5.13.F

Project justifications for transformer replacement programs

Ausgrid

Content

1 INTRODUCTION

1.1 Transformers on Ausgrid's network

Transformers form an integral part of the equipment in zone, subtransmission and distribution substations. They are designed to transform electricity from higher to lower voltages allowing the voltage supplied to customers to be within the allowable range whilst enabling efficient transmission of electricity across the network.

As at June 2017, Ausgrid has approximately 34,200 transformers on the network. These range from large power transformers in subtransmission substations, through to distribution transformers installed in chambers, in kiosks and on poles. There are 1,670 instrument transformers and 172 reactive plant located in subtransmission and zone substations.

The planned replacement program targets some of the oldest transformers on the Ausgrid network, consisting of those in Sydney Central Business District (CBD) distribution substations that have an obsolete construction. The average age of these assets is 53.6 years.

1.2 Changes in technology

The core technology associated with transformers remains the same. There have been some improvements in design such as the installation of resin bushings which provide improved safety outcomes over existing oil filled porcelain and external tapchangers, making it easier to maintain the most unreliable component of the transformer.

1.3 Working out what we need to replace

The majority of Ausgrid's distribution transformers are treated reactively. Ausgrid plans to replace a small group of CBD conservator style transformers that are all over standard life of 45 years. These assets have performed well considering their age and loading but are experiencing functional failures and significant oil leaks. Due to the access restrictions to underground substations in the CBD, transformer replacement is often difficult and requires coordination with traffic control and outages with sensitive loads.

The condition of major transformers is informed by testing conducted as part of routine maintenance to inform treatment when deemed to have conditionally failed or in the event of functional failure. The decision to repair or to replace a transformer is subject to a cost benefit analysis undertaken at the time treatment requirements are identified.

1.4 Summary of programs

In total Ausgrid expects to invest $33.3 million (real FY19 direct costs) on replacing or refurbishing transformers and reactive plant in the 2019-24 regulatory period. Ausgrid also replaces distribution transformers reactively on conditional or functional failure (refer to Attachment 5.13K (Reactive replacement programs) for further details). Planned replacement of transformers is also undertaken as major projects (typically 33kV and above), refer to Attachment 5.14 for further detail in regards to these projects.

The following programs are discussed in further detail below:

- Distribution transformers ($18.0 million)
- Power transformers (included in Attachment 5.13K (Reactive replacement programs))
- Instrument transformers ($9.5 million)

- Reactive plant ($5.8 million).

2 DISTRIBUTION TRANSFORMERS

2.1 Program description

Ausgrid has a planned program to replace distribution transformers located in Sydney CBD substations that have reached the end of their serviceable lives. Deterioration of the housing is leading to major oil leaks compromising the insulation and leading to functional failures.

The planned program which covers the replacement of CBD distribution transformers is:

- Sydney CBD Distribution Transformer Replacement (REP_01.03.07).

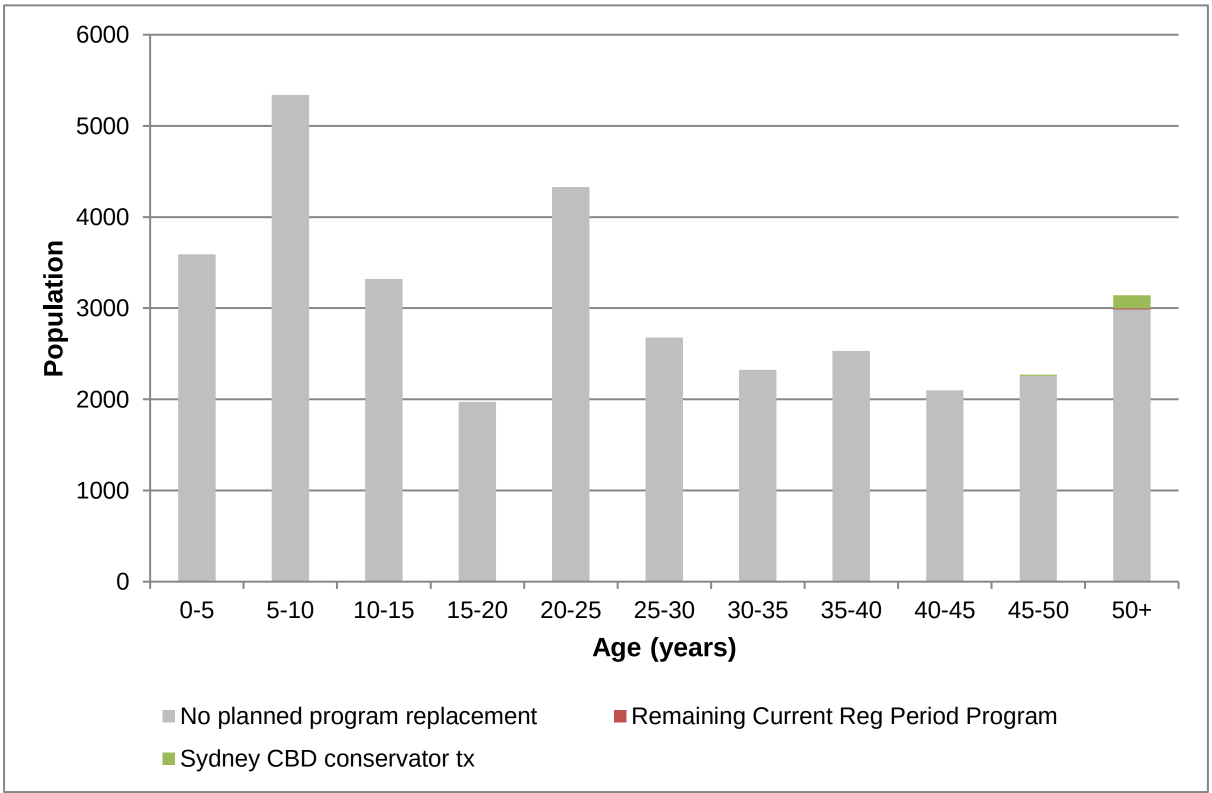
This program continues from the current regulatory period. Ausgrid expects to replace 165 CBD transformers at a total direct cost of $18.0 million ($, real FY19). These assets are to be replaced with modern equivalent transformers. This replacement program is expected to continue beyond the 2019-24 regulatory period due to the volume of assets and the access difficulty within the CBD.

