Eskom	Standard	Technology

Title: **STANDARD FOR STRANDED FLEXIBLE CONDUCTOR SELECTION**

Unique Identifier: **240-68971972**

Alternative Reference Number: **N/A**

Area of Applicability: **Engineering**

Next Review Date: **STABILISED**

COE Acceptance

Subhas Maharaj

Senior Manager: Substation Engineering

Date: 22/2/2021

DBOUS Acceptance

Amelia Mtshali

Senior Manager: Design Base & Operating Unit Support

Date: 25/02/2021

This document is **STABILISED.** The technical content in this document is not expected to change because the document covers: *(Tick applicable motivation)*

1	A specific plant, project or solution	
2	A mature and stable technical area/technology	x
3	Established and accepted practices.	x

This letter is for multiple documents:

PCM Reference: **Design Substations**
SCOT Study Committee Number/Name: **Substations**

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Compiled by	Approved by	Authorized by
[signature]	[signature]	[signature]
Braam Groenewald	**Braam Groenewald**	**Phineas Tlhatlhetji**
Corporate Specialist-Substations	**Corporate Specialist-Substations**	**Senior Manager-Substation Engineering**
Date: 13-10-2015	Date: 13-10-2015	Date: 13/10/2015

Supported by SCOT/SC

[signature]

Phineas Tlhatlhetji

SCOT/SC Chairperson

Date: 13/10/2015

PCM Reference: **240-53459042**

SCOT Study Committee Number/Name: **Substations**

Content

Figures

Tables

1. Introduction

The use of flexible stranded conductors for busbars was and still is widely employed in modern HV and EHV outdoor air insulated substations (AIS). The "structure" must, however, have enough strength to withstand the significant axial and lateral mechanical stresses that develop due to wind and ice loadings, Aeolian vibration and mechanical forces as a result of the short circuit currents that may occur on, or near the busbar system. These stresses are imposed on the flexible conductors and transferred to the strain and suspension supporting structures, composed of insulators and substructures (steelwork supports and support foundations). The mechanical requirements to ensure the strength in the flexible conductors do not necessarily lead to conductors with a high current carrying capacity and one generally has to increase the size of the conductor bundle to satisfy the current rating of the bus system. The current requirements should be checked to make sure that it is satisfied (see Table 3). The mechanical stresses on equipment can be quite severe with stranded conductors since with short-circuits they clench together and tear at the armature fittings, as is the case with stranded flexible conductors connected in parallel where bundle collapse occurs. The flexibility of the stranded conductors requires larger portal clearances due to larger conductor deflections under fault conditions and due to sag under its own weight.

The corona and thermal performance of flexible conductors is inherently worse than that of tubular conductors due to the smaller surface areas that are available, leading to higher voltage gradients and higher running temperatures respectively. Corona performance can be improved by selecting the correct conductor diameter and bundle sub-conductor spacing. The corona performance of the selected stranded flexible conductor and bundle configuration can be predicted by carrying out the relevant calculations (see Table 4).

2. Supporting clauses

2.1 Scope

This standard details the standard flexible stranded conductor sizes that are to be employed for given span lengths and busbar fault levels.

The conductor sizes provided in the table are based on worst possible conditions where feeders may auto-reclose onto a fault that has not been cleared, This condition is applicable to transmission level voltages of 220 kV and above, but may not be applicable to sub-transmission level voltages.

A general description of the boundary conditions is provided together with the classification of busbar fixing configuration that needs to be applied.

The standard does not cover HVDC converter stations.

2.1.1 Purpose

The purpose of this document is to provide the designer tables of the best choice of flexible conductor for given voltage levels and fault currents.

2.1.2 Applicability

This document shall apply throughout Eskom Holdings Limited Divisions.

2.2 Normative/informative references

Parties using this document shall apply the most recent edition of the documents listed in the following paragraphs.

2.2.1 Normative

[1] ISO 9001 Quality Management Systems.

[2] Substation Layout Design Guide.

[3] South African Grid Code.

