Eskom	**Standard**	**Technology**

Title: **STANDARD FOR TUBULAR CONDUCTOR SELECTION**

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COE Acceptance

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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	
3	Established and accepted practices.	x

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PCM Reference: **240-53459042**
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Eskom	Standard	Technology

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Content

1. Introduction

The use of rigid conductors for busbars is widely employed in modern HV and EHV outdoor air insulated substations (AIS). The "structure" must, however, have enough strength to withstand the significant 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 tubular conductors and the supporting structures, composed of insulators and substructures (steelwork supports and support foundations). The mechanical requirements to ensure the strength in the tubular conductors inherently leads to a conductor with a high current carrying capacity and one seldom has to increase the size to satisfy the current rating of the bus system. Nevertheless, the current requirements should be checked to make sure that it is satisfied (see Table 3). The mechanical stresses on equipment is lower with tubular conductors and with a short-circuit they do not clench together and tear at the armature fittings, as is the case with stranded flexible conductors connected in parallel where bundle collapse occurs. The rigidity of the tubular conductors also offers an opportunity for smaller portal clearances due to smaller conductor deflections under fault conditions and due to its own weight.

The corona and thermal performance of tubular conductors is inherently better than that of bundled flexible conductors due to the larger surface areas that are available, leading to lower voltage gradients and lower running temperatures respectively. Again, the corona performance of the selected tube can be predicted by carrying out the relevant calculations (see Table 4).

The document provides optimised choices of tubular conductor and strength of the support post insulators for various voltage levels.

2. Supporting clauses

2.1 Scope

This standard provides tables of the best choice of tubular conductor and strength of the support post insulators for voltages from 6,6 kV to 765 kV..

2.1.1 Purpose

The aim of this document is to provide the designer tables of the best choice of tubular conductor and strength of the support post insulators 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
Transmission Voltage Level	Voltage level of 220 kV and above.
Sub-transmission Voltage Level	Voltage level of 132 kV and below.
Boundary Condition	The type of fixing at supports.
Phase-to-earth	Between a phase and a point of zero potential
Phase-to-phase	Between two different phases
Static Forces	Sustained force
Dynamic Force	Time varying force

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
RAD	Relative air density

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

The process that is followed for each of the components of the tubular bus system, viz. tubular conductor (maximum stress and maximum deflection) and support 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 tubular 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. The order in which these are given is an attempt to provide a logical and understandable presentation of the subject concerned. Only a brief description is given here. The designer should consult the Substation Layout Design Guide 41-3.

Figure 1 is a high level flow diagram produced to illustrate the design process described above. It summarises the process into a much condensed form and was produced to conform in the order that the subject is presented in the Substation Layout Design Guide.

