OPTIONS EVALUATION REPORT (OER)

Manage Multiple Contingencies in Sydney North 330 kV Area

OER 000000001491 revision 4.0

Ellipse project no(s): Sydney North 330kV Smart Grid Controls

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Change history

Revision	Date	**Amendment**
1.0	16 August 2021	Initial issue
2.0	8 November 2021	Minor update addressing external review comments
2.1	20 December 2021	Further update addressing external review comments
2.2	14 January 2022	Added commercial evaluation with failure rate sensitivity

Executive summary

The National Electricity Rules (NER) clause S5.1.8 requires TransGrid to consider the effects of non-credible (e.g. multiple) contingencies which could potentially endanger the stability of the power system and give rise to cascading failures. In those cases where the consequences of such events are likely to be severe disruption, including market impacts and loss of supply to large load areas, there would be benefits in considering installation of emergency controls to minimise disruption and significantly reduce the probability of cascading failures.

TransGrid studies indicate that significant voltage and dynamic stability constraints may arise under the non-credible contingencies of two or more 330 kV lines, these being [redacted]. Such failures can result in significant supply disruptions and unserved energy in the Sydney North area. The extent of the supply disruptions can be reduced by installation of emergency control schemes to manage system response in the event of such multiple contingencies, giving rise to avoided unserved energy benefits. Therefore, the identified need for this project is economic benefits.

Only one option is considered feasible to address the need/opportunity, due to the specific capability requirements for emergency control schemes. The option involves the implementation of a SCADA/protection based control scheme. The evaluation results for this option appear in Table 1 below.

Table 1 - Evaluated options

Option	Description	Direct capital cost ($m)	Network and corporate overheads ($m)	Total capital cost[1] ($m)	Weighted NPV (PV, $m)	Rank
Option A	Introduce control scheme using a SCADA/ Protection-based Hybrid Special Protection System (SPS)	9.61	2.36	11.97	15.07	1

Option A, being the preferred option, was selected because this is the only technically and economically feasible option and it is projected to deliver greater benefits in net present value terms than the base case.

Other potential options, including augmenting transmission lines and undergrounding the existing equipment to prevent impact from extreme weather conditions, were considered but not progressed due to their significantly higher cost and lack of commensurate benefits for the additional cost.

[1] Total capital cost is the sum of the direct capital cost and network and corporate overheads. Total capital cost is used in this OER for all analysis.

1. Need/opportunity

The National Electricity Rules (NER) clause S5.1.8 requires TransGrid to consider the effects of non-credible (e.g. multiple) contingencies which could potentially endanger the stability of the power system and give rise to cascading failures. In those cases where the consequences of such events are likely to be severe disruption, including market impacts and loss of supply to large load areas, there would be benefits in considering installation of emergency controls to minimise disruption and significantly reduce the probability of cascading failures.

The need for this project is thus economic benefits, where avoided unserved energy benefits can be realised.

NSW experience of multiple contingency events

During drought conditions in 2001, widespread bushfires in NSW caused four of the six 330kV circuits south of Bayswater and Liddell power stations to trip repeatedly. The affected line pairs were 31 / 32 between Bayswater and Sydney, and 81 / 82 between Liddell and Newcastle.

Under these conditions, the Network Controller switched the circuits back into service to the extent permitted by the fires, and just managed to avoid a system voltage collapse by restoring one circuit only 50 seconds before a second parallel circuit tripped.

Similarly, during bushfires in December 2002, various combinations of three, four and five concurrent line outages occurred in the network. The outages usually involved the line pairs 21 / 22 between the Central Coast and Sydney North, 25 / 26 between the Central Coast and Sydney West, 5A1 / 5A2 (500kV) between Eraring and Kemps Creek, and 76 / 78 between Wallerawang and Sydney South.

There was an observed increase in the number of unplanned transmission network outages in NSW during summer 2019-2020, mainly due to the impact of bushfires. These contingent events involved multiple transmission lines tripping around the Snowy area and a significant reduction in available generation, leading to a Lack of Reserve (LOR2) condition in NSW. These historical events indicate that multiple contingencies have a realistic probability of occurring.

