ElectraNet Transmission Line Cost Review

ElectraNet Pty Ltd

Transmission Line Cost Review Report

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Document history and status

Revision	Date	Description	By	Review	Approved
A	20/12/2018	DRAFT for Client review	Project Team	Tim Johnson	Ahsan Siddique
B	09/01/2019	Final draft	Project Team	Tim Johnson	Ahsan Siddique
C	07/02/2019	Overall revision and inclusion of Victoria 275kV HVAC option review	Project Team	Tim Johnson	Ahsan Siddique
D	11/02/2019	Minor mods following Client feedback	Tim Johnson	Ahsan Siddique	Ahsan Siddique

Contents

1. Executive Summary

In June 2018, ElectraNet published a draft report on its SA Energy Transformation Regulatory Investment Test for Transmission (RIT-T) investigation of interconnector options between South Australia and the eastern states and alternative non-interconnector options.

This Project Assessment Draft Report (PADR) was accompanied by a Basis of (Cost) Estimate report that sets out how the cost estimates of options considered in the economic assessment were derived.

This report presented cost estimates for three potential interstate transmission lines (presented as cost per kilometre of line):

- From SA to NSW
- From SA to Victoria
- From SA to Queensland via NSW

For each line the cost estimate was based on a weighted average of costs from a number of vendors and from the TNSP or AEMO.

In response to stakeholder submissions on the PADR, ElectraNet commissioned Jacobs to undertake an independent review of the process by which the transmission line cost values were derived and to recommend any changes. The ElectraNet and Jacobs proposed values are shown below.

Summary of transmission line costs

Line	Description	ElectraNet PADR cost $m/km	Jacobs proposed cost $m/km
NSW option	330kV double circuit AC line (740km)	1.013	1.061
Victoria option	275kV double circuit AC line (420km)	0.891	0.964
Queensland option	400kV HVDC line with metallic return (1,450km)	0.716	0.655

The costs are 2017-2018 financial year values and present costs may be different due to inflation and market changes. However, Jacobs expects the percentage changes in costs for the three lines should be similar.

Jacobs also observed that the ElectraNet functional specification for the Queensland option included three key requirements:

- The structure type was to be selected from the following options:
  - Self-supporting lattice tower
  - Alternate Chainette structure for remote and non-agricultural land
  - Alternate steel monopole for environmentally sensitive locations
- The wind return period was 2000-years

- The conductor clearance to ground was increased from 9.0m as specified in AS/NZS 7000:2016 to 11.0m. This was stated to be due to electric field considerations.

In the Jacobs proposed cost the wind return period was reset to 400 years for consistency with the other lines and the conductor clearance reset to the AS/NZS 7000:2016 value.

Other changes are detailed in the report and include adding a greater proportion of Chainette towers to the SA to Queensland cost estimate for one of the vendor's submissions. Following this change approximately half of the weighted average price for this line was from predominantly Chainette structures while the other half was from an (unspecified) combination of bridged and self-supporting towers and from a vendor that did not comment on tower type.

One vendor provided sufficient detail for the comparative costs for three tower types to be identified as shown below:

- Chainette adjusted price $700k/km
- Self-supported tower price $932k/km
- Tension tower price $1025k/km

This vendor also provided prices for the two other lines. While these prices are higher than those given in the ARCMesh submission on the PADR, the difference between Chainette and self-supported tower costs is similar.

Jacobs has also evaluated the suitability of Chainette structures in Australia. Chainette structures require a large footprint and are not suitable for cropping land, where they may interfere with farm activities. This structure type will introduce a new asset class and the impact on long term maintenance cost can be very high. A full-scale test and evaluation should be carried out before introducing Chainette structure in a very long transmission line asset.

2. Important note about your report

The sole purpose of this report and the associated services performed by Jacobs is to undertake an independent review of the costing assessment undertaken by ElectraNet as part of the Project Assessment Draft Report (PADR) for the South Australia Energy Transformation Project (SAET) and of comments on the PADR from ARCMesh Pty Limited, restricted to review of the costs of the transmission line parts of each document. The work was undertaken in accordance with the scope of services set out in the contract between Jacobs and ElectraNet (the Client). That scope of services, as described in this report, was developed with the Client.

In preparing this report, Jacobs has relied upon, and presumed accurate, any information (or confirmation of the absence thereof) provided by the Client and/or from other sources. Except as otherwise stated in the report, Jacobs has not attempted to verify the accuracy or completeness of any such information. If the information is subsequently determined to be false, inaccurate or incomplete then it is possible that our observations and conclusions as expressed in this report may change.

Jacobs derived the data in this report from information sourced from the Client (if any) and/or available in the public domain at the time or times outlined in this report. The passage of time, manifestation of latent conditions or impacts of future events may require further examination of the project and subsequent data analysis, and re-evaluation of the data, findings, observations and conclusions expressed in this report.

Jacobs has prepared this report in accordance with the usual care and thoroughness of the consulting profession, for the sole purpose described above and by reference to applicable standards, guidelines, procedures and practices at the date of issue of this report. For the reasons outlined above, however, no other warranty or guarantee, whether expressed or implied, is made as to the data, observations and findings expressed in this report, to the extent permitted by law.

This report should be read in full and no excerpts are to be taken as representative of the findings. No responsibility is accepted by Jacobs for use of any part of this report in any other context.

This report has been prepared for the benefit of the Client only and no third party may rely, and the Client must not permit any third party to rely, on the report.

Please refer to Appendix C for a brief profile of Jacobs and the pen portrait of the team members who worked on this task.

3. Introduction and scope of work

In June 2018, ElectraNet published a draft report on its SA Energy Transformation Regulatory Investment Test for Transmission (RIT-T) investigation of interconnector options between South Australia and the eastern states and alternative non-interconnector options.

This Project Assessment Draft Report (PADR) was accompanied by a Basis of (Cost) Estimate report that sets out how the cost estimates of options considered in the economic assessment were derived.

This report presented cost estimates for three potential interstate transmission lines (presented as cost per kilometre of line):

- From SA to NSW
- From SA to Victoria
- From SA to Queensland via NSW

All costs presented in the report are 2017-2018 financial year and exclusive of GST, unless otherwise indicated.

Summary data including PERT[1] adjusted estimates of transmission line costs are shown below.

Table 1: Summary of lines and costs (ElectraNet adjusted rates)

Line	Description	P50 Cost. $m/km
NSW option	330kV double circuit AC line (740km)	1.013
Victoria option	275kV double circuit AC line (420km)	0.891
Queensland option	400kV HVDC line with metallic return (1,450km)	0.716

These costs are line costs only and exclude the substation costs that would be required at each end of the interconnector and for terminal stations along the interconnector path to connect renewable energy zones.

In response to stakeholder submissions on the PADR, ElectraNet commissioned Jacobs to undertake an independent review of the process by which the transmission line values were derived and to recommend any changes. The scope of work is given below.

Task 1: Independent review on SA-QLD 400kV HVDC line costs in the PADR.

Task 2: Independent review on SA-NSW 330kV HVAC line costs in the PADR.

Task 3: Independent review on SA-VIC 275kV HVAC line costs in the PADR.

Task 4: Response to relevant aspects of ARCMesh submission on the PADR.

Task 5: Providing an independent view on the use of chainette and guyed structure options.

[1] PERT is defined in Section 4.55 of this report. P50 refers to the PERT calculated mean value.

4. Task 1: Independent review on SA-QLD HVDC line costs in the PADR

ElectraNet has sought pricing data from four sources (three contractors and Queensland transmission system operator Powerlink) in order to determine an appropriate estimation of anticipated South Australia (SA) to Queensland (QLD) transmission line costs. The contractors selected by ElectraNet[2] have relevant Australian experience in the construction of transmission lines.

A functional specification for the line was provided with the terminal points being Davenport in SA and Bulli Creek in Queensland (this was subsequently amended to Western Downs). The specification was drawn up by ETSE Consulting Pty Ltd and reviewed by ElectraNet prior to issue.

The functional specification included three key requirements that are discussed later in this report:

- The structure type was to be selected from the following options:
  - Self-supporting lattice tower
  - Alternate Chainette structure for remote and non-agricultural land
  - Alternate steel monopole for environmentally sensitive locations
- The wind return period was 2000-years
- The conductor clearance to ground was increased from 9.0metres as specified in AS/NZS 7000:2016 to 11.0metres. This was stated to be due to electric field considerations.

Having received the market information, ElectraNet conducted an in-person workshop-based review of the received costs in coordination with relevant state operators for each of the proposed line options (Powerlink in the Queensland case). This review was used to evaluate the received pricing and validate proposed amendments which enabled a standardisation of pricing necessary to determine a comparable $/km rate for each vendor.

Jacobs has reviewed the contractor submissions and the various amendments alongside the corresponding information provided. From this, evaluations of the amendments have highlighted a number of changes that should be made to provide more accurate comparisons. To enable a more standardised comparison Jacobs has created revised amendments using input from relevant design experts. It should be noted that these amendments are limited in scope by the information provided by ElectraNet and the contractor submissions.

Each contractor price has been analysed and amended as follows (details of the Powerlink pricing have not been provided and so no amendments have been made):

4.1 Vendor 1

Description	Commentary
Submission price	$ 749,049/km
ElectraNet amended price	$ 695,000/km
Jacobs amended price	$ 749,049/km
Basis of estimate	ElectraNet Line Parameters, Excel spreadsheet
Scope coverage	The estimate includes for the design, material supply and construction of a 1,420km long, 400kV HVDC transmission line between SA and QLD.
Market coverage	SA & QLD (via NSW)
Structure types	Stated to be single circuit (bridge towers) / steel lattice tower

[2] Jacobs is aware of the identities of the Vendors approached by ElectraNet but, at ElectraNet's request, has redacted their names in this report

Description	Commentary
Findings	Vendor one has supplied a straight-forward high-level pricing of the option which includes relevant assumptions around structure spacing and design inputs. The noted material supply clearly covers key components of line transmission, including the combination of towers used. The construction section of the estimate is similarly methodical and appears to adequately price and consider the key elements of the proposed line. Allowance for design work has also been included, though it is not stated what this specifically allows for. Jacobs has reviewed the suspension tower weight of 18 tonne and considers this is appropriate for a 400-year, not 2000-year wind return period (although Vendor one has stated 2000-years in its response). See also discussion in **Section 4.6**. Vendor one also stated the line has a single circuit bridge tower configuration. ElectraNet made a single amendment to this price, changing the noted space between structures from 400m to 440m. The basis for this change in spacing has not been provided and Jacobs note that a simple alteration of this parameter in the estimate does not account for other design considerations. Specifically, increasing the tower spacing will require taller towers to maintain acceptable height of the wires which increases the mass of the towers. Therefore, Jacobs has maintained the 400m spacing and made no amendments to the price. A possible amendment is the addition of a 2000-year parameter for the QLD proportion of the line, which is explored in **Section 4.6** of this report.

