Substation Asset Methodology – Framework

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1. Introduction

1.1 Purpose

Powerlink purpose is to Connect Queenslanders to a World Class Energy Future.

The role of Powerlink's asset management system is to enable delivery of safe, reliable and affordable electricity to Queenslanders. It ensures the organisation's assets are managed in a such manner to meet Powerlink's purposes and optimise network flexibility.

In order to implement the organisation's Asset Management Strategy specific asset management methodologies are developed for each major network asset group within Powerlink.

This document sets out the whole of life management philosophy for Substation High Voltage Plant and Infrastructure assets covering all lifecycle stages (shown in Figure 1 below), as defined in the Strategic Asset Management Plan (SAMP).

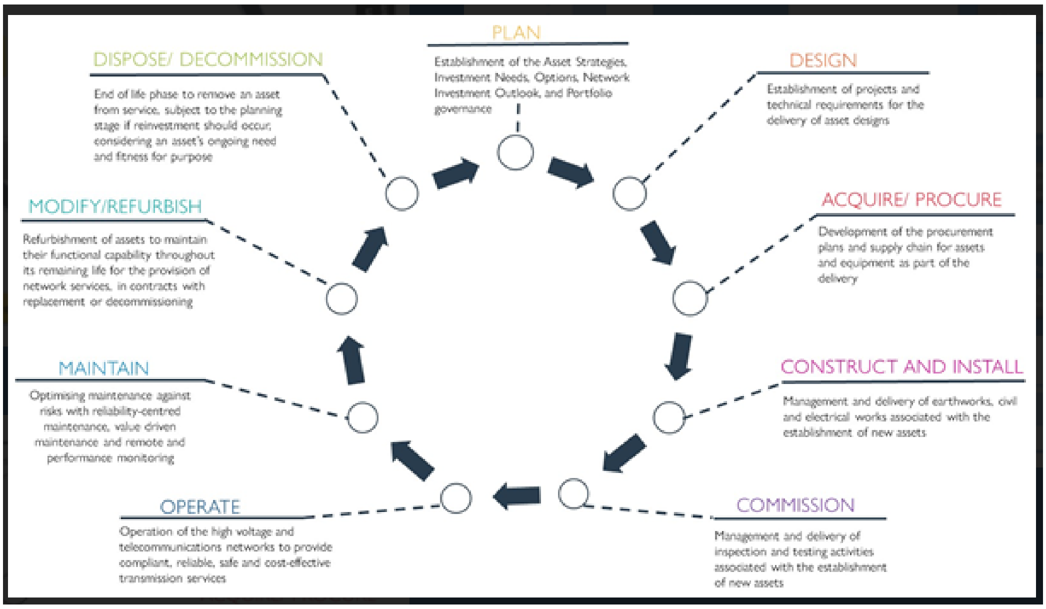

Figure 1 – Lifecycle Stages

This document acts as a reference for the development of equipment strategies and maintenance and project budgets and forecasts.

1.2 Scope

The scope of this document covers the asset life cycle of the following high voltage substation plant and substation infrastructure components owned, maintained and operated by Powerlink:

- all high voltage substation equipment (including circuit breakers, disconnectors, instrument transformers, earth switches, surge arrestors, power transformers, earthing transformers);
- all busbars and conductors (overhead) located inside the substation security fence;
- all reactive plant (including all capacitor banks, series and shunt reactors, earth reactors/resistors, static var compensators, statcom devices);
- all substation site infrastructure including station supplies (station supply transformers and standby supply generators and associated equipment), substation earthing system (including earth grid and all earth connections), site establishment (access road and internal substation roadways, drainage and oil containment systems and blast walls and signage);

- all structures and foundations located within substations and maintained by Powerlink, excluding communication and transmission lines structures.
- all substation land within the substation security fence and to a distance of five meters outside (excluding helipad and wash downs).
- all substation buildings including control buildings, work sheds and other storage facilities, fire protection systems, cable trenches, switchyard lights and associated high voltage (>1 kV) power cabling located inside substations.
- Substation AC auxiliary supply systems (incl. diesel generators) and
- compressed air systems, where applicable.

1.2.1 Objectives

This Methodology/Framework forms a part of Powerlink's asset management system documentation as shown in the diagram below. It sets out how the following key performance areas are to be addressed:

- Levels of Service
- Lifecycle Management
- Asset Management Drivers
- Asset Management Activities (including maintenance, condition assessments, life extensions, technical investigations, reporting, auditing and benchmarking)
- Environmental and Safety Compliance

1.2.2 Document Hierarchy

Powerlink's document hierarchy for substation assets is as follows.

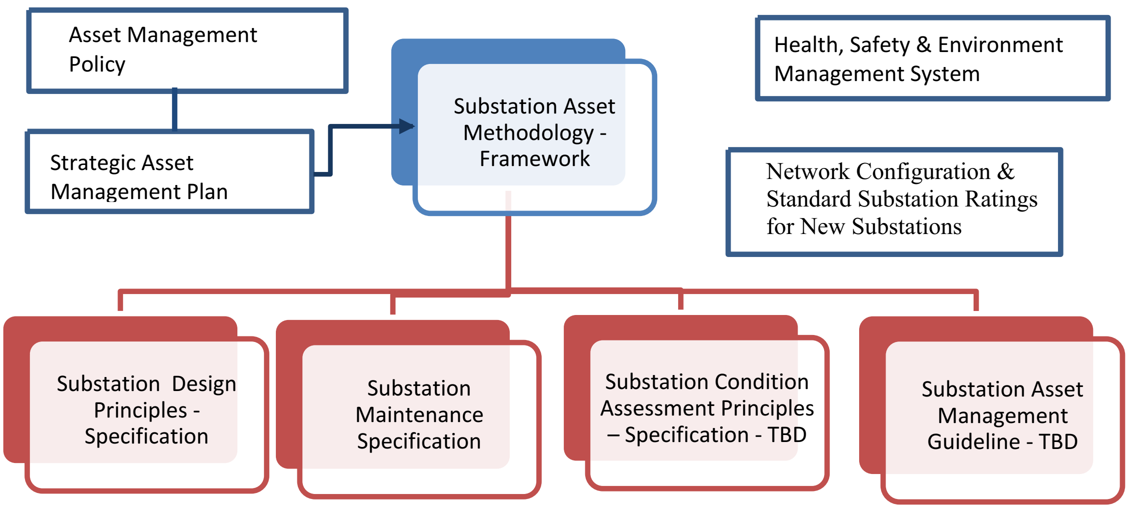

Figure 2 – Document Hierarchy

1.3 References

Document Code	Document title
AS 2067:2016	Substations and High Voltage Installations Exceeding 1kV ac
AS/NZS 3000:2018	Wiring Rules
A2884570	Network Configuration – Selection for New Substations - Framework
Electrical Safety Act	Electrical Safety Act *2002* (Qld)
Electrical safety code of practice - Works	Electrical Safety Code of Practice *2010* – Works (Qld)
Electrical Safety Regulation	Electrical Safety Regulation *2013* (Qld)
Electricity Act	Electricity Act *1994* (Qld)
EPA	Environmental Protection Act *1994* (Qld)
IEC 61850	International Electrotechnical Commission (2018) *Communication networks and systems for power utility automation*
ISO 55000:2024	Asset Management-Vocabulary, overview and principles
ISO 55001:2024	Asset Management-Management Systems-Requirements
ISO 550002:2024	Asset Management-Management Systems-Guidelines for the application of ISO55001
Land Asset Methodology	Powerlink (2018) *Land Asset Methodology*
NER	National Electricity Rules
Work Health and Safety Act	Work Health and Safety Act *2011* (Qld)
Work Health and Safety Regulation	Work Health and Safety Regulation *2011* (Qld)