The age profile highlighting the identified programs for replacement against the total population of distribution transformers on the network is shown in Figure 1.

2.2 Background

There are a total of approximately 33,600 distribution transformers across the Ausgrid network of which 1,300 are CBD Distribution transformers (less than 4%). The age profile of these assets is shown in Figure 1 below. Figure 1 also shows the number of transformers planned to be replaced this regulatory period. As can be seen, the number of assets targeted for planned replacement is very low (less than 1%) relative to the number of distribution transformers on the network.

Figure 1. Age profile of distribution transformers (as at June 2017)



2.3 Risks – Consequence and likelihood

The key consequences that can result from a loss of this function are shown in Table 1 below.

Table 1. Consequences from loss of function for distribution transformers

Consequences	Descriptions
Harm to the public, communities and workers	Fire caused by a loss of insulation, further propagated by the presence of highly flammable oil within the transformer tank.
	Structural damage to the substation as a result of over-pressure within the transformer tank leading to a tank rupture.
	Interruptions to electricity supply for an extended period can affect a single customer or whole communities in the form of transport systems, traffic controls, emergency services, business and communication systems, critical infrastructure and vulnerable customers including those on life support systems. Loss of supply within the CBD is more broadly unacceptable compared to other parts of the Ausgrid network. Restoration of supply can be more difficult due to the access restrictions with the Sydney CBD.
Harm to the environment	Mineral oil spills can lead to environmental contamination.
Damage to property	Damage to surrounding property and other substation equipment as a result of a transformer explosion or fire.

Over the 5 year period from 2012/13 to 2016/17, from the population of 1,300 Sydney CBD transformers, Ausgrid has experienced on average 111 failures per year. These high failure rates validate that these assets are at end of life. Most causes of failures recorded against the Sydney CBD transformers were oil related including oil leakage from the transformer tank and other components of the asset (seals and gaskets). Instances of 'low oil' were recorded regularly. Other failure modes include:

- Overheating
- Deteriorating transformer windings
- Corrosion of the tank.

The failure modes described above all relate to the deterioration of assets over time. Therefore as the asset ages, it deteriorates, increasing the likelihood of failure. The standard technical life of distribution transformers is 45 years. Assets older than 45 years are more prone to functional failure. Given the average age of these assets is 53.6 years, the likelihood of failure and therefore of consequence realisation is high as reflected by the average number of failures experienced over the last five years.

2.4 Treatment analysis

Assessment of the planned treatment solutions considered for distribution transformers is shown in Table 2.

Table 2. Treatment options for managing distribution transformers

Treatment options	Treatment overview
1 Repair the distribution transformer	Undertake repairs to the distribution transformer as conditional issues are identified.
2 Refurbish the distribution transformer	Replacement of the oil, gaskets and repairs to the tank, this could be done offsite as part of Ausgrid's rotables process and then placed into inventory stock for reuse on future projects.

Treatment options	Treatment overview
3 Replace the distribution transformer	Replacement of the distribution transformer.

The different treatment options are all utilised at different points in the asset's lifecycle. A repair may be completed where practical and efficient. A repair or refurbishment treatment does not remove the inherent risk of the design and costs a similar order of magnitude and is therefore not the preferred option.

The Sydney CBD transformers targeted for replacement next period are all older than their standard technical life, have condition issues and have a history of failures supporting a replacement approach. Given the types of failure modes, repairs are not efficient, as often they require relocation of the asset to a workshop, removal of oil and welding or replacement of gaskets. Undertaking these works is cost prohibitive given the comparative cost to replace and would require the network to be in an abnormal state for the duration of the repair.

Ausgrid has in place a rotables process whereby each conditionally or functionally failed transformer is evaluated for repair or replacement. Transformers that are selected for repair are removed from service, repaired and placed into inventory stock for reallocation onto future projects. This process minimises network interruption and provides the optimal investment outcome.

2.5 Options

Each of the proposed distribution transformer programs has undergone an assessment of options to mitigate risks associated with the asset failing. The serious safety and electricity supply risks to the public, communities and workers makes a 'run to failure' reactive approach unacceptable. The remaining options are applied to the Sydney CBD conservator distribution transformers. These options and the assessment are set out in Table 3 below.

Table 3. Program options for managing distribution transformers

Program needs options	Option overview
1 Reactive	Implement treatment such as replacement when the transformer fails. Refurbishment/repairs will be carried out if the condition issue is minor and spare components are available for the repair.
2 Conditional treatment	Implement treatment such as replacement when inspections identify that they have deteriorated to the point of condition-based failure.
3 Planned treatment	Implement planned treatment of all transformers, at their technical standard life of 45 years. Individual assets are built into a priority list of assets to be treated. Assets are replaced in a systematic way based on their individual level of risk.

A reactive treatment is generally considered suitable for distribution transformers, however, given the unique risks associated with the Sydney CBD, a reactive approach is unacceptable for this small sub-class of the population. The Sydney CBD transformers targeted for replacement have all been assessed as conditionally failed and therefore form part of a planned program. The conditional and reactive components of this program are included in Attachment 5.13.K (Reactive replacement programs) of this document with other reactive programs.

2.6 Costing and volumes

The asset access issues including confined space requirements as well as the additional planning and traffic control requirements for the Sydney CBD increases the unit rate for undertaking these works when compared to other distribution transformers on the network. The cost for reactive and conditional replacement is included in Attachment 5.13.K (Reactive replacement programs) of this document.