4.2 Vendor 2

Description	Commentary
Submission	$ 628,826/km (without electrical material procurement)
ElectraNet amended price	$ 763,000/km
Jacobs amended price	$ 749,106/km
Basis of estimate	ElectraNet Line Parameters, Cost Plan Cover Letter
Scope coverage	The Vendor two estimate pricing includes for the construction and logistics of a 1,420km 400kV HVDC transmission line between SA and QLD, including a 7% wet weather allowance and a 5% risk allowance. While substructure and tower materials are included, line electrical materials have been specifically excluded. It is not stated whether design costs were similarly excluded.
Market coverage	SA & QLD (via NSW)
Structure types	Not stated
Findings	Vendor two has supplied a somewhat opaque high-level pricing of the option which states assumptions regarding constructability but limited information around structure spacing and design considerations. The noted material supply exclusion clearly omits key components of line transmission and the combination of towers used is not stated.

Description	Commentary
	Because of the noted exclusions ElectraNet has made significant amendments to this price. The 5% risk allowance has been removed and an allowance for access tracks has been added alongside a materials build-up for the excluded line materials. The ElectraNet estimated cost of the adjustment for materials is $113k per km, which is substantially higher than similar pricing itemised by Vendor one ($51k per km) and Vendor three ($30k per km). There does not appear to have been an adjustment for design work. Given the opacity of Vendor two's submission Jacobs has not been able to establish consideration of many design inputs (e.g. wind loads, tower types etc.) and has therefore assumed this is in keeping with other submissions. ElectraNet's pricing for the omitted materials has been maintained in Jacobs amended price based on its relatively conservative assumptions and clear build-up. In contrast, the wet weather and risk allowances have not been removed given they are likely to be underpinned by the contractor's real-world experience and represent a material cost to the project. Jacobs has also assumed the contractor's price already includes an allowance for access tracks given the submissions commentary around constructability considerations. Finally, an allowance for design work has been added based on the percentages used in other submissions (1%). Jacobs notes that a reduction of circa $70k per km could be made if a materials allowance similar to the Vendor one / Vendor three estimates was assumed.

4.3 Vendor 3

Description	Commentary
Submission	$ 1,016,436/km
ElectraNet amended price	$ 832,000/km
Jacobs amended price	$ 767,878/km
Basis of estimate	SA & QLD ElectraNet Line Parameters, SA Energy Transformation Report, 3rd Interconnect Transmission Line – Option 1. Report plus Excel spreadsheet
Scope coverage	The Vendor three estimate pricing includes for the design, material supply and construction of a 1,467km 400kV HVDC transmission line between SA and QLD, including a 30-day wet weather allowance and nominal risk allowances.
Market coverage	SA & QLD (via NSW)
Structure types	37% suspension structures (self-supporting); 57% Chainette; 8% tension
Findings	Vendor three has supplied a highly detailed pricing of the option which categorizes components on a state by state basis and includes a clear identification of the basis of estimate. The estimate sets out a comprehensive construction methodology which includes material supply, the combination of towers and design allowances. Submission documentation clearly itemises a 2000-year wind load design [3]requirement for the length of the line and excludes the cost of establishment and supply of concrete batching plants. It is noted that the suspension tower weight is 22 tonne which Jacobs considers appropriate for this wind return period. Based on the received information and correspondence it appears Vendor three's submission has been reviewed by ElectraNet in more detail and consultation than the other contractor submissions. At an initial stage an error of tower duplication was discovered in section B of the estimate which, with Vendor three's endorsement, was corrected, reducing the submission by $59,675 per km. Beyond this, the key adjustment made by ElectraNet is a change in the spacing of the towers from 426m to 550m. This can be contrasted with the ElectraNet assumption of 440m for its Vendor one adjustment and similarly does not make consideration of design impacts. Wet weather and risk allowances have been retained and there does not appear to have been an adjustment for the omitted concrete batching plant. Considering the noted tower design consequences when changing tower spacing, Jacobs has opted to maintain the 426m spacing. A review of the tower pricing highlighted an apparent discrepancy in the Chainette towers erection cost, which appears to be disproportionally more expensive than the other tower types despite a lower weight and an anticipated straight forward construction methodology. Jacobs has used the erection costs for the other tower types to establish a ratio of supply to erection cost and applied this ratio to the Chainette structures, giving a unit reduction of $130,671 to the Chainette erection costs. Jacobs notes that this assumption may be conservative as Chainette structures are considered by others to be quicker and simpler to erect.

[3] Elsewhere in the Vendor three submission for the three lines there is mention of a 100-year return period for all of the lines. Jacobs considers this is a typographical error.

Description	Commentary
	Jacobs also observed that no Chainette towers were included in the QLD component of the line estimate (presumably due to concerns around wind-loading). This design decision has not been substantiated by the Jacobs design review and the mix between suspension and Chainette towers has been revised to 80% Chainette and 20% suspension. An allowance for concrete batching plants has also been added, while wet weather and risk allowances were maintained. A possible further amendment is a reduction of the 2000-year parameter for the SA and NSW portion of the line, which is explored in **Section 2.3** of this report.

4.4 Summary of vendor prices

The three vendors submitted prices and the base case variances applied by ElectraNet and by Jacobs are summarised below.

Table 2: SA-QLD Summary Price

Vendor	Submitted price $/km	ElectraNet amended price $/km	Variance from submitted to amended value	Jacobs amended price $/km	Variance from submitted to amended value
Vendor 1 - Vendor one	749,047	695,000	-7%	749,047	0%
Vendor 2 – Vendor two *(Refer note below)*	628,826	763,000	21%	749,106	19%
Vendor 3 - Vendor three	1,016,436	832,000	-18%	767,878	-24%

Note: It should be noted that the high variance for the Vendor two price is due to this vendor explicitly stating that some line components were considered as 'free issue'

Jacobs notes that the amendments it considers appropriate have brought the three vendor prices to a similar level but that the price provided by Powerlink of $550,000/km is significantly lower. Limited details to support this price has been sighted in an email in which it was stated that around 1100 km was considered to be guyed tower and 330km self-supporting structures.

4.5 Review of PERT analysis

Fundamentally a PERT analysis is a statistical tool that is based on a beta distribution and utilises a weighted average incorporating the optimistic, pessimistic and most likely values. This analysis technique is typically used in a scheduling context and allows the evaluations of dependencies with the application of selective judgement of the likelihood of input values.

ElectraNet opted to adapt the traditional PERT analysis and use it on the vendor's quotations and pricing provided by Powerlink. The selection of this method has been driven by the number of estimate data points available and limited comparability of estimate details.

Contrasting the traditional PERT analysis where three values (best case, most likely and worst case) are inputted in the formula, in this report we have cases where four, five and six prices input were available. To accommodate more than three values in a PERT analysis, ElectraNet redistributed the weights among the inputs. Jacobs considers it is a reasonable approach, however, Jacobs notes that the term 'PERT analysis' is not the correct terminology for the analysis done by ElectraNet. For clarity, this report will use the term 'adjusted PERT' to refer to the methodology adopted by ElectraNet (and also by Jacobs as shown below) which derives from the PERT analysis.

The adjusted PERT analysis used by ElectraNet for the 400kV HVDC Transmission Line Costs incorporates the amended pricing and is shown below alongside the Jacobs amended pricing:

Table 3: ElectraNet adjusted PERT Analysis HVDC Option

Vendor	ElectraNet amended price $/km	Jacobs amended price $/km	Weighting	Designation
Powerlink	550,000	550,000	1	Optimistic
Vendor 1 - Vendor one	695,000	749,000	2	Most likely
Vendor 2 – Vendor two	763,000	749,000	2	Most likely
Vendor 3 - Vendor three	832,000	768,000	1	Pessimistic
Adjusted PERT Value	**716,000**	**719,000**		

The adjusted PERT analysis used by ElectraNet considers the Vendor one and Vendor two pricing to be as likely as each other (given a weighting of 2) while the Vendor three pricing is designated to be the most pessimistic and least likely (along with Powerlink, both with a weighting of 1). The distribution of values used is a simple low-to-high range that makes limited qualitative judgement of the amended pricing.

Fundamentally, this means the detailed and transparent pricing provided by Vendor three is considered of less weight than more high-level submission provided by Vendor one and the opaque Vendor two submission. Also, using Jacobs' amended prices the Vendor three price is very similar to that for the other two vendors and so could be considered a third 'most likely' price.

Given the detail, transparency and accessibility of the Vendor one and Vendor three prices Jacobs considers these should be assigned a higher likelihood of accuracy (and hence weighting) than the price from Vendor two. Additionally, given the insufficient detail in the Powerlink pricing, and its status as an outlier in the range of values, it is appropriate to consider this a 'least likely' scenario. Jacobs made further modifications on the ElectraNet adjusted PERT that reflects these qualitative judgements is shown below:

Table 4: Jacobs Adjusted PERT Analysis for SA-QLD HVDC Option

Vendor	ElectraNet amended price $/km	Jacobs amended price $/km	Weighting	Designation
Powerlink	550,000	550,000	1	Optimistic
Vendor 1 - Vendor one	695,000	749,000	3	Most likely
Vendor 2 – Vendor two	763,000	749,000	2	Likely
Vendor 3 - Vendor three	832,000	768,000	3	Most likely
Adjusted PERT Value	**794,000**	**733,000**		

4.6 Assessment of the likely cost impact of the 2,000-years wind return period compared with a 400-year period

Jacobs has carried out an assessment of the impact of a higher wind loading on the tower weight by estimating the base width and structure weight as a function of bending moment at ground line. The bending moment was assessed from the wind speed corresponding to the wind return period. Based on this, Jacobs concludes that the weight of structures designed for a wind return period 400-years can be 20% lighter than those designed for a 2000-year return period.

Please refer to **Appendix 1** for the detailed calculation.

