Asset Management Plan DC Supply Systems 2020-25

January 2019

Part of the Energy Queensland Group

Executive Summary

This Asset Management Plan (AMP) covers the class of assets relating to Direct Current (DC) Supply Systems, including batteries and battery chargers, in substations and distribution assets.

DC systems provide the direct current supply used by control and protection systems within substations such as the protection relays and circuit breaker solenoids and on distribution assets such as reclosers and sectionalisers.

EQL manages more than 4,700 battery systems across Queensland, employing a number of different battery types, including VRLA (valve regulated lead acid), VRNC (value regulated nickel cadmium) and wet lead acid types, as well as AC chargers designed to suit the battery installation.

DC service failure can introduce the following significant risks:

- Complete failure of DC supply leading to loss of protection, communications and substation control.
- Release of toxic chemicals.
- Uncontrolled release of stored energy, usually as a fire or explosion.

Key asset challenges for DC systems include the continuous improvement of asset data quality and the standardisation and improvement of procurement and maintenance processes across Energy Queensland Limited (EQL) to drive efficiency, deliver customer outcomes and mitigate risks. EQL will also continue to improve safety and the cost-effective management of this asset class.

With technology constantly evolving, particularly in the area of battery storage, it is important for EQL to keep up with improved technological advances in order to continually improve the quality of asset management of DC systems across the state.

Document Tracking Details

Network and Non-Network Document Hierarchy Reference Number	Regulatory Proposal Chapter Reference	Document	File Name
NET AMP – 005	7.031	Asset Management Plan - DC Supply Systems	EGX ERG 7.031 Asset Management Plan - DC Supply Systems JAN19 PUBLIC

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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 (Legacy organisation: Energex Limited); and
- Northern and Southern Regions (Legacy 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 Asset Management Plan is to demonstrate the responsible and sustainable management of batteries and chargers used with assets forming part of the EQL electrical network. The objectives of this plan are to:

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

This Asset Management Plan 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 (ESCOP)*
- *Work Health & Safety Act 2014*
- *Work Health & Safety Regulation 2011*
- Ergon Energy Corporation Limited Distribution Authority No D01/99
- Energex Limited Distribution Authority No. D07/98.

This Asset Management Plan forms part of Energy Queensland's strategic asset management documentation, as shown in Figure 1. It is part of a suite of Asset Management Plans which collectively describe Energy Queensland's approach to the lifecycle management of the various assets which make up the network used to deliver electricity to its customers. 0 contains references to other documents relevant to the management of the asset class covered in this plan.

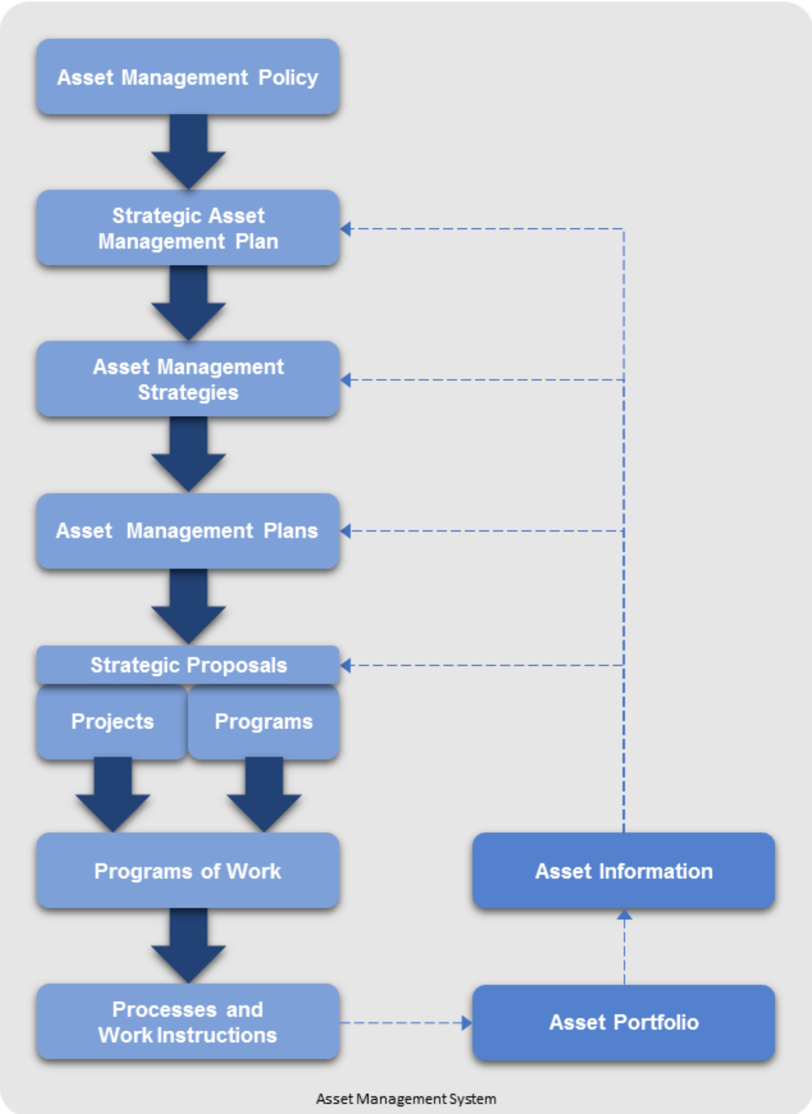

Figure 1: Energy Queensland Document Hierarchy

1.2 Scope

This AMP covers the following assets:

- Substation batteries and battery chargers, and;
- Lines batteries and battery chargers (for reclosers and sectionalisers).

Many customers, typically those with high voltage connections, own and manage their own network assets including DC Supply Systems 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

DC systems are relatively low capacity, low volume, and low-cost assets and are typically asset managed on a population basis using periodic inspection for condition and serviceability and through systemic review of recorded performance.

Based upon asset quantities and replacement costs, EQL substation DC systems have a replacement value of the order of $26.4 Million (2018 $), (Northern and Southern regions $8.7 Million, South East region $17.7 Million). 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. Figure 2 provides an indication of the relative financial value of EQL substation DC systems compared to other asset classes. Proactive management of this asset type is an essential part of achieving our corporate vision and strategic purpose.

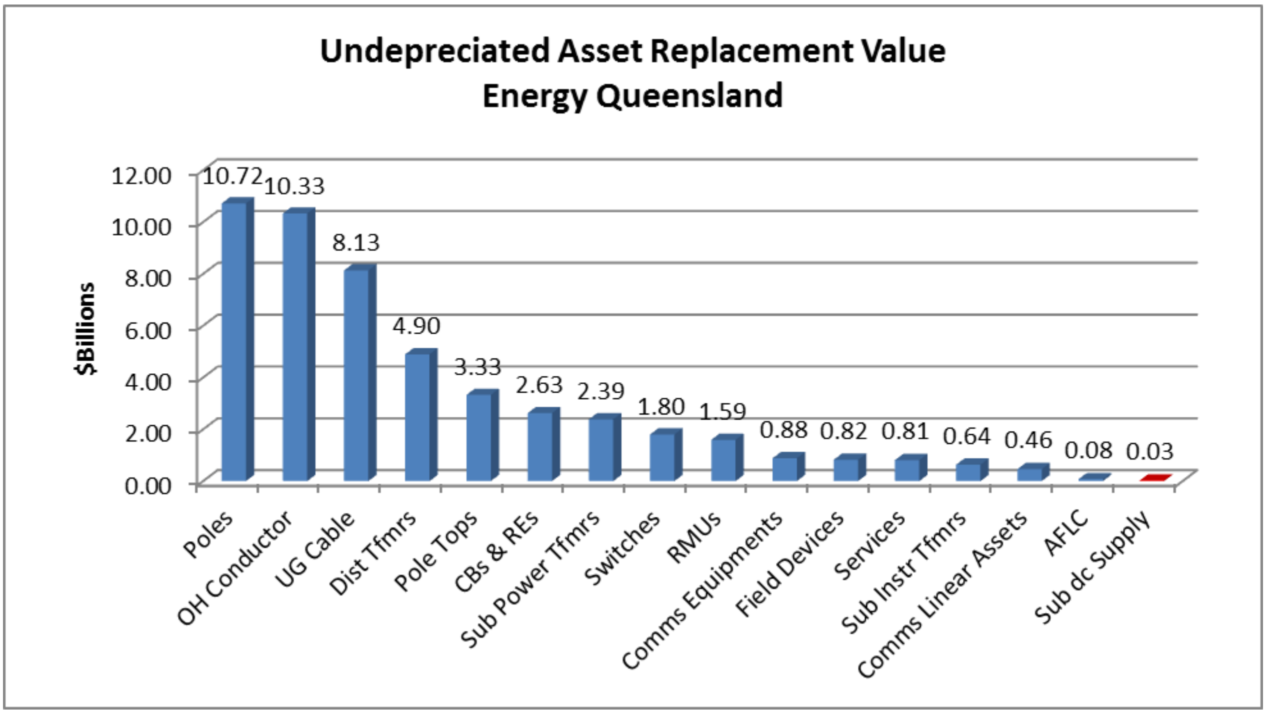

Figure 2: Total Current Replacement Cost

1.4 Asset Function and Strategic Alignment

Protection, communications, and SCADA (Supervisory Control and Data Acquisition) systems all typically employ DC (direct current) power. DC power provides power supply stability for these particular assets, especially during times of power network instability. Power supply stability allows critical substation safety and control services to function reliably and consistently whenever required. Similarly, the protection and control functions on distribution devices such as sectionalisers and reclosers rely on DC supply from batteries.

Protection systems act to de-energise electrical assets under fault conditions. This is necessary to support the electrical safety of EQL staff and public, so is an essential element in discharging EQL's regulatory safety for its staff, customers and the general public in relation to its assets.

SCADA systems provide monitoring of distribution network system parameters and provide remote control to facilitate day to day safe operation of network assets. SCADA systems support efficient network operation and are an essential part of achieving the corporate reliability performance standards.

Communication systems facilitate network operational communications, protection scheme communications and SCADA.

DC supply systems allow protection, SCADA and communications systems to function reliably during times of power system disturbance in the rare event of complete loss of AC (Alternating Current) supply to a site. Such events can occur as a result of outages, asset failure, emergency (fault) situations, disaster situations (such as cyclones and floods), and Black System (mass system loss) situations.

Table 1 below details how DC supply systems contribute to the corporate strategic asset management objectives.

Relevant Asset Management Objectives	Relationship of Asset to Asset Management Objectives
Ensure network safety for staff, contractors and the community	Diligent and consistent maintenance and operations of DC supply systems support ongoing network protection, communication and SCADA functionality, ensuring safety for all stakeholders.
Meet customer and stakeholder expectations	DC services facilitate ongoing SCADA and communication functions supporting effective operations of the distribution network. In turn, effective and efficient network operations and management directly supports network reliability and promotes delivery of a standard high quality electrical energy transport service.
Manage risks, performance standards and asset investment to deliver balanced commercial outcomes	Failure of DC services can lead to loss of essential protection, communication and remote control. Such loss can result in disruption of the electricity network and increased public safety risk. Proactive replacement and 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 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
Asset Operations Delivery	EGM Distribution
Asset Manager	EGM 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 Descriptions

DC systems provide the direct current supply used by control and protection systems within substations such as the protection relays and circuit breaker solenoids, and on distribution assets such as reclosers and sectionalisers. The following sections provide a description of the various assets covered in this AMP.

2.1.1 Battery

A battery is a device that produces electrons through electrochemical reactions and contains positive (+) and negative (-) terminals. A battery consists of one or more electrochemical cells, which transform stored chemical energy directly into electrical energy and vice versa. When an external load connects the positive and negative terminals, electrons cross from the negative to the positive terminal, creating an electrical current.

Batteries are ganged together (in battery strings) to achieve the designed voltage and amperage capacity levels. For safe, long term charging, all batteries in a battery string must be of the same type.

EQL employs three types of batteries across the different substations and lines:

- Wet lead acid – the electrolyte is a water based acid which must be periodically maintained and checked for electrolyte level.
- Valve regulated lead acid absorbed glass mat (VRLA) – the electrolyte is absorbed in thin fibreglass mats sandwiched between lead plates and effectively immobilised. The batteries are effectively sealed but employ overpressure valves to release excess gas (hydrogen, oxygen) that might form in overcharging conditions. VRLA batteries are virtually maintenance-free and stored/used at any angle. Lead acid batteries have low self-discharge rates (i.e. low ongoing electrical losses).
- Valve regulated nickel cadmium (VRNC) – nickel cadmium (Ni-Cad) batteries employing a flooded cell design with nickel hydroxide and metallic cadmium as electrodes and the electrolyte held in fibreglass mat separators. The batteries are effectively sealed but employ overpressure valves to release excess gas that might form in overcharging conditions. These batteries are virtually maintenance-free and stored/used at any angle. Nickel cadmium batteries have a high self-discharge rate (i.e. high ongoing losses). Care must be taken when disposing of nickel cadmium batteries due to the toxicity of cadmium.

