Asset Management Plan Substation Transformers

Part of the Energy Queensland Group

Executive Summary

This Asset Management Plan (AMP) covers the class of assets known as Substation Transformers.

Substation power transformers change the voltage in an electricity network between the levels used for transmission, sub-transmission and distribution. Other relevant assets included in this AMP are substation regulators and reactors. Regulators produce a standard voltage output regardless of changes to input voltage or load conditions. Reactors introduce inductive impedance into networks, which can be used to regulate the impacts of reactive power, fault current and harmonic voltages in networks.

Energy Queensland Limited (EQL) manages 1,340 large power transformers, comprising 723 large power transformers in the Northern and Southern (Ergon Energy) regions, and over 617 large power transformers in South East (Energex) region.

EQL manages 98 large power voltage regulators, comprising 91 large power voltage regulators in the Northern and Southern region and 7 large power voltage regulators in South East region.

EQL manages 109 large reactors in the Northern and Southern region.

These assets include 1,178 On-Line Tap Changers (OLTCs), used to change transformer output voltage while the transformer is still operating, of which there are 594 OLTCs in the Northern and Southern region and 624 OLTCs in South East region.

The only specific regulatory performance standards for power transformers, regulators, or reactors relate to maintaining voltage within specified tolerances. OLTCs or regulators are required to ensure EQL achieves the regulatory voltage tolerance standards.

Because of the large energy transfer requirements, failure of these assets can substantially influence reliability performance. These assets feature prominently in Safety Net contingency plans required by EQL's Distribution Licences.

EQL employs all reasonable measures to ensure it does not exceed minimum reliability service standards, assessed as:

- System Average Interruption Duration Index (SAIDI); and
- System Average Interruption Frequency Index (SAIFI).

Key actions for the lifecycle asset management of assets contained in this AMP include reviewing and aligning approaches to condition assessment, investigating causes of defects in OLTCs, and increasing the volume of substation asset replacement in the Northern and Southern regions to address the existing Network Access Restrictions and deliver a long-term sustainable program of replacement.

EQL is also investigating the potential use of biodegradable oils in transformers, to improve asset longevity and reduce environmental impact. Emerging issues such as the need for in-situ oil conditioning capability are also being addressed.

Work is continuing with respect to the alignment of maintenance and operating practices from EQL legacy organisations, to drive efficiency, deliver customer outcomes, and mitigate risks across all EQL operations.

Revision History

Revision date	Version number	Description of change/revision
31/01/2019	1	AER Document Initial release

Document Approvals

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1 Introduction

Energy Queensland Limited (EQL) was formed 1 July 2016 and holds Distribution Licences for the following regions:

- South East Region (Organisation: Energex Limited); and
- Northern and Southern Regions (Organisation: Ergon Energy Corporation Limited).

There are variations between EQL's operating regions in terms of asset base and management practice, as a result of geographic influences, market operation influences, and legacy organisation management practices. This Asset Management Plan (AMP) reflects the current practices and strategies for all assets managed by EQL, recognising the differences that have arisen due to legacy organisation management. These variations are expected to diminish over time with the integration of asset management practices.

1.1 Purpose

The purpose of this document is to demonstrate the responsible and sustainable management of Circuit Breakers and reclosers in substations and on feeders on the 11kV and above network. The objectives of this plan are to:

1. Deliver customer outcomes to the required level of service.
2. Demonstrate alignment of asset management practices with EQL's Strategic Asset Management Plan and business objectives.
3. Demonstrate compliance with regulatory requirements.
4. Manage the risks associated with operating the assets over their lifespan.
5. Optimise the value Energy Queensland derives from this asset class.

This Asset Management Plan (AMP) will be updated periodically to ensure it remains current and relevant to the organisation and its strategic objectives. Full revision of the plan will be completed every five years as a minimum.

This Asset Management Plan is guided by the following legislation, regulations, rules and codes:

- *National Electricity Rules (NER)*
- *Electricity Act 1994 (QLD)*
- *Electrical Safety Act 2002 (QLD)*
- *Electrical Safety Regulation 2013 (QLD)*
- *Electrical Safety Code of Practice 2010 – Works (Qld) (ESCOP)*
- *Work Health & Safety Act 2014 (QLD)*
- *Work Health & Safety Regulation 2011 (QLD)*
- Ergon Energy Corporation Limited Distribution Authority No D01/99
- Energex Limited Distribution Authority No. D07/98

This Asset Management Plan forms part of EQL Strategic Asset Management documentation as shown in Figure 1. It is part of a suite of asset management plans, which collectively describe EQL's approach to the lifecycle management of the various assets used to deliver electricity to its customers.

Appendix 1 contains references to other documents relevant to the management of the asset class.

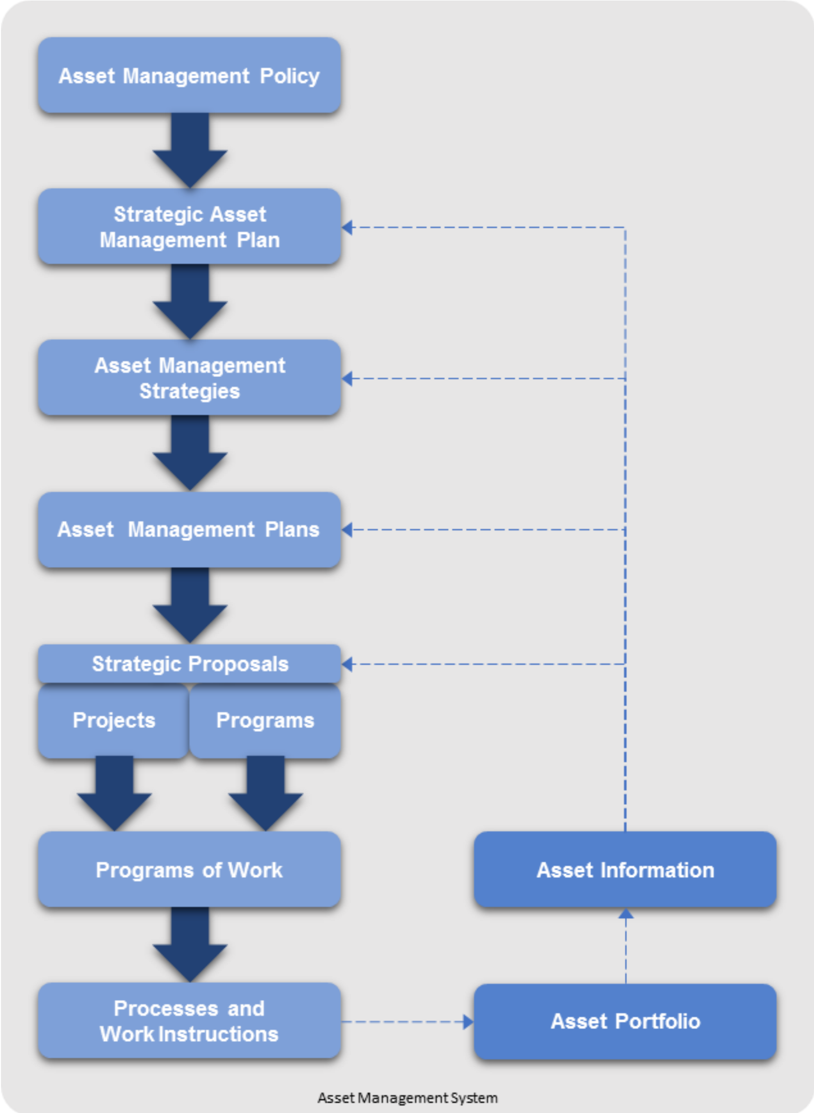


Figure 1: EQL Asset Management System

1.2 Scope

This asset management plan covers the following assets:

- Substation power transformers
- Substation regulators
- Substation reactors
- On-load tap changers
- Oil containment systems and bunding.

Many customers, typically those with high voltage connections, own and manage their own network assets including transformers and ancillary equipment. EQL does not provide condition and maintenance services for third party assets, except as an unregulated and independent service. This

AMP relates to EQL owned assets only, and excludes any consideration of such commercial services.

1.3 Total Current Replacement Cost

Substation power transformers are high capacity, low volume, high cost assets, and are typically asset managed on an individual basis using periodic inspection for condition and serviceability, and through systemic review of recorded performance.

Based upon asset quantities and replacement costs, EQL substation transformers, regulators and reactors have a replacement value in the order of $2.4 billion (Northern and Southern region $730 Million, South East region $1.65 billion). This valuation is the gross replacement cost of the assets, based on the cost of replacement of modern equivalents, without asset optimisation or age assigned depreciation. **Error! Reference source not found.** provides an indication of the relative financial value of EQL substation transformers, regulators and reactors compared to other asset classes.

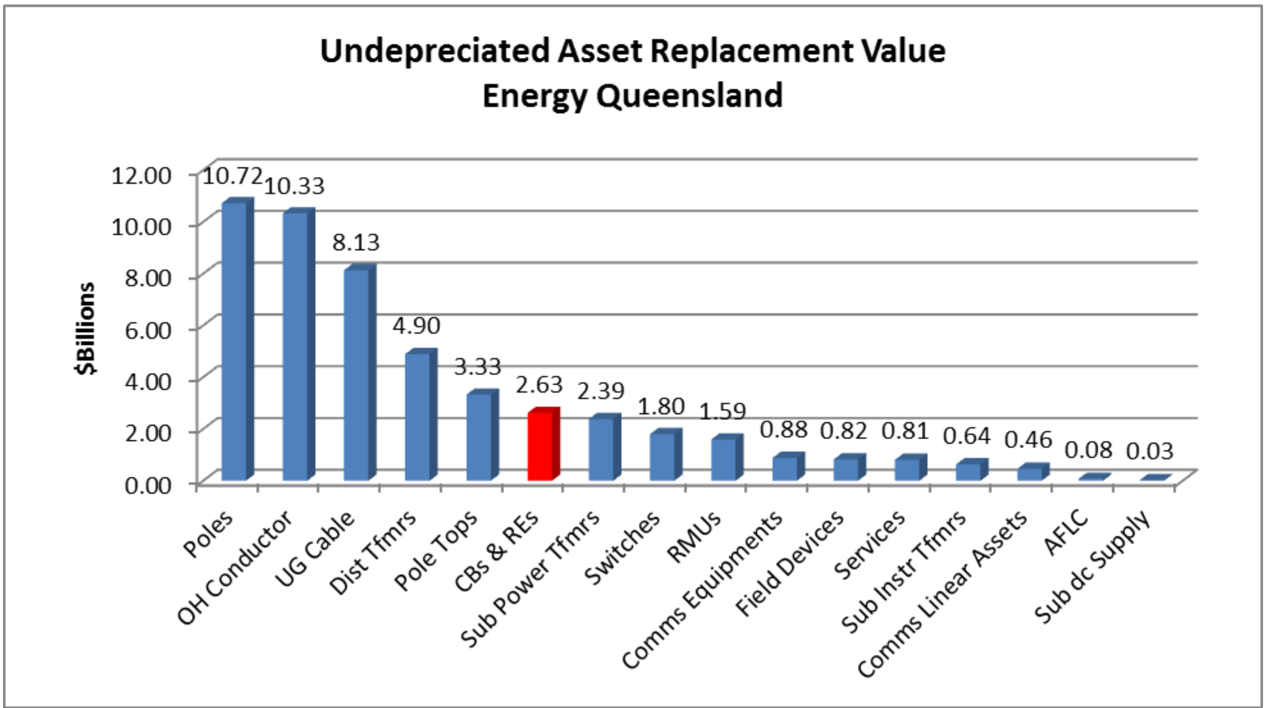


Figure 2: EQL – Total Current Asset Replacement Value

1.4 Asset Function and Strategic Alignment

The function of a power transformer is to change the voltage in an electricity network between the levels used for transmission, sub-transmission and distribution. This enables use of cost-effective infrastructure to achieve efficient transportation of electrical energy across distances. The other assets covered under this management plan contribute to this function either through performing voltage regulation or ancillary functions, and are discussed in more detail in later sections.

Error! Reference source not found. details how substation transformers, regulators and reactors contribute to EQL's corporate strategic asset management objectives.