Assuming a $2500 per ton of fabricated steel rate (sourced from a recent international tower supply contract) the cost of suspension tower proposed by each vendor are as follows:

Table 5: Assessment of Tower Weight

Vendor	Cost of suspension tower	Tower weight (tonne)
Vendor 1 - Vendor one	$45,000	18.00
Vendor 2 – Vendor two	N/A	N/A
Vendor 3 - Vendor three	$59,384	23.75

Based on Jacobs' experience of 400kV tower designs, it appears that the Vendor one submission may well have assumed a 400-year wind return period (typical wind speed 44m/s) while Vendor three has used a 2000-year wind return period. There is insufficient information to determine the loadings used by Powerlink and Vendor two and so Jacobs has assumed that they have adopted the 2000-year period given in the functional specification. Jacobs' experience is that tower weight has an approximately 60% contribution to the overall cost of transmission line construction. Therefore, the 20% difference in tower weight for the two return periods will change the overall line cost by 12%.

Jacobs has considered two scenarios for the impact of wind return period changes based on its understanding that the 2000-year return period was imposed by Powerlink.

- Scenario 1 assumes that the Powerlink criterion will apply for the section of the line that is in Queensland, with a 400-year criterion for the sections in NSW and South Australia
- Scenario 2 assumes that Powerlink agrees to a 400-year return period in line with the other TNSPs and so the whole line has a 400-year return period.

These scenarios are shown below for Jacobs amended costs and the adjusted PERT weightings. Note that the Vendor one cost increases in Scenario 1, while the other Vendors and Powerlink costs decrease.

Table 6: Adjusted PERT for SA-QLD HVDC Option with WRP 2000-years only for QLD Part (Scenario 1)

Vendor	Jacobs amended cost $/km	Jacobs amended cost adjusted as scenario 1 $/km	Weighting	Designation
Powerlink	550,000	514,360	1	Optimistic
Vendor 1 - Vendor one	749,000	790,345	3	Most likely
Vendor 2 – Vendor two	749,000	700,465	2	Likely
Vendor 3 - Vendor three	768,000	718,234	3	Most likely
Adjusted PERT Value	**733,000**	**715,669**		

For Scenario 2 the Vendor one price is unchanged while the other prices decrease to a greater extent than in Scenario1.

Table 7: Adjusted PERT for SA-QLD HVDC Option with WRP 400-years (Scenario 2)

Vendor	Jacobs amended cost $/km	Jacobs amended cost adjusted as scenario 2 $/km	Weighting	Designation
Powerlink	550,000	484,000	1	Optimistic
Vendor 1 - Vendor one	749,000	749,000	3	Most likely
Vendor 2 – Vendor two	749,000	659,120	2	Likely
Vendor 3 - Vendor three	768,000	675,840	3	Most likely
Adjusted PERT Value	**733,000**	**675,196**		

4.7 Assessment of the impact of the reduction of 2m of tower height.

Jacobs has carried out an assessment by estimating the base width and structure weight as a function of bending moment at ground line. The bending moment comparison was based on typical tower heights of 60m and 62m. Based on this, a 5% reduction in tower weight is estimated to be gained from a 2m reduction in tower height.

Please refer to **Appendix 2** for the detailed calculation.

Using the ratio of mass change to price change given in **Section 4.6**, the reduction of tower height, and corresponding weight, is anticipated to achieve a cost saving of 3%. It is assumed that all vendors and Powerlink have submitted pricing that accounts for the additional height requirement and as a result this saving has been applied universally. The revised PERT analysis below incorporates this adjustment.

Table 8: Adjusted PERT for SA-QLD HVDC Option with the Impact of 2m Reduction in Tower Height

Vendor	Jacobs amended price $/km	Jacobs amended price adjusted for tower height $/km	Weighting	Designation
Powerlink	550,000	533,500	1	Optimistic
Vendor 1 - Vendor one	749,000	726,530	3	Most likely
Vendor 2 – Vendor two	749,000	726,530	2	Likely
Vendor 3 - Vendor three	768,000	744,960	3	Most likely
Adjusted PERT Value	**733,000**	**720,926**		

4.8 Assessment of costs for a 400-year return period and a reduction of 2m in tower height

This assessment is made to provide a more direct comparison with the costs of the lines to NSW and Victoria.

Table 9: Impact of 400-year Wind Return Period and 2m Reduction in Tower Height

Vendor	Jacobs amended price $/km	Jacobs amended price adjusted for 400-year return & tower height $/km	Weighting	Designation
Powerlink	550,000	469,480	1	Optimistic
Vendor 1 - Vendor one	749,000	726,530	3	Most likely
Vendor 2 – Vendor two	749,000	639,346	2	Likely
Vendor 3 - Vendor three	768,000	655,565	3	Most likely
Adjusted PERT Value	**733,000**	**654,940**		

4.9 Assessment of costs for a 400-year return period outside Queensland and a reduction of 2m in tower height

This assessment is made for completeness, assuming scenario 1 given in **Section 4.6**: the Powerlink 2000 year wind return period will apply for the section of the line that is in Queensland, with a 400-year criterion for the sections in NSW and South Australia.

Table 10: Impact of Hybrid 2000/400 Year Wind Return Periods and 2m Reduction in Tower Height

Vendor	Jacobs amended price $/km	Jacobs amended price adjusted for hybrid 2000/400year returns & tower height $/km	Weighting	Designation
Powerlink	550,000	498,929	1	Optimistic
Vendor 1 - Vendor one	749,000	766,634	3	Most likely
Vendor 2 – Vendor two	749,000	679,451	2	Likely
Vendor 3 - Vendor three	768,000	696,687	3	Most likely
Adjusted PERT Value	**733,000**	**694,199**		

Jacobs notes that this combination of scenario 1 and a 2m reduction in tower height has a smaller impact on the modified PERT value but considers a hybrid criterion for wind return period along a single transmission line is unlikely to be adopted. This is because the more stringent criterion is partially negated by the less stringent criterion for more than 50% of the line length and so the reduction in probability of failure may not lead to a cost effective economic outcome.

4.10 Comparison of maintenance costs for self-supporting and Chainette structures

Due to the absence of Chainette towers in Australia Jacobs has not been able to make a direct comparison of maintenance costs but notes that the maintenance approach adopted will have an impact on the cost. Jacobs considers that a reliability centred maintenance (RCM) approach has the potential to lead to a reduced maintenance cost for Chainette towers compared to self-supporting towers (see also **Section 9.4.1)**. The reasons are stated below:

- Due to the flexibility of the cross-rope assembly, the structure is practically insensitive to foundation movements (equal or unequal), creep in guys or slipping of anchors; [1]
- Eskom reported its lowest fault rates in lines with Chainette towers; [2]
- Bird pollution flashover can be eliminated completely [3].

The Eskom fault rates are illustrated in the figure below.

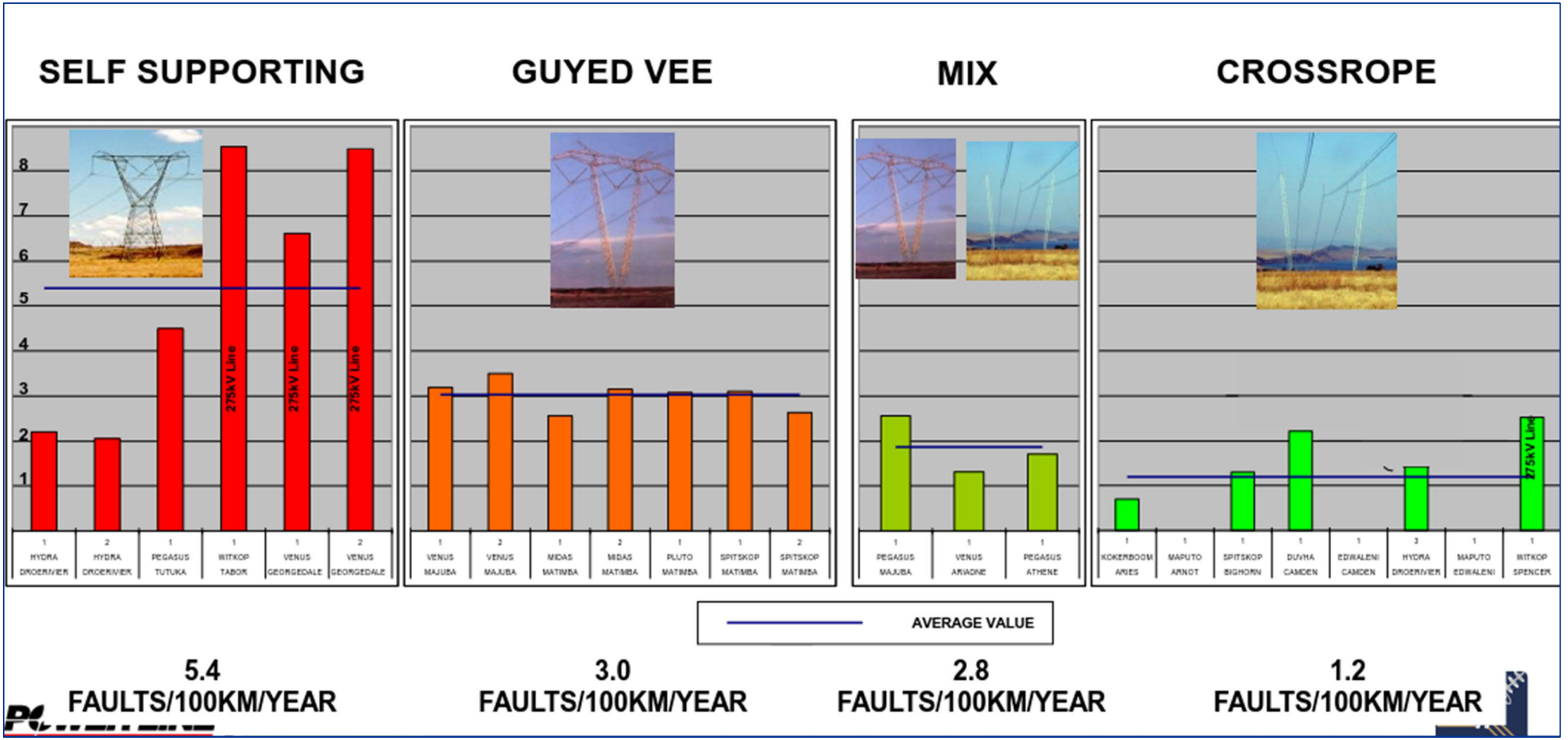


Figure 1: Lower Fault Rate with Chainette Towers

5. Task 2: Independent review of SA-NSW 330kV HVAC line costs in the PADR

While Jacobs' analysis has examined the costs of the SA-QLD 400kV HVDC in detail it is also important to consider this on a relative basis, particularly against the SA-NSW 330kV AC line option. ElectraNet's approach to pricing this option is similar to that for the HVDC line, with pricing obtained from five contractors and TransGrid the TNSP.

