Substation Asset Methodology – Framework

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1. Introduction

1.1 Purpose

The role of Powerlink's asset management system is to ensure the organisation's assets are managed to optimise flexibility and cost-efficiency. The practices seek to acieve a balance between reliability, risk and efficiency. In order to implement the organisation's Asset Management Strategy specific asset management methodologies must be developed for each major asset group within Powerlink.

This document sets out the whole of life management philosophy for Substation Plant covering all three stages of an asset life cycle (as per ISO 55000) including planning, design, construction, acquisition, operation, maintenance, renewal, life extension and disposal. It acts as a reference for the development of maintenance and project budgets and forecasts.

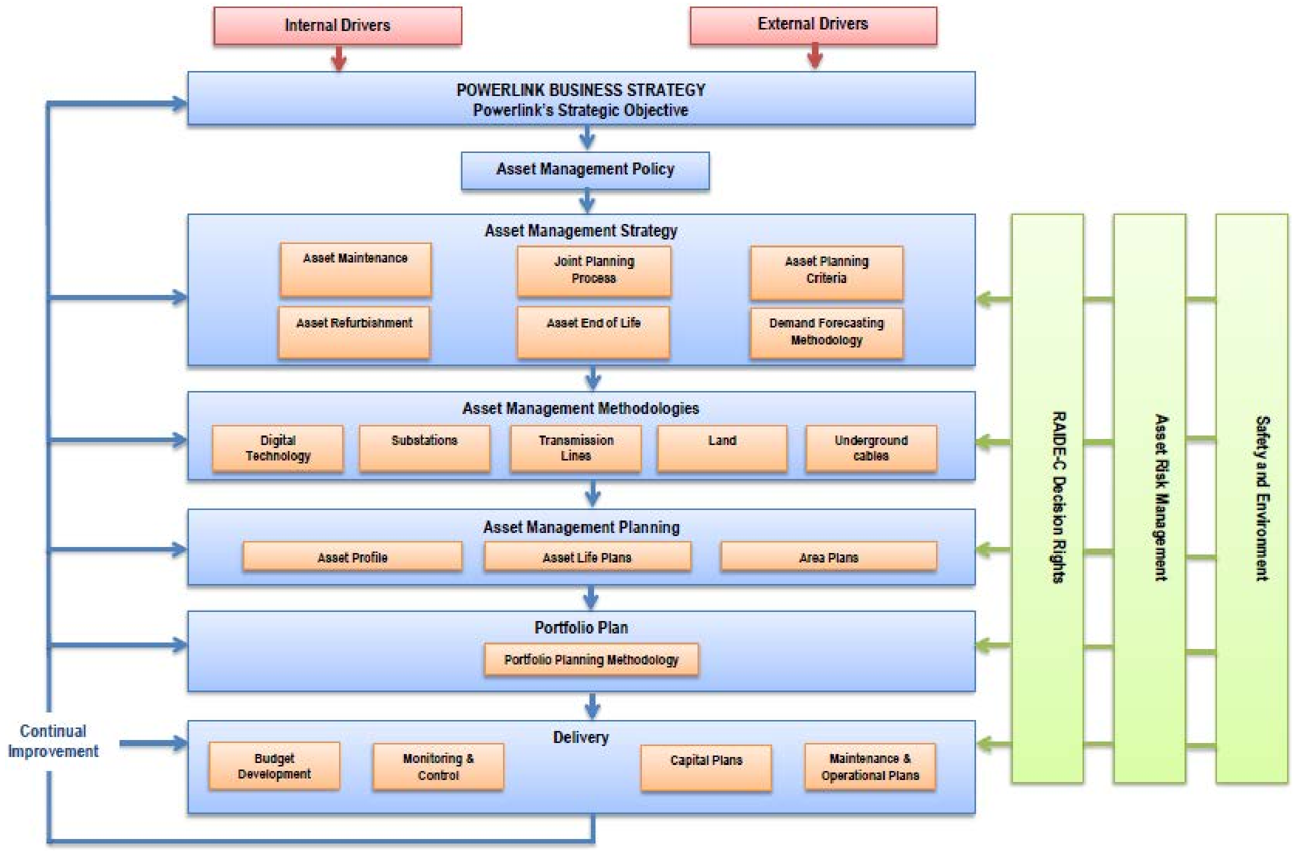
1.2 Scope

This document covers the asset life cycle of the following high voltage substation plant and substation infrastructure components:

- 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 substations fences and maintained by Powerlink;
- 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 supply transformers, direct and alternative substation supply systems (station supply transformers, battery banks, chargers, controllers, standby supply generators), oil separation systems, noise enclosures, and signage;
- all structures and foundations located within substations and maintained by Powerlink, excluding communications structures;
- all substation land within the substation security fence and to a distance of five meters outside, earthing, fences, and marshalling kiosks;
- all buildings, roadworks, cable trenches, switchyard lights and associated cabling located inside substations; and
- compressed air systems, where applicable.

