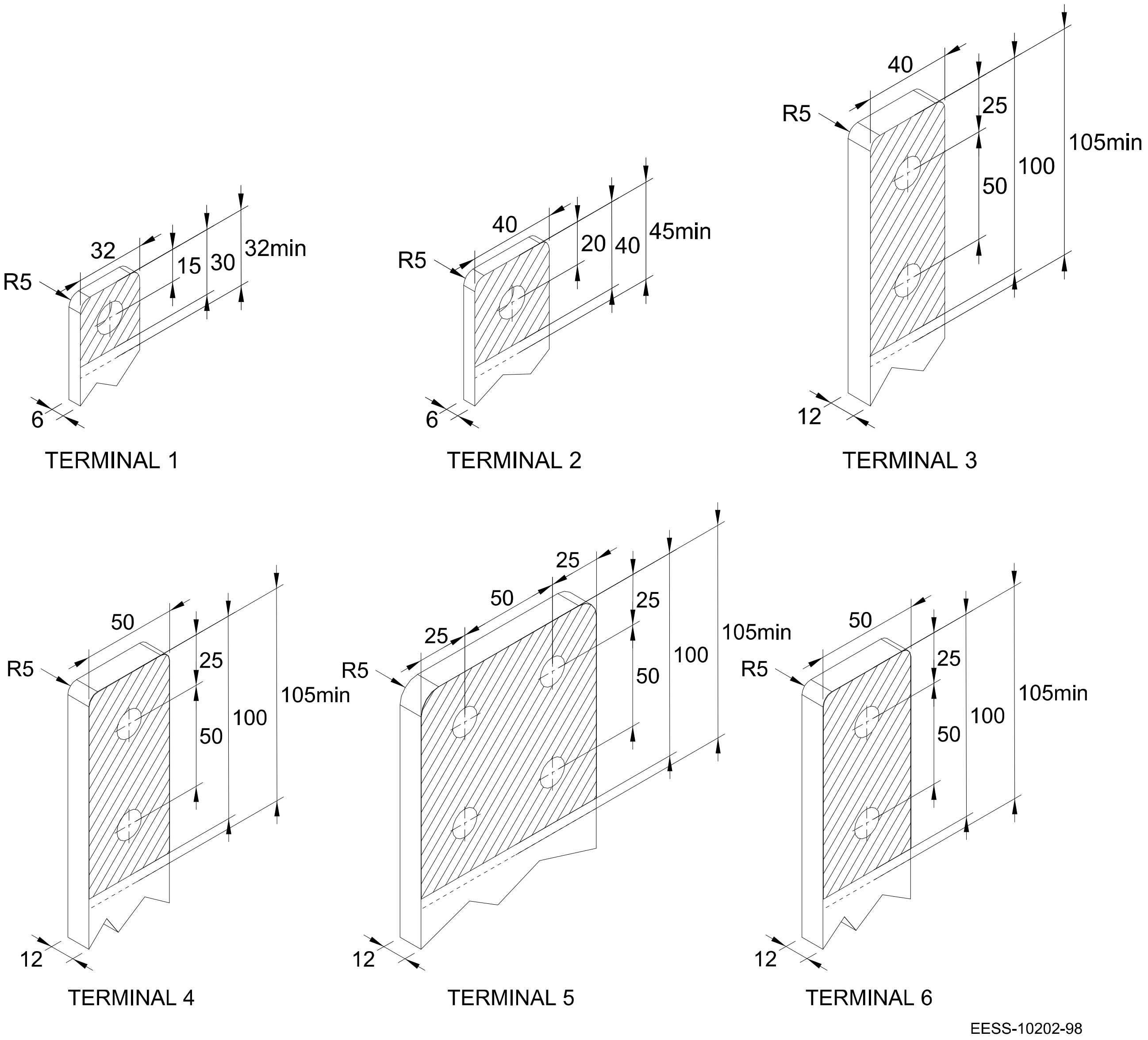

Figure 2: Aluminium Terminal palms 1 to 6

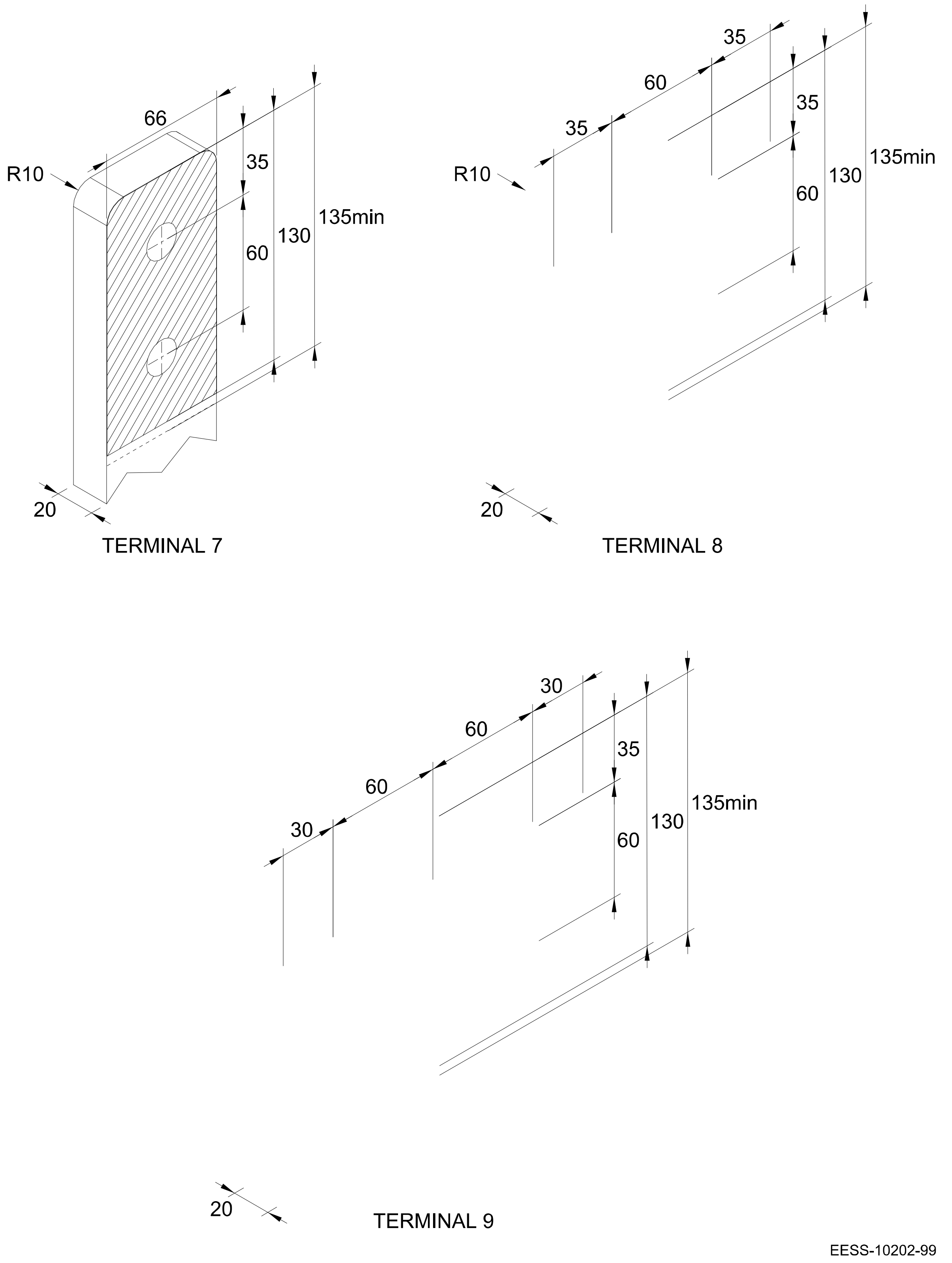

