Energy Infrastructure Investments

Directlink Joint Venture

Directlink
Revenue Proposal

Attachment 9.3

Phacelift Consulting
Bottom Up Cost Study

Effective
July 2015 to June 2020

May 2014

Bottom Up Cost Study

Operational Expenditure Forecast

Directlink

(High Voltage DC Link)

Prepared for
Directlink Joint Venture

May 2014

Operational Expenditure Forecast for Directlink

Contents

Executive Summary

The Directlink Joint Venture ('the Company') is required to submit a proposal to the Australian Energy Regulator (AER) for a transmission revenue determination covering the 5 year regulatory period July 2015 to June 2020 ('the revenue submission"). The Company engaged Phacelift to assist in the preparation of this revenue submission. Phacelift has prepared an Operational and Maintenance Model ('O&M Model) to forecast direct costs incurred by the Company. The intention is for the Company to include the results of the O&M Model in their submission to the AER.

In November 2013 the Company submitted a request to the AER proposing to use a bottom up cost study rather than the 'revealed cost' method in their revenue submission. The AER accepted this request.

This report explains how Phacelift has produced a bottom up direct operational and maintenance expenditure ('O&M Direct Cost') for the revenue submission.

Phacelift's approach commenced with a diagnostic review of the Company's Directlink maintenance practices using two lines of enquiry. The first line of enquiry focussed on the Directlink technology and related services. The second line of inquiry focussed on the processes and resources deployed for operating and maintaining the Directlink asset. By breaking down the Directlink technology into its smallest items, patterns suitable for modelling were identified (as explained in Appendix B). Similarly, by breaking down the key processes and resources to lower levels the effectiveness and appropriateness of these elements could be assessed. From these two streams of enquiry, the analysis found maintenance practices to be reactively based due to multiple and frequent faults of Directlink components (particularly HV DC cables and Integrated – Gate Bipolar Transistors) – the reactive maintenance practices were forced upon the Company as a result of the unpredictable nature of the component failures, as it disrupted the planned maintenance practices.

It was observed that the frequent faults had lowered the reliability of Directlink. To prevent a continuation of this lower reliability (or a further deterioration in reliability) the Company has:

(a) instigated a CAPEX strategy to refresh the critical components of Directlink, and
(b) commenced a review of maintenance processes and resourcing to better apply maintenance practices.

It is envisioned that these steps will put a line under the low level of reliability and return Directlink to the initial level of reliability. The O&M Model has incorporated the direct cost of undertaking the revised maintenance processes with the additional resources.

The 5 year regulatory forecast has been prepared using 2013/14 costs ('the reference year'). Costs that were incurred earlier than this year have been referred to this year using appropriate escalation factors. This approach has provided a reasonably transparent method for tracking cost inputs and providing an audit trail for the revenue submission. The total direct cost forecast by the O&M Model is shown in the following table:

Table 1: Total direct cost forecast by the O&M Model

Budget	No escalation from 2014$	Escalated from 2014$
2015/16	$3,485,361	$3,578,335
2016/17	$2,873,302	$3,029,946
2017/18	$2,947,670	$3,191,699
2018/19	$2,894,263	$3,218,478
2019/20	$2,921,368	$3,336,174
Total	$15,121,964	$16,354,632

Phacelift's methodology in producing these values is explained in Appendix A of this Report, which is supported by an O&M Model (developed in Microsoft Excel). The Excel Workbook contains over 70 worksheets. A list of the worksheets in provided in Appendix C of this Report. The process maps and organisation structure analysis associated with the second line of enquiry are shown in Appendices D to G.

1. Bottom Up Cost Study

Introduction

The AER has provided the Direct Link Joint Venture ('the Company') with a Regulatory Information Notice regarding the information to be presented to the AER in relation to a transmission revenue determination for the 5 year regulatory period commencing July 2015.

In November 2013 the Company submitted their forecasting methodology to the AER. The submission requested that the Company be permitted to use a bottom up cost analysis, rather than a 'revealed cost' analysis in its regulatory submission. The AER has permitted the Company to use the bottom up analysis approach.

The Company engaged Phacelift[1] to assist in preparing the regulatory submission. The scope of work required Phacelift to prepare a direct cost forecast of the O&M expenditure in the 5 year regulatory period using a bottom up cost study methodology. The direct cost forecast was not to include insurance, corporate costs, and other similar costs. Phacelift has undertaken a bottom up study to prepare an O&M Direct Cost that can be used by the Company as part of their Regulatory Reporting Statement.

