TransGrid

TransGrid Revenue Proposal
2018/19 – 2022/23

Appendix G

Capital expenditure projects

Capital expenditure projects

Appendix G Capital Expenditure Projects

G.1 Capital Project details

This appendix provides further details of capital projects and programs not covered in the main revenue proposal.

G.1.1 Augmentation projects – load driven $451m

G.1.1.1 Powering Sydney's Future $331m

The Powering Sydney's Future project is detailed in the main proposal and Appendix B Project Specification Consultation Report.

G.1.1.2 New Transformer and 66kV Switchbays at Macarthur 330/66kV Substation $8m

Background: The Endeavour Energy 66 kV network in the Macarthur area is supplied from TransGrid's Ingleburn and Macarthur substations and Endeavour Energy's Nepean substation.

Project Need: High local peak load growth in the Macarthur area is creating a capacity constraint on the Endeavour Energy 66kV network. This load growth is caused by extensive new housing developments where there have been land releases. Also as a result of this growth, the distribution network service provider, Endeavour Energy is planning new substations, Menangle Park Zone Substation and Mt Gilead Zone Substation to be supplied by TransGrid's Macarthur substation

Options: For augmenting the transmission supply capacity to the area the options considered include:

> Inter-trip schemes on the Endeavour Energy network
> Installing another 132/66kV transformer at Endeavour Energy's Nepean substation
> Installing a second 330/66 kV transformer at TransGrid's Macarthur substation.

Economical and feasible options to supply the new zone substations were limited to connecting the Zone Substations to TransGrid's Macarthur substation via new switch bays.

Efficient solution & rationale: The installation of a second 330/66kV transformer and two 66kV switchbays at the Macarthur 330/66kV Substation is the preferred option to relieve constraints within the Endeavour Energy 66 kV network and connect the new zone substations.

Need ID	Need Description	Year Expected	Project Cost $million June-18	Expenditure 2018/19 – 2022/23
1437	EnE - Switch bay at Macarthur BSP for connection of Menangle Park ZS	2020	1.33	1.29
1444	EnE - Switch bay at Macarthur BSP for connection of Mt Gilead ZS	2023	1.37	1.37
1438	Macarthur 330/66kV second Tx	2022	5.03	5.03
		Total	7.73	7.69

G.1.1.3 New 132kV Switchbays to connect new loads $12m

Background: In addition to western Sydney area supplied from Macarthur substation, three additional areas are experiencing high localised load growth due to residential and commercial development. They are the Vineyard/Riverstone East precinct in western Sydney, South West Sydney (including new Badgerys Creek airport) and new residential precincts in Canberra.

Project Need: As the respective distribution network service providers, ActewAGL and Endeavour Energy are planning new zone substations to supply these areas:

- Box Hill Zone Substation in western Sydney connecting to TransGrid's Vineyard substation
- Kemps Creek Zone 132 kV bus, which will be initially build in the form of a distribution switching-station, but will be expanded to a 330kV/132kV transmission bulk supply point in the future
- Strathnairn (formerly West Belconnen) Zone substation connecting to TransGrid's Canberra substation
- Molonglo Zone Substation in ACT, connecting to Actew AGL's Canberra – Woden 132 kV transmission line (A-1). This connection will require rearrangement of A1 connection to planned TransGrid's Stockdill Drive substation.

Options: Economical and feasible options were limited for these needs other than connecting the Zone Substations or lines (i.e. A1 line) to respective transmission substations via new switch bays.

Efficient solution & rationale: TransGrid plans to augment the following TransGrid's substations to cater for the connection of new distribution zone substations:

- one switchbay at Vineyard substation,
- one switchbay at Canberra substation.
- rearrangement of the connection of A1 line to the planned Stockdill Drive substation as a loop-in-loop-out connection.
- construction of a new 132 kV distribution switching station at TransGrid's Kemps Creek substation

Timing will be optimised based on the timing of the new zone substations.

The estimated approximate costs of the augmentations are shown in the following table:

Need ID	Need Description	Year Expected	Project Cost $million June-18	Expenditure 2018/19 – 2022/23
1443	ActewAGL - Switch bay for connection of Strathnairn ZS (formerly West Belconnen ZS)	2020	1.68	1.64
1695	ActewAGL - Rearrangement of A1 connection to	2021	1.97[1]	1.97

[1] The cost of Rearrangement of A1 line connection to Stockdill for establishment of Molonglo ZS is estimated to be $3.59 million. Given the uncertainly of demand growth in ACT, there is a possibility that Molonglo ZS establishment will be delayed. The probability of the

Need ID	Need Description	Year Expected	Project Cost $million June-18	Expenditure 2018/19 – 2022/23
	Stockdill for Molonglo ZS Establishment			
691	EnE - Switch bay at Vineyard BSP for connection of Box Hill ZS	2023	1.59	1.59
1687	EnE - Distribution switching station (132 kV) at Kemps Creek for South Western Sydney Development	2024	10.45	6.52
		Total	15.69	11.72

G.1.1.4 Projects driven by economic benefits and developments additional to demand forecasts $100m

Probabilistically planned projects due to new spot loads $36m

Background: AEMO's demand forecast for New South Wales is presented in terms of strong, neutral and weak economic and consumer outlooks, where neutral is most likely. TransGrid is aware that new large industrial and mine loads could connect in the period and understands that these are unlikely to be included in the AEMO or DNSP forecasts.

However, these are subject to uncertainty as they depend on future economic conditions and commodity prices.

Project Need:

As supplying large new spot loads could cause network constraints and require augmentations to meet reliability standards, TransGrid commissioned an external review to research what loads were possible in the period, and to consider the probability of these based on robust criteria such as the existence of planning approval. The result was that 66 new potential demands were identified with around 350MW of load which was not considered in other demand forecasts.

With the information on spot loads in combination with AEMO's forecast TransGrid undertook a probabilistic planning analysis as follows:

- Each new possible demand was given a probability weighting based on a synthesis of AEMO's strong, neutral and weak scenarios and the likelihood of individual new connections occurring by considering their individual drivers such as commodity prices.
- Network analysis was undertaken to identify constraints which would be caused if these loads connected. These included transmission line overloading, low voltages and voltage instability under system normal as well as transmission contingencies.
- Augmentation projects to address these needs were identified and costed. They included transmission line connections, new capacitor banks and switchbay projects.
- A forecast for each augmentation project was created based on the likelihood of spot loads which drove the project occurring. This probability accounted for both the likelihood of the load and the

project proceeding prior to 2022 is considered to be 55% and therefore a probability weighted cost of $1.97 million is included in the revenue proposal likelihood of it occurring in AEMO's low, medium and high scenarios (meaning they were discounted significantly).