The received pricing was adjusted as deemed appropriate and consolidated using a PERT analysis. During the collation of these estimates, the submission provided by Vendor four was highlighted by ElectraNet as having inconsistencies in their substantially higher line pricing, particularly the costing of structures. Upon review against the other submissions, this price was discarded from consideration and PERT analysis. Vendor one also provided a relevant cost for the SA-NSW line which ElectraNet explained was inadvertently excluded.

To enable an equitable comparison to the pricing presented in **Section 4**, Jacobs has conducted an additional analysis and amendment exercise on the pricing provided by all five of the vendors for the SA-NSW line option. It should be noted that TransGrid submitted a price of $1,230,000/km which was reduced to $1,080,000 by ElectraNet to exclude the internal cost of project delivery and align with the pricing provided by other vendors..

5.1 Vendor 1

Description	Commentary
Submission price	$ 1,052,762/km (average $/km of 2 very similar price options provided)
ElectraNet amended price	N/A
Jacobs amended price	$ 1,052,762/km
Basis of estimate	ElectraNet Line Parameters, Excel spreadsheet
Scope coverage	The estimate includes for the design, material supply and construction of a 330kV AC transmission line.
Market coverage	SA & NSW
Structure types	Stated to be double circuit (D/CCT towers) / steel lattice tower
Findings	Vendor one has supplied a straight-forward high-level pricing of the option which includes relevant assumptions around line capacity and design inputs. The noted considerations of the estimate cover key components of line transmission, including the towers used, line length (700km) and line configuration. The stated wind return period is 400 years. ElectraNet inadvertently excluded this pricing from its considerations and agrees that it should have been included. Jacobs has maintained the submitted pricing without amendment.

5.2 Vendor 2

Description	Commentary
Submission	$ 752,039/km (excluding line electrical materials)
ElectraNet amended price	$ 1,051,000/km

Description	Commentary
Jacobs amended price	$ 968,333/km
Basis of estimate	ElectraNet Line Parameters, Cost Plan Cover Letter. As for the QLD option some key components were assumed to be free issue.
Scope coverage	The Vendor two estimate pricing includes for the construction and logistics of 330kV HVDC transmission line between SA and QLD, including a 7% wet weather allowance and a 5% risk allowance. While substructure and tower materials are included, line materials have been specifically excluded. It is not stated whether design costs were similarly excluded.
Market coverage	SA & NSW
Structure types	Not stated
Findings	Vendor two has supplied a somewhat opaque high-level pricing of the option which states assumptions regarding constructability but limited information around structure spacing and design considerations. The noted material supply exclusion clearly omits key components of line transmission and the combination of towers used is not stated. Because of the noted exclusions ElectraNet has made significant amendments to this price. The 5% risk allowance has been removed and an allowance for access tracks has been added alongside a materials build-up for the excluded line materials. The ElectraNet estimated cost of the adjustment for materials is $113k per km, which is substantially higher than similar pricing itemised by Vendor one ($51k per km) and Vendor three ($30k per km). There does not appear to have been an adjustment for design work. ElectraNet's pricing for the omitted materials has been maintained based on its relatively conservative assumptions and clear build-up. In contrast, the wet weather and risk allowances have not been removed given they are likely to be underpinned by the contractor's real-world experience and represent a material cost to the project. Jacobs has also assumed the contractor's price already includes an allowance for access tracks given the submissions commentary around constructability considerations. Finally, an allowance for design work has been added based on the percentages used in other submissions (1%). Jacobs notes that a reduction of circa $70k per km could be made if a materials allowance similar to the Vendor one / Vendor three estimates was assumed.

5.3 Vendor 3

Description	Commentary
Submission	$ 1,113,636/km
ElectraNet amended price	$ 1,113,000/km
Jacobs amended price	$ 1,122,858/km
Basis of estimate	ElectraNet Line Parameters, SA Energy Transformation Report, 3rd Interconnect Transmission Line – Option 2. Report plus Excel spreadsheet
Scope coverage	The Vendor three estimate pricing includes for the design, material supply and construction of a 330kV AC transmission line between SA and NSW, including a 30day wet weather allowance and nominal risk allowances.
Market coverage	SA & NSW
Structure types	91% suspension structures (self-supporting); 9% tension
Findings	Vendor three has supplied a highly detailed pricing of the option which categorizes components on a state by state basis and includes a clear identification of the basis of estimate. The estimate sets out a comprehensive construction methodology which includes material supply, the combination of towers and design allowances. Submission documentation states a wind zone consideration of “II and III”, a line length of 698km and excludes the cost of establishment and supply of concrete batching plants. In contrast to Vendor three’s submission for a SA-QLD interconnector, ElectraNet appears to have made no tangible amendments to the pricing of the SA-NSW interconnector. Wet weather and risk allowances have been retained and there does not appear to have been an adjustment for the omitted concrete batching plant. Jacobs has noted a small error in the calculations of foundations portion of the ‘Section B’ which, when corrected, reduces the estimate by $145k. An allowance for concrete batching plants has also been added, while wet weather and risk allowances were maintained.

5.4 Vendor 4

Description	Commentary
Submission	$ 1,836,458/km
ElectraNet amended price	N/A
Jacobs amended price	$ 1,209,142/km
Basis of estimate	ElectraNet Line Parameters, EC14171 Interconnector NSW Option Estimate plus Excel spreadsheet
Scope coverage	The Vendor four estimate includes for the design, material supply and construction of a 330kV AC transmission line between SA and NSW in an alternative route to the other submissions.

Description	Commentary
Market coverage	SA & NSW
Structure types	91% suspension structures (self-supporting); 9% angle structures
Findings	Vendor four has supplied a straight-forward high-level pricing of the option which includes information around, assumptions, line capacity and design inputs. The noted considerations of the estimate cover key components of line transmission, including the towers used, line length (300km for the SA component of the line) and line configuration. ElectraNet have reviewed Vendor four's submission and highlighted several inconsistencies within the provided pricing, particularly the tower spacing which appears to be 319m. In addition to this, the individual tower costs were noted to be unexpectedly high and the cost of the 'survey and design' equates to roughly 1% of the entire line cost, which was deemed to be unlikely in the context of transmission line construction. These concerns, and the availability other costings considered to be of more reliability, drove ElectraNet to exclude this pricing from further consideration. Jacobs broadly supports the concerns raised by ElectraNet in relation to the tower costs and spacings used by Vendor four and notes that these are the key drivers of the survey and design costs, which appear to be a derivative percentage. In consideration of the design constraints, and given the very high tower costs, the spacing has been amended from 319m to a more optimal 500m. On-costs such as mobilisations, overheads and design costs have been also adjusted on a percentage basis to match the revised costs calculated based on the larger spacings. Wet weather and risk allowances are assumed to be captured by these on-costs. Jacobs recognises that given these substantial changes a low weighting in the PERT analysis is appropriate for this line.

5.5 Vendor 5

Description	Commentary
Submission	$ 700,000 /km
ElectraNet amended price	$ 700,000 /km
Jacobs amended price	$ 808,500/km
Basis of estimate	ElectraNet Line Parameters, Email dated 22/08/17
Scope coverage	The Vendor five pricing includes for the material supply and construction of a 275kV AC transmission line between SA and NSW. Vendor five later clarified that the pricing was for a 330kV line.
Market coverage	SA & NSW
Structure types	Not stated

Description	Commentary
Findings	Vendor five has supplied an opaque high-level pricing of the option which provides limited information regarding assumptions and no information around structure spacing and design considerations. A wet weather allowance has not been included in the pricing. ElectraNet has supplied a small number of clarifications sought from the vendor around their pricing, which provide only limited additional insight. Given the opacity of Vendor five's submission, Jacobs has not been able to establish consideration of many design inputs (e.g. wind loads, tower types etc.). Considering the comparatively lower cost estimate provided by this Vendor when compared against others, Jacobs adjusted the price to cover for the noted exclusion of wet weather costs and potential differences in wind loads and tower types, allowing alignment with the other vendor quotes.

5.6 Summary of vendor prices

The five vendor submitted prices and the base case variances applied by ElectraNet and by Jacobs are summarised below. It should be noted that the high variance for the Vendor two price is due to this vendor explicitly stating that some line components were considered as 'free issue'. Conversely, Vendor four's price has been reduced significantly thanks to the increase in tower spacing, reducing the estimated number of tower by roughly 1/3.

Table 11: SA-NSW Summary Price

Vendor	Submitted price $/km	ElectraNet amended price $/km	Variance from submitted to amended value	Jacobs amended price $/km	Variance from submitted to amended value
Vendor 1	1,052,762	-	n/a	1,052,762	0%
Vendor 2	752,039	1,051,000	40%	968,333	29%
Vendor 3	1,113,636	1,113,000	0%	1,122,858	1%
Vendor 4	1,836,458	-	n/a	1,209,142	-34%
Vendor 5	700,000	700,000	0%	808,500	12%

5.7 Review of PERT analysis

As previously stated, ElectraNet incorporated the pricing of TransGrid as well as Vendor's two, three and five into their adjusted PERT model for the 330kV SA-NSW line. While it can be reasonably argued Vendor four's tower pricing is disproportionate (in the context of the available information) the underlying reason for this remains ambiguous. It is not known if Vendor four was contacted to provide a detailed breakdown of their tower pricing.

ElectraNet has advised it inadvertently excluded the Vendor 1 pricing from its considerations and agrees that it should have been included.

Resolving these questions would allow a more in-depth review of the costing information would also allow a more qualitatively weighted PERT analysis of pricing. Because of the limited number of data points used in an adjusted PERT analysis the inclusion or exclusion of significant outliers substantially changes the analysis outcome.

The adjusted PERT analysis used by ElectraNet is exemplary of this and the inclusion of Vendor four's estimate materially changes the cost per km of the line (see below).