2.2.2 Informative

None

2.3 Definitions

2.3.1 General

Definition	Description
Ampacity	Current carrying capacity
Boundary Condition	The type of fixing at supports
Dynamic Force	Time varying force
Phase-to-earth	Between a phase and a point of zero potential
Phase-to-phase	Between two different phases
Static Forces	Sustained force
Sub-transmission Voltage Level	Voltage level of 132 kV and below
Transmission Voltage Level	Voltage level of 220 kV and above

2.3.2 Disclosure classification

Controlled disclosure: controlled disclosure to external parties (either enforced by law, or discretionary).

2.4 Abbreviations

Abbreviation	Description
AIS	Air Insulated Substations
HVDC	High Voltage Direct Current

2.5 Roles and responsibilities

Group lead engineers need to be fully briefed on the contents of this document. They will in turn be expected to instruct their direct reports in its use.

2.6 Process for monitoring

The tables at the end of the document are to become part of the design documentation.

2.7 Related/supporting documents

Transmission Line Design

3. Document content

3.1 Requirements

The process that is followed for each of the components of the flexible bus system, viz. stranded flexible conductor (maximum stress and maximum conductor deflection) and strain/suspension insulators can by-enlarge be categorised into the following order:-

- Reference calculation
- Static condition
- Dynamic condition
- Dynamic condition with auto-re-close
- Combined static and dynamic forces
- Safety factor
- Test for limits

The behaviour of the flexible busbar system under static and dynamic conditions is dependent upon a number of factors. One of these factors is the type of support system employed, viz. boundary condition.

Only a brief description is given here. The designer should consult the Substation Layout Design Guide.

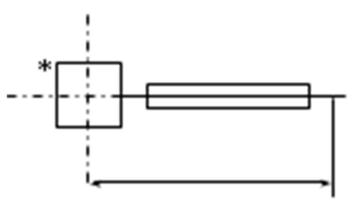
3.2 The Span of the Flexible Busbar Conductor

The span of the flexible conductor bus employed is dependent upon:-

- The boundary conditions of the busbar system employed, i.e. the support system employed at the ends of each bus (both ends strained, one end strained + one end suspended, both ends suspended). The designer should employ the “both ends suspended” option to determine the phase spacing.
- The minimum allowable phase-to-earth and phase-to-phase clearances between items of equipment in a three-phase system
- Bus bundled sub-conductor spacing (so) and conductor diameter (dc)
- The maximum allowable sag of the bus flexible conductor
- The maximum allowable stress in the conductors under extreme dynamic conditions - mechanical characteristics of the material (the alloy employed) such as the 0,2% Proof Stress (see Table 5)
- The maximum horizontal deflection of the bus conductors – required to calculate the phase-to-phase clearance between phase conductors and ensure that minimum values are not infringed.

Table 1: Maximum Spans: Busbars and Stringers

System Nominal Voltage (kV)	Phase-To-Phase Spacing (metres)	Average Effective Length Of Strain String * (metres)	Conductor Tension (kN/phase)	Max. Span In Metres Between Suspension Points				
				1 x 160 (mm^2)	1 x 400 (mm^2)	1 x 800 (mm^2)	2 x 400 (mm^2)	2 x 800 (mm^2)
11	0,914	0,9	9,0	68	43	30	27	18
			4,5	48	31	21	19	13
22	0,914	1,2	9,0	58	37	26	22	15
			4,5	41	26	18	16	11
33	0,914	1,4	9,0	49	31	21	16	11
			4,5	34	22	15	11	8
44								
66	1,83	1,6	4,5	52	34	23	21	15
			4,5	52	34	23	21	15
88	2,44	2,0	4,5	73	44	30	29	20
			9,0	103	62	42	41	28
			4,5	73	47	32	29	20
132	3,048	2,5	9,0	100	64	44	39	27
			18,0	-	91	61	56	38
			4,5	71	45	31	28	19
220+	4,57	3,0	18,0	-	115	79	75	52
			9,0	-	76	52	49	34
275+	4,57	3,5	18,0	-	-	-	61	42
			9,0	-	-	-	38	26
330+	7,01	Straight 4,3	18,0	-	-	-	94	64
		Vee 4,7	9,0	-	-	-	67	46
400+	7,01	Straight 4,7	18,0	-	-	-	-	61
		Vee 5,25	9,0	-	-	-	-	43



