GHD Advisory

VNI - Independent Verification and Assessment

TransGrid

27 October 2020

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1. Executive summary

TransGrid and the Australian Energy Market Operator Limited (AEMO) have jointly progressed the Victoria to New South Wales (NSW) Interconnector (VNI) Upgrade.

The VNI Upgrade will increase the export capability from Victoria to NSW by approximately 170 megawatts (MW), and involves the:

- Installation of an new 500/330 kV transformer South Morang Terminal Station
- Re-tensioning the 330 kV South Morang – Dederang transmission lines, as well as associated works (including replacement of series capacitors) to allow operation at thermal rating.
- Install Modular Power Flow Controllers (MPFC) on both 330 kV Upper Tumut – Canberra and 330 kV Upper Tumut – Yass lines.

The NSW component of the project that will be delivered by TransGrid involves:

- Supply of Smart Wires MPFC – Smart Wires i3600 Unit
- Major substation augmentation works within Stockdill 330kV substation to facilitate installation of installation of the Smart Wires i3600 unit
- Installation and commissioning of the Smart Wires i3600 Unit at Stockdill and the Smart Wires i2600 Unit SmartValves at Yass Substation
- Minor transmission line augmentation works around Stockdill 330kV substation
- Ancillary works including design, procurement and installation of secondary systems equipment at eight surrounding TransGrid substations.

The project addresses the identified need for investment to realise net market benefits by increasing the power transfer capability from Victoria to NSW currently subject to thermal, voltage stability, and transient stability limitations.

TransGrid as the Transmission Network Service Provider (TNSP) in NSW has progressed though the Regulatory Investment Test for Transmission (RIT-T) process as evidenced through the publication of the following reports:

- The Project Specification Consultation Report (PSCR), which sought feedback on the identified need and proposed credible options to address the need. Published in November 2018.
- The Project Assessment Draft Report (PADR), which identified and sought feedback on the preferred option which delivers the highest net market benefit and other issues. Published in August 2019.
- The Project Assessment Conclusions Report (PACR), which concludes on the preferred option and provides a summary of the submissions received on the PADR. Published in February 2020.

GHD considered whether TransGrid had developed a prudent and efficient solution to meet the investment need. Across the RIT-T process TransGrid progressed two options with a weighted net market benefit NPV difference of $11 million.

Overcoming the current thermal constraint on the Canberra -Upper Tumut 330kV lines became the single investment need as network stability issues and voltage stability limitations will be improved by the proposed preferred options under other RIT-Ts currently in progress (Victorian Reactive Power Support, Western Victoria Renewable Integration, Project EnergyConnect (PEC), and HumeLink).

The two options progressed in the PACR considered different solutions to address the thermal issues:

- Option 1 - Uprating of the Canberra – Upper Tumut 330 kV line
- Option 2 (the preferred option) - Installation of MPFC on the 330 kV Upper Tumut - Canberra line and 330 kV Upper Tumut – Yass line to increase the transfer capacity on Lower Tumut / Upper Tumut – Canberra/Yass cut-set by 170 MW to 220 MW.

The PACR does not detail the costs differences between the two option differences detailed above, but the PADR indicates a $17 million difference in favour of option 2.

Both options achieve an increase in transfer capacity of 170 MW.

When considering the merits between the two options, GHD looked at option 1 and assessed other Flexible AC Technology Systems (FACTS) technologies and conventional solutions such as Phase Shifting Transformers (PSTs) in section 4.3.4. Based on our research of the technologies and costs, that other alternate technologies would cost more than Option 2 and hence would not be the more efficient in meeting the project investment scope (TransGrid did not provide information directly but discussion with TransGrid indicated that the project planning team made the same assessments during the PADR and PACR project development stages).

The selection of the option 2 solution carries some risk which could result in project and higher asset management costs for this solution:

- The Smart Wires MPFC is a relatively new technology and had not yet been developed for current ratings that would be required for installation on the 330kV Upper Tumut – Canberra Line
- Smart Wires is a comparatively small supplier with limited local representation in Australia.

Section 4.4.3 details work performed to help assess MPFC impacts on network stability.

The selection of the option 2 also has additional benefits as they avoid some of the outage impacts to the market that will occur during the 330kV upgrade. However, the differences are not considered material. MPFCs have additional direct benefits increasing the transfer capacity beyond 170 MW.

On balance, highlighting the higher risk, GHD considers that the installation of MPFCs is the more prudent and efficient solution to meet the project investment scope.

The refinement and specification development for the MPFC and related substation, transmission line and protection systems scope are consistent with electricity industry practice.

The CPA capex forecast of $45.0 million is supported by tender results and the overall forecast totals are within the nominal ±20% range of GHD's comparative estimate, and therefore we consider the overall CPA forecast to be reasonable and an efficient outcome.

Summary of the CPA capex forecast

Summary

The following is a summary of the key findings from the GHD review.

Table 1 Summary of GHD review

Verification	
Scope	Project scope options have been progressed and are supported by appropriate analysis to support decision making processes. The Smart Wires MPFC option selected is designed to deliver 170 MW and to address the thermal capability of 330 kV transmission circuits between Canberra and Upper Tumut. Issues related to stability limits have been left to other RIT-T projects to resolve. The PADR assessment did not identify any technical issues with these MPFC and further modelling in the PACR stage was conducted to assess the potential for control interactions between the MPFC and nearby generators.
Substation work packages	Substation work packages are aligned with the scope and were adequately presented in procurement processes.
Transmission line work packages	Transmission line work packages are aligned with the scope and were adequately presented in procurement processes.
Smart Wires System costs	The variation to GHD comparative estimate is -5% and therefore we consider the costs for the Smart Wires system to be reasonable and an efficient outcome for the project.
Direct costs	The variances for the GHD comparative estimates to the CPA forecast values for the direct costs were -6% and within the nominal ±20% range, and therefore we consider the direct project costs to be reasonable and an efficient outcome for the project. The exception is the transmission line augmentation work, where the variance was outside the range, however the value of the variance is small, less than 1% of the total VNI capex.
Project overheads	The overheads are reasonable for this small project size – our comparative estimate of overheads for a project of this size based on owners scope of work requirements is reasonable and within 8% of GHD's comparative estimate.

Verification	
Overheads – Direct Labour	GHD supports the need for secondary systems technical specialists (direct labour) to provide oversight and direct involvement in the successful testing and commissioning of the Smart Wire systems and protection systems, due to both the complexity, wide area nature of the system and newness of the technology.
Change in forecast from PACR to CPA	GHD supports TransGrid's statement that the CPA capex forecast reflects pricing based on efficient market-based costs of delivering the VNI Project, which was not available at the time of publishing the PACR.
CPA capex forecast	The CPA capex forecast is supported by tender results and the overall forecast totals are within the nominal ±20% range, and therefore we consider the overall CPA forecast to be reasonable and an efficient outcome.
Project schedule	GHD considers the project schedule phasing to be consistent with the project delivery schedule and that the delivery timeframe is achievable, with the manufacture of the Smart Wires system and successful factory acceptance testing to be the critical milestones to meet the schedule.
Procurement process	Smart Wires MPFC represent almost 50% of the total capex forecast. This was a sole source approach, typical for projects involving technology available from the one supplier. GHD has not been given the final version of the Smart Wires contract, only extracts that detail pricing. Procurement for other project elements have been sourced from existing panel arrangements following industry practice processes.

Conclusion

GHD considers the scope development and costs identified by TransGrid are reasonable for this type of complex project involving new technology and fast response control systems. GHD considers these factors would have resulted in the careful development work with Smart Wires, the commercial performance requirements, and TransGrid's inclusion of specialist control, secondary system and communication roles in the project team throughout the duration of the project.

From our assessment, we note that generally the TransGrid CPA forecasts are slightly higher than the GHD comparative estimates on a work package basis, and the total CPA forecast overall 6% higher (which is well within the GHD range of ±20% variance for reasonableness).

TransGrid's substations, secondary systems and transmission line costs are based on market tested pricing and will be more accurate, as GHD's comparative estimate is a Class 4 estimate with an accuracy of ±30%.

2. GHD scope

TransGrid has engaged GHD to perform and independent verification and assessment of specific elements to support their VNI Contingent Project Application (CPA) submission.

GHD's scope is limited to the assessment of the NSW component of the assets that are relevant to TransGrid's CPA.

GHD's scope includes the following elements:

1. VNI scope

An assessment of project scope, having regard to key project elements such as substation and transmission lines upgrades and the installation of the specialised equipment MPFCs to consider reasonableness and appropriateness of the scope given the project objectives.

2. Capex forecast

An assessment of the reasonableness of the capex forecast, taking into account good commercial and engineering practice and includes an assessment of the capex forecast costs including contracted services, plant and project overheads. The scope excludes any assessment of risk identification, quantification and risk management strategy on the basis that no allowance for risk is included in the capex forecast.

3. RIT-T to CPA variances

GHD will identify any difference between the cost estimate in the PACR and the CPA. Where the differences are material GHD will determine the reason for the variation and will consider the justification and reasonableness of the variation with regards to achieving the capex objectives.

4. Project schedule phasing

An assessment of the capex forecast expenditure profile over the financial periods of the project.

5. Procurement

An assessment of the reasonableness of the procurement process to achieve the required outcomes for VNI.

Limitations

This report has been prepared by GHD for TransGrid and may only be used and relied on by TransGrid for the purpose agreed between GHD and the TransGrid as set out above.

GHD otherwise disclaims responsibility to any person other than TransGrid arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

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The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described thought out this report. GHD disclaims liability arising from any of the assumptions being incorrect.

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GHD has prepared comparative estimates using information reasonably available to the GHD employee(s) who prepared this Report, and based on assumptions and judgments made by GHD.

The comparative estimates has been prepared for the purpose of supporting TransGrid in their CPA submission and must not be used for any other purpose.

The comparative estimates are a preliminary estimate only in 2019 real Australian dollars. Actual prices, costs and other variables may be different to those used to prepare the comparative estimates and may change. Unless as otherwise specified in this Report, no detailed quotation has been obtained for matters identified in this Report. GHD does not represent, warrant or guarantee that the works can or will be undertaken at a cost which is the same or less than the comparative estimates.

Where estimates of potential costs are provided with an indicated level of confidence, notwithstanding the conservatism of the level of confidence selected as the planning level, there remains a chance that the cost will be greater than the planning estimate, and any funding would not be adequate. The confidence level considered to be most appropriate for expenditure modelling purposes will vary depending on the conservatism of the user and the nature of the project. The user should therefore select appropriate confidence levels to suit their particular risk profile.

3. Background

3.1 Background to the VNI project

The VNI minor upgrade was included in the:

- AEMO 2018 Integrated System Plan (ISP)
- 2019 Electricity Statement of Opportunities (ESO), which reconfirmed the importance of completing the VNI minor upgrade before the forecast closure of Liddell Power Station
- AEMO's draft 2020 ISP released on 12 December 2019, which labelled the VNI minor upgrade a "no regret" action (i.e. it has no downside).

These documents noted that VNI is currently restricted by thermal, voltage stability, and transient stability limitations.

The 2019 ESO identified a risk of supply-demand shortfalls which may lead to reliability standard breaches in Victoria in the short term if unplanned generator outages were to occur during extreme heat conditions.

The investment need and the corresponding scope development have been progressively tested through the RIT-T process, with each stage subject to stakeholder review and feedback. TransGrid and AEMO have progressively defined and assessed the project investment need and scope as evidenced through the following documents:

- PSCR published in November 2018
- PADR published in October 2019
- PACR submitted to the Australian Energy Regulator (AER) in February 2020.

3.1.1 Project specification consultation report

The PSCR outlined three aligning drivers:

1. AEMO's 2018 ISP recommended several investments in transmission which should be undertaken and completed as soon as practicable (called "group 1 developments")[1]. These recommendations included investment to increase Victorian transfer capacity to NSW, to capture positive net market benefits through more efficient sharing of generation resources between states.
2. The 2018 TransGrid Annual Planning Report[2].
3. The ISP recommendation aligned with the conclusions of the 2018 Victorian Annual Planning Report[3]

[1] Section 6.3.1 of AEMO's 2018 ISP, available at http://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/ISP/2018/Integrated-System-Plan-2018_final.pdf.

[2] Section 2.1.3 of TransGrid's 2018 TAPR, available at https://www.transgrid.com.au/news-views/publications/Documents/Transmission%20Annual%20Planning%20Report%202018%20TransGrid.pdf.

[3] Section 3.8 of AEMO's 2018 VAPR, available at https://www.aemo.com.au/-/media/Files/Electricity/NEM/Planning_and_Forecasting/VAPR/2018/2018-Victorian-Annual-Planning-Report.pdf.

In summary the identified need was to alleviate current and projected limitations on power transfer capacity from Victoria to NSW, caused by both thermal and stability limitations. These limitations add to market costs through less efficient sharing of generation resources between states.

TransGrid and AEMO considered three broad options to address the current VNI limitations, the base case as identified in the 2018 ISP, and two other options that would increase the VNI transfer capability but at higher costs, and sought consultation on these options. The base case included a number of further options which GHD has considered further in section 4.3 in reviewing the development of the scope to arrive at the final VNI solution.

3.1.2 Project assessment draft report

The PADR incorporated the feedback on the proposed options in the PSCR and further validated the investment need.

The investment need remained fundamentally unchanged and was summarised though the following quote in the PADR.

"The identified need for investment is to realise net market benefits by increasing the power transfer capability from Victoria to New South Wales. Alleviating current and projected limitations on this transfer corridor will reduce market costs, through more efficient sharing of generation resources between states, and greater access to diverse supply sources" [4].

The PADR consider the same three broad options to address VNI limitations. The base case was refined into two options – uprating the Canberra – Upper Tumut 330kV line or the installation of a MPFC. Both of these solutions would provide an increased VNI transfer capacity to 170 MW and costs benefit analysis showed that the installation of MPFCs would have a net NPV benefit of $11 million compared to the original solution identified in the 2018 ISP.

GHD provides a review of MPFC technology and the refinement of the design and configuration in section 4.3.

3.1.3 Project assessment conclusions report

The PACR incorporated feedback on the proposed preferred option outlined in the PADR and revalidates the investment need.

The PACR assessed the same four credible options to increase transfer capacity with adjustments to cost forecasts reflecting additional information on the project options.

Table 2 below updates and summarises the four credible options assessed.

[4] Victoria to New South Wales Interconnector Upgrade – Project Assessment Draft Report, page 14

Table 2 Summary of the credible options considered in the PACR[5]

Option	Description	Option cost ($M Real $2018)	Gross market benefits - NPV	Weighted net market benefit - NPV
1	**Base Option** • One new 500/330 kV transformer at South Morang Terminal Station • Re-tensioning the 330kV South Morang - Dederang Transmission lines and associated works (inc replacement of series capacitors) • 330 kV Upper Tumut - Canberra line upgrade	$99	356	257
2	**Base option with modular power flow controllers** • One new 500/330 kV transformer at South Morang Terminal Station • Re-tensioning the 330kV South Morang - Dederang Transmission lines and associated works (inc replacement of series capacitors) • Install MPFC on both 330 kV Upper Tumut on the Canberra & 330 kV Upper Tumut- Yass lines	$87	355	268
3	**Additional higher capacity upgrades in NSW** • One new 500/330 kV transformer at South Morang Terminal Station • Re-tensioning the 330kV South Morang - Dederang Transmission lines and associated works (inc replacement of series capacitors) • Bring forward one leg of Humelink, new 500kV line between Snowy and Bannaby including connection into 330kV network.	$628	750	123
4	**Additional higher capacity upgrades in NSW in Victoria** • Two new 500/330 kV transformers at South Morang Terminal Station • New 330 kV South Morang - Dederang Line	$947	827	-120

[5] Victoria to New South Wales Interconnector Upgrade - rit-t Project Assessment Conclusion Report – Tables 1 & 2, pages 5 & 6.