1.4 Defined Terms

Terms	Definition
DCA	Dedicated Connection Assets – non network assets for customer connection (fully contestable and non-regulated)
DNA	Designated Network Asset – network asset for the customer connection (design, construction and ownership is contestable and non-regulated)
IUSA	Identified User Shared Assets – network assets for the customer connection (>10 M design, construction and ownership is contestable – non regulated)
SOCI	Security of Critical Infrastructure legislation
CEATI	Centre for Energy Advancement through Technological Innovation
EPRI	Electric Power Research Institute
CIGRE	International Council on Large Electric Systems
MSP	Maintenance Service Provider

Terms	Definition
High Voltage Live Substation Work	High voltage live substation work on exposed parts of high voltage electrical equipment as defined in Electrical Safety Regulations.
CMMS - SAP	Computerised maintenance management system - SAP is the enterprise business application which supports the core processes of asset management, including project management and maintenance, materials, finance and human resources. SAP facilitates the flow of information between all asset management functions within Powerlink, including those activities undertaken by external maintenance service providers.

Table 1 - Identified Hazards and Control Measures

Performance Related Hazard	Network Operations Consequence	Residual Network Operations Risk	Safety/Environment Consequence	Residual Safety/Environment Risk	Risk Control Treatment
Unplanned substation outages	Short-term interruption to supply; ongoing network constraint impacting pool price	Moderate [D3]	Minor impacts to an area of low environmental significance over a short term (< 3 months)	Low [D2] (assuming all initiated replacement need dates are met)	• Substation Entry procedure • Design and acquisition • Condition monitoring • Timely Re-investment and refurbishments • Emergency Response Procedures • Timely re-investment /replacement • Maintained oil separation system
Hazardous step or touch voltages at or near Substations	Short-term interruption to supply; ongoing network constraint impacting pool price	Low [E3]	Single serious injury/illness requiring hospitalisation e.g. amputation, paralysis, loss of vision/hearing/mobility	Low [E3]	• Earthing grid design • Substation Security • Routine testing & audits • Annual fault level review • Managing of neighbouring landholders and substation land
Structural failure in extreme wind	Extended interruption to supply or ongoing power surges; outages across multiple areas	Low [G4]	Multiple serious injury / illness requiring hospitalisation e.g. amputation, paralysis, loss of vision/ hearing/mobility	Low [G4]	• Substation Entry procedure • Design and acquisition • Routine civil inspection & Condition assessments • Risk & condition monitoring (Health indices for civil components) • Timely re-investment /replacement
Foundation integrity	Extended interruption to supply or ongoing power surges; outages across multiple areas	Low [F4]	Single serious injury / illness requiring hospitalisation e.g. amputation, paralysis, loss of vision/ hearing/mobility	Low [F3]	• Substation Entry procedure • Design and acquisition • Routine civil inspection & condition assessments • Risk & condition monitoring (Health indices for civil components) • Timely re-investment /replacement

Performance Related Hazard	Network Operations Consequence	Residual Network Operations Risk	Safety/Environment Consequence	Residual Safety/Environment Risk	Risk Control Treatment
					• Restricted access zones
Mechanical & Electrical failure of high voltage Equipment incl. Catastrophic Failures	Short-term interruption to supply; ongoing network constraint impacting pool price	Moderate [D3]	Single fatality or incurable fatal illness	Moderate [F5]	• Substation Entry procedure • Design and acquisition • Routine substation and civil inspection, oil/SF6 samples, Partial discharge and other electrical tests • Condition assessments • Timely re-investment /replacement • Risk & condition monitoring (Health indices for HV equipment) • Restricted access zones
Mechanical failure of overhead insulator, overhead conductor and associated hardware	Short-term interruption to supply; ongoing network constraint impacting pool price	Low [E3]	Single serious injury / illness requiring hospitalisation e.g. amputation , paralysis, loss of vision/ hearing/mobility	Low [E3]	• Design and acquisition • Routine inspection • Condition assessment reports • Timely re-investment /replacement • Risk & condition monitoring (Health indices for HV equipment) • Restricted access zones
General Deterioration of Components	Short-term interruption to supply; ongoing network constraint impacting pool price	Low [E3]	Minor injury / illness that may require medical treatment e.g. cuts, burns, strains, etc.	Very Low [F2]	• Design and acquisition • Equipment Strategies • Maintenance Procedures • Timely re-investment /replacement/refurbishments • Risk & condition monitoring (Health indices for HV equipment) • Condition assessments & Audits • Restricted access zones
Incorrectly Performed Maintenance	Short-term interruption to supply; ongoing network	Moderate [D3]	Minor injury / illness that may require medical treatment e.g.	Low [E2]	• PPE, • Maintenance Procedures • Audits

Performance Related Hazard	Network Operations Consequence	Residual Network Operations Risk	Safety/Environment Consequence	Residual Safety/Environment Risk	Risk Control Treatment
	constraint impacting pool price		cuts, burns, strains, etc.		• Training • Signage • Restricted Access Zone • SAHVEA • Adequate supervision • Pre work risk assessment
General Deterioration of Components resulting in harm to the environment (oil leaks or SF6 leaks)	Minor voltage/frequency dips without loss of supply; short-term network constraint	Low [D2]	Moderate impacts to an area of environmental significance over a longer term (<6 months) Material environmental harm	Moderate [D3]	• Design and acquisition • Oil separation systems • Maintenance (water samples) • Audits • SF6 management (detection, repairs and reporting) • Online monitoring of SF6 density
Increased noise levels	N/A	N/A	Heightened attention from local media and/or heightened local community concern Stakeholder concerns require local government and broader engagement Risk to reputation and public confidence in PQ within the impacted community	Low [D2]	• Sound enclosures where required • Design and acquisition for allowable sound levels • Periodic noise modelling and measurements • Purchase of low noise equipment