Figure 3: Aluminium Terminal palms 7 to 9

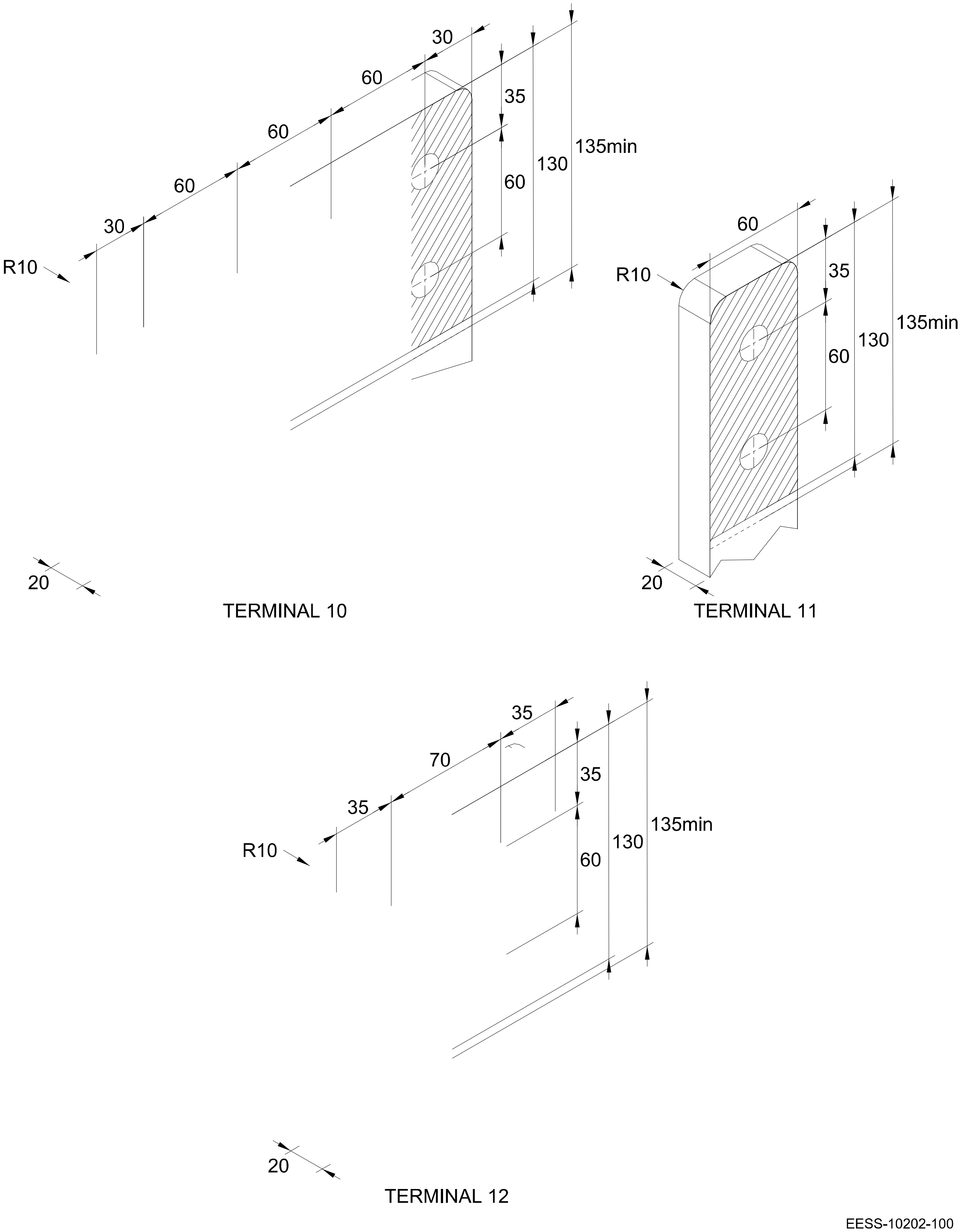

Figure 4: Aluminium Terminal palms 11 and 12