> The outcome of this analysis is a probability weighted investment amount for demand scenarios which may occur.

Efficient solution & rationale:

The total probability weighted cost is forecast at $36 million for the 5 year regulatory period, a reduction of 35 per cent when compared to the full value of the possible projects.

The forecast projects include

> Installing two capacitor banks at Narrabri for the Narrabri Gas Project connection
> Reconductoring 969 line with higher operating temperature conductor for the Shenhua coal mine
> Installing reactors and static VAR compensators at Broken Hill and Buronga for the Hawson's Iron Project connection
> Installation of dynamic reactive support (e.g. a Static Compensator) for mitigating voltage instability at Beryl area, which could result with the connection of new mining loads (Bowdens Silver Project near Mudgee and Cockatoo Mine near Ilford)

Need ID	Need Description	Year expected	Likelihood/ Probability	Project Cost ($m)	Probability Weighted Project Cost ($ m)	Expenditure 2018/19 – 2022/23
1698	Hawson's Iron Project, connecting to X2 line	2020	0.75	26.8	20.1	19.8
1693	Narrabri Gas Project connection up to 40 MW in Essential Energy's Network	2020	0.54	4.9	2.7	2.2
1489	Shenhua Coal Mine connection up to 40 MW	2023	0.57	6.1	3.5	3.3
1316	Mining loads connecting near Beryl	2021	0.55	19.4	10.7	10.7
Total				57.0	37.0	36.0

Investment timing will be optimised based on the timing of the connection projects.

This approach is preferable in these circumstances as it leads to lower capital expenditure and transmission prices but provides an allowance so that new loads can connect and be supplied.

Projects that deliver economic benefits $38m

Background: A number of opportunities (16 opportunities) have been identified that deliver economic benefits with relatively low cost investments.

Project Need: Projects have been identified in a number of areas:

- Improvement in power quality, e.g. voltage unbalance

- Reduction in load restoration time
- Improvement in network resilience during extreme weather events
- Improvements in operational efficiencies
- Improving ability to respond in grid emergencies

Options: Available network and non-network options have been considered.

Efficient solution & rationale:

The following table summarises the opportunities for economic improvements and estimated approximate cost. The costs are based on the most economic and feasible option.

Need ID	Need Description	Year Expected	Project Cost ($ millions)	Expenditure 2018/19 – 2022/23
1460	Transposition of Line 87 and 8C/8E	by 2023	1.23	1.23
1412	Provide Auto Ctrl of Capacitor	by 2023	0.07	0.07
1421	Transformer AVR function change	by 2023	0.12	0.12
1484	Snowy Area 330 kV Smart Grid Controls	by 2023	3.29	3.29
1487	Eraring-Kemps Creek 500kV Smart Grid Controls	by 2023	2.61	2.61
1491	Sydney North West 330 kV Smart Grid Controls	by 2023	3.04	3.03
1425	Load shedding scheme for mitigating risks	by 2023	0.15	0.15
1472	Making the Grid Smarter – Yass Area 330 kV Smart Grid Controls	by 2023	4.03	4.03
1480	Travelling Wave Fault Locators on 132 kV Lines to improve reliability	by 2023	2.49	2.49
1458	Include 8G1 feeder in tripping scheme	by 2023	0.03	0.03
1399	Yass 330kV Bus CB Capacity Augmentation	by 2023	5.14	5.14
1482	Sydney South 330kV Smart Grid Controls	by 2023	1.79	1.79
1522	Bayswater to Sydney West 330kV Smart Grid Controls	by 2023	2.78	2.78
1473	North West 330kV Smart Grid Control	by 2023	3.58	3.58
1416	Tomago 330 kV Bus Capacity Augmentation	by 2023	5.18	5.17
1423	Improve TG's Operational Telephone Network (OTN)	by 2023	2.61	2.61
	Total		38.2	38.2

Dynamic Voltage Support $24m

Background: The Federal Government has committed to increase the electricity generation from renewable sources up to 20% of the total generation by 2020. A significant proportion of this generation is likely to come from wind and solar farms connected to the outer edge of the grid.

Project Need: Renewable sources (in particular wind and solar) connected to the outer, weak parts of the NSW transmission system will likely create voltage control and instability issues. Successfully achieving 20% of generation from renewable sources will require augmentation of the grid using dynamic reactive power support.

Options: The following technology options were considered for meeting the reactive power support need:

- Static Var Compensators (SVCs)
- Synchronous Compensators
- Static Compensators (STATCOMs)
- A combination of two or more of the above

Efficient solution & rationale:

Dynamic reactive power compensation will be required at least at two transmission locations, likely to be in south west part of the network and in the northern part of the network. Given the uncertainty of the location of future renewable generation connections and the level of potential stress on the transmission system, it has been estimated that there is approximately 60% likelihood that 2xSVCs will be required.

Need ID	Need Description	Year Expected	Likelihood/ Probability	Project Cost ($million)	Probability Weighted Project Cost ($million)	Expenditure 2018/19 – 2022/23
1650	Dynamic voltage support for enabling connection of renewable generation	2021	0.6	40.94	24.57	23.78
			Total	40.94	24.57	23.78

G.1.2 Augmentation projects – reliability and security driven $41m

G.1.2.1 Second Supply to the Australian Capital Territory $37m

Background: TransGrid was granted a licence in early 2015 to provide electricity transmission services in the ACT. A condition of the licence was for TransGrid to provide two independent, geographically separate 330 kV supplies to the ACT, the first of which is the existing Canberra 330/132 kV substation. A solution was proposed which would comply with the licence conditions which involved the establishment of a switching station at Wallaroo together with associated 330 kV line connections, which passed the regulatory test. After review by the ACT Government, the Wallaroo area was set aside for land developments and became unavailable for the new 330 kV switching station. An alternative site, near Stockdill Drive, was then recommended by the ACT Government.

The Stockdill Drive solution is a variation on the Wallaroo project where components of work associated with establishing a Wallaroo equivalent 330 kV switching station and associated line works are considered to be prescribed work for which a regulatory test has been approved. Components of work in addition to this, such as additional line diversions (if required), are considered as non-regulated and will be negotiated with (and funded by) the ACT government.