1.3 Objectives

Substation assets forms part of Powerlink's asset management system documentation with the following key elements shown in the diagram below:

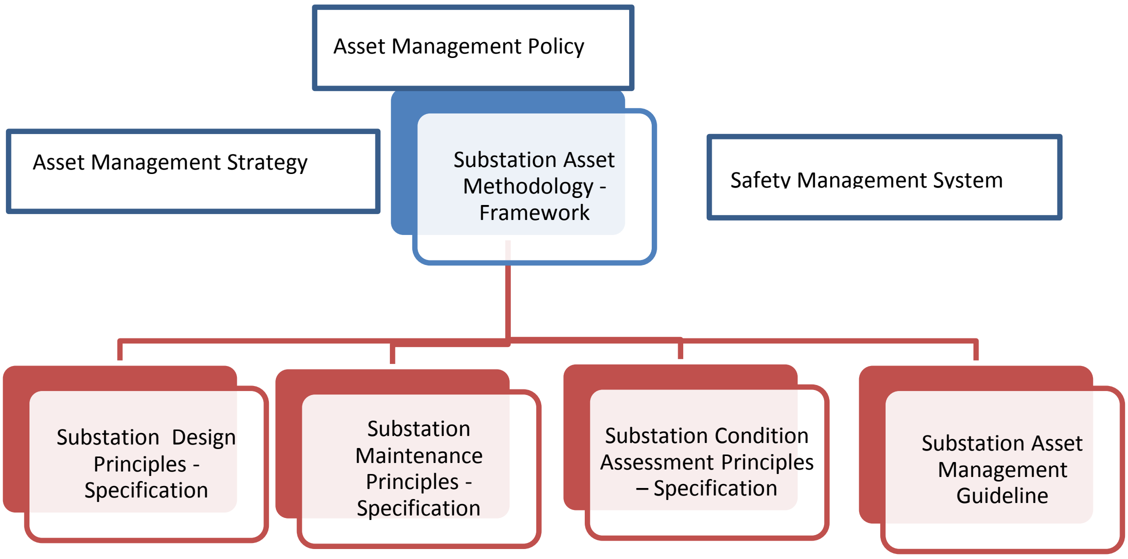


The Substation Asset Methodology sets out how the following key performance areas are to be addressed:

- 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

1.4 Document Hierarchy

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



1.5 References

Document Code	Document title
CEATI	Centre for Energy Advancement through Technological Innovation
Cigre	International Council on Large Electric Systems
ISO 55000	ISO (2014) *Asset Management Standards*
IEC 61850	International Electrotechnical Commission (2018) *Communication networks and systems for power utility automation*
Electricity Act	Electricity Act *1994* (Qld)
Electrical safety code of practice Works	Electrical Safety Code of Practice *2010* – Works (Qld)
Electrical Safety Act	Electrical Safety Act *2002* (Qld)
Electrical Safety Regulation	Electrical Safety Regulation *2013* (Qld)
EPA	Environmental Protection Act *1994* (Qld)
EPRI	Electric Power Research Institute
Land Asset Methodology	Powerlink (2018) *Land Asset Methodology*
NER	National Electricity Rules
Safe Access to HV Electrical Apparatus	Queensland Electricity Entity Standard (2015) for *Safe Access to High Voltage Electrical Apparatus*

Document Code	Document title
Work Health and Safety Act	Work Health and Safety Act *2011* (Qld)
Work Health and Safety Regulation	Work Health and Safety Regulation *2011* (Qld)

1.6 Defined terms

Terms	Definition
IUSA	Identified User Shared Assets
DCA	Dedicated Connection Assets
SAP	Computerised maintenance management system - SAP is the enterprise business application which supports the core processes of asset management, including project management and maintenance. SAP facilitates the flow of information between all asset management functions within Powerlink, including those activities undertaken by external maintenance service providers.
ITOMS	International Transmission Operations & Maintenance Study (ITOMS) This program consists of measuring performance in terms of service level and cost/productivity within transmission operations and maintenance. The methodology is also used for capital spending, asset management, operational processes and key performance indications.
RIN	Regulatory Information Notice. The Australian Energy Regulator collects information from regulated businesses in order to undertake its functions. The AER uses Regulatory Information Notices (RIN) to collect information, at the time it is making a regulatory determination about that business and annually throughout the regulatory period.