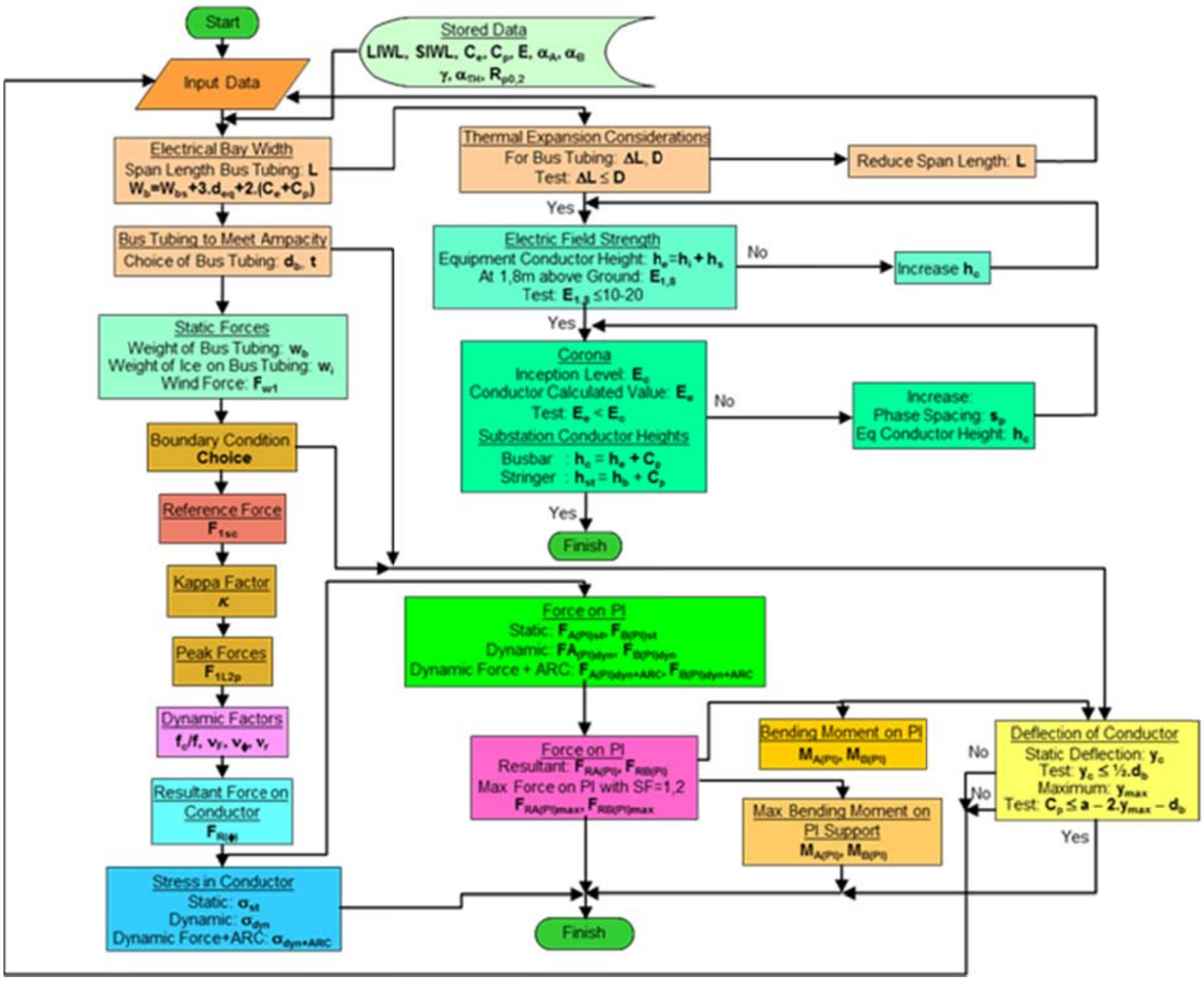

Figure 1: High Level Process Flow Diagram for Dimensioning Post Insulators and Bus Tubes

3.1 Rigid Bus Design is an Iterative Process

If the calculations indicate that the conductor chosen will not to be suitable, then a number of options are available. By changing the variables one at a time or combinations thereof will eventually provide the best techno-economic solution. The variables are as follows:-

- Conductor span length
- Conductor phase spacing
- Conductor size
- Conductor shape (should only use round tubular conductors at levels of MV and above)
- Conductor material (alloys)

- Conductor height - Although theoretically speaking, the height of the conductor is a design variable in the choice of a tubular conductor, the conductor is normally sized for mechanical strength, i.e. to withstand short circuit, wind and ice loadings on it. This generally results in a bus tube that is oversized for electrical purposes, both in terms of current carrying capacity and corona performance. Although it is necessary to check it, the surface voltage gradient on the tube is in virtually all practical cases, an order of magnitude lower than the corona inception value. This is clearly demonstrated in the examples in the Substation Layout Design Guide 41-3.

Table 1: Minimum Parameters vs. Busbar Fault Level (kA) for Given System Voltage Levels (kV) [Feeder Auto-Reclose]

Busbar I_{fault} (kA)	System Voltage (U_n) kV						
		765	**400**	**220 and 275**	**88 and 132**	**66**	**11-33**
12,5	**Phase Spacing (m)**	14	5,5	4	3	1,8	1
	Span (m)	16	20	16	13,2	9	6
	Tube	200x6	250x6	200x6	200x6	120x6	80x8
	Alloy	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	8	6	6	6	6	6
16	**Phase Spacing (m)**	14	5,5	4	3	1,8	1
	Span (m)	16	20	16	13,2	9	6
	Tube	200x6	250x6	200x6	200x6	120x6	80x8
	Alloy	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	8	6	6	6	6	6
20	**Phase Spacing (m)**	14	5,5	4	3	1,8	1
	Span (m)	16	20	16	13,2	9	6
	Tube	200x6	250x6	200x6	200x6	120x6	120x6
	Alloy	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	8	6	6	6	6	6
25	**Phase Spacing (m)**	14	5,5	4	3	1,8	1
	Span (m)	16	20	16	13,2	9	6
	Tube	200x6	250x6	200x6	200x6	120x6	120x6
	Alloy	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	8	6	6	6	6	8