Project Need: The investment is required to comply with the reliability obligations as set out in the ACT Electricity Transmission Supply licence.

Options: Options considered include:

> Diverting lines 01 and 3C into the new Stockdill substation and installing a transformer connected to ActewAGL's Woden line.

> Diverting lines 01, 7 and 3C into the new Stockdill switching station and installing capacitors at Williamsdale
> Diverting lines 01 and 3C into the new Stockdill switching station and installing capacitors at Williamsdale

Efficient solution & rationale: By December 2020, TransGrid plans to establish Stockdill substation and divert lines 01 and 3C into the new Stockdill substation and install a transformer connected to ActewAGL's Woden line.

The total prescribed cost of the TransGrid component of the project is forecast at $37.4 million in total. The installation of the transformer at Stockdill provides a more efficient solution to both this need and the replacement of one of the Canberra 330/132kV transformers considered together.

G.1.2.2 Reliability improvement at Molong and Mudgee $11m

Background: TransGrid's NSW transmission licence requires planning the transmission system to meet the transmission reliability standard prescribed by the NSW government. The transmission planning standards for NSW have been reviewed by IPART during 2015-2016, and a revised reliability standard has been approved in late 2016.

Project Need: While almost all the transmission supply points in the NSW transmission system meet the new reliability standard, the supply reliability at Molong and Mudgee fall below the required standard.

Options:

Molong: Options considered include network and non-network options, but the economic and feasible options were limited to a single network solution.

Mudgee: Options considered include:

- Non network solutions - demand management
- Construction of a 132 kV busbar at Mudgee substation (Essential Energy),
- Installation of a three-way switch at the Mudgee 132 kV tee.
- Convert essential Energy's Mudgee manual changeover to an automated changeover scheme

Efficient solution & rationale:

Molong: The economic and feasible solution is installation of a second 132/66 kV transformer at Molong at a forecast cost of approximately $3.93 million. No other economically feasible options are available.

Mudgee: The most economic and feasible option is installation of a three-way switch at the Mudgee 132 kV tee at a forecast cost of approximately $7.48 million.

G.1.3 Replacement projects

G.1.3.1 Circuit Breaker Replacement Program $70m

Project Need: TransGrid has a population of over 1,600 circuit breakers installed over a range of voltages, types, operational histories and age. The individual impact of a circuit breaker failure varies with location but there can be significant consequences in terms of power system insecurity, safety and property damage.

A risk analysis has identified that around 240 circuit breakers (approximately 15% of the total population) should be replaced in the upcoming regulatory period to effectively manage cost, safety and reliability risk.

Options: Risk reduction measures such as replacement; refurbishment; or holding additional spares were considered to properly manage the overall risk profile of the organisation.

For the circuit breakers that have been identified for action, refurbishment is not an economically viable option. This is due to lack of ongoing manufacturer support and spare parts, the limited effectiveness of refurbishments to successfully address the range of failure mechanisms and remnant safety risks.

As a result, replacement has been proposed for the program.

Efficient solution & rationale: The following steps were taken to produce a replacement program:

- The available condition data was analysed to assess the remaining life/failure risk of each circuit breaker
- Consequences for each failure mode were assessed based on criticality in the network and estimated risk to personnel and the environment
- The combination of consequence and probability of failure are combined to estimate risk cost for each circuit breaker
- A NPV (Net Present Value) evaluation of the risk cost compared to the cost of replacement was undertaken to ensure that replacement is justified.
- A safety evaluation was completed – ALARP – "As low are reasonably practicable" to ensure that regulatory requirements regarding safety performance are met.
- Additional efficiencies were also implemented into the program by combining the replacement of separate circuit breakers and associated current transformers (where they also had a risk of failure) in order to achieve a lower combined required capital expenditure.

G.1.3.2 Rebuild Transmission Line 86 $70m

Background: 330kV Transmission Line 86 between Tamworth and Armidale was originally constructed in 1982 using composite wood pole structures. It is the only 330kV line of this construction - the rest of TransGrid's 330kV lines which are mostly constructed with steel towers. The composite wood pole structures are made by joining two smaller wood poles with a metallic sleeve.

Project Need: Wood rot beneath the metallic joint sleeve is prevalent throughout the line, and a number of structures have been replaced with concrete poles since 2011 due to this decay. The composite wood pole structures are not as strong as steel towers or concrete poles, so Line 86 was designed and constructed to a lower set of criteria more comparable to other TransGrid wood pole lines than the criteria used on the 330kV steel towers and is considered to be less secure. As a result, its construction utilised shorter span lengths and smaller conductor than other 330kV lines, which in turn reduces the rating of the line. The condition issues further reduce the security of the line.

Options: Limited options are available for composite wood poles with identified condition issues, which need to be addressed by replacement with concrete poles due to their longer life and efficiency of construction. Options considered include:

- Rebuild the line, replacing the existing composite wood pole structures with concrete poles using the existing conductor
- Rebuild the line, replacing the existing composite wood pole structures with larger concrete pole structures and restring with larger conductor

Efficient solution & rationale: Option 2 is the preferred option proposed. The rebuild involves the progressive replacement of the existing composite wood pole transmission line with new concrete pole structures and a new larger conductor, optimising span lengths where possible. Concrete poles have a longer life than that of presently available wood poles. Additional benefits are expected with this option in the longer term through enabling an increase in power flows through the northern NSW region.

This project is estimated to cost $70.25 million.

G.1.3.3 Communications networks $38 million

Project Need: The existing assets servicing TransGrid's medium bandwidth microwave communications backbone network are used to service protection and communication links throughout many parts of the network. High speed communications are increasingly required between sites to maintain the visibility and control of unmanned high voltage transmission sites within the network and to facilitate the remote interrogation and analysis of conditions and assets at all sites within TransGrid's network.

Additional operational benefits have been identified in the deployment of fibre optic links throughout the network to increase data capacity capabilities. These benefits include increased visibility and remote monitoring of assets, reduced maintenance requirements as assets can report imminent failure, remote analysis of failures before sending technicians to site, increased visibility of higher quality CCTV systems, and it allows for the full utilisation of the increased capabilities of modern technologies.

The installation of an interconnected fibre optic network addresses TransGrid's long term vision of an intelligent network with real time asset management capabilities and continues work that commenced during the present regulatory control period (2014-18).