1.7 Monitoring and compliance

The Monitoring and Compliance of this framework is achieved by:

- Performing periodic reviews of relevant standards,
- Review of design advice for each project,
- Maintenance services,
- Auditing process,
- Review of maintenance plans and measurement documents (via SAP),
- Undertaking inspections, condition assessments, asset data auditing, pre-work and other risk assessments, and
- Defect reporting as outlined in this document.

This document should be reviewed every three years to ensure compliance is maintained with legislation and industry standards.

1.8 Risk management

To successfully manage Substation assets in accordance with Powerlink's Asset Risk Management Framework, it is necessary to identify and manage a range of hazards and risks. The following tables summarises the identified hazards and their corresponding control measures.

Table 1 - Identified Hazards and Control Measures

Performance Related Hazard	Residual Safety Risk	Risk Control Treatment
Unplanned substation outages	Moderate	• Policies and Procedures • Maintenance Procedures • Emergency Response Procedures
Hazardous step or touch voltages at Substations	Moderate	• Policies and Procedures • Routine testing • Audits • Fault level review
Structural failure in extreme wind	Moderate	• Policies and Procedures • Routine civil inspection • Condition assessment reports • Audits
Foundation integrity	Moderate	• Policies and Procedures • Routine civil inspection • Condition assessment reports • Audits
Mechanical failure of high voltage Equipment	Moderate	• Policies and Procedures • Routine civil inspection • Condition assessment reports • Audits
Mechanical failure of overhead insulator and associated hardware	Moderate	• Policies and Procedures • Routine inspection • Condition assessment reports
Mechanical failure of OHEW conductor (or associated hardware)	Moderate	• Policies and Procedures • Routine inspection • Condition assessment reports
General Deterioration of Components	Moderate	• Design Standards • Equipment Strategies • Maintenance Procedures • Refurbishment Plan • Condition assessment reports • Audits
Catastrophic Failure of Components	Significant	• Maintenance Procedures • Asset Management Plan • Equipment Strategies • Design Standards • Condition assessment reports • Emergency Response Procedures
Incorrectly Performed Maintenance	Moderate	• Maintenance Procedures • Audits • Training
Environmental pollution due to oil leaks or SF6 leaks	Significant	• Oil separation systems • Maintenance Procedures • Audits • Water Samples • SF6 reporting • Online monitoring of SF6 density
Increased noise levels	Low	• Sound enclosures where required • Technical specifications for allowable

Performance Related Hazard	Residual Safety Risk	Risk Control Treatment
		sound levels • Periodic noise measurements

Table 2 – Other Associated Hazards and Control Measures

Other Associated Hazards	Residual Safety Risk	Risk Control Treatment
Lightning strikes	Moderate	• Design Standards
Flood	Moderate	• Design Standards • State Planning Guideline compliance • Policies and Procedures
Acts of Theft and Vandalism	Moderate	• Policies and procedures • Design Standards
Exposure to EMF	Moderate	• Site Radiation Folders • Policies and Procedures • Monitoring of bare hand work levels
Working at Heights	Moderate	• Policies and Procedures • Pre work risk assessment
Unauthorised access to substations	Moderate	• Design Standards for Substation Security • Maintenance Policies and Procedures
Electric shock to personnel	Low	• QEE Safe Access to High Voltage Apparatus • 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 however substation plant also exists at lower voltages for the purposes of providing customer connections, substation local supply as well as for reactive support equipment. A summary of assets that are 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 though various state and federal laws and regulations, connection access agreements, procurement agreements, National Electricity Rules, customer and consumer panels and landholder relations.

2.2.1 Safety Compliance

Powerlink is required to ensure substations are owned, maintained and operated in a manner that is electrically 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 principles). These requirements are aligned in Powerlink's Safety Management System and Electrical Safety Management System.

The Work Health and Safety Act requires 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 design, operation, maintenance, replacement and retirement of 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.

To ensure substations are safe and are operated in a way that is electrically safe, Powerlink has established design and maintenance measures.