Option	Description	Option cost ($M Real $2018)	Gross market benefits - NPV	Weighted net market benefit - NPV
	• Bring forward one leg of Humelink, new 500kV line between Snowy and Bannaby including connection into 330kV network.			

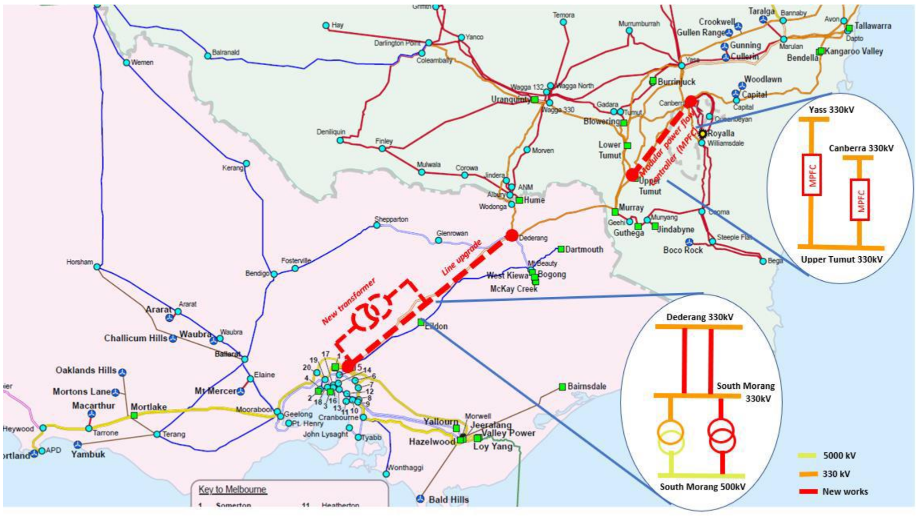
The preferred option identified in the PACR is **Option 2**, with an expected capital cost of $87 million - expected to deliver the greatest net benefits of all options, across all four scenarios considered (December 2019 dollars).

The estimated NPV benefit for Option 2 was approximately $268 million which is slightly larger than the NPV benefits of Option 1 of $257 million. The sensitivity analysis conducted in the PACR considered high and low cost scenarios of +/- 30%, however the scenarios only considered both options increasing by 30% or both decreasing by 30%.

GHD's report does not directly consider the benefits associated with Option 1 and 2 (or any other options) and also does not evaluate the decision making process to select the preferred option except to the extent of verifying an efficient scope and capital forecasts have been developed for the preferred option. The PACR indicates a difference in gross market NPV benefit of $11 million (Real $2018) in favour of Option 2 which means that both the benefits and the costs defines the selection of Option 2 as the preferred option.

The preferred option is shown in Figure 1. The aim was to commission the project works by 2022-23.

Figure 1 Preferred option (Option 2 from PADR)[6]



[6] Victoria to New South Wales Interconnector Upgrade - Project Assessment Draft Report, page 4

3.2 The CPA investment scope

As outlined in the Capex Forecasting Methodology for VNI Minor Upgrade Project, the project will increase the export capability of VNI from Victoria to NSW by approximately 170 MW, and involves the:

1. Installation of an new 500/330 kV transformer South Morang Terminal Station
2. Re-tensioning the 330 kV South Morang – Dederang transmission lines, as well as associated works (including replacement of series capacitors) to allow operation at thermal rating
3. Install MPFC on both 330 kV Upper Tumut – Canberra and 330 kV Upper Tumut – Yass lines. (TransGrid's scope)

The third component of the project, being the installation of MPFC on the Upper Tumut – Canberra and Upper Tumut – Yass line, relates to work in NSW that TransGrid will undertake. This involves:

- Supply of Smart Wires MPFC – Smart Wires i3600 Unit
- Major substation augmentation works within Stockdill 330kV substation to facilitate installation of installation of the Smart Wires i3600 unit
- Installation and commissioning of the Smart Wires i3600 Unit at Stockdill and the Smart Wires i2600 Unit SmartValves at Yass Substation
- Minor transmission line augmentation works around Stockdill 330kV substation
- Ancillary works including design, procurement and installation of secondary systems equipment at eight surrounding TransGrid substations.

3.3 The CPA capex forecast

As detailed by the Capex Forecasting Methodology for VNI Minor Upgrade Project, the capex forecast for the project is detailed in Table 3 below.

Table 3 Total forecast capex for the VNI project by category ($M, Real $2018)

Category of VNI capex	Capex ($M, Real $2018)
Substations (including Smart Wires)	34.5
Transmission lines	0.4
Secondary systems	2.6
Direct labour	3.6
Network and corporate overheads	3.6
Real input costs	0.3
Total capex	**45.0**

4. VNI scope

4.1 Scope assessment methodology

GHD has used the following methodology and steps to review the project scope:

1. The project investment scope

Determine if TransGrid has identified the functional requirements to meet the project investment need identified in the RIT-T process and the PACR findings. This will provide the definition for the scope requirements for TransGrid's VNI capital expenditure investment and CPA.

6. Assessment of options and scope refinement

TransGrid has systematically assessed the options to determine the most efficient solution within the investment scope and that further refinements of the preferred solution are reasonable.

7. Asset performance requirements

The specified performance parameters of the upgraded VNI asset have been assessed to verify that the performance requirements defined for the transmission lines, substations and specialist plant represent an efficient approach to meeting the objectives of the project.

8. Scope definition for procurement of work packages

The specified work packages for procurement have been assessed to verify that the specifications are efficient to provide the asset performance requirements. This will include whether the building blocks in the estimates align with the quantities specified in the tender quantity schedules and whether they are complete (or with gaps) and without duplicates.

9. Summary of the scope review

Section 4.6 summarises the key findings from GHD's scope assessment. This presents findings for each of the above steps and verification outcomes with respect to whether:

- The optimised project scope reflects the approach a prudent TNSP would adopt
- Procurement work packages have been developed to align with the work scope requirements and are clearly specified in the Request for Tender (RFT) for the optimised scope
- The schedule quantities developed for the scope align with the RFT defined requirements
- Scope requirements and specifications provided to tenderers are appropriate and cover the requirements to enable competitive pricing.

4.2 The project investment scope

In reviewing whether the project investment scope meets the investment need, GHD started with a review of the stated investment need defined in various key documents.

In the PSCR the VNI investment need was stated as:

"to alleviate current and projected limitations on power transfer capacity from Victoria to New South Wales. These limitations result in market costs through less efficient sharing of generation resources between states."[7]

The transfer capability to NSW from Victoria is currently limited by:

- Thermal capacity of the 500/30 kV at South Morang Terminal Station
- Thermal capacity of the 330 kV South Morang to Dederang circuits
- A transient stability limitation on transfers in the case of a loss of the Hazelwood to South Morang line
- In addition generation from Victoria and from Southern NSW will compete for the limiting thermal capacity of the 330 kV transmission circuits between Canberra and Upper Tumut.

Increasing the transfer capability from Victoria to NSW by 170 MW was consistently found by TransGrid and AEMO to capture higher net benefits compared to other options which aimed for higher transfer capacities.

The PADR described the same investment need however it also assessed the impact of an additional voltage stability constraint on transfers to provide for the potential loss of Alcoa Portland Potline potlines, which was identified in the 2018 AEMO ISP.[8]

The PADR stated that although the primary driver of the RIT-T is to increase the Victoria to NSW transfer capability, some options would also improve NSW to Victoria import capability and this would increase the benefits of the options being considered.[9] The additional benefits of these other options did not change the preferred option within the overall investment scope to enable the 170 MW transfer capacity north from Victoria to NSW.

GHD has taken the selected option from the PADR to define the starting point for the assessing the options which TransGrid further considered prior to arriving at the final scope defined as Option 2 in the PACR – based on the installation of MPFC.

The scope in the PADR for "Option 1 – ISP base case" (ref PSCR p9) can be used to define the investment scope (Table 4) as the starting point for solution optimisation. This will assist to verify that the final detailed VNI scope definition is efficient to meet this high level project investment scope.

This NSW investment scope is therefore required to provide the following functional requirements to achieve the increase the transfer capacity to 170 MW:

- Improve the transient stability limitation for transfers in the case of a loss of the Hazelwood to South Morang line
- Increase the limiting thermal capacity of the 330 kV transmission circuits between Canberra and Upper Tumut.

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[7] Victoria to New South Wales Interconnector Upgrade RIT-T PSCR, page 6.

[8] Victoria to New South Wales Interconnector Upgrade RIT-T PADR, page 14

[9] Victoria to New South Wales Interconnector Upgrade RIT-T PADR, page 14

Table 4 PADR option 1 - ISP base case

State scope	Description
Victoria	Installation of a new 1,000 megavolt amperes (MVA) 500/330 kV transformer at South Morang Terminal Station
	Re-tensioning the South Morang – Dederang 330 kV lines and associated works (including uprating of series capacitors) to allow the line to run to thermal rating of 1,038 megavolt amperes (MVA)B (or to 82 C)
NSW	Options in NSW to improve transient stability constraints (Three alternative variants considered) Options to increase thermal capacity in NSW – uprate Canberra - Upper Tumut 330kV transmission line

The analysis conducted for the PSCR showed that various technologies were considered at this stage of planning to identify the optimum solution to increase the transient stability and thermal limitations. The options at this time to improve transient stability included:

- Installation of a braking resistor
- Installation of a synchronous condenser with inertia support
- Installation of an Static VAr Compensator (SVC)
- Installation of batteries with fast response inverters.

Uprating of the Canberra – Upper Tumut 330kV line at this stage was the only option considered within the NSW scope for increasing the thermal transfer capacity. Prior to the submission of the PADR, TransGrid identified a further credible option to install MPFC (Option 2 - PADR p5) in response to stakeholder feedback.

The PADR assessment did not identify any technical issues with these MPFC and further modelling in the PACR stage was conducted to assess the potential for control interactions between the MPFC and nearby generators.

The refinement and assessment of these options through to the PACR stage and to the CPA stage are considered in the following section.

4.3 Assessment of options and scope refinement

As detailed below the scope has been progressively refined through the RIT-T process.

The following details the full scope of options considered for the NSW component only to be delivered by TransGrid but overall needs to be considered in the context of the wider VNI options.

4.3.1 PSCR options

The PSCR identified three primary options, with details including additional variations within each option. Option 1 is consistent with the scope of augmentation recommended by the 2018 ISP. The other options at higher costs would need to deliver additional benefits to be considered viable options.

The analysis conducted for the PSCR showed that various technologies were considered at this stage of planning to identify the optimum solution to increase the transient stability and thermal limitations. The options at this time to improve transient stability have been detailed above.

Table 5 PSCR options [10]

Description	PSCR estimated cost ($ million)
Option 1 – ISP base case	
Installation of a new 500/330 kV transformer at South Morang	29
Re-tensioning the South Morang – Dederang 330 kV lines and associated works (including uprating of series capacitors) to allow the line to run to thermal rating	17
Installation of a braking resistor Three other options considered as detailed in the PSCR refer above.	13
Uprating of the Canberra – Upper Tumut 330 kV line	28
Total option 1	**87**
Option 2 – Additional higher capacity upgrades in New South Wales	
Installation of a new 500/330 kV transformer at South Morang	29
Re-tensioning the South Morang – Dederang 330 kV lines and associated works (including uprating of series capacitors) to allow the line to run to thermal rating	17
Installation of a braking resistor (or preferred option to address stability limitation)	13
Uprating of the Canberra – Upper Tumut 330 kV line	28
Uprating selected existing 330 kV lines between Snowy and Sydney (in addition to the Canberra – Upper Tumut 330 kV line) *	36-112
Total option 2	**123-199**
Option 3 – Additional higher capacity upgrades in Victoria and NSW	
Installation of a new 500/330 kV transformer at South Morang	29
Replace the existing South Morang – Dederang 330 kV lines with higher capacity conductors and associated work (including uprating of series capacitors) to allow the line to run to thermal rating.	*
Installation of a braking resistor (or preferred option to address stability limitation)	13
Uprating of the Canberra – Upper Tumut 330 kV line	28

[10] Victoria to New South Wales Interconnector Upgrade PSCR, page 10

Description	PSCR estimated cost ($ million)
Uprating selected existing 330 kV lines between Snowy and Sydney (in addition to the Canberra – Upper Tumut 330 kV line)	36-112*
Total option 3	*

* Subject to further investigations for the PADR

4.3.2 PADR options

The PADR detailed the considerations made by AEMO and TransGrid in assessing the ten submissions received post the publication of the PSCR.

The PSCR proposed options to improve stability limits, however the PADR removed the requirement to address specific investment to improve stability limits. TransGrid studies found that interconnector transient and voltage stability limitations will be improved by the proposed preferred options under other RIT-Ts currently in progress (Victorian Reactive Power Support, Western Victoria Renewable Integration, PEC, and HumeLink).

The PSCR proposed upgrading the 330 kV Upper Tumut – Canberra line to increase the transmission capacity between Snowy and load centres in NSW as the base case option. However, an alternate option using MPFCs could achieve a similar increase in transfer capacity at a lower cost. As such, the PADR proposes MPFCs to increase utilisation of the 330 kV cut set between Snowy and Yass/Canberra, as the preferred solution.

Table 6 PADR options[11]

Description	PADR estimated cost ($ million)
Option 1 – ISP base case	
Installation of a new 500/330 kV transformer at South Morang	38.5
Re-tensioning the South Morang – Dederang 330 kV lines and associated works (including uprating of series capacitors) to allow the line to run to thermal rating of 1,038 megavolt amperes (MVA)B (or to 82 C)	21
Uprating of the Canberra – Upper Tumut 330 kV line	38
Total option 1	**97.5**
Option 2 – ISP base option with modular power flow controllers	
Installation of a new 500/330 kV transformer at South Morang	38.5

[11] Victoria to New South Wales Interconnector Upgrade RIT-T PADR, Table 5, 6 and 5, pages 23 - 25

Description	PADR estimated cost ($ million)
Re-tensioning the South Morang – Dederang 330 kV lines and associated works (including uprating of series capacitors) to allow the line to run to thermal rating of 1,038 megavolt amperes (MVA)B (or to 82 C)	21
Installation of MPFC on the 330 kV Upper Tumut - Canberra line and 330 kV Upper Tumut – Yass line to increase the transfer capacity on Lower Tumut / Upper Tumut – Canberra/Yass cut-set by 170 MW to 220 MW.	21
Total option 2	**80.5**
Option 3 – Additional higher capacity upgrades in Victoria and NSW	
Installation of a new 500/330 kV transformer at South Morang	38.5
Re-tensioning the South Morang – Dederang 330 kV lines and associated works (including uprating of series capacitors) to allow the line to run to thermal rating of 1,038 megavolt amperes (MVA)B (or to 82 C)	21
Bring forward one leg of HumeLink, a new 500 kV line between Snowy and Bannaby including connection into existing 330 kV network, as proposed under TransGrid's RIT-T for reinforcing Southern NSW, rated at 3,300 MVA .	550
Total option 3	**610**
Option 4 – Additional higher capacity upgrades in New South Wales and Victoria	
Installation of two new 1000 MVA 500/330 kV transformers at South Morang Terminal Station	77
New 330 kV single circuit line rated at 1,038 MVAB in parallel with the existing South Morang – Dederang 330 kV lines.	415
Bring forward one leg of HumeLink, a new 500 kV line between Snowy and Bannaby including connection into existing 330 kV network, as proposed under TransGrid's RIT-T for reinforcing Southern NSW, rated at 3,300 MVA.	550
Total option 4	**1,042**

4.3.3 PACR options

Table 6 above, summarises the credible options considered in the PACR.

As detailed in section 3.1.3, the PADR Option 2 – ISP base option with MPFCs was identified as the preferred option.