Table 1: Minimum Parameters vs. Busbar Fault Level (kA) for Given System Voltage Levels (kV) [Feeder Auto-Reclose] (Continued)

Busbar I_{fault} (kA)	**System Voltage (U_n) kV**						
		765	**400**	**220 and 275**	**88 and 132**	**66**	**11-33**
31,5	**Phase Spacing (m)**	14	5,5	4	3	1,8	1,8
	Span (m)	16	20	16	13,2	9	6
	Tube	200x6	250x6	200x6	200x6	160x6	120x6
	Alloy	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	8	8	8	8	8	8
40	**Phase Spacing (m)**	14	5,5	4	3	1,8	1,8
	Span (m)	16	20	16	13,2	9	6
	Tube	200x6	250x6	200x6	200x6	160x8	120x6
	Alloy	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25	6061 T6	AlMgSi0.5T25
	PI (kN)	8	10	10	10	12,5	12,5
50	**Phase Spacing (m)**	14	5,5	4	3,5	-	-
	Span (m)	16	20	16	13,2	-	-
	Tube	200x6	250x6	200x6	200x8	-	-
	Alloy	AlMgSi0.5T25	AlMgSi0.5T25	6061 T6	6061 T6	-	-
	PI (kN)	8	12,5	12,5	16	-	-
63	**Phase Spacing (m)**	14	5,5	4	-	-	-
	Span (m)	16	20	16	-	-	-
	Tube	200x6	250x8	200x8	-	-	-
	Alloy	AlMgSi0.5T25	6061 T6	6061 T6	-	-	-
	PI (kN)	8	16	18	-	-	-

Table 2: Minimum Parameters vs. Busbar Fault Level (kA) for Given System Voltage Levels (kV) [No Feeder Auto-Reclose]

Busbar I_{fault} (kA)	System Voltage (U_n) kV						
		765	**400**	**220 and 275**	**88 and 132**	**66**	**11-33**
12,5	**Phase Spacing (m)**	-	-	-	3	1,8	1
	Span (m)	-	-	-	13,2	9	6
	Tube	-	-	-	120x6	120x6	80x8
	Alloy	-	-	-	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	-	-	-	6	6	6
16	**Phase Spacing (m)**	-	-	-	3	1,8	1
	Span (m)	-	-	-	13,2	9	6
	Tube	-	-	-	120x6	120x6	80x8
	Alloy	-	-	-	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	-	-	-	6	6	6
20	**Phase Spacing (m)**	-	-	-	3	1,8	1
	Span (m)	-	-	-	13,2	9	6
	Tube	-	-	-	120x6	120x6	80x8
	Alloy	-	-	-	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	-	-	-	6	6	6
25	**Phase Spacing (m)**	-	-	-	3	1,8	1
	Span (m)	-	-	-	13,2	9	6
	Tube	-	-	-	120x6	120x6	80x8
	Alloy	-	-	-	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	-	-	-	6	6	6

Table 2: Minimum Parameters vs. Busbar Fault Level (kA) for Given System Voltage Levels (kV) [No Feeder Auto-Reclose] (Continued)

Busbar I_{fault} (kA)	System Voltage (U_n) kV						
		765	400	220 and 275	88 and 132	66	11-33
31,5	Phase Spacing (m)	-	-	-	3	1,8	1
	Span (m)	-	-	-	13,2	9	6
	Tube	-	-	-	120x6	120x6	120x6
	Alloy	-	-	-	AlMgSi0.5T25	AlMgSi0.5T25	AlMgSi0.5T25
	PI (kN)	-	-	-	6	8	8
40	Phase Spacing (m)	-	-	-	3	1,8	1,8
	Span (m)	-	-	-	13,2	9	6
	Tube	-	-	-	160x6	160x6	120x6
	Alloy	-	-	-	AlMgSi0.5T25	AlMgSi0.5T25	6061 T6
	PI (kN)	-	-	-	6	8	10
50	Phase Spacing (m)	-	-	-	3	1,8	-
	Span (m)	-	-	-	13,2	9	-
	Tube	-	-	-	160x6	160x6	-
	Alloy	-	-	-	6061 T6	6061 T6	-
	PI (kN)	-	-	-	8	12,5	-
63	Phase Spacing (m)	-	-	-	3	1,8	-
	Span (m)	-	-	-	13,2	9	-
	Tube	-	-	-	200x6	160x8	-
	Alloy	-	-	-	6061 T6	6061 T6	-
	PI (kN)	-	-	-	12,5	16	-