Each of the assets identified for planned replacement (Sydney CBD transformers) are in poor condition and have exceeded their technical life. The volume of planned replacement works proposed is based on the balance between risk of failure and the practicality of delivering replacement in the high density CBD environment. Each Sydney CBD distribution transformer included in the program has been prioritised to address the highest risks first and maximise the amount of risk reduction.

Ausgrid's unit rate for the REPEX categories covering distribution transformers is generally in line with Ausgrid's calculated benchmark unit cost. Ausgrid has forecast replacement of a significant number of CBD distribution transformers that are at end of life, however, this program accounts for only 0.5% of the total population of distribution transformers. Some distribution transformers are also replaced as part of limited life pole transformer substations, kiosk replacement work or outdoor enclosure replacement work. Ausgrid's forecast for the 2019/20 – 2023/24 regularity period including the substation programs is for less replacement work of distribution transformers than Ausgrid's repex analysis volumes.

The Sydney CBD transformer program forms part of the overall investment being proposed for the replacement of distribution transformers, refer to the Ausgrid Reset RIN template '2.2 REPEX' for details in regard to the overall investment proposed for this asset category during 2019-24.

The summary forecast for these replacement programs is shown in Table 4. The costs are shown in direct costs only.

Table 4. Forecast for distribution transformation

Direct Costs (real $FY19)	2019/20	2020/21	2021/22	2022/23	2023/24
CBD distribution transformers					
Volumes	33	33	33	33	33
Unit cost	$109,560	$109,260	$109,188	$109,201	$109,105
Total costs ($m)	**$3.62**	**$3.61**	**$3.60**	**$3.60**	**$3.60**

3 POWER TRANSFORMERS

3.1 Program description

Ausgrid has conditional programs to replace power transformers located in Ausgrid's zone and subtransmission substations that are approaching the end of their serviceable lives. Power transformers are one of Ausgrid's most critical, high value assets. The loss of a power transformer can lead to:

- A safety risk predominately to workers or the community in the event of a transformer fire
- A significant loss of supply depending on the configuration of the network
- An environmental incident from the escape of oil into the environment.

There are five main programs relating to the management of power transformers:

- System spare transformer – ZN (REP_02.02.06)
- Transformer replacement (utilising existing holdings) – ZN (REP_02.02.53)
- System spare transformer – TS (REP_03.02.05)
- Transformer replacement (utilising existing holdings) – TS (REP_03.02.42)
- Noisy transformers – ZN/TS (DOC_11.04.03).

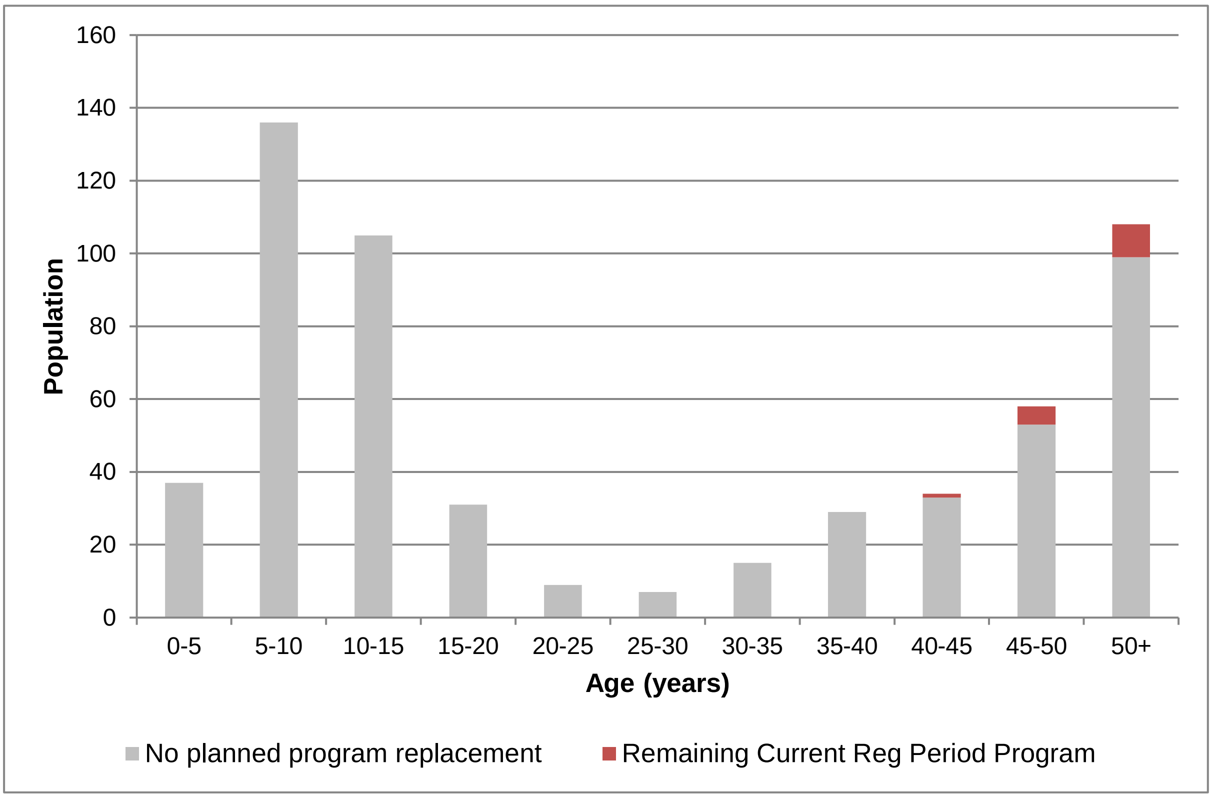
These programs continue from the current regulatory period. Ausgrid expects to replace 20 transformers in the 2019-24 period as part of replacement programs, the expenditure is captured as part of the reactive programs captured in Attachment 5.13.K (Reactive replacement programs). These assets are replaced with modern equivalent transformers. Ausgrid also has an additional program to upgrade oil containment systems for power transformers to manage the environmental risks from leaking transformers and meet legislative compliance obligations for oil storage. Details of this program can be found in Attachment 5.13.J (Other replacement programs).