Table 12: ElectraNet Adjusted PERT Values

Vendor	ElectraNet values $/km	ElectraNet weightings
TransGrid	1,080,000	2
Vendor 1	-	N/A
Vendor 2	1,051,000	2
Vendor 3	1,113,000	1
Vendor 4	-	N/A
Vendor 5	700,000	1
Adjusted PERT Value	**1,013,000**[4]	

Mirroring the analysis provided in **section 4.5**, Jacobs has generated a revised PERT of the TransGrid and five Vendors amended values which is shown below:

Table 13: Jacobs Adjusted PERT Analysis for 330kV SA-NSW Option

Vendor	ElectraNet amended price $/km	Jacobs amended price $/km	Weighting	Designation
TransGrid	1,080,000	1,080,000	2	Likely
Vendor 1	-	1,052,762	3	Most likely
Vendor 2	1,051,000	968,333	1	Optimistic
Vendor 3	1,113,000	1,122,858	3	Most likely
Vendor 4	-	1,209,142	1	Pessimistic
Vendor 5	700,000	808,500	1	Optimistic
Adjusted PERT Value	**1,035,714**	**1,061,167**		

[4] Note values are rounded

6. Task 3: Independent review on SA-VIC HVAC line cost in the PADR

Along with the review of the SA-QLD 400kV HVDC and SA-NSW 330kV AC options the SA-VIC 275kV AC line is also subject to a detailed review of the cost for the transmission line. ElectraNet's approach to pricing this option is like other options, with pricing obtained from three contractors and from AEMO (Australian Energy Market Operator):

The received pricing was adjusted as deemed appropriate and consolidated using a PERT analysis. Vendor one also provided a relevant cost for the SA-VIC line which ElectraNet explained was inadvertently excluded.

To enable an equitable comparison to the pricing presented in **Task 1 and Task 2**, Jacobs has conducted an analysis and amendment exercise on the pricing provided by all three of the vendors for the SA-VIC line option plus a fourth vendor that was not used in the ElectraNet analysis. It should be noted that AEMO submitted a price of $810,000/km which includes the switch bays. AEMO reference price for the transmission line (275kV double circuit, 610MVA) is $752.000/km.

6.1 Vendor 1

Description	Commentary
Submission price	$ 969,634/km
ElectraNet amended price	$710,000/km
Jacobs amended price	$ 969,634/km
Basis of estimate	ElectraNet Line Parameters, Excel spreadsheet
Scope coverage	The estimate includes for the design, material supply and construction of a 275kV AC transmission line.
Market coverage	SA & VIC
Structure types	Double circuit (D/CCT towers) / steel lattice tower
Findings	Vendor one has supplied a straight-forward high-level pricing of the option which includes relevant assumptions around line capacity and design inputs. The noted considerations of the estimate cover key components of line transmission, including the towers used, line length and line configuration. The stated wind return period is 400 years. Jacobs has maintained the submitted pricing without amendment.

6.2 Vendor 2

Description	Commentary
Submission	$ 667,240/km (excluding line electrical materials)
ElectraNet amended price	$ 1,000,000/km
Jacobs amended price	$ 882,686/km
Basis of estimate	ElectraNet Line Parameters, Cost Plan Cover Letter. Key components were assumed to be free issue.

Description	Commentary
Scope coverage	The Vendor two estimate pricing includes for the construction and logistics of 275kV HVDC transmission line between SA and VIC, including a 7% wet weather allowance and a 5% risk allowance. While substructure and tower materials are included, line materials have been specifically excluded. It is not stated whether design costs were similarly excluded.
Market coverage	SA & VIC
Structure types	Not stated
Findings	Vendor two has supplied a somewhat opaque high-level pricing of the option which states assumptions regarding constructability but limited information around structure spacing and design considerations. The noted material supply exclusion clearly omits key components of line transmission and the combination of towers used is not stated. Because of the noted exclusions ElectraNet has made significant amendments to this price. The 5% risk allowance has been removed and an allowance for access tracks has been added alongside a materials build-up for the excluded line materials. The ElectraNet estimated cost of the adjustment for materials is $113k per km, which is substantially higher than similar pricing itemised by Vendor one ($51k per km) and Vendor three ($30k per km). There does not appear to have been an adjustment for design work. ElectraNet's pricing for the omitted materials has been maintained based on its relatively conservative assumptions and clear build-up. In contrast, the wet weather and risk allowances have not been removed given they are likely to be underpinned by the contractor's real-world experience and represent a material cost to the project. Jacobs has also assumed the contractor's price already includes an allowance for access tracks given the submissions commentary around constructability considerations. Finally, a 1% allowance for design work has been added based on the percentages used in other submissions. Jacobs notes that a reduction of circa $70k per km could be made if a materials allowance similar to the Vendor one / Vendor three estimates was assumed.

6.3 Vendor 3

Description	Commentary
Submission	$ 1,312,920/km
ElectraNet amended price	$ 1,016,000/km
Jacobs amended price	$ 1,241,849/km
Basis of estimate	ElectraNet Line Parameters, SA Energy Transformation Report, 3rd Interconnect Transmission Line – Option 3.
Scope coverage	The Vendor three estimate pricing includes for the design, material supply and construction of a 275kV AC transmission line between SA and VIC.
Market coverage	SA & VIC
Structure types	100% suspension structures (self-supporting)
Findings	Vendor three has supplied a highly detailed pricing of the option which categorizes components on a state by state basis and includes a clear identification of the basis of estimate. The estimate sets out a comprehensive construction methodology which includes material supply, the combination of towers and design allowances. However, Jacobs considers the preliminaries cost for this line is disproportionally higher when compared with the SA-NSW line. Although the SA-NSW line is longer than the SA-VIC one, the preliminary costs were expected to be more proportional with the project cost. To address this difference, Jacobs made a reduction in the preliminaries costs for this Vendor (reduction of approximately $29,000,000) An allowance for concrete batching plants has also been added, while wet weather and risk allowances were maintained.

6.4 Vendor 4

Description	Commentary
Submission	$ 700,000 /km
ElectraNet amended price	$ 700,000 /km
Jacobs amended price	$ 700,000/km
Basis of estimate	ElectraNet Line Parameters, Email dated 22/08/17
Scope coverage	The Vendor four pricing includes for the material supply and construction of a 275kV AC transmission line between SA and VIC.
Market coverage	SA & VIC
Structure types	Not stated

Description	Commentary
Findings	Vendor four has supplied an opaque high-level pricing of the option which provides limited information regarding assumptions and no information around structure spacing and design considerations. A wet weather allowance has not been included in the pricing. ElectraNet has supplied a small number of clarifications sought from the vendor around their pricing, which provide only limited additional insight. Given the opacity of Vendor five's submission, Jacobs has not been able to establish consideration of many design inputs (e.g. wind loads, tower types etc.) and has therefore assumed this is in keeping with other submissions.

6.5 Summary of vendor prices

The vendors submitted prices and the base case variances applied by ElectraNet and by Jacobs are summarised below. It should be noted that the high variance for the Vendor two price is due to this vendor explicitly stating that some line components were considered as 'free issue'.

Table 14: SA-VIC Summary Price

Vendor	Submitted price $/km	ElectraNet amended price $/km	Variance from submitted to amended value	Jacobs amended price $/km	Variance from submitted to amended value
Vendor 1	969,634	710,000	-36.57%	969,634	0%
Vendor 2	667,240	1,000,000	33.28%	882,686	24%
Vendor 3	1,312,920	1,016,000	-12.92%	1,241,849	-5%
Vendor 4	700,000	700,000	N/A	700,000	N/A

6.6 Review of PERT analysis

ElectraNet incorporated the pricing of AEMO as well as Vendors one, two and three into their adjusted PERT model for the 275kV SA-VIC line. The adjusted PERT analysis used by ElectraNet is presented below.

Table 15: Comparison of PERT Values

Vendor	ElectraNet values $/km	ElectraNet weightings
AEMO (includes switch bays)	810.000	2
Vendor 1	710,000	1
Vendor 2	1,000,000	2
Vendor 3	1,016,000	1
Adjusted PERT Value		**891,000**

Mirroring the analysis provided in section 4.5, Jacobs has generated a revised PERT of the AEMO and three Vendor amended values which is shown below:

Table 16: Jacobs Adjusted PERT Analysis for 330kV SA-SA Option

Vendor	Jacobs amended price $/km	Weighting	Designation
AEMO (excludes switch bays)	752,000	2	Likely
Vendor 1	969,634	3	Most likely
Vendor 2	882,686	1	Optimistic
Vendor 3	1,241,849	3	Most likely
Vendor 4	700,000	1	Optimistic
Adjusted PERT Value	**963,984**		

7. Summary of the costs for each option

From the forgoing, Jacobs considers the most reasonable estimate for the HVDC line to Queensland to be that derived in **Section 4.8**, for the HVAC line to NSW given in weighting within **Section 5.7,** and for the HVAC line to VIC within **Section 6.6.**

Note it is not a comparison between the options because each line has different characteristics, locations and length which precludes a direct comparison between them.

Table 17: Comparison of Jacobs recommended cost estimates and ElectraNet PADR estimates

Line	ElectraNet adjusted cost $m/km	Jacobs adjusted PERT cost $m/km
Queensland 400 kV HVDC option	0.716	0.655
NSW 330 kV HVAC option	1.013	1.061
Victoria 275kV HVAC option	0.891	0.964

This table shows that ElectraNet has estimated the line to NSW to cost $297K/km more than the HVDC line to Queensland, while the Jacobs analysis shows a difference of $406K/km, an increase in differential of $109K/km.

However, it should be recognised that there are considerable uncertainties in these numbers and that's why it's standard practice to undertake sensitivity analysis on cost estimates as part of economic assessments.

It is important to note that the Table 17 above cannot be interpreted as a recommendation about the total cost for each option available in the Project Assessment Draft Report (PADR). Especially for the SA-QLD 400kV HVDC where a significant cost with the converter stations will impact the total project cost. The total capital cost estimate review is not part of this report.

The Vendor and TNSP costs are 2017-2018 financial year values and present costs may be different due to inflation and market changes. However, Jacobs expects the percentage changes in costs for the three lines should be similar.

8. Task 4: Response to relevant aspects of ARCMesh submission on the PADR

8.1 Comment on basis for the line design in the ARCMesh report

The ARCMesh approach is consistent with that specified by ElectraNet as noted in **Section 4** as a combination of:

- Self-supporting lattice towers
- Alternate Chainette structures for remote and non-agricultural land
- Alternate steel monopoles for environmentally sensitive locations

ARCMesh has proposed a combination of lattice / self-supported towers and guyed towers, with the proportion of guyed towers varying for the direct and indirect routes that it discusses. The philosophy for these differences appears reasonable.