+ See Note 4

+ Determined by phase-to-phase clearance considerations

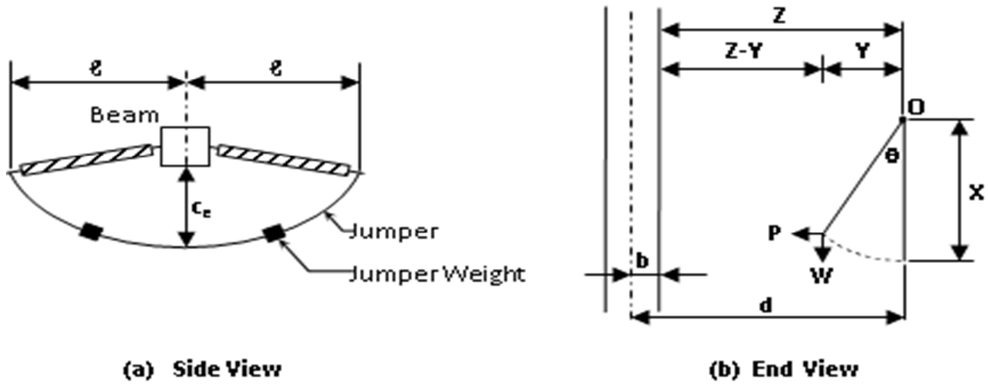


Figure 1: Jumper Clearances

Notes:

$$sag = \frac{9{,}8.w_c.L^2}{8.T_c}$$

w_c = Conductor mass in kg/m

L = Actual span length between the supports in metres

T_c = Conductor tension in Newtons

Conductor spacing for - twin conductors :150 mm

- triple conductors :165 mm

To calculate the spans, the tensions used were 90 % of the values given in the table.

The Stringer spans for voltages from 220 kV to 400 kV may be determined by phase to earth clearances and for these voltages reference should also be made to Table 2.

$$sag = \frac{\text{Phase Spacing (Phase Clearance + Conductor Spacing)}}{2}$$

Table 2: Maximum Spans: Stringers on Extended Bays

System Nominal Voltage (kV)	Bay Size (m)	Distance To Steelwork 'x' (m)	Conductor Tension (kN/Phase)	Max Span In Metres Between Strain Beams					
				1 x 160 mm²	1 x 400 mm²	1 x 800 mm²	2 x 400 mm²	2 x 800 mm²	
66	7,620	1,67	+ 1 4,5	55	37	26	24	18	*
			+ 2 3,0	48	32	23	22	16	
88	8,53	1,48	4,5	68	48	34	33	24	*
	10,36	3,25	4,5	77	48	34	33	24	
132	12,192	2,62	4,5	76	50	36	33	24	*
220	15,240	2,90	9,0	-	80	57	54	38	
	18,288	5,85	9,0	-	82	58	55	40	*
275	15,240	2,94	9,0	-	-	-	42	31	
	18,288	5,85	9,0	-	-	-	45	33	*
330	23,774	4,40	9,0	-	-	-	72	52	
400	23,774	4,40	9,0	-	-	-	-	46	

+ Determined by phase-to-phase clearance considerations.

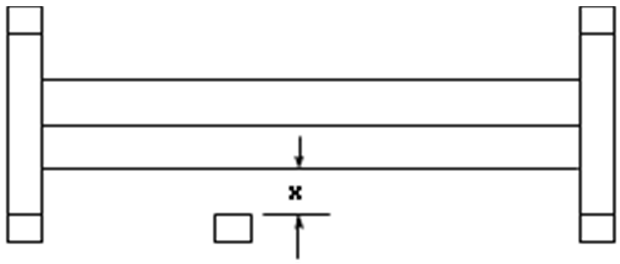


Figure 2: Stringer Phase-to-Earth Clearance to Free Standing Column

where:-

x **=** Distance from centre line of phase to edge of steelwork.