As discussed above, this option does not include investments to address stability limitations. Rather this would be addressed contingent upon other RIT-Ts. In particular, the South Morang transformer component of VNI and Western Victoria Transmission Network Project and PEC RIT-T preferred options will achieve a 170 MW increase in the stability limitations.

The PACR presents that since the PADR:

- The Western Victoria Transmission Network Project has become committed and has moved into the implementation phase
- PEC has completed the final stage of the RIT-T process and received AER approval.

The MPFC therefore needs only to address the thermal capability of 330 kV transmission circuits between Canberra and Upper Tumut.

Since the publication of the PADR, further technical assessments have been conducted to confirm the technical feasibility of the MPFC. The PCAR provided the following statements[12]:

- Dynamic assessment – RMS (root mean square) dynamic simulations were undertaken to assess the impact of the MPFC devices on Victoria – NSW Interconnector transient stability. The assessment was based on a selection of eight National Energy Market system snapshots with a wide range of demand levels, and generation profiles. The study confirms that MPFC will not have any material adverse impact on the Victoria – NSW interconnector transient stability limits.
- Control interaction and Sub Synchronous Torsional Interaction (SSTI) assessment – simulation studies were undertaken to investigate potential control interaction issues and thermal generator SSTI issues due to the addition of the proposed MPFC on the 330 kV Upper Tumut – Canberra and 330 kV Upper Tumut – Yass lines. These assessments reveal that the MPFC devices do not lead to unstable interactions (control interactions) with other dynamic devices in the power system, and that SSTI risks due to the addition of MPFC devices are minimal.
- Control interactions – the coordinated operation of the MPFC device(s) with other dynamic devices (including power electronic inverter-based wind and solar plants) in the vicinity of the line ends were established using EMT (Electro Magnetic Transient) simulations.
- SSTI – screening level damping analysis and another industry accepted screening technique ("Unit Interaction Factor (UIF)") were used to identify potential SSTI issues with Gas Turbine generators in the southern subsystem.

On the basis of these studies, the PCAR indicates that AEMO and TransGrid were satisfied that the MPFC solution is technically feasible.

4.3.4 Refinement and assessment of PACR options

GHD reflected back on TransGrid's development of the scope since the issue of the PACR and the NSW investment scope and the process to considering all reasonable technical solutions to increase the transfer capacity of VNI by 170 MW. In discussions with TransGrid it was apparent that various FACTS were considered prior to reaching the two competing alternatives (Option 1 and Option 2) that could provide this increase in transfer capacity.

Recapping, the two NSW scope alternatives were:

- The base option scope - 330 kV Upper Tumut - Canberra line upgrade (Option 1)
- The alternate base option scope – installation of MPFCs on both the 330kV kV Upper Tumut on the Canberra & 330 kV Upper Tumut- Yass lines (Option 2)

[12] Victoria to New South Wales Interconnector Upgrade – Project Assessment Conclusions Report, page 19

The focus of these two option were to overcome transmission line thermal constraints. The transient stability limits did not require further consideration due to the status of other transmission developments occurring. However the consideration of other FACTS technologies were also still need to address this matter during this period. The two options selected and the assessment of costs are shown in Table 7 below.

Table 7 Comparison of costs for options to increase thermal capacity

Option	PADR costs ($M $2019-20)	PACR costs ($M 2019-20)
Option 1 - 330 kV Upper Tumut - Canberra line upgrade	$38M (Table 5 p23)	Not specified in the PACR. Based upon email exchanges between GHD and TransGrid, the total for VNI Option 1 increased from $97.5 M to $106 M. Hence assumed cost increase to $46.5M for the NSW transmission line work
Option 2 - installation of MPFCs	$21M (Table 6 p24)	$41M

The increase in cost of the NSW works associated with the MPFC preferred option followed refinement of the scope and design requirements for MPFCs and additional protection system upgrades to ensure reliability is maintained under fault conditions. This resulted in the capital cost of the works increasing by approximately $20 million since the PADR analysis[13] .

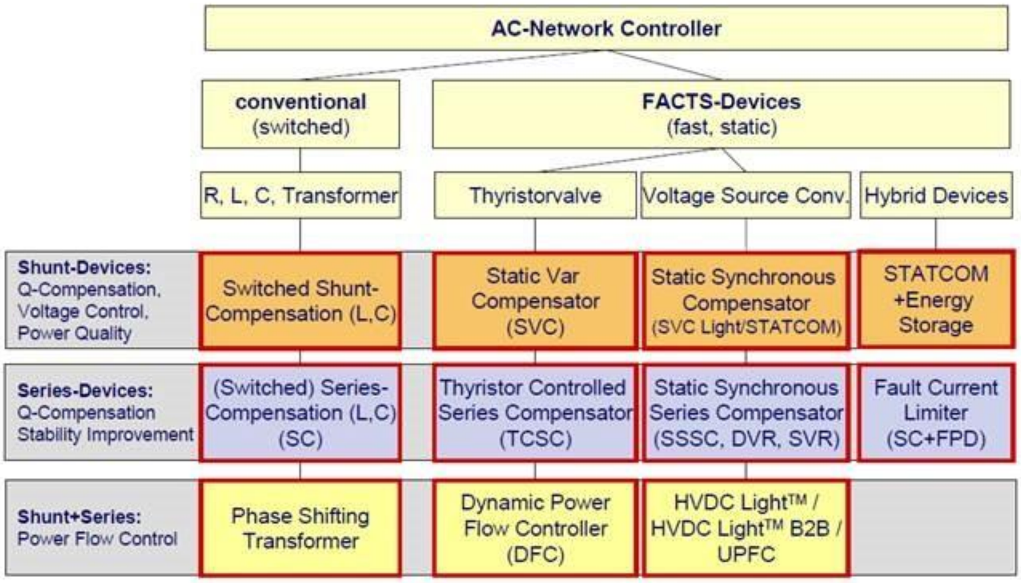
The PACR does state that an increase in costs of the NSW works for Option 1 was based on further scoping assessment which provided greater information on site specific environmental conditions (such as design and construction requirements due to ice loadings, bushfires risk, outages, and access to construction locations) and work methodologies[13]. The actual increase in the NSW portion of the work was not defined but based on the difference from the PADR to the PACR this increase is inferred to be $1.5 million.

The PACR includes costs for the market impact of the outages - $4.6 million for Option 1 and $1.4 million for Option 2 (PACR Table 13).

GHD has considered a review of the transmission line upgrade and other potential technology solutions to the MPFC are warranted due to the closeness in costs and in consideration of the cost increases for both options from the PADR to the PACR. For this purpose a brief explanation of FACTS technology is appropriate.

[13] Victoria to New South Wales Interconnector Upgrade – Project Assessment Conclusions Report, page 18

Figure 2 Conventional and FACTS AC-network control technologies



Shunt compensation devices – reduces the reactive power flow required to keep voltages on the system within acceptable boundaries and are traditionally used to manage transient stability issues. If located at the load end, this then forms a parallel path for reactive power supply from the shunt compensation devices and the transmission line supply – shared between the two supply systems. The thermal capacity to supply additional MW along the transmission line is partly increased as a result. Shunt compensation has a smaller impact though on the ability to change the flow between two parallel transmission line pathways (such as the 330kV Upper Tumut – Canberra line and the 330kV Upper Tumut - Yass line). This type of reactive power compensation, either switched or controlled, are connected between the line and ground on transmission lines at particular nodes. The types of shunt compensation devices include Static Synchronous Compensators (STATCOMs) and SVCs.

Series compensation devices - when a transmission line has a high value of reactance to resistance ratio, the inductive reactance of the transmission line can be altered by introducing series capacitors which also results in lower voltage drop. This series compensation directly reduces the impedance on the transmission line which can be used to balance the flow on two parallel transmission line pathways (such as the 330kV Upper Tumut – Canberra line and the 330kV Upper Tumut - Yass line). This form of compensation is connected in series with the transmission lines at particular nodes. This compensation will give more control of power flow through the line and also improves the dynamic stability limit of the power system.

Options considered by TransGrid

TransGrid considered options that could provide the required reactive power support, both series and shunt systems in the development of the options during the development of the PADR and the PACR.

- TransGrid considered options for the purpose of increasing transient stability constraints. SVCs, as well as synchronous condensers (which can also provide system strength and inertia to the system), were considered. This no longer became necessary after other transmission projects either committed by other TNSPs or approved by the AER alleviated transient stability limitations.

- TransGrid considered various options to increase the thermal limitation of the VNI though power flow control. The more effective technologies suitable for power flow control that were initially considered by TransGrid were PSTs, Switched Series Capacitors and Thyristor Controlled Series Compensators (TCSC); then later Static Series Compensators (the Smart Wires Modular Power System Controller being a subset).

These studies found:

– Switched series capacitors were not sufficiently fast enough to provide the control needed under contingent event scenarios so were discarded early. Also with fixed series capacitors there is potential to destabilise the shaft mechanical oscillation modes of thermal generators.

– TCSCs were a feasible technical solution, however they have had limited application internationally due to costs (typically over $100 Million), and for the case for VNI, the thermal upgrade of the transmission lines was a clearly lower cost solution.

– PSTs are conventional technology which TransGrid intent to use for PEC. For the VNI project, four single phase 330kV PSTs would be required with a rating of 3600A installed on the 330 kV Upper Tumut - Canberra line which would be a much greater cost compared with upgrading the thermal capacity of the line (Option 1). This option was discarded as a result.

– The Smart Wires MPFC is a relatively new technology and had not yet been developed for current ratings that would be required for installation on the 330kV Upper Tumut – Canberra Line. However the development of larger capacity units began in the UK in 2019, with the support and need initially identified by National Grid in the UK. TransGrid used this opportunity to explore the option with Smart Wires. The Smart Wires system solution (Option 2) also provides additional benefits installed on both the 330kV Upper Tumut – Canberra line and the 330kV Upper Tumut - Yass line compared to that achievable by the thermal upgrade of the Upper Tumut -Canberra line alone.

– MPFC technology has other future advantages – the modular design enabling the ability to upgrade or be relocated to other constrained parts of the network if upgrades superseded the need for current configurations.

GHD can confirm that TransGrid has considered reasonable options before adopting the MPFC solution as a viable option (Option 2) compared to upgrades to the 330kV transmission lines (Option 1).

Smart Wires has installed, tested and improved designs since the first 100 SmartValves were installed on the TVA network (United States) in 2012. As at June 2020, 595 modular units have been installed in the United States, United Kingdom, Ireland and Australia (Western Power, TransGrid and AusNet). A further 286 units are scheduled to be installed through to March 2021.

TransGrid progressed with the development of the MPFC solution as the preferred solution. The MPFC are only currently available from one supplier with a patent on the transformers that are used to connect directly onto feeder cables. Being a sole source supplier has meant that a competitive procurement process was not feasible for this technology.

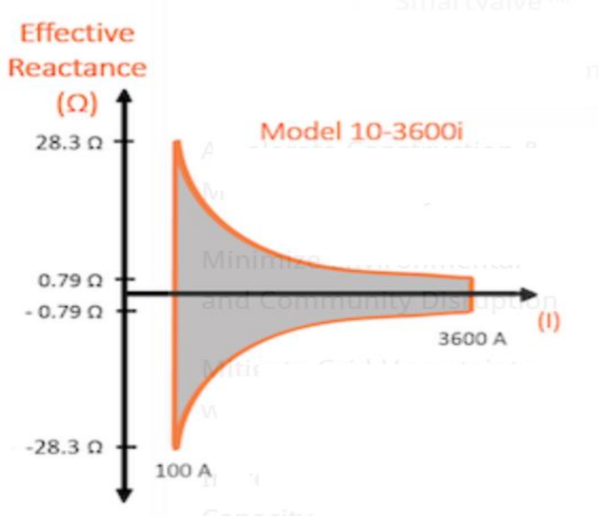
The forecast capex for VNI ($45.0 million - Real $2018), which has been largely defined now by contracted project costs, has increased since the PACR. The cost of Option 2 now appears to be only marginally lower than GHD's calculated costs for the transmission line scope in Option 1 of $46.5 million. The following two points still supports the selection of Option 2 as the preferred option - the NPV benefits of Option 2 were shown to be higher compared to Option 1 ($11 million - Real $2018)[14] and the brownfield nature of transmission line upgrades would have also likely seen an increase in costs for Option 1.

Since the isse of the PACR, TransGrid and Smart Wires have together worked on the specification of the system to optimise performance and costs.

SmartValve can inject the voltage independently of the line current, thus increasing the effective reactance injection when operated below the rated value, as shown below in Figure 3[15]. For the increase in thermal capacity to be achieved, the required supply of reactance is needs to be supplied at the upper end of the operating range. For ths to be achieved, the rated capacity of the SmartValve may be to above that of the required operating current in order to achieve the necessary correction in the transmission line impedance.

The final design of the Stockdill system (45 x i3600 units) will require a reactive voltage injection of 2830 V at an operating line current of 2570 A and under emergency operating condition, a current of 2900 A for 2 hours. The effective reactance is a function of the injected current created by the injection voltage as a proportion of the line current. The required reactance is a function of the change in relative impedance of the transmission lines on the system to balance the flows across the network and determined by system modelling.

Figure 3 Effective reactance capacity over operating current range[15]



GHD's opinion is that TransGrid has worked effectively with Smart Wires to arrive at the optimum scope for the MPFC systems. It is evident that the design specification for SmartValves at both Stockdill and Yass went through several changes as different sizes and numbers of units which were identified in various documents at various stages of the project development.

We have provided a summary of the VNI scope definition in Appendix A.

[14] Victoria to New South Wales Interconnector Upgrade – Project Assessment Conclusions Report, Table 14, section 6.3.2

[15] SmartValve – 10-3600i data sheet

4.4 Asset performance requirements

Modular power system controllers

The performance requirements of the MPSCs have been defined in the "Modular Power Flow Control (MPFC) – Technical Specification" documents. This document also contains technical requirements for TransGrid input control parameters to achieve the required performance of the MPSCs. Schedule 1.5.4 contains the following requirements and asset performance tests:

- Response time - the time average 15s or less when operated within specified limits. The maximum time to inject will be 30s when operated within specified limits:
  - Ability to enter Injection Mode
  - Ability to enter Monitoring Mode.
- Fixed Injection Capability - >99% of time the absolute error between the target set point and the injected reactance is less than 6% when current is greater than 600 A RMS and less than 12% when current is less than 600 A RMS:
  - Validate Fixed Reactance Injection Mode (inductive set point)
  - Validate Fixed Reactance Injection Mode (capacitive set point).
- Fixed Voltage Injection - error between injected voltage and set point voltage is no more than 1.5 times the total error based on measurements in the Factory Acceptance Test (FAT):
  - Validate Fixed Voltage Injection Mode (reactive set point)
  - Validate Fixed Voltage Injection Mode (capacitive set point)
- Loss of Communications - when devices are set to maintain prior set point following loss of communications, they do so for 6 out of 6 tests:
  - SmartValve Response after failure of communications when devices set to maintain prior operating mode upon communication failure
  - SmartValve Response after failure of communications when devices set to enter monitoring mode upon communication failure.
- Time to operate following auto reclose - 100% of time devices reinject within 120 seconds of reclose.
- Test Automatic Bypass due to a System Event Causing High Current (fault current) - SmartValve bypasses 100% of the time when a system event drives the line current above the specified bypass threshold (fault current).
- Quality of the Communications Link – a test to be specified by TransGrid for their own system

GHD considers this performance test regime and performance requirements are consistent with the investment need - achieve the additional 170 MW of transfer capacity for the VNI transmission interconnector.

Substation and transmission lines

The design specifications for the balance of plant (substation, transmission and secondary systems) is consistent with the operating and control systems requirements for the MPFCs to achieve the required performance outcomes using standard TransGrid's designs.

4.5 Scope definition for procurement of work packages

As detailed in section 10, TransGrid split the scope definition into different scope packages to support the design and construct tenders detailed in that section.