2.1.2 Battery Charger

A battery charger is a rectifier designed to deliver a stabilised and relatively harmonic-free DC supply from an AC supply source. Substation battery chargers are typically designed to deliver the entire standing load of the substation as well as the maximum charging load of the associated battery banks.

The AC charger for a lead acid battery is essentially a constant voltage device. The AC charger for a Ni-Cad battery is essentially a constant current device.

2.1.3 DC distribution board

A DC distribution board is typically an arrangement of DC buses, fuses, links and circuit breakers that allow individual DC power circuits and systems to be segregated, separately protected and isolated, while maintaining DC supply services to the rest of the substation infrastructure. In many substations, battery chargers and battery banks are duplicated, with all circuit switching and configuration occurring via the DC distribution board.

2.2 Asset quantity and physical distribution

Table 3 details the population of substation battery banks in Northern and Southern Regions, by output voltage.

Communication sites and remote community generation sites have been excluded from these numbers. The variations in voltage reflect the diverse range of different control systems, protection systems, communications systems and even circuit breaker types found in Northern and Southern Regions substations.

Voltage	Wet Lead Acid	VRLA	VRNC
12V	0	2	1
24V	0	6	0
30-32V	2	49	2
48-50V	2	154	16
110V	0	162	3
120-125V	0	14	6
Unknown	1	3	0
Total	**5**	**392**	**28**

Table 3: Northern and Southern Regions - substation battery bank population

Table 4 details the population of substation battery chargers in Northern and Southern Regions, by output voltage.

Voltage	Quantity
12	5
24	3
30 - 32	39
48 - 50	149
110	162
122-125	20
Unknown	2
Total	**377**

Table 4: Northern & Southern Regions – substation battery charger population

Of the 2,758 reclosers and sectionalisers recorded in the Northern and Southern Regions, 1,390 units contain batteries. Table 5 provides a quantity breakdown by primary switched voltage.

Primary Voltage	Quantity
11kV	853
22kV	197
33kV	69
12.7kV	106
19.1kV	165
Total	**1,390**

Table 5: Northern & Southern Regions – lines recloser battery bank populations

Table 6 details the population of substation battery banks (likewise for battery chargers) in the South East Region, by output voltage.

Voltage	Wet Lead Acid	VRLA	VRNC
24V	0	160	0
30V	0	80	107
48V	0	150	1
110V	0	358	0
Total	**0**	**748**	**108**

Table 6: South East region - substation battery bank populations

Table 7 details the population of lines asset type battery systems by primary asset type and voltage.

Component	12V VRLA	24V VRLA
Recloser	459	366
Sectionaliser	0	106
LTS (load transfer switch)	0	1181
Total	**459**	**1653**

Table 7: South East region - lines battery bank populations

2.3 Asset age distribution

The DC system age profiles are detailed in the figures below. The expected lifetimes of batteries and chargers are impacted by many factors including the required functionality, obsolescence, design and technology employed. As a rough guide, wet lead acid and VRLA batteries typically last between 5-8 years, VRNC batteries last around 21 years, and battery chargers last between 20-45 years.

Northern and Southern Regions

Data detailing year of installation for substation batteries is sparse, with almost 70% of banks have an un-recorded age. Figure 3 details the age profile of battery banks in the Northern and Southern Regions where the year of manufacture is recorded; however there is insufficient information available to determine the expected life period for these assets.

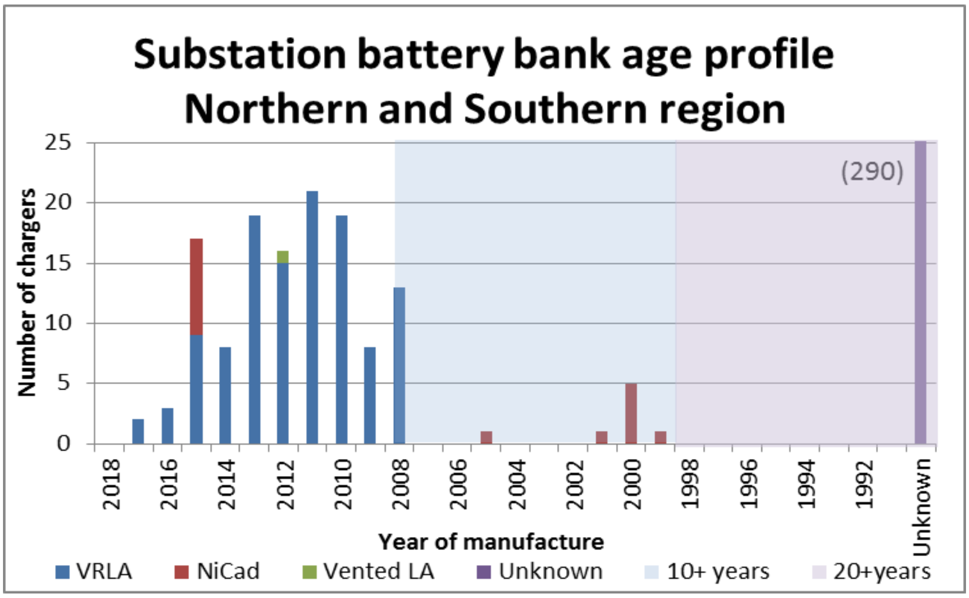

Figure 3: Northern and Southern Regions age profile of substation battery banks (where age is recorded)

Data detailing year of installation or manufacturer data for substation battery chargers in the Northern and Southern Regions is also sparse with no records available for almost 40% of the population. Figure 4 demonstrates the age profile for substation battery chargers where the age is recorded, however, there is insufficient information available to determine the expected life period for these assets.

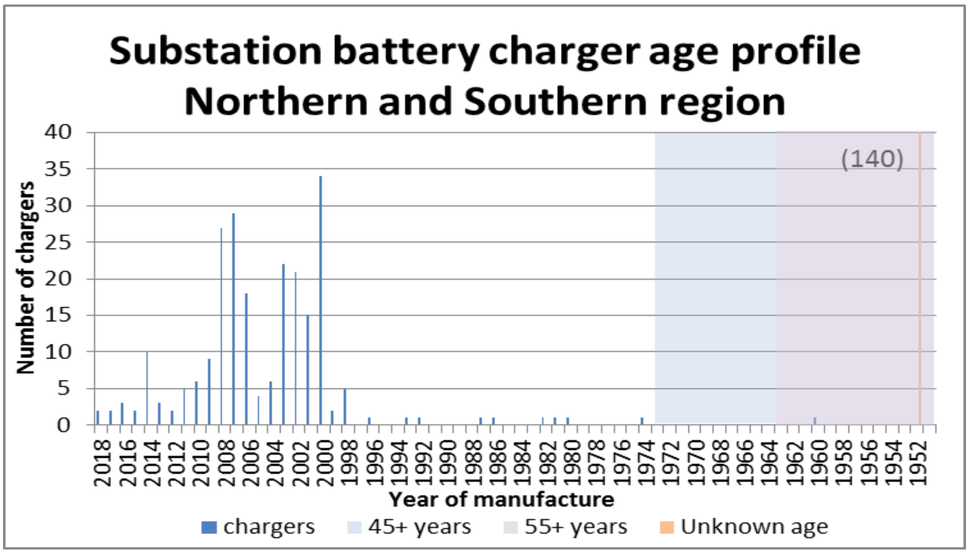

Figure 4: Northern and Southern Regions substation battery charger age profile (where age is recorded)

South East Region

The age profiles for VRLA and Ni-Cad battery banks in the South East Region are shown in Figure 5. Although there are several VRLA battery banks that are past the replacement age of six years, this is due to previously inaccurate data. After a recent audit where the data was clarified, these banks have now been programmed for proactive replacement. Note that individual cell replacements would have occurred throughout the bank life.

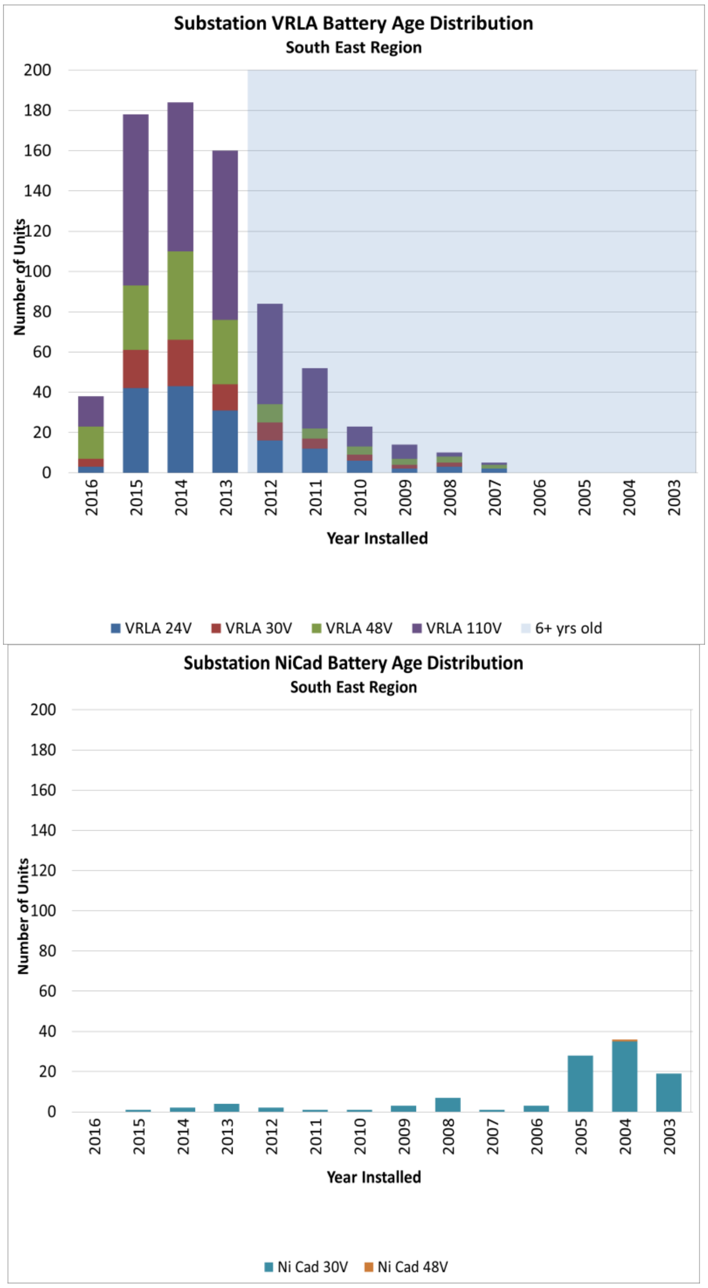

Figure 5: South East Region substation battery bank age profile

The battery charger age profile in the South East Region is illustrated in Figure 6. A proactive replacement strategy for battery chargers was recently instigated in the South East Region. The expected lifetime of battery chargers varies depending on the technology, manufacturer and environment. It was previously suggested that the newer SCR (silicon controlled rectifier) chargers have an expected lifespan of 30 years, compared to a 40 year lifespan for older types, but this is to be reviewed (refer to section 7.8 of Emerging Issues).

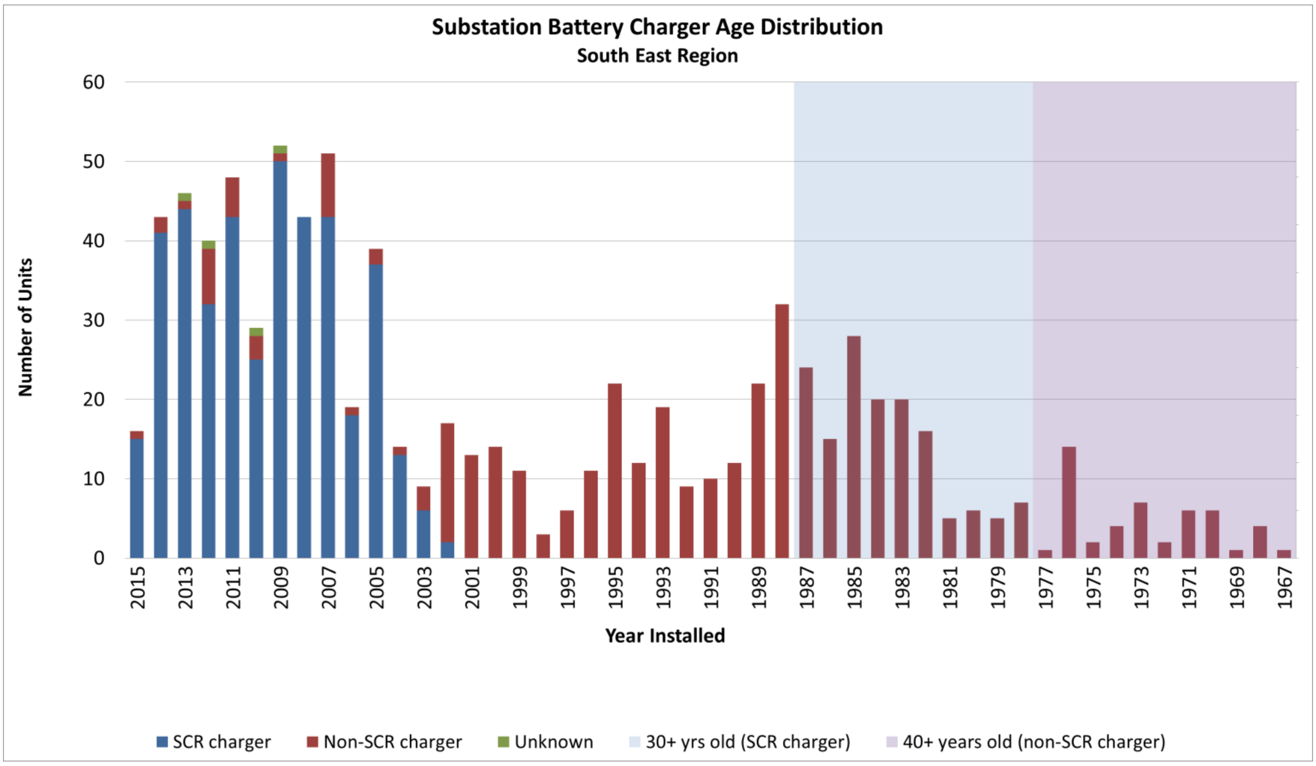

Figure 6: South East Region substation battery charger age profile

The age profile of substation battery system monitors (BSM's) shown in Figure 7 is similar in trend to the battery charger age profile in Figure 6 above.