Table 2 – Other Associated Hazards and Control Measures

Other Associated Hazards	Residual Network Operations Risk	Residual Safety Risk	Risk Control Treatment
Lightning strikes	Moderate [C3]	Low [E3]	• Design Standards
Flood	Low [G4]	Low [G5]	• Design Standards • State Planning Guideline compliance • Policies and Procedures
Acts of Theft and Vandalism	Low [D2]	Low [F4]	• Substation Security • Policies and procedures • Design Standards
Exposure to EMF	N/A	Very low [G3]	• Site Radiation Folders • Design Standards • Policies and Procedures • Monitoring of bare hand and other live work exposure levels
Working at Heights	N/A	Low [E3]	• Design Standards • Policies and Procedures • Training requirements • Pre work risk assessment • Use of appropriate aids and tools
Unauthorised access to substations	Moderate [E4]	Moderate [F5]	• Substation Security • Design Standards for Substation Security • Maintenance Policies and Procedures
Electric shock to personnel	Low [F3]	Moderate [F5]	• SAHVEA • Policies and Procedures • Training • Switching sheets • Live work procedures • Design standards

2. Framework

2.1 Asset Profile

Powerlink owns, maintains and operates substation plant at a range of voltages. Nominal transmission voltages in the network include 330kV, 275kV, 132kV and 110kV although some substation equipment operates at lower voltages typically for the purposes of providing customer connections, substation local supply and as a part of reactive support. An overview of the number of assets covered by this methodology is provided in the Powerlink Annual Report. For the purpose of this document, switching stations are treated as substations.

2.2 Stakeholder Requirements

Powerlink has a large number of stakeholders whose requirements are defined through various state and federal laws and regulations, connection access agreements, procurement agreements, National Electricity Rules, customer and consumer panels and landholder relations rules.

Powerlink's' Asset Management Policy requires compliance with all legislative provisions.

2.2.1 Safety Compliance

Powerlink is required to ensure substations are secured, maintained and operated in a manner that is electrically and mechanically safe and complies with the Electrical Safety Act, Electrical Safety Regulation, the Work Health and Safety Act, Work Health and Safety Regulation, and relevant Codes of Practice (including Safety in Design and AS 3000). These requirements are aligned in Powerlink's Health Safety and Environment Policy and Electrical Safety Framework.

The Work Health and Safety Act require the safety risk to be eliminated or minimised so far as is reasonably practicable (SFAIRP). In Powerlink this is facilitated by utilising a corporate risk matrix to make appropriate decisions related to planning, acquisition, design, construction, commissioning, operation, maintenance, refurbishment, replacement and disposal of the substation high voltage equipment and other substation plant.

To design substations that ensure safe access to primary plant, Powerlink utilises the Queensland Electricity Entity Standard for Safe Access to High Voltage Electrical Apparatus.

In addition, Powerlink has established training, design and maintenance measures.

Design measures include:

- Safety in Design as per the Work Health and Safety Act
- Adequate electrical and maintenance clearances
- Adequate perimeter fencing (substation security fence) and adequate substation building security systems
- Earthing arrangements to restrict step and touch potentials and transfer voltages
- Protection systems including circuit breaker fail scheme
- Adequate and accurate signage
- Adequate structural soundness
- Adequate mechanical links
- Restricted/controlled access to substations (authorised personnel only)
- Adequate training for substation entry authorisation
- Asbestos registers
- Radiation folders
- Mechanical barriers
- SF6 equipment low gas alarms and trips

- High temperature trips.

Maintenance measures include:

- Personal protective equipment and training
- Routine inspections of high voltage equipment and other plant and substation security patrols,
- Civil substation inspections
- Monitoring of outage data
- Routine earthing system tests
- Routine service/testing of major equipment
- Routine SF6 and oil sampling where appropriate
- On line condition monitoring (routine and condition based) as applicable
- Working at heights procedures
- Risk and condition monitoring
- Restricted access zones when required
- Fire protection devices maintenance
- All switching and safety equipment routine testing as per relevant standards and legislative requirements
- Live Works methods, when required.

In addition, annual calculation of fault levels is performed followed by a review of continuous current and fault current ratings of substation plant.

2.2.2 Availability and Reliability of Supply

Powerlink's reliability of supply obligations stem from a combination of our Transmission Authority and Transmission Network Licence, associated state legislation and the National Electricity Rules.

The Australian Energy Regulator imposes and monitors a number of performance criteria (STPIS –Service Target Performance Incentive Scheme) associated with availability of transmission network critical and non-critical elements.

For substation assets, a fundamental determinant for reliability and availability of supply involves establishing the optimum minimal but flexible substation configuration at the **design** stage of the lifecycle, which requires balancing reliability against capital expenditure for each configuration. For higher reliability requirements related to the 275kV transmission backbone and major customers, a more robust configuration is typically employed (e.g. breaker and a half arrangement). Where a lower level of reliability is considered appropriate, which generally applies to 132kV and 110 kV network assets, a less robust configuration is employed (e.g. folded bus or H bus arrangements). A separate asset management document for network configuration informs development of options for the investment decision-making process. In addition, type of HV equipment and adequate maintenance clearances can reduce significantly requirements for maintenance outages.

In the **operation and maintenance** phases of the asset life cycle, the use of live substation techniques to reduce maintenance outages and improve reliability and availability has been broadly implemented. Powerlink employs live substation techniques to significantly reduce the requirement for 275kV network outages, and higher risk outages affecting multiple network elements (e.g. busbars) and major customer loads. Further exploitation of live substation techniques is pursued as part of this methodology to continue to optimise reliability and availability of supply outcomes while maintaining safety targets.

On an ongoing basis, Powerlink monitors the performance of substation asset availability using a Network Information Management System (NIMS) and other associated processes to continually review the root cause of each event and establish improvement actions. Monitoring of equipment performance and availability is also achieved through annual review of condition scores (health indices) utilising data collected through routine, condition based and corrective maintenance activities. Detailed condition assessments, maintenance audits and on-line monitoring of plant are also employed and utilised to identify change in reliability and availability of substation assets. In addition, Powerlink produces a Network Investment Outlook which is updated on an annual basis and provides an overview of future capital investment projects as well as significant forecasted operational refurbishment projects. Planned and timely **replacement** or planned and timely de-energisation (**retirement)** of substation high voltage equipment greatly contributes to maximising availability and reliability of the transmission network and ensuring safe operation without adverse impact on workforce and public.

2.2.3 Conformance with National Electricity Rules

As a registered Transmission Network Service Provider, Powerlink is obliged to conform to the relevant National Electricity Rules that govern the operation of the National Electricity Market.

In terms of conforming to the National Electricity Rules, the selection of plant and equipment forming part of substation assets must support a range of outcomes, including but not limited to:

- function through a range of voltages and frequencies
- adequate thermal and short term (fault) ratings
- provision of accurate metering installations through the installation and maintenance of instrument transformers consistent with accuracy class requirements and performing routine accuracy testing of metering installations
- required fault clearance times through installation of circuit breakers with appropriate operating characteristics, in conjunction with their associated protection and telecommunications systems
- supply of adequate AC and DC systems to support required reliability and availability for protection schemes and circuit breaker operations.