Asset Management Objectives	Relationship of Asset to Asset Management Objectives
Ensure network safety for staff,	Diligent and consistent inspection, maintenance, and renewal

contractors, and the community	supports asset performance and hence safety for all stakeholders.
Meet customer and stakeholder expectations	Continued asset serviceability supports network reliability and promotes delivery of a standard quality electrical energy service at optimal cost.
Manage risks, performance standards, and asset investment to deliver balanced commercial outcomes	Failure of this asset can result in increased public safety risk, disruption of the electricity network, and disruption of customer amenity. Understanding asset performance allows optimal investment to achieve intended outcomes. Asset longevity assists in minimising capital and operational expenditure.
Develop asset management capability and align practices to the global ISO55000 standard	This AMP is consistent with AS/ISO55000 objectives and drives asset management capability by promoting continuous and targeted improvement.
Modernise the network and facilitate access to innovative energy technologies	This AMP promotes replacement of assets at end of economic life as necessary to suit modern standards and requirements.

Table 1: Asset Function and Strategic Alignment

1.5 Owners and stakeholders

The key roles and responsibilities for the management of this asset class are outlined in Table 2.

Role	Responsible Party
Asset Owner	Chief Financial officer
Operational Control	EGM Distribution
Maintenance Control	EGM Strategy, Asset Safety & Performance

Table 2: Stakeholders

2 Asset Class Information

The following sections provide a summary of the key functions and attributes of the assets covered in this AMP.

2.1 Asset Description

The function of a power transformer is to change the voltage in an electricity network between the levels used for transmission, sub-transmission and distribution. This enables use of cost effective infrastructure to achieve efficient transportation of electrical energy across distances. Along with performing the function of voltage transformation, power transformers also ensure that phasing is coordinated between network levels. Many power transformers also provide an earth reference point for the load side circuits which is critical for network protection to operate as designed.

EQL operates a highly varied population of substation power transformers, as a result of the amalgamation of legacy organisations and councils, and procurement from various suppliers over the last 60 years. The main criteria used to classify power transformers are the following:

- Primary, secondary, or tertiary voltage
- Power rating
- Vector group
- Impedance
- Tap changer type
-

The substation power transformers used by EQL contain large volumes of oil, which is used as the insulation medium in conjunction with paper wrapping around the internal windings. Physical dimensions of the power transformers vary significantly across the asset population and are determined by many of the above criteria, as well as the evolution of transformer design over the period.

2.1.1 Tap Changers

Tap changers are complex switches used to control the output voltage of a transformer by switching the output terminals of a winding between a series of multiple connection points embedded in the winding (taps).

In most large transformers (typically greater than 2-3MVA), tap changers called on-load tap changers (OLTCs), are installed. The function of an OLTC is to change the output voltage of its associated power transformer whilst on-load (i.e. with no interruption to load current) and without any section of the transformer winding short-circuiting. Most tap changer designs employ one of two switching principles, the high-speed resistor type OLTC and the reactor type OLTC.

Typically, the tap changer oil, which is affected by arcing as connections are broken and made to change the winding ratio, is separated from the transformer winding oil to prevent contamination. Newer generation tap changers use vacuum interrupters to quench the switching arc, while older generation units employ oil quenching. OLTCs fitted with vacuum interrupters can withstand more operations and require less maintenance than traditional units, and are generally considered to be more reliable.

Smaller transformers (typically <2-3MVA), and a few (larger) specifically designed transformers, are fitted with off-load tap changers, which are designed without load making and breaking capacity, so the transformer must be removed from service to allow switching between the different taps on the tapped winding.

2.1.2 Substation Regulators

A voltage regulator produces a fixed magnitude steady state output voltage, regardless of changes to its input voltage or load conditions. In substations, regulators are typically used to control the output voltage of a fixed tap power transformer. Substation power regulators are usually configured to not introduce an additional phase shift. The zero-degree phase shift is important for managing meshed network interconnections which require phasing to match in order to operate.

Whilst the function performed by the regulator is different from that of a power transformer, the similarities in design and failure modes result in them being treated in a similar way through asset lifecycle management practices.

2.1.3 Substation Reactors

Large substation reactors are typically of similar construction and design to a power transformer and introduce inductive impedance in an electrical circuit. This can be used to compensate for reactive power (shunt reactor) to manage voltage drop, or limit fault current (series reactor) to ensure downstream assets remain within ratings, as well as absorb/limit harmonic voltages. Whilst the function performed by the reactor is different from that of a power transformer, the similarities in design and failure modes result in them being treated in a similar way through asset lifecycle management practices.

2.2 Asset Quantity and Physical Distribution

Table 3 lists the substation transformer, regulator and reactor population by asset type.

Asset Type	Northern & Southern region	South East Region	Total
Power transformers	723	617	1,340
Substation regulators	91	7	98
Substation reactors	109	0	109

Table 3: Asset population

During the lifetimes of existing substation transformer assets, there have been several different network asset management companies managing sections of the electricity networks. Each of these legacy electricity companies designed their networks with operating voltages that suited the distances and loads to be serviced at those times. This also determined the power transformation ratios, resulting in a large number of standard voltage levels to be managed across the various legacy asset bases.

A series of design reviews over the intervening years has found it to be generally uneconomic and imprudent to consolidate the voltage levels across the legacy asset base, due to the cost of changing subtransmission feeder assets and insulation. There have been some small improvements made as a result of network augmentation, driven by large scale changes in rural demographics and industry.

The variation in operating voltage and vector group causes unique operational and logistics requirements associated with the management and replacement of these assets, particularly with regards to spares holding and procurement. These aspects are discussed in later sections of the document.

Table 4 summarises the voltage ratios for power transformers, regulators, and oil filled reactors in EQL.

Asset Class	Northern and Southern Regions	South East Region	Primary Voltage (kV)	Secondary Voltage (kV)
Power Transformers	✓		220 (unregulated network)	132, 66
	✓	✓	132	110, 11
	✓		132	66, 22
	✓	✓	110	33, 11
	✓		66	33, 22, 11, 6.6, 3.3
		✓	66	11
	✓		33	22
	✓	✓	33	11, 6.6, 3.3
Regulators	✓		66	66
	✓	✓	33	33
	✓		22	22
	✓		11	11
Oil Filled Reactors	✓		132	Not applicable
	✓		110	Not applicable
	✓		66	Not applicable
	✓		33	Not applicable
	✓		11	Not applicable

Table 4: Voltage Transformation Ratios – EQL

Table 5 lists the number of tap changers by general type.

Region	Vacuum OLTC	Oil OLTC	Offline Tap changers	Total
Northern & Southern	94	602	97	793
South East	327	297	0	624
Total	421	899	97	1417

Table 5: Tap Changer quantities – EQL

Table 6 lists the various transformer configurations employed by EQL.

Transformer vector groups
Delta Star (both DY1 and DY11)
Star Delta
Star-Star
Auto-transformer
Delta Star-Star
Delta Star Delta

Table 6: Transformer vector groups – EQL

2.3 Asset Age Distribution

Figure 3 details the age profile of Northern and Southern Regions substation power transformers and regulators.[1]

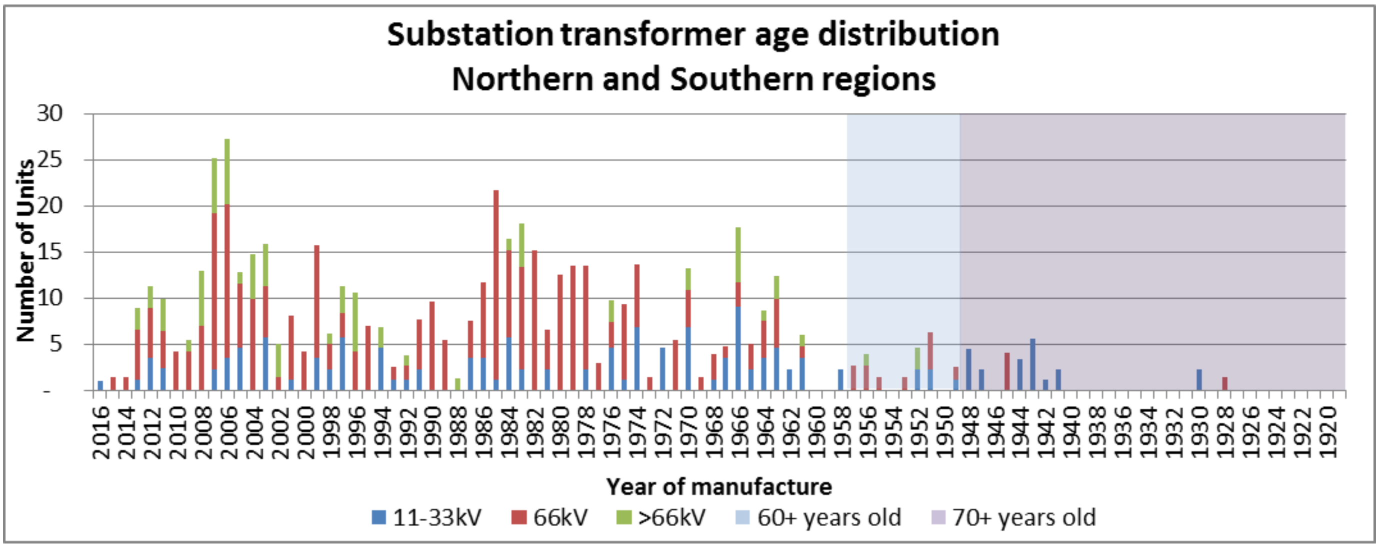


Figure 3: Substation power transformer age profile – Northern and Southern regions

[1] Source : 2016/17 Ergon Energy RIN data

There are 47 power transformers that are older than 60 years in the Northern and Southern regions. Figure 4 details the age profile of South East Region substation power transformers and regulators[2].

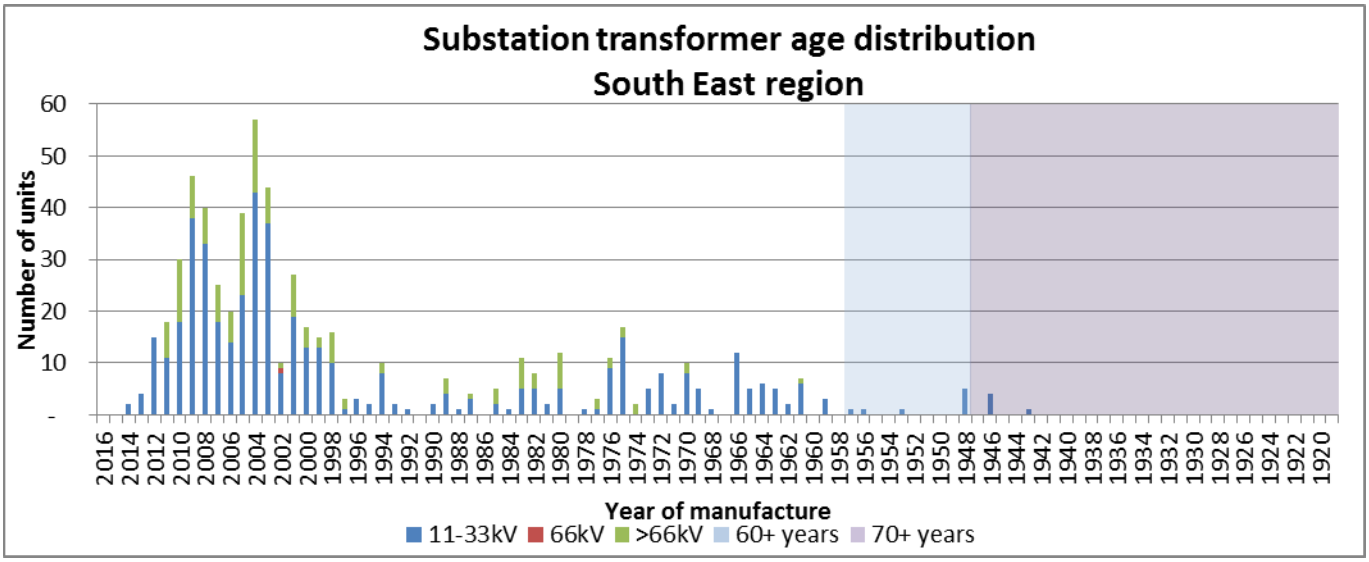


Figure 4: Substation power transformer age profile –South East region

There are 13 power transformers that are older than 60 years in South East region.