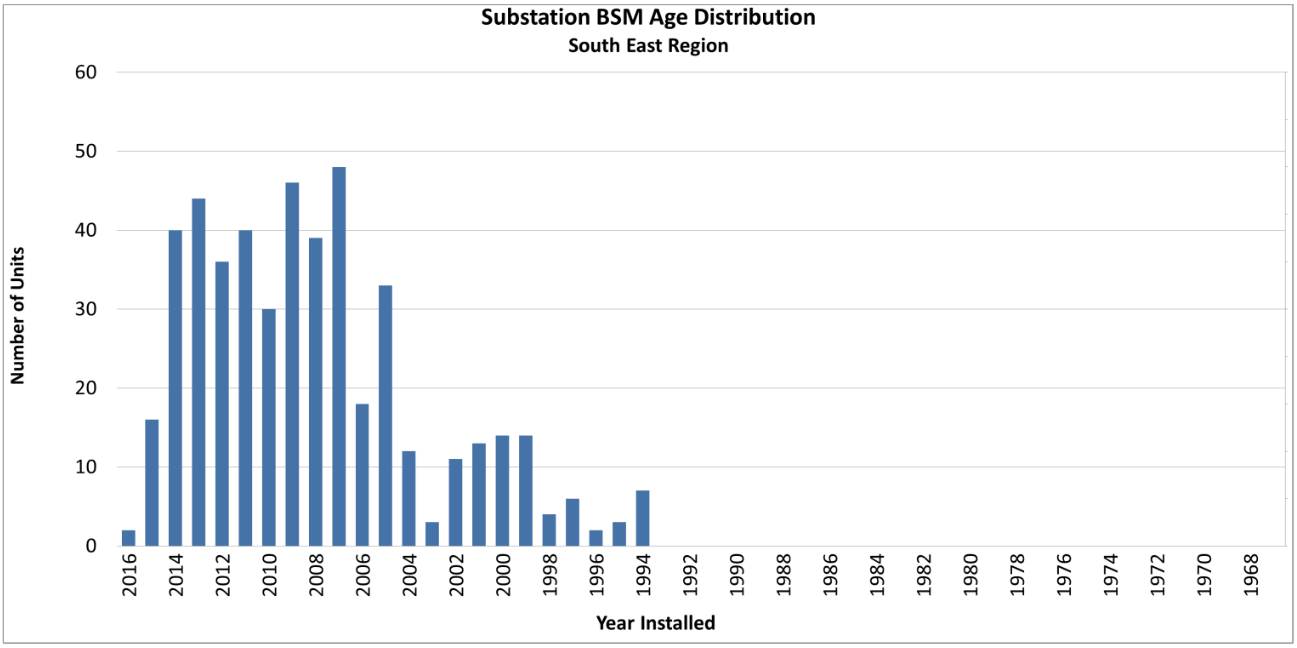

Figure 7: South East Region substation battery system monitor (BSM) age profile

Figure 8 below shows the age profile of recloser and sectionaliser battery banks using the best available data, but the data for LTS's (line transfer switches) is not available to be shown (lines asset battery systems in the South East Region have not required significant focus of attention to date).

All line battery banks are VRLA type and are proactively replaced on a 5 year replacement cycle. Whilst there appears to be multiple banks that are outside of the 5 year band, it should be noted that data inaccuracies are present. It has been confirmed that they are currently programmed for replacement in the future.

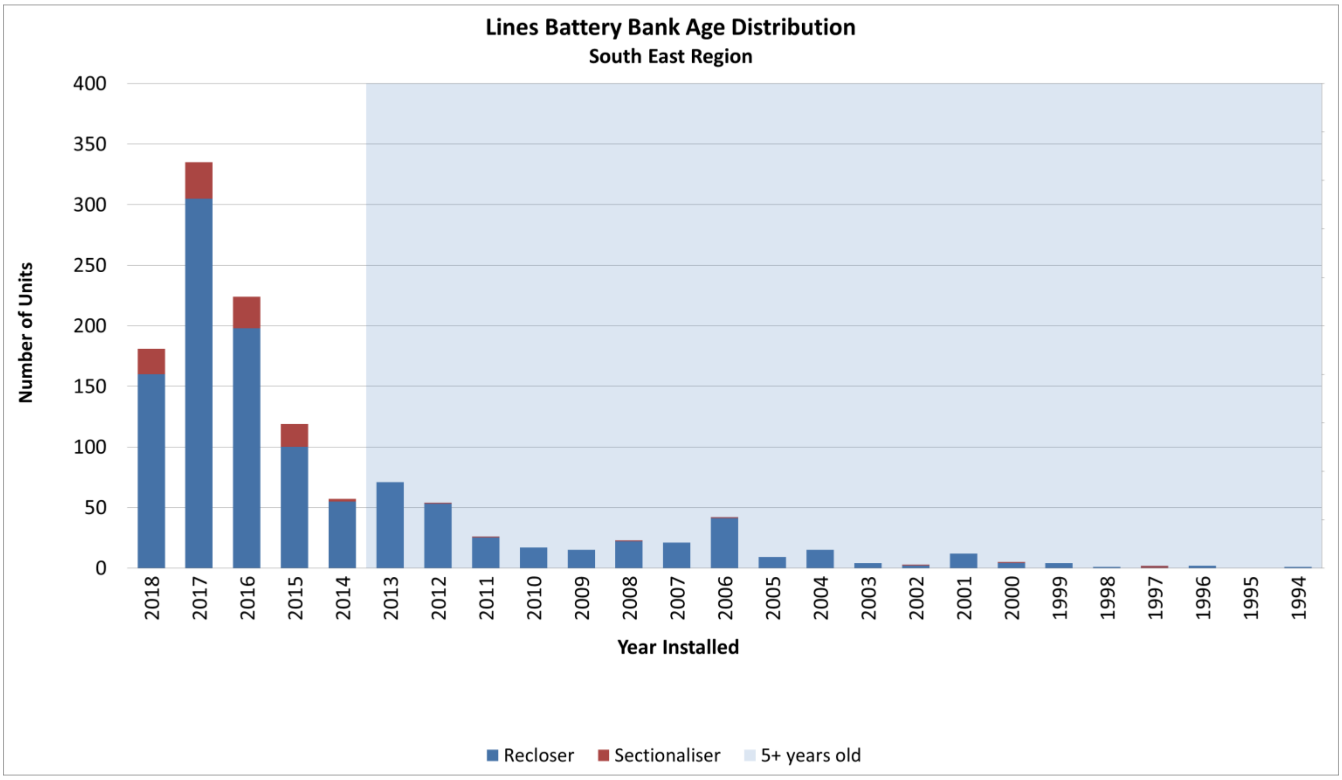

Figure 8: South East Region line (excluding LTS) battery bank age profile (as of Aug 2018)

2.4 Population trends

The number of battery and charger systems is expected to remain relatively constant over time.

EQL intends to standardise upon battery and charger suppliers, so there will be a gradual reduction in the number of different brand types as each individual asset has a different end of economic life (as there will always be some variation in brands as items go out on period contract, and suppliers may change). The same variation in asset life applies for battery system capacity (i.e. Amp-hour rating), as over time a large number of different capacity systems have been used. Ideally, these are to be standardised, but battery charger capacity and space constraints are issues that will slow the standardisation process.

Nickel cadmium batteries are progressively being phased out by legislation in various countries around the world due to the toxicity of cadmium when disposed in landfill. There is currently no such legislation in place in Queensland. EQL utilises lead acid (VRLA) batteries for all new installations and nickel cadmium battery banks are only installed as like-for-like replacements. Where both chargers and batteries must be replaced together, VRLA batteries and appropriate chargers assets are used.

Potential also exists for some reduction in the number of battery and charger systems in each substation where DC-DC converter reliability can be demonstrated, and the risks associated with such failure can be correctly managed.

2.5 Asset life limiting factors

The following sections outline the life limiting factors of different asset types covered in this AMP.

2.5.1 Batteries

Table 8 describes the key factors that influence the life of batteries and as a result have a significant bearing on the programs of work implemented to manage the asset lifecycle.

Factor	Influence	Impact
Average battery temperature over time	Efficacy of the chemical reaction process.	Reduction in overall electron storage capability.
Operating environment	Dust, chemicals.	Corrosion, localised overheating.
Number of deep discharge cycles	Efficacy of the chemical reaction process.	Reduction in electron storage and discharge capability (no discharge cycles can be harmful and too many is also harmful).
Level of discharge	Ability to recharge to the intended capacity.	Reduction in overall bank ability to supply load demand.
Recharging rate	Ability to absorb additional electrons is impacted by the battery charge level.	Charge rate must be managed to maximise battery longevity.
Overcharging	Excess charging results in gas production out of the electrolyte and overpressure gas release by the regulating valves.	Loss of electrolyte, reducing battery capacity.
Extended float charging (Nickel cadmium batteries)	So-called memory effect (there is scientific debate about the cause).	Reduction in the ongoing ability to discharge to the level required.

Table 8: Battery life limiting factors

2.5.2 Battery Chargers

Table 9 describes the key factors that influence the life of battery chargers and as a result, have a significant bearing on the programs of work implemented to manage the asset lifecycle.

Factor	Influence	Impact
Operating temperature	Aging of electrical components	Reduction of maximum output of device, increased output of AC ripple
Operating environment	Dust, chemicals	Corrosion, localised overheating
Input harmonics and noise	Surge absorption capability	Overheating
Failure of microprocessor management units	Aging of electronics, dust, chemicals	Charger failure

Table 9: Charger 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 DC supply system 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 DC systems 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 as low as reasonably practicable (ALARP).

The main components of this asset class each consist of a similar population differing in age, brand, technology, material, construction design, technical performance, purchase price and maintenance requirements. Each 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 consistent with manufacturers' advice, good engineering operating practice, and historical performance, with intent to achieve the longest practical asset life overall.

Life extension techniques will be applied where practical and will be 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.

DC systems provide an essential service to critical substation components including protection, communication and SCADA. DC systems hardware is designed to be fault tolerant, and deliver a stabilised DC supply to those critical components whenever substation primary plant is energised.

DC supply assets are expected to supply a substation for up to 10 hours after the loss of AC supply. A loss of this duration typically only occurs after, for example, widespread natural disaster situations, and is mitigated by use of portable generators.

Lines asset batteries are specified to allow successful operation of the primary switch up to 36 hours after loss of AC supply. Loss of supply for such durations is very rare. The steady state operating load on these devices is very small, so typically a single battery is adequate for this purpose.

3.2 Legislative requirements

Regulatory performance outcomes for this asset include compliance with all legislative and regulatory standards, including the *Electrical Safety Act 2002 (Qld)*, the *Electrical Safety Regulation 2013 (Qld)*, and the Queensland Electrical Safety Codes of Practice.

The *Electrical Safety Act 2002 (Qld)* Section 29 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 it 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.

EQL is responsible for defining the extent of inspection, testing and maintenance, including standards and interval timing, taking into account overall safety and performance obligations.

EQL has an obligation to provide adequate protection of its power system assets[1], maintain transmission, sub transmission and distribution voltages within statutory limits, and provide the customer with acceptable quality and reliability of supply including voltage levels[2]. Substation protection, Intelligent Electronic Devices (IEDs), On-Load Tap Changer (OLTC) control circuitry, Automatic Voltage Regulators (AVRs), and most Circuit Breakers (CBs) require a DC power supply.

The *National Electricity Rules* (NER) stipulate minimum fault clearing times for transmission and sub-transmission lines[3], which typically require communications assisted protection schemes. Without high-speed communications, protection-clearing times will not meet the *National Electricity Rules* requirements and may adversely affect power system stability.