Table 3: Ampacity of Aluminium Tubular Conductors

Outer Diameter (d_o) (mm)	Wall Thickness (t_w) (mm)	Cross-Sectional Area (mm²)	Mass per Metre (kg)	Continuous Current Rating for E-AlMgSiO,5F22		Continuous Current Rating for E-AlMgSiO,5 F 25	
				65 ° (A)	**85° (A)**	**65° (A)**	**85° (A)**
63	4	741	2,00	1150	1530	1110	1480
	5	911	2,46	1280	1700	1240	1640
	6	1074	2,90	1380	1830	1330	1770
	8	1382	3,73	1560	2070	1510	2000
80	4	955	2,58	1400	1860	1350	1800
	5	1178	3,18	1560	2070	1510	2000
	6	1395	3,77	1690	2240	1630	2160
	8	1810	4,89	1920	2550	1850	2460
	10	2199	5,94	2110	2790	2040	2690
100	4	1206	3,26	1690	2240	1630	2160
	5	1492	4,03	1880	2490	1820	2400
	6	1772	4,78	2040	2710	1970	2620
	8	2312	6,24	2320	3070	2240	2960
	10	2827	7,63	2540	3360	2450	3240

Table 3: Ampacity of Aluminium Tubular Conductors (Continued)

Outer Diameter (d_o) (mm)	Wall Thickness (t_w) (mm)	Cross-Sectional Area (mm²)	Mass per Metre (kg)	Continuous Current Rating for E-AlMgSiO,5F22		Continuous Current Rating for E-AlMgSiO,5 F 25	
				65 ° (A)	85° (A)	65° (A)	85° (A)
120	4	1458	3,94	1950	2580	1880	2490
	5	1806	4,88	2170	2880	2090	2780
	6	2149	5,80	2370	3140	2290	3030
	8	2815	7,60	2700	3580	2610	3460
	10	3456	9,33	2960	3920	2860	3790
	12	4072	10,99	3130	4150	3020	4010
160	4	1960	5,29	2520	3330	2430	3220
	5	2435	6,57	2790	3700	2690	3570
	6	2903	7,84	3060	4050	2950	3910
	7	3365	9,08	3270	4330	3160	4180
	8	3820	10,31	3490	4630	3370	4470
	10	4712	12,72	3830	5070	3700	4900
	12	5579	15,06	4060	5380	3920	5200

Table 3: Ampacity of Aluminium Tubular Conductors (Continued)

Outer Diameter (d_o) (mm)	Wall Thickness (t_w) (mm)	Cross-Sectional Area (mm²)	Mass per Metre (kg)	Continuous Current Rating for E-AlMgSiO,5F22		Continuous Current Rating for E-AlMgSiO,5 F 25	
				65 ° (A)	85° (A)	65° (A)	85° (A)
200	4	2463	6,65	3030	4010	2930	3870
	5	3063	8,27	3410	4520	3290	4360
	6	3657	9,87	3720	4920	3590	4750
	8	4825	13,0	4270	5660	4120	5470
	10	5969	16,1	4680	6200	4520	5990
	12	7087	19,1	4990	6610	4820	6390
250	5	3848	10,4	4140	5490	3900	5300
	6	4599	12,4	4520	5990	4370	5780
	8	6082	16,4	5190	6870	5010	6640
	10	7540	20,4	5700	7560	5500	7300
	12	8972	24,2	6100	8080	5890	7800
	14	10380	28,0	6420	8500	6200	8210
	16	11762	31,8	6640	8800	6410	8500

Table 3: Ampacity of Aluminium Tubular Conductors (Continued)