TransGrid studies have identified critical non-credible contingencies for two or more 330 kV lines, these being [redacted] which could lead to cascading failures in the Greater Sydney load area. Such a multiple contingency event could result in voltage collapse in the Sydney area. Refer to Figure 1 for a network overview.

Figure 1 - [redacted]

[redacted]

Such simultaneous failures to multiple transmission lines can result in significant supply disruptions in the Greater Sydney load area. The extent of the supply disruptions can be reduced by installation of emergency control schemes to manage system response in such events.

If TransGrid does not proceed with this project, there will be a potential impact on customers through reduced reliability and unexpected unserved energy in the event of this type of high-impact-low-probability event.

2. Related needs/opportunities

- Need 1473 – Manage Multiple Contingencies in North West NSW 330 kV Area
- Need 1522 – Manage Multiple Contingencies in Sydney West 330 kV Area

3. Options

3.1 Base case

The base case under this need is to not facilitate the introduction of a control scheme using both SCADA and Protection systems. The primary risk of TransGrid not addressing this need is a cost of unsupplied demand/unserved energy to customers in the Greater Sydney area. This risk can increase with the increased demand and increased power transfer in the target area in the future. The expected involuntary load shedding could reach a maximum of 1,500 MW. This is based on the expected power transfer levels in the Sydney North transmission cut-set at times of high summer demand. Simultaneous tripping of 2 or more lines in this cut-set can result in cascade tripping of remaining lines resulting in involuntary load shedding.

3.2 Options evaluated

Option A — Introduce control scheme using a SCADA/Protection-based Hybrid Special Protection System (SPS)

This option involves the implementation of a SCADA/Protection-based Hybrid Special Protection System (SPS) for the Sydney North West 330 kV area to prevent or minimise the effect of widespread interruptions and a partial or full system collapse in the event of critical non-credible multiple contingencies.

The scope of works includes:

> Installing a new SCADA and protection system to monitor the status of feeders [redacted] and to monitor the MW flow south on lines [redacted] and to enable tripping of feeders and generators in response to the measured status and flows.

> Making any necessary changes to secondary systems, including metering and control systems, at affected substations.

> Ensuring that appropriate system data will be fed to the TransGrid SCADA system so that Control Room staff can use this information for network operations.

> Undertaking necessary analysis to determine conditions for arming the scheme, determining load feeders and generation to be selected.

The implementation of the option can significantly reduce the local demand at risk, which can be calculated as follows:

The risk cost was calculated by considering the worst-case outage of multiple 330 kV lines within the Sydney North Area cut-set shown in Figure 1 causing a loss of maximum load of 1,500 MW.[2] To reflect that the load may not be at the peak in the areas affected at the time of the incident, a moderating factor is applied to the load. This load moderating factor is calculated based on the daily average demand compared to the maximum demand on a peak demand day. Based on recent historical high demand days,[3] the average demand is calculated to be about 0.7 times the maximum demand. Hence, a load moderating factor of 0.7 is used.

The load restoration time is estimated to be 8 hours.[4] During works to restore the load, it is expected that the demand will decrease over time, as such a restoration factor of 0.5 is used to account for this.

The probability of such an incident occurring is deemed to be based on the combinations of the events in which two elements of the cut-set are lost simultaneously. That is, the system collapse incident is deemed to happen

[2] This event is noted to occur during severe bushfires, and it is expected that the total NSW load will be at maximum demand resulting in 1,500 MW load lost due to the worst case combination of multiple 330 kV line outages.

[3] 31st January 2019 is an example.

[4] Restoration time is based on TransGrid Control Room historical experience, experience with black start training simulations, and OM666 Black Start. During black start training simulations, a multi-machine simulation environment using PowerWorld Trainer is used with participation of operating staff from AEMO, TransGrid, NSW Distribution Network Service Providers and major generator operators. The 8 hour duration is estimated based on the load restorations observed during these black start simulations taking into account the magnitude of the interrupted load.

whenever any two of the lines in the cut-set are tripped coincidentally. Thus, the transmission line failure rates in the Electricity Transmission Reliability Standards[5] are used to calculate the probability. In this case, the overall failure probability is estimated to be 1.047%. Refer to Appendix B for details of this estimate.