2.2.4 Connection Agreements

Connection access agreements specify each customer's requirements with regards to the availability and reliability of connection which impact substation connection arrangements and determine connection point details.

Powerlink has an established business process for obtaining outages that involves negotiation with all interested parties (generators and customers). In addition, Powerlink has competency in live work to reduce the impact of routine and some condition-based maintenance and projects on the electricity market.

On an annual basis, Powerlink reviews the minimal number of insurance and maintenance spares in order to meet the requirements of a dynamic and very diverse substation plant population in regulated asset base. Where and when necessary, Powerlink also uses Network Support agreements and load curtailment measures. All planned outages are managed and co-ordinated by Real Time Network Operations.

When dealing with potential new nonregulated connections to the transmission network, Powerlink identifies parts of the connection access assets that are subjected to the contestability rule (as defined by AER). This rule defines three types of connection assets:

- A dedicated connection asset (DCA) services in which design, construction, ownership, operation and maintenance can be provided by any party on commercial terms; and
- Contestable Identified User Shared Assets (IUSA) which can be designed, constructed and owned by a third party but for which Powerlink will be responsible for operation and maintenance and
- A designated network asset (DNA) which can be designed, constructed and owned by any party on commercial terms

IUSA and DNA require TNSP to provide control, operation and maintenance as negotiated and non-contestable services, respectively and need to comply with Powerlink's design standards and equipment strategies.

DCA assets can be operated by any appropriately qualified provider.

3. Lifecycle Management

Electricity transmission assets including high voltage substation equipment and related infrastructure are high cost assets with a relatively long expected operating life.

During the Planning and Investment phase it is important to influence design, configuration and topology aspects of the substation asset to provide a platform for achieving desired reliability, availability and maintainability at minimal investment and life cycle cost whilst keeping flexibility to expand if needed.

In order to achieve the best outcome for stakeholders, Powerlink must consider the asset's whole of life cost and balancing this with values the assets provide to various stakeholders.

Minimising this cost is the basis of Powerlink's asset management approach and involves the following:

- optimisation of the standards, configurations and the design process
- consideration of the asset's expected operating life
- effective management of the asset's lifecycle through targeted maintenance, refurbishment, modifications, life extension, replacement and disposal activities.

This approach is often referred to as Lifecycle Management and includes all stages as defined in the SAMP and shown in Figure 1 above.

3.1 The Planning and Investment stage (Plan, Design, Acquire/Procure, Construct & Install, Commission)

This covers multiple lifecycle stages in Powerlink (Plan, Design, Acquire/Procure, Construct and Install and Commission.

It starts with assessment of the network needs, condition driven needs and strategic property acquisition planning (if required) as well as conceptual design of the most suitable network and substation configuration for the prospective customer's needs, particular environment, function, required capacity, availability and reliability that meets customer expectations.

Where electricity customer is involved, the customer's needs are communicated and understood across all relevant parts of the business and the Connection and Access agreement is signed that complies with relevant legislation and regulatory framework, especially the NER and Transmission Network Licence.

A number of options are considered, costed and communicated to ensure the most economical option that meets requirements is used.

Once all the requirements are clarified and agreed upon and the majority of the layout is known, specific objectives are defined in order to:

- achieve the desired levels of service over the life of the asset;
- ensure the expected or desired asset life is achieved;
- optimise total lifecycle costs;
- ensure the maintainability and supportability of the asset over its intended life; and
- allow for the potential use of live maintenance techniques.

At the end of this **Planning** stage, all technical details are determined through **Design** process and the required documentation and drawings (including technical specifications for the equipment) are produced. The design is then cheeked using Safety in Design process to ensure it is safely constructable and maintainable.

The next phase of the planning and investment stage includes project scoping and estimating. The contestability rule is applied and the required process for public consultation (Regulatory Investment Test for Transmission –RIT-T) is initiated if required. The final step is the business case approval and publication of the RIT-T report.

This is followed by the production of final **Design**, determination of **Procurement** methods, contracts, project and Construction management, variations, testing, **Commissioning,** production of "as per built" documentation, recording all required substation plant data in the computerised maintenance management system/asset register (SAP) and financial asset values and final handover of the built substation to the relevant maintenance service provider, asset management group, operational engineering and Real Time Network Operations.

3.2 Operation, Maintenance and Refurbishment stages (Operate, Maintain, Modify/Refurbish)

Geographically, Powerlink operates a long, skinny transmission system, most of which hugs the coast of Queensland. The energy transformation is driving the change of transmission network extending it more inland and reducing what previously has been a significant separation between load and generation centres. One historical fact about Queensland transmission network remains and that is there is little meshing within the network. Outages are difficult to obtain due to the impact of energy transformation on network stability and reduced network strength and must be planned and coordinated carefully to minimise their number and duration.

The Operation, Maintenances and Refurbishment stage is the longest stage of all. For the majority of substation assets this stage is typically expected to last around 40-60 years, although where customers specify a requirement for connections over a shorter period, this can be achieved by application of modified standards.

It starts a day prior to the first partial energisation with ensuring that all relevant substation plant data for energised equipment (including all circuit rating reports) are readily available, all relevant operation and maintenance documentation is provided to maintenance service providers and routine maintenance plans are established as works progress and equipment is energised. At the end of construction works and upon final energisation all relevant documents and training should be completed and all maintenance plan established and in place.

Due to the different failure modes in some types of substation equipment and associated safety risks, it may not be possible to achieve 40 years' service life for all substation equipment. Prior to replacement, repairs, major overhauls, refurbishment and life extension options are considered. If replacement is required, the replacement strategy is focused on use of alternative equipment that has reduced safety consequences, if possible and commercially viable.

In contrast some substation equipment can be fully operational and safe to operate in excess of 40 years, confirmed by both their condition and operational and financial performance. Monitoring condition and performance activities may be undertaken as part of routine maintenance, condition based, emergency and deferred corrective maintenance, partial component replacement and/or life extension, equipment modifications, desktop and detailed condition assessments, technical and fault investigations, review of asset performance, reporting, audits and benchmarking.

Sometimes the maintenance activities identify a need for improvement of substation plant and drive innovation. The drivers for this can be related to work, health and safety, legislative or other compliance or to ensure optimum service life expectancy and cost. These can be made through refurbishment projects or changes of maintenance methodologies, processes and tools and involves any activities required to bring them up to present day standards or to meet improved safety or operational requirements. Examples of such activities are:

- installation of improved physical security measures
- installation of noise suppression systems to meet environmental standards, where appropriate
- upgrade of substation earthing systems
- replacement of plant items containing polychlorinated biphenyl (known as PCB) or asbestos to meet WH&S requirements
- installation of improved oil separation systems to meet council or state environmental requirements
- replacement of power transformer bushings to reduce safety risk and potentially extend life of power transformer
- replacement of circuit breaker operating mechanisms, poles or their parts to achieve expected service life
- replacement of hybrid modules disconnector/earth switch drives

- Installation of additional safety equipment (eye wash, showers, heat stroke prevention kit, etc.)
- Use of drones or robots for maintenance inspections
- Installation of safety barriers

3.2.1 Maintenance

Maintenance strategy for substation plant is established using a Reliability-Centred Maintenance (RCM) model.