This report describes the approach and details of the cost study undertaken by Phacelift. It is supported by an O&M Model (in Microsoft Excel), and by process analysis associated with Directlink maintenance practices.

This report contains a summary of the O&M Model (Appendices A and B). It also contains a view of the Directlink maintenance cycle (Appendix D), and process maps for the Maintenance Management Information System and Condition Monitoring, both of which play a role in the maintenance cycle (Appendices E and F respectively).

Appendix G shows the current Directlink organisational structure, along with a revised structure for the period 2015/16 to 2019/20 and a brief statement of responsibilities for each role.

Qualifications of the consultants

This report was prepared for Phacelift by Peter Egger and Dr Martin Gill. Peter has a Bachelor degree in Electrical Engineering (UNSW), a Post Graduate Master degree in Business Administration (AGSM) and a Post Graduate degree in Risk Management (Monash University). Between 1964 and 1996, Peter worked for Pacific Power (a NSW electricity generation and transmission company, with generation capacity of 12,000MW) as an engineering specialist, engineering manager, and senior manager in business administration activities, gaining wide experience in the electricity industry and government reform programs. Functional experience at the engineering level included Power System Development, Power System Operation, substation and transmission line design, substation construction, technical services including protection, metering, communications and HV testing, and power station maintenance. This background provided a sound platform for entry into business and management consulting activities in 1997. Peter has undertaken consulting working in good business practice for the last 17 years.

[1] Phacelift Consulting Services Pty Ltd

Martin graduated with a Bachelor of Engineering (Honours) in Electrical & Electronic Engineering and a Bachelor of Science in applied mathematics and computing science, both degrees from the University of Adelaide. Dr Gill has a Masters degree in Military Electronic Systems Engineering (from Shrivenham UK), and a Doctorate in Information Technology (University of South Australia). Martin has lead product development teams across a broad range of industries including electricity metering and fault monitoring equipment for high voltage distribution networks. Since moving into consulting Martin has undertaken due diligence reviews of major utility projects. He has also worked with clients to develop cost benefit analysis models for a range of utility clients.

Both Peter and Martin are well suited to undertake a diagnostic study of the Directlink asset and to translate that study into an O&M direct cost using a bottom up methodology.

Curriculum Vitae are included in Appendix I.

Approach

Phacelift's approach to the Bottom Up Cost Study commenced with a diagnostic review of the Company's maintenance practices to form a view on the nature of the maintenance practices deployed by the Company and how those practices would contribute to the O&M Direct Cost forecast. The diagnostic review used two lines of enquiry. The first line of enquiry examined the Directlink technology and maintenance applied to this technology. The second line of enquiry focused on the processes used and resources deployed by the Company to address the unique nature of the Directlink assets.

Directlink technology

The starting point for the examination of the Directlink technology was the Single Line Diagram (schematic of the converter stations). The Single Line Diagram shows the equipment used in the Directlink HVDC link (Appendix B lists identified components). Before examining the Single Line Diagram, an understanding of the electrical context of Directlink had to be formed. This context is shown in the high level schematic diagram in Figure 1:

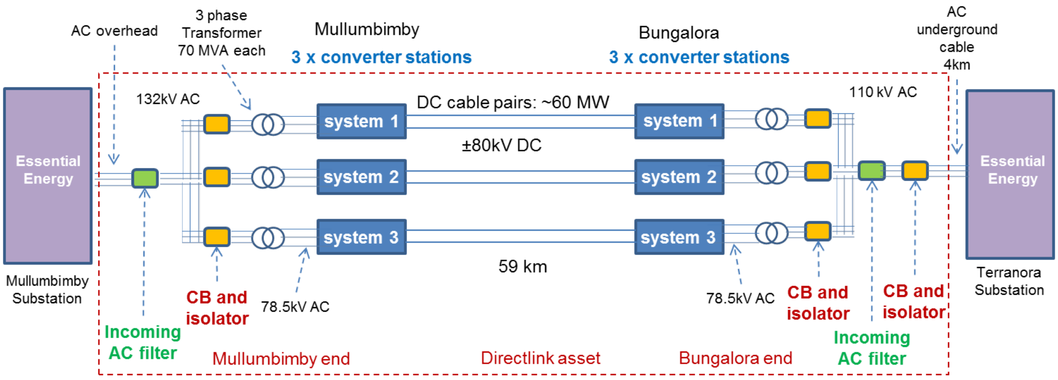


Figure 1: Electrical context for Directlink

At the highest level, Directlink consists of three separate connections between Essential Energy's Mullumbimby and Terranora substations. Each DC connection requires a pair of converter stations (a total of six converter stations). Directlink uses three DC cable pairs to connect the AC substations. The key point in this figure is the large number of components used in the conversion from AC to DC and back to AC in the Directlink asset.