Based on phase-to-phase spacing and clearances

All conductor tensions 4 kN per phase.

Table 3: Maximum Spans: 800 mm^2 (Bull) Stringers between Yards

L.V. Yard Steelwork (kV)	Transmission Voltage (kV)	Conductor Per Phase	H.V. Yard Steelwork (kV)						
			33	44	66	88	132	275	400
			Maximum Span In Metres Between Strain Beams						
33	11	1	23		28	32	36		
		2	15		20	22	25		
	22	1	21		28		35		
		2	13		19	31	24		
	33	1	18		26	30	34	40	
		2	11		18	20	24	28	
44	44	1	-	-					
		2	-	-					
66	66	1	-	-	26	30	34	40	
		2	-	-	18	21	24	28	
88	88	1	-	-	-	36	37	43	55
		2	-	-	-	24	26	31	38
132	132	1	-	-	-	-	36	42	53
		2	-	-	-	-	24	29	37
275	220	1	-	-	-	-	-	58	74
		2	-	-	-	-	-	40	51
	275	2	-	-	-	-	-	33	47
400	330	2	-	-	-	-	-	-	55
	400	2	-	-	-	-	-	-	53

Based on current Eskom steelwork phase-to-phase spacing and clearances

Conductor Tension: up to and including 132 kV - 4 kN / Phase 275 kV and above 8 kN / Phase.

Table 4: Maximum Spans: 400 mm^2 (Centipede) Stringers between Yards

L.V. Yard Steelwork (kV)	Transmission Voltage (kV)	Conductor Per Phase	H.V. Yard Steelwork (kV)						
			33	44	66	88	132	275	400
			Maximum Span In Metres Between Strain Beams						
33	11	1	33		40	47	52		
		2	21		28	32	35		
	22	1	29		39	46	50		
		2	18		26	30	34		
	33	1	25		37	42	48	57	
		2	14		25	28	33	40	
44	44	1	-						
		2	-						
66	66	1	-	-	37	42	48	57	
		2	-	-	24	29	33	40	
88	88	1	-	-	-	48	52	61	79
		2	-	-	-	34	36	43	55
132	132	1	-	-	-	-	50	62	76
		2	-	-	-	-	33	40	52
275	220	1	-	-	-	-	-	82	104
		2	-	-	-	-	-	55	72
	275	2	-	-	-	-	-	45	65
400	330	2	-	-	-	-	-	-	75
	400	2	-	-	-	-	-	-	-

Based on phase-to-phase spacing and clearances

Conductor Tension : Up to and including 132 kV, 4 kN / Phase; 275 kV and above - 8 kN / Phase.

Table 5: Maximum Spans: 160 mm2 (Hornet) Stringers between Yards

L.V. Yard Steelwork kV	Transmission Voltage kV	Conductors Per Phase	H.V. Yard Steelwork (kV)				
			33	44	66	88	132
			Maximum Span Between Strain Beams				
33	11	1	50	-	64	73	80
	22	1	44	-	60	69	77
	33	1	37	-	56	65	73
44	44	1	-	-			
66	66	1	-	-	56	65	73
88	88	1	-	-	-	77	79
132	132	1	-	-	-	-	76

Example:

HV yard steelwork	:	275 kV
LV yard steelwork	:	132 kV
Transmission voltage of span	:	132 kV (i.e. the lower voltage)
Conductor	:	2 x 800 mm2.

From Table 2 the distance between the strain beams should not exceed 29 metres.

Maximum Spans for Stringers between Yards of Different Voltages - Two successive Attachment Points at Different Levels

It often occurs that the spans in a section of an overhead conductor are on sloping ground and in many instances the supports are at considerably different levels. This makes the calculation of sags and tensions a little more difficult, while the checking of the actual sag in practice is more complicated than that on level ground. In other cases, when crossing a road with transformer connections, it is frequently necessary to string between beams designed for different voltages (see Figure 3). It is not only necessary to check the sag of the conductor, but also to calculate the position of the lowest point on the conductor and the actual height above ground for clearance purposes.