As this program is conditionally driven, a forward forecast of specific replacement work is not able to be determined, so the currently identified programs for replacement against the total population of power transformers on the network is shown in Figure 2.

3.2 Background

Power transformers are used in Ausgrid's zone and subtransmission substations to change the voltage received at 132kV to 66kV or 33kV to supply the subtransmission network and further reduce the voltage to 11kV to supply the distribution network. There are a total of 569 zone and subtransmission transformers in service across the Ausgrid network. The age profile of these assets is shown in Figure 2.

Figure 2. Age profile of power transformers (as at 30 June 2017)

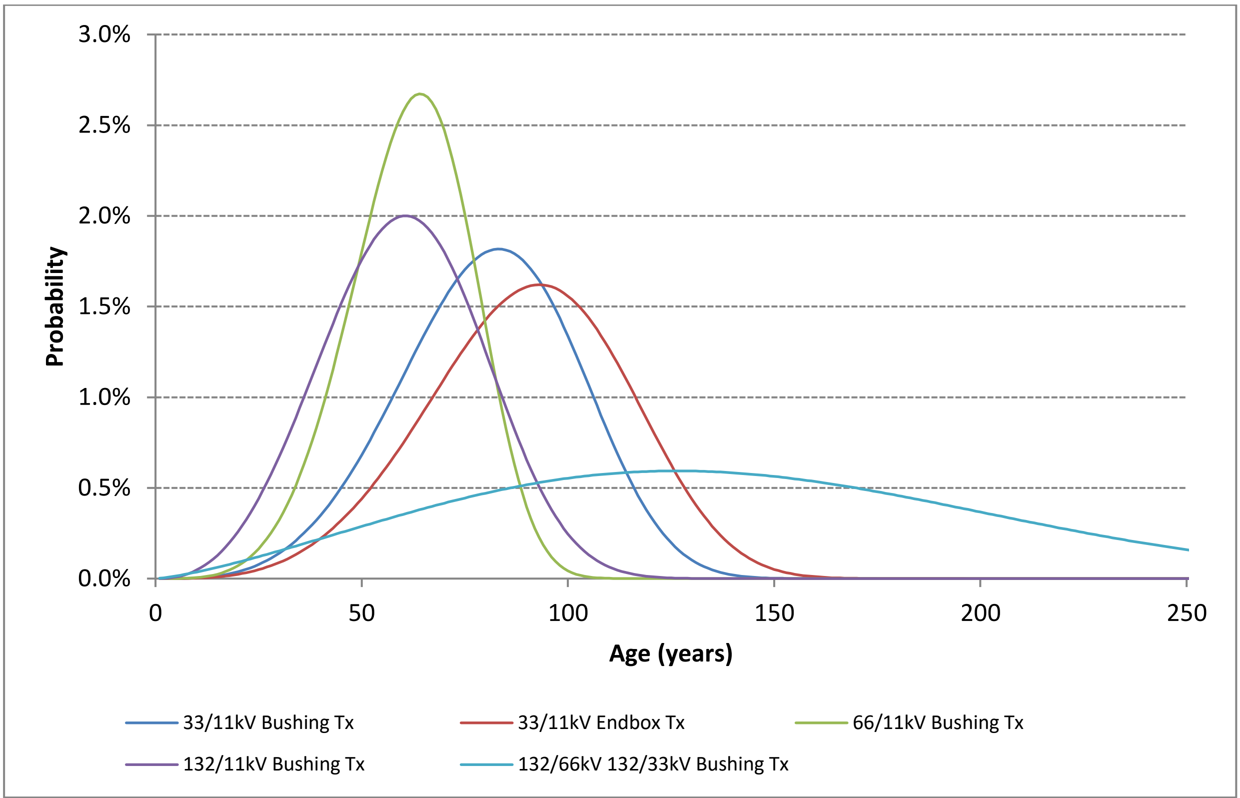


Previous network security requirements led to a large number of transformers installed in the last two regulatory periods as shown by the transformers between five and fifteen years of age. In the current regulatory period, Ausgrid has installed significantly less transformers, focusing on “end of life” replacement.

Based on historical replacement works, the average age of transformers replaced due to “end of life” decisions is approximately 50 years. As shown in the age profile, Ausgrid has 108 transformers over 50 years of age.

Ausgrid has strong historical data on the end of life decisions for power transformers (winding failures only) that have been used to develop the probability distribution shown in Figure 3 which enables linkage between the transformer age and the probability of failure.

Figure 3. Power transformer "end-of-life" probability distribution



However, the majority of recent end of life decisions have been based on the condition of the tapchanger or the transformer gaskets and seals. The need to replace power transformers is driven by:

- Network load constraints (captured as part of the augmentation plan), or
- When a transformer is no longer fit for service, technically or economically.

3.3 Risks – Consequence and likelihood

The consequence of failure of a power transformer will vary on the nature of the failure, the design and condition of the unit and its location. However, because all of these assets are located within substations, generally contain large volumes of mineral oil and pose a dangerous ignition source, the consequences of a catastrophic failure can be significant.

The key consequences that can result in a loss of this function are shown in Table 5 below.

Table 5. Consequences from loss of function for power transformers

Consequences	Descriptions
Harm to the public, communities and workers	Fire caused by a loss of insulation, further propagated by the presence of highly flammable oil within the transformer tank.
	Structural damage to the substation as a result of over-pressure within the transformer tank leading to a tank rupture.
	Interruptions to electricity supply for an extended period can affect a single customer or whole communities in the form of transport systems, traffic controls, emergency services, business and communication systems, critical infrastructure and vulnerable customers including those on life support systems. Long impacts on network security and reliability due to long restoration and replacement times due to the difficulty in moving and replacing/repairing transformers.