RCM provides a rigorous and verifiable analysis framework for identifying only those maintenance tasks that are applicable and effective in managing possible failures. RCM analyses are undertaken by facilitated review teams of technical experts and field personnel with the greatest knowledge of the Network Assets being analysed. RCM also identifies those failures that cannot be dealt with effectively by maintenance alone and thus require other approaches to deal with them. This ensures that only practical, achievable and effective maintenance tasks are adopted. These are verified and checked periodically through various benchmarking with other electricity transmission authorities In Australia and overseas.

Prior to, or at the commissioning of a new type of substation plant item, a formalised Reliability-Centred Maintenance analysis is organised to analyse potential failure modes and countermeasures resulting in the development of the appropriate routine maintenance regime for that type of plant item.

Substation Plant consists of a mixture of static and moving plant of varying sophistication and complexity. Typical substation plant failure modes relate to their inherent design characteristics, surrounding environment, applied electrical load and stress and duty cycle.

Powerlink's strategy for substation plant maintenance is based on an RCM applied philosophy of non-invasive local and remote performance monitoring and condition assessment by condition monitoring and testing, with invasive maintenance only being performed on a scheduled basis where there is no practical alternative.

Wherever it is cost effective to do so, remote performance and condition assessment of substation plant is undertaken.

Substation maintenance is broadly grouped into three main categories: Routine maintenance (often referred to as time based), condition-based maintenance and corrective maintenance (includes emergency and deferred corrective).

3.2.1.1 Routine Maintenance

The nature of failure modes of substation plant means that the RCM-developed maintenance strategy is primarily based on the assessment of condition using visual inspection, on-line condition monitoring and periodic testing including various measurements. There is a limited amount of time or duty based scheduled restoration or discard tasks. Various levels of routine scheduled maintenance are applied as part of this strategy. They are:

3.2.1.1.1 Routine Substation Maintenance (RSM)

RSM is a non-invasive, visual inspection of all substation plant in a location, conducted on a regular basis as specified by the maintenance specification. RSM does not require network outages.

3.2.1.1.2 Service Level Maintenance

Service Level Maintenance is conducted on specified plant in accordance with the appropriate maintenance specification and generally consists of more detailed and focused non-invasive condition monitoring and testing tasks, such as contact resistance checks, bushing capacitance measurement, measurement of circuit breaker open and close times, but also includes lubrication and cleaning services where required. The grouping of individual tasks is done in such way that all services of substation equipment require outages. As a guideline, approximate outage durations are provided in Table 3 as a high-level guidance only.

Where practical and possible, service level maintenance is carried out on live equipment (for an example, disconnector service), subject to availability of live substation resources.

In addition to the service level maintenance, oil and gas samples are taken periodically and whilst for power transformers oil samples an outage is not required, outages are required for samples to be taken from instrument transformers and circuit breakers.

3.2.1.2 Condition based

Continuous performance monitoring, routine scheduled maintenance, visual inspection, condition monitoring, and testing are all used to detect deterioration of condition or degradation of substation equipment performance that will, if allowed to continue, result in equipment/asset failure sometime in the future. Condition Based Maintenance restores the condition or performance of the asset to an acceptable level. This is done using work prioritisation/risk category methods.

Reduction of planned outage time and cost to carry out condition-based maintenance is a major objective. This is achieved by:

- use of live maintenance techniques
- optimum work packaging and scheduling
- use of on-line, remote monitoring and on line technical support where practical.

3.2.1.3 Corrective Maintenance

Typically, corrective maintenance requires network outages and involves higher costs and therefore the asset management objective is to reduce corrective maintenance to a minim level possible. It is broadly grouped in two categories emergency and deferred corrective maintenance.

3.2.1.3.1 Emergency Corrective

Emergency corrective maintenance is the immediate work that must be performed to minimise the danger to public or personnel and prevent further equipment damage and to restore the system to service. The emergency work is typically initiated through the Network Incident Management process requesting that staff be immediately called out to rectify a situation. In majority cases this is identified through protective devices operation indicating that fault has occurred resulting in network element outage. However emergency corrective maintenance can be also instigated by poor test results.

3.2.1.3.2 Deferred Corrective

Deferred corrective maintenance includes all work associated with rectifying a faulty function of substation equipment (often associated with equipment secondary functions), which is not emergency in nature. In addition to the actual "hands on" work to rectify a fault, this category of maintenance also includes the subsequent investigations and reports relating to in service equipment failures.

3.2.1.4 Maintenance Support

Maintenance support tasks are those activities which are related to the ongoing maintenance and operation of the plant, but which do not specifically involve the plant itself. Examples include carrying out risk assessments, defect analysis and periodically reviewing the main substation plant item populations to consider changes in reliability performance. Maintenance tasks resulting from these investigations and reviews are documented as quality procedures and incorporated into the policies, procedures and secondary documentation for the different plant groups. Typically for substation plant, the defects are analysed and the results are used to modify maintenance and assist with selection of new plant.

The fault level and capacity of substation plant items are analysed annually, and recommendations are submitted where potential encroachments are noted. These reviews are also included in the substation condition assessments as required replacements can be better coordinated resulting in saving of costs associated with projects initiation, establishment of contracts and site establishment for example.

Table 3 - Asset Maintenance Types

Maintenance Type		Activity	Frequency	Estimated Outage Duration (days)

Maintenance Type		Activity	Frequency	Estimated Outage Duration (days)
Routine Maintenance	Routine (Preventative /Scheduled) Maintenance	Routine Substation Maintenance	6 months	0
		Routine Civil Inspection	2 yearly	0
		CB Service (for most CBs)	12 yearly	3-5
		CT & EMVT Oil Sampling	3 yearly	1-2
		Isolator/ES Service	6/12 yearly	3-5
		Power Transformer Service	6 yearly	3-5
		Tapchanger Service	6 yearly	3-5
		Power Transformer – Oil Sample	2 yearly	0
		Bushing Testing (delayed start applies)	6 yearly	Incl. in outage duration for transformer service
		Power Transformer OTI/WTI Testing	6 yearly	Incl. in outage duration for transformer service
		Power Transformer Mid Life condition review	@ 24 years	3-5
		Earth Grid Injection Testing	10/15 yearly	3
		Infra-Red Inspection	2 yearly	0
		Oil Containment System Service	2 yearly	0
		Switching and Safety Equipment Testing	6 monthly	0
		Partial Discharge scanning (selected sites only)	1 yearly	0
		Update of fault level signage	1 yearly	0
		Inspection of overhead hardware and earth wire attachments inside substation security fence	6 yearly	1-5
	Condition Based Maintenance	Investigation and/or repair of minor insulating fluid leaks (oil,SF_6)	As required, generally indicated by results of routine inspection or testing and is prioritised.	3-10
		Corrosion treatment on structures and plant		3-10
		Site infrastructure repair e.g. Erosion on roadways, painting of building		0
		Substation signage and on site drawings update	As required, generally indicated by results of routine	0