Design measures include:

- safety in design as per the Work Health and Safety Act
- adequate perimeter fencing (substation security fence)
- 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
- adequate training for substation entry authorisation
- restricted/controlled access to substations (authorised personnel only)
- asbestos registers
- radiation folders
- mechanical barriers.

Maintenance measures include:

- routine inspections of equipment and security
- monitoring of outage data

- routine earthing system tests
- routine service of major equipment
- routine SF6 and oil sampling where appropriate
- on line condition monitoring as applicable
- working at heights procedures
- condition assessment reports
- restricted access zones when required.

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

2.2.2 Environmental Compliance

Over the asset life cycle, substations are operated and maintained in compliance with relevant environmental legislation.

During the planning and investment phase, environmental compliance issues within an existing or new substation under construction are managed within Powerlink's Environmental Management Systems, based on specific Environmental Management Plans that address the relevant compliance issues for the site and works. The handover of newly constructed assets into the operation and maintenance phase provides a stage-gate that ensures the assets meet environmental compliance criteria and that Environmental Work Plans are established for each site for ongoing management of environmental compliance issues, under a structured approach, that provides mechanisms for continual improvement or refinement of management practices.

In the operation and maintenance phase of the substation asset, significant environmental compliance issues include containment of insulating materials (hydrocarbons and SF_6) and suspended solids, soil erosion and sedimentation, site drainage and noise generated by substation plant.

Powerlink has implemented a range of compliance monitoring strategies that involve:

- establishment of oil containment systems,
- routine testing and sampling of substation oil containment and discharge systems
- monitoring, detection and management of SF_6 leaks using on line SF_6 density trending and specialised detection camera technology
- programs of routine civil inspection to monitor the effectiveness of site drainage and presence of excessive soil erosion and sedimentation issues
- programs of routine substation electrical plant inspection to monitor the integrity of oil containment systems and any other vessels containing insulating fluids
- management of asbestos containing materials
- responsible disposal of contaminated materials and equipment
- provision of oil spill kits
- periodic oil testing to monitor PCB content.

Management of physical access to substations and the surrounding land is addressed within the Land Asset Methodology Framework.

The land inside the substation is managed in the similar way but at different frequency to ensure adequate availability and reliability of electricity supply.

2.2.3 Availability and Reliability of Supply

Powerlink's reliability of supply obligations stem from a combination of our Transmission Authority, associated state legislation and the National Electricity Rules. In addition, the Australian Energy Regulator imposes and monitors a number of performance criteria associated with availability of transmission network critical elements.

For substation assets, a fundamental determinant for reliability and availability of supply involves establishing the optimum 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 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.

On an ongoing basis, Powerlink monitors the performance of substation asset availability using a Forced Outage Database and 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 SAP defect notifications, change in equipment health indices, detailed condition assessments, maintenance audits and on-line monitoring of plant to identify change in reliability of substation assets. In addition, Powerlink produces an Asset Management Plan which is updated on an annual basis and provides an overview of capital investment projects as well as significant operational expenditure. Planned and timely replacement of substation high voltage equipment greatly contributes to the increased availability and reliability of the transmission network.

2.2.4 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 the substation asset 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
- provide accurate metering installations through the installation of instrument transformers consistent with accuracy class requirements
- achieve required fault clearance times through installation of circuit breakers with appropriate operating characteristics, in conjunction with the associated protection system
- supply of adequate AC and DC systems to support required reliability and availability for protection schemes.

2.2.5 Connection Agreements

Connection access agreements specify each customer’s requirements with regards to the availability and reliability of connection which impacts substation connection arrangements and determines 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. Where and when necessary Powerlink will also use Network Support agreements and load curtailment measures . All planned outages are managed and co-ordinated by Network Operations.

From 1 July 2018, a new rule will be implemented, to introduce more contestability for non-regulated connections to the transmission network. This will change the traditional way of progressing connection enquiries and requirements to provide additional public information around connections. This rule change introduces two 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.