Loss of DC supply can render many protection systems at a substation inoperative. Without adequate protection, step and touch potentials during power system faults are unlikely to meet the requirements of the Electrical Safety Code of Practice[4] and the regulations[5]. Lack of adequate protection may expose EQL to increased risk of extensive plant damage under fault, with consequential asset replacement and remediation costs. In addition, uncontrolled system fault events can affect the external environment, with impacts such as air pollution, oil spillage and bush fire initiation, which compromises EQL's ability to achieve its environmental duty and associated obligations[6].

Loss of DC supply can render SCADA and Communications systems inoperative at the substation (some substations have a dedicated and independent DC supply to mitigate this risk). Such a loss will have an adverse effect on EQL's ability to operate and control its network assets, and hence meet the minimum service standards (MSS) defined in EQL's Distribution Authorities and the Service Target Performance Incentive Scheme (STPIS) performance targets defined under the NER.

Dangerous electrical events (DEEs) are defined in legislation[7]. DEEs are typically circumstances involving a high voltage asset, where a person would not have been electrically safe had they been exposed to the event. EQL assigns DEEs into two categories as follows:

- Unassisted DEEs - incidents that might have been prevented via a utopian maintenance program, and;
- Assisted DEEs - incidents where the root cause of failure occurs outside the control of any maintenance program (eg lightning strike).

EQL includes complete loss of HV protection at a substation as a DEE because of the electrical safety implications.

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1 EQL has a duty to ensure that its works are electrically safe, refer Electrical Safety Act 2002 (Qld) s29
2 Refer to Electrical safety Regulation 2006 (Qld) s11
3 NER, Chapter 5, Schedule 5.1
4 Electrical safety Code of Practice 2010 (Qld), s3.5. Note these definitions are not mandatory, but may be used as a reference standard in the Courts.
5 Refer to Electrical safety Regulation 2006 (Qld) s196
6 Detailed in the Environmental Protection Act 1994 (Qld) and associated regulations
7 Electrical Safety Act 2002 (Qld), s12

3.3 Performance requirements

Corporate performance outcomes for this asset are rolled up into Asset Safety & Performance group objectives, principally the following key result areas (KRA):

- Customer Index, relating to Customer satisfaction with respect to delivery of expected services
- Optimise investments to deliver affordable & sustainable asset solutions for our customers and communities

Corporate Policies relating to establishing the desired level of service are detailed in 0.

Under the Distribution Authorities, EQL is expected to operate with an 'economic' customer value-based approach to reliability, with "Safety Net measures" for extreme circumstances. Safety Net measures are intended to mitigate against the risk of low probability vs high consequence network outages. 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. Complete DC supply system failure can be a reason for complete substation outage and may impact Safety Net compliance.

EQL is expected to employ all reasonable measures to ensure it does not exceed minimum service standards (MSS) for reliability, assessed by feeder types as

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

Complete DC supply system failure can be a reason for complete substation outage and may impact SAIDI/SAIFI performance. DC supply system element failures typically have negligible impact upon SAIDI and SAIFI.

Both Safety Net and MSS performance information are publicly reported annually in the Distribution Annual Planning Reports (DAPR). MSS performance is monitored and reported within EQL daily.

DEEs are generally reviewed for severity on an individual basis, with response and investigation driven by severity of incident. DEE volumes are reported monthly. Climatic and seasonal variation influences Northern and Southern Regions DEE volumes substantially – accounting for over 20% variation year on year. Because of this influence, there is no overall specific maximum target benchmark for annual DEE numbers other than the intent to minimise the quantities.

3.4 Current levels of service

Northern and Southern Regions

Figure 9 below, provides a recent history of the number and costs of corrective work orders related to substation battery chargers in Northern and Southern regions. The data suggests ongoing routine work, such as resolving circuit earth faults, and minor component repairs will continue to be the norm for these assets.

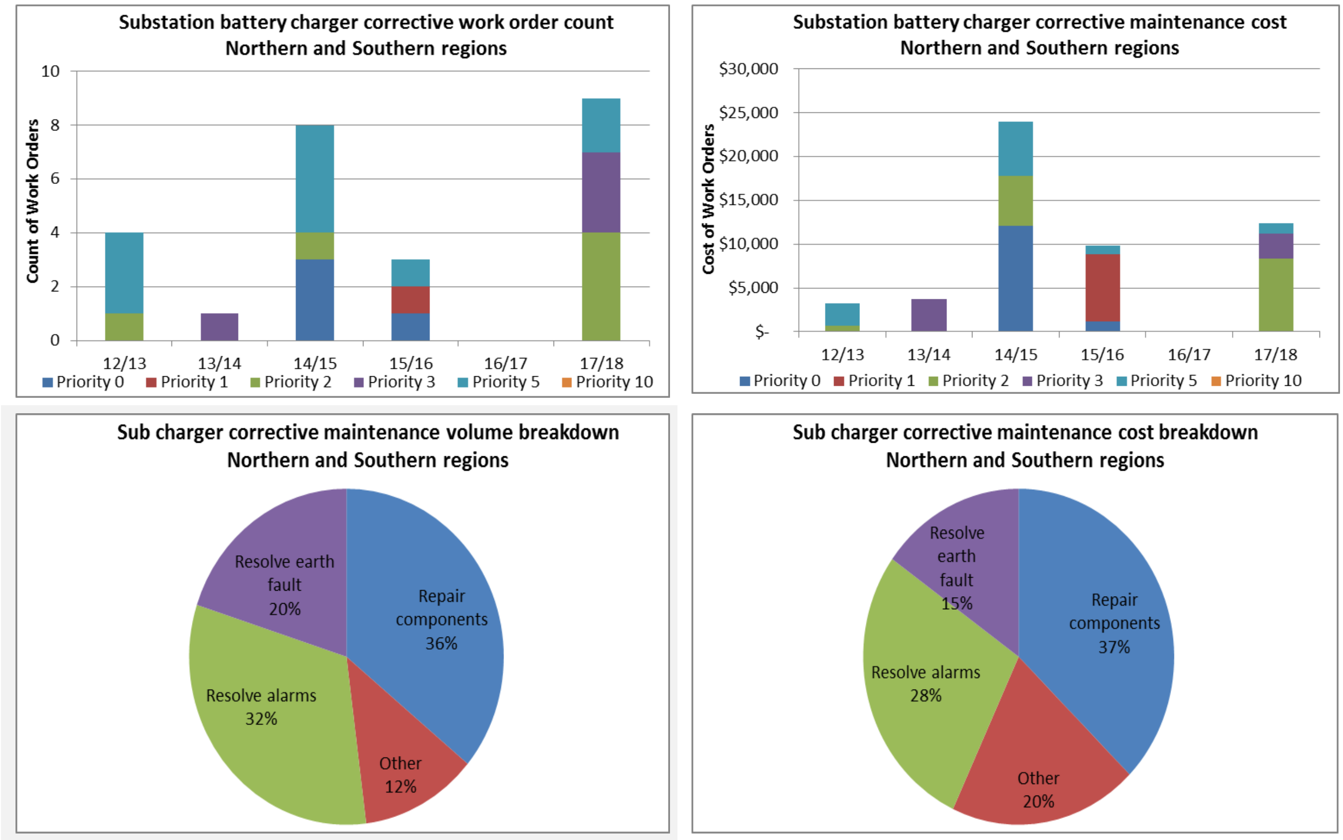


Figure 9: Substation battery charger corrective work orders – Northern and Southern Regions

Figure 10 below provides a recent history of the number and costs of corrective work orders related to substation batteries in Northern and Southern regions.

In the Northern and Southern Regions, there were 77 defects recorded for all substation battery systems over six years, most of which were in the 2017/18 financial year. A review of the defect recording system in early-mid 2017 identified a data transfer failure that prevented recording of defects. Correcting this flaw resulted in large number of defects being presented, commencing around November 2017. As all substation batteries are inspected and tested annually, it is expected a high volume of defects and corrective work orders will be recorded across financial years 17-18 and 18-19. Subsequent year volumes are expected to be substantially reduced to a new, more typical volume. Similarly, corrective maintenance costs are expected to peak over the same time period before falling to a more routine, level.

A breakdown of the corrective works involved reveals that a number of minor tasks were outstanding, such as replacing signage or handles (shown as other in the charts), as well as a number of individual batteries showing signs of early failure, such as terminal corrosion, impedance change, or cell failure, (shown as Replace Battery in the chart). Given the defect recording issue detailed above, it is likely the “Replace battery” component costs (~60%) will remain substantially the same, although become spread over the entire routine replacement period cycle period, while “Other” costs (~36%) should substantially reduce as the various once-off type defects are resolved.

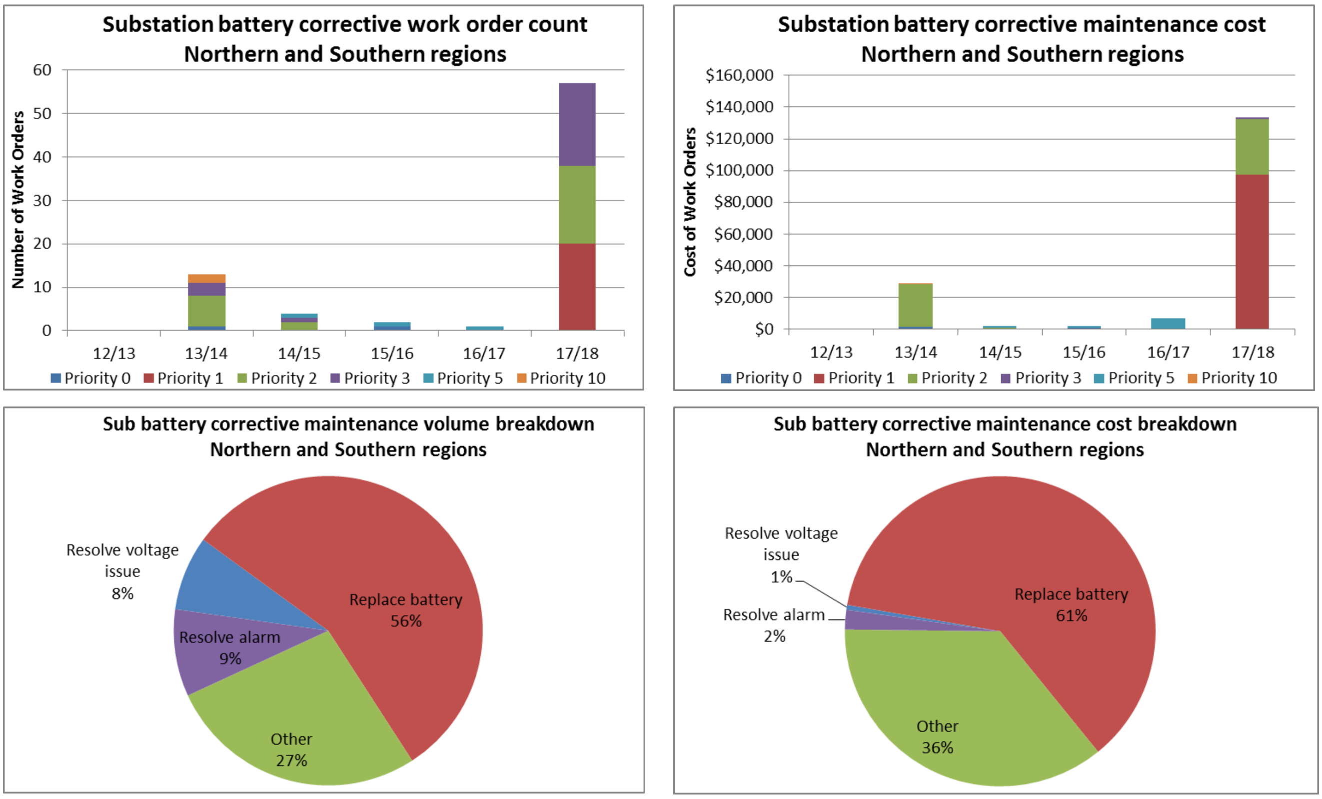


Figure 10: Substation battery corrective work orders – Northern and Southern regions

South East Region

Corrective maintenance costs in the South East Region for substation DC systems are substantially higher than for lines assets (such as for reclosers and sectionalisers), as shown in the breakdown below. (However, it is conceivable that some corrective maintenance of battery systems may occur under general recloser/sectionaliser maintenance. Note that the recloser and sectionaliser data includes both battery and charger breakdowns.) Data is based on analysis of the corrective maintenance in the financial year 2017-18 when this information became available through the use of codes recorded on the corrective maintenance work orders. This information is continuing to build over time.