Consequences	Descriptions
Harm to the environment	Mineral oil spills can lead to environmental contamination.
Damage to property	Damage to surrounding property and other substation equipment as a result of a transformer explosion or fire.

The most common failure modes associated with power transformers include:

- Failure of the windings
- Failure to contain oil
- Tapchanger contact degradation.

A failure of the winding can lead to an electrical short circuit, over-pressure within the tank, tank rupture/explosion and fire. A failure of the tank seals and gaskets leads to the escape of insulating oil, reducing the insulation property of the transformer and leading to oil escape which may result in damage to the environment. Tapchangers contain moving parts which are the most likely transformer components to fail. Ausgrid still contains a large number of transformers with the tapchangers mounted inside the main transformer tank. Repairing these tapchangers can often be costly and limited spare parts are available.

3.4 Treatment analysis

Assessment of the planned treatment solutions considered for power transformers is shown in Table 6.

Table 6. Treatment options for managing power transactions

Treatment options	Treatment overviews
1 Repair the power transformer	Undertake repairs to the power transformer as conditional issues are identified.
2 Refurbish the power transformer	Replacement of the gaskets, renewal of the bushings or replacement of the tapchanger.
3 Replace the power transformer	Replacement of the power transformer.

The different treatment options are all utilised at different points in the asset's lifecycle. A repair may be completed where practical and efficient, particularly where insulation has been compromised. Ausgrid utilises an economic model to assess transformer options based on:

- The existing transformers remaining life
- The cost to maintain the existing transformer in a serviceable condition
- The cost to replace and maintain a new transformer
- The expected technical life of the new transformer.

The lowest cost option is then implemented. This assessment is performed on each transformer when a major maintenance or repair is required.

3.5 Options

Ausgrid has considered several options for managing the power transformers. These options and the assessment are set out in Table 7.

Table 7. Program options for managing power transformers

Program needs options	Option overviews
1 Reactive	Implement treatment such as replacement, refurbishment or repairs when the transformer fails.
2 Conditional treatment	Implement treatment such as replacement when inspections identify that they have deteriorated to the point of condition-based failure.
3 Planned treatment	Implement planned treatment prior to power transformer assets failing as part of a priority list.

The most prudent approach is a conditional treatment program for power transformers. This leverages the information able to be collected as part of maintenance to inform the treatment decision making. Each transformer is assessed individually using a cost benefit approach, assessing treatment costs to determine the lowest whole of life cost option.

Due to the long lead times for new transformers, this approach is supported by a spares strategy. Spare transformers are held for most configurations, reducing the time to undertake replacement. The reduced replacement timeframes enable Ausgrid to achieve maximum life from its power transformers, without compromising the security of the network.

Due to amalgamations of county Councils in the past and the asset acquisition from the former NSW Electricity Commission, Ausgrid has a diverse range of power transformers consisting of numerous manufacturers and model types, covering a broad age profile. It is important that Ausgrid manage the risk of equipment failure with appropriate strategies such as having spares able to meet the different configurations across the network. As such Ausgrid conducts Spares Requirement Analysis (SRA) using the Poisson distribution to calculate asset availability and hence minimum holdings in each transformer category.

3.6 Costing and volumes

The funding for any replacement work resulting from the conditional approach to power transformer replacement work forms part of the reactive expenditure (refer to Attachment 5.13.K (Reactive replacement programs)). Due to the various projects undertaken across the Ausgrid network, there is potential for surplus transformers to be used in preference to the emergency spare transformers. A transformer may become surplus when it is removed from service but remains serviceable. This can occur when augmentation works change the requirements for a transformer. Utilising surplus transformers reduces the overall cost in the event of transformer replacement. Due to the variability in the treatment option, a unit rate and volume is impractical.

As Ausgrid maintains 23 different transformer spare categories for the 569 installed transformers, there can be works required to accommodate the allocated transformer upon installation. These works vary in cost depending on the size of the transformer and degree of modification required.

Refer to the Ausgrid Reset RIN template '2.2 REPEX' for details in regard to the overall investment proposed for this asset category during 2019-24.

In the 5 year period between 2012/13 and 2016/17, Ausgrid had initiated an average of 2.8 power transformer replacement works a year resulting from the conditional treatment approach taken. In addition to this volume, Ausgrid's major projects have decommissioned a number of poor condition transformers. Considering the impact of the major projects, the average age for Ausgrid's power transformer fleet has remained consistent over the last five years. Whilst there are a large number of young power transformers, a significant portion are above the standard life of 50 years. Based on historical replacement volumes, asset age and the impact of reduced augmentation and major substation replacement projects, Ausgrid has forecast future power transformer replacement requirements at 5 annually which equates to 0.9% of the population.

4 INSTRUMENT TRANSFORMERS

4.1 Program desciption

Instrument transformers perform an important metering, protection and safety role on the network. Ausgrid has implemented programs to mitigate known failure modes of instrument transformers installed in zone and subtransmission substations. The four main conditional programs are:

- Post-type voltage transformers – Zone substations (REP_02.02.41)
- Post-type current transformers – Zone substations (REP_02.03.12)
- Post-type voltage transformers – Subtransmission substations (REP_03.02.27)
- Post-type current transformers – Subtransmission substations (REP_03.03.09).

Instrument transformers that are part of switchgear and transformers are not included in these programs. The programs are continuing from the current regulatory period and include planned and conditional aspects to the programs. The total value of these programs is expected to be $9.5 million ($, real FY19) in the 2019-24 regulatory period.

The age profile highlighting the identified programs for replacement against the total population of instrument transformers on the network is shown in Figure 4.