8.2 Comment on the line construction cost for the Chainette option

The ARCMesh submission notes the per km transmission line cost with the Chainette structures 'should be approximately $520,000/km' and further describes this as a conservative estimation. It also suggests a price of $720,000/km for self-supported towers. Though ARCMesh has not provided the specifics of these prices, Jacobs notes that these values closely approximate to the $716,000/km P50 price and the Powerlink price of $550,000/km both given in the ElectraNet issued documents. ARCMesh's use of a combination of these prices leads to a lower overall price than estimated by ElectraNet.

ARCMesh also notes that 'it appears that the ElectraNet P50 value has been costed using predominantly self-supporting towers'. While this assumption may have been reasonable based on the evidence available to ARCMesh at the time of its submission, Jacobs has seen evidence that the pricing data used by ElectraNet has considered a combination of both tower types.

In particular, both the Vendor three and Powerlink prices are based on a preponderance of guyed towers and Vendor one proposed an (unspecified) combination of bridged and self-supporting towers (note that Powerlink and Vendor one did not provide a breakdown and that Vendor two did not comment on tower type).

Further, Jacobs has reassessed the Vendor three split between guyed and self-supporting towers and increased the fraction of guyed towers from 55% to 73%, with the fraction of self-supported towers reducing from 37% to 19% (the explanation for this change is given in **Section 4.3**). The remaining 8% of towers are tension structures. This revised split is similar to that assumed by ARCMesh.

The Vendor three pricing is detailed and allows prices for the three tower types to be determined. Also, as amended by Jacobs, it is considered to have a high weighting and so approximately half of the Jacobs weighted price for the HVDC line is for a predominately guyed line (sum of Powerlink and Vendor three options). Also, it should be noted that the Jacobs adjusted price for Vendor three shows the Chainette sections to have a significantly lower price than the free-standing tower sections:

- Vendor three Chainette adjusted price $700k/km
- Vendor three self-supported tower price $932k/km
- Vendor three tension tower price $1025k/km

While these prices are higher than those assumed by ARCMesh the differential from a self-supported tower is not dissimilar.

In summary, Jacobs considers that the ARCMesh view that Chainette construction costs are lower than self-supporting tower costs is consistent with the prices received from the Vendors approached by ElectraNet.

However as there are no Chainette towers presently in Australia there is some uncertainty regarding any impacts of complying with Australian Standards on designs used elsewhere. Chainette towers also have a larger footprint – see **Section 9.2** – and land acquisition costs should be considered – noting that their use is likely to be limited to regions where land costs are expected to be low, so this factor may not be significant.

9. Task 5: Providing independent view of the use of Chainette and guyed structure options

9.1 Introduction to Chainette structures

The Chainette structures were thoroughly investigated in Canada as an alternative to the guyed towers at extra high voltage line. The more the voltage level, the heavier the crossarm and the higher the crossarm elevation. The following table will give an idea-

Table 18: Crossarm weight and elevation at different voltage level

Voltage Level	Crossarm weight (tonne)	Elevation (m)
132kV	0.5	20
230kV	1.0	25
330kV	2.0	35
735kV	5.0	45

Installation of heavy crossarms on guyed structure is complex and some erection operations can be unsafe. Chainette structures were introduced to remove the crossarm from the line structures to get significant benefit in overall structure weight and structure installation effort.

9.2 Pros/cons and risk comparison between self-supporting structures and Chainette/guyed structures

The major benefit of Chainette structures are considered to be:

a) The Chainette structures are significantly lighter in weight compared to self-supporting towers under same duty [1].

   The table below showing the evolution of 735kV towers designed by Hydro Quebec illustrates this point-

Type of tower	Weight
Self-supporting tower (1965)	65 tonnes/km
Self-supporting tower (1974)	42 tonnes/km
Guyed V towers (1976)	31 tonnes/km
Chainette towers (1977)	19 tonnes/km

The typical design criteria for 765kV line in Canada considers a three-phase line each phase of which comprises 4 conductors of 35mm in diameter. The ground wires have a diameter of 13mm. Weights and wind spans are limited to 520m and the ratio of wind to weight span is limited to 1.2. The maximum ice load corresponds to an accumulation of 32mm in radial thickness. Design wind pressure is 0.8kPa on the cables and 1.8kPa on the masts.

An overall saving on cost is illustrated in the following figures. [2]

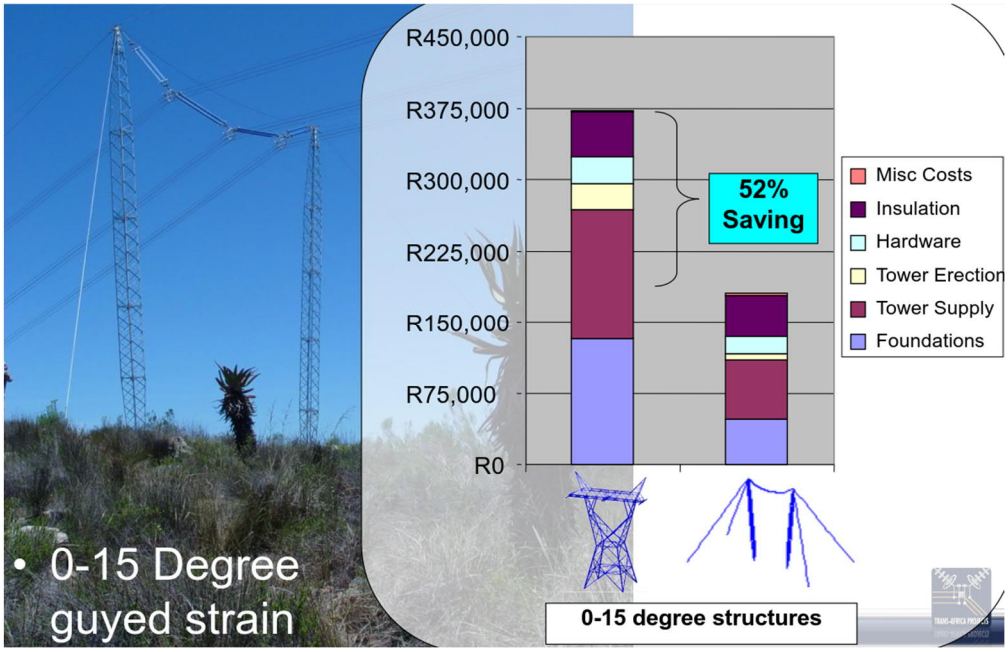


Figure 2 Cost Reduction Associated with Chainette Towers (Single Circuit DC Tower)

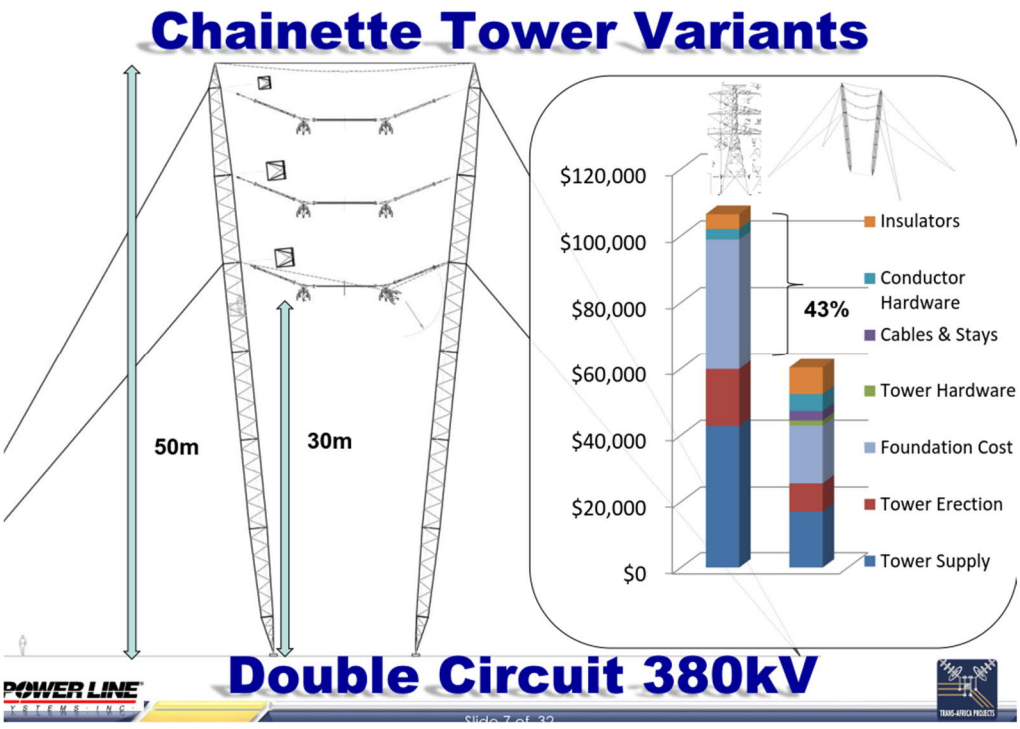


Figure 3: Cost Reduction Associated with Chainette Towers (Double Circuit AC Tower)

b) It provides compact phase spacing (electrically efficient), low fault rate and high level of lighting protection;

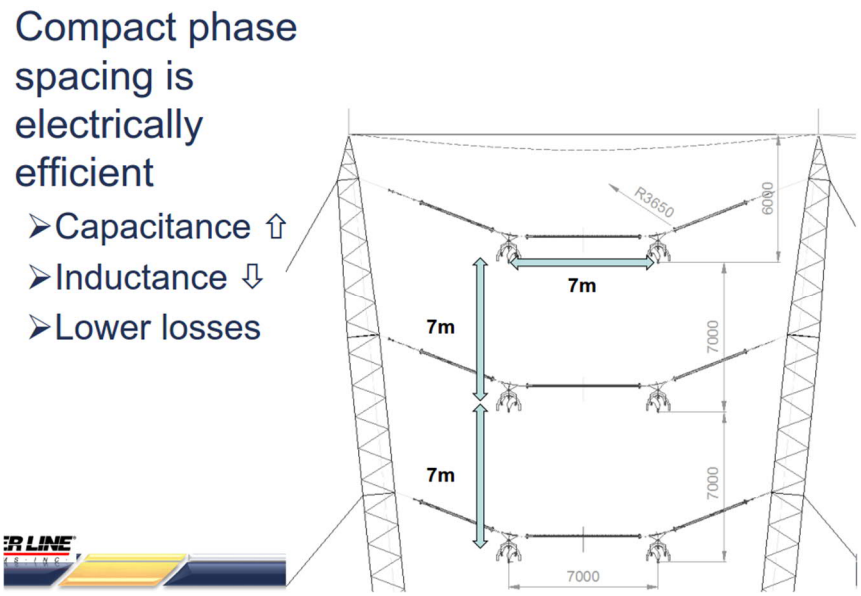


Figure 4: Compact Design of Chainette Towers

c) It allows faster installation (9 structures can be erected a day); [3]
d) Suitable for live line maintenance.