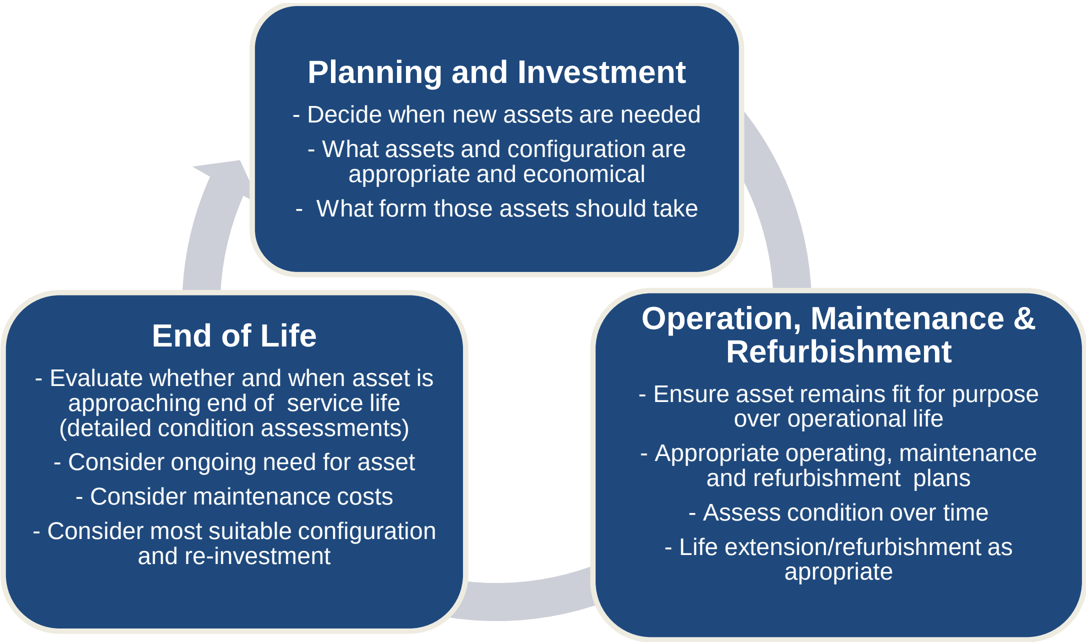
Powerlink will identify whether the proposed connection meets contestability criteria as per NER.

3. Lifecycle Management

Electricity transmission assets 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. In order to achieve the best outcome for its stakeholders, Powerlink must consider the asset's whole of life cost. 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.
- the 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 three main stages:



3.1 The Planning and Investment stage

This stage involves assessment of the network need and property acquisition planning as well as conceptual design of the most suitable substation configuration for the prospective customer's needs, particular environment, function, required capacity, availability and reliability meets customer expectations. Where a major electricity customer is involved, General Manager Business Development is responsible to ensure the customer's needs are communicated and understood and the connection agreement complies with relevant legislation and regulatory framework, especially the NER.

A number of options are considered and costed l 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 stage, all technical details are determined and the required documentation and drawings are produced.

The final phase of the planning and investment stage includes project scoping and estimating. The contestability rule is applied and the required process for public consultation is initiated if required. The final stage is the business case approval.

This is followed by the 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 (Powerlink utilises SAP for both) and final handover.

3.2 Operation, Maintenance and Refurbishment stage

Geographically, Powerlink operates a long, skinny transmission system, most of which hugs the coast of Queensland. There is significant separation between load and generation centres. There is little meshing within the network. Outages are difficult to obtain and must be planned and coordinated carefully to minimise the 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 years, although where customers specify a requirement for connections over a shorter period, this can be achieved by application of modified standards.

It starts with final handover ensuring that all relevant substation plant data are readily available, all relevant training and operation and maintenance documentation is provided to maintenance service providers and that all routine maintenance plans are established. Due to the different failure modes in some types of substation equipment and associated safety risk increase, it may not be possible to achieve 40 years' service life for all substation equipment. The strategy is to replace with alternative equipment that presents reduced safety exposure, if possible and commercially viable.

In contrast substation equipment in some operating context can be fully operational and safe to operate in excess of 40 years. To achieve this, both their condition and performance have to be monitored with relevant activities undertaken to ensure their optimum performance. Such activities may include, but are not limited to routine maintenance, condition based, emergency and deferred corrective maintenance, partial component replacement and/or life extension, equipment modifications, desktop and detailed condition assessments, technical 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. These can be made through Refurbishment 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 extend life of power transformer
- replacement of circuit breaker operating mechanisms or their parts to achieve expected service life.

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.

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.

3.2.1.1 Routine scheduled

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, condition monitoring, and testing. 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 policy. All equipment will remain live during an RSM.