The scope packages included in these tenders largely align with the VNI scope definition detailed in Appendix A. The high level specifications for the Smart Wires system are summarised below in Table 11 which was contained in more detailed under equipment specific requirements in the "Modular Power Flow Control (MPFC) – Technical Specification". This reflects the final stage of refining the scope of the major plant.

Table 8 Smart Wire system high level specification

Smart Valve and System Specification	Stockdill	Yass
System Specification	45 x i3600 units	6 x i2600
Maximum Continuous Current	2570 amps	1741 amps
Maximum Emergency Current & Duration	2900 amps for 2 hrs	1890 amps for 15 min
Maximum Voltage Injection	2830 V	566 V
Minimum Current Injection	100 amps	200 amps
Maximum Operating Voltage	365 kV	365 kV

As found in section 10, the design and construction tenders for the balance of plant are based upon appropriate scope specifications. The specifications which include the TransGrid concept designs and TransGrid's Standard Design Manual and Standard Construction Manual are consistent with electricity industry practice for transmission networks.

The specified work packages for procurement have been assessed to verify that the specifications are efficient to provide the asset performance requirements as detailed in section 10.

GHD reviewed the scope of the concept design works and concluded it is reasonable and realistic to meet the investment need.

4.6 Summary of the scope review

Findings	
1	The selection of MPFCs to address the thermal capability of 330 kV transmission circuits between Canberra and Upper Tumut carries some additional risk, as: • The Smart Wires MPFC is a relatively new technology and had not yet been developed for current ratings that would be required for installation on the 330kV Upper Tumut – Canberra Line • Smart Wires is a comparatively small supplier with limited local representation in Australia.

Verification	
Project investment scope	As detailed above, the project investment scope aligns with the investment need and has undergone appropriate option analysis.
Asset Performance requirements	Based upon the analysis performed a decisions made, the selection of the options has come down to addressing the thermal capability of 330 kV transmission circuits between Canberra and Upper Tumut. MPFCs have been selected as the preferred option to deliver 170 megawatts. Issues related to stability limits have been left to other RIT-T projects to resolve. The PADR assessment did not identify any technical issues with these MPFC and further modelling in the PACR stage was conducted to assess the potential for control interactions between the MPFC and nearby generators.
Scope definition for procurement of work packages	The scope packages included in design and construction tenders reflect the relevant subcomponents of the VNI scope definition. GHD reviewed the scope of the concept design works and concluded it is reasonable and realistic to meet the investment need.
CPA scope definition	The CPA scope definition is clear and has been replicated in Appendix A.

5. Capex forecast review

5.1 TransGrid's capex forecasting process

During the RIT-T process and development of the VNI project, TransGrid developed Class 4 estimates corresponding to the PADR based on historical costs from TransGrid's Success Cost Estimating Database.

Costs for the credible options were estimated in three parts:

- Network option costs in NSW were developed by TransGrid
- AusNet Services developed the costs for the Victorian network options
- Vendors provided costs for non-network options.

For each option, the costs were varied by ±30% as a worst-case scenario to test the reasonableness of the anticipated market benefits, and the robustness of any underlying assumptions that may impact on the value of market benefits. The following components were included in the analysis:

- Equipment and services procurement
- Installation/construction works
- All station upgrade works:
    - Plant and equipment
    - Civil works
    - Labour
- Project management
- Contracts.

GHD initially provided analysis of TransGrid's Class 4 estimates considering an assessment of the reasonableness of the preferred network option estimated costs. This analysis is provided in Appendix B.

The results of the tender outcomes and signed contractual arrangements for the supply of the MPFCs specialist equipment are now reflected in the CPA capex forecast in this section. This review provides an assessment of the efficiency of the costs obtained through the procurement process using GHD's comparative estimates for the project scope.

5.2 Assessment approach

5.2.1 Variance range

Full details of the methodology and assumptions used in the preparation of comparative estimates are provided in Appendix C. Our reference comparative estimates for similar projects are used as a test for reasonableness of the forecast costs being efficient. The comparative estimates are based on inputs from completed projects throughout Australia for similar types of 330 kV substation and transmission projects, older project costs escalated and weighted against new project data being entered.

The technology adopted for the MPFCs is to be provided by Smart Wires technology and is relatively new.

GHD has used two alternative approaches to provide comparative estimates for this specialist equipment.

The first approach uses the unit base pricing provided by Smart Wires on their website available for use by network owners in feasibility studies for potential applications.

The second approach reviewed international pricing for comparable power electronic devices such as STATCOMs, SVCs and TCFCs.

GHD's comparative estimates were developed corresponding to the scope in PACR and was conducted to build the comparative building block model in readiness of final market tested pricing.

The contracted pricing obtained by TransGrid for each work package is compared using the same model.

Where the variation to the comparative estimate is less than ±20%, GHD considers the TransGrid's CPA proposed costs are reasonable and no further detailed assessment is undertaken.

For costs elements where the variation is outside the nominal range, GHD has reviewed any known project specific issues or omissions in GHD's comparative costs to identify the potential reasons.

5.2.2 Tendered costs

The tendered costs and the sole source supplier costs are reviewed in this section to consider whether the procurement process has achieved efficient costs for this project. These are some direct supplied equipment from TransGrid within these costs that have been sourced via period contracts with suppliers.

The review is conducted to a second level of cost categories and further analysed if the variance is +/-20% of more from GHD's comparative estimates. The second level cost categories derived from tender schedules for the CPA has differed from categories used in previous TransGrid estimates for the PACR submission.

GHD has made some adjustments to align the scope categories to achieve a like for like comparison. In particular, contractor project management, design and drawing, and plant costs have been reallocated to align with GHD's cost estimating methodology.

5.2.3 TransGrid direct labour and indirect costs

The direct costs and overheads have been reviewed in detail in section 6. This consists of two separate parts:

- A bottom up review of the costs estimates to aid transparency, and where appropriate the supporting spreadsheet to the calculation have been checked
- A benchmark review of the total to assess whether TransGrid's costs fall with an expected range for this of project and complexity.

5.3 CPA capex forecast

Table 9 below summaries the proposed CPA capex forecast.

Table 9 Total forecast capex for the VNI project by category ($M, Real $2018)

Category of VNI capex	Capex ($M, Real $2018)
Substations (including Smart Wires)	34.5
Transmission lines	0.4
Secondary systems	2.6
Direct labour	3.6
Network and corporate overheads	3.6
Real input costs	0.3
Total capex	**45.0**

5.4 Assessment outcomes

5.4.1 CPA tender and contracted costs

Table 10 below details the tender outcomes relating to substations, representing the material component of the capex forecast. The two tender results in Table 10 represent 92% of the total tendered cost.

GHD has been provided with documentation, as detailed below to support these tender outcomes. GHD has further discussed the procurement process in section 10.

Table 10 Substation and transmission line tender outcomes ($M, Real $2018)

Category of VNI capex	Verification	Capex ($M, Real $2018)
Smart Wires	Agreed to TransGrid contract with Smart Wires.	20.7
[redacted]	Agreed to [redacted] tender offer.	12.1

5.4.2 Comparative estimates

Table 11 shows a comparison of GHD comparative estimates with the following forecasted cost estimates:

- CPA forecast
- PACR (align with the data provided in the CPA forecasting methodology)[16] .

[16] this breakdown differs from Appendix A which was based on previous data provided to GHD. The previous data appears to be incorrect based on our comparative estimates and the final CPA forecast breakdown

Table 11 Comparison of estimates ($M, Real $2018)

Activity	PACR $ M	CPA forecast* $ M	GHD comparative estimates $ M	Variance GHD to CPA	
				Δ Total $ M	Δ Total %
Direct construction costs					
Smart Wires	21.44	21.32	20.40	(0.92)	-5%
Substation augmentation	9.05	12.52	10.90	(1.62)	-15%
Substation secondary works	2.25	2.60	2.49	(0.11)	-4%
TL 01 & TL 3C Stockdill works	2.50	1.11	1.47	(0.36)	25%
Direct costs total	**35.23**	**37.54**	**35.26**	**(2.28)**	**-6%**
TransGrid Direct Labour	-	3.60	7.09	0.11	-8%
TransGrid Corporate & network overheads	5.23	3.60			
Total	**40.46**	**44.74**[17]	**42.01**	**(2.73)**	**-4%**

* breakdown into cost categories will slightly differ from the CPA breakdown for like for like comparison to GHD estimates

From the comparisons shown in Table 11, the variances for the GHD comparative estimates to the CPA forecast values for both the direct costs and the overall forecast totals are within the nominal ±20% range, and therefore we consider the overall CPA forecast to be reasonable and an efficient outcome. The exception is the transmission line augmentation work, where the variance is outside the range, however the value of the variance is small, less than 1% of the total VNI capex.

The following provides an analysis of the variance for cost categories and explanations of the adjustments necessary to provide like for like comparison with GHD estimates, and assessment of the costs increases since the VNI capex forecast submitted in the PACR.

5.5 TransGrid's VNI capex forecast process

TransGrid adopted a three step process in forecasting the capex for VNI:

1. The capex forecast was developed through:
   - Prices obtained through the tender process in place of earlier forecast (PADR and PACR) using internal estimates form the costs held in TransGrid's the Success Estimating System
   - A bottom-up estimate of indirect costs (network and corporate overheads) substituting for the business-as-usual percentage allowances based on historic projects held in the Success Estimating Database
2. A VNI Capex Summary and associated VNI Capex Forecast Model were developed to record cost inputs, align costs to a common reference year, and group costs for input into the Post Tax Revenue Model (PTRM). Similar to the capital accumulation model, the VNI Capex Forecast Model capex costs are allocated across years and regulatory asset classes and applies real input cost escalation.

[17] CPA capex forecast less real input costs

The VNI capex forecast generated in step 1 is split by:

- Financial year for project cash flows
- Regulatory asset category
- Commodity type, with real input cost escalators applied to labour only.

The following table summarises the regulatory asset classes that have been approved in Table 4-1 of the AER 2018-23 Revenue Determination, and their relevance to the VNI capex forecast.

De-escalation of current pricing followed the AER approved real material and labour cost escalation factors as part of the current 2018-23 Revenue Determination. For labour, the cost escalator is a simple average of forecasts provided by Deloitte Access Economics and BIS Oxford Economics. The real material cost escalators were set to zero by the AER.

3. The outputs from the VNI Capex Forecast Model are used as inputs to the PTRM.

Table 12 Relevant asset categories for VNI

Asset class	Impacted by VNI
Transmission Lines (2018-23)	Yes
Underground Cables (2018-23)	No
Substations (2018-23)	Yes
Secondary Systems (2018-23)	Yes
Communications (short life) (2018-23)	No
Business IT (2018-23)	No
Minor Plant, Motor Vehicles & Mobile Plant (2018-23)	No
Transmission Line Life Extension (2018-23) real material cost escalators	No
Land and Easements	No

5.6 Review of CPA work packages

5.6.1 Review approach

Our approach to this review has adopted the following steps:

- For the GHD comparative estimates, where possible, we used the standard historic construction costs we have for substation and transmission line equipment to generate an independent estimate for the identified scope for the work packages
- For the Smart Wires equipment, we developed a comparative estimate based on available unit costs data from Smart Wires and units costs of difference FACTs technology
- We used GHD's own benchmark costs for corporate and network overheads in the comparative estimates.

5.6.2 Smart Wires work packages

The Smart Wires technology has been sole sourced being the only current supplier and developer of the technology. GHD has taken a different approach to deriving a comparative estimate

The first approach uses the unit base pricing provided by Smart Wires on their website available for use by network owners in feasibility studies for potential applications. The unit budget costs were however not provided for the size of the units being developed for the TransGrid project. Our analysis used the variables that determine total installed costs (Power – MVAr and Current Rating – Amperes) and determined the multipliers that explain the variable costs ($ per kVar). Adjustments were made to allow for the number of current transformers required in each module to meet the specified MVar and current rating. This was calibrated with the data that Smart Wires provided for budget pricing.

Our model then calculates a total for the supply of product and services by Smart Wires (not including site installation costs) summarised below in Table 13. The earlier current rating specification defined for the PADR, compared to the PACR explains the lower total estimated costs at that stage of the project development for the Smart Wires systems.

Table 13 GHD comparative estimates for Smart Wire systems ($M, Real $2018)

Project stage	Smart Wires system	Manuf. costs	Design & oversight	Transport	Import duty	Contingency	Total
PADR	9 x SV 5-1800i 6 x SV 1800i	5.8	3.0	0.5	0.1	1.4	**10.8**
PACR and CPA	45 x SV 3600i 6 x SV 2600i	14.0	3.0	0.5	0.1	2.6	**20.2***

- The total for Stockdill - $18.5 million and for Yass - $1.6 million

The second approach reviewed international pricing for comparable power electronic devices such as STATCOMs, SVCs and TCSCs. The costs were derived from several sources including recent installed costs in Australia for SVCs and STATCOMS.[18] These references that included comparative costs ranged in dates from 2003 through to 2018, and hence reasonable escalation rates were applied to the earlier costs. The results of this review is shown in Figure 4. The cost for the Smart Wires MPFCs for the VNI project is plotted on the chart indicating relative position.

[18] References -

SmartValve Project Cost Estimates – Oct 2019

SmartValve™ 10-3600i – Technical Specification - 2019

FACTS - For Cost Effective and Reliable Transmission of Electrical Energy – Siemens - 2003

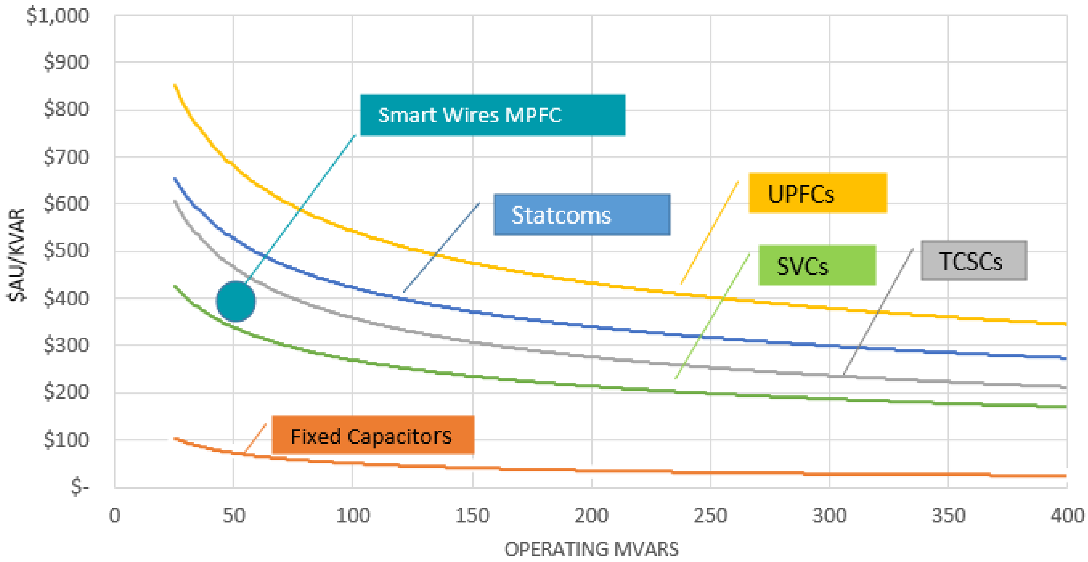
Estimates of Comparative Costs for Uprating Transmission Capacity – IEEE Transactions on Power Delivery – April 2009

A Comprehensive Comparison of FACTS Devices for Enhancing Static Voltage Stability – IEEE – 2007

Various supplied costs available for SVCs and Statcoms installed in Australia and internationally

UPFC with series and shunt FACTS controllers for the economic operation of a power system - Department of Electrical Engineering, Indian School of Mines, Dhanbad 826004, India – 15 May 2015

Figure 4 Comparative FACTS installed costs - $A2018



The unit pricing for the Smart Wires MPFC is less than TCSCs – a more direct completing technology solution. TCSCs use thyristors to control fixed capacitors and reactors to provide faster and more variable response compared to fixed capacitors. They require a much larger footprint compared to the MPFC solution and the system components are required to be insulated to the system voltage (330kV in this case), all contributing to much larger costs overall for manufacture, supply and installation.