In addition, it is possible that multiple line contingencies would not result in a cascading failure if the MW flow across this cut-set is not high enough. A moderating factor is introduced to reflect this by using the percentage of time where the cut-set flow is expected to exceed about 1200 MW.[6] Based on recent historical high demand days[7], and possible increase in flows on this cut-set following the retirement of Liddell Power Station and increased renewable generation in northern NSW areas, this cut-set flow moderating factor is calculated as 1.

Unserved Energy Risk Cost

Unserved energy is calculated as:

$$\begin{aligned}Unserved\ Energy &= (Load\ Moderating\ Factor * Maximum\ MW\ at\ risk) * (Load\ Restoration\ Factor \\ &* failure\ duration) * (Overall\ failure\ rate * Cutset\ Flow\ Moderating\ Factor)\end{aligned}$$

$$Unserved\ Energy\ = (0.7 * 1500\ MW) * (0.5\ *\ 8\ hrs) * (1.047\% * 1)$$

$$Unserved\ Energy\ = 43.97\ MWh\ per\ year^{8}$$

The risk cost of unserved energy is thus calculated as follows:

$$Risk\ Cost\ of\ Unserved\ Energy\ =\ Unserved\ Energy\ *\ VCR^{9}$$

The expected commissioning date for this option is in 2027-28.

The expected expenditure profile for this option was estimated using the MTWO Estimating System. The estimates in the table below have an uncertainty of ± 25% and exclude capitalised interest.

Table 2 – Option A expected expenditure

	Total Project Cost	FY2023/24	FY2024/25	FY2025/26	FY2026/27	FY2027/28
Estimated P50 Cost non-escalated ($m 2020-21)	11.97	0.58	1.15	6.26	3.92	0.06

It is estimated that an amount up to $1.5 million (included in Table 2, above) is required to progress the project from DG1 to DG2. This is to cover activities such as site visits, development of concept design, and commencement of project approvals and early procurement of long lead-time items.

This project is expected to be completed in an estimated 49 months following the approval of DG1.

[5] Electricity Transmission Reliability Standards, IPART, December 2015, https://www.ipart.nsw.gov.au/files/sharedassets/website/trimholdingbay/electricity_transmission_reliability_standards_-_december_2015.pdf.

[6] If this cut-set flow is greater than 1200 MW, trip of any two of the parallel 330kV paths can trip the remaining parallel path and results in severe undervoltage conditions leading to widespread interruptions.

[7] 31st January 2019 is an example.

[8] This calculation of unserved energy is based on FY2021 and expected to increase based on the load forecast in TransGrid's 2021 TAPR. This increase is captured in the commercial evaluation section.

[9] The Value of Customer Reliability (VCR) is based on figures published by AER in its Value of Customer Reliability - Final Report on VCR Values December 2019, with annual adjustment published on 18 December 2020. In this case figure of $43,032/MWh (escalated at assumed inflation rate, 2.16%) in NSW for the central scenario (100%) in the commercial evaluation section is used.

3.3 Options considered and not progressed

Introducing SCADA and Protection systems is the only feasible option to acquire capabilities provided by SCADA and Protection systems. Consequently, Option A is the only technically and economically feasible option to address the identified need.

Other potential options, including adding more transmission lines via separate routes (this will require building at least two new transmission lines between Eraring / Vales Point and Sydney load centre via separate routes, for a length of about 86 km) or undergrounding the existing equipment (this will require undergrounding at least two transmission lines of the cut-set, for a length of about 86 km) to prevent impact from extreme weather conditions, were considered but not progressed due to their significantly higher cost and lack of commensurate benefits for the additional cost.

4. Evaluation

4.1 Commercial evaluation methodology

The economic assessment undertaken for this project includes three scenarios that reflect a central set of assumptions based on current information that is most likely to eventuate (central scenario), a set of assumptions that give rise to a lower bound for net benefits (lower bound scenario), and a set of assumptions that give rise to an upper bound on benefits (higher bound scenario).

Assumptions for each scenario are set out in the table below.