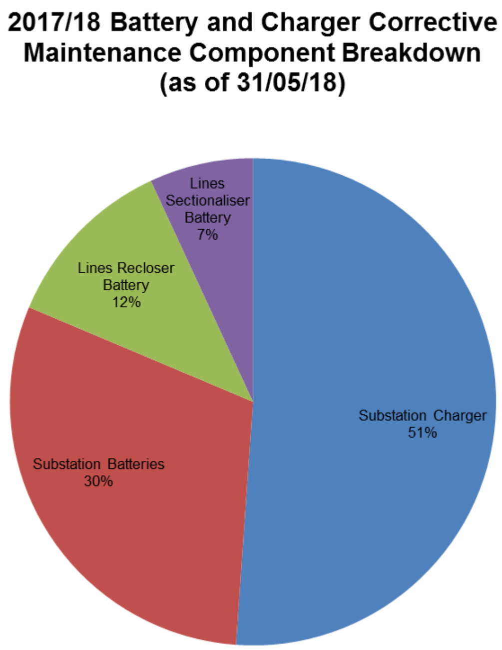
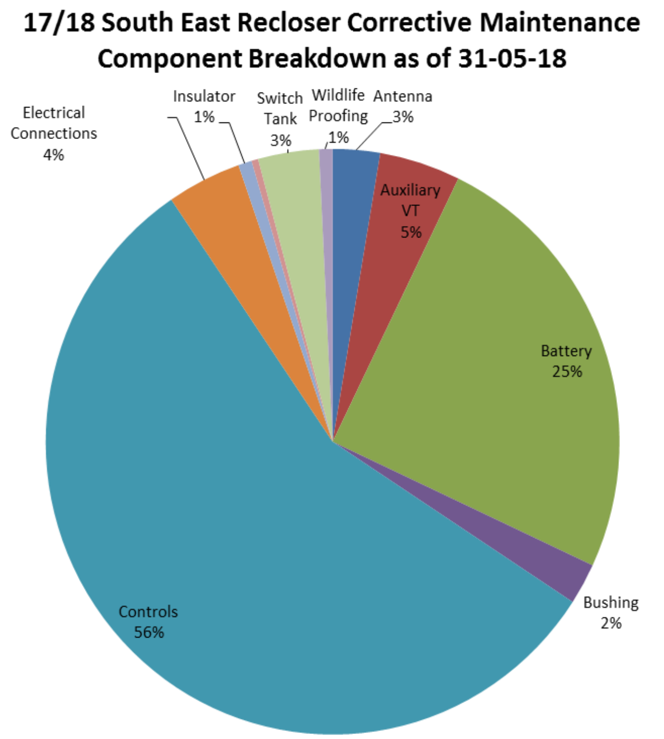


Figure 11: South East Region DC system corrective maintenance breakdown

For reclosers and sectionalisers, battery issues form a significant portion of the overall corrective maintenance costs, as illustrated in green below in Figure 12.



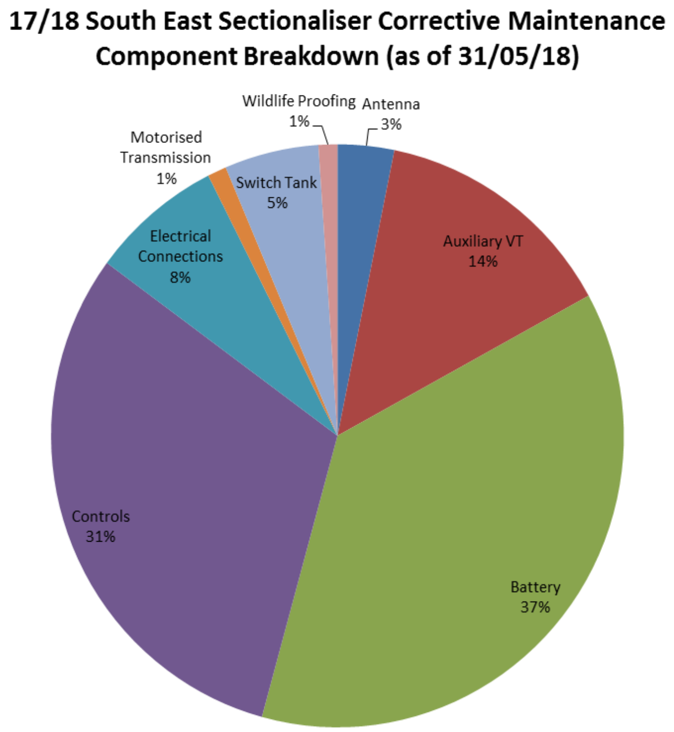


Figure 12: Corrective maintenance cost for reclosers and sectionalisers – South East Region

Substation battery and charger corrective maintenance works equates to around a third of all South East Region substation works, as shown in Figure 13.

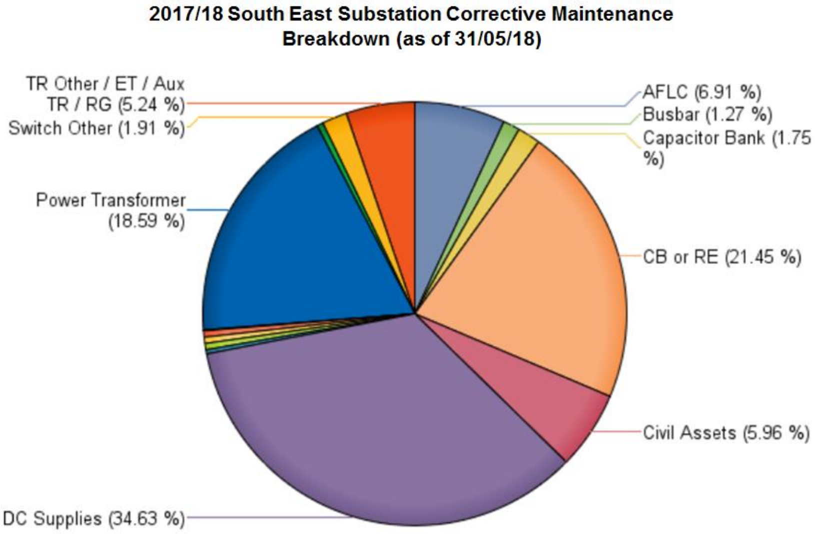


Figure 13: South East Region substation corrective maintenance breakdown

Corrective maintenance figures for substation DC supply systems for the South East Region are shown in Figure 14, showing that there are corrective maintenance works required for around 20-25% of substation battery systems in the South East Region each year from 2012-13.

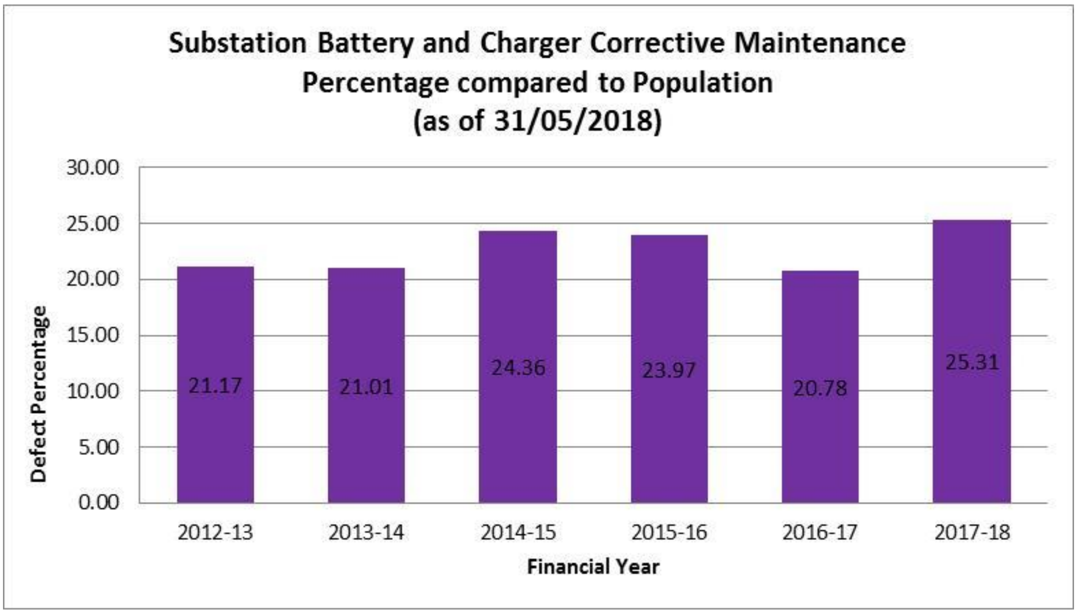


Figure 14: South East Region substation DC system corrective maintenance (as of 31/05/18)

Figure 15 below shows the battery corrective data only. Although the number of reactive jobs has not increased, the associated costs generally have (excluding 2016).

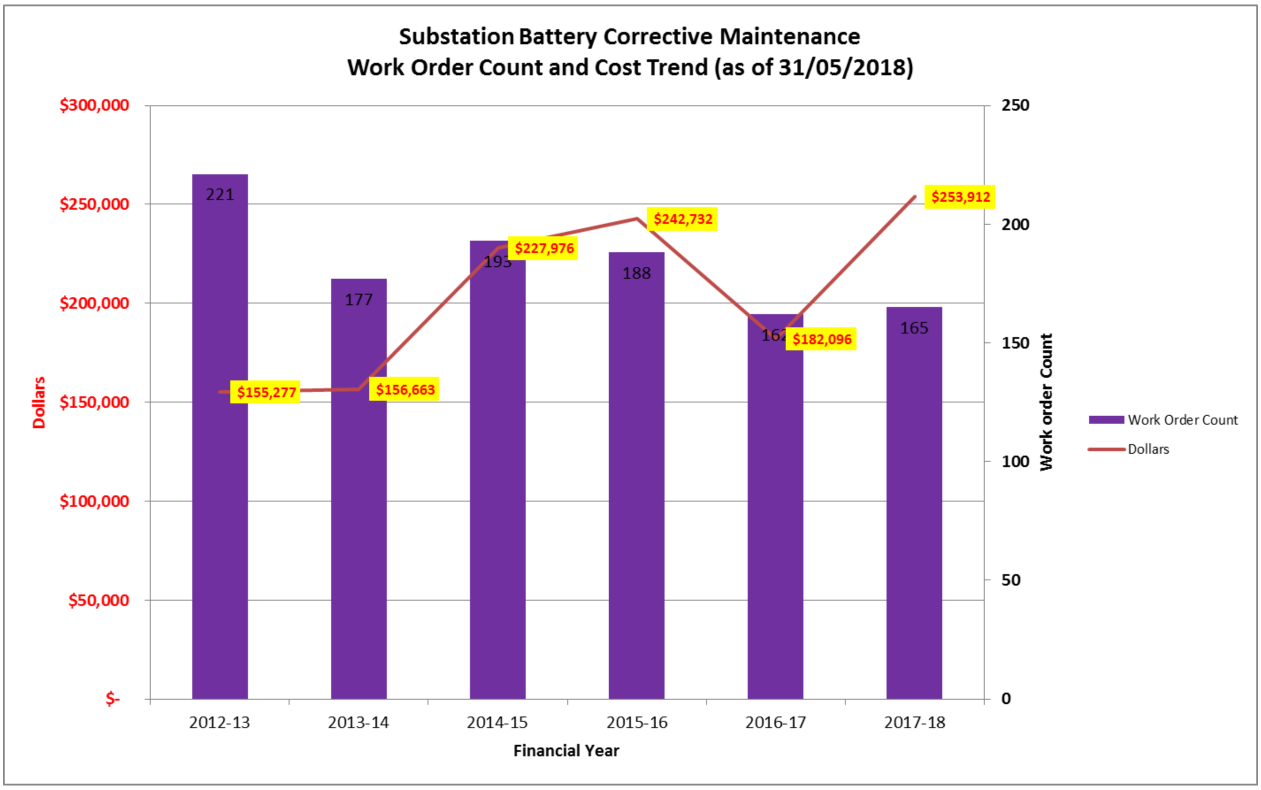


Figure 15: South East Region substation battery corrective maintenance

The corrective data for batter changers only is shown in Figure 16 below, where there is a clear upward trend in the amount of corrective maintenance required over the last few years; this is seen in the number of jobs as well as the cost. Note that the apparent drop in 2016 shown may be related to the change in strategy from a 5 year replacement cycle to a 6 year replacement cycle, whereby many battery bank replacement projects were deferred.