The age profile for power transformers and regulators is also representative of the age profile of the OLTC fleet across the Northern, Southern and South East regions.

2.4 Population Trends

The Northern and Southern regions have a significantly higher quantity of older substation transformer and regulator assets. This is likely due to the typically lower loads that the assets have been required to supply, and the resultant extension on their useful life. While life extension of the asset is desirable, the proportion of assets that have exceeded the expected life presents a risk that needs to be monitored and managed in order to meet asset management objectives.

In the South East region, a large number of transformer assets were installed between 2004 and 2010 as a result of substantial load growth in the region. A significant number of older transformer assets were removed as a result of this growth, as they could not meet demand within prescribed security standards.

The Northern and Southern regions began purchasing power transformers with vacuum tap changers in the early-to–mid 2000’s, while the South East region did so in 2000. The OLTCs in the EQL network are progressively being replaced with vacuum type units as they reach end of life, as vacuum type units are more reliable, they typically require lower maintenance, and are able to withstand more operations between maintenance cycles than OLTC units.

[2] Source : 2016/17 Energex RIN data

2.5 Asset Life Limiting Factors

Table 7 describes the key factors that influence the life of the assets covered by this AMP, and as a result have a significant bearing on the programs of work implemented to manage the lifecycle.

Factor	Influence	Impact
Oil quality	Gradual increase in contaminants leading to deterioration of materials and components used in construction; particularly the oil, paper insulation, gaskets, and bushings.	Reduction in insulating capability, creation of “sludge” supporting winding hot spot development, deterioration of winding insulation performance, leading to reduction in useful life
Environment	Outdoor, corrosive, or coastal environments result in degradation of the physical asset and components; particularly the tank, bushings, gaskets, and instrumentation.	Reduction in useful life and component failure.
Loading	Heating of the winding resulting in degradation of the paper insulation. Loading above cyclic rating can lead to very rapid deterioration.	Accelerated ageing leading to reduction in useful life. Internal fault leading to failure (potentially catastrophic).
Through-Faults	Electrical and mechanical stress on internal windings	Stress cycles leads to accumulative physical damage, ultimately causing internal fault leading to failure (potentially catastrophic)
Moisture	Degradation of paper insulation and oil. Combined with heat, even at low loadings, can result in bubble inception.	Accelerated ageing leading to reduction in useful life. Internal fault leading to failure (potentially catastrophic).
Obsolescence	Inability to source components required to maintain or repair the asset; particularly the OLTC and bushings.	Unable to return to service in the event of a failure resulting in early replacement.
Operations (moving components – OLTC)	Mechanical wear on moving components and degradation of insulation associated with the arcing products caused by switching operation.	Drives maintenance required to replace or repair consumable components such as contacts and oil. Accelerated ageing leading to reduction in useful life. Internal fault leading to failure
Design	Varies based on make and model and only becomes apparent through operational experience. Typically associated with materials used (e.g. oil) and designs of components and mechanisms (e.g. tap changers).	Operational remediation to ensure expected life Early replacement.

Table 7: Substation Power Transformer, Regulator, and Reactor Life Limiting Factors

3 Current and Desired Levels of Service

The following sections define the level of performance required from the asset class, measures used to determine the effectiveness of delivering corporate objectives, and any known or likely future changes in requirements.

3.1 Desired Levels of Service

This asset class will be managed, consistent with corporate asset management policy, to achieve all legislated obligations and any specifically defined corporate key performance indicators, and to support all associated key result areas as reported in the Statement of Corporate Intent (SCI).

Safety risks associated with this asset class will be eliminated “so far as is reasonably practicable” (SFAIRP), and if not able to be eliminated, mitigated SFAIRP. All other risks associated with this asset class will be managed to “as low as reasonably practicable” (ALARP).

This asset class consists of a functionally-alike population that differs in age, brand, technology, material, construction design, technical performance, purchase price, and maintenance requirements. The population will be managed consistently based upon generic performance outcomes, with an implicit aim to achieve the intended and optimised life cycle costs contemplated for the asset class and application.

All inspection and maintenance activities will be performed consistent with manufacturers’ advice, good engineering operating practice, and historical performance, with intent to achieve longest practical asset life overall.

Life extension techniques will be applied where practical, consistent with overall legislative, risk, reliability, and financial expectations. Problematic assets such as very high maintenance or high safety risk assets in the population will be considered for early retirement.

Assets of this class will be managed by ongoing individual condition assessment and maintenance, and proactively replaced near to and prior to calculated end of life. End of economic asset life will take into account ongoing maintenance and retention costs, replacement costs and benefits, potential future maintenance and retention costs, and risk, and be determined principally by Condition Based Risk Methodology (CBRM) analysis techniques. Replacement will be considered on a project specific basis, and holistic analysis of nearby assets will be performed to support optimal life cycle cost and customer impact.

3.2 Legislative Requirements

The assets described in this AMP are not specifically referenced in legislation, and therefore are expected to achieve general obligations surrounding asset safety and performance and service delivery. These obligations include compliance with all legislative and regulatory standards, including the Queensland Electrical Safety Act 2002 and the Queensland Electrical Safety Regulation 2013 (ESR).

The Queensland Electrical Safety Act 2002 s29 imposes a specific Duty of Care for EQL, which is a prescribed Electrical Entity under that Act:

1) An electricity entity has a duty to ensure that its works—
    a. are electrically safe; and
    b. are operated in a way that is electrically safe.

2) Without limiting subsection (1), the duty includes the requirement that the electricity entity inspect, test and maintain the works.

Under its distribution licences, EQL is expected to operate with an ‘economic’ customer value-based approach to reliability, with “Safety Net measures” aimed at managing low probability high consequence outage risks. EQL is expected to employ all reasonable measures to ensure it does not exceed minimum service standards (MSS), assessed by feeder type, as:

- System Average Interruption Duration Index (SAIDI), and
- System Average Interruption Frequency Index (SAIFI).

Safety Net targets are described in terms of the number of times a benchmark volume of energy is undelivered for more than a specific time period.

Loss of substation power transformers, regulators, or reactors is usually a significant event and may require Safety Net contingency plans to be exercised.

Both Safety Net and MSS performance information is publically reported annually in the Distribution Annual Planning Reports (DAPR).

The National Electricity Rules (NER) require that the voltage magnitudes at all energised busbars at any substation be within the relevant limits set by the relevant NSP, and within 90% and 110% of nominal voltage in steady state conditions.

3.3 Performance Requirements

There are no specific business targets relating to substation transformer, regulator, or reactor performance. However, these assets are considered critical in nature as they are of high value, require significant lead time to procure, and failure events have the potential to result in safety consequences, as well as substantial and extended customer load interruption. As a result, these assets are proactively managed on an individual basis with the intent of replacement prior to failure.

Maintenance and testing of substation power transformers, regulators, and reactors is conducted regularly, with performance against defined criteria monitored, and issues addressed to ensure these assets reach the end of their economic life.

Defects identified via inspection programs are classified and prioritised according to the EQL Substation Defect Classification Manual. Identified defects are scheduled for repair according to a risk-based priority scheme (P1/P2/C3/no defect). The P1 and P2 defect categories relate to priority of repair, which effectively dictates whether normal planning processes are employed (P2), or more urgent repair works are initiated (P1). Additionally, a classification of C3 aims to gather information to inform or create a “watching brief” on possible problematic asset conditions.

The following sections provide a summary of performance against these measures as a defect rate.

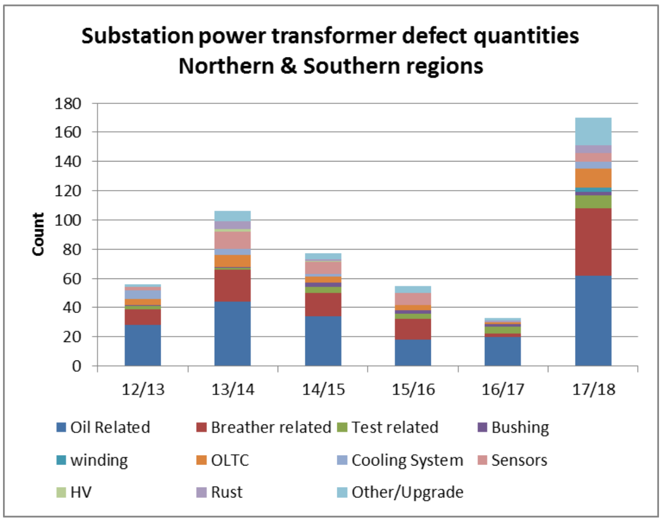
There is a corporate intent that no material environmental issues are created as a result of EQL activities and operation. Substation power transformers, regulators, and reactors carry substantial volumes of mineral oil, typically between 5,000 and 10,000 litres. A significant discharge of oil from a leaking transformer at a substation may compromise this strategic intent, and may possibly constitute an offence under the Environmental Protection Act 1994.

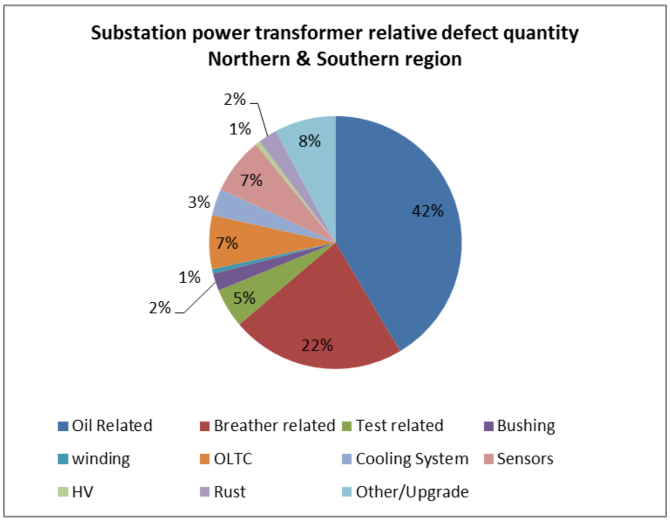
3.4 Current Levels of Service

There are no records of Dangerous Electrical Events (DEE) associated with substation transformers, regulators, or reactors in EQL. This is due to the inherent level of safety built into the design of the units installed such as pressure relief valves and the protection systems which are used to limit exposure to fault current. As a result of these measures, substation transformers typically fail in a passive manner. Whilst performance history in EQL has been free of DEEs there have been numerous incidents in other organisations of catastrophic failure of substation transformers leading to major fires and flying debris. As such safety remains an important measure of performance which EQL continues to be monitor.

There have been no material environmental issues related to EQL substation power transformers over the last seven years.

Figure 5 provides a breakdown of corrective maintenance data for substation power transformers in the Northern and Southern regions. Similar data is available for regulators and reactors, and for those asset types, total corrective maintenance expenditure is around 5% of that for substation power transformers. Figure 5 demonstrates the substantial effort made to manage oil related issues, as this directly supports the corporate environmental objective, and also supports transformer longevity.