3.2.1.1.2 Service Level Maintenance

Service Level Maintenance is conducted on specified plant in accordance with the appropriate maintenance policy, and generally consists of more detailed and focused non-invasive condition monitoring and testing tasks, such as contact resistance checks, or the collection of oil or gas samples for dissolved gas analysis (DGA) testing. Where practical, service level maintenance is carried out on live equipment however planned outages will be required on most equipment.

3.2.1.1.3 Overhaul

Overhauls are conducted on specified plant in accordance with the appropriate maintenance policy. Overhauls are generally invasive requiring a planned outage.

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 performance of substation plant that will, if allowed to continue, result in asset failure sometime in the future. Condition Based Maintenance restores the condition or performance of the asset to an acceptable level before failure occurs. Reduction of planned outage time and cost to carry out condition based maintenance is a major objective. This will be achieved by:

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

3.2.1.3 Emergency Corrective

Emergency corrective maintenance is the immediate work that must be performed to minimise the danger to personnel and equipment and to restore the system to service. The emergency work is typically initiated through Network Operations requesting that staff be immediately called out to rectify a situation.

3.2.1.4 Deferred Corrective

Deferred corrective maintenance is all work associated with rectifying an unacceptable plant condition to an acceptable condition, 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 plant failures.

3.2.1.5 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 the recommendations are submitted where potential encroachments are noted.

Table 3 - Asset Maintenance Types

Maintenance Type		Activity	Frequency
Preventative Maintenance	Routine Preventative Maintenance	Routine Substation Maintenance	6 months
		Routine Civil Inspection	Annual
		CB Service	6/12 yearly
		CT/VT Oil Sampling	3 yearly
		Isolator/ES Service	6/12 yearly
		Power Transformer Service	6 yearly
		Tapchanger Service	6 yearly
		Power Transformer – Oil Sample	2 yearly

Maintenance Type		Activity	Frequency
		Bushing Testing	6 yearly
		Power Transformer OTI/WTI Testing	6 yearly
		Earth Grid Injection Testing	10 yearly
		Infra-Red Inspection	2 yearly
		Oil Containment System Service	2 yearly
		Switching and Safety Equipment Testing	6 monthly
		Update of fault level signage	1 yearly
		Inspection of overhead hardware and earth wire attachments inside substation security fence	5 yearly
	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
		Corrosion treatment on structures and plant	
		Site infrastructure repair e.g. Erosion on roadways, painting of building	
		Substation signage and on site drawings update	As required, generally indicated by results of routine inspection or testing
Corrective Maintenance	Emergency	**Immediate** work that must be performed to prevent danger to personnel, equipment or system performance	Initiated through Control Centre requests
	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.	

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 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), replacement of battery banks if they fail routine test, etc.

3.3 End of Life

End of Life involves the actions required to either de-energise or plan the timely removal and disposal of an asset that is no longer required for successful operation of the network, has reached a level of unacceptable risk if it were to remain energised, or has actions required to replace it with new asset.

4. Asset Management Drivers

Substation plant assets represent a significant percentage (between 30% and 40%) 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. This can only be achieved by setting appropriate asset management strategies from the beginning of each substation's lifecycle. Powerlink assets live in a dynamic environment that needs 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
- 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 (innovation).

External Influencing Factors

- Demand and energy consumption
- Changes in electricity generation sector
- Innovation and technology
- Environment and duty
- Emerging issues
- Change of legislation and/or engineering standards
- Change of customer 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. A number of substation assets fail while in service typically as a result of random or inherited design failures.

Powerlink's' asset management system aims to minimise the number of such failures. 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 health indices. These are updated on an annual basis. Based on these and additional information provided by maintenance service providers and availability and forced outages reports, desktop and detailed condition assessments are initiated. Condition assessment provides an indication 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 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 combine into functional groups that make up individual assets and the assets combine together to comprise a substation.

Powerlink applies condition assessments to assess the risks associated with 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 refurbishment or reinvestment where this is considered necessary. Difficulties associated with obtaining access to operational assets and associated costs may results in Powerlink carrying out replacement or major refurbishment projects at the asset level or even at a substation level. The economic analysis indicates that the replacement of the individual plant items in a piecemeal fashion may not always result in the optimum cost savings. For this reason it is important to consider all options for replacement or major refurbishment.. The substation plant methodology includes condition assessment activities at each level to enable this to occur. These activities are initiated and managed by Powerlink's Substation Asset Strategy team.