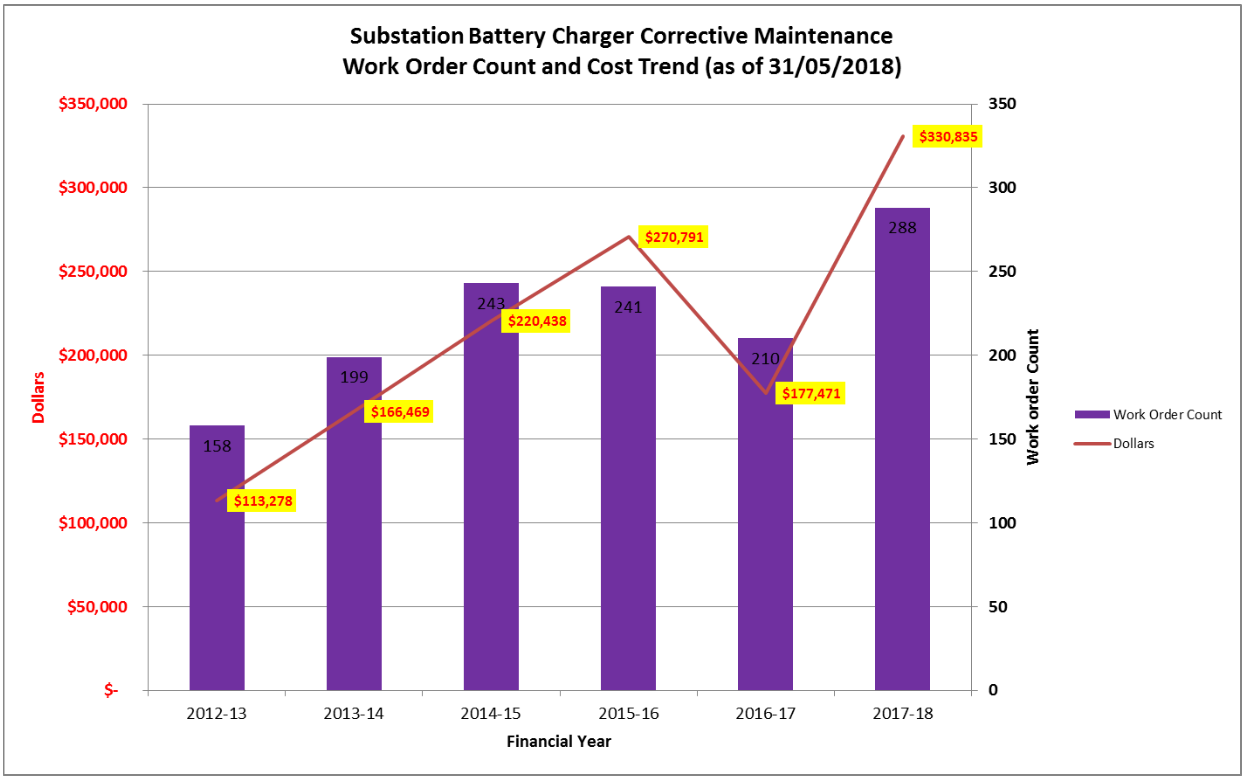


Figure 16: South East region substation battery charger corrective maintenance

DC supply system failures are recorded in EQL's eSafe systems and classified as DEEs. While based upon the same basic software, Ergon Energy and Energex used their eSafe records systems slightly differently, attributing to differences in data records.

Figure 17 below details Ergon Energy's eSafe history of events related to loss of AC services or battery charger in substations. These incidents are complete reliance upon the battery systems. Of charger-related issues (i.e. excluding loss of AC) in the last five years (from 2013 to 2017), there was an average of 2.4 failures per annum.

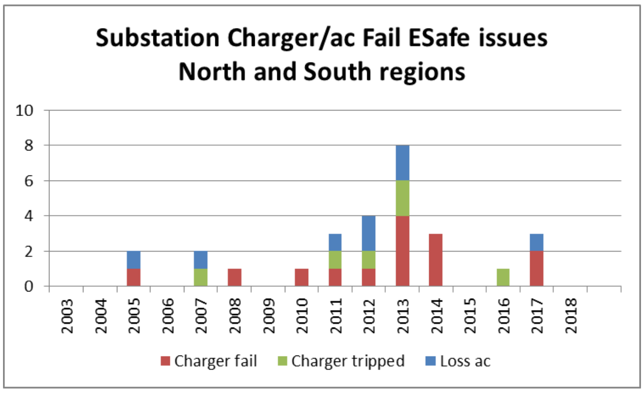


Figure 17: North and South Regions - substation AC failures (reliance on DC services)

Energex's eSafe history does not include loss of AC supply events or battery charger failures.

Figure 18 shows that the number of recorded eSafe incidents related to substation battery failure is very low, with a failure rate of just 0.19% per annum of the Northern and Southern Regions battery population and 0.11% for the South East Region.

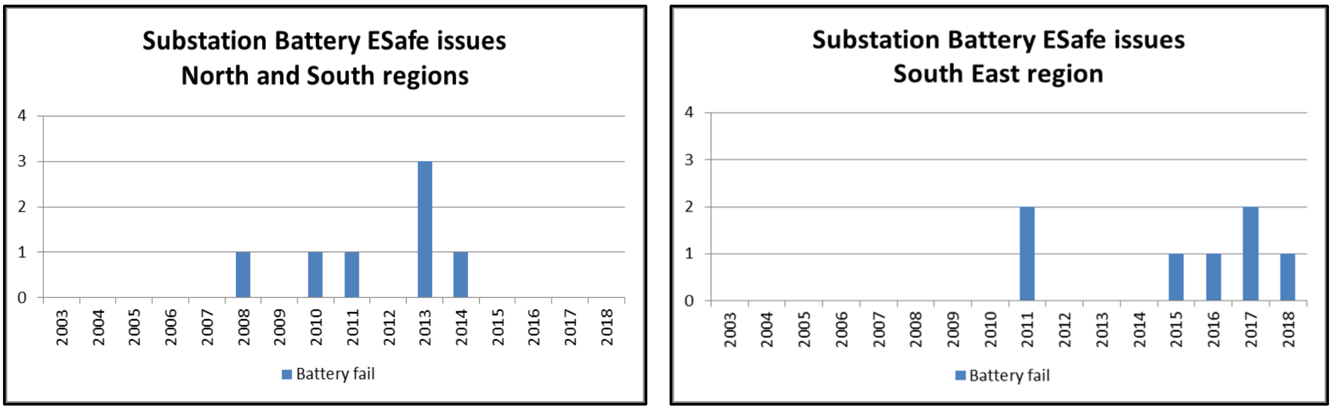


Figure 18: eSafe incident volumes by region (as of March 2018) – substation DC batteries

4 Asset Related Corporate Risk

As detailed in Section 3.2, Queensland legislation details that EQL has a duty to ensure its works are electrically safe. This safety duty requires that EQL 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[8].

Failure of a DC system risks public and staff safety, most notably by potential loss of protection, communications and substation control.

Figure 19 below provides a threat-barrier diagram for EQL substation DC system assets. Figure 20 provides a threat barrier diagram for lines asset dc supplies. Many threats are unable to be controlled (e.g. third party damage), although EQL undertakes a number of actions to mitigate them SFAIRP.

EQL's safety duty results in most inspection, maintenance, refurbishment and replacement works and expenditure related to DC systems being entirely focused upon preventing and mitigating battery and battery charger failure.

The asset performance standards described in Section 3.3 detail EQLs achievements to date in respect of this safety duty. The following sections detail the ongoing asset management journey necessary to continue to achieve this performance in the future.

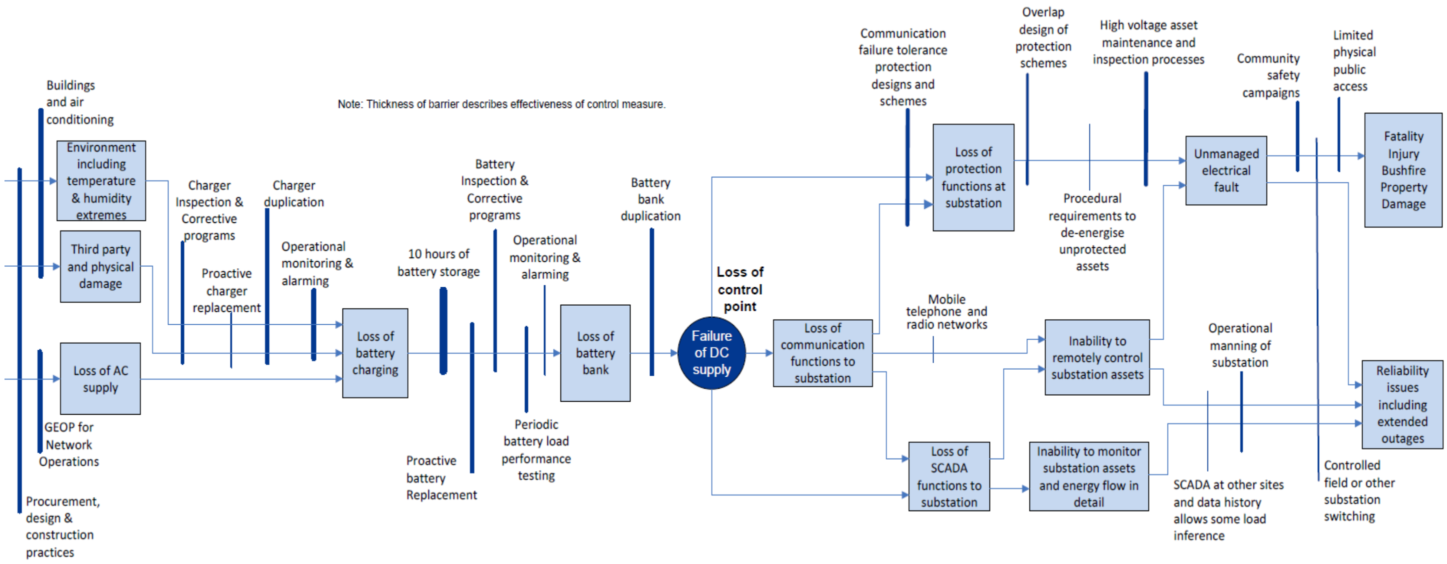


Figure 19: Substation DC system threat barrier diagram

[8] Queensland Electrical Safety Act 2002 s10 and s29

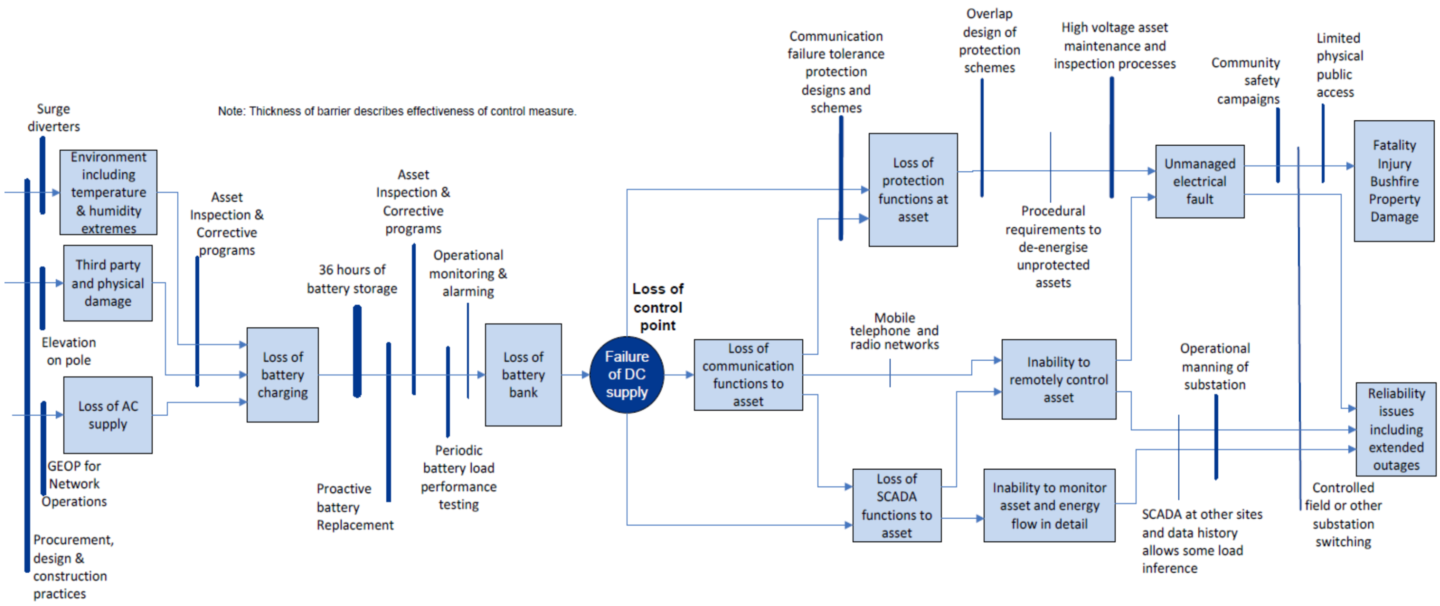


Figure 20: Lines asset DC supply threat barrier diagram

5 Health, Safety & Environment

Cadmium (Cd) is an extremely toxic industrial and environmental pollutant classified as a human carcinogen (Group 1 – according to International Agency for Research on Cancer; Group 2a – according to Environmental Protection Agency (EPA, USA) and 1B carcinogen classified by European Chemical Agency). There is no safe level of cadmium exposure. Dependent upon concentration, it can cause lung, liver, and kidney disease and failure, and various bone diseases including gout, decalcification, and softening. It is considered a neurotoxin. The body cannot easily excrete Cadmium. Cadmium is a regulated trackable waste product.

Lead (Pb) is a toxic industrial and environmental pollutant. It is classified as a probable human carcinogen (group 2A). Dependent upon concentration, it causes headaches, stomach pains, anaemia, kidney damage, nerve and brain damage, and infertility. Lead is eventually excreted by the body. Lead is a regulated trackable waste product.

EQL batteries are mostly sealed (valve regulated) batteries requiring no maintenance or direct handling of electrolytes, lead, or cadmium electrodes. The few remaining wet lead acid battery banks are being progressively phased out at end of life.

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 AC ripple issues with Chloride battery chargers

Valve regulated lead acid (VRLA) batteries are used in many substations in the South East Region. The associated Chloride brand rectifier type battery chargers employ a filter or smoothing capacitors on the output circuit to store power during the peaks.