If beams designed for different voltage levels are employed, the conductors will generally be attached to beams with different conductor phase spacing at either end, so that the calculations need to be based on the effective phase spacing at the centre of the span. This is the point where the conductor sag is the greatest and when swung through 90o, is the point of closest approach between two phases.

$s_{eff} = {}^{1}/_{2}.[s_{HV}+s_{LV}]$

where:-

s_{eff} = Effective phase spacing

s_{HV} = Phase spacing on HV steelwork in (m)

s_{LV} = Phase spacing on LV steelwork in (m)

Calculating the effective conductor phase spacing is a fairly simple task. It is the mid-point of the span regardless of the separation of the two portal structures. What is more complex is calculating the conductor sag at the mid-point where the conductor attachment heights are at different levels. The detail behind the calculation procedure is provided here and only the result is applied here to calculate the maximum span length.

The sag calculations are similar to those used for supports at the same level with the modification that the calculations are done on the equivalent complete span length. Span lengths are always measured horizontally on the survey. If, however, the slope of the ground is known, it is a fairly simple matter to determine the actual span length on the slope from the horizontal span length and the ground slope.

The calculations are based on the parabolic formulae, which is sufficiently accurate so long as the tension ratio is greater than 2. If the tension ratio is less than 2, a correction should be applied.

$\frac{T_c}{w_c} < 2 \rightarrow$ Apply correction factor

$\geq 2 \rightarrow$ Do not apply correction factor

where:-

T_c = Initial horizontal tension in the span before wind and ice loading, and before conductor creep at the average temperature of the coldest month in Newtons (N)

w_c = The weight of the conductor per unit length (N/m)

Tables 3,4 and 5 respectively applying to 800 mm^2 "Bull", 400 mm^2 "Centipede" and 160 mm^2 "Hornet" conductors give the maximum span lengths that are permissible for those stringers.