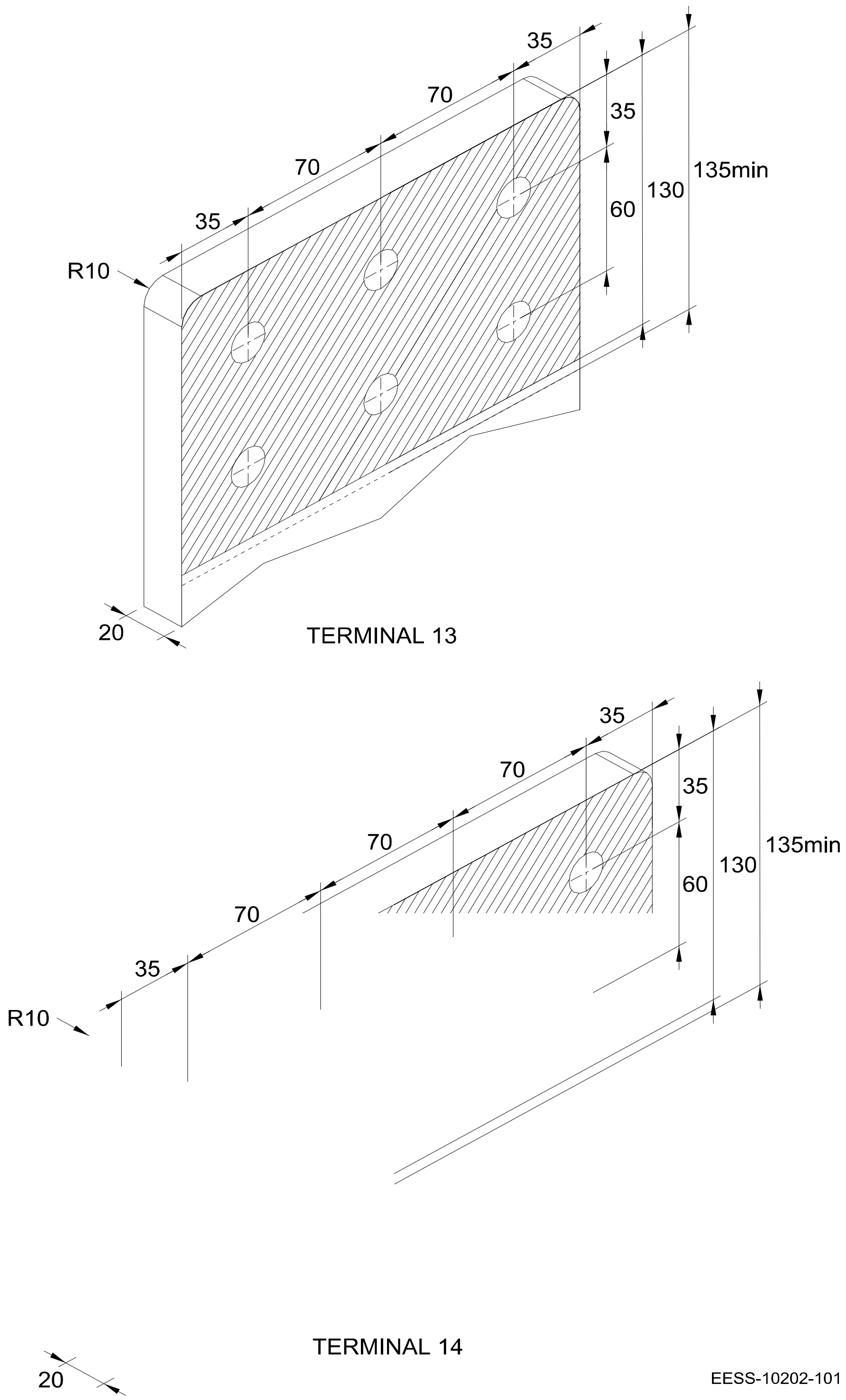

Figure 5: Aluminium Terminal palms 13 and 14

Appendix A

Revision History

Revision date	Version number	Author	Description of change/revision
December 2024	11	John Lansley	Remove Tables B6 Updated Annex D to incorporate terminal palm standard