A common failure mode of this particular charger is due to the drying out of the filter capacitors. When this occurs, there is an increase in AC ripple superimposed on the DC output of the battery charger, which degrades the battery's ability to sustain reversible electrochemical reactions, prematurely "aging" the battery.

The at-risk Chloride chargers are an older technology design and do not include a staging charge function (event type). This lack further degrades the battery ability to sustain repeatable electrochemical reactions and also acts to prematurely age the battery.

There is an active works program in place to replace all Chloride battery chargers, and similar brand chargers employing similar design, across the South East Region.

Similar problems have been evident in the Northern and Southern Regions.

Routine maintenance and inspection criteria are being modified to proactively test for AC ripple across all EQL substations.

6.2 Design standardisation

Many substations contain DC supply systems that were designed prior to the development of current design standards, and for various design, reasons do not meet the current design standards.

Non-compliance with current standards is not necessarily a driver for replacement as the associated change in risk achieving compliance is minimal. In those circumstances, condition and age based like-for-like replacement of DC system components will continue to be the most cost-effective solution.

6.3 Standing load issue

A recent audit identified that there are some substations in the South East Region where the total substation steady-state DC load is approaching the rated capacity of the charger. This risks charger overload and failure during times of high DC current draw, such as deep cycle battery recharge events. Failure to recharge within an appropriate time has a deleterious effect on the battery life due to build-up of lead sulphate on the cell plates and adversely risks the business's ability to respond to events that repeat over multiple days.

It is likely that high standing loads are due to incremental substation upgrades involving additional DC loading occurring within the substation over time.

Where the steady state load current is greater than 70% of the rated charger output, the charger has been programmed for replacement.

6.4 Battery system monitors

A Battery System Monitor (BSM) is a standalone unit capable of monitoring a complete 24 V, 30 V, 48 V or 110 V battery installation, and is employed to alert upon battery failure and other issues that require immediate attention.

In the South East Region, many BSMs contain outdated firmware and are incapable of detecting all of the failure modes and problems of the modern batteries installed. These units are progressively being replaced by current standard BSMs.

For instance, a Mini CSU-2 BSM was employed for 110V DC 160Ah and 300Ah battery banks. They are an obsolete design but many remain in service throughout the network. When the Mini CSU-2 units fail, or if major works are conducted at the substation, they are replaced by current standard BSM’s.

EQL has scheduled a review of the use of BSM’s across all regions which will impact future design and procurement strategies. This review is scheduled for the fourth quarter of 2018.

6.5 Manual handling of batteries

EQL has recently recorded several manual handling incidents related to substation batteries.

Battery “monoblocs” are heavy, due to the metals employed, typically weighing around 30kg. The relatively short life (up to 7 years) and numbers employed across EQL means that there is a regular pattern of battery transport and handling, presenting injury risk to maintenance staff.

EQL has initiated a review of battery handling practices and battery mounting systems in substations to reduce the risks associated with manual handling.

6.6 Lines based plant batteries

Assets such as reclosers and sectionalisers are often located on poles in various parts of the distribution network. These distributed devices employ self-contained control units to support the protection, control, and communication functions associated with the asset. Batteries are an integral part of each control unit to support operation and function during dynamic system operation and supply outages.

Battery failure typically manifests as complete loss of functionality of the primary device. Upstream backup protection schemes are typically in place to assure network protection functions remain available, however, backup scheme operation significantly extends outage size and duration.

Because of their harsh operating environment in Northern and Southern Regions (compared to the typical substation environment), batteries tend to deteriorate quickly and typically fail between three and five years dependent upon daily temperature variations and extremes. In order to achieve the requisite reliability performance standards, lines asset batteries are replaced proactively every three years.

In contrast, recloser and sectionaliser batteries in South East Region (a relatively temperate environment) are replaced every five years.

6.7 GUSS batteries

Grid utility support systems (GUSS) are essentially large battery systems with appropriate chargers/invertors that are connected at key locations in the distribution network specifically to provide voltage support at high voltage. The GUSS unit was designed by Ergon Energy and constructed by third party suppliers, as an innovation initiative intended to achieve cost effective voltage stability across lightly loaded SWER system lines.

GUSS battery systems are currently managed by local lines depot staff. Batteries are extremely heavy – the order of 63 kilograms each, and must be man-handled into position behind air filters and screens. First installed in 2015, GUSS battery performance experience remains relatively developmental, as some considerable period is required to establish actual operating conditions, such as frequency and duration of battery deep-draw events.

GUSS battery performance is still being monitored and assessed.

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 Data quality

Collecting and maintaining accurate data about DC systems across the EQL network is a major challenge. Along with previous poor data collection practices, there are also continuing challenges such as incorrect age profiling due to individual battery replacement as opposed to entire battery string replacement.

There is very little asset information recorded for substation DC distribution boards across EQL, including age, condition, installation date, manufacturer and maintenance history.

Action 7.1-1: Continue to review and update practices surrounding the effective collection and maintenance of accurate data on EQL’s DC systems.

7.2 Standardisation of EQL procurement and replacement strategies

Past practice for legacy organisation Ergon Energy was to replace VRLA battery banks every seven years and VRNC batteries every 20 years. This practice has been in place since 2011.

Recent practice for legacy organisation Energex is to replace VRLA battery banks in substations every six years and VRNC batteries every 20 years. The 6 year VRLA replacement practice commenced in 2015 at the commencement of the 2015-2020 regulatory period. Prior to this, VRLA battery banks were replaced every five years.

Battery replacement cycles are inherently linked to factors including battery design (including the chemistry used), installation and operating conditions, battery charger technology and discharge cycles (i.e. usage).

While both legacy organisation maintenance regimes were essentially the same, the purchasing arrangements were independent, resulting in different selections of manufacturers for chargers and batteries. Anecdotally, the Energex version VRLA battery does not perform as well as the Ergon Energy equivalent (although other factors such as commissioning, and installation procedures could also be impacting this). With the advent of EQL, works are already underway to achieve common suppliers and equipment.

Performance generally supports the preference to employ equipment purchased under Ergon Energy period contracts, however, the new equipment is a different size, generally larger, and it is proving problematic to apply a like-for-like replacement when being installed into the South East substations.

With existing purchasing contracts expiring in 2020, the routine design and purchasing reviews are scheduled for 2019, with an EQL standard purchasing contract to be established shortly thereafter.

EQL must also decide upon a general battery replacement strategy for all substations, balancing risk of failure against the ongoing cost of replacement. This decision is not clear cut, as the history and issues described in these sections are clearly influencing basic performance, including historical purchasing standards and maintenance practices.

Action 7.2-1: Resolve procurement and replacement strategies for substation battery systems across EQL.

7.3 EQL expenditure approach for batteries

Legacy organisation Ergon Energy replaced batteries as operating expenditure (Opex), and this practice continues for the Northern and Southern Regions. Legacy organisation Energex replaced battery banks as capital expenditure (capex) and individual cells which failed in service as opex, and this continues for the South East Region. As it moves to introduce standard practices, EQL must determine which financial treatment is appropriate for these assets.

Action 7.3**-**1**:** Resolve the basic financial treatment of battery replacement (capex vs opex) to be consistent across EQL.

7.4 Battery temperature compensation

In the South East Region, the battery charger float voltage is a standard value and applied irrespective of the ambient temperature. This means that the battery manufacturers' recommendations for float voltage levels with respect to temperature are neglected.

In addition, historical practice has been to leave the temperature compensation probe unattached to the batteries. In consequence, some batteries are being over-charged in hotter temperatures. The effectively reduces overall battery life.

Action 7.4-1: Review practices for battery charger installation and commissioning, considering best practices for achieving the intended design.

7.5 Battery charger nuisance tripping in South East region

In recent years, the South East Region has experienced a large number of substation battery charger disruptions due to tripping of the main incoming AC circuit breaker. The initiating condition is usually a power system fault on the network at any voltage from 275kV down to 11kV. When these faults occur, there is a voltage dip on the network and hence on the 230V system inside the substation.

Field crews must attend each impacted substation, and often just reset the AC circuit breaker to restart the battery charger again.

Some of the sites have had the incoming AC circuit breaker changed from a 20A D-curve to a 25A D-curve, following the results of the previous investigation into the issue back in 2011. However, the issue remains unresolved.

Action 7.5-1: Investigate nuisance tripping of battery charger circuit breakers in the South East Region.

7.6 Stores procedures for batteries

EQL Stores holds a number of batteries at various locations around the state. There must be sufficient batteries available to support the restoration of any failed battery system at any time, due to the risk of widespread and prolonged customer supply failure should DC system failure occur.

A minimum warehouse stock level of this asset is maintained based on historic usage and known future requirements.

Disconnected batteries (as typically occur in storage) self-discharge. VRLA batteries discharge typically around 1-2% per month in storage, whereas VRNC batteries discharge typically around 5-8% per month in storage. Batteries that are completely discharged are rarely able to be restored as the battery components fail irretrievably.

All stores systems employ a first in-first out system, but there can still be long periods of storage which impacts eventual in-service life. A recent survey of batteries at the Energex Eagle Farm Distribution Centre found some batteries that were 18 months old that have not entered service. These may not be fit for service, or at the least, no longer have their name-plate capacity (i.e. 300Ahr). Installation of aged battery strings may be contributing to poor performance rates and the overall maintenance costs, as described in 3.4. In some situations, these batteries may be placed into service with no consideration for their state of charge and whether a refreshing charge is required.

In addition, pallets of batteries in some storage areas do not appear to be appropriately signed and secured, with suitable allowances for staff Workplace Health and Safety (WH&S).

Action 7.6-1: Review battery procurement and storage processes, including procurement volumes and rates, maintenance in storage practices, and the possibility of just-in-time delivery from suppliers, in order to subsequently establish a standard management strategy for EQL.

7.7 Ongoing operation and supply of GUSS units

GUSS units were designed by and manufactured specifically for Ergon Energy but the manufacturer has determined that they are unable to economically continue this practice. The last remaining GUSS units in the country are programmed to be installed in the near future, and after that, there will be no more manufactured. Discussions with the manufacturers on issues such as maintenance of installed units and access to spare parts are ongoing.

Action 7.7-1: Resolve the future procurement and maintenance procedures surrounding the use of GUSS units in the Northern and Southern regions.

7.8 Battery charger corrective maintenance and replacement strategies

As described in section 3.4, the cost of corrective maintenance of substation battery chargers in the South East region has increased significantly in recent years. Further investigation into the increasing charger costs showed that material costs (shown in red below in Figure 21) are only a small portion of the corrective maintenance costs (shown in blue below in Figure 21). This indicates that the majority of costs are not attributed to charger replacement, but rather, to resolving charger issues (this is discussed further in this AMP in Section 7 Emerging Issues, such as nuisance tripping).

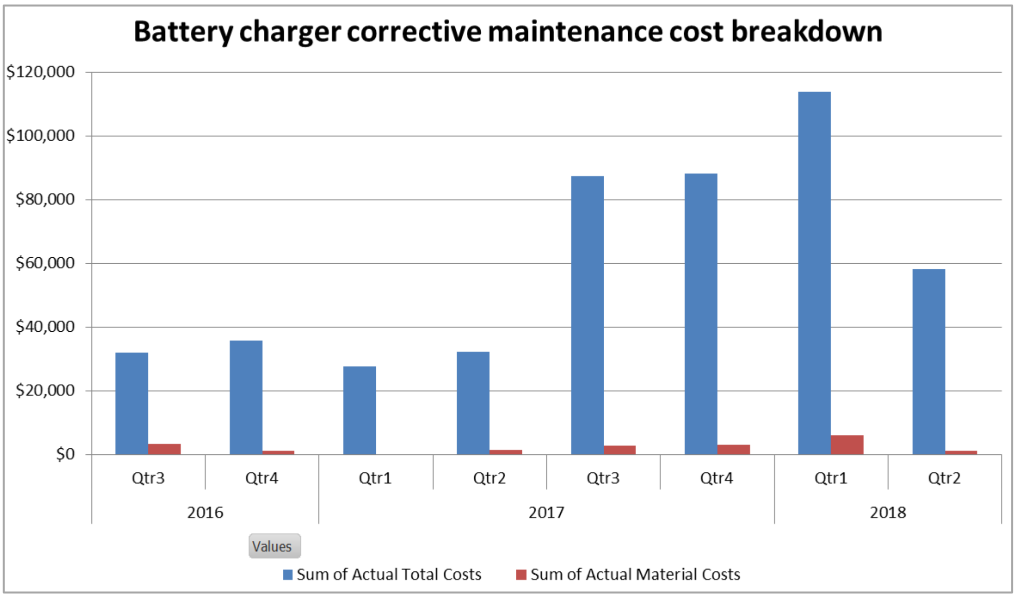


Figure 21: Battery charger corrective maintenance costs over 2016-18 in the South East Region

A proactive replacement strategy for battery chargers was very recently instigated in the South East region, and it is hoped that this may help to improve the issue. However, achieving an optimum replacement cycle may be difficult as the expected lifetime of battery chargers varies depending on the technology, manufacturer and environment. It was previously suggested that the newer SCR (Silicon Controlled Rectifier) battery chargers have an expected lifespan of 30 years, compared to a 40 year lifespan for older types, but this is to be reviewed.