Options and Rationale: There were two options identified and an economic evaluation of risks and benefits was carried out to determine the most efficient solution per communication locale, these options, when they were identified as the most efficient solution, include:

- Upgrade to fibre optic backbone - deemed appropriate where upgrades would result in completion of high speed backbone to extend to all sites in the network
- Continue with a microwave backbone - deemed an efficient solution to reduce risk at a site where fibre optic option was not justifiable.

G.1.3.4 Protection Relay Replacement Programs $59m

Background: Protection systems detect faults on the network and send control signals to circuit breakers to separate the assets with the fault from the network. This protects network assets and helps maintain the stability of the power system during contingency events. Protection relays are components of the protection systems.

To comply with the National Electricity Rules (NER) for system stability and reliability requirements, TransGrid has separate primary and back-up protection schemes.

Project Need: As protection assets have aged, manufacturer support has ceased and/or spares have been depleted. This has led to conditions where assets cannot be replaced or repaired with a reliable like-for-like unit. As probabilities of failure increase for assets, the increasing risks associated with non-operation or mal-operation of protection need addressing.

There are additional operational benefits to be realised from the replacement of older technologies with modern microprocessor based assets. These include self-monitoring capabilities and notification of asset failures, reduction in maintenance required due to the self-checking functionality, remote interrogation and analysis of fault data, and potential for improved asset management through remote confirmation of installed asset base.

Options and Rationale: Several options have been identified and an economic evaluation of risks and benefits carried out to determine the most efficient solution per asset grouping. These options include:

> Run to failure - not considered an efficient solution due to the resultant increases in risk and maintenance costs

> Replace all assets - deemed an efficient solution where assets are no longer supported and defect rates are high

> Replace higher risk assets - deemed an appropriate solution where replacing all assets is not economically viable

This replacement program is proposed to minimise risks of adverse consequences to TransGrid's network and subsequently to the NEM.

G.1.3.5 Secondary System Renewal/Replacement $100m

Project Need: The modernisation of secondary systems at a site as a whole offers benefits and opportunities and is raised where the condition of various categories of automation assets require addressing such as: protection relays, control systems, AC distribution, DC supply systems, market meters and where there is a substantial number of individual assets targeted for replacement.

Identified benefits include reduced maintenance requirements, minimal reinvestment over the life of the assets, improved operational efficiencies, better utilisation of TransGrid's high speed communications network, improved visibility of all assets using modern technologies, and reduced reliance on routine maintenance and testing.

Options and Rationale

There are several options identified and an economic evaluation of risks and benefits has been carried out to determine the most efficient solution per site. These options, when they are identified as the most efficient solution, include:

> Run to failure – this solution is evaluated as the base case for all proposed needs, but does not rank well when reasonable risk reduction can be achieved through investment

> IEC-61850 deployment - deemed an efficient solution where cables are to be replaced and site can meet the organisation's strategy for an intelligent transmission network

> Secondary system building (SSB) installation - deemed an appropriate solution where the building, infrastructure and/or cabling cannot support an additional secondary system renewal

> Complete in-situ replacement - deemed appropriate where the building, infrastructure and cabling can support a complete secondary system renewal

> Strategic asset replacement - deemed the efficient solution to reduce risk at a site where no other options are justifiable.

In the current regulatory period, TransGrid has implemented new secondary systems with combined protection and achieved cost savings and size reductions compared to traditional secondary systems with separate protection and control relays. Further, TransGrid is currently deploying the first IEC-61850 system on the New South Wales transmission network which achieves further savings by significantly reducing the number of traditional copper-core cables through the use of optical fibre cables between the switchyard and relay room.

G.1.3.6 Steelwork Renewal $47m

Project Need: Major steelwork in substations is used to support overhead conductors and is an essential component in a functioning substation. Failure of major steelwork components have the potential to seriously impact on the serviceability of a substation and multiple outages are likely.

Some substation sites built in the 1960's, and especially those located in more corrosive environments near to the coast, have steelwork that is reaching end of life.

There are three aspects to the developing issue:

> Corrosion of nuts from the fasteners holding the structure together.
> Erosion of galvanising from the steel members, followed by more rapid erosion of the underlying steel once the protective zinc layer is consumed.
> Corrosion of structure holding down bolts and structure support plates which anchor the gantries to the concrete foundations.

A desktop study of all substations identified those most likely to be affected by corrosion. The assessment was based on exposure to corrosion and age in the first instance.

Seven sites with the highest risk were surveyed on a sample basis, and a condition assessment of remaining life and associated probability of failure was made using observed information and standard corrosion rates for steel and zinc. The corrosion rate information allows an estimation of reduction of steel cross sectional area and strength and this was used in combination with data on wind events to estimate failure probabilities if the steelwork remains untreated.

The probability of failure of the gantries and the likelihood of the possible consequences occurring, including injury to staff, damage to other equipment and loss of supply were evaluated.

Action at this time is required to achieve increased life from the identified substation infrastructure. Delay will result in an earlier need to rebuild the affected substations, or if no action is taken, the risk of large scale failures will increase.

Options: Options to extend the life of the affected substations have been compared include various methods to address the specific condition issues identified: fastener (and fitting replacement) to address corroded nuts; selected member replacement coupled with painting to address loss of galvanising; and repairs where possible on holding down bolts and supporting plates.

Where holding down bolts cannot be repaired, measures such as partial replacement of holding down bolts (very difficult and expected to be costly) and the use of mass concrete have been considered.

Efficient solution & rationale: Various risk mitigation methods were compared, and an NPV evaluation was undertaken. The highest NPV and most cost effective solution has been included in the proposed renewal program.

This program is estimated to cost $46.59 million in total.

G.1.3.7 Instrument Transformers, Bushing and Disconnector Replacement Programs $58m

Project Need: Failure of oil filled bushings, current and voltage transformers (CTs and VTs) will result in a fault on the high voltage network. In most cases such a fault will lead to the automatic disconnection of several items of equipment.

An explosive failure may also result in injury to people, damage to nearby equipment and outages of nearby services. This is a particular issue for a group of older style 'hairpin' type design CTs that have a history of explosive failure and are fitted with porcelain insulators.

Explosive failure of a bushing will usually lead to the opening of the transformer or reactor tank resulting in transformer fire and loss of the entire asset, which is of much higher value than the bushing itself and therefore has a very high consequence.