Outer Diameter (d_o) (mm)	Wall Thickness (t_w) (mm)	Cross-Sectional Area (mm²)	Mass per Metre (kg)	Continuous Current Rating for E-AlMgSiO,5F22		Continuous Current Rating for E-AlMgSiO,5 F 25	
				65 ° (A)	85° (A)	65° (A)	85° (A)
300	7	6443	17,4	5810	7700	5610	7440
	8	7339	19,8	6140	8130	5930	7850
	10	9111	24,6	6720	8900	6490	8600
	12	10857	29,3	7180	9510	6930	9190
	14	12579	34,0	7490	9930	7230	9590
	16	14275	38,5	7770	10300	7500	9950
	18	15947	43,0	7920	10500	7650	10140
315	8	7716	20,8	6420	8510	6200	8220
	10	9582	25,9	7060	9360	6820	9040
	12	11423	30,8	7540	9990	7280	9650
	14	13239	35,7	7850	10400	7580	10050
	16	15030	40,6	8150	10800	7870	10430
	18	16795	45,3	8380	11100	8090	10720

Table 3: Ampacity of Aluminium Tubular Conductors (Continued)

Outer Diameter (d_o) (mm)	Wall Thickness (t_w) (mm)	Cross-Sectional Area (mm²)	Mass per Metre (kg)	Continuous Current Rating for E-AlMgSiO,5F22		Continuous Current Rating for E-AlMgSiO,5 F 25	
				65 ° (A)	85° (A)	65° (A)	85° (A)
350	8	8595	23,2	7060	9350	6820	9030
	10	10681	28,8	7770	10300	7506	9950
	12	12742	34,4	8230	10900	7950	10530
	14	14778	39,9	8600	11400	8310	11010
	16	16789	45,3	8910	11800	8610	11400
	18	18774	50,7	9130	12100	8820	11670
400	10	12252	33,1	8750	11600	8450	11200
	12	14627	39,5	9360	12400	9040	11980
	14	16977	45,8	9810	13000	9480	12560
	16	19302	52,1	10100	13400	9760	12940
	18	21602	58,3	10300	13700	9950	13230

Table 4: Corona Inception (E_c) vs. Calculated Voltage Gradient on the Tube (E_m) for Given System Voltage Levels (kV) and Tube Sizes

Tube OD (mm)	Corona Inception (E_c-kV/cm)	Calculated Voltage Gradient on the Tube (E_m-kV/cm) System Voltage (U_n) kV						
		765	**400**	**275**	**220**	**132**	**88**	**66**
80	18,671	-	11,958 NC	8,760 NC	7,608 NC	4,481 NC	2,987 NC	2,250 NC
120	18,056	14,013 NC	8,703 NC	6,414 NC	5,131 NC	3,302 NC	2,202 NC	1,659 NC
160	17,682	11,119 NC	6,981 NC	5,171 NC	4,137 NC	2,677 NC	1,785 NC	1,346 NC
200	17,422	9,317 NC	5,093 NC	4,392 NC	3,514 NC	2,285 NC	1,523 NC	1,149 NC
250	17,187	7,819 NC	5,008 NC	3,745 NC	2,996 NC	1,959 NC	1,306 NC	0,985 NC

Table 5: Electrical and Mechanical Properties of Various Aluminium Alloys

ALLOY TYPE	HULETT'S S.A.		ASA STANDARD		DIN STANDARD	
	D50STF	**D65STF**	**6063T6**	**6061T6**	**AlMgSi,5F22**	**AlMgSi,5F25**
Electrical resistivity at 20 ^{o}C (max.) in Ω mm^2 / m	0,03133	0,037	0,0325	0,0431	0,03333	0,03571
Specific mass kg / m^3	2703	2703	2703	2703	2703	2703
Modules of elasticity E in N / m^2	$65,66.10^{9}$	$69,12.10^{9}$	69.10^{9}	70.10^{9}	70.10^{9}	70.10^{9}
Thermal co-efficient of expansion per ^{o}C	23.10^{-6}	23.10^{-6}	23.10^{-6}	23.10^{-6}	23.10^{-6}	23.10^{-6}
0,2 % Proof stress in MPa Rp0,2	170	240	214	276	160	195

4. Authorization

This document has been seen and accepted by:

Name and surname	Designation
Braam Groenewald	Corporate Specialist - Substations
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5. Revisions

Date	Rev.	Compiler	Remarks
Feb 2014	1	AJS Groenewald	First Issue.

6. Development team

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

- Abre le Roux Technology Group East London
- Braam Groenewald Technology Group Johannesburg
- Enderani Naicker Technology Group Johannesburg
- Phineas Tlhatlhetji Technology Group Johannesburg
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- Thys Bouwer Technology Group Johannesburg
- Leon Kotze Technology Group Johannesburg
- Rob Stephen Technology Group Durban

7. Acknowledgements

With thanks to all members of the development team.