The main disadvantage is the foot print of Chainette towers. It occupies a large area at its base, will appear less attractive for inhabited regions. Also, Chainette will require larger clearing area of vegetation at the structure positions. The average foot print of a 60m tall Chainette tower can be 60m x 80m. [4]

9.3 Comments on cascade failure and mitigation

The Chainette towers provides anti-cascade benefit against single phase broken condition (zero impact on single phase broken condition). But this structure has two additional failure modes under security condition:

- Broken guy
- Cross-rope assembly breakage.

Under certain conditions critical cross-rope breakage and/ or broken guys can cause complete failure of several towers in a series and it is recommended to use stop structure at a regular interval.

The cost implication (with respect to conventional self-supporting structures) can be eliminated by optimising the frequency of stop structure as part of the following design and maintenance effort -

- Fast emergency response system (ERS) structure availability and
- Modular mast configuration design of Chainette structures to allow fast re-construction.

9.4 Using Chainette in Australia

9.4.1 Technical challenges

The Chainette structures have never been used in Australia. As stated in earlier clause, Chainette structures were introduced to reduce the impact of weight and elevation of crossarm. Up to 500kV level, the crossarm weight and height may not be significant enough to offer comparative benefit against conventional structure types.

Canada had carried out full scale testing, a 4km experimental line (constructed some 100 km north-east of Montreal) before it was used in long transmission lines. The site of the line comprising 11 towers of which 9 were Chainette towers, was selected so that topography and soils were representative of a variety of conditions.

The construction and safety methodology and practices as well as availability of the construction equipment in Australia are not similar to that of Canada. It may cause significant cost and schedule impact if the potential contractors are not exposed to build such structures. This is evident from the Chainette structure erection costs received from different vendors. One vendor has quoted significant high erection cost (3x times the procurement cost) and other vendors have quoted similar to that of the conventional towers.

The impact of maintenance with respect to Australian practice is also unknown. Chainette structures have lots of hardware fittings, a new major component type (cross-rope) and at least six stays per structure. All these components will require significant regular inspection and may increase the yearly maintenance cost significantly.

Chainette structures can be a good asset but it will not be prudent to introduce in a very long transmission line without a test line to identify any common mode difficulty during construction and maintenance. Because single common mode failure may lead to multiple and costly fixes on long transmission lines.

9.4.2 Community challenges

The footprint of Chainette structures are approximately 80m x 60m. We have used data available from the Australian Government Department of Agriculture and Water Resources to develop an understanding of land use patterns in South Australia, New South Wales and Queensland, particularly in relation to areas where the proposed Davenport (SA) to Bulli Creek (QLD) alignment intersects with the various land uses.

South Australia:

Within South Australia the predominant land-use intersected by the proposed 400 kV DC line is classified as ‘grazing native vegetation’, with the remainder of the area comprising small portions of cropping land, ‘grazing modified pastures’, and ‘nature conservation’ areas.

The ‘grazing native vegetation’ land use category describes land that has had relatively low levels of human intervention and which is used primarily for grazing by domestic stock. Conversely, the ‘grazing modified pastures’ class includes land that is used for pasture and forage production and where native vegetation has been largely replaced by introduced species. It should be noted that land under pasture (‘grazing modified pastures’) may be under rotation such that, in any given year, the same area may be used for cropping. Land under cropping is used for primary production of any range of crops, including cereals, hay, sugar and cotton.

The ‘nature conservation’ land use identified in South Australia predominately relates to ‘residual native cover’ where the land is mainly unused, or is being used for conservation of native vegetation, wildlife or resources.

New South Wales:

Where the alignment crosses into NSW, ‘grazing native vegetation’ is again the dominant land use class. ‘Nature conservation’ areas relating to residual native cover are also present. A ‘nature conservation’ area classified as ‘other conserved area’ is also in close proximity to the alignment, and includes heritage agreements, conservation arrangements and registered property agreements.

Queensland:

Dominant land uses intersected by the alignment in QLD include ‘grazing native vegetation’, ‘nature conservation’, ‘dryland cropping’, and ‘grazing modified pastures’. The nature conservation land use comprises land classified for ‘residual native cover’ and in some locations the alignment intersects land classified as ‘national park’ (a protected area for ecosystem conservation and recreation).

The dominant land uses within each state that will be intersected by the alignment are summarised in Table 19 below.

Table 19: Dominant Land Uses Intersected by the Alignment (From Most Prevalent Along the Proposed Alignment to Least Prevalent)

Land Use	States
Grazing native vegetation	SA, NSW, QLD
Grazing modified pastures	SA, QLD
Cropping	SA, QLD
Nature conservation *National park* *Other conserved area* *Residual native cover*	SA, NSW, QLD

The use of such wide based structures in the transmission alignment should consider interaction with various land use classes and potential impact to native vegetation and other conservation values.

Within the 'grazing native vegetation' land use class, clearance of native vegetation should be minimised so far as possible. It is probable that a reduced clearance footprint may be achieved by use of a Chainette structure. This structure has a greater extent than lattice structures, however as vegetation clearance is limited to the footings (i.e. it isn't necessary to clear an 80 m x 60 m pad at the base of the structure), impact to native vegetation may be reduced.

Chainette structures might also be utilised in areas classed as 'grazing modified pastures' – however, as mentioned previously, this land use may be under rotation and converted to cropping land in the future. Given the size of the structure, Chainette are not suitable for cropping land, where they may interfere with farm activities.

10. References

[1] Cigre TB 22-04 Validation of a Chainette Tower For a 735kV Line

[2] "Development of 3rd Generation 400kV Chainette Towers" presented in "2015 PLS-CADD Advanced Training & User Group Meeting"

[3] ELP_IRR_OEB_20130328 – EWT LP Responses to Ontario Energy Board Interrogatories

[4] CBIP Manual

Appendix A. Assessment of Wind Speed Impact on Weight

Tower weight comparison: 400 WRP vs 2000 WRP (wind return period)

Calculation parameters for 400 WRP

Region	A	
Terrain Category	2	
Line Reliability	4	
Return Period	400	
Top Conductor height	60	m
Earthwire height	60	m
Wind Speed	44	m/s
Typical Bending Moment of Suspension	5533.333	kn-m

Calculation parameters for 2000 WRP

Region	A	
Terrain Category	2	
Line Reliability	6	
Return Period	2000	
Top Conductor height	60	m
Earthwire height	60	m
Wind Speed	48	m/s
Typical Bending Moment of Suspension	6333.33	kn-m

Base width Assumption

(Ref- CBIP Manual)

$B = k\sqrt{M}$

B = Base width of tower at ground level in centimeters
M = Overturning moment, in kg-m
K = A constant

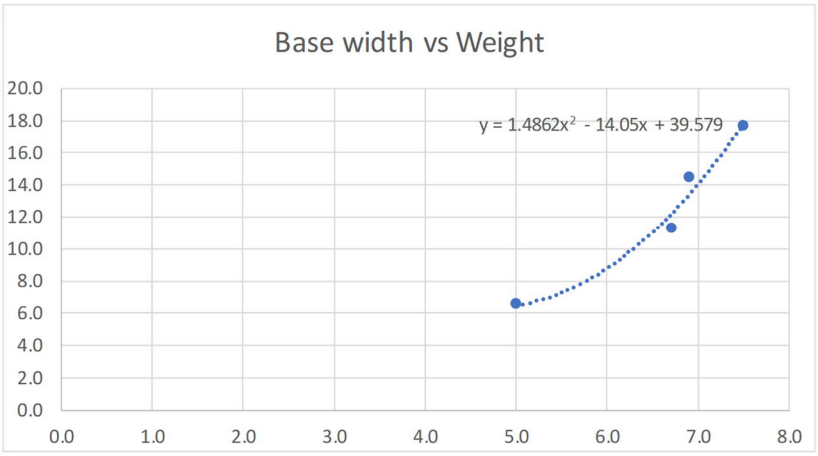
The value of K varies from 1.35 to 2.5 and 1.93 is an average value.

Base width (400 WRP)	**10.1 m**	**Basewidth (2000 WRP)**	**10.8 m**

Tower weight estimation - according to basewidth

TABLE 3.2
Base width top hamper width and height for typical 66/132/220/400 kV standard towers