Table 3 – Scenario Based Sensitivities

Parameter	Central scenario	Lower bound scenario	Higher bound scenario
Discount rate	4.8%	7.37%	2.23%
Demand Growth	Medium (POE50)	Low (POE90)	High (POE10)
Capital cost	100%	125%	75%
Operating expenditure	100%	125%	75%
VCR	100%	70%	130%
Scenario weighting	**50%**	**25%**	**25%**

Since the central scenario represents the most likely scenario to occur, we have weighted it at 50 per cent. The other two scenarios reflect extreme combinations of assumptions designed to stress test the results. Accordingly, these scenarios are weighted at 25 per cent each.

The parameters used in this commercial evaluation are in **Error! Reference source not found.** below.

Table 4 – Parameters used in commercial evaluation

Parameter	Parameter Description	Value used for this evaluation
Discount year	Year that dollar values are discounted to	FY2020/21
Base year	The year that dollar value outputs are expressed in real terms	FY2020/21 dollars
Period of analysis	Number of years included in economic	25 years

	analysis with remaining capital value included as terminal value at the end of the analysis period.	
VCR	Value of customer reliability	AER Latest VCR (escalated)[10], $43,032/MWh

The capex figures in this OER do not include any real cost escalation.

4.2 Commercial evaluation results

The commercial evaluation of the technically and commercially feasible options is set out in Table 5. Details appear in Appendix A.

Table 5 – Commercial evaluation (PV, $ million)

Option	Capital Cost PV	OPEX Cost PV	Central scenario NPV	Lower bound scenario NPV	Higher bound scenario NPV	Weighted NPV	Ranking
Option A	9.41	2.15	11.61	-1.62	38.70	15.07	1

Considering that the overall failure rate is dependent on the TransGrid Asset Management Bushfire impact probability calculation, the above NPV calculation is repeated with an Overall Failure rate assumed as half of the 1.047% calculated in Appendix B.4 (i.e. 0.523%). The resulting Commercial evaluation results in a Weighted NPV of $2.90 million indicating that this project is economical even if the failure rate is lower (refer Appendix B.4 for commercial evaluation details).

4.3 Preferred option

The preferred option is Option A. This option would see the introduction of control scheme using both SCADA and Protection systems.

The preferred option was selected because this is the only technically and commercially feasible option that meets the identified need that results in higher benefits in NPV terms compared to the base case.

Capital and Operating Expenditure

The preferred option requires capital expenditure of $11.97 million and additional operating expenditure of $0.24 million per year.

Regulatory Investment Test

As the estimated cost of this option is above the $6 million threshold then it is expected that a RIT-T will be required and has been considered in the project Program.

5. Optimal Timing

The test for optimal timing of the preferred option has been undertaken. The approach taken is to identify the optimal commissioning year for the preferred option where net benefits (including avoided costs and safety

[10] The Value of Customer Reliability (VCR) is based on figures published by AER in its Value of Customer Reliability - Final Report on VCR Values December 2019, with annual adjustment published on 18 December 2020. In this case figure of $43,032/MWh (escalated at assumed inflation rate, 2.16%) in NSW.

disproportionality tests) of the preferred option exceeds the annualised costs of the option. The commencement year is determined based on the required project disbursement to meet the commissioning year based on the OFS.

The results of optimal timing analysis is:

- Optimal commissioning year: 2027/28[11]
- Commissioning year annual benefit: $2.1 million
- Annualised cost: $0.68 million

Based on the optimal timing assessment, the project is expected to be completed in the 2023-2028 Regulatory Period.

6. Recommendation

The recommendation is to progress with Option A.

Based on the details listed in Section 3, this option will incur a capital cost of approximately $11.97 million in P50 non-escalated 2020/21 dollars. It is estimated that an amount up to $1.5 million is required to progress the project from DG1 to DG2, which is included in the capex estimate. Optimal commissioning year of 2027/28 is recommended.