SVCs are shunt reactive devices and use similar technology to the series TCSCs devices, however the market for these devices are much larger and economies of scale and technology maturity assists in bringing down unit costs.

Statcoms and the Smart Wires systems both use voltage source invertor technology. Statcoms provide shunt reactance and are insulated to the system voltage (330kV) and connected to the phases through power transformers to supply the rated MVar capacity. This technology is continuing to develop as the market grows. The Smart Wires system is placed in series with the conductor and the patented single core modular transformers are able to supply multiple low-power invertors and to also inject reactive voltage back into the power line conductor. The modular design also facilitates manufacturing and installation efficiencies.

The unit cost for the Smart Wire MPFC appears to be less than that for STATCOM unit costs. This may suggest that the costs are currently below sustainable business costs, however the pricing may be currently positioned to obtain market entry to compete with alternate transmission line reconductoring solutions. Smart Wares has stated the aim to achieve unit costs of $US100/kVar in the future. GHD's view that sustainable installed costs of between $A300 and $A400 per kVar will provide a cost effective alternative to upgrading transmission lines in Australia in the future.

Table 14 Comparison of Smart Wires allowances ($M, Real $2018)

Activity	PACR $ M	CPA forecast $ M	GHD comparative estimates $ M	Variance GHD to CPA	
				Δ Total $ M	Δ Total %
Supply, design and testing at Stockdill Substation	17.42	19.47	18.54	(0.93)	-5%
Supply, design and testing at Yass Substation	3.02	1.61	1.61	0	0%
Spares	1.01	0.24	0.24*	0	0
Total	**21.44**	**21.32**	**20.40**	**(0.93)**	**-5%**

* GHD has adopted the contracted cost of spares

We can verify that the forecast cost for the Smart Wires installations is an efficient outcome, based on the configurations to be constructed at each substation, and the costs negotiated with Smart Wires to supply and assist in the design and commissioning works. The variance for the Yass installation shows an exact match. GHD's comparative model was initially based of an incorrect rating of 1800 amps and a 37% variation was being indicated. Once the rating was changed to 2600 amps in GHD's comparative estimate the variance reduced to zero.

5.6.3 Substation augmentation work packages

The substation works involved augmentation, civil and secondary works at Stockdill and Yass Substations.

This work is to include:

- Installation of Smart Wire MPFC at existing Stockdill Substation, involving 45 i3600 SmartValves units
- Installation of 6 x i2600 SmartValves units at Yass Substation
- Civil works for extension of switchyard at Stockdill Substation, including earthgrid extensions and additional security fencing
- Construction of 330 kV disconnector bypass at Stockdill Substation
- Modifications to gantry and landing span structure at Stockdill Substation
- LV cabling to the control room at both substations
- Modifications to protection, control systems, SCADA and communications at both substations.

Table 15 shows a summary of the forecast costs for the substation augmentation works.

Table 15 Comparison of substation augmentation works estimates ($M, Real $2018)

Activity	PACR $ M	CPA forecast $ M	GHD comparative estimates $ M	Variance GHD to CPA	
				Δ Total $ M	Δ Total %
Civil works	6.87	8.10	7.12	(0.98)	-14
Electrical & secondary system works	1.05	3.36	2.76	(0.60)	-22

Activity	PACR $ M	CPA forecast $ M	GHD comparative estimates $ M	Variance GHD to CPA	
				Δ Total $ M	Δ Total %
Major plant, equipment & materials	1.13	1.06	1.02	(0.04)	-4
Total	**9.05**	**12.52**	**10.90**	**(1.62)**	**-15**

The overall variance of -15% is within the nominal ±20% range for assessing costs, and therefore we consider the CPA forecast for substation augmentation costs to be reasonable and an efficient outcome.

During the initial comparison with GHD estimates larger variations were evident in the substations costs and the transmission line costs. TransGrid's own costs for transmission lines in the PACR were also much higher TransGrid has listed in the CPA forecasts for these costs.

- Substation works

  TransGrid allocated the design and project management, general and ancillary services for Stockdill substations works to civil and electrical works and a very small component to the direct transmission line costs. To provide a like for like comparison to GHD's estimates we adjusted the allocations which mainly resulted in transferring some mobilisation, project management and plant costs to transmission lines. This results in a lower cost for the substation costs in total and respectively to the sub categories under substations

- Civil works

  We assumed a switchyard extension of 2,925 sq m, including allowance for excavation of local heavy rock, disposal of waste material, extension to the existing earthgrid, additional drainage and cable ducting and new security fencing. Our allowances for civil works have been based on industry standard average activity costs, and the contractor's pricing will have more specifically considered the site and any local conditions.

  The variation with GHD's comparative estimate is 14% which is within the +/-20% range.

- Electrical & secondary system works

  An omission was identified in GHD's initial comparative estimate build-up which did not include installation costs for the secondary systems works. After this correction, the variance for electrical and electrical and secondary works was still outside the nominal ±20% range.

  We were unable to determine the exact reasons however GHD's view is that there may be some additional costs for LV cabling and communications that we have not fully appreciated. The monetary value of the difference (a variance of $0.6 million) is considered small at around 1% of the total capex forecast.

- Major plant, equipment & materials

  The variation was -4% which did require further consideration. The variation however would have been larger had we not adjusted for project management and plant costs and transferred a proportion to transmission line costs.

5.6.4 Substation secondary work package

To mitigate the risk of incorrect operation of distance protection relays due to the Smart Wires installation on the 330 kV transmission feeders (TL01 at Stockdill and TL02 at Yass substation), the substation secondary work package includes upgrades 26 protection relays at Stockdill and Yass substations.

Table 16 shows a summary of the forecast cost and GHD comparative estimate for the secondary system works at Stockdill and Yass Substations.

Table 16 Comparison of substation secondary works estimates ($M, Real $2018)

Activity	PACR $ M	CPA forecast $ M	GHD comparative estimates $ M	Variance GHD to CPA	
				Δ Total $ M	Δ Total %
Secondary system material & equipment	1.58	1.60	1.59	(0.02)	-1
Secondary system plant (relays)	0.02	0.50	0.4	(0.1)	-25
Commissioning and modifications	6.40	0.49	0.5	(0.01)	1
Total	**2.25**	**2.60**	**2.49**	**(0.11)**	**-4**

The overall variance of -4% is well within our nominal range of ±20% for assessing reasonableness, and therefore we are of the opinion that the forecast cost of $2.60 million is reasonable for the protection upgrade works. The monetary value of the variance for the secondary system relay costs is immaterial.

5.6.5 Substation works summary

Table 17 shows a summary of all substation works, including the supply, installation and commissioning of the Smart Wires units at Stockdill and Yass Substations.

Table 17 Comparison of combined substation works estimates ($M, Real $2018)

Activity	PACR $ M	CPA forecast $ M	GHD comparative estimates $ M	Variance GHD to CPA	
				Δ Total $ M	Δ Total %
Smart Wires supply, testing, commissioning	21.44	21.32	20.40	(0.92)	-5
Substation augmentation works	9.05	12.52	10.90	(1.62)	-15%
Secondary system works	2.25	2.60	2.49	(0.11)	-4%
Total	**32.73**	**36.44**	**33.79**	**(2.65)**	**-8%**

The total substation works forecast is largely composed of the Smart Wires supply, installation, testing and commissioning costs. The variance is -8% for the total substation works which is within our nominal range to not further investigate the differences.

5.6.6 Transmission line work package

The transmission line works are comprised of the replacement of two existing structures – TL 01 Structure 282A and TL3C Structure 16B – with new concrete poles, together with a notional 100 m of Twin Olive ACSR conductors, one OPGW, one Grape ACSR OHEW and standard fittings and insulators.

Table 18 shows a comparison between the forecasts and the GHD comparative estimate for the replacement of two structures on transmission lines TL 01 and TL 3C.

Table 18 Comparison of transmission line works estimates ($M, Real $2018)

Activity	PACR $ M	CPA forecast $ M	GHD comparative estimates $ M	Variance GHD to CPA	
				Δ Total $ M	Δ Total %
Civils, access roads, footings & concrete structures	2.50	1.10	1.47	0.36	25%
Total	**2.50**	**1.10**	**1.47**	**0.36**	**25%**

As discussed under the substation augmentation work package, TransGrid had allocated the design and project management, general and ancillary services for Stockdill substation works to civil and electrical works and a very small component to the direct transmission line costs. To provide a like for like comparison to GHD's estimates we adjusted the allocations which mainly resulted in transferring some mobilisation, project management and plant costs to transmission lines. This results in a higher cost for the transmission line works however the adjustment still shows a variance of -25% which for the relatively small costs involved this could be explained by the of the contractor overheads.

Overall the substation and transmission lines works were competitively procured and hence the market based pricing will more accurate than GHD's estimate of the costs. The monetary value of the variance is less than 1% of the total capex forecast.

We are satisfied that the TransGrid forecast cost for the transmission line work in the CPA are reasonable when considered bundled with the substation costs. The allocation of contractor project management and plant costs would result in a different split of costs between substations and transmission lines.

6. Direct labour and indirect costs

6.1 Review of cost estimates

6.1.1 TransGrid cost forecasts

Table 19 details the incremental labour and indirect costs that have been incurred and forecasted as required to deliver VNI.

Table 19 Direct labour & indirect capex ($M, Real $2018)

Indirect capex element	Comments / reference	Direct labour costs ($ million)	Network and corporate overheads ($ million)	Total ($ million)
Actual labour and indirect costs	Capex incurred on the VNI Project from 1 July 2018 to 30 September 2020	0.8	2.2	2.9
Works delivery	Refer 6.1	2.3	1.0	3.4
Project development	Refer 6.2	0.5	0.3	0.8
Insurance	-		0.1	0.1
Total		**3.6**	**3.6**	**7.2**

6.1.2 Works delivery capex forecast

The Labour and Indirect Costs Forecast for VNI Minor Upgrade Project details the forecasting methodology and assumptions and is supported by the VNI TransGrid Labour and Indirect Costs Spreadsheet.

As detailed in both TransGrid has estimated that 13 additional roles will be required and associated costs detailed in Table 20 below.

Table 20 Direct labour ($M, Real $2018)

Indirect capex element	Comments / reference	Total ($ million)
Labour	• 8 project management roles: ○ 2 Project Managers ○ 3 Project Resources ○ 1 Safety Officer ○ 3 Site Managers ○ General Support. • The secondary systems specialist roles ○ Control Technician ○ Secondary Systems Technician ○ Telecommunications Technician ○ Substation Fitter • Phased over the life of the project • Standard labour rate	2.6

Indirect capex element	Comments / reference	Total ($ million)
Sustenance	-	0.3
Travel	-	0.2
Recruitment	-	0.2
Other	-	0.1
Total		**3.4**

6.1.3 Project development costs

The Labour and Indirect Costs Forecast for VNI Minor Upgrade Project details the forecasting methodology and assumptions and is supported by the VNI TransGrid Labour and Indirect Costs Spreadsheet.

These detail 41 additional roles project management, site management a technical roles phased across the project with partial allocation to the VNI project and include:

- 6 roles for project management within the VNI Project Team
- 11 roles resourced to specifically support the VNI Program
- 5 roles allocated from the core team of the Major Projects Division
- 19 other support and corporate roles allocated from the Major Projects Division.

6.2 GHD assessment of overhead costs

The first part of the assessment reviewed the build of the costs based on head count and hours required over the project duration, including costs already incurred in the early project development phase. This is a bottom up approach to estimating the project development and works delivery labour costs.

A second question relates to benchmarking the overall costs as to whether these owner costs are prudent and efficient.

GHD has used guiding metrics to arrive at an independent estimate of reasonable owner costs and used comparably major civil and electrical industry projects as a guide. This comparison needs to take into consideration of the scale of the VNI project, the allocation and management of risks, and the components TransGrid includes in their corporate and network overheads estimate, as distinct from other comparative estimates, and distinct from the actual capex allocation provided through the AER through Regulated Information Notices (RIN) reporting process.

Generally speaking, the larger the project, the smaller the project development and management owner costs will be as a percentage of the total. Hence smaller projects will result in a relatively higher percentage due to a proportion of fixed overhead costs.

The outsourcing model will also affect the level of resources required at the interface point with contracted development and construction services. The procurement of contracted services for the VNI project is based on supply from three separate contractors, the largest being the procurement of the Smart Wires MPFCs representing around 50% of the total project costs. There are little to no project element costs for TransGrid in areas such as property and easement acquisition, biodiversity offset costs, and stakeholder engagement.

Generally various reports on infrastructure projects, including transmission projects indicate project management costs in total for all phases of a project with project controls managed by the owner are in the range of 9-15 per cent of total project costs.

Ernst & Young Transport in 2011 prepared a report for the NSW Department of Transport titled "Infrastructure – Project Cost Benchmarking Study". The study collected data from eight road and rail authorities across Australia for projects above $0.50 Billion in total cost – ranging up to $1 Billion.

Overall this report found the average owner costs (excluding design costs) for road projects as a percentage of total construction costs was 11%. Including detailed design work the average percentage increased to 14%.

There were 14 road projects selected for analysis with owner costs (without design) varying from 7% to 16%. Removing the two outliers the range was from 8% to 14%. The average owner costs (excluding design costs) for rail projects was 16%. Including detailed design the average percentage increased to 21%. There were 14 rail projects selected for analysis with owner costs (without design) varying from 8% to 30%. Removing the two outliers the range was from 9% to 20%. This illustrates a relatively flat distribution between these ranges for both road and rail projects.

The effect of scale of these projects is significant affecting the above average costs as shown below in Table 21[19].

Table 21 Owner costs as percentage of total construction cost[20]

Total construction costs	Rail owner costs (%)	Road owner costs (%)
(<$100M)	26.4	19.4
($100M-$1000M)	15.0	11.3
(>$1000M)	11.5	-

A guideline of direct relevance to transmission projects is the MISO21 published "MTEP19 Transmission Cost Estimation Guide", which was last updated in December 2019. The MISO transmission planning process and role is similar to AEMO in Australia.

This guide is prepared to support MISO planning staff in developing cost estimates and deriving benefit-to-cost ratios for solutions proposed for the expansion of the MISO transmission network. In this respect this process is similar to the RIT-T process under the Australian NER.

[19] Including design costs

[20] Infrastructure – Project Cost Benchmarking Study - Ernst & Young, fig 52 page 83

[21] The Midcontinent Independent System Operator (MISO) is an Independent System Operator providing open-access transmission service and monitoring the high-voltage transmission system in the Midwest United States and Manitoba, Canada and southern United States which includes much of Arkansas, Mississippi, and Louisiana.

MISO's transmission cost estimation guide describes the approach and cost data that MISO uses in developing its cost estimates. This document assumptions and cost data are reviewed annually with stakeholders.