Maintenance Type		Activity	Frequency	Estimated Outage Duration (days)
			inspection or testing and is prioritised.	
		Repairs/replacements of air condition devices in the control buildings	As required, generally indicated by results of routine inspection or testing and is prioritised.	0
		Replacement of high voltage equipment where there are indications of imminent failure (bushing & instrument transformer oil leaks, circuit breaker operating mechanism deteriorated times, etc.)	As required, generally indicated by results of routine inspection or testing and is prioritised.	3-30
Corrective Maintenance	Emergency	**Immediate** work that must be performed to prevent danger to personnel, equipment or system performance	Initiated through Control Centre and Incident Management Team requests	1-15
	Deferred	All work, including subsequent investigations and reports, associated with rectifying an unacceptable plant condition to an acceptable state that is not an emergency in nature.	Initiated by Incident Management team or MSPs and prioritised.	3-30

3.2.2 Refurbishment

Refurbishment of substation plant is triggered where plant does not function in accordance with the original design, identified through condition assessment, routine inspection, servicing or testing activities.

Refurbishment may also be required where plant, equipment or site infrastructure no longer complies with relevant legislation and statutory requirements, or on changed customer's expectations and/or requirements.

Typical refurbishment activities involve the replacement of specific items of plant or equipment forming part of a switching bay asset (e.g. instrument transformer due to poor physical condition or oil sampling results), work to repair main tank corrosion, oil leaks and other defects on power transformers, or work to upgrade or repair degraded infrastructure (e.g. erosion on roadways, poor drainage, corrosion on support structures), substation building repairs, etc.

3.3 End of Life (Dispose/Decommission)

End of Life involves the actions required for assets and plant that has reached a level of unacceptable risk if it were to remain energised. These actions can be categorised as plans for timely:

- De-energisation
- Seeking non-network solutions
- Replacement
- Removal and disposal of an asset if it is no longer required for successful operation of the network
- Life extension where possible.

As condition indicators are used to calculate health index for each piece of substation equipment, these are used to instigate detailed condition assessments and review of enduring need for these assets. Upon their completion, the options are formulated and risk assessment and risk calculations are performed to determine the best option. This process must involve forecasting to allow sufficient time for project initiation, scoping, approvals and design, acquisition, construction and installation and commissioning to be completed before identified risks become unacceptable.

4. Asset Management Drivers

Substation plant assets represent a significant percentage of network assets within Powerlink. Due to the nature of their design and construction they have a typical service life of 40 years.

It is critical to manage these assets in such a way as to achieve not only the optimum operating life but to do so at the minimal lifecycle cost whilst maintaining required reliability and availability of electricity supply, safe environment for personnel and public and meet all compliance requirements and customer needs. This can only be achieved by setting appropriate asset management strategies from the beginning of each substation equipment lifecycle.

Powerlink operates its assets in a dynamic environment and need to take into account a range of internal and external factors and respond in an appropriate and timely fashion.

Internal Influencing Factors

- Condition assessments & changes in the equipment health indices
- Failure data
- Technical investigations and research
- Corporate Risk Framework
- Data modelling and reporting
- Fault and defect statistical data
- Substation plant ratings
- Compliance issues
- Changes of work methods
- Changes in the work force
- Feedback from maintenance.
- Continuous improvement process
- Research and development and innovation.
- Changes in internal organisation structure.

External Influencing Factors

- Changes in demand and energy consumption
- Changes in electricity generation sector
- Innovation and technology
- Environment and duty
- Emerging issues (increase of ambient temperatures, for example)
- Change of legislation and/or engineering standards
- Change of customer requirements
- Change of stakeholder requirements
- Change of regulatory environment
- Obsolescence (lack of availability of spare parts and/or technical support)
- Changes in electricity distribution sector.

4.1 Condition Assessment

Most Powerlink substation plant assets deteriorate through a mixture of deterioration processes as a result of environmental conditions, wear out, electrical stress, exposure to faults and network loading. The end-of-life of a substation asset is determined by its performance (measured through availability and corrective and condition-based maintenance cost trend) and condition of its components. Typically, the asset is declared at the end of its life when performance is significantly deteriorated and major components are deteriorated, or the safety of workers or the public is assessed as compromised based on SFAIRP principle.

A number of substation assets fail while in service typically as a result of random or inherited design failures or random network conditions leading to insulation overstress. Sometimes these changes are identifiable through condition monitoring but often are not.

Powerlink's' asset management system aims to minimise the number of failures in service. Typically, Powerlink substation assets are expected to last for 40 years, however this can vary between items depending on design, construction, installation, maintenance, duty and environmental conditions. For example, most modern transmission circuit breakers are expected to last up to 40 years although this is dependent on technology. Circuit breakers that switch generators or reactive plant are operated more frequently and may require major refurbishment or replacement after half the nominal life. They often reach the maximum rated number of operations after 25-30 years of service.

Substation equipment condition is monitored using equipment condition scores (health indices). Improved IT systems enable their live update. They are used for calculation of safety and network risks driven by plant condition. Based on these and additional information provided by maintenance service providers and availability and forced outages reports, desktop and detailed condition assessments are initiated. A condition assessment report provides an overview of defective and deteriorated items and may initiate further investigation and analysis of the data to determine the level of deterioration. It provides estimated remaining service life for each asset, equipment and/or component. Where possible the holistic condition of all assets at a substation is assessed collectively to arrive at the optimum solution for refurbishment, retirement or reinvestment for the site.

4.1.1 Condition Assessment Process

For the purposes of condition assessment, substations can be viewed as a hierarchical construction of plant and equipment items. The items are combined into functional groups that make up individual financial assets and these functional groups and financial assets are combined together to comprise a substation.

Powerlink applies condition assessments to assess the risks arising from the deteriorated condition of the substation plant from a range of perspectives including impact on safety, network operations, business strategy, finance and contractual obligations, impact on major stakeholders, project costs, and environmental and cultural heritage. Condition assessments combined with planning reports are also used as a basis for the development of options for non-network solutions, refurbishment or reinvestment where this is considered necessary. Difficulties associated with obtaining access to operational assets and associated mobilisation and construction site establishment costs may result in Powerlink carrying out replacement or major refurbishment projects at the asset level or even at a substation level. The economic analysis indicates that in some instances the replacement of individual plant items in a piecemeal fashion may not result in the optimum cost savings. For this reason it is important to consider all options for non-network solution, item replacement or major refurbishment. The substation plant methodology includes condition assessment activities at the lowest possible level to enable this to occur.