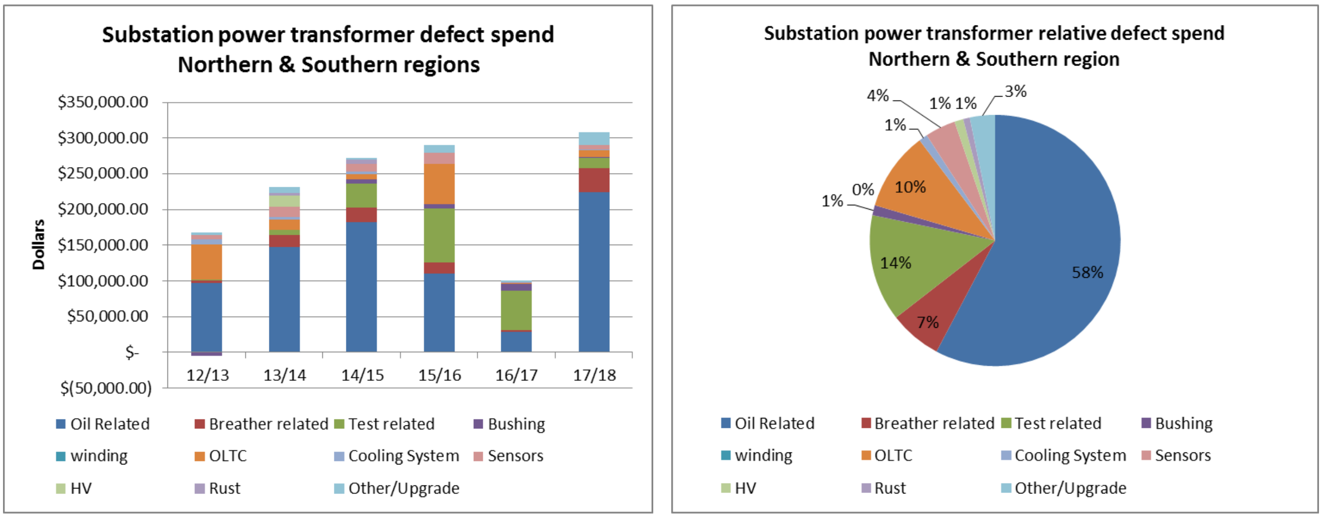


Figure 5: Substation power transformer corrective maintenance statistics – Northern & Southern regions

Figure 6 provides a breakdown of corrective maintenance data for South East region. The South East region data only covers the 2017/2018 financial year, coinciding with the introduction of a Maintenance Strategy Support System, which allowed data to be broken down into asset components. Figure 6 demonstrates the substantial effort made to manage OLTC issues in the South East region, necessary to ensure EQL meets the voltage tolerance standards required by legislation.

Defect Remediation Quantities	
Tap Changer	92
Cooling System	44
Controls	27
Conservator	8
Connections	5
Cable Box	2
Main Tank	2
Surge Arrestor	1
Bushing	1
Grand Total	182

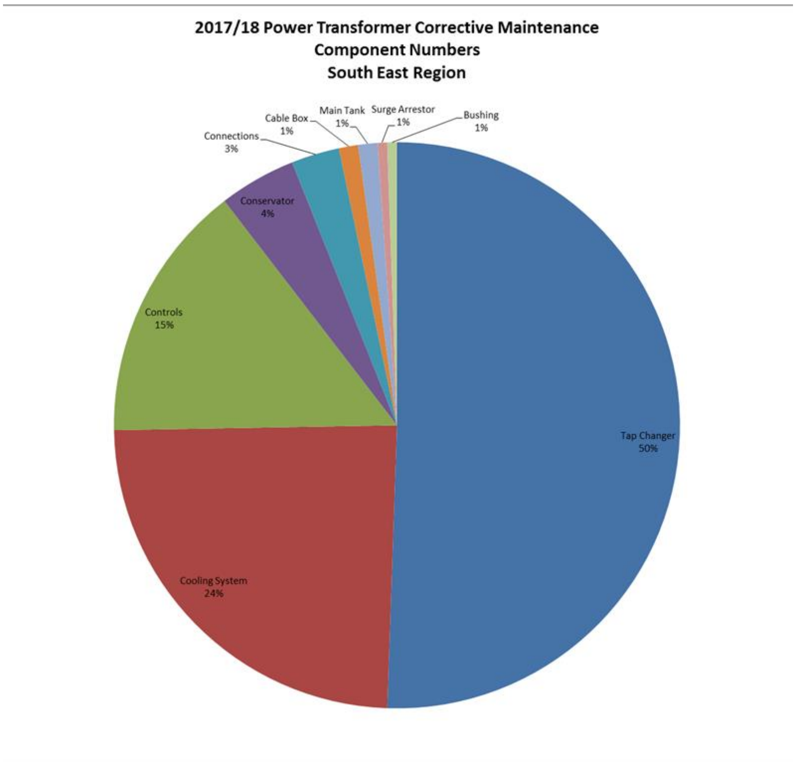


Figure 6: Substation power transformer corrective maintenance statistics – South East region

Asset failures typically occur where the programs in place to manage the assets do not identify and rectify an issue prior to it failing in-service. Failures typically result in or expose the organisation to risk, and represent the point at which asset related risk changes from being proactively managed to retrospectively mitigated.

Figure 7 documents the recent transformer failure history in South East region. Over the last 10 years, an average of three significant failures of substation power transformers occur every year, with at least one resulting in unrepairable outcomes. Over the last 10 years, almost half of all significant failures were related to OLTC issues. This is reflective of the volume of corrective work orders detailed in Figure 6.

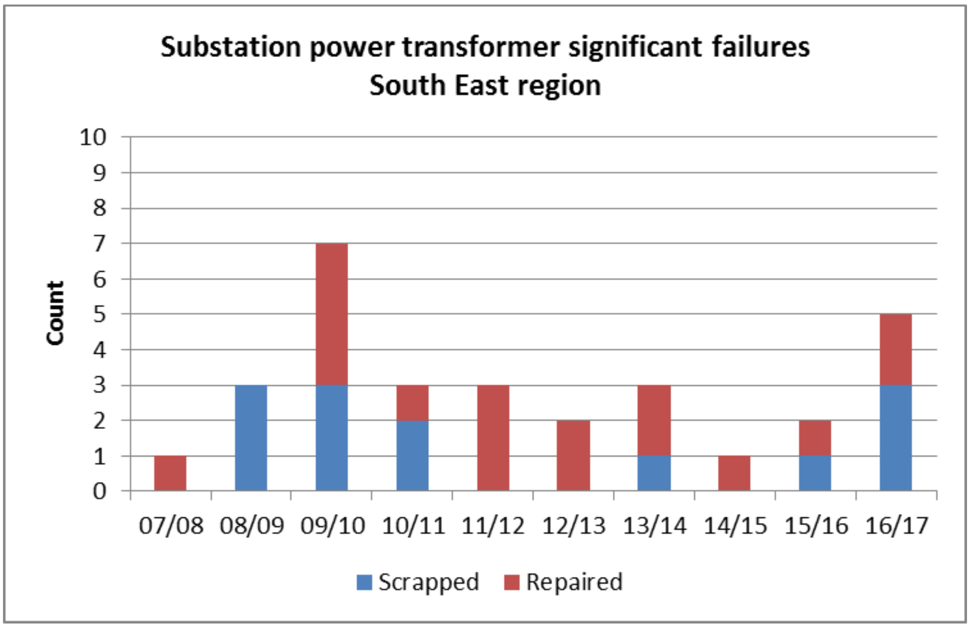


Figure 7: Substation power transformer significant failure history – South East region

4 Asset Related Corporate Risk

As detailed in Section **Error! Reference source not found.**, EQL has a Duty to ensure its assets are electrically safe. This safety duty requires EQL to take action So Far as is Reasonably Practicable (SFAIRP) to eliminate safety related risks, and where it is not possible to eliminate these risks, to mitigate them SFAIRP[3]. Risks in all other categories are managed to levels as low as reasonably practicable (ALARP).

Figure 8 provides a threat-barrier diagram for substation transformers, regulators and reactors. The "threats" (or hazards) presented in the diagram are applicable to all asset types covered in this document. Many threats are unable to be controlled (e.g. lightning), although EQL undertakes a number of actions to mitigate them SFAIRP/ALARP.

Failure of a transformer risks public and staff safety in several ways, most notably:

- Explosive failure leading to projectile motion of objects, including ceramic and metal shards
- Significant oil fire, with associated heat and toxic gas impacts

EQL's safety Duty results in most inspection, maintenance, refurbishment and replacement works, and expenditure related to substation transformers, regulators, and reactors, being entirely focused upon preventing and mitigating failure.

The asset performance outcomes described in Section 3.4 detail EQL's achievements to date in respect of this safety Duty. The following sections detail the ongoing asset management journey necessary to continue to achieve to high performance standards into the future. Action items are raised where relevant, detailing the specific actions that EQL will undertake as part of program delivery of this Asset Management Plan.

[3] QLD Electrical Safety Act 2002 s10 and s29

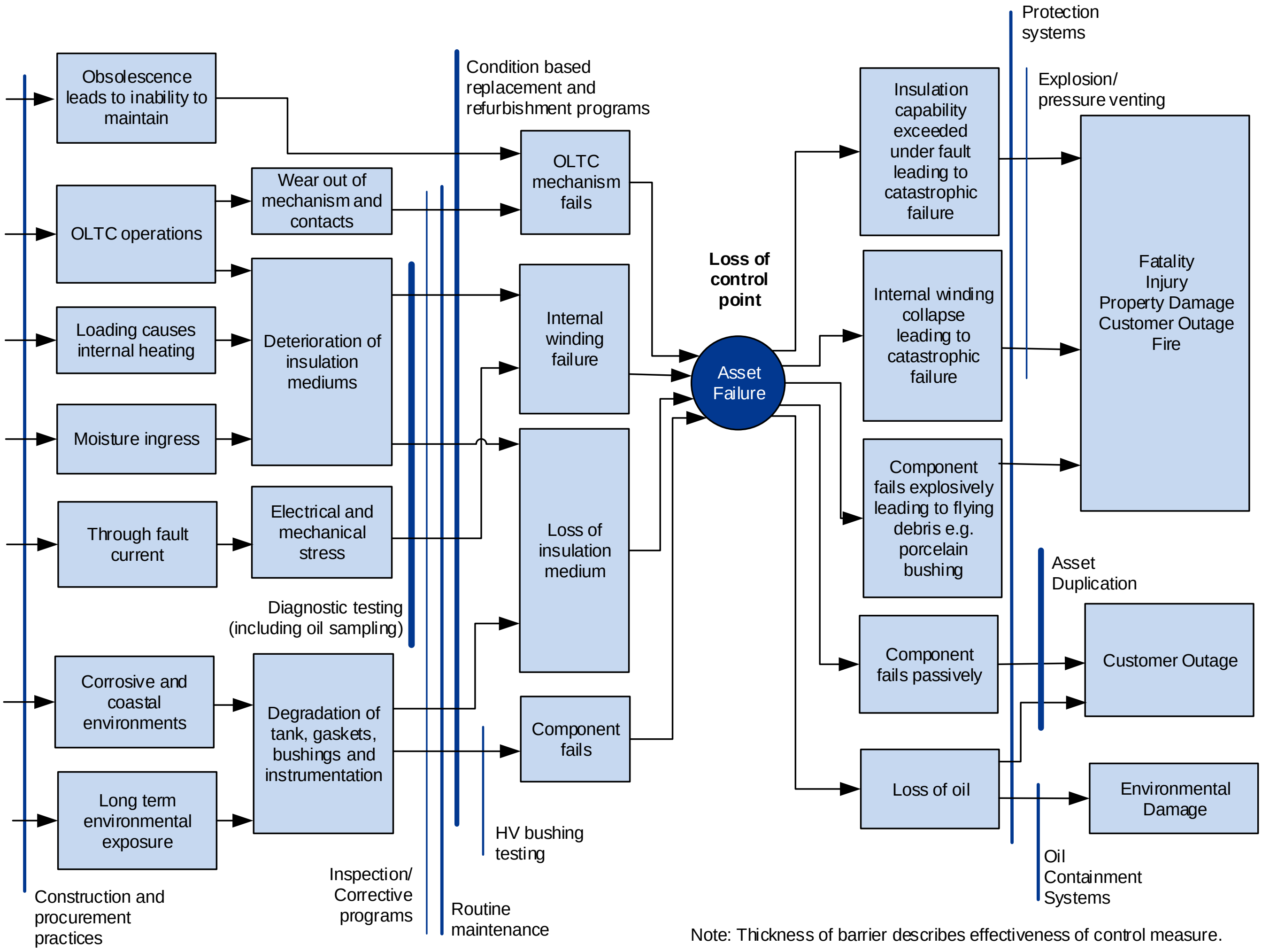


Figure 8: Threat Barrier Diagram for substation power transformers, regulators and reactors

5 Health, Safety & Environment

Polychlorinated biphenyl chemicals (PCBs) were commonly used in transformer oils until the 1970s. They accumulate in transformer windings, so that replacing the transformer oil does not guarantee complete removal of the chemical. When released in the environment, PCBs linger and bioaccumulate, becoming absorbed in the fatty tissues of animals and slowly transmitted through the food chain to humans. PCBs can cause liver damage, nervous system damage, and are considered to be carcinogenic.

Oil is considered to be PCB free if the concentration is less than 2 ppm. Oil with PCB concentration greater than 50ppm is considered scheduled waste and must be disposed of only via authorised companies.