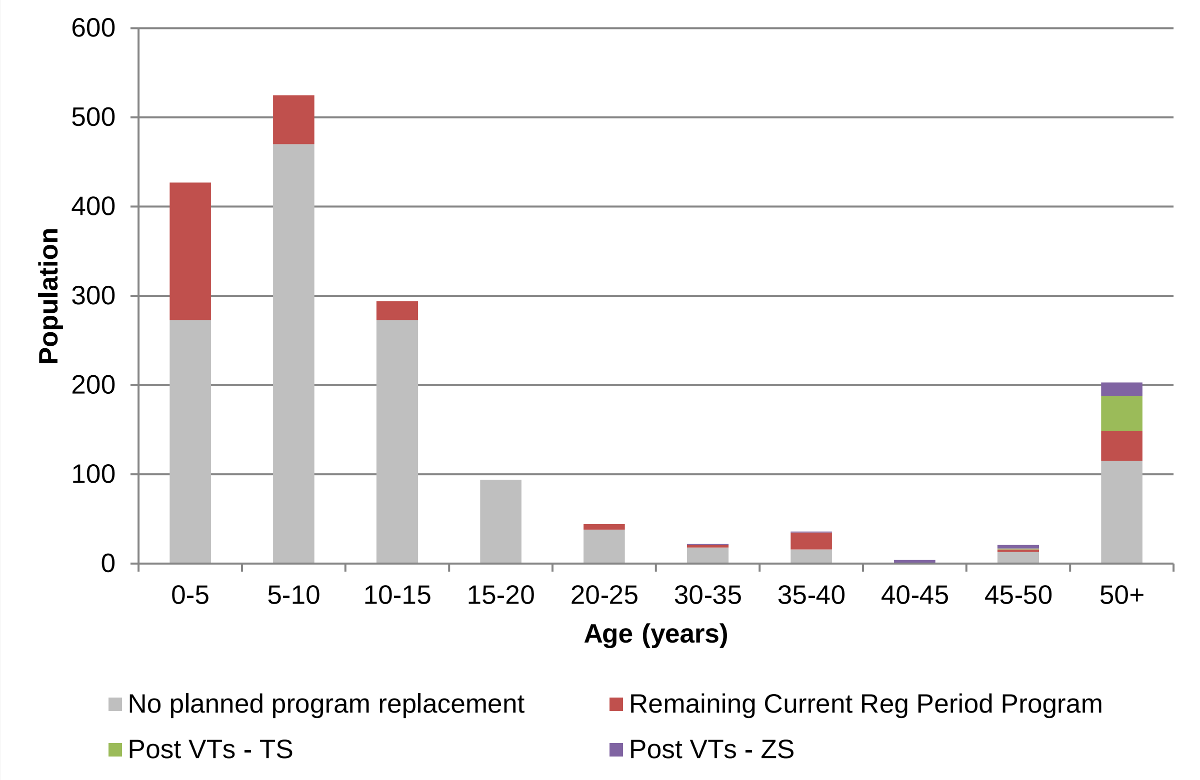
4.2 Background

There are 1,670 instrument transformers that are stand-alone equipment on Ausgrid's network (instrument transformers that are components of other equipment have been excluded). The two categories of instrument transformer on the Ausgrid network are current transformers and voltage transformers. The instrument transformer sets (one for each phase voltage) are located within transmission and zone substations. These operate at voltages ranging from 33kV and 66kV to 132kV. 13% of Ausgrid's instrument transformers are over the standard life of 45 years.

There is a diverse range of instrument transformers with various manufacturers and model types and Ausgrid has maintenance and testing schedules in place to mitigate the risk of equipment failure as far as reasonably practical.

The age profile of instrument transformers on the network is shown in Figure 4 below.

Figure 4. Age profile of instrument transformers (as at 30 June 2017)



Ausgrid has had significant issues with a proportion of the recently installed population of voltage transformers manufactured by Arteche that has resulted in safety alerts, due to a number of catastrophic failures caused by a manufacturing defect. The access to switchyards at times has been restricted until proactive testing could be completed. As a result of this and an identified manufacturing deficiency which results in catastrophic failure, Ausgrid has initiated a program to remove these assets from the network within the current regulatory period. In the 2019-24 period, Ausgrid is planning to complete the replacement of a number of legacy oil filled 33kV three phase units which are in poor condition.

The primary function of instrument transformers is to provide secondary current or secondary voltage measurements used in metering, control and protection systems. As such instrument transformers protect the safety of the public and Ausgrid workers and maintain reliability on the network.

4.3 Risks – Consequence and likelihood

The key consequences that can result in a loss of this function are shown in Table 8 below.

Table 8. Consequences from loss of function for instrument transformers

Consequences	Descriptions
Harm to the public, communities and workers	Fire caused by a loss of insulation, further propagated by the presence of highly flammable oil within the instrument transformer tank.
	Explosive failure of porcelain insulation could impact on the safety of workers if they are in the vicinity.
	Interruptions to electricity supply for an extended period can affect a single customer or whole communities in the form of transport systems, traffic controls, emergency services, business and communication systems, critical infrastructure and vulnerable customers including those on life support systems.

Consequences	Descriptions
Harm to the environment	Mineral oil spills can lead to environmental contamination.
Damage to property	Damage to surrounding property and other substation equipment as a result of an instrument transformer explosion or fire.

Ausgrid has experienced approximately 42 notifications for failures annually for 2012/13 – 2016/17, which represents 2.5% of the population annually.

The key failure modes experienced are:

- Loss of insulation
- Corroded tank and steelwork.

4.4 Treatment analysis

Assessment of the planned treatment solutions considered for instrument transformers is shown in Table 9.

Table 9. Treatment options for instrument transformers

Treatment options	Treatment overviews
1 Repair the instrument transformer	Undertake repairs to the instrument transformer as conditional issues are identified.
2 Refurbish the instrument transformer	Replacement of the oil to renew the insulating medium.
3 Replace the instrument transformer	Replacement of the instrument transformer.

The different treatment options are all utilised at different points in the asset's lifecycle. A repair may be completed where practical and efficient, particularly where insulation has been compromised.

4.5 Options

The options to mitigate the risk of instrument transformers in substations are reactive, conditional or planned treatment. The serious safety and electricity supply risks to workers makes a 'run to failure' reactive approach unacceptable. These options are assessed in Table 10.