Sl. No.	Type of Tower	Width at Concrete level (mm)	Width at Top Hamper (mm)	Width at top hamper/width at concrete level	Total height above ground level (mm)	Base width at concrete level: Total height above concrete level	Vertical spacing between conductors (mm)	Horizontal distance between conductors (mm)	Tower weight (kgs)
1	2	3	4	5	6	7	8	9	10
1	66 kV: Double Circuit								
	A (0—2°)	3,075	1,000	1:3.08	19,600	1:6.1	2,170	4,270	1,382
	B (2°—30°)	4,400	1,075	1:4.10	18,895	1:4.3	2,060	4,880	2,100
	C (30°—60°)	4,500	1,150	1:3.91	20,090	1:4.4	2,440	6,000	2,782
2.	66 kV: Single Circuit								
	A (0—2°)	1,675	760	1:2.20	15,910	1:9.5	1,030	4,040	1,064
	B (2°—30°)	2,590	915	1:2.80	15,425	1:6	1,030	4,270	1,283
	C (30°—60°)	3,050	1,220	1:2.50	16,240	1:5.3	1,220	4,880	1,783
3	132 kV:Double Circuit								
	A (0—2°)	4,050	1,250	1:3.24	26,230	1:6.4	3,965	7,020	3.10
	B (0—15°)	5,490	1,540	1:3.56	26,545	1:4.83	3,965	7,320	3.97
	C (15°—30°)	4,880	1,665	1:2.87	26,545	1:5.44	3,965	7,320	4.60
	D (30°—60°/D.E.)	6,400	1,840	1:3.47	28,060	1:4.38	4,270	8,540	6.00
4.	132 kV: Single Circuit								
	A (0—2°)	3,920	1,300	1:3.0	23,140	1:6	4,200	7,140	2.17
	B (0—15°)	4,224	1,400	1:3.0	22,060	1:5.2	4,200	6,290	2.89
	C (15°—30°)	4,828	1,600	1:3.0	22,685	1:4.7	4,200	7,150	3.74
	D (30°—60°/D.E.)	6,135	2,000	1:3.0	24,060	1:4	4,200	8,820	4.82
5.	220 kV:Double Circuit								
	A " "	7,000	2,260	1:3.09	31,650	1:4.52	5,200	9,900	4.15
	B " "	8,900	2,500	1:3.56	31,300	1:3.52	5,200	10,100	6.04
	C " "	10,344	3,000	1:3.45	29,900	1:2.90	5,200	9,700	8.69
6.	220 kV Single Circuit								
	A " "	4,500	1,500	1:3.0	28,555	1:6.3	5,200	8,500	2.57
	B " "	5,300	1,700	1:3.12	29,080	1:5.48	5,250	10,500	3.60
	C " "	7,000	2,000	1:3.50	31,680	1:4.52	6,700	12,600	5.04
7.	220 kV: Single Circuit Horizontal Configuration								
	A " "	4,000	2,640	1:1.5	18,050	1:4.51	—	7,400	
	B " "	4,800	3,300	1:1.5	18,600	1:3.9	—	8,800	
	C " "	5,800	3,600	1:1.61	20,200	1:3.5	—	8,800	
8.	400 kV: Single Circuit								
	A (0—2°)	5,000	2,000	1:2.5	34,100	1:6.82	7,800	12,760	6.517
	B (2°—15°)	6,700	2,000	1:3.35	33,100	1:4.94	7,800	12,640	11.261
	C (15°—30°)	6,900	2,200	1:3.13	33,010	1:4.78	7,800	14,000	14.473
	D (30°—60°/D.E.)	7,500	2,400	1:3.12	33,410	1:4.45	8,100	16,200	17.603
9.	± 500 kVDC								
	A+0 (Susp.)	10,000	2,200	0.220	35,900	0.2803	---	12,800	---
	B+0 (Susp.)	10,000	2,600	0.260	35,400	0.2843	---	13,300	---
	B+0 (Tension)	10,000	2,600	0.260	35,750	0.2815	---	15,400	---
	C+0 (Tension)	11,400	3,000	0.2632	35,925	0.3193	---	14,300	---
	D+0 (Tension)	11,400	3,000	0.2632	35,875	0.3198		18,700	---



X	Y
Base Width	Weight
5.0	6.5
6.7	11.3
6.9	14.5
7.5	17.6
10.1	**49.9**
10.8	**62.1**

Weight for 400 WRP (A):	**49.9 Ton**	**Weight for 2000 WRP (B):**	**62.1 Ton**

Weight difference (B-A) - per tower 12.1 Ton

Approximate reduction in weight if 400 WRP is selected (instead of 2000 WRP)	**20%**

Appendix B. Assessment of Height Impact on Weight

Tower weight comparison: 60m high vs 62m high

Calculation parameters for 60m

Region	A	
Terrain Category	2	
Line Reliability	4	
Return Period	400	
Top Conductor height	60	m
Earthwire height	60	m
Wind Speed	44	m/s
Typical Bending Moment of Suspension	5533.33	kn-m

Calculation parameters for 62m

Region	A	
Terrain Category	2	
Line Reliability	6	
Return Period	400	
Top Conductor height	62	m
Earthwire height	62	m
Wind Speed	44	m/s
Typical Bending Moment of Suspension	5717.78	kn-m

Base width Assumption

(Ref- CBIP Manual)

$B = k\sqrt{M}$

B = Base width of tower at ground level in centimeters

M = Overturning moment, in kg-m

K = A constant

The value of K varies from 1.35 to 2.5 and 1.93 is an average value.

Estimated base width (for a 60m tower)	**10.1 m**	**Estimated base width (for a 62m tower)**	**10.3 m**

Base Width	Weight
5.0	6.5
6.7	11.3
6.9	14.5
7.5	17.6
10.1	49.9
10.3	52.7

(see Appendix 1 for reference about this table)

Estimated weight (for a 60m tower)	**49.9 Ton**	**Estimated weight (for a 62m tower)**	**52.7 Ton**

Weight differene 2.7 Ton

Approximate reduction in weight (60m vs 62m) 5%

Appendix C. About Jacobs

C.1 Company profile

Jacobs is a leading projects firm, with global capability in strategic consulting, project management, engineering, design, construction and commissioning

Our combined business operates across the world, in North and South America, Asia Pacific, Europe, the Middle East and Africa.

We have over 66,000 staff serving a multitude of sectors including:

- Power and energy
- Water and environment
- Mining and metals
- Aerospace and defence
- Buildings
- Oil and gas

With 2014 revenues of nearly $12.7 billion, we are one of the world's largest and most diverse providers of technical, professional, and construction services.

General Information about Jacobs	
Name	Jacobs
Legal Form	Jacobs Engineering Group Inc
Country of Registration/ Incorporation	United States of America
Head Office Address	155 North Lake Avenue Pasadena, California 91101 United States
Area of Main Business	Aerospace & Defense; Automotive & Industrial; Buildings; Chemicals; Food, Beverage, Forest & Consumer Products; Mining & Minerals; Mission-Critical & High-Tech Facilities; Nuclear; Oil & Gas Upstream); Pharmaceuticals & Biotechnology; Power & Utilities; Refining & Petrochemicals (Downstream); telecommunications; Transportation; and Water & Wastewater
Number of staff	Engineers: 60,500 Others: 5,500

C.2 Jacobs Power Sector Capability

Jacobs has a significant power sector group. We provide technical consultancy, engineering design and management services for all stages of power project development and operation. Additionally, we have experience in resource development disciplines such as mining and oil and gas, allowing us to provide clients, with a fully integrated project service.

We have skills and experience in the following areas:

- Power transmission and distribution;
- Power generation projects, both thermal and renewable energy;
- CDM, carbon credits and climate change;
- Environmental impact assessment, auditing and management systems; and
- Regulatory and power markets.

We offer a comprehensive range of services to all sectors of the power industry, including:

- Owner's Engineer;
- Lender's Engineer;
- Engineering, procurement and construction management (EPCM); and
- Detailed design and consulting.

Jacobs' Power business covers the full range of power generation and transmission projects, covering all aspects of services from pre-feasibility, bankable feasibility, front end engineering, tendering and contract award, owner's engineer services during construction, site supervision, and commissioning and defects liability period support.

Jacobs can provide project management, detailed design and owner's engineering services related to all facets of power transmission and generation projects including:

- Site selection
- Transmission route selection studies
- Topographical and geotechnical surveys, specifications
- Environmental studies, approvals and community consultation
- Equipment specifications
- Plant and civil/structural detailed design and specifications
- Specification, tendering and EPC contract award
- Fuel supply and management of equipment interfaces
- Environmental support and compliance with IFC and Equator principles, AMDAL studies management
- Grid connection system studies
- Project and contract management
- Capital cost estimating
- Construction / commissioning management (site superintendent)
- Design Review
- 3rd party inspection services
- Due Diligence
- Feasibility and concept studies

C.3 Transmission Line capability

Jacobs' Power business covers the full range of transmission sector services and technology, including transmission lines, system planning studies, substations, HVDC, SCADA and automation, smart grids, condition monitoring, asset management, electrical safety and market regulatory advice.

Jacobs can provide project management, detailed design and owner's engineering services related to all facets of transmission lines projects including:

Transmission Lines
▪ Constraint analysis and line route selection ▪ LIDAR, topographical and geotechnical surveys ▪ Environmental studies, approvals and community consultation ▪ PLS CADD line profiling ▪ Electrical design, insulation coordination and specifications ▪ Earthing and induction studies and mitigation ▪ Structural design for lattice towers, steel poles and substation gantries ▪ Preparation of assembly and fabrication drawings ▪ Preparation of foundation design and drawings ▪ Installation specifications ▪ Tower prototyping & testing support / witnessing ▪ Capital cost estimating ▪ Construction/ contract management (Site/Construction supervision) ▪ Design Review

C.4 About the Team

Dr. Tim Johnson: **Team Leader**

Dr Tim Johnson is a UK Chartered Engineer with extensive experience in a progression of scientific, technical, engineering and management posts. He has consulted and advised on coal, oil, nuclear, gas and renewable energy power stations and electricity and gas transmission lines.

Recently he has undertaken many Project Director and Peer Review roles on feasibility and due diligence studies on fossil fired and renewable energy power plants and transmission lines worldwide as well as significant Owner's and Lenders' Engineering roles on gas turbine, reciprocating engine and wind turbine powered plants, and electricity transmission lines up to 500kV. He has been based in Australia (initially Perth now Adelaide) for the last 6 years from where he has directed, managed or provided technical input to projects for local and international clients including several for SA and WA Government departments. He recently advised ElectraNet on the case for reinforcing the transmission lines supplying Davenport substation near Port Augusta.

Jorge Ferreira - Senior Consultant - Cost Management Services

Jorge is a highly qualified professional with 15 years of expertise in civil engineering, project management and cost estimating working in both national and multinational companies. His experience is across a number of sectors including marine infrastructure, O&G, mining, renewable power generation and hospitals.

These roles have provided him with a wide range of skills with particular expertise in development of technical and commercial documentation, estimating, risk identification, analysis and simulation and dispute resolution.

Ahsan Siddique – Principal Consultant – Transmission Lines

Ahsan has been in the electricity industry for 17 years during which he has been responsible for design and leading the development of transmission lines in Australia, South East Asia and South Asia ranging from 132kV to 500kV. Most recently, Ahsan has led the Jacobs and PSC's transmission line design team for several

Western Power, ElectraNet and Power & Water transmission lines project and emergency restoration projects. He has lead several long 400kV transmission lines (Quad ACCC and Quad ACSR-LL) and towers (including 100+m tall river crossing towers) with successful full scale load testing.

Ahsan is also an expert in PLS CADD, TOWER and POLE software and has provided training to local and overseas Utilities engineers.