Testing for presence of PCBs is not a routine oil test. Only in preparation for major maintenance, oil change, or disposal of all transformers, reactors, and regulators, the oil is tested for presence of PCBs.

Figure 9 and Figure 10 below provide a view of the power transformers in EQL recorded as containing PCBs.

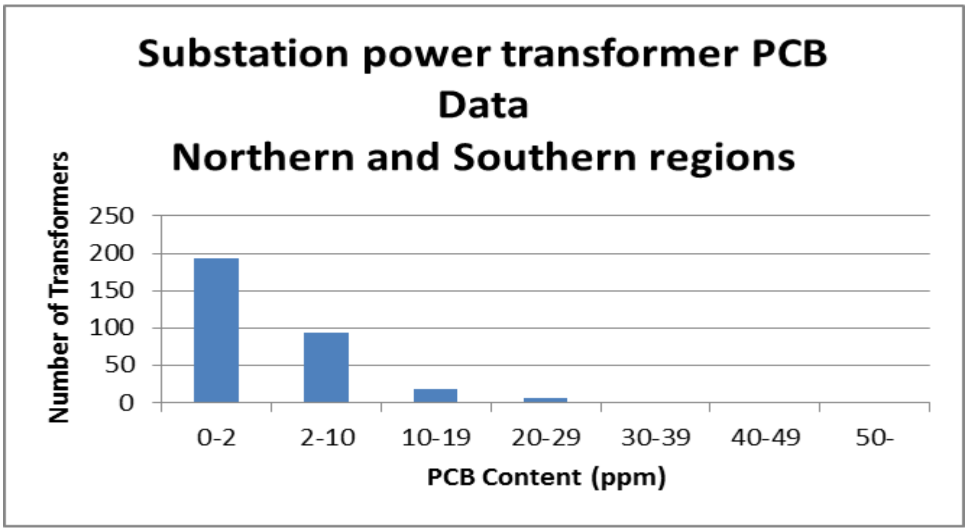


Figure 9: Substation transformers containing PCB - Northern and Southern regions

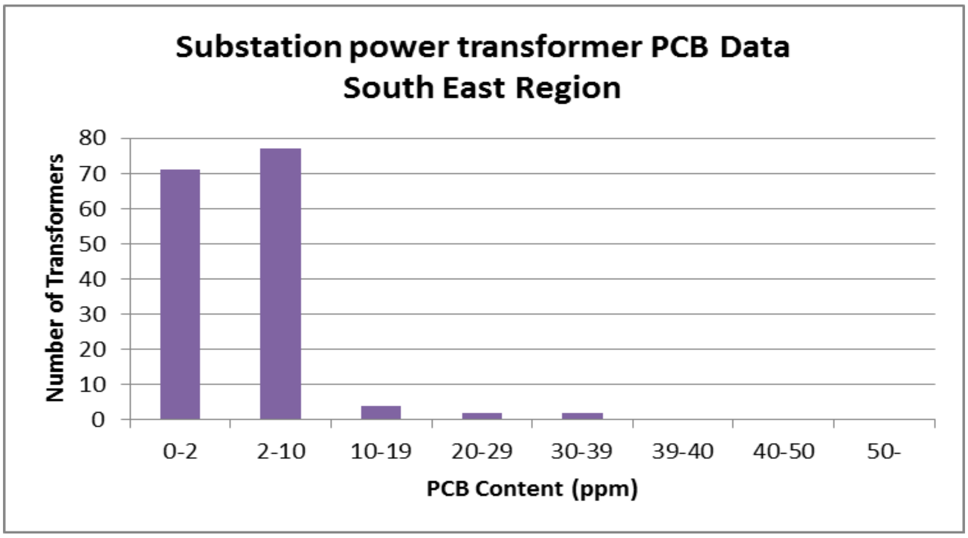


Figure 10: Substation transformers containing PCB – South East region

6 Current Issues

The following sections outline current issues that have been identified as having the potential to impact EQL's ability to meet corporate objectives.

6.1 Wet Paper Insulation in Substation Power Transformer Population

Moisture ingress has been observed as a key cause of defects from the data recorded in the Northern and Southern regions. Moisture results in deterioration of the transformer insulation, and can lead to reduction in useful life or asset failure if not addressed. Of the substation power transformers in the Northern and Southern regions, 61 currently exceed the maintenance acceptance criteria P2 level for moisture. Figure 11 details the power transformer fleet average Water Content of Paper (WCP) based upon Dissolved Gas Analysis (DGA) results. There is a disparity between regions in calculation of WCP, which EQL intends to resolve.

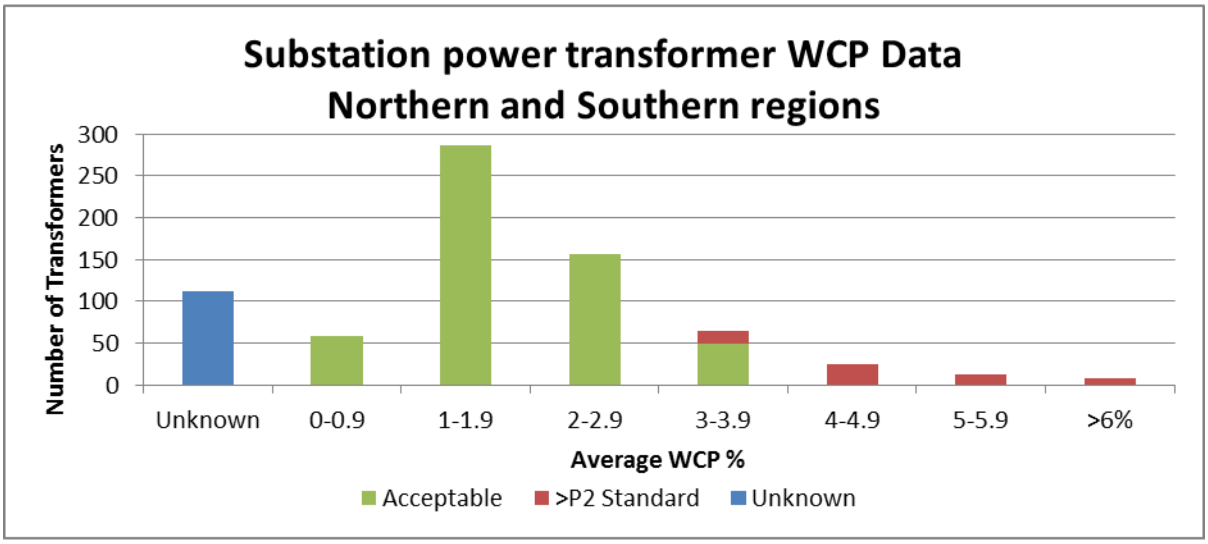


Figure 11: Substation power transformer WCP – Northern and Southern Regions

The numbers of units exhibiting issues indicates a potential need for review of current maintenance and inspection practices. A review of maintenance activities will be undertaken to identify and address any opportunities to reduce the number of units experiencing moisture ingress. This will include a review of the adequacy of the breather systems and the practices for changing the silicon desiccant.

Assets already identified as containing high levels of moisture in the Northern and Southern regions are being addressed by a program of oil dry out where it is viable, using on-site dry-out units. These mobile units are attached to in-service transformers, and actively work to remove moisture from transformer oil. Typically, each unit is applied to a "wet" transformer for a period of around three months, with most observable improvement in oil moisture content occurring in the first two weeks. Once the dry-out unit is removed, moisture equilibrium between oil and insulation is achieved after 6 weeks. EQL currently owns 13 on-site dry-out units. The dry-out program cycles the mobile units between sites in a movement plan that is prioritised based on the observed moisture in the transformers. The condition of the transformers is re-evaluated on completion of the program to determine the impact on residual life for the asset population. This practice has now been expanded to manage wet transformers in the South East region.

Forecast programs of maintenance to manage this issue have been developed for the Northern and Southern regions, in accordance with the criteria for on-site dry-outs. If the issue is not addressed through maintenance, it will lead to reduction in useful life for the units affected and result in an increase to the asset replacement forecast.

Action 6.1-1: Review and align the algorithms used to determine the average Water Content of Paper (WCP), to ensure a common EQL approach to the condition assessment of substation transformers, regulators, and reactors.

Action 6.1-2: Review maintenance activities to identify and address any opportunities to reduce the number of substation transformers experiencing moisture ingress. This review should include consideration of the adequacy of the breather systems and practices for changing the silicon desiccant.

6.2 Problematic Tap Changers

Another other key trend of in-service failure is associated with OLTCs. Depending upon location, network configuration, and load, some OLTCs are required to operate frequently to achieve the defined regulatory voltage standards. Frequency of operation directly influences the maintenance periods and life of OLTC units. This trend in performance is being monitored.

Figure 6 shows that tap changers were the most significant cause of corrective maintenance related to power transformers in the South East region during 2017–18.

Figure 12 shows the raw count of corrective maintenance work orders by manufacturer. Figure 13 shows the corrective maintenance in the South East region normalised by OLTC manufacturer.

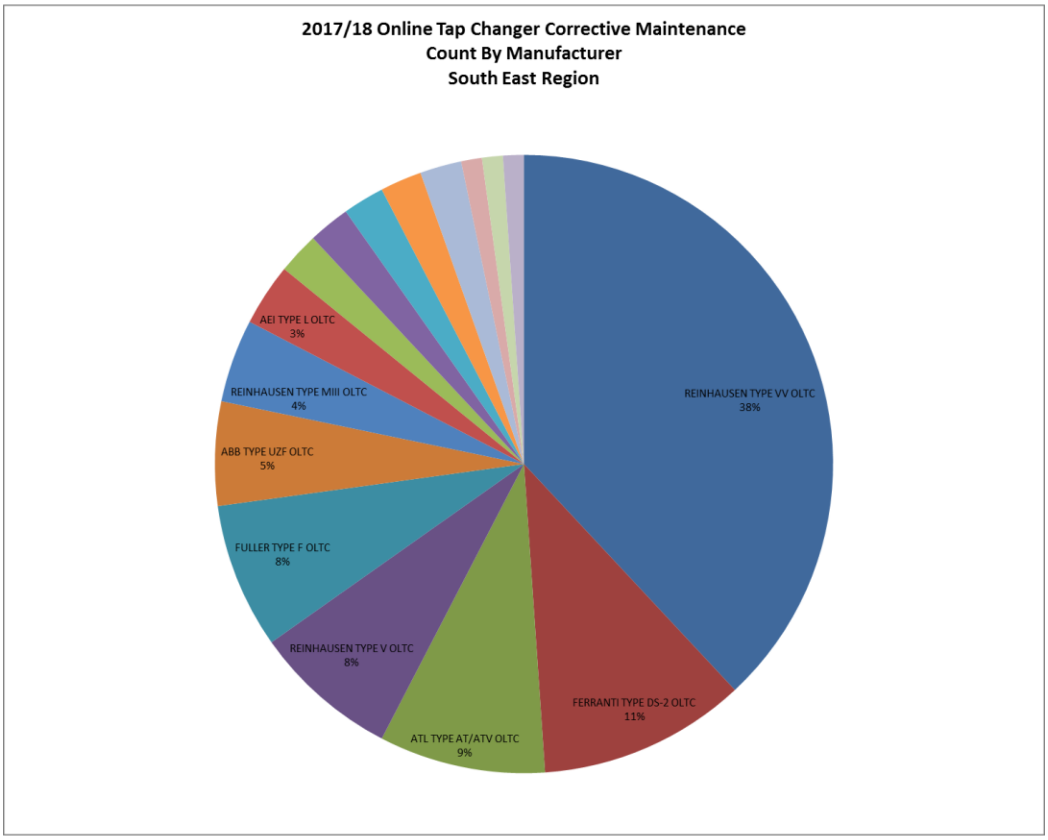


Figure 12: Percentage of corrective maintenance work for OLTCs - South East region (2017/18)