Disconnectors are predominantly mechanical devices and deteriorate due to erosion of electrical contacts, wear and corrosion, leading to unreliable operation. This affects the ability to access equipment and may delay return to service of equipment after work. Forced outages can also result if the disconnector deteriorates to the point that it cannot support normal load current.

Options: To address high risk instrument transformers and bushings, two options have been considered apart from run to failure. Refurbishment of oil filled instrument transformers or bushings requires specialised knowledge, skills, process and equipment. Incorrectly completed work is likely to result in explosive failure of the equipment. The refurbished units will also retain dangerous components which are subject to possible explosive failure such as porcelain.

Due to the specialist skills and equipment, there is no known supplier of services to refurbish this type of equipment, including TransGrid's own internal resources.

The cost to refurbish a disconnector which is at the end of its life has been assessed as higher than the cost of purchasing a new unit. Refurbishment would also retain some components that may also fail early. Refurbished disconnectors would not be supported by the original suppliers (who in most cases are no longer in business).

The second option considered is the replacement of these assets which will effectively address the identified risk, introduce modern design and materials and be supported by modern manufacturers.

Efficient solution & rationale: Oil filled bushings, CTs and VTs have been analysed to assess their remaining life and corresponding probability of failure. This assessment takes into account their age, analysis of samples of insulating oil and known type issues.

Available data on disconnector performance is limited and age, CIGRE failure information and service staff experience have been used to identify problem types. Failure probability has been estimated on the basis of the information available.

The replacement program contains

- 550 instrument transformers (single phase units), representing 9% of the population
- 85 bushings (for 15 transformers or reactors), representing 6% of the population
- 40 disconnectors, representing 1% of the population

The combined total of these programs is forecast to be $57.8 million.

G.1.3.8 Sydney East Transformer Replacements $16m

Project Need: Sydney East substation has four 330/132 kV transformers. The No. 1, 2 and 3 transformers were originally installed when the substation was commissioned and are approaching the end of their serviceable lives.

The original transformers suffer from tapchanger barrel leaking, which has caused a degree of carbon contamination into the transformer windings. Failure of a tapchanger can lead to explosive failure of the transformer. Most of the bushings on these transformers have deteriorated and one transformer has been removed from service for this reason.

Test results indicate that the paper insulation is at end of life, and therefore the transformers have an increasing likelihood of failure in response to disturbances on the network.

Options: Refurbishment of these transformers will not gain any additional life and is not likely to address the leaking tapchanger issue. It will also not be possible to remove carbon already introduced into the transformer tank.

Refurbishment of the original transformers would require an overhaul of three separate units for each three-phase bank and is not cost effective in this case. Based on these condition issues, refurbishment would not effectively address the identified risks.

Consideration of the peak load forecast showed that it was likely that replacing two of the transformers and retiring the third was a feasible option. The value of load at risk and network redundancy was used to estimate the failure risk cost for use in an NPV calculation.

Efficient solution & rationale: A wide range of condition data was used to estimate the likelihood of failure of these transformers. The failure rate was estimated using a standardised failure curve based on TransGrid's experience and industry survey information and matched against the transformer condition.

The result of the economic evaluation showed that the preferred option is to retire No.1 transformer and replace the No.2 and 3 transformers. The total capital expenditure required is forecast to be $16.42 million.

G.1.3.9 SCADA Replacement $16m

Project Need: TransGrid utilises a SCADA system to operate, control and monitor the High Voltage network remotely from a centralised Control Centre. The high reliability, support and complexity of the SCADA system equates to an asset life more in line with IT infrastructure at 7 years. The current SCADA system will have been in service 7 years by 2022.

Options: TransGrid believes that replacement is the only viable solution to be planning for at this stage of the asset lifecycle. Replacement will ensure that TransGrid's SCADA system continues to reflect the most recent technology available, including security features and functionality that will enhance situational awareness and the operability of the modern transmission network.

Efficient solution & rationale: The exact form of the replacement, whether upgrade or complete replacement, will be decided as part of the project implementation.

The total capital expenditure required is forecast to be $15.7 million.

G.1.3.10 Static VAR Compensator (SVC) Refurbishment $17m

Project Need: An SVC is a device that provides stability to the voltage on the transmission. An SVC typically comprises a series of fixed or switched capacitors, reactors and harmonic filters, and is automated via a sophisticated control system. The need for transmission level SVCs will continue into the foreseeable future, and is expected to grow as renewable technologies increasingly replace traditional synchronous generation.

Key considerations are market impacts and energy not served due to the failure of the SVC control system, as well as the increased replacement costs required to accelerate the recovery. Increasing maintenance on the equipment does not reduce the probability of failure.

Two SVCs in operation on the TransGrid network have been identified as approaching their end of life condition, being either primary or secondary components, or facing obsolescence with the discontinuation of manufacturer support.

Options and Rationale: For both proposed SVC projects, an economic evaluation of risks and benefits is carried out to determine the most efficient solution per site. Options considered include:

- Maintain the asset - This option involves retaining the existing SVC systems and performing routine and corrective maintenance as required. This is not considered an efficient solution due to the resultant increases in risk and maintenance costs
- Full system replacement - This option replaces the existing SVC system with a modern solution compatible with existing TransGrid standards. This will efficiently reduce risks, improve maintenance efficiencies, and maintain the system stability requirements of the network and the market.

The SVC projects are expected to cost approximately $17.27 million.

G.1.3.11 Battery and Charger Replacements $13m

Project Need: Battery and charger systems are used throughout the TransGrid network to provide continuous visibility and control of a site even when the high voltage supply at the substation is unavailable. The availability of an uninterruptible power supply is crucial particularly during a black system event. Given the well-known life expectancy of battery and charger systems, some replacements will be required in the upcoming regulatory period.

Options and Rationale: Several options were identified and an economic evaluation of risks and benefits has been carried out to determine the most efficient solution per site. Options considered include:

- Run to failure - not considered an efficient solution due to the resultant increases in risk and maintenance costs
- Complete replacement of all assets - deemed inappropriate due to the remaining life and capability of many assets to meet their performance requirements
- Strategic asset replacement - deemed the efficient solution to reduce risk while maintaining economic benefits to the network. The battery and charger projects involve replacement of 18% of chargers, and 43% of batteries. They are expected to cost approximately $13.48 million.