In section 3.4 of this guide, project overheads applied to cover costs for developing and delivering a potential project are aggregated into three categories with the percentage of total project costs applied:

- Project management (including mobilisation and demobilisation) - 5.5%
- Engineering, environmental studies, testing and commissioning – 3.0%
- Administrative and general overhead – 1.5%

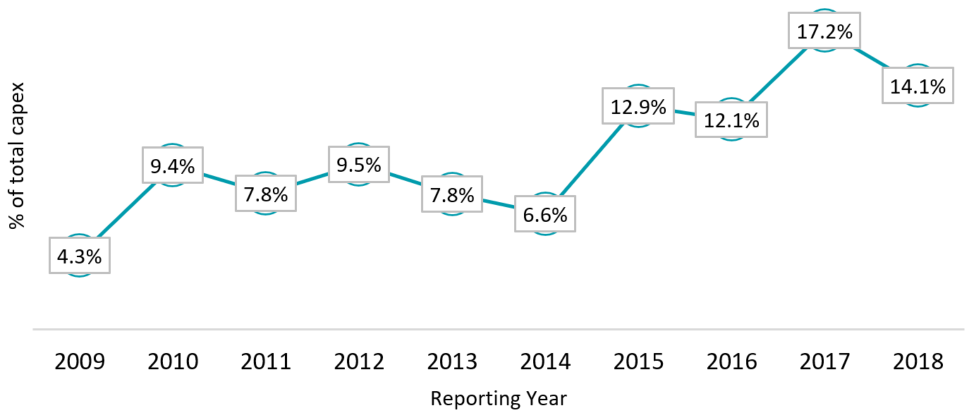
The costs for the transmission and substations projects therefore includes a total margin of 10% for overheads. This is a margin on the total project estimate rather than a cost mark-up of the individual transmission and substation costs.

The costs for routing analysis, public outreach, the regulatory approval and permitting processes, property tracts and mapping, land owner negotiations, land acquisition and condemnation fees appears under direct "Land Costs". In comparison with TransGrid's corporate and network overheads, the MISO guide also does not appear to cover the planning and regulatory approvals which is part of MISO's own management costs and are likely to be recovered by other mechanisms.

GHD's own experience and data relating to major transmission line projects also indicates project overhead costs align closely with the range found with the road projects which is also consistent with the MISO estimated project overheads. The key difference for the VNI project is the relatively lower scale of this project compared to the average size of projects considered in these documents.

TransGrid reports annually on its actual overheads allocated with capex to AER through RINs. The reported data shows that following FY14 the level of allocated costs increased to percentage margins like those in the comparative reports[22]. The total capex program for TransGrid include a range capital works with differing complexity, scale and type (replacement, growth, brownfield, greenfield).

Figure 5 TransGrid capex overheads - reported margin [23]



[22] GHD is not aware of the reason for the apparent increase in FY15

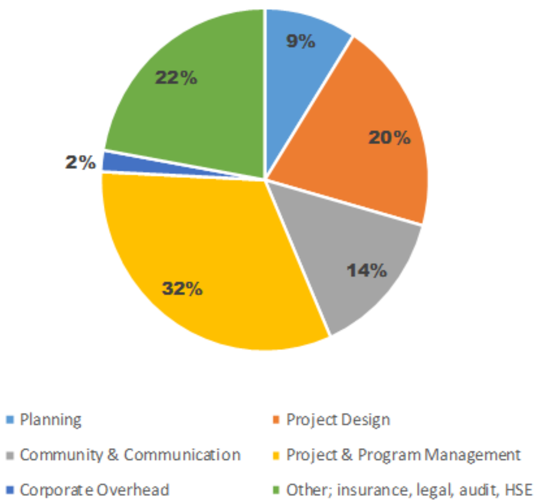
[23] https://www.aer.gov.au/system/files/TNSP%202018%20Data%20report%20-%2024%20July%202019%20-%20FINAL%20for%20publication.xlsm

The methodology of reporting capex overheads appears to have from 2014 to 2015. This has relevance to how this data needs to be interpreted with respect to analysing efficiency. What is included as direct costs versus overheads with respect to individual large projects, and overall in annual reporting had to be considered. It would appear without further analysis that margins reported from 2015 to 2018 are more reflective of the overhead allocations being applied to Contingent Project Applications.

GHD considers that the assessment of overhead costs and cost breakdowns in the Ernst & Young report would be a reasonable start before overlaying for the smaller VNI project expenditure and particular scope elements of the project.

Figure 6 shows the breakdown of costs over the category of expenditure from the projects analysed on the Ernst & Young report Using this category breakdown and considering which categories partly or fully apply to the VNI project an estimate of reasonable project overheads can be made.

Figure 6 Project overhead cost breakdown



These comparative estimate categories could be compared to TransGrid's categories using comments included below in Table 22.

Table 22 TransGrid VNI project overheads comparative scope

Scope	Project overheads (Roads)	Applicable to the VNI Project	Apply to VNI	Comments
Planning	1.26%	50%	1.26%	A reduced degree of planning would be required as the works are within existing substation sites.
Community & Communication	1.96%	75%	1.47%	Low degree of community and communication costs would apply to works contained within TransGrid substations sites.
Corporate Overhead	0.28%	100%	0.28%	A similar degree of corporate overhead would be applicable.
Project Design	2.80%	85%	0.42%	85% of project design assumed to be contracted to service providers. TransGrid is conducting pre design work for the Smart Wires system.
Project & Program Management	4.90%	100%	4.90%	TransGrid has oversight and interface management of the design by separate parties and the construction of the work. TransGrid is required to provide the overall commissioning of the control and communication systems to operate with the separate MPSC systems.

Scope	Project overheads (Roads)	Applicable to the VNI Project	Apply to VNI	Comments
Other Costs	2.80%	100%	2.80%	Considered split 40% work delivery, 40% development and 20% other indirect
Total project overheads	**14.00%**		**9.13%**	9.2% of total project costs for a project above $250 million

As indicated above, total project overheads in Table 50 needs to be adjusted for the scale of the project. Scaling is a combination of different exponential factors applied to estimated fixed and variable components of a typical size project (the assumption being a 11% margin is applicable to a project valued at $250 million). Table 23 provides comparative adjustments for larger and for smaller project sizes and 15.2% is GHD's benchmark project overheads for VNI.

Table 23 Scale factors – project overhead margin

Project size ($ million)	Composite scale factor	Applicable % project overhead
2,000	0.53	4.9
1,500	0.58	5.3
500	0.81	7.4
250	1.00	9.1
100	1.33	12.2
50	**1.66**	**15.2**
25	2.57	23.4

TransGrid has oversight and interface management of the design by separate parties and the construction of the work. It also is required to provide the overall commissioning of the control and communication systems to operate the separate MPFC systems over a wide area network.

The $7.2 million included by TransGrid in the CPA capex forecast represents 16.1% of the total capex and is very close to the % project overhead shown in Table 23 and hence is within the expected range of costs for projects of this equivalent size and complexity (+/-20%).

6.3 Summary of the CPA capex forecast

Verification	
Smart Wires System costs	The variation to GHD comparative estimate is -5% and therefore we consider the costs for the Smart Wires system to be reasonable and an efficient outcome for the project.
Direct costs	The variances for the GHD comparative estimates to the CPA forecast values for the direct costs were -6% and within the nominal ±20% range, and therefore we consider the direct project costs to be reasonable and an efficient outcome for the project. The exception is the transmission line augmentation work, where the variance was outside the range, however the value of the variance is small, less than 1% of the total VNI capex.
Overheads	The overheads are reasonable for this small project size – our comparative estimate of overheads for a project of this size based on owners scope of work requirements is reasonable and within 8% of GHD's comparative estimate.
Overheads – Direct Labour	GHD supports the need for secondary systems technical specialists (direct labour) to provide oversight and direct involvement in the successful testing and commissioning of the Smart Wire systems and protection systems, due to both the complexity, wide area nature of the system and newness of the technology.

7. Real input cost escalations

The details that the forecast real input cost escalation has been calculated by multiplying the labour cost components of the tendered expenditure, property costs, and indirect expenditure by the forecast real labour cost escalators allowed by the AER in its revenue determination for the 2018-23 regulatory period.

Consistent with that determination, no real input cost escalation was included for non-labour components of the expenditure.

The real labour input cost escalators for 2018-19 to 2021-22 are set out in Table 24. These are converted into a cumulative index from the 2017-18 year.

Table 24 Real labour input cost escalator and cumulative index

	2017-18	2018-19	2019-20	2020-21	2021-22
Real labour input cost escalator	N/A	0.81%	0.95%	1.21%	1.46%
Cumulative index	1.000	1.008	1.018	1.030	1.045

8. Changes in capex forecast from RIT-T PACR

8.1 Review of changes in capex forecast

The CPA capex forecast is $45.0 million and the corresponding capex forecast in the PACR was $40.5 million[24]. This section reviews the differences between the capex forecast for the VNI Project in the CPA and the capex forecast published in the RIT-T PACR on 14 February 2020, and an introduction with the initial capex forecast in the PADR.

As detailed in the Capex Forecasting Methodology for VNI Minor Upgrade Project, the capex forecast in the PADR was a class four estimate[25], meaning that only 1 to 15 per cent of project specifications were defined, resulting in a likely variation to the final cost of between -30 per cent to +50 per cent. The capex forecast in the PADR was developed internally using historical costs from their “Success” cost estimating database.

The NSW component of costs in the PADR was estimated to be $21 million which increased to $40.9 million in the PACR. Our assessment indicates the following as the key reasons for this increase:

- The Smart Wires system costed in the PADR had a lower current rating capacity as we detailed in section 5.6.2. GHD’s comparative estimate indicates the difference would have added around $9 million.
- Page 6 of the CPA Capex Methodology states that the final capex forecast for substations of $13.2 million, is an increase of $4.2 million from the PADR forecast of $9.0 million

24 The PACR forecast capex of $40.9 million in $2019-20

25 A “Class 4” under AACE International Recommended Practice and Estimate Classification.

- TransGrid also states on Page 6 that the final capex forecast of $7.2 million for direct labour and overheads is $2.1 million higher than the PACR forecast of $5.3 million. Our review of the Success estimates supporting the PACR shows an allowance of $2.9 million and $1.9 million in the PADR both based on standard overhead norms in the database. Hence overhead increase of around $5 million from the PADR forecasted costs to the CPA forecast

In summation the above totals around $18-20 million of additional costs over the $21 million in the PADR which equates to $39-42 million. This explains 90% of the increase in costs from the PADR to the current CPA capex forecasts.

GHD's comparative estimate of $42.1 million corresponds to the scope of work defined in the PACR and in RFT documentation ($42.3 million with real input costs). This estimated value is between the PACR forecast of $40.5 million and the CPA forecast of $45.0 million.

GHD supports TransGrid's statement in the CPA forecast methodology that the final capex forecast reflects information on the prudent and efficient market-based costs of delivering the VNI Project, which was not available at the time of publishing the PACR. This final forecast reflects the outcomes of further negotiations and refinement with Smart Wires for the modular power flow controllers and competitive procurement processes with multiple bidders for the sub-station, transmission line and secondary system works.

TransGrid has indicated the step changes in costs from the RIT-T PACR to the CPA capex forecast as shown in Table 25 below.

Table 25 Changes in capex forecast from RIT-T PACR

Variance component	Details	Total ($ million)
MPFC	The final capex forecast for MPFC is 21.3 million, a decrease of $0.1 million from the estimate included in the PACR.	(0.1)
Substations	The final capex forecast for substations is $13.2 million, an increase of $4.2 million from the PADR forecast of $9.0 million.	4.2
Transmission lines	The final capex forecast for transmission lines is $0.4 million, a decrease of $2.1 million from the PACR forecast of $2.5 million	(2.1)
Secondary systems	The final capex forecast for secondary systems is $2.6 million, an increase of $0.4 million from the PACR forecast	0.4
Indirect costs	The final capex forecast of $7.4 million for direct labour and overheads is $2.1 million higher than the PACR forecast of $5.3 million	2.1
Total		**4.5**

GHD has provided the comparisons of changes in costs by cost categories in Table 26 below and diagrammatically in Figure 7. Our analysis of the $4.5 million increase between the PACR and final capex supports the analysis reported by TransGrid except that GHD considered that adjustments to the CPA forecast breakdown was warranted as follows:

- Substations – GHD identified in section 5.5 that a relocation of contractor overheads such as mobilisation, plant and project management costs provides a different total costs for substation augmentation of $12.6 million which is lower than TransGrid's total of $13.2 million. Hence compared to the PACR this is an increase of $3.5 million which is less than the $4.2 million stated by TransGrid.

- Transmission lines – GHD's relocation of contractor overheads increased the costs identified by TransGrid's of $0.4 million to $1.1 million. The difference to the PACR would then be a decrease of $1.4 million which is less than the $2.1 million identified by TransGrid.
- Secondary Systems – The change of 0.4 million identified by TransGrid is unchanged after the reallocation of overheads by GHD
- Direct labour and indirect costs – GHD found the same change of $2.1 million as identified by TransGrid.

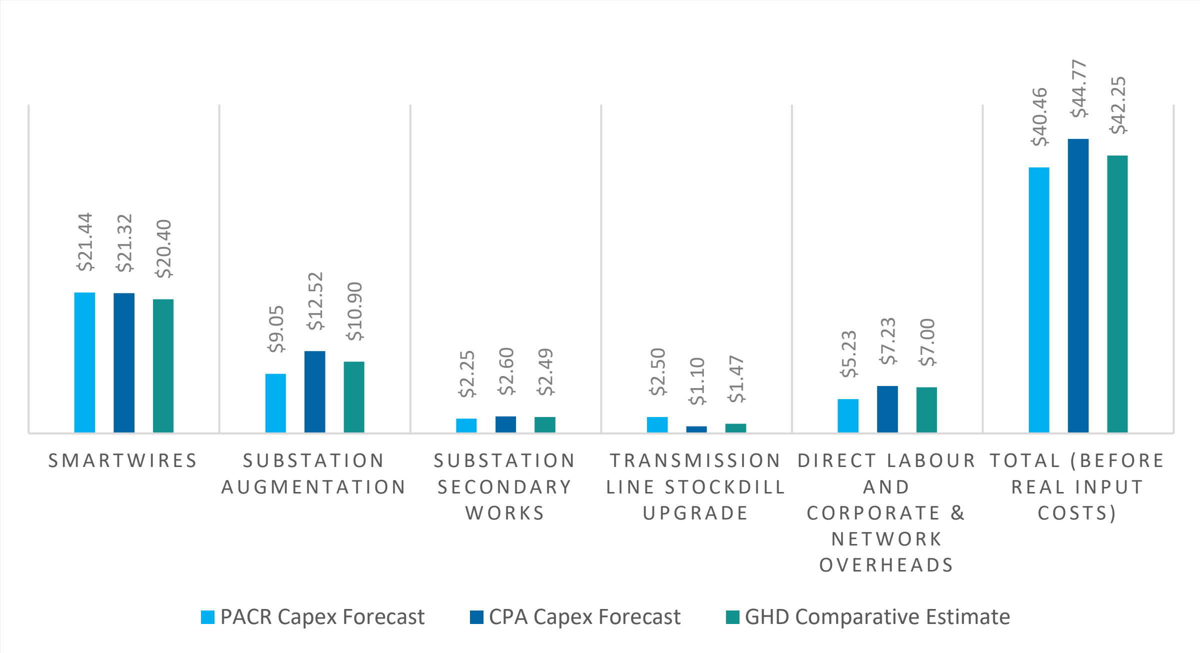
The two prime reasons for the increase is consistent with TransGrid's findings. Firstly, the additional civil and electrical works costs which was as a result of a tendering process compared to estimated costs in the PACR. Secondly the increase in TransGrid's direct labour and indirect costs which is a result of a bottom up review of the expected resources required.

GHD is of the opinion, as detailed in section 6 that the bottom up build of the expected resource requirements for direct TransGrid labour and corporate overheads for the VNI Project is reasonable for this size and type of project. In particular the oversight and direct involvement of secondary control systems specialists is warranted for the successful testing and commissioning of the Smart Wire systems. These costs included in this scope item were identified by TransGrid as necessary following clarifications on the technical performance of the modular power flow controller. This is required to enable the safe operation of the network.