The replacement strategy always considers use of non-network solutions, modern or improved technological solutions for substation equipment which can reduce potential for safety risks, improve availability and reliability or reduce environmental footprint. These improvements are driven by the relevant equipment strategies.

4.1.2 Condition Data

4.1.2.1 Plant Item Level

Plant items such as circuit breakers, instrument transformers, isolators, earth switches, power transformers, reactive power plant (capacitors, reactors and SVCs), busbars and substation structures are the building blocks from which the substation is constructed. In addition there are many elements that comprise substation infrastructure such as substation earthing system, buildings, fire protection systems, roads, switchyard lighting, oil separation systems, noise enclosures, substation auxiliary supply, and substation security systems. The condition of these items is monitored during routine inspection and servicing as applicable. Defects are reported and recorded in SAP and the data is analysed using equipment health indices. This information is used to identify the need for detailed or desktop condition assessments and to identify and manage corrective and condition based maintenance programs. Where common defects are noted for a population of items, the information can be used to trigger operational refurbishment projects.

Condition information for primary plant items can include details on:

- fluid containment and grades of metal corrosion from visual inspection
- contact and current carrying path resistances and localised hot spot temperatures
- insulation resistance, capacitance and dielectric information for graded insulation systems
- dissolved gas analysis and oil quality information from oil-insulated plant
- moisture and contaminant information from SF_6 insulated plant
- operations counts and hour run meters from mechanical switching devices
- electrical partial discharge measurements to detect insulation breakdown
- performance tests undertaken during service such as circuit breaker travel and operating time measurements
- details of failed and replaced components
- insulating paper condition expressed as degree of polymerisation (DP) value
- number of initiated alarms
- condition of civil structural components.

Determination of the complete condition of a plant item requires analysis of the appropriate parameters, weighting each result in a manner determined by the importance of the parameter and then combining the information to give a total result for each item. This provides a holistic representation of the condition or health of the item and provides a means to rank the condition of each item within the population. Powerlink utilises a health index methodology for this.

Health index is a consistent and logical means of combining relatively complex and diverse condition information about a specific equipment item. It gives a total score between 1 and 10 representing the item's overall condition relative to that of the other items within the specific equipment population. Application of health index requires engineering expertise, statistical data and knowledge of replacement methods. To be of use in assessing future actions, the health index profile for an equipment type needs to bear a relationship with the probability of failure or hazard rate for equipment items, particularly those at the deteriorated end of the curve. This requires calibration with real failure data. In addition, the algorithm is designed to provide a predictive assessment of how the health index profile will change in the future as an item's condition goes through the process of further deterioration.

Health index provides a means to identify items that are performing satisfactorily as well as those that are performing poorly enabling resources to focus on those items that should be targeted for detailed condition assessment to form basis to plan their repair, refurbishment, reinvestment, de-energisation or retirement. They are not used to instigate actions, until the detailed condition assessment or investigations are undertaken. Health index information can be used to identify outliers to be investigated for potential corrective and condition-based maintenance activities.

4.1.3 Engineering Data

Engineering information relating to the designed performance of the asset is collated. This could include information on structure, electrical ratings and capacity, and layout design. It also includes consideration of an individual item's performance in the service environment, design vulnerabilities and assumptions, historical performance of similar assets and industry experience as well as any change in standards or legislation. This activity is undertaken by strategies and standards groups.

4.1.4 Condition Assessment Report

The Condition Assessment Report for substation plant assets is the product of the Condition Assessment and Engineering Data investigations. The Condition Assessment Report will take the engineering, loading and condition data and apply analytical techniques, modelling, expected future performance criteria, based on probability of failure curves and probabilistic evaluation to determine the decision criteria for the risk assessment. This activity will be undertaken by Powerlink strategies engineers, planning engineers and connection and development managers (regarding future performance requirements) and design groups in consultation with the respective maintenance service provider for the asset.

The objectives of the Condition Assessment Report are to:

- determine and document the condition of the equipment or assets with respect to the decision criteria
- determine estimated remaining service life for each equipment and component of substation infrastructure
- provide an input for:
    - life extension,
    - corrective and condition based maintenance recommendations,
    - high level scope of work for refurbishment, or
    - replacement, energisation or retirement of the equipment, assets or substation.

4.2 Technical Investigations and Research

To support substation asset strategies, technical specialists are engaged from time to time to assist with investigations and recommend and review technical solutions. Investigations can be initiated by an engineering task request for internal specialists or through a commercial arrangement with a subcontractor or industry specialist. These activities include research into new technologies (non-conventional instrument transformers for example), providing design input for new equipment types, ultimate substation layouts, investigations of life extension methods, investigation of emerging issues (such as copper and silver corrosive sulphur phenomenon) and any other innovative ways of using new or existing technology.

4.3 Innovation, Technology and Emerging Issues

4.3.1 Climate Change Adaptation

Climate change adaptation dictates that the resilience and durability of the transmission network needs to be assessed and its susceptibility to issues that may arise as a result of changes in climatic conditions. Climate change and its resulting impacts have the potential to shorten the life and reduce the capability of substation plant. The impact of the different physical parameters from climate change on individual substation items needs to be assessed to understand the potential risk to assets and the network.

Projected impacts of climate change in Queensland are:

- increase in number of days with temperatures over 35^{0}C
- increase in number of severe storm events and flash flooding
- more frequent and severe droughts and increased fire risk
- decrease of days with certain wind speeds.

4.3.2 Connection of renewable energy sources & energy storage facilities

One area of change due to technology and production improvements as well as environmental pressures is the increase of renewable energy sources connected to the electricity grid. The impact of change in generation mix on the transmission network is significant and requires careful assessment and analysis.

One of the outcomes is a weak and not very stable network, increased number of substations and increased complexity in managing assets with varying customised substation layouts and varying expected service lives.

In addition, there is a requirement to manage multiple customers which have not participated in energy sector before.

It is clear that one of the most important enablers for transition to renewable energy sources are various energy storage technologies.

Determining and learning their capabilities and limitations and the best way to connect and integrate into the existing transmission network in Queensland will continue over the next decade.

4.3.3 Internet of Things (Substations Digitalisation)

There is an ever-increasing number of substation equipment that are monitored and automated through the use of devices which have the ability to be connected via digital networks.