[11] This is the earliest date that project can be completed based on OFS 1473A

Appendix A – Option Summaries

Project Description	Manage Multiple Contingencies in Sydney North 330 kV Area		
Option Description	Option A — Introduce control scheme using both SCADA and Protection systems		
Project Summary			
Option Rank	1	Investment Assessment Period	25
Asset Life	40	NPV Year	2021
Economic Evaluation			
NPV @ Central Benefit Scenario (PV, $m)	11.61	Annualised CAPEX ($m)	0.68
NPV @ Lower Bound Scenario (PV, $m)	-1.62	Network Safety Risk Reduction (PV, $m)	25.01
NPV @ Higher Bound Scenario (PV, $m)	38.70	ALARP	n/a
NPV Weighted (PV, $m)	15.07	Optimal Timing	2027/28
Cost			
Direct Capex ($m)	9.61	Network and Corporate Overheads ($m)	2.36
Total Capex ($m)	11.97	Cost Capex (PV, $m)	9.41
Terminal Value ($m)	6.58	Terminal Value (PV, $m)	2.14

Appendix B – Overall Failure Probability Calculation Method

As aforementioned, the probability of an overall failure event is deemed to be based on the combinations of the events in which two elements of the cut-set are lost simultaneously. That is, the overall failure event is deemed to happen whenever any of the two lines in the cut-set are tripped coincidentally. Then the probability of any two lines being tripped in the cut-set can be further combined to get the total overall failure probability.

This Appendix B provides the estimation method of the probability for the tripping of any two lines.

B.1 General two-line tripping event

Assume Line A and Line B are the two lines to trip. It is known that:

a. F_A and F_B stand for the transmission line failure rates per year[12];

b. *X* stands for the exact hour when Line A trips, *Y* stands for the exact hour when Line B trips. *X*, *Y* are considered within one-year duration (0 – 8760 Hours);

c. *T* stands for the restoration time after the tripping for Line A and Line B[13];

d. The tripping of Line A and Line B are absolutely independent.

Without loss of generality, it can be concluded that (*X, Y*), as ***two-dimensional continuous random variables,*** follow a two-dimensional uniform distribution. The ***probability density function*** (***pdf***) of the (*X, Y*) is thus:

$$\boldsymbol{f(X,Y) = \begin{cases} \dfrac{F_A}{8760} \times \dfrac{F_B}{8760}, & for\ 0 < x < 8760, 0 < y < 8760 \\ \\ 0, & for\ other\ x\ and\ y \end{cases}}$$

It is equivalent to describe the event where Line A and Line B DO NOT trip together as:

a. *X* is at least *T* earlier than *Y*; or

b. *Y* is at least *T* earlier than *X*.

Then, the event where Line A and Line B trip together can be represented as:

$$\boldsymbol{\begin{cases} X - Y \le T \\ Y - X \le T \end{cases} or\ |X - Y| \le T}$$

Therefore, the probability of Line A and Line B to trip simultaneously is:

$$\boldsymbol{P(B.1)\{\ |X - Y| \le T\} = \iint f(X,Y)dxdy = \frac{F_A}{8760} \times \frac{F_B}{8760} \times \iint dxdy}$$

B.2 Two-line tripping event lead by intense bushfire events for close transmission line structures

It is also assumed, apart from the general situations in B.1, that in intense bushfire events, there is a certain proportion of the impacted transmission lines that are deemed to be so close to each other (within less than 1 km)

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[12] Converted from the 330kV Transmission line failure rates per decade of 2.4 per 100km as in Electricity Transmission Reliability Standards, IPART, December 2015, https://www.ipart.nsw.gov.au/files/sharedassets/website/trimholdingbay/electricity_transmission_reliability_standards_-_december_2015.pdf.

[13] 330kV transmission line Restoration mean time of 17.8 hours post failure as in Electricity Transmission Reliability Standards, IPART, December 2015, https://www.ipart.nsw.gov.au/files/sharedassets/website/trimholdingbay/electricity_transmission_reliability_standards_-_december_2015.pdf

in the same cut-set that the tripping of two lines at the same time is possible. In this certain situation, the overall failure rate is calculated based on the minimum of the probabilities of the two lines to trip due to bushfire impact.