Table 26 Comparison of capex forecasts ($M, Real $2018)

Activity	PACR forecast $ M	CPA forecast[26] $ M	GHD comparative estimate $ M
Direct construction costs			
Smart Wires	21.44	21.32	20.04
Substation augmentation	9.05	12.52	10.90
Substation secondary works	2.25	2.60	2.49
TL 01 & TL 3C Stockdill upgrade	2.50	1.10	1.47
Direct Costs total	**32.73**	**$37.54**	**$34.92**
TransGrid Direct Costs	-	3.62	7.00
Corporate & network overheads	5.23	3.61	
Total	**40.46**	**44.77**	**42.25**

Figure 7 Cost difference of changes from the PACR to the CPA forecast ($M, Real $2018[26]



8.2 Summary of changes in capex forecast

Table 27 provides a summary of GHD findings related to the review of the project schedule phasing and capex recognition.

Table 27 Change in capex forecast - findings, qualifications and verification

Verification	
1	GHD supports TransGrid's statement that the CPA capex forecast reflects pricing based on efficient market-based costs of delivering the VNI Project, which was not available at the time of publishing the PACR. This final forecast reflects the outcomes of further negotiations and refinement with Smart Wires for the modular power flow controllers and competitive procurement processes with multiple bidders for the substation, transmission line and secondary system works.
2	GHD also supports the need for secondary systems technical specialists (direct labour) to provide oversight and direct involvement in the successful testing and commissioning of the Smart Wire systems and protection systems, due to both the complexity, wide area nature of the system and newness of the technology.

[26] The breakdown to cost categories is based on GHD's relocation of project overheads and plant costs and will differ to TransGrid's breakdown into the cost categories

9. Project schedule phasing

9.1 Project phasing and capex recognition

Table 28 Total forecast capex for VNI project ($M, Real 2017-18, including indirect costs)

	2018-19	2019-20	2020-21	2021-22	Total
Total capex	0.3	3.5	13.7	27.5	**45.0**

The capex recognition is based on the cost expenditures contained in the project schedules for the balance of plant (substations, secondary systems and transmission lines) and for the negotiated delivery schedule with Smart Wires.

GHD considers the manufacture period of 3 months and successful factory acceptance testing to be the critical milestones to meet this schedule. The balance of plant (design and construction) is a relatively small and normal transmission industry scope of work and should be completed within the timeframe set in the schedules.

9.2 Summary of project schedule phasing

Table 29 provides a summary of GHD findings related to the review of the project schedule phasing and capex recognition.

Table 29 Project scheduling phasing - findings, qualifications and verification

Verification	
1	GHD considers the project schedule phasing to be consistent with the project delivery schedule and that the delivery timeframe is achievable, with the manufacture of the Smart Wires system and successful factory acceptance testing to be the critical milestones to meet the schedule.

10. Procurement

10.1 Introduction

To deliver the project, TransGrid has:

- Adopted a sole sourcing arrangement with Smart Wires which is typical for projects involving technology available from the one supplier
- Leveraged existing panels to deliver design and construction services for other project elements. This decision was based upon the relatively high degree of certainty associated with the works and supplier capabilities and leverages previous panel evaluation process.

Table 30 details the tender components.

Table 30 VNI tender components

Tender	Details	Detailed in section
Design	Smart wires - design, manufacture and supply and commissioning of the Smart Wires MPFC including: • Smart Wires i3600 unit to be erected and installed at the 330kV Stockdill substation. This will allow the 330 kV Upper Tumut – Canberra and Upper Tumut – Yass lines to balance power flows and increase transfer capability, and • Smart Wires i2600 unit and associated equipment to be installed at the Yass 330kV substation.	Section 10.7
	Substation design work for Stockdill 330kV substation to facilitate installation of Smart Wires i3600 unit. This includes providing HV civil and structural design drawings and investigation reports and safety in design report and register.	Section 10.2
	Transmission design work including initial scoping, concept design and standard development, detailed design	
	Secondary system design work including relay notification forms, relay test instructions, automation design and bill of materials, and	
Construction	Major substation construction (augmentation) works at Stockdill 330kV substation to facilitate installation of Smart Wires i3600 unit. This includes: • Civil, site and structural works including: bulk earthworks; footings, trenching and conduits; and gantry structures, and • Electrical and secondary system works including: the installation of the disconnector by-pass bay; all earthing connections and the modification of existing landing span structure and conductors.	Section 10.3 and 10.6
	Minor substation construction works at Yass. This will involve installation of SmartValves on proposed SmartPods, low voltage cabling to the control room with installation of trenches, HV connection work, the installation of Smart Wires antenna and other works associated with the installation and commissioning of the SmartBanks modules.	
	Transmission line construction work including civil and structural works associated with installing new 330kV structures, installing new foundations, stringing works (notional 100m Span Length from new structures to substation gantry), meeting earthing requirements.	
	Secondary system construction work including protection replacement works, subsequent testing and commissioning support	

Tender	Details	Detailed in section
Direct	HV major plant, equipment and materials for Stockdill 330kV substation [DN: Mansour to include examples of the type of plant and equipment]. This will be provided as free issue items to the suppliers who are undertaking the major substation construction work at the Stockdill 330kV substation	Section 10.4
	Procurement of transmission line equipment (ie. poles and insulators). This will be provided as free issue items to the suppliers who are undertaking transmission line construction work at the Stockdill 330kV substation	Section 10.5

10.2 Design

The Capex Forecasting Methodology for VNI Minor Upgrade Project outlines that a competitive tender process to procure design works for the Stockdill substation and for the transmission line construction works utilising an existing panel seen as consistent with industry practice.

The tenders were based on the Victoria - NSW Interconnector Upgrade Design Brief and concept designs, which were supported by TransGrid's Standard Design Manual and Standard Construction Manual.

The Victoria - NSW Interconnector Upgrade Design Brief adequately defines the scope.

The design tender does not cover Smart Wires MPFC as this was subject to a separate tender process detailed below.

Substation design

The Victoria – NSW Interconnector Upgrade Design Brief details the Stockdill and Yass substation scopes consistent with the scope described in Appendix A apart from installation of Smart Wire MPFC which will be performed by TransGrid under Smart Wire supervision.

Transmission line design

The RFT issued was based on concept designs and were supported by TransGrid's Standard Design Manual and Standard Construction Manual. Suppliers were asked to provide detailed designs to achieve technical compliance. The RFT was supported by:

- NSW Interconnector Upgrade Design Brief
- Design sketches

10.3 Construction

The Capex Forecasting Methodology for VNI Minor Upgrade Project outlines that a competitive tender process was undertaken to procure the major substation works at the Stockdill substation and minor substation works at Yass utilising an existing panel. The same for the delivery of transmission line construction works at the Stockdill substation.

Internal VNI Construction Sourcing Memos dated 18 March 2020 and 29 June 2020 details that two panel members were selected to progress cost estimates on the following scope of works:

- Bench Extension at Stockdill Substation and all associated works
- Transmission Line landing span and structure augmentation
- Secondary Systems replacement
- Erection and installation of the Smart Wires modular power flow controller

Substation construct

The RFP VNI Construction and Connections details the Stockdill and Yass substation scopes consistent with the scope described in Appendix A apart from installation of Smart Wire MPFC which will be performed by TransGrid under Smart Wire supervision.

The tender is further supported by the following documents developed by TransGrid:

- Construction responsibility matrix
- Drawings
- Reference documents

Transmission line construct

The tenders were based on the concept designs and supported by TransGrid's Standard Design Manual and Standard Construction Manual.

- Construction responsibility matrix
- VNI Constructions Substations RFP Summary - Rev C.pdf outlines the required scope of works consistent with the scope detailed in Appendix A.
- Drawings
- Reference documents

10.4 HV plant and equipment

The Capex Forecasting Methodology for VNI Minor Upgrade Project outlines that TransGrid intends to use a directly procured approach using current period contracts for the HV plant and equipment required at the Stockdill substation. Transmission line equipment

Transmission line equipment required at the Stockdill substation will be delivered using the same process as detailed above.

10.5 Secondary system

Secondary systems will be delivered using the same process as detailed above.

10.6 Smart Wires

The Capex Forecasting Methodology for VNI Minor Upgrade Project outlines that the MPFC solution is a proprietary technology that can only be provided by Smart Wires so a sole source approach was required.

The same document details that the Smart Wires i3600 unit is currently still in the product development phase and has not:

- Completed final design and component equipment (type) testing
- Completed manufacturing and final product type testing
- Been installed and commissioned on any other transmission network, globally.

TransGrid provided high level specifications to Smart Wires and based upon their initial proposal contract negotiation further progressed with a focus on the allocation of risks to conclude a contract. Based on the information provided to GHD, an initial and comprehensive technical specification was provided by Smart Wires for TransGrid's consideration. This included:

- Equipment specific schedules (4) covering, equipment specific requirements, type test and performance test requirements for each installation.
- The types tests requires 9 x 1-3600i units to be tested which are newly developed modular units for this project.
- A schedule of Principle obligations during warranty
- Component failure rate schedule, and
- Separate schedules (8) covering recommended maintenance, technical support and other general information sought by TransGrid

The contract includes separate portions for supply and payment throughout the progress of the contract, the final portions being successful performance testing of each system at Stockdill and Yass. GHD reviewed the performance test requirements which are a comprehensive list of tests that correspond to the performance requirements in the modelling work and required to reliably meet the 170MW of transfer capacity asset performance requirements discussed in section 4.4 of our report.

GHD was not provided with the commercial details of the Liquidated Damages (LDs) regime which is one key mechanism for the sharing of risk. From discussions with TransGrid staff our understanding is that LDs are linked to the performance outcomes at a rate based on loss of value if the capacity increase of 170MW is not fully achieved and due to the performance of the Smart Wires systems. This is standard practice in contracts for the supply of new generation capacity.

The date for practical completion is scheduled for 4 August 2021[27], one month after performance testing is completed.

GHD considers that TransGrid has achieved an outcome in the negotiations with Smart Wires that is well positioned to manage the risks and at reasonable costs given the sole source negotiation process required.

[27] Annexure A to TransGrid's General Conditions of Contract

10.7 Summary of TransGrid's procurement process

Table 31 provides a summary of GHD findings related to the review of the procurement project schedule phasing and capex recognition.

Table 31 Project procurement - findings, qualifications and verification

Findings	
1	The use of existing equipment and contractor supply panels is consistent with industry practice for a project of this size.
2	The design and construction tenders are based upon appropriate scope specifications. The specifications which include the TransGrid concept designs and TransGrid's Standard Design Manual and Standard Construction Manual are consistent with electricity industry practice for transmission networks.
3	Smart Wires costing has been based upon a sole source negotiation process due to the proprietary nature of the Smart Wires technology. The process undertaken to establish the supply contract is consistent with the approach undertaken for other specialised technology and service, such as the upgrade of existing HVDC systems.
4	As indicated by the Capex Forecasting Methodology for VNI Minor Upgrade Project and the Modular Power Flow Controllers for the Victoria to NSW Interconnector (VNI) Upgrade at Stockdill 330Kv Substation and Yass 330Kv Substation Sourcing Strategy document, there is risk associated with the Smart Wires systems.
5	GHD considers that TransGrid has achieved an outcome in the negotiations with Smart Wires that is well positioned to manage the risks and at reasonable costs given the sole source negotiation process required.

Limitations
GHD has not been given the final version of the Smart Wires contract, only extracts that detail pricing, and an earlier version of the technical and commercial schedules.

Appendices

Appendix A - VNI scope

The NSW component of the VNI scope as reproduced from the OFS and the Capex Forecasting Methodology is as follows:

A.1 Stockdill works

1. Stockdill substation works

The proposed works at Stockdill Substation will involve the following:

- Bench extension
- All civil works associated with the bench extension
- Earthgrid extension
- Installation of the disconnector by-pass:
  - 330kV Switch Disconnector;
  - Insulator Station Post;
  - 330kV Capacitive Voltage Transformer;
  - 2 x 330kV Pantograph (Vertical) Switch Disconnectors;
- Installation of Smart Wire MPFC
- Expand security fence for the new substation extension
- Installation of gantry structure
- Installation of all steel support structures
- LV cabling to the control room (monitor the bypass)
- Control & automation interfacing
- Update existing control system automation and SCADA to configure Smart Wires MPFC
- Install communication links between MPFC and control room for remote operation of the units and monitoring purpose
- Installation of communication channel switches
- Installation of Smart Wires Antenna in close proximity to or on the control building
- All required communications cabling
- Modification of existing landing span structure and conductors
- Protection setting modifications
- All HV connection work
- All other works associated with the installation & commissioning of the MPFC modules
- Erection, installation and commissioning of each component of the MPFC

- Modify Line 01 protection system in accordance with the operation status of SmartValves.

2. Stockdill transmission line works

- Notional 100m span length from new structures to substation gantry
- TL 01 Structure 282A replacement
- TL 3C Structure 16B replacement
- Pole foundation as per existing structure 1-282A as per scoping works for Stockdill substation development
- All new 330kV structures will have:
  - Two 330kV Concrete pole structures based on existing designs for the landing span
  - structures
  - Twin Olive conductors
  - One standard Type B 72F OPGW
  - One Grape OHEW
  - Standard structure earthing
  - Standard fittings and insulators
  - An allowance of 10% for sagging and off cuts has been included.
- 1 month site establishment per new structure.

3. Design, supply and commissioning of Smart Wires MPFC at Stockdill substation

The solution will involve installation of 45 x i3600 SmartValves units within a new Smart Pods installation at Stockdill Substation. The SmartValves installation will be connected in series with the conductor.

The installation of SmartPods and SmartValves is related to the substation civil and structural work, low voltage cabling to the control room with installation of trenches, HV connection work, the installation of Smart Wires antenna and other works associated with the design, installation and commissioning of the Smart Wires system.

A.2 Yass works

1. Yass substation works

The proposed works at Yass Substation will involve the following:

- Installation of six (6) i2600 SmartValves on proposed SmartPods
- LV cabling to the control room (monitor the bypass)
- Control & automation interfacing
- Update existing control system automation and SCADA to configure Smart Wires systems
- Installation of communication channel switches

- Protection setting modifications
- All SmartValves Installation connection work
- All other works associated with the installation & commissioning of the SmartValve units modules.

2. Design, supply and commissioning of Smart Wires MPFC at Yass substation

The proposed solution will involve the addition of six (6) i2600 SmartValves units inside the proposed Smart Pods installation at Yass Substation - part of an earlier TransGrid project.

A.3 Protection & communication systems

The scope of works requires upgrading of protection relays on the 330 kV feeders at Yass and Stockdill 330/132kV substation. This would see the replacement of all standard distance protection schemes to line differential schemes.

The upgrade is required to mitigate the risk of mal-operation of distance protection relays due to Smart Wires installation on 330kV TL 02 at Yass and TL 01 at Stockdill.

Table 32 provides is a list of all protection panels, which will require either relay or scheme modification.