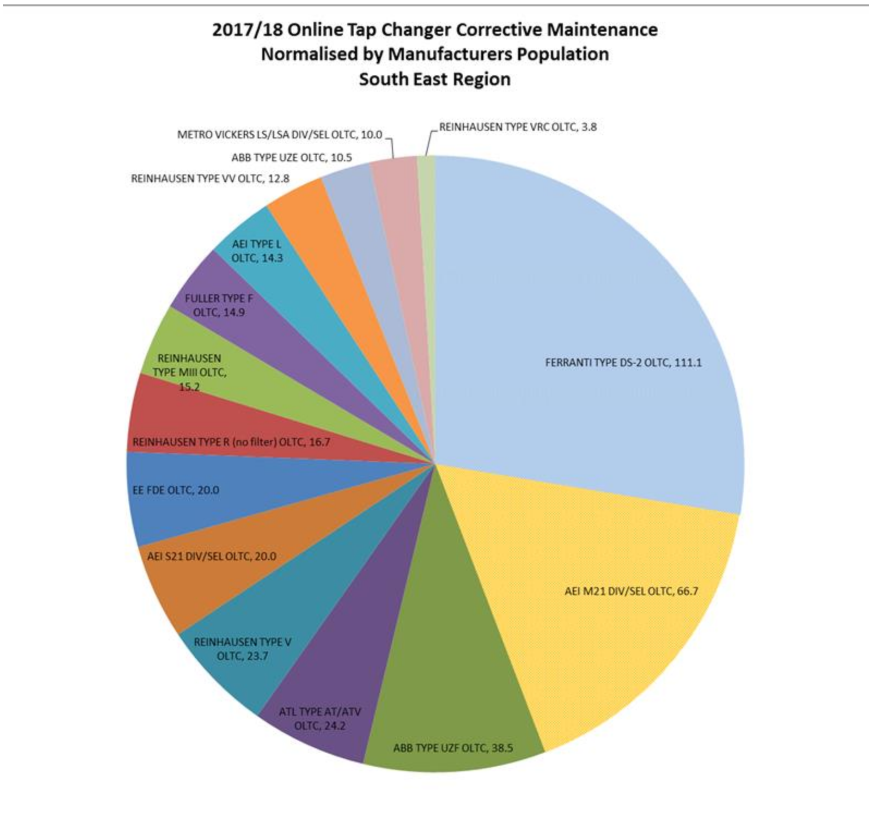


Figure 13: Corrective maintenance normalised by OLTC manufacturer - South East region (2017/18)

Figure 12 shows that the population of Reinhausen type VV OLTCs are the most problematic in terms of the numbers of corrective maintenance tasks performed. The main cause for corrective maintenance was a “stuck between taps” condition for the South East region in 2017-18. The next most problematic OLTC type is the Ferranti type DS2 with similar issues. Figure 13 shows that when normalised against the population, the Reinhausen type VV OLTC contributes a small percentage of the total; this is due to the very large asset population of this type of OLTC. Conversely Figure 13 shows the Ferranti OLTC is the most problematic when normalised against the installed population due to the very low number of remaining units. It should be noted that the issues with the Ferranti OLTCs in 2017-18 are all associated with a single transformer. This transformer is programmed to be replaced in 2027.

Action 6.2-1: Investigate the common Online Tap Changer (OLTC) failure mode of 'stuck between taps' on the population of Reinhausen type VV, and Ferranti type DS2 OLTCs to drive performance improvement and mitigate risk within this asset class.

6.3 Bushing Failure

A bushing is an insulated device that allows the conductor that connects the transformer to the network to pass safely through the grounded outer metal tank of the transformer. In-service failures of transformer bushings tend to be explosive in nature resulting in shrapnel being dispersed across a wide area. Bushing failure often initiates complete transformer failure and replacement particularly in older units where replacement bushings can no longer be sourced. All bushings are periodically inspected and bushings greater than 66kV are periodically tested for defects. Partial discharge (PD) testing is employed regularly during routine substation inspection to identify incipient faults. Bushings are repaired if practical and replaced when necessary. This trend in performance is being monitored.

6.4 Oil Containment

A significant discharge of oil from a leaking transformer at a substation may comprise an offence under the Environmental Protection Act 1994 (EP Act). The penalties imposed for such offences will vary depending upon a variety of factors including culpability and the seriousness of the harm or potential harm, which are dependent upon factors including the amount of contaminant released, and the sensitivity of the receiving environment.

If EQL were to operate its substations in a way that creates a risk of environmental harm without acting to mitigate that risk, that could comprise wilful harm on the basis of recklessness. Penalties for these offences can be above $1 million for corporations, and only marginally less for corporate executive officers as individuals.

A considerable number of EQL sites have potential run-off that is ultimately directed into the Great Barrier Reef Marine Park and numerous potable water sources. Given the risk associated with release of oil from substations, EQL has intent to take all reasonable and practicable measures to avoid or minimise likelihood of oil release. Standard EQL policy is to employ suitably designed bunding and released-oil management systems for all new or replaced oil-filled substation transformers.

In 2012, Ergon Energy Corporation Limited recognised that it had a number of substations without any transformer oil bunding infrastructure. These sites were risk prioritised for the environmental impacts and a capital works program commenced. EQL has continued this program.

6.5 Maintenance Strategy Support System

Legacy organisations Energex Limited and Ergon Energy Corporation Limited have developed and implemented a record system for all failures, incorporating a requirement to record the asset component (object) that failed, the damage found, and the cause of the failure. EQL has adopted this approach and continues to align this practice.

This Maintenance Strategy Support System (MSSS) dataset is building over time and starting to provide the systemic information necessary to support improvements in inspection and maintenance practices. There is an expectation that this will also support and influence standard design and procurement decisions.

6.6 Network Access Restrictions

Network Access Restrictions (NARs) are a process control used to limit access to assets and sites where safety risks have been identified, and where the assets must remain in service to continue to provide supply to customers. Typically an NAR will involve either an exclusion zone being set around the asset while in-service, or requirements to switch the asset out prior to accessing the site. Other circumstances may require particular procedures to be undertaken in addition to the usual safety mitigations associated with a task being performed.

The network investment undertaken in the Northern and Southern regions in recent history has been directed towards managing the safety risks in the overhead distribution network due to the greater exposure to customers and the broader community. These programs have included defect management, small copper conductor replacement, and remediation of clearance to ground and clearance to structure issues. During this period of focus on the distribution network, risks in substations were managed through the NAR processes resulting in an increasing number of restrictions across sites.

Whilst an NAR is an effective short-term risk mitigation method, the restrictions imposed on operations are significant. Additional costs are incurred to undertake routine work at substations where NARs are in place, in order to maintain the exclusion zones and undertake work safely. Similarly, the cost of asset replacement projects increase substantially to accommodate the staging requirements necessary to work at the site for an extended period. Outage durations and therefore customer impacts associated with undertaking work at sites with NARs are also extended significantly as a result of the additional requirements. NARs are not considered an appropriate risk mitigation for long term management of safety issues, and so ultimately asset replacement or maintenance is required to return the site to a fully operational state.

In order to deliver a sustainable program of works and balance network risk, customer outcomes, and cost, it is necessary at this stage to increase the volume of substation asset replacement to address the sites with existing restrictions, and to ensure that the assets are removed from the network prior to requiring NARs to be implemented. This will have a flow on effect to the investment and resourcing required to deliver the programs. Programs of replacement will be forecast in accordance with the methodologies outlined in Section 9.

Action 6.6-1 Increase the volume of substation asset replacement in the Northern and Southern region to address the existing Network Access Restrictions, and to deliver a long term sustainable program of replacement where assets are removed from the network prior to requiring a Network Access Restriction to be imposed due to condition.

7 Emerging Issues

The following sections outline emerging issues which have been identified as having the potential to impact on EQL's ability to meet corporate objectives in the future.

7.1 Proportion of Population Approaching End of Life

EQL has a large population of substation power transformers that are approaching end of life, particularly in the Northern and Southern regions. In order to manage network risk, maintain current levels of customer service, and ensure sustainable programs in the longer term, the rate of replacement of substation power transformers will need to increase.

The increase in the number of replacements will require substantial capital investment and will present operational challenges, particularly in the areas of procurement and resources to undertake the works. The program of transformer replacement will be managed on a risk basis within the portfolio of capital expenditure required for EQL. The program of transformer replacement will be optimised within broader constraints to ensure it is deliverable and sustainable, with replacements aligned with other major site works for efficiency wherever possible.

Forecast programs of replacement to manage this issue have been developed in accordance with the CBRM methodology. Refer to Section 9.5.2 for further information. Assets that cannot be replaced due to constraints in this program will require additional operational expenditure to manage the network risk.

7.2 Corrosive Sulphur

A world-wide increase in the number of cases where relatively young transformers failed after just a few years of service has been reported across the industry. The additive Dibenzyl Disulfide (DBDS) was added to transformer oil, which is now understood to have led to a phenomenon known as 'Corrosive Sulphur'. The cause has been attributed to dielectric breakdown of the inter-turn insulation, due to copper sulphide (Cu_2S) growing within the paper insulation. Copper sulphide is conductive, and in situations where the crystal growth is encouraged, eventually there is sufficient insulation conductivity to cause a flashover between internal components leading to a fault and significant internal damage .

Transformers that are at risk of copper sulphide growth typically operate continuously above 80°C, have low oil oxygen content (i.e. are fully closed and employ nitrogen filled bags), and filled with low refining grade insulating oils.

There are also records of an additional failure mechanism, where sulphur ions react with silver contained in tap changer contacts and collector rings, forming silver sulphide (AgS). The silver sulphide is believed to build up dendrite crystals over time, which dislodge into the oil with tap changer operation. The AgS particulates reduce the oil insulation properties, and eventually flashover failures result.

Although DBDS is known to be present in oil in 50-60% of the Northern and Southern region transformers, and all South East region transformers manufactured between 2003 – 2010, few of these tend to operate in the targeted high load temperature regime. There have been recent unconfirmed reports of failure of transformers operating in low temperature regimes, with an apparent contribution of corrosive sulphur and silver sulphide dendrites to the failures.

A failure of an 80 MVA 110 kV transformer at Coomera Substation (South East region) in November 2012 is considered likely (but not proven) to have been caused by silver sulphide contamination of silver plated tap changer contacts.

Passivators, additives to transformer oils, designed to attract and capture sulphur, can be used to manage this issue and provide an alternative to complete oil replacement. Passivating agents must be reapplied over time as the chemical properties are exhausted. A passivation component has been added to 227 critical (larger size) substation transformers in South East region to prevent potential silver sulphide contamination. The effectiveness of these passivators is still being evaluated in trials.

Action 7.2-1 Review the effectiveness of the use of oil passivator in transformers to manage the corrosive sulphur the asset population to determine if an ongoing program is required across all regions

7.3 Changing Load Profiles

The useful life of a transformer is directly related to the loading which causes heating of the internal windings and degradation of the paper insulation. Historically, power flow has been in a single direction from generation to customer and load cycles have varied over the course of a 24 hour period as demand for electricity changed throughout the day. The cyclic loading allowed for transformers to run at higher load during shorter periods during which the useful life is used at a greater rate as this was compensated for during the lightly loaded periods.

While the prevalence of distributed energy resources such as solar PV, generation and batteries, the traditional power flow is changing and it is possible for load to flow in either direction. The result is that transformers are beginning to see a more continuous load cycle as they provide load to customers during periods of peak usage and then experience reverse power flow as the customer generation feeds back to the grid. This has a direct impact on the way transformers are rated and their potential useful life.

Energy Queensland is continuing to monitor the effects of distributed energy resources on load cycles and the impacts on the life of transformers to ensure the lifecycle of the assets is managed.

Action 7.3-1 Monitor the effects of distributed energy resources on load cycles and the resultant impacts on the useful life of transformers.

8 Improvements and Innovation

The following sections outline any improvements or innovations to asset management strategies relevant to this asset class, being investigated by EQL.

8.1 Biodegradable Oils

Biodegradable oils offer significant benefits over the currently used mineral oils. They offer the potential for reduced environmental harm after spillage, and promote winding longevity by absorbing moisture from the paper insulation. Biodegradable transformer oil can be retrofitted to existing transformers, with the potential to substantially extend transformer life. This type of oil is used extensively in other countries, especially where very strict environmental laws apply.

Use of biodegradable oil would also be beneficial for distribution transformers, especially in locations where oil release into sensitive environments is possible (e.g. water courses, oceans, islands etc.). It is important that a case-by-case assessment be considered for the use of biodegradable oils, as there is a requirement to ensure suitable spares, handling equipment and maintenance processes support this alternative.