This technology brings many benefits for the management of assets such as:

- Real time condition data
- Self-monitoring
- Remote access and improved remote operation of the substation equipment
- Better data analysis
- Increased data and therefore increased accuracy in determination of end of service life
- Reduced exposure of workers to potential safety risks
- Reduced installation and construction times by using optic fibre cables
- Reduced size and cost of cable trenches

It also raises and increases some other risks such as:

- Compromised cyber security
- Change of required skills
- Loss of rapid intervention skills and technical knowledge
- Risks associated with loss of communications
- Shorter expected service life of these devices when installed outdoor
- Installation, maintenance and performance of merging units

Powerlink is monitoring and actively influencing these technological developments and preparing for their full implementation in the future when appropriate driven communication protocols are matured.

In addition, digital engineering is being explored to enable improved electronic records management and enable cost efficiencies in design. There is a strong consideration given to 3D on site imaging and enablers for geographical visualisation of substation equipment and infrastructure.

4.3.4 Use of Unmanned Aerial Vehicles (UAV) and Robots

Powerlink is at early stage of using UAV inspection techniques and robots inside substations. The benefit is potential efficiency in utilising UAVs in Powerlink substations through increased number of inspections, emergency management and identification of early signs of deterioration without a need for outages and working at heights and with reduced exposure of workers to electric and magnetic fields and catastrophic failures. Powerlink is doing this with consideration of its obligations under Work Health and Safety legislation to ensure that UAV's and robots do not pose a risk to staff, equipment and members of the public and provide cost efficient maintenance.

5. Emergency Response and Network Security

5.1 Emergency Response

Cyclones and natural disasters are a part of the Queensland climate. While substation assets have performed well during cyclones and other natural disasters, specific measures are taken to improve resilience in these events such as:

- appropriate backup for substation AC supplies in cyclonic areas including increased fuel supply for diesel generators and increased number of portable plug-in diesel generators.
- appropriate spare equipment levels and maintenance incl. arrangements to share spares with other Transmission Network Service Providers where applicable
- contingency plans in place where required
- flood monitoring measures
- increased co-operation and utilisation of Bureau of Meteorology services and data and internal mapping capabilities

5.2 Substation Security

Substation security needs to take into account the different levels of threat posed to an asset of this type and threats posed by the asset of this type to the public.

The transmission network is part of National Critical Infrastructure and higher levels of security measures are required at critical substations to meet minimum standards of overall security (as per SOCI).

Other levels of threat include theft and vandalism. Substations have become a target for theft and vandalism due to the presence of attractive materials (e.g. prolific use of copper), remoteness and isolation, and low occupancy of Powerlink personnel. Apart from causing financial loss, such thefts constitute electrical safety incidents and are often reportable to Electrical Safety Office.

Powerlink continues to assess requirements and accordingly invest in the security of our critical transmission assets with a focus on improving deterrent and especially detection measures at higher risk sites.

Substations will remain accessible only to authorised and competent personnel and escorted visitors.

6. Supporting Activities

6.1 Risk Management

To successfully manage Powerlink's substation assets, it is necessary to identify and manage a range of risks, including those not directly related to the performance of the asset. These are analysed using the corporate risk framework. There is a range of risk mitigation and risk reduction measures employed such as condition based oil, SF_6 and water discharge samples, restricted access zones, increased frequency of inspection and service, PD scanning and innovative work methods such as live work, development of contingency plans and selective component replacement. The outcome is to provide a structured approach for the identification, assessment and treatment of hazards ensuring the management of risks to a level that is deemed to meet criteria of being So Far As Reasonably Practicable (SFAIRP).

6.2 Project Handovers

The construction of new substation assets, plant item replacement or life extension of assets involves the interaction of design, construction, project management, material acquisition, maintenance service providers, and strategies groups both within and external to Powerlink. The transition from the practical completion of a substation asset to becoming a maintainable and operational asset requires the recording and communication of critical information and related data about the asset.

The Project Handover process has been implemented to provide the conduit for transferring design and construction information between the Designers, Construction Contractor and the Maintenance Service Providers. It also provides an opportunity for co-operation between the asset management, asset design and construction and asset maintenance and operation groups to discuss the assets and the project handover process, and to ensure that opportunities for improvement are implemented through future projects and equipment strategies.

6.3 Strategic Spares

An annual review of substation plant strategic spares is performed to ensure that:

- the quality, quantity and location of spares are adequate and appropriate.
- the storage practices and facilities of spares are satisfactory to ensure component life span is not compromised as a result of incorrect or inadequate storage practices.
- adequate spares have been supplied for new assets and component changes.
- the spares which are no longer required are identified and sold or otherwise disposed of.

In addition, the maintenance of strategic spares is organised and conducted at appropriate intervals.

6.4 Documentation

The conveying of specific asset management requirements is achieved through this Substation Asset Methodology framework and a number of other asset management documents that are reviewed regularly and promote the development of documentation and field guides to ensure substation plant strategies remain relevant and are in accordance with good industry practice.

6.5 Strategic Linkages

Channels of active communication are maintained with other Transmission Network Service Providers (TNSP) to facilitate emergency restoration activities, provide discussion forums for work delivery protocols such as live work and share information on the implementation of new technology and major plant statistical data.

The active participation with various international and local power research institutes (UQ, QUT, TIC, EPRI and CEATI) as well as participation in various CIGRE and IEC and Australian Standard bodies of work ensures the strategy can be kept up to date with technology developments.

7. Health, Safety and Environment

The design and implementation of substation plant maintenance strategies incorporate Powerlink's Health, Safety and Environment Policy. This includes the use of risk management processes to ensure the safety of workers, the safety of the public and the safety of plant and equipment. All major plant failures are investigated with recommendations provided and implemented.

Risk assessment processes are also used to identify and appropriately manage environmental risks such as:

- containment of PCBs in older equipment;
- containment of insulating oil in equipment such as transformers and circuit breakers.

- management of operational noise from substation plant.
- containment of SF_6 in switchgear and instrument transformers.
- containment of hydrocarbon fuels such as diesel for generators.
- presence of asbestos in older buildings and equipment; and
- management of vegetation inside and outside substations.

Appendix A. List of Documentation to be provided at Project Handover

The minimum maintenance documentation shall include the following:

- Locality plan
- Project Scope Report
- Project Management Plan
- Project Drawing Index
- Geotechnical Report
- Project notes and specification
- Design specification
- Design Reports
- List of essential drawings
- Equipment specifications and copies of equipment purchase orders
- Equipment O&M Manuals
- All Civil Design drawings and structural calculations
- All Electrical Design drawings (General arrangement, section drawings, etc.)
- Project Environmental Management Plan
- Project Environmental Work Plans
- Project Weed Management Plan
- Environmental Close Out Reports
- Environmental Flora & Fauna
- Copies of equipment nameplates
- List of all design drawings
- Single line diagram
- Substation layout drawings
- Evidence of all SAP data being populated
- Construction photos
- List of defects identified during project activities
- Copies of all O&M manuals from equipment manufacturers
- Copies of all factory and commissioning test results and reports
- Earth grid design reports and grid injection test results
- Circuit Ratings reports