Table 10. Program options for managing instrument transformers

Program needs options	Option overviews
1 Reactive treatment	Repair, refurbish or replace when the instrument transformer fails. Run to end of life approach.
2 Conditional treatment	Implement treatment to replace, refurbish or repair instrument transformer when condition-based problems have been identified.
3 Planned treatment	Implement treatment of the instrument transformer prior to the assets failing. Individual assets are built into a priority list of assets to be treated. Assets are replaced in a systematic way starting from the most risky assets.

The most efficient treatment available to Ausgrid is replacing the instrument transformer. There are a small number where Ausgrid is planning on conducting this in a planned manner as they have already been deemed conditionally failed. After this backlog is removed, a conditional approach will be implemented informed by the testing that Ausgrid conducts on a routine basis as part of maintenance.

4.6 Costing and volumes

Condition testing has been performed on instrument transformers for a number of years and the proposed volumes are based on predicted conditional failures. The assessment criteria for conditional testing is reviewed periodically based on asset performance history to maintain an appropriate level of risk. Ausgrid is planning to complete the replacement of a number of legacy oil filled 33kV three phase units which are in poor condition. Ausgrid is proposing a consistent volume of instrument transformer replacement work throughout the regulatory period. These programs form part of the overall investment being proposed for the replacement of instrument transformers, they can also be captured during Major Projects or as a reactive failure. Refer to the Ausgrid Reset RIN template '2.2 REPEX' for details in regard to the overall investment proposed for this asset category during 2019-24.

Assets which have known corrective issues identified have been included in a planned program. Ausgrid has completed a planned replacement program during the previous regulatory period to remove identified aged assets. This will continue for the legacy 33kV population of three phase units and a future volume of conditional replacement work based on historic conditional replacement rates has been allowed for. The combination of these programs has been estimated at 1% of the population annually, which infers a 100 year asset life.

The summary forecast for these replacement programs is shown in Table 11. The costs shown are direct costs only.

Table 11. Forecast for instrument transformers

Direct Costs (real $FY19)	2019/20	2020/21	2021/22	2022/23	2023/24
Post VTs - ZN					
Volumes for replacement	6	6	6	6	6
Unit cost	$99,244	$98,850	$98,620	$98,447	$98,173
Total costs ($m)	**$0.60**	**$0.59**	**$0.59**	**$0.59**	**$0.59**
Post VTs - STS					
Volumes for replacement	9	9	9	9	9
Unit cost	$99,245	$98,851	$98,621	$98,448	$98,174
Total costs ($m)	**$0.89**	**$0.89**	**$0.89**	**$0.89**	**$0.88**
Post CTs - ZN					
Volumes for replacement	1	1	1	1	1
Unit cost	$139,271	$138,559	$138,022	$137,725	$137,521
Total costs ($m)	$0.14	$0.14	$0.14	$0.14	$0.14
Post CTs - STS					
Volumes for replacement	2	2	2	2	2
Unit cost	$139,271	$138,559	$138,022	$137,725	$137,521

Direct Costs (real $FY19)	2019/20	2020/21	2021/22	2022/23	2023/24
Total costs ($m)	**$0.28**	**$0.28**	**$0.28**	**$0.28**	**$0.28**

5 REACTIVE PLANT

5.1 Program description

Ausgrid has two planned programs to replace and refurbish reactive plant. These programs cover the equipment which has been identified as approaching end of life and have the potential to compromise the operation of Ausgrid's network. The planned programs are:

- Power reactors – Subtransmission substations (REP_03.02.40)
- Neutral earthing resistors – Subtransmission substations (REP_02.02.59)

The total value of these programs in the 2019-24 regulatory period is $5.8 million.

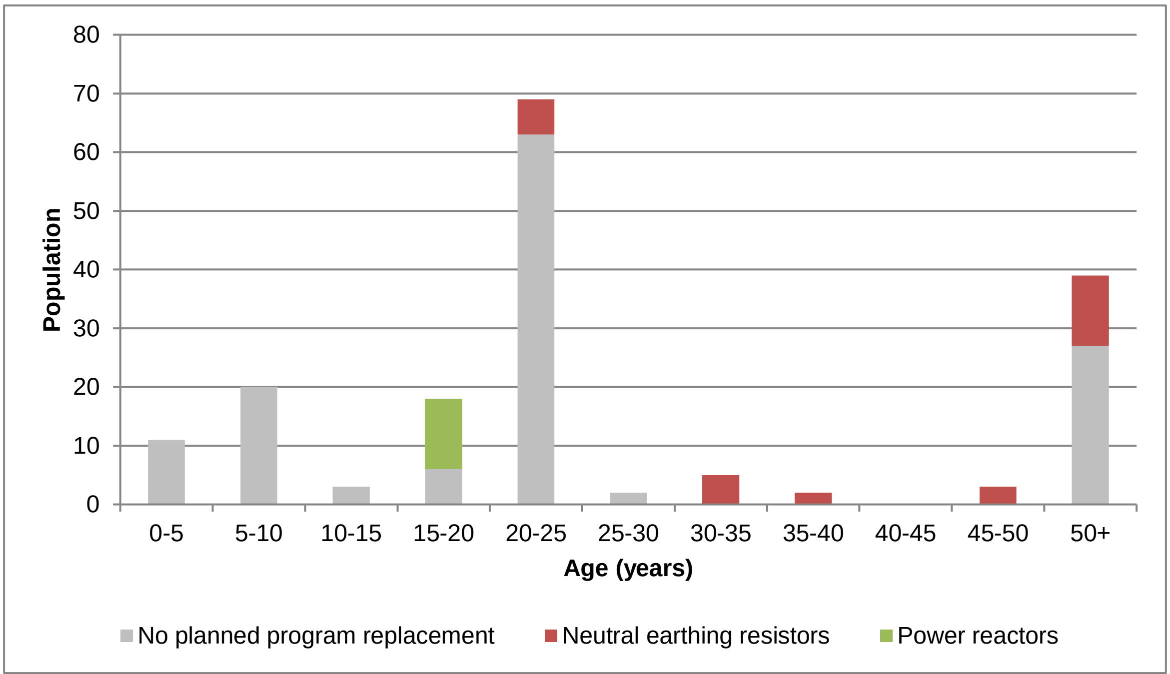
The age profile highlighting the identified programs for replacement against the total population of reactive plant on the network is shown in Figure 5.