G.1.3.12 415V Distribution System Replacements $15m

Background: 415V AC distribution systems power important but less critical substation ancillary systems. These systems include lighting, air conditioning, security and transformer cooling. They remain an integral component of substation sites for the foreseeable future.

Project Need: Following safety incidents and a review of asset condition there is a need to replace 415V AC distribution systems in 7% of our substations.

TransGrid has experienced an increase in the number of safety incidents related to the 415V AC systems across all substation sites over the past two years. An investigation into these incidents has highlighted the poor condition of aging 415V AC distribution infrastructure as a major contributing factor. A project was initiated to identify all 415V system defects and several sites with a high concentration of defects were identified and subject to further investigation including risk assessment.

Options and Rationale: For projects raised, an economic evaluation of risks and benefits has been carried out to determine the most efficient solution per site. Options considered include:

- Maintain the assets - This option involves retaining the existing 415V AC systems and performing routine and corrective maintenance as required. This is not considered an efficient solution in any project due to the resultant increases in risk and maintenance costs, and does not address the significant safety issues identified.
- Upgrade to AS3000 compliant systems - This option replaces the existing 415V AC distribution system site wide with a modern solution compatible with AS3000 standards. This will efficiently reduce risks, improve maintenance efficiencies, and ensure the safety of staff and contractors at the sites.

The 415V distribution system replacement projects are forecast to cost $14.52 million.

G.1.3.13 Control Building Capital Works $4m

Project Need: Condition assessments of substation buildings were completed for over 90 substations during late 2015 and early 2016. Substation buildings are primarily required to ensure that housed electronic equipment is in a secure, weatherproof environment. The asset life of a substation building is limited if water ingress and resultant structural damage occurs. The potential consequences from a water leak/ingress could range from a minor disturbance within the staff amenities to a major loss of load if network equipment is damaged.

A list of 11 priority substation sites were identified as requiring roof works during the 2019-23 regulatory period to mitigate risks to network equipment, and potential structural damage as a result of water ingress. Two sites are less than 10 years old; 5 sites are between 32-49 years old; and four sites are over 50 years old.

Options and Rationale: Options considered included:

- do nothing and allow the roof and building structures to fail;
- undertake roof replacement works at each site.

The roof replacement works is the most efficient option that manages the risk and also provides ongoing opex savings.

The total capital expenditure required is forecast to be $3.58 million.

G.1.4 Security and Compliance project details

G.1.4.1 Substation Lighting Replacement $8m

Project Need: Reviews of existing motion detection and lighting systems have identified performance issues. Movement activated lighting is designed to switch on the light circuits when it detects an encroachment to the perimeter fence. It is designed to work as a deterrent via providing a signal to the would-be intruders that their presence has been detected. This also assists the CCTV camera system to achieve clear recording via providing sufficient lighting. Both of these measures reduce the risk to members of the public due to unauthorised entry. Some systems have been unreliable and there have been increased costs due to repair and call-outs.

A review of lighting levels identified elevated safety risks at some sites where lighting was inadequate.

Options: Options considered to reduce the risk were:

- Do nothing
- Installation of movement activated lighting only.
- Installation of movement activated lighting and the replacement of existing operational lighting to meet current standards.

Efficient Solution and Rationale: A risk based cost benefit analysis was performed which identified that the combined benefit of lighting replacement and the installation of movement activated lighting was justified for a number[2] TransGrid sites.

The substation lighting replacement program is forecast to cost $8.16 million.

G.1.4.2 Substation Noise Non-Compliance $11m

Project Need: TransGrid has about 100 sites (substations and switching stations) that contain equipment with the potential to cause a noise nuisance. In NSW, noise nuisance (or pollution) is regulated through the Protection of the Environment Operations Act 1997. Guidelines for managing industrial noise are set out in the NSW Industrial Noise Policy, which the Environmental Protection Authority uses to set noise limits for new developments, and also existing developments - particularly when noise complaints are received.

A risk assessment identified six substation sites that are considered high risk of being non-compliant. The substations are Dapto, Griffith, Molong, Muswellbrook, Orange 132kV, and Wagga 132kV.

Options: Options considered include:

- do nothing until a non-compliance is issued by the Environmental Protection Authority
- the installation of noise walls around the offending transformers at these sites
- Replacement of the transformer which is the primary source of noise at the site

Efficient solution and rationale: The risk based cost benefit analysis identified there is a net benefit in installing noise walls at the identified sites with exception of Molong. In conjunction with an assessment of the transformer at Molong and corresponding risk of failure, the most effective solution for the noise issue at Molong has been determined to be replacement of the transformer rather than construction of noise walls.

---

[2] Further details can be found in the confidential version of the supporting project documentation.

The noise walls and transformer replacement are forecast to cost $10.57 million.

G.1.4.3 Motion Detector and CCTV Replacement $15m

Project Need: A gap analysis of TransGrid's existing substation sites against good industry practice has revealed that:

- Failure of CCTV and passive infrared motion detectors incur high corrective maintenance cost
- The performance of the detectors is deteriorating resulting in the generation of false alarms
- There is an increased risk to members of the public due to failures of these key deterrent and response measures.

Replacing motion detectors and CCTV reduces the risk of undetected unauthorised entries, high corrective maintenance cost and callout cost for investigating false alarms.

Options: The following options were considered:

- Do nothing
- Replacement of motion detectors with modern day equivalents
- Replacement of motion detectors with thermovision cameras
- Replacement of CCTV and Digital Video Recorder units with modern day equivalents.

Efficient solution and rationale: The risk based cost benefit analysis was performed which identified the net benefit of the replacement of motion detectors and CCTV systems at a number[3] of sites. The replacements are forecast to cost $15.48 million.

G.1.4.4 Electric Fence Topping Replacement $4m

Project Need: The purpose of electric fence topping is to provide intruder deterrence and resistance to penetration or climb over. Existing electric fence topping at some[4] installations are out of service due to pulse generator unit failures and some[5] of the remaining sites are experiencing high corrective maintenance costs to maintain this control[6].

Options: The following options were considered:

- Do nothing
- Replacement of electric topping with barbed wire
- Replacement of electric topping with razor wire

Efficient Solutions and Rationale: A risk based cost benefit analysis was performed which identified the net benefit of the replacement of electric fence topping with razor wire at a number[7] of sites. The replacement is expected to cost $4.14 million.