Many of the same DGA diagnostic tests currently used for mineral oil are still applied to biodegradable oil. EQL's DGA service provider already has the experience and capacity to perform the requisite analysis.

A trial of biodegradable oil in substation transformers is underway at Comet substation, to confirm the efficacy for Queensland tropical conditions.

Action 8.1-1: Establish procedures and maintenance acceptance criteria to manage the use of biodegradable oil in substation transformers, using results from the trial of this medium at Comet Substation.

8.2 Oil Conditioning

Contaminants and particulates in transformer oil develop into sludge, promoting localised overheating of the winding due to loss of cooling oil flow. This overheating degrades the winding insulation, and the contaminated oil typically also becomes acidic which further degrades the insulation paper. The insulating properties of contaminated oil become reduced, which if untreated, eventually leads to flashover and winding failure.

Replacing the oil can mitigate the failure risks, but this can be logistically challenging and expensive. It also introduces additional oil handling and other environmental management risks. Oil conditioning (removal of particulates and gases) can assist, but at the expense of loss of DGA chemical accumulative history. This can affect the interpretation of future DGA which may indicate that the transformer is in better health than may actually be the case.

In-situ oil conditioning is a relatively cheap alternative as it removes the expense associated with disconnection and transport to and from another location to undertake the work. Ergon Energy Corporation Limited had initiated purchase of the requisite equipment, but the supplier was unable to deliver and the supply project foundered. The costs at the time supported complete payback of the units after just two applications, when compared to complete oil replacement.

Action 8.2-1: Investigate alternate suppliers of in situ oil conditioning systems and re-establish processes to support the application of this technology as a cost-effective means of extending transformer life, to deliver customer outcomes and mitigate risk.

8.3 Voltage Control for Reverse Power Flow

With distributed generation proliferating throughout the distribution network, some transformers may potentially inject power back into the supply network. As most voltage regulation control is designed to manage the low voltage side voltage of the transformer, reverse power flow creates significant bus voltage management issues.

Action 8.3-1: While the problem of reverse power flow affecting voltage control is still in its infancy, monitor minimum transformer loading to detect encroaching back feed situations. This will trigger voltage control logic redesign.

8.4 Online Condition Monitoring

The condition of substation power transformers is proactively monitored through a combination of inspection and testing processes. DGA is undertaken on oil samples collected on a routine basis, with results analysed over the life of the asset to provide insight into the internal condition and remaining life. This testing is also used to determine whether maintenance or refurbishment of an asset is required in order to ensure that the unit continues to function as required to the end of its economic life.

Given substation transformers are long life assets, with necessary frequent inspections and testing, the potential exists to establish cost-effective online sensors to monitor condition and send data back to be centrally analysed in near real time or any chosen interval. This will reduce overall long-term maintenance costs through a reduced cycle of site visits and less time on site. In addition, the information offers potential for extending maximum operating rating levels, possibly delaying augmentation works.

Action 8.4-1: Investigate the opportunity to establish online condition monitoring for power transformers to deliver efficiency in maintenance programs and mitigate network risk. Areas of focus should include high voltage bushing monitoring, partial discharge monitoring, harmonics monitoring, and dissolved gas analysis.

8.5 Further Progression Towards Risk Based Maintenance Management

EQL generally employs condition-based maintenance practices, including simple cycle driven periodic inspections and tests. With the development of individual asset history data, EQL may find opportunities to rethink maintenance practices, to better target solutions for problematic asset types and reduce inspection and maintenance for more reliable assets types. This will have many benefits, including increased in-service time, decreased maintenance costs, and ultimately better overall reliability for customers without compromising on staff and public safety.

Action 8.5-1: Review substation power transformer data history and develop strategies that progress towards reliability centred inspection and maintenance.

9 Lifecycle Strategies

The following sections outline the approach of EQL to the lifecycle asset management of this asset class.

9.1 Philosophy of Approach

Substation transformers, regulators, and reactors are considered critical in nature as they are of high value, require significant lead time to procure, and failure events have the potential to result in safety consequences, as well as substantial and extended customer load interruption. The critical nature of these assets combined with the relatively low population makes it prudent and cost effective to manage them on an individual basis and to replace them when they are approaching end of life and prior to failure.

The condition of substation transformers, reactors and regulators are proactively monitored through a combination of inspection and testing. Dissolved Gas Analysis is undertaken on oil samples collected on a routine basis, with results analysed over the life of the asset to provide insight into the internal condition and remaining life. This testing is also used to determine whether maintenance or refurbishment of an asset is required in order to ensure that the unit continues to function as required to the end of its economic life.

9.2 Supporting Data Requirements

9.2.1 Historical Failure Data

There is a disparity between asset records being kept in the Northern and Southern regions and the South East region. Historical data capture practices restrict the ability to analyse the data associated with this asset class without substantial manual effort and offers significant potential for improved asset management.

Legacy organisation Ergon Energy developed and implemented a recording system for all failures, incorporating a requirement to record the asset component (object) that failed, the damage found, and the cause of the failure using the Maintenance Strategy Support System (MSSS) in Ellipse; the current Enterprise Asset Management (EAM) System. Energex maintained records of transformer failures and causes in a separate database outside of corporate systems. EQL has adopted the MSSS approach and is building this system of record over time, providing the information necessary to support improvements in inspection and maintenance practices. There is an expectation that this will also support and influence standard design and procurement decisions. Alignment of failure and defect data capture across regions is required to take full advantage of the larger data set available across the state.

Action 9.2-1: Align and improve defect, failure and dangerous electrical event data capture processes and reporting methodologies to ensure consistency across EQL.

9.2.2 Condition Assessment Data

In order to assess transformer condition, an ongoing regime of inspection and testing is required, with a need for commensurate data records to support population issue identification as well as individual asset performance.

EQL's use of CBRM provides a platform for defining economic end of life for substation power transformers, regulators, and reactors, as well offering significant potential for condition-based and reliability-centred maintenance and inspection practices.

The data required for asset assessment includes routine inspection and maintenance records as well as test result records relating to internal condition. Data collection may require commissioning information as a benchmark, historical DGA sampling results, and electrical test results. In order to collect this information accurately and efficiently, the in-field asset management devices and systems of record must be configured accordingly and provide the necessary functionality.

EQL is currently replacing the legacy Enterprise Asset Management systems under a renewal project. This presents an opportunity to ensure that the new systems are configured to meet the data requirements necessary to support the asset management objectives including provision for online condition monitoring sensor information.

Action 9.2-2: Incorporate asset condition data requirements in the new Enterprise Asset Management system being proposed for EQL, to ensure the accurate and efficient capture of data from the field including provision for online condition sensor information.

9.3 Acquisition and Procurement

Substation power transformers, regulators and reactors are procured on an as needed basis driven by condition-based replacement, network augmentation, and replacement of assets which have failed in-service. Contracts for these assets typically span at least several years for various logistical and pricing reasons and are based on technical specifications guided by the needs of the network. The contract periods determine the opportunity available to change technical specifications and improve asset performance by engineering out identified defects, standardising products, or implementing newer technologies.

As outlined in Section 7.1, the volume of substation power transformer replacement required in the Northern and Southern regions in order to deliver customer outcomes and manage network risk is forecast to increase, presenting a challenge for procurement. Refer to Section 9.5.2 for further information on program requirements.

The Substation Power Transformer contract for EQL is due for renewal with the development of the technical specification currently underway. This presents an opportunity to address the issues of population variation and design specific failure modes at the acquisition stage of the lifecycle subject to cost. EQL ensures that asset lifecycle management objectives and analysis is considered during technical specification and contract renewal as a part of standard process.

9.4 Operation and Maintenance

Operation and maintenance includes planned and corrective maintenance. Operation and maintenance procedures are supported by a suite of documentation which describes in detail the levels of maintenance applicable, the activities to be undertaken, the frequency of each activity, and the defect and assessment criteria to which the condition and testing are compared to determine required actions. The relevant documents are included in Appendix 1 for reference.

The following sections provide a summary of the key aspects of the operation and maintenance of substation power transformers, regulators and reactors as they relate to the management of the asset lifecycle.

EQL has a commenced the ongoing process of alignment of maintenance practices between regions where it is prudent and efficient. This alignment will occur over a number of years to maintain compliance with maintenance tolerances during any transition.

9.4.1 Preventive Maintenance

Preventive maintenance consists of inspection, testing, and routine maintenance activities as follows:

- In-Service Condition Assessment – periodic inspection of external condition and operational checks of ancillary equipment to identify defects. Inspections are also used to collect condition data for performance/risk analysis and replacement programs.
- Out of Service Condition Assessment – electrical testing undertaken to determine the condition of components that cannot be accessed while the asset is in service. This includes high voltage testing of the transformer bushings for voltages 66kV and above.
- Non-Intrusive Maintenance – a combination of detailed inspection, functional checks, electrical testing and routine restoration activities intended to restore serviceable items to an acceptable condition. Non-intrusive maintenance does not require access to components inside the main tank, conservator or bushings.
- Intrusive Maintenance (tap changer only) – a combination of detailed inspection, functional checks, electrical testing, and routine restoration activities intended to restore serviceable items to an acceptable condition. Intrusive maintenance requires access to components inside the diverter/selector switch tanks.
- Specialist Survey (oil sampling) – collection of oil samples from the main tank and tap changer to enable dissolved gas analysis and other chemical tests. The oil sampling and testing program, combined with subsequent analysis, provides information such as moisture content, indications of thermal hot spots, oil acidity and breakdown voltage, and types of incipient faults such as electrical discharge activity.
- An online partial discharge survey and a thermographic survey of all assets within the substation site complement the routine visual inspection.
- Moisture removal from oil – use of low level heating units on in-service transformers. The units are mobile and shifted around the population on a priority basis to manage high moisture content transformers, as identified by DGA analysis.

9.4.2 Corrective Maintenance

Corrective maintenance is generated from preventive maintenance programs, ad-hoc inspections, public reports, and in-service failures. Minor corrective actions usually occur during routine inspection and maintenance activities to avoid scheduling another visit to the site. Subsequent scheduling of required corrective actions that did not occur at the time of inspection is performed as specific corrective maintenance activities.

The triggers for corrective and forced maintenance include:

- Defects found during the inspection and maintenance activities
- Fault indication on protection and monitoring equipment located on the transformer or associated circuit breaker (post-trip)
- Poor voltage regulation
- Oil re-sampling recommended when the DGA analysis results indicate an emerging abnormal plant condition
- Other equipment failure symptoms.

9.4.3 Strategic Spares

The critical nature and long delivery timeframes of substation power transformers, regulators, and reactors supports the requirement to hold a stock of strategic spare units that may be used to replace (permanently or temporarily) an asset that has incurred damage due to a fault or failure. Spares may be either purchased as a new asset or recovered from service under an augmentation project if they are assessed as still having useful life. There are no strategic spares held for OLTCs, however, in some specific instances recovered units may be retained to provide a direct replacement for similar in-service units.

Strategic spares holdings for these asset classes are determined through assessment of the populations, failure rates and provisioning period in order to provide a high probability of a spare being available when required. This requirement is balanced against the cost of holding spares and the risk associated with not having a spare available. Consideration is also given to the storage location of spares in this category due to the logistics associated with transporting them when required across the state.

EQL maintains a register of the strategic spare assets which includes their storage location and asset attributes. The strategic spares are recorded in corporate systems in a separate stores holding from operational stock to ensure they are available for use when required. Strategic spares are regularly maintained to ensure they remain serviceable and ready for use.

The variation in voltage ratio, power rating, vector group, impedance, and voltage tapping range creates complexity in the calculation of spares holdings for substation power transformers. The management dilemma is to balance the requirement to hold a unit in every category versus the risk of exceeding reliability and Safety Net performance standards in the event of a failure. Inevitably, this translates to a complex cost benefit analysis that must account for a substantial variation in types, voltages, and capacities, as well as logistical challenges, such as transport restrictions in place for the very large size transformers as a result of the asset’s inherent weight and size in relation to the capacity of local bridges and roads, traffic restrictions and local availability of suitably rated cranes and trucks.

Action 9.4-1: Investigate opportunities to manage the risk associated with in-service failure across the diverse populations of substation transformers without holding every variation as a spare. Areas of focus should include use of mobile units and site specific contingency planning.