The replacement strategy always considers use of modern or improved technological solutions for substation equipment which can reduce safety risks, improve availability and reliability or reduce environmental footprint. These improvements are driven by Substation Asset Strategy team through development of specific 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 buildings, roads, fences, switchyard lighting, oil separation systems, noise enclosures, substation auxiliary supply, and direct current supply 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 annually using equipment health indices. This information is used to identify corrective and condition based maintenance programs, as well as to initiate desktop and detailed condition assessments. 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
- number of initiated alarms.

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 equipment population. Application of health index requires engineering expertise, statistical data and judgement. 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 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 now, or in the near future to form basis to plan their repair, refurbishment or reinvestment. Health index information is used to identify outliers 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
- provide an input for:
    - life extension,
    - corrective and condition based maintenance recommendations,
    - high level scope of work for refurbishment, or

- re-investment into 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 a 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 installation of semi pantograph disconnectors, ultimate substation layouts, investigations of various life extension methods, investigation of emerging issues (such as copper and silver corrosive sulphur phenomenon) and any other innovative ways of using new 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

4.3.2 Connection of renewable energy sources

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 the increased number of substations and increased complexity in managing assets with varying expected service lives.

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 computing 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 safety risks

It also 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 in Queensland climate conditions

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.

4.3.4 Use of Unmanned Aerial Vehicles (UAV)

Powerlink is currently evaluating the use of autonomous UAV inspection techniques inside substations. The benefit is potential efficiency in utilising UAV's in Powerlink substations through increased quantity of inspections, emergency management and reduction in risk to personnel. Powerlink also has obligations under Work Health and Safety legislation to ensure that UAV's do not pose a risk to staff, equipment and members of the public.

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 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 diesel generators.
- appropriate insurance spare levels.
- arrangements to share spares with other Transmission Network Service Providers where applicable.
- contingency plans in place where required.
- flood monitoring measures.

5.2 Network Security

Substation security needs to take into account the different levels of threat posed to an asset of this type. The transmission network is part of National Critical Infrastructure and higher levels of security measures are required at major substations to meet minimum standards of overall security. 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.

Additionally, all substation security needs to meet a minimum standard to ensure public safety.

Powerlink will continue 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.

The 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, locating strategic spares, 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 Strategy Group, Incident Management Groups, Construction Management, the Project Team and the Maintenance Service Providers 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 Technical Training

Operation and Services Delivery (OSD) provides a strategy for the delivery of technical training to reinforce key concepts and strategies with service providers across the asset lifecycle. Technical training is initially delivered by plant manufacturers or their agents.

Powerlink has an obligation to ensure that training is available for Maintenance Service Providers so that they are competent to perform work on all transmission assets, including those newly introduced.

6.5 Documentation

The Substation Strategies Team conveys asset management requirements through the Substation Asset Methodology framework and a number of asset management documents that are reviewed every two years and promote the development of documentation and field guides to ensure substation plant strategies remain relevant and are in accordance with good industry practice.

6.6 Strategic Linkages

The Substation Asset Strategies team develops and maintains strategic linkages internally within Powerlink and with the relevant stakeholders in order to ensure a seamless integration of network topography is maintained.

Alignment is maintained between Principal Maintenance Service Providers such as Energy Queensland and Operation & Service Delivery, to ensure consistency in the provision of maintenance services.

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 power research institutes (such as EPRI and CEATI) as well as participation in various CIGRE bodies of work ensures the strategy can be kept up to date with technology developments.

6.7 Benchmarking

Powerlink participate in benchmarking with other worldwide located electricity entities through bi-annual data submission via ITOMS.

In addition RIN (Regulatory Information Notice) are analysed and benchmarked with other TNSPs in Australia.

7. Health, Safety and Environment

The design and implementation of substation plant maintenance strategies incorporate Powerlink's Health, Safety and Environment Policy and Powerlink's Safety Management System. 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;
- containment of sulphuric acid in batteries;
- presence of asbestos in older buildings and equipment; and
- management of vegetation inside and outside substations.

8. Forward Planning

A ten year forward plan is prepared per regional area and network segments basis, outlining the projects by type, location and expected completion date as well as scheduled condition assessments.

All routine maintenance plans are entered into SAP by outage group. These are combined with project outages and assessed 12 months in advance to minimise requirements for outages and ensure network security is maintained

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
- Equipment specifications and copies of equipment purchase orders
- Equipment O&M Manuals
- All Civil Design drawings and structural calculations
- All Electrical Design drawings
- 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