5.2 Background

Ausgrid has 35 three phase resistor sets (across 16 sites) used for neutral earthing of transformers. Ausgrid has 111 single phase power reactors and 26 three phase neutral earthing reactors. The function of neutral earthing resistors or reactors is to limit the earth fault currents through the neutral point of a transformer. Power reactors are used to regulate the voltage and reactive power associated with the power system to allow control of power flows within the network.

The age profile of these assets is shown in Figure 5. Also shown is the age profile of the assets that are planned to be replaced.

Figure 5. **Volumes by financial year for instrument transformers**



As shown in Figure 5, 24% of the assets in this class are over the standard asset technical life of 45 years. Ausgrid is proposing to replace all the neutral earthing resistors installed within subtransmission substations. For power reactor equipment, Ausgrid is proposing to refurbish a small number that are prematurely ageing.

Based on the condition of the enclosures and equipment, Ausgrid's fleet of neutral earthing resistors are approaching end of life. When these assets fail to perform their function they place a greater strain on the network and delay fault clearing.

Four 132kV air core reactor sets purchased and installed by Ausgrid in the early 2000s have degraded paintwork. Left untreated this has the potential to prematurely end their serviceable life.

5.3 Risk – Consequence and likelihood

The key consequences that can result in a loss of this function are shown in Table 12 below.

Table 12. Consequence from loss of function for reactive plant

Consequences	Descriptions
Harm to the public, communities and workers	Increased fault levels across the network has the potential to increase the risk to public, communities and workers (for example if a line falls to the ground the increased fault level increases the potential for harm – step and touch potential increases).
	Delay in disconnecting supply from a downstream fault of a circuit breaker has the potential to put the general public at risk (for example if a line falls to the ground but is not rapidly disconnected).
Damage to property	Damage to surrounding property and other substation or mains equipment as a result of higher fault levels.
	Customer equipment can be damaged due to voltages fluctuating outside of acceptable limits.

There have been 3 recorded failures in the 5 year period from 2012/13 – 2016/17 associated with neutral earthing resistors and 49 associated with power reactors.

The key failure modes for neutral earthing resistors are:

- Fails open circuit
- Flashover.

The key failure modes for power reactors are:

- Degraded insulation
- Inadequate surface protection.

5.4 Treatment analysis

Assessment of the planned treatment solutions considered for reactive plant is shown in Table 13.

Table 13. Treatment options for managing reactive plant

Treatment options	Treatment overviews
1 Repair the reactive plant	Undertake repairs to the reactive plant as conditional issues are identified.
2 Refurbish the reactive plant	The outside housing can be reconditioned and repainted and any bushings cleaned/replaced as necessary.
3 Replace the reactive plant	Replacement of the reactive plant.

The neutral earthing resistor design is such that any failures are not detected until called upon to operate (hidden failure modes), therefore a replacement is the most prudent option.

The air core reactor sets have degraded paintwork. Due to the scale of the installation requiring significant scaffolding and a complete removal of the paint before reapplication, a refurbishment is proposed rather than spot repairs.

5.5 Options

The options considered for the treatment of reactive plant are summarised in Table 14 below.

Table 14. Program options for managing reactive plant

Program needs options	Option overviews
1 Reactive	Implement treatment such as replacement when the reactive plant fails.
2 Conditional treatment	Implement treatments to repair or replace reactive plant when inspections/ testing identify they have deteriorated to the point of conditional failure based on a set of criteria.
3 Planned treatment	Implement planned treatment prior to reactive plant failing. Individual assets are built into a priority list of assets to be treated. Assets are replaced in a systematic way starting from the most risky assets.

Neutral earthing resistors have known condition issues. A planned replacement approach ensures that all the assets will be replaced in a sustainable manner with the lowest customer impact.

The air core reactors have identified condition issues that if left to degrade further will not be cost effective to address, as such a planned refurbishment is chosen.

5.6 Costing and volumes

Ausgrid is proposing planned replacement volumes in categories where there has been no sufficient expenditure in the past. This is due to emerging condition issues which have not been treated historically. These programs form part of the overall investment being proposed for the replacement of reactive plant, refer to the Ausgrid Reset RIN template ‘2.2 REPEX’ for details in regard to the overall investment proposed for this asset category during 2019-24.

It is noted that:

- The volume and unit rate for power reactor refurbishment is per three phase set
- The volume and unit rate for neutral earthing resistors is per subtransmission substation.

Each site in the neutral earthing resistors program will require a site specific design taking into account the fault levels at the location as well as the protection requirements, it is intended that the resistors be replaced with reactors due to their easier ability to maintain (due to one reactor per transformer rather than one bank of resistors per site). All of Ausgrid's subtransmission earthing resistors will be targeted over the period.

The summary replacement forecast is shown in Table 15. The costs shown are direct costs only.

Table 15. Forecast for reactive plant

Direct Costs (real $FY19)	2019/20	2020/21	2021/22	2022/23	2023/24
Power reactors					
Volumes for refurbishment	1	1	1	1	0

Direct Costs (real $FY19)	2019/20	2020/21	2021/22	2022/23	2023/24
Unit cost	$763,312	$760,139	$757,339	$756,065	$0
Total costs ($m)	**$0.76**	**$0.76**	**$0.76**	**$0.76**	**$0**
Neutral earthing resistors					
Volumes for replacement	2	2	2	2	2
Unit cost	$282,230	$280,543	$279,559	$278,820	$277,645
Total costs ($m)	**$0.56**	**$0.56**	**$0.56**	**$0.56**	**$0.56**