G.1.4.5 Transmission Line Low Spans Correction $3m

---

[3] Further details can be found in the confidential version of the supporting project documentation.
[4] Further details can be found in the confidential version of the supporting project documentation.
[5] Further details can be found in the confidential version of the supporting project documentation.
[6] There have been fatalities at other network service providers' sites when members of the public have found access.
[7] Further details can be found in the confidential version of the supporting project documentation.

Background: Transmission lines are designed and constructed to achieve standard electrical clearances of the conductor at specific operating conditions. The currently accepted industry standard is AS7000 for the Design of Overhead Lines, which specifies minimum electrical clearances that should be achieved when the conductor reaches its maximum operating temperature (also commonly referred to as the line design temperature).

Project Need: A number of transmission lines have known spans violating AS7000 minimum clearances (low spans) at the maximum foreseeable operating temperature. These low spans pose a risk to public safety.

Options: TransGrid has conducted a risk assessment on the identified low spans. The risk assessment method evaluates each low span violation in accordance with multiple risk criteria, including magnitude (height and area), location and violation temperature. The spans have then been ranked accordingly, and categorised as presenting a higher risk and lower risk to public safety. The remediation options considered include:

> Remediate all low spans
> Remediate higher risk low spans only, with the lower risk spans addressed by means of administrative control measures

Efficient solution & rationale: The remediation of higher risk low spans has been proposed to reduce the level of risk to public safety across the network. TransGrid is required to fulfil the requirements of AS5577 Electricity Network Safety Management Systems, and the public safety risk presented by the low spans must be reduced As Low As Reasonably Practical (ALARP). The proposed remediations are expected to mitigate the public safety risk to an acceptable level.

This project is forecast to cost $3.01 million.

G.1.5 Non-network (business support) projects

G.1.5.1 IT projects

Pervasive Security $3m

The network of the future will rely on new technologies that will increase the vulnerability to cyber-attacks. Similarly to all utilities, TransGrid must invest in implementing security systems appropriate to the critical infrastructure it manages. Security is paramount to successfully integrate and operate Information Technology and Operational Technology (OT). TransGrid proposes to invest to provide security on networks and information as well as the integration and communications within and across those components. This will establish the foundation to enable security analytics specifically in utilising big data for persistent threat detection.

Infrastructure Enablement $15m

All of the physical devices and associated software within the Corporate Data Network (CDN) and Information Infrastructure are progressively reaching end of life during the upcoming regulatory period. The business needs a replacement program as there is an increased risk the hardware will progressively fail leading to interruption to service availability for the IT Service portfolio. Infrastructure enablement will refresh the physical devices, hardware and software that deliver IT and OT services that will reach the end of life. TransGrid will also invest in developing cloud capability that will enable rapid deployment of on-demand, scalable computing resources at low cost.

Enterprise Analytics Platform $8m

TransGrid needs the ability to capture and analyse real-time information across IT and OT which will in turn improve forecasting, analytics and reporting capabilities. TransGrid proposes to invest to build on the 2016-2018 Information Management Program of Work with master data, single source of truth, information architecture, information management governance and data mining. The investment will also be used to develop and implement a hybrid content architecture incorporating structured and unstructured, corporate and operational data, big data, 3rd party data feeds, social media, rich media and digital assets for better decision making and network management across lines of business.

Intelligent Asset Design $3m

Leveraging investments on integration, enterprise asset management and spatial solutions, this program of work will expand on a current 3D modelling initiative to further consolidate asset design capability, gain efficiencies in asset design and embed engineering and regulatory standards to demonstrate compliance.

Intelligent Operations Centre $10m

Intelligent Operations Centre provides broader context when monitoring and controlling assets from remote locations, which will drive advanced predictive maintenance. TransGrid has proposed to invest in developing a common operating picture integrated with monitoring systems to optimise and standardise the approach to asset monitoring and control. Additionally TransGrid plans to leverage common platforms (integration, analytics, geospatial, MEAP) and develop location-based services to improve safety and efficiency on the field.

Digital Field Force $9m

Digital Field Force will optimise maintenance costs while improving field force safety and network security and reliability. This will be done through prudent investment in a number of new technologies. Innovative devices will provide situational awareness to improve safety on field works. Dynamic and automated scheduling and dispatching and new mobile solutions will increase field productivity.

Digital Enterprise $38m

TransGrid uses integrated enterprise solutions to enable secure connection with the wider industry, businesses and customers. The current enterprise resource planning (ERP) application, Ellipse version 8.3, comprises a suite of applications that provide asset management, resource planning, financial services and warehousing functions. The information managed by the ERP forms the foundation of TransGrid’s asset management decision making and portfolio optimisation activities. It is proposed to invest in a fit-for-purpose enterprise solution and new technologies enabling operational excellence and efficiencies.

Corporate Data Network $12m

The Corporate Data Network (CDN) provides the switching, routing and load balancing services to enable endpoint devices to connect to enterprise applications and intra server data transfer. The CDN comprises Cisco switches and routers and F5 load balancers. The CDN is monitored and managed using the SolarWinds network management software. The current Asset life for physical network devices is 5 years. Data communications also enables Unified Communications services including Video Conferencing, Instant Messaging, desktop sharing and electronic mail. Physical screens, voice gateways together with Call Manager, Jabber, Webex and Microsoft Exchange software enable these services. These assets have a life of 5 years. All of these physical devices and associated software will progressively reach end of life during the upcoming regulatory period.

G.2 Network Augmentation Investment Probabilistic Planning Methodology

Network augmentation investments increase the transmission capacity in the network, achieve the defined reliability standard and allow customers access to lower cost electricity. Key drivers for augmentation investments are local demand growth, reliability standards, voltage control issues and market opportunities which generate a net benefit to customers. Investment needs tend to be locational.

A probabilistic planning methodology was used to assign a weighted probability to each proposed network augmentation investment occurring, in each of the AEMO demand growth scenarios[8] strong (formerly high),neutral (formerly medium) and weak (formerly low). These augmentations are for investments that would need to occur during the period 2018/19 to 2022/23 (Regulatory Control Period – RCP).

TransGrid identified network constraints though modelling of the NSW transmission electricity system to determine where potential network augmentation investments could be required. Furthermore, load growth projects identified by the NSW and ACT DNSPs were also modelled to confirm if constraints were identifiable.