9.5 Refurbishment and Replacement

The following sections outline the practices used to either extend the life of the asset through refurbishment or to replace the asset at the end of its serviceable life.

9.5.1 Refurbishment

Refurbishment activities aim to extend the life of assets and postpone the need for complete replacement. An economic assessment of the cost and potential useful life is used to determine whether refurbishment is viable. Refurbishment activities are determined via assessment of the condition and can vary in complexity, from resolving corrosion issues and off-site moisture removal, through to component replacement or a full rewinding of the asset.

As outlined in previous sections, EQL has observed condition issues in its population of substation power transformers, regulators and reactors associated with moisture, tap changer end of life, and bushing defects and failures. Refurbishment provides an alternative to complete replacement of the asset and assists in reducing the impacts of the increasing program of replacement. It also provides an opportunity to introduce components with higher reliability and lower maintenance cost, to reduce operational costs.

9.5.2 Replacement

EQL has proactive replacement programs for substation power transformers, regulators, and reactors. Where practical, timing of replacement is coordinated with other necessary works occurring in the substation to promote works efficiencies. Replacement is also coordinated with network augmentation requirements to deliver the lowest net present value cost to customers and avoid duplication of works.

EQL use Condition Based Risk Management to forecast the end of useful life of substation transformers, regulators and reactors. This process combines asset data, engineering knowledge, and practical experience to define the current and future condition, performance, and risk for modelled assets. This information is summarised and presented as a Health Index (HI). The following figures show the relationship between the HI, remaining life, and the probability of failure.

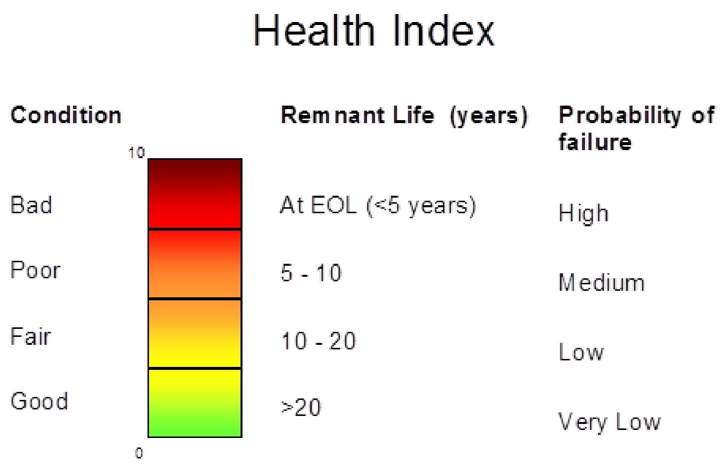


Figure 14: CBRM Health Index

EQL has set a HI threshold of 7.5 as the point to initiate consideration of planned replacement of the assets covered in this AMP. This recognises that projects of this nature typically take several years to design and commission, and that assets continue to degrade beyond the threshold value while they remain in service. Refer to the Condition Based Risk Management Application Document for further detail on the CBRM process. In-service failure rate provides a measure of the performance of the proactive replacement programs initiated from CBRM, and is used as an ongoing calibration input for the models.

The program of replacement is managed on a risk basis within the portfolio of capital expenditure required for EQL. Forecast programs of replacement required to manage the lifecycle of the EQL population of substation power transformers, regulators, and reactors are outlined in Section 10.

9.6 Disposal

At the time of the disposal of any asset containing oil, EQL test for presence of PCBs to determine the appropriate disposal methodology in accordance with the Part 6 (Management of PCBs) of the Queensland Environmental Protection (Waste Management) Regulation 2000.

Assets that have reached end of life are salvaged for useable components to provide maintenance spares before being sold for scrap or disposed of accordingly. Assets that are recovered prior to end of life due to augmentation or other network requirements that cannot be reused in the network may be sold to other organisations (such as mining companies) before disposal is considered.

10 Program Requirements and Delivery

The programs of maintenance, refurbishment, and replacement required to outwork the strategies of this AMP are documented in Network Program Documents and reflected in corporate management systems. Programs are typically coordinated to address the requirements of multiple asset classes at a higher level such as a substation site or feeder to provide delivery efficiency and reduce travel costs and overheads. The Network Program Documents provide a description of works included in the respective programs as well as the forecast units.

Program budgets are approved in accordance with Corporate Financial Policy. The physical and financial performance of programs is monitored and reported on a monthly basis to manage variations in delivery and resulting network risk.

11 Summary of Actions

The following provides a summary of the specific actions noted throughout this AMP for ease of reference:

Action 6.1-1: Review and align the algorithms used to determine the average Water Content of Paper (WCP), to ensure a common EQL approach to the condition assessment of substation transformers, regulators, and reactors.

Action 6.1-2: Review maintenance activities to identify and address any opportunities to reduce the number of substation transformers experiencing moisture ingress. This review should include consideration of the adequacy of the breather systems and practices for changing the silicon desiccant.

Action 6.2-1: Investigate the common Online Tap Changer (OLTC) failure mode of 'stuck between taps' on the population of Reinhausen type VV, and Ferranti type DS2 OLTCs to drive performance improvement and mitigate risk within this asset class.

Action 6.6-1 Increase the volume of substation asset replacement in the Northern and Southern region to address the existing Network Access Restrictions, and to deliver a long term sustainable program of replacement where assets are removed from the network prior to requiring a Network Access Restriction to be imposed due to condition.

Action 7.2-1 Review the effectiveness of the use of oil passivator in transformers to manage the corrosive sulphur the asset population to determine if an ongoing program is required across all regions

Action 7.3-1 Monitor the effects of distributed energy resources on load cycles and the resultant impacts on the useful life of transformers.

Action 8.1-1: Establish procedures and maintenance acceptance criteria to manage the use of biodegradable oil in substation transformers, using results from the trial of this medium at Comet Substation.

Action 8.2-1: Investigate alternate suppliers of in situ oil conditioning systems and re-establish processes to support the application of this technology as a cost-effective means of extending transformer life, to deliver customer outcomes and mitigate risk.

Action 8.3-1: While the problem of reverse power flow affecting voltage control is still in its infancy, monitor minimum transformer loading to detect encroaching back feed situations. This will trigger voltage control logic redesign.

Action 8.4-1: Investigate the opportunity to establish online condition monitoring for power transformers to deliver efficiency in maintenance programs and mitigate network risk. Areas of focus should include high voltage bushing monitoring, partial discharge monitoring, harmonics monitoring, and dissolved gas analysis.

Action 8.5-1: Review substation power transformer data history and develop strategies that progress towards reliability centred inspection and maintenance.

Action 9.2-1: Align and improve defect, failure and dangerous electrical event data capture processes and reporting methodologies to ensure consistency across EQL.

Action 9.2-2: Incorporate asset condition data requirements in the new Enterprise Asset Management system being proposed for EQL, to ensure the accurate and efficient capture of data from the field including provision for online condition sensor information.

Action 9.4-1: Investigate opportunities to manage the risk associated with in-service failure across the diverse populations of substation transformers without holding every variation as a spare. Areas of focus should include use of mobile units and site specific contingency planning.

Appendix 1 – References

It takes several years to integrate all documents after a merger between two large corporations. This table details all documents currently authorised/approved for use in either organisation, and therefore authorised/approved for use by EQL, that support this Asset Management Plan.

Organisation	Document Number	Title	Type
Ergon Energy Energex	EPONW01 EX 03595	Network Asset Management Policy	Policy
Ergon Energy Energex	PRNF001 EX 03596	Protocol for Network Maintenance	Protocol
Ergon Energy Energex	PRNF003 EX 04080	Protocol for Refurbishment and Replacement	Protocol
Ergon Energy Energex	STNW0330 EX 03918	Standard for Network Assets Defect/Condition Prioritisation	Standard
Ergon Energy Energex	STNW1125 EX01105	Standard for Power Transformers	Standard
Ergon Energy Energex	STNW1126 EX04131	Standard for On-Load Tap Changers	Standard
Ergon Energy Energex	STNW1128 EX04133	Standard for Neutral Earthing Resistors and Reactors	Standard
Ergon Energy Energex	STNW1160 EX STD00299	Maintenance Acceptance Criteria	Manual
Ergon Energy	EP26	Risk Management Policy	Policy
Ergon Energy	EP51	Defect Management Policy	Policy
Ergon Energy	SGNW0004	Network Optimisation Asset Strategy	Strategy
Ergon Energy	STNW0717	Standard for Preventive Maintenance Programs for 2017-18	Standard
Ergon Energy Energex		Substation Defect Classification Manual	Manual

Appendix 2 – Definitions

For the purposes of this Asset Management Plan, the following definitions apply:

Term	Definition
Condition Based Risk Management	A formal methodology used to define current condition of assets in terms of health indices and to model future condition of assets, network performance, and risk based on different maintenance, asset refurbishment, or asset replacement strategies.
Corrective maintenance	This type of maintenance involves planned repair, replacement, or restoration work that is carried out to repair an identified asset defect or failure occurrence, in order to bring the network to at least its minimum acceptable and safe operating condition. An annual estimate is provided for the PoW against the appropriate category and resource type.
Current transformer	Current transformers are used to provide/transform currents suitable for metering and protection circuits where current measurement is required.
Distribution	LV and up to 22kVnetwork, all SWER networks
Forced maintenance	This type of maintenance involves urgent, unplanned repair, replacement, or restoration work that is carried out as quickly as possible after the occurrence of an unexpected event or failure; in order to bring the network to at least its minimum acceptable and safe operating condition. Although unplanned, an annual estimate is provided for the PoW against the appropriate category and resource type.
Instrument Transformers	Refers to Current Transformers (CTs), Voltage Transformers (VTs) and Metering Units (MUs)
Metering Units	A unit that includes a combination of both Current Transformers and Voltage Transformers for the purpose of statistical or revenue metering
PCB	Polychlorinated Biphenyls are synthetic chemicals manufactured from 1929 to 1977 was banned in 1979 and found in transformers, voltage regulators and switches
Preventative maintenance	This type of maintenance involves routine planned/scheduled work, including systematic inspections, detection and correction of incipient failures, testing of condition and routine parts replacement designed to keep the asset in an ongoing continued serviceable condition, capable of delivering its intended service
Subtransmission	33kV and 66kV networks
Transmission	Above 66kV networks
Voltage Transformers	Voltage or potential transformers are used to provide/transform voltages suitable for metering and protection circuits where voltage measurement is required.

Appendix 3 – Acronyms and Abbreviations

The following abbreviations and acronyms may appear in this asset management plan.

Abbreviation or acronym	Definition
AIDM	Asset Inspection & Defect Management system
ALARP	As low as reasonably practicable
AMP	Asset Management Plan
Augex	Augmentation Expenditure
CBRM	Condition Based Risk Management
CB	Circuit Breaker
CT	Current Transformer
CVT	Capacitor Voltage Transformer
DEE	Dangerous Electrical Event
DGA	Dissolved Gas Analysis
DLA	Dielectric Loss Angle
EQL	Energy Queensland Limited
ESCOP	Electricity Safety Code of Practice
ESR	Queensland Electrical Safety Regulation (2013)
HV	High voltage
IoT	Internet of Things
ISCA	In-Service Condition Assessment
LDCM	Lines Defect Classification Manual
LV	Low Voltage
LVR	Low voltage regulator
MSS	Minimum Service Standard
MSSS	Maintenance Strategy Support System
MU	Metering Unit
MVAr	Mega-VAr, unit of reactive power
NER	Neutral Earthing Resistor
NEX	Neutral Earthing Reactor
OLTC	On-load tap-changers
OTI	Oil Temperature Indicators

PCB	Polychlorinated Biphenyls
PD	Partial discharge
POC	Point of Connection (between EQL assets and customer assets)
POEL	Privately owned Electric Line
PRD	Pressure Relief Device
QLD	Queensland
REPEX	Renewal Expenditure
RIN	Regulatory Information Notice
RMU	Ring Main Unit
SCAMS	Substation Contingency Asset Management System
SDCM	Substation Defect Classification Manual
SFAIRP	So far as is reasonably practicable
SHI	Security and Hazard Inspection
SVC	Static VAR Compensator
THD	Total Harmonic Distortion
VT	Voltage Transformer
WCP	Water Content of Paper
WTI	Winding Temperature Indicators
WTP	Wet Transformer Profile