Table 32 Protection relay upgrades

Substation name	Design deliverables	Relays
Yass	330 kV Feeder 2 to Upper Tumut (New Relays)	2
	330 kV Feeder 3 to Lower Tumut (New Relays)	2
	Feeder 3J to Gullen Range (New Relays)	2
	Feeder 4 to Marulan (New Relays)	2
	Feeder 5 to Marulan (New Relays)	2
	Feeder 9 to Canberra (New Relays)	2
Upper Tumut	330 kV Feeder 2 to Yass (New Relays)	2
Lower Tumut	330 kV Feeder 3 to Yass (New Relays)	2
Gullen Range	330 kV Feeder 3J to Yass (New Relays)	2
Marulan	330 kV Feeder 4 to Yass (Scheme Change)	0
	330 kV Feeder 5 to Yass (Scheme Change)	0
Canberra	330 kV Feeder 9 to Yass (New Relays)	2
Stockdill	330 kV Feeder 01 to Upper Tumut	1

Substation name	Design deliverables	Relays
	Change No. 1 to Line differential scheme (Replace the current PCS-902 with a PCS-931)	
	330 kV Feeder 3C to Williamsdale Change No. 1 to Line differential scheme (Replace the current PCS-902 with a PCS-931)	1
Upper Tumut	330 kV Feeder 01 to Stockdill (New Relays)	2
Williamsdale	330 kV Feeder 3C to Stockdill (New Relays)	2

Appendix B - Review of initial VNI estimates

B.1 Comparison of capex forecasts

Table 33shows a comparison of the earlier capex forecasts against the GHD comparative estimates:

- TransGrid's estimate version 4
- P50 BOE estimate
- PACR forecast (based on TransGrid's supplied cost breakdowns in May 2020)

Table 33 Comparison of estimates ($ million, real 2017/18)

Activity	TransGrid success V4 $ M	TransGrid BOE P50 $ M	PACR $ M	GHD comparative estimate $ M
Direct construction costs				
Smart Wires	18.58	16.98	21.44	20.41
Substation augmentation	6.47	7.76	9.74	10.90
Substation secondary works	3.19	3.21	3.21	2.49
TL 01 & TL 3C Stockdill upgrade	2.15	2.15	3.14	1.47
Direct Costs total	**30.39**	**30.11**	**37.53**	**35.27**
Corporate & network overheads	1.96	1.96	2.94	7.09
Total	**32.35**	**32.06**	**40.46**	**42.36**

B.2 Comparison of earlier work package estimates

1. **Smart Wires work packages**

We compared the earlier estimated costs for the Smart Wires installations at Stockdill and Yass Substations. The estimated costs for the Smart Wires installations, were based on the configurations to be constructed at each substation corresponding to each estimate at the time, and the base costs and unit cost per MVAr that Smart Wires advised TransGrid to apply.

Table 34 Comparison of Smart Wires allowances ($ million, $2017/18)

Activity	TransGrid success V4 AUD M	TransGrid BOE P50 AUD M	PACR AUD M	GHD comparative estimate AUD M
Supply, design and testing at Stockdill Substation	-	14.95	17.42	18.54
Supply, design and testing at Yass Substation	-	1.54	3.02	1.61
Equipment supply	16.68	-	-	-
Installation	0.52	-	-	-
Spares	0.50	0.50	1.01	0.25
Foreign exchange hedging allowance	0.86	-	-	-

Activity	TransGrid success V4 AUD M	TransGrid BOE P50 AUD M	PACR AUD M	GHD comparative estimate AUD M
Total	**18.57**	**16.98**	**21.44**	**20.41**

The original design for the Stockdill installation was for nine 5 MVAr units which was the basis for the original TransGrid estimate, with the design refined to forty five 1 MVAr units. While the MVar capacity remained the same the current rating was need to be increased from 1800 amperes to 3600 amperes at Stockdill and 2600 amperes at Yass.

Smart Wires provided costing information, which were a fixed cost component of US$1.1 million per project and a variable component of:

- US$0.19 million per device for the SmartValve 5 -900i 900 Amp 5 MVAr unit
- US$0.15 million per device for the SmartValve 5 -1800i 1800 Amp 5 MVAr unit
- US$0.23 million per device for the SmartValve 5 -2700i 2700 Amp 5 MVAr unit
- US$0.30 million per device for the SmartValve 10 - i3600 3600 Amp 10 MVAr unit

TransGrid earlier estimates were based on this data and then updated for the PACR through design and scope clarification with Smart Wires.

2. **Substation augmentation work packages**

The substation works involved augmentation, civil and secondary works at Stockdill and Yass Substations.

This work is to include:

- Installation of Smart Wire MPFC at existing Stockdill Substation, involving 45 i3600 SmartValves units
- Installation of 6 i2600 SmartValves units at Yass Substation
- Civil works for extension of switchyard at Stockdill Substation, including earthgrid extensions and additional security fencing
- Construction of 330 kV disconnector bypass at Stockdill Substation
- Modifications to gantry and landing span structure at Stockdill Substation
- LV cabling to the control room at both substations
- Modifications to protection, control systems, SCADA and communications at both substations.

Table 35 shows a summary of the forecast costs for the substation augmentation works.

Table 35 Comparison of substation augmentation works estimates ($ million, $2017/18)

Activity	TransGrid success V4 AUD M	TransGrid BOE P50 AUD M	PACR AUD M	GHD comparative estimate AUD M
Civil works	5.45	5.38	6.87	6.09

Activity	TransGrid success V4 AUD M	TransGrid BOE P50 AUD M	PACR AUD M	GHD comparative estimate AUD M
Electrical & secondary system works	0.49	1.24	1.74	1.36
Major plant, equipment & materials	0.53	1.14	1.14	0.98
Total	**6.47**	**7.76**	**9.74**	**8.43**

3. Substation secondary work package

Table 36 shows a summary of the forecast cost and GHD comparative estimate for the secondary system works at Stockdill and Yass Substations.

Table 36 Comparison of substation secondary works estimates ($ million, $2017/18)

Activity	TransGrid success V4 AUD M	TransGrid BOE P50 AUD M	PACR AUD M	GHD comparative estimate AUD M
Secondary system material & equipment	0.89	0.90	0.90	0.83
Secondary system plant (relays)	0.02	0.02	0.02	0.02
Commissioning and modifications	2.32	2.29	2.29	2.32
Total	**3.23**	**3.21**	**3.21**	**3.17**

4. Substation works summary

Table 37 shows a summary of all substation works, including the supply, installation and commissioning of the Smart Wires units at Stockdill and Yass Substations.

Table 37 Comparison of combined substation works estimates ($ million, $2017/18)

Activity	TransGrid success V4 AUD M	TransGrid BOE P50 AUD M	PACR AUD M	GHD comparative estimate AUD M
Smart Wires supply, testing, commissioning	18.58	16.98	21.44	20.41
Substation augmentation works	6.47	7.76	9.74	8.43
Secondary system works	3.23	3.21	3.21	3.17
Total	**28.28**	**27.95**	**34.39**	**32.01**

5. Transmission line work package

The transmission line works are comprised of the replacement of two existing structures – TL 01 Structure 282A and TL3C Structure 16B – with new concrete poles, together with a notional 100 m of Twin Olive ACSR conductors, one OPGW, one Grape ACSR OHEW and standard fittings and insulators.

Table 38 shows a comparison between the forecasts and the GHD comparative estimate for the replacement of two structures on transmission lines TL 01 and TL 3C.

Table 38 Comparison of transmission line works estimates ($ million, $2017/18)

Activity	TransGrid success V4 AUD M	TransGrid BOE P50 AUD M	PACR AUD M	GHD comparative estimate AUD M
Civils, access roads, footings & concrete structures	2.15	2.15	3.14	2.89
Total	**2.15**	**2.15**	**3.14**	**2.89**

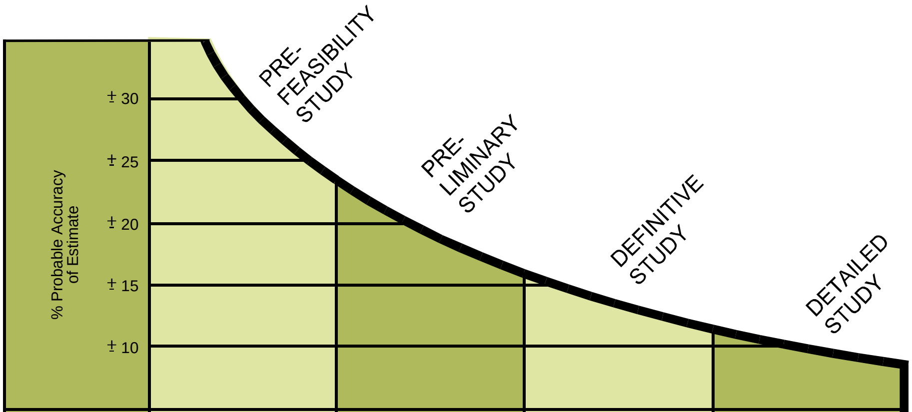
Appendix C - Unit cost benchmarking methodology and assumptions

C.1 Estimate accuracy for assessment

In assessing the VNI estimate, consideration must be given to the level of accuracy that can be achieved in generating indicative cost estimates for the network augmentation work packages identified.

The graph shown in Figure 8 indicates the levels of accuracy that can be expected for estimates prepared for capital works at various stages of project development. Due to the different levels of engineering input, and completeness in the design, there are various levels of accuracy that can be reasonably expected in forecasts.

Figure 8 Standard estimate accuracy levels



Type of Estimate	Order of Magnitude	Preliminary	Definitive	Detailed
Provided Documentation	• Product capacity and Location • Cost Data on Similar Projects • Major Equipment List	• Preliminary Equipment List • Engineering Line Diagram • Plant Outline General Arrangement • Maps and Surveys • Bench Test Results • Nature of Facilities	• Equipment Specifications and Vendor Quotations • Construction Schedule • Electrical One Lines • Piping and Instrumentation Flow Diagrams • Soil Data and Architect Features • Site Survey and Labour Complete	• Bulk Material Specifications and Vendor Quotes • Construction Specification and Sub Contractor Quotations • Engineering Advanced Approximately 10%
Definition of Scope of Work	Conceptual	Approximate	Clearly Described Essentially Complete	Complete. Well Detailed
Estimating Procedure	Factoring	Combination of Factoring and Quantity Take-Off	Most Quantity Take-Off. Very little Factoring	Complete Quantity Take-Off
Use of Study	Comparison/ Rejection	Final Feasibility	Budget	Funding

Table 39 shows the classification of estimates as defined in the AACE International *Recommended Practice No. 17R-97 Cost Estimating Classification System*.

Table 39 AACE IRP No. 17R-97 generic cost estimate classification matrix[28]

Estimate class	Primary characteristic	Secondary characteristic			
	Level of project definition Expressed as % of complete definition	**End usage** Typical purpose of estimate	**Methodology** Typical estimating method	**Expected accuracy range** Typical +/- range relative to best index of 1 (a)	**Preparation effort** Typical degree of effort relative to least cost index of 1 (b)
Class 5	0% to 2%	Screening or Feasibility	Stochastic or judgement	4 to 20	1
Class 4	1% to 15%	Concept Study or Feasibility	Primarily stochastic	3 to 12	2 to 4
Class 3	10% to 40%	Budget, Authorisation or Control	Mixed, but primarily stochastic	2 to 6	3 to 10
Class 2	30% to 70%	Control or Bid/Tender	Primarily deterministic	1 to 3	5 to 20
Class 1	50% to 100%	Check Estimate or Bid/Tender	Deterministic	1	10 to 100

a. If the range index value of 1 represents +10/-5%, then an index value of 10 represents +100/-50%

(a) If the cost index of 1 represents 0.005% of project costs, then an index value of 100 represents 0.5%

The level of information available to us for assessing the augmentation work packages was typical of concept study level. Therefore, we consider our comparative estimates are based on 1% to 15% project definition and should be classified as Class 4 estimates with an accuracy of ±30%.

C.2 Unit cost and capex forecasting assessment methodology

GHD has adopted a nominal criterion of ±20% as the first pass for comparing the TransGrid estimates with our reference comparative estimates for similar projects as a test for reasonableness.

Where there are is a variance between the TransGrid allowance for a network capacity augmentation project and our comparative estimate of less than ±20%, GHD will consider the TransGrid estimate to be reasonable and realistic, and no further detailed assessment will be undertaken.

For those TransGrid estimates where the variation is outside our nominal range, GHD reviewed any known project specific issues to identify the potential reasons, and where appropriate adjusted our switchbay configuration or switchyard construction factor.

C.3 Data sources

The data sources used for the development of unit rates include:

[28] AACE International, *Recommended Practice No. 17R-97: Cost Estimating Classification System (TCM Framework: 7.3 – Cost Estimating and Budgeting)*, 12 August 1997, p. 2

- Costs for large specialised equipment from recent projects that TransGrid has undertaken
- Contract and procurement costs available for recent projects completed by electricity utilities
- Material cost data that may be obtained from suppliers
- Market cost data available through recent operational and capital expenditure reviews for electricity transmission utilities
- Recent asset valuations by GHD
- Cost data available in the public domain, including standard labour costs.

As such, these costs may not necessarily reflect the actual costs for individual asset material cost or installation costs held in the TransGrid Success estimating system.

GHD has also considered recent project or vendor cost information provided by TransGrid, where these have been market tested through a tender process, or can be demonstrated to be material costs provided directly by suppliers.

Our market data costs have been used in project cost comparative estimates for both substation and transmission works, and potential augmentation works to support the development of Renewable Energy Zones in Queensland and NSW. These building block costs have also been used as benchmarks for unit rate comparisons for capital and operational expenditure reviews for Australian electricity utilities.

C.4 Unit rates

Our standard estimating unit rates have been based on the following:

- Our standard 330 kV and 220 kV switchbay configurations, and HV substation switchyard establishment components
- Our standard transmission line configurations for overhead lines on steel support structures (towers and poles)
- All steel support structures considered to have normal or typical foundations.

The following adjustment factor has been applied to the unit rates in our estimates:

- Remote area working allowance of 5% for labour costs.

C.5 Inclusions and exclusions

GHD considers our comparative estimates to be class 4 (±30%), based on the level of project definition and network data available in the public domain.

Our estimates include consideration of the following:

- No contingency allowance in line with the TransGrid Success PEC Contract and Plant estimates
- No allowance for any overtime associated with an accelerated construction program based on a 6-day working week
- Project specific costs as nominated by TransGrid for design and development, site mobilisation and demobilisation, and site management and operation

- Land acquisition costs for new substations, as specified by TransGrid in the Success Contract and Plant estimates[29]

The following have been excluded from the estimates:

- No Goods and Services Tax allowance
- All new transmission lines are assumed to be on flat or undulating terrain, and therefore no terrain factors have been included
- No consideration of construction difficulties with transmission line support structure foundations
- No separate consideration of any transmission line crossings
- All substation sites to be extended have sufficient spare space available for the extension, the land is flat and suitable for construction, and has ready access
- No relocation works are required within existing substations for the proposed augmentations
- No switching costs associated with work on existing 330 kV and/or 220 kV lines
- No allowance for costs associated with line easements, other than any specific lump sum allowances included in the TransGrid Contract and Plant estimates.

C.6 Comparative estimate approach

GHD has used market data available to develop standard building block costs for switchbays, substation establishment, transmission line structures and conductor stringing.

This generated an estimate for the primary and secondary plant based on a building block approach, and provided us with a benchmark of our understanding of typical market costs against the TransGrid estimated costs.

In generating the final project estimate for each work package, we have used the lump sum allocations nominated by TransGrid for project-specific costs such as:

- Project design and development
- Site mobilisation, management and operating costs
- Land acquisitions

Where TransGrid has included these project-specific costs in the Success estimates, GHD has adopted these values in our comparative estimates so that these particular allocations do not distort any comparison of the substation and transmission line primary and secondary building block estimates.

[29] Success version 5 estimates for transmission line and substation uprate, and substation augmentations

Appendix D - Glossary

Term	Definition
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
CI	Control Interaction
CPA	Contingent Project Application
EMT	Electro Magnetic Transient
ESO	Electricity Statement of Opportunities
FACTS	Flexible AC Technology Systems
ISP	Integrated System Plan
LD	Liquidated Damages
MPFC	Modular Power Flow Controller
MVA	Megavolt Amperes
MW	Megawatts
NSW	New South Wales
OFS	Option Feasibility Study
PACR	Project Assessment Conclusion Report
PADR	Project Assessment Draft Report
PEC	Project EnergyConnect
PST	Phase Shifting Transformers
PSCR	Project Specification Consultation Report
PTRM	Post Tax Revenue Model
RIT-T	Regulatory Investment Test for Transmission
RFT	Request for Tender

Term	Definition
SSTI	Shaft Torsional Interaction Issues
STATCOM	Static synchronous compensators
SVC	Static VAr Compensator
TCSC	Thyristor Controlled Series Compensators
TNSP	Transmission Network Service Provider
VNI	Victoria to New South Wales Interconnector

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