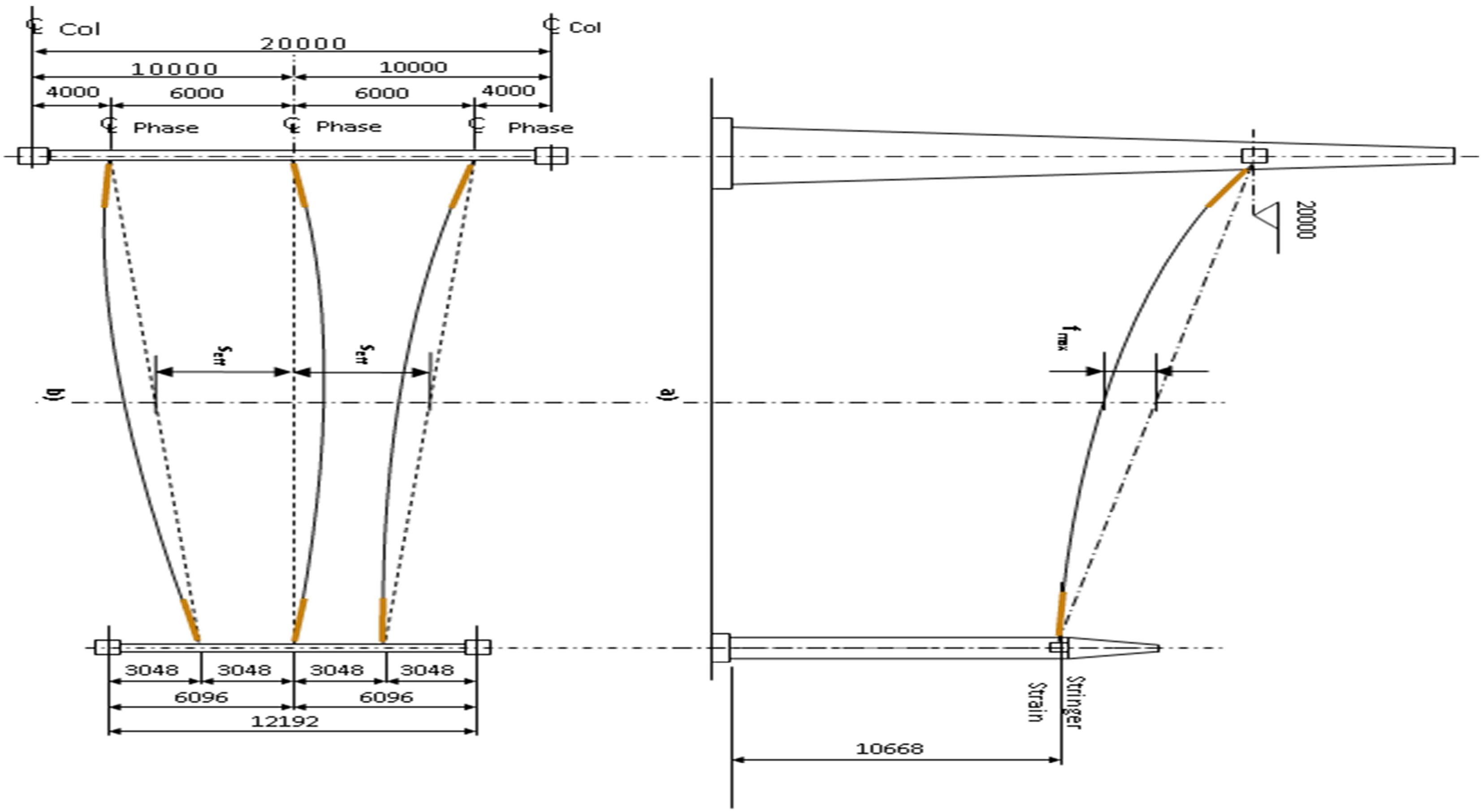


Figure 3: Maximum Spans of Stringers between Yards

3.3 Permissible Conductor Temperatures for Busbars, Stringers and Connections

Above a critical temperature, conductors start to anneal and lose mechanical strength. For aluminium, very little loss of strength occurs at temperatures up to 80°C, while at 90°C the loss of strength is small enough to ignore (± 15 % if the conductor is operated continuously at 100°C for a period of 1 year).

For substation applications, the tensions used are well below the ultimate strengths of the conductors, and a small loss of strength is therefore not a significant factor in the design. Furthermore, the constants assumed for the heat balance equation are somewhat pessimistic in that:

a) ambient temperatures rarely exceed 25-35°C, especially in winter when the loads are high

b) a solar radiation of 0,112 watts/cm2 is exceptional, and,

c) a wind velocity of 1,6 kph (0,44 m/s) is low.

Finally, circuits are frequently duplicated and consequently tend to operate at only 50 % rating or less for most of the time. On this basis it is concluded that an ultimate temperature of 90oC for aluminium conductors in substation applications is acceptable, and standard conductors can now be selected to match standard equipment current ratings as follows:-

Table 6: Conductor Selection to Meet Thermal Limit Current

400 amperes	**:**	**1 x 150 mm^2 "Hornet"**	**- 470A**	**at 90°C**
800 amperes	**:**	**1 x 400 mm^2 "Centipede"**	**- 860A**	**at 90°C**
1250 amperes	**:**	**1 x 800 mm^2 "Bull"**	**- 1353A**	**at 90°C**
1600 amperes	**:**	**2 x 400 mm^2 "Centipede"**	**- 1720A**	**at 90°C**
2500 amperes	**:**	**2 x 800 mm^2 "Bull"**	**- 2706A**	**at 90°C**
3150 amperes	**:**	**3 x 800 mm^2 "Bull"**	**- 4059A**	**at 90°C**