Advice was also obtained from EY[9] to identify potential third party load projects such as mining, gas and industrial process (in addition to those identified by TransGrid and the DNSPs) that could occur within NSW and require TransGrid network augmentation investment during this RCP and the next one. This analysis of potential third party load projects was based on available economic market assumptions and included an assessment of the likelihood of projects proceeding. An assignment of the probability of each AEMO demand growth scenario occurring[10] was also provided. TransGrid then analysed each of the third party load projects identified by EY to determine what TransGrid network augmentation investment (if required) would be needed.

All constraints were documented and potential options were identified and evaluated to determine a preferred option to resolve the constraint.

The probability of projects proceeding was also extended to cover those investments identified by TransGrid and the DNSPs. See Table 1 below:

Table 1 - Likelihood of a Network Augmentation Investment Proceeding

Likelihood	Probability	Comment
Very Low	10%	Probability assigned by EY. These investments have a very low likelihood of proceeding as network modelling shows a constraint most likely won't be identified, requiring resolution during the RCP
Low	30%	Probability assigned by EY. These investments have a low likelihood of proceeding as network modelling shows a constraint could be identified, requiring resolution during the RCP

[8] AEMO's 2016 National Electricity Forecast Report (NEFR) contains three scenario based demand forecasts (strong, neutral, weak) whilst as a comparison, the AEMO's 2015 National Electricity Forecast Report (NEFR) contained three scenario based demand forecasts (high, medium and low economic growth)

[9] EY Report to TransGrid on load developments 2016-10-10C

[10] Report TransGrid 2015-10-13a (merged)

Moderate	60%	Probability assigned by EY. These investments have a medium likelihood of proceeding as network modelling shows a constraint may be identified, requiring resolution during the RCP.
High	75%	Probability assigned by TransGrid. These investments have a high likelihood of proceeding as network modelling shows a constraint will most likely be identified, requiring resolution during the RCP.
Certain	100%	Probability assigned by TransGrid. These investments are expected to proceed as a constraint requiring action has already been identified, requiring resolution during the RCP.

The likelihood of a network augmentation investment proceeding was determined using a range of inputs including forecast load demand, potential generation patterns, similar historical events, and legislative requirements. An assessment of the likelihood of network augmentation investments required during RCP is shown below.

G.2.1.1 Miscellaneous Secondary Systems Works in conjunction with DNSPs

Need 1694, 1448, and 1440 are investments required as an augmentation at one location requires a corresponding augmentation at a remote location, for instance protection replacements programs where the replacements of an aged relay at one end of the line (and potential telecommunications assets) requires replacements of the remote end of the line for the system to work as a scheme.

A likelihood of certain was assigned to this investment. Endeavour Energy provided an estimate of $500k over the RCP, and it is expected that Ausgrid and Essential Energy will also require a similar level of investment, totalling $1.5 million over the RCP. Historical investment of this type during the 2014-2018 Regulatory Control Period (up to Nov 2016, 2.5 years) is $1.2 million.

G.2.1.2 Compliance Projects

Needs 1649, 1696, and 1697 are investments to comply with the Electricity transmission reliability standards[11] and have been assigned a likelihood of certain.

Need DCN335 is an investment to comply with the Australian Capital Territory Electricity Transmission Supply Code[12], and has been assigned a likelihood of certain.

[11] Independent Pricing and Regulatory Tribunal (IPART) Energy transmission reliability standards, Energy – Supplementary Draft Report, September 2016

[12] Australian Capital Territory Utilities (Technical Regulation) (Electricity Transmission Supply Code) Approval 2016 (No1)* 11 July 2016

G.2.1.3 Minor Augmentations to reduce restoration times of an outage

Needs 1460, 1412, 1421, 1484, 1487, 1491, 1425, 1472,1480, 1458, 1399, 1482, 1522, 1473, 1416, and 1423 are minor network augmentation investments that reduce restoration times of an unplanned outage to improve operation of the network. They are beneficial as they provide improve system security for high impact low probability contingency events and have been assigned a likelihood of certain.

G.2.1.4 Western Sydney Developments

These needs are in response to developments by the NSW Department of Planning and Infrastructure, both in progress and soon to commence. They are located within the Western Sydney area including the Greater Macarthur Land Release, Vineyard and Riverstone East precinct developments and the Broader Western Sydney Employment Area.

Needs 1687, 691, 1437, and 1444 have been assigned a likelihood of certain as these investments are required to facilitate the developments because the Endeavour Energy network is constrained and can’t provide the required supply.

Need 1438 has been assigned a likelihood of low (weak growth scenario), moderate (neutral) and certain (strong) as the likelihood of investment within the RCP is dependent of the timing of the load demand increase and the Endeavour Energy network providing supply in the interim.

G.2.1.5 Canberra Area Developments

These needs are in response to residential developments by the Australian Capital Territory Government. Need 1443 (Establish Strathnairn (formerly West Belconnen ZS)) has been assigned a likelihood of certain as it is required to facilitate the West Belconnen Residential Development. Need 1695 Molonglo is required due to supply land residential releases and was assigned a likelihood of low (weak growth scenario), moderate (neutral) and certain (strong) as the likelihood of investment within the RCP is dependent of the load demand increase.

G.2.1.6 Beryl Area Investment

Need 1316 is in response to load demand growth in the area due to third party load projects and underlying growth. An investment likelihood of low (weak growth scenario), moderate (neutral) and certain (strong) within the RCP was assigned to cater for varying load demand increases.

G.2.1.7 Dynamic Voltage Support

Need 1650 is for the investment of dynamic voltage support at Parkes and Buronga is to support the network in these areas to facilitate the connection of new renewable generation. A moderate likelihood of investment proceeding was assigned based the connection requests and connection enquiries received and the projects which are proceeding to formalisation of the Offer to Connect. It is anticipated this rate will remain constant.

G.2.2 Potential third party load projects

Needs 1698, 1693, and 1489 are for projects identified by EY, that TransGrid have analysed to determine if network augmentation investment is required. The likelihoods assigned by EY have been used for these investments.

A weighted investment probability for the occurrence of each investment was determined by multiplying the probability value for the 'likelihood' of that investment proceeding by the probability of each AEMO demand growth scenario (strong, neutral, and weak) occurring and then summating these three values.
A weighted investment augmentation cost was determined by multiplying the above weighted investment probabilities by the preferred option augmentation cost.
The total augmentation program expenditure is the summation of all these weighted project augmentation costs excluding all Contingent Projects.