Action 7.8-1: The Asset Lifecycle Planning team is to work with substation maintenance teams to investigate battery charger issues in order to re-evaluate a more efficient and prudent maintenance system.

Action 7.8-2: The Network Standards group is to investigate if the expected lifespan of battery chargers should be reduced, as well as the most appropriate charging technology. The asset lifecycle management of battery chargers will be revised based on the outcome of the investigation.

7.9 Remote (SCADA) monitoring

In the Northern and Southern Regions, not all substations are monitored by SCADA and not all DC supply system components are monitored by SCADA. The level of SCADA monitoring reflects the size of the substation. There is an active works program in place for Northern and Southern regions to progressively upgrade and install SCADA systems and to implement DC system monitoring and alarms.

In the South East Region, there are no voltage, current, or temperature analogue values for the battery systems connected to SCADA. In Northern and Southern Regions, standard design includes battery voltage. Across all regions, digital alarms are employed to alert of immediate problems.

Action 7.9-1: Establish the appropriate monitoring arrangements, including essential operational and asset lifecycle management information.

7.10 Commissioning and maintenance records

Charger and battery commissioning information requirements differ across EQL regions.

In the South East Region, there are often no commissioning records available for the battery and charger system as a whole. Currently, commissioning records practices differ according to if the installation is new or if it is a programmed replacement, but this needs to be reviewed.

While battery technology has advanced substantially over recent years, asset information and records, including commissioning and maintenance information requirements have not kept pace with this development.

Action 7.10-1: Review battery and charger commissioning and replacement procedures, with specific emphasis upon information records.

7.11 Previous design practices

Substations are designed to remain in service for many years. Battery and charging technology and operational knowledge have substantially developed over recent years. In consequence, historical substation layout and space limitations have resulted in sub-optimal (by modern standards) locations for batteries. In consequence, some substations have batteries in small cramped locations such as under substation desks and poorly ventilated enclosures.

Cramped installation locations present staff with WH&S risks and impacts battery performance due to inadequate ventilation and uneven temperature gradients across the batteries which can contribute to accelerated aging and premature battery failure.

Action 7.11-1: Review in-service battery installations across EQL with a view to determining the optimal location based upon the layout of each substation, and staff working conditions, also taking into account any potential near-future major works.

7.12 Previous poor battery spacing during installation

In the South East Region, the manufacturers' installation instructions for spacing of batteries have not always been followed in the past. Mutual heating from touching batteries, particularly in an already hot environment, can shorten battery life.

Action 7.12-1: Review the inadequate spacing of batteries in the South East Region and where appropriate initiate design changes to better achieve intended battery life.

7.13 Policy for battery discharge testing

Battery discharge tests are not completed across the whole network on a regular basis. As such, the business has limited information as to whether the installed system will last the required 10 hour duration in an emergency. Battery discharge tests at commissioning are not performed within the South East Region, and as a result, the actual capacity of each battery system is not known.

Action 7.13-1: Review battery discharge test practices to confirm battery systems are sufficient at commissioning as well as at the current life cycle replacement time. Economic considerations should be taken into account as discharge tests on all battery systems may not be feasible.

7.14 AC ripple on DC battery system

Investigations have shown that there is excessive AC ripple on the DC battery systems in some substations in the South East Region, such as described in Current Issues section 6.1. The ripple comes from three main sources: poorly designed battery chargers, aged battery chargers with failed output smoothing capacitors, or DC/DC power supplies with poor specifications running off the DC bus.

AC ripple has a detrimental effect on battery life, as it causes heating within the battery, excessive gassing and deterioration of the plate active material.

Action 7.14-1: Investigate the level of AC ripple at different substations across the South East Region with battery chargers of varying ages. Use this data to feedback into the asset replacement decisions for battery chargers and the type of battery chargers that are purchased.

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 Battery technology development

There is significant research and development in battery technology, driven by the growth in renewable energy generation and a need for stabilised delivery output regardless of variability of input energy source.

Common battery types now include nickel-metal hydride, lithium ion, lithium polymer, lithium cobalt, lithium manganese, and magnesium ion. Battery technology and other means of electrical storage (e.g. super-capacitors) continue to be the focus of many research organisations.

As research developments move to market, they need to be assessed for the benefits they might bring to the EQL's DC supply systems. Available commercial battery types are periodically reviewed to determine the benefits of changing current standards.

Currently, valve regulated gel lead acid batteries (VRLA) are the battery of choice due to environmental and safety risks.

8.2 Use of DC-DC converters

In some situations, particularly where large battery banks are already necessary for the substation and capacity is available, use of DC-DC converters offers potential to reduce overall DC system complexity and provide a cost-effective and reliable DC supply without additional battery systems. Several such systems are already installed, and performance is being monitored to confirm long term adequacy.

9 Lifecycle Strategies

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

9.1 Philosophy of approach

The consequences associated with complete DC supply failures have the potential to turn into significant safety events. Therefore, DC supply systems are required to be highly reliable and fault tolerant, incorporating designs with several potential layers of redundancy.

To support this approach, all battery banks are assessed regularly and replaced proactively. Many are also monitored by SCADA.

9.2 Supporting data requirements

Historically, it was not considered cost-effective to record detailed attribute data for the various batteries and chargers used across the network. The advancement in technology, asset management discipline, and corporate external reporting imperatives have together acted to change this approach. EQL recognises the need to improve the data quality associated with this asset class and has initiated improvements in the capture of information at time of commissioning as well as where prudent in association with other works. Further improvements will be undertaken with the implementation of the new Enterprise Asset Management System which is currently proposed. This will include an alignment of asset hierarchy. The following is a summary of key data requirements to manage the asset lifecycle of DC Supply Systems.

Battery information required:

- Unique operational identifier.
- Battery bank installation date.
- Brand and type.
- Bank voltage and Ahr capacity.
- Individual numbers of batteries employed to achieve the required voltage and capacity.
- Periodic and ad hoc inspection data.
- Battery maintenance history including cell voltage before and after load testing.
- Monobloc manufacture date.
- Battery and monobloc install dates (including when replaced out of synch with the battery bank replacement).
- Monitoring alarm data.
- Cell/monobloc failure history data.

Battery charger information required:

- Unique operational identifier.
- Battery charger manufacture date.
- Battery charger installation date.
- Brand and type.
- Charger voltage and VA output capacity.
- Periodic and ad hoc inspection data.
- Charger maintenance history.
- Charger settings history.
- Monitoring alarm data.
- Failure history data.

Action 9.2-1: Implement asset data structure changes in the new Enterprise Asset Management system being proposed for EQL to enable the consistent and accurate capture of data for DC Supply Systems. This will improve failure and condition monitoring capability to support the asset management objectives.

9.3 Acquisition and procurement

Batteries and chargers are subject to typical corporate procurement arrangements, employing standard purchase specifications, and period contracts – typically three years with one or two annual extension options.

All procurement is consistent with Queensland Government purchasing guidelines.

9.4 Operation and maintenance

Operation and maintenance include 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 0 for reference.

9.4.1 Preventive maintenance

All substations are inspected six monthly as part of routine hazard inspections. Battery banks are inspected as part of this task with specific in-service condition assessments. In Northern and Southern regions, battery diagnostic testing is conducted every 12 months, which includes a basic loading test of the battery banks. In South East region, battery diagnostic testing is less scheduled, and not performed at all where BSMs are installed.

Loading tests typically reveal individual battery cells that are unable to discharge stored energy as intended. Individual battery monoblocs (a series of battery cells connected in series as a single purchased unit) are replaced if they do not perform as intended.

For reclosers and sectionalisers, battery banks are inspected as part of regular in-service pole condition assessments. Sectionalisers across EQL are assessed at intervals varying between 30 and 96 months (depending on the region, sectionaliser type and pole material). Assessment intervals for reclosers vary from 12 to 36 months (depending on the region and if the recloser is remotely monitored).

9.4.2 Corrective maintenance

Corrective maintenance occurs following detection of battery bank or battery cell or charger failure.

9.4.3 Spares

EQL replaces failed units in this asset class with current standard stock items. A minimum warehouse stock level of these classes is maintained based on historic usage and known future requirements.

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

There is little refurbishment associated with batteries and chargers. Both are relatively maintenance-free assets. However, the findings of the AC ripple investigation described in section 7.14 may have an impact on this.

9.5.2 Replacement

Battery banks

In the Northern and Southern Regions, there is a 7 year replacement cycle for VRLA battery banks, except for reclosers, sectionalisers and other pole mounted units, which have a 3 year cycle.

In the South East Region, VRLA battery banks in substations are replaced every 6 years, and lines battery banks (for reclosers or sectionalisers) are replaced every 5 years.

Nickel-Cadmium battery banks are replaced every 20 years across EQL.

Battery replacement is triggered as a routine maintenance task.

Battery monitor systems are not proactively replaced unless major works are planned in a substation that has an older battery monitoring unit.

Battery chargers

In the Northern and Southern Regions, battery chargers are operated as run-to-failure, and not proactively replaced.

Historically in the South East Region, chargers were not replaced on any replacement strategy because 98% of the charger data attributes were blank in NFM (database containing South East Region asset data). Following a recent audit by the Asset Lifecycle group, a proactive replacement strategy was instigated.

Currently, the expected lifetime for SCR (silicon controlled rectifier) type chargers (e.g. current contract Brodribb) is 30 years and 40 years for older technologies. However, this is to be reviewed (as discussed in section 7.8).

Battery chargers must be reprogrammed or replaced if the associated battery bank battery type is changed.

9.6 Disposal

Batteries and chargers contain toxic materials and must be recycled. EQL has appropriate procedures for safe removal of this asset from service. EQL recycles all electronics equipment and batteries through registered and certified waste disposal companies. Refer 0for the relevant documents.

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 7.1-1: Continue to review and update practices surrounding the effective collection and maintenance of accurate data on EQL's DC systems.

Action 7.2-1: Resolve procurement and replacement strategies for substation battery systems across EQL.

Action 7.3-1**:** Resolve the basic financial treatment of battery replacement (capex vs opex) to be consistent across EQL.

Action 7.4-1: Review practices for battery charger installation and commissioning, considering best practices for achieving the intended design.

Action 7.5-1: Investigate nuisance tripping of battery charger circuit breakers in the South East Region.

Action 7.6-1: Review battery procurement and storage processes, including procurement volumes and rates, maintenance in storage practices, and the possibility of just-in-time delivery from suppliers, in order to subsequently establish a standard management strategy for EQL.

Action 7.7-1: Resolve the future procurement and maintenance procedures surrounding the use of GUSS units in the Northern and Southern regions.

Action 7.8-1: The Asset Lifecycle Planning team is to work with substation maintenance teams to investigate battery charger issues in order to re-evaluate a more efficient and prudent maintenance system.

Action 7.8-2: The Network Standards group is to investigate if the expected lifespan of battery chargers should be reduced, as well as the most appropriate charging technology. The asset lifecycle management of battery chargers will be revised based on the outcome of the investigation.

Action 7.9-1: Establish the appropriate monitoring arrangements, including essential operational and asset lifecycle management information.

Action 7.10-1: Review battery and charger commissioning and replacement procedures, with specific emphasis upon information records.

Action 7.11-1: Review in-service battery installations across EQL with a view to determining the optimal location based upon the layout of each substation, and staff working conditions, also taking into account any potential near-future major works.

Action 7.12-1: Review the inadequate spacing of batteries in the South East Region and where appropriate initiate design changes to better achieve intended battery life.

Action 7.13-1: Review battery discharge test practices to confirm battery systems are sufficient at commissioning as well as at the current life cycle replacement time. Economic considerations should be taken into account as discharge tests on all battery systems may not be feasible.

Action 7.14-1: Investigate the level of AC ripple at different substations across the South East Region with battery chargers of varying ages. Use this data to feedback into the asset replacement decisions for battery chargers and the type of battery chargers that are purchased.

Action 9.2-1: Implement asset data structure changes in the new Enterprise Asset Management system being proposed for EQL to enable the consistent and accurate capture of data for DC Supply Systems. This will improve failure and condition monitoring capability to support the asset management objectives.

Appendix 1. References

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

Legacy 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**	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	SGNW0038	Poles and Towers Inspection Strategy	Strategy
Ergon Energy	STNW0717	Standard for Preventive Maintenance Programs for 2017-18	Standard
Energex	00569	Network Risk Assessment	Procedure
Energex	354	Overhead Network Condition Assessment Manual	Manual
Energex	WP1199	Battery Systems in Substations	Work Practice
Energex	TSD0079d	Technical Instruction: Substation Battery Chargers and Batteries	Technical Instruction

Appendix 2. Definitions

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 22kV (and some 33kV) networks, 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 and was banned for use in 1979 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.
Sub transmission	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
AC	Alternating current
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
DC	Direct current
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)
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
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
SCADA	Supervisory Control and Data Acquisition

Abbreviation or acronym	Definition
SCAMS	Substation Contingency Asset Management System
SDCM	Substation Defect Classification Manual
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