Assume Line A and Line B are the two lines to trip. F_A and F_B stand for the probabilities for transmission line A and B to trip due to the impact of bushfire events per year[14];

Therefore, the probability of Line A and Line B to trip simultaneously in B.2 is:

$$\boldsymbol{P(B.2) = Minimum(F_A, F_B)}$$

Depending on the geographical information for target transmission lines, the proportion in B.1 and B.2 are estimated as: proportion (B.1) and proportion (B.2).

B.3 Overall failure rate calculation for this project:

In this project, transmission line 25/26 are double circuit lines, which indicates the scenario, for this particular transmission line path, described in B.2 will always happen. This leads to:

Proportion (B.1) (25/26) = 0%, Proportion (B.2) (25/26) = 100%.

To capture the generic tripping events for double circuit lines, Proportion (B.2) is further split into Proportion (B.2.1), Proportion (B.2.2), standing for accountabilities of non-bushfire events (general events less bushfire events, following the calculation method in B.1), and bushfire events (exclusive bushfire events, following the calculation method in B.2), respectively.

At the same time, for other two-line tripping combinations, including [redacted] scenario described in B.1 will always happen as the distances between the lines in the combinations are far away enough. This leads to:

Proportion (B.1) (all combinations excluding 25/26) = 100%, Proportion (B.2) (all combinations excluding 25/26) = 0%.

Therefore, with terms multiplied by 0% ignored, the overall failure rate is:

$$P(Overall) = Proportion(B.1)(excluding\ 25/26) * P(B.1)(excluding\ 25/26) + Proportion(B.2.1)(25/26) * P(B.2.1)(25/26) + Proportion(B.2.2)(25/26) * P(B.2.2)(25/26)$$

The Proportion (B.2.1) (25/26) and Proportion (B.2.2) (25/26) are based on the historical tripping events data[15], and calculated to be 87.5% and 12.5%, respectively.

Line No.	Proportion (B.1) (excluding 25/26)	P(B.1) (excluding 25/26)	Proportion(B.2.1) (25/26)	P(B.2.1) (25/26)	Proportion(B.2.2) (25/26)	P(B.2.2) (25/26)
[redacted]	100.00%	0.02100%	0.00%	n/a	0.00%	n/a
[redacted]	100.00%	0.02670%	0.00%	n/a	0.00%	n/a
[redacted]	100.00%	0.03030%	0.00%	n/a	0.00%	n/a

[14] From TransGrid Asset Management Bushfire impact probability calculation. Average probability to impact structure groups of 0.136% and 52.8 groups of structures (Average 5 structures per group) are adopted, as the bushfire intensity is predicted to be low to mild in the target area and thus moderate numbers of structures could be impacted by on bushfire event.

[15] From Historical Tripping Events, TransGrid Operation Team. In this case, 1 out of 8 tripping events are recorded to be caused by bushfire events.

Line No.	Proportion (B.1) (excluding 25/26)	P(B.1) (excluding 25/26)	Proportion(B.2.1) (25/26)	P(B.2.1) (25/26)	Proportion(B.2.2) (25/26)	P(B.2.2) (25/26)
[redacted]	100.00%	0.02200%	0.00%	n/a	0.00%	n/a
[redacted]	100.00%	0.02500%	0.00%	n/a	0.00%	n/a
[redacted]	0.00%	n/a	87.50%	0.02780%	12.50%	7.180%
Total	0.1250%		0.02433%		0.8975%	

The overall failure rate is therefore calculated as:

P (Overall) = 0.1250% + 0.02433% + 0.8975%= 1.0468%

B.4 Commercial evaluation sensitivity to failure rate:

Considering that the above overall failure rate is dependent on the TransGrid Asset Management Bushfire impact probability calculation, the NPV calculation presented in Section 4.2 is repeated with an Overall Failure rate assumed as 0.523% (i.e. half of 1.047%). The resulting Commercial evaluation results are as given below.

Commercial evaluation sensitivity (PV, $ million)

Option	Capital Cost PV	OPEX Cost PV	Central scenario NPV	Lower bound scenario NPV	Higher bound scenario NPV	Weighted NPV	Ranking
Option A	9.41	2.15	1.09	-6.21	15.64	2.90	1