Table 7: Standard Aluminium Conductors to SANS 182

Reference Area mm^2 (Old Code Ref)	Number and Diameter of Wires (mm)	Nominal Dia. (mm)	Mass Per Km (kg)	Max. Resistance at 20°C (Ohms/km)	Breaking Strength (kN)	Current Rating Amperes	
						75°C	90°C
25 (Midge)	7/2,12	6,36	68	1,187	4,1	118	146
40 (Mosquito)	7/2,65	7,95	106	0,756	6,1	155	194
63 (Fly)	7/3,35	10,05	169	0,473	9,3	206	259
100(Wasp)	7/4,25	12,75	272	0,294	14,6	273	348
160 (Hornet)	19/3,35	16,75	461	0,175	24,7	371	478
250 Cockroach	19/4,25	22,25	742	0,108	38,8	495	649
400 (Centipede)	37/3,75	26,25	1127	0,072	59,6	634	842
500 (Scorpion)	37/4,25	29,75	1447	0,056	75,6	712	940
630 (Cicada)	61/3,75	33,75	1862	0,044	96,0	849	1152
800 (Bull)	61/4,25	38,25	2391	0,034	121,8	985	1350

Notes: -

Temperature coefficient of resistance = 0,00403 per ^{o}C

$R_{t2} = R_{t1}.[1+0,00403(t_2+t_1)]$

Current rating equations

$$I_{75}=\frac{0,2655.d^{0,448} - 0,0212.d}{R_{20}.1,22165.10^5}$$

$$I_{90}=\frac{0,379.d^{0,448} - 0,0273.d}{R_{20}.1,2821.10^5}$$

Table 8: Corona Inception (E_c) vs. Calculated Voltage Gradient on the Conductor (E_m) for Given System Voltage Levels (kV) and Conductor Sizes

Conductor	Conductor OD (mm)	Bundle		Corona Inception (E_c-kV/cm)	Calculated Voltage Gradient on the Tube (E_m-kV/cm)						
					System Voltage (U_n) kV						
		Configuration	No Sub-conductors		765	400	275	220	132	88	66
Hornet	**16,75**	Flat	1	18,868	-	-	-	-	15,648 NC	10,432 NC	8,541 NC
			2		-	-	-	16,914 MG	11,228 NC	7,486 NC	6,322 NC
Centipede	**26,25**		1	17,714	-	-	-	16,734 MG	10,751 NC	7,167 NC	5,914 NC
			2		-	-	14,923 NC	11,938 NC	7,818 NC	5,212 NC	4,433 NC
Bull	**38,3**		1	16,932	-	-	15,414 NC	12,331 NC	7,961 NC	5,308 NC	4,413 NC
			2			15,424 NC	11,099 NC	8,879 NC	5,923 NC	3,949 NC	3,379 NC
			3		-	12,408 NC	9,099 NC	7,279 NC	4,821 NC	3,214 NC	2,783 NC
Centipede	**26,25**	Circle	6	17,714	16,304 MG	-	-	-	-	-	
Bull	**38,3**			16,932	12,335 NC	-	-	-	-	-	-

MG – Marginal (Avoid)

NC – No Corona (Corona is absent)

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Abre le Roux	Chief Engineer –
Braam Groenewald	Corporate Specialist – Substation Engineering
Derrick Delly	Chief Engineer – Substation Engineering
Enderani Naicker	Chief Engineer – Substation Engineering
Ian Hill	Senior Technologist – Substation Engineering
Mark Peffer	Chief Engineer – Substation Engineering
Phineas Tlhatlhetji	Senior Manager - Substation Engineering
Rukesh Ramnarain	Chief Engineer – Substation Engineering
Sipho Zulu	Chief Engineer – Substation Engineering
Theunus Marais	Chief Engineer – Substation Engineering

5. Revisions

Date	Rev	Compiler	Remarks
Oct 2015	1	AJS Groenewald	First Issue.

6. Development team

The following people were involved in the development of this document:

- Abre le Roux — Substation Engineering, Technology Group
- Braam Groenewald — Substation Engineering, Technology Group
- Enderani Naicker — Substation Engineering, Technology Group
- Phineas Tlhatlhetji — Substation Engineering, Technology Group

7. Acknowledgements

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