Within this context, a Single Line Diagram (representing one of the connections) was available. The Single Line Diagram allows individual components of equipment that make up the Directlink asset to be identified. A component breakdown analysis was performed using this source of information. In the O&M Model the worksheet tab 'Components in Schematic' shows the analysis of the Single Line Diagram. This analysis identifies the various components and number of each. The adjacent tab 'Grouped Components' summarises the total counts of similar components. These Grouped counts are then transferred to the appropriate component worksheet.

The component breakdown considers the three phases on the AC side and the three poles on the DC side. From the Single Line Diagram an AC Circuit Breaker (within the Converter Station shown in Figure 1) breaks down into a total of 18 identical single phase components for the six converter stations.

The component breakdown analysis was undertaken in two ways. In one approach similar components were grouped together along with the total number in the Directlink system (as shown in Appendix B). In a second approach the components were laid out as consecutive items per asset class (e.g. circuit breaker). The first approach was used to produce the O&M Model and the results contained in this report. The second approach was used as a cross-check to validate the inputs used in the model.

After the breakdown had revealed the number of components in use within Directlink, it was necessary to identify the maintenance applied to each component. Several sources where used. These included the Company's automated maintenance management information system (Maintenance Connection), documented maintenance procedures (including work instructions), invoices from contractors undertaking the maintenance and discussion with the Company's staff.

The model's methodology was then applied to the information on individual worksheets associated with preventative maintenance tasks, resulting in itemised results across many worksheets (see worksheet tabs labelled 0000 to 0180). The model includes additional worksheets to capture the costs of other activities undertaken by the Company's staff in the maintenance of Directlink. For example these worksheets describe the activities required to undertake Cable Repairs and to provide Site Security. A full list of the worksheets is presented in Appendix C.

Each worksheet lists the preventative maintenance tasks applied to the identified component as obtained from the Company. Through discussions with the Company's staff and a review of Original Equipment Manufacturer (OEM) information, the time required to undertake the listed maintenance was identified. Using the number of components and the time to undertake the maintenance (or the invoices presented by contractors, or a combination of both), it was possible to calculate the cost of those tasks. When this was combined with the frequency of the maintenance the total O&M Direct Cost for the identified components was calculated.

Types of maintenance events

The scope of work required Phacelift to identify operational and maintenance costs for preventative, corrective and unforeseen maintenance.

APA use Maintenance Connection as their Maintenance Management Information System (MMIS). Maintenance Connection stores details of preventative maintenance tasks and the schedule of when these tasks should be undertaken. As such preventative maintenance tasks were readily identified and highly traceable (Maintenance Connection is discussed in Appendix A).

Both corrective and unforseen maintenance tasks are recorded in the MMIS as Corrective Maintenance. The O&M Model has identified and described a range of tasks which have been entered into the MMIS as Corrective Maintenance tasks, for example the O&M Model captures costs associated with Cable Repairs, IGBT Replacement and Control System Repairs. This means that there was no need to separately forecast corrective and unforseen maintenance tasks. Directlink process maps

Maintenance of an asset relies on an integrated set of processes and resources. The second line of enquiry focused on understanding the current set of maintenance processes and their supporting resources, including a view on what was desired as good practice for Directlink.

The key processes were identified as:

- The Directlink maintenance cycle[2] (Appendix D);
- The Maintenance Management Information System and how it was used (Appendix E).
- The Condition Monitoring process and how it was deployed (Appendix F).

The supporting resources were identified as:

- The current organisational structure;
- The future organisational structure;
- Role responsibilities for the 5 year regulatory period.

Phacelift developed the process maps based on good business practice, as customised for the unique maintenance environment presented by the Directlink asset. The process maps were prepared in consultation with the Directlink maintenance staff. The process maps provide the pathway to ensure sustainable operation of the Directlink asset.

The key resources were identified in their current state and in a subsequent state that would permit the Company to efficiently manage the Directlink technology across the 5 year regulatory period (refer to Appendix G). Phacelift developed the resource structures based on an assessment of current practice, current job descriptions approved by the Company and good business practice. The structures and roles were prepared in consultation with the Directlink Operations Manager.

Clarification

The Company subcontracts the operating and maintenance of Directlink to APA Operations (EII) Pty Ltd (APA) who provides the resource to perform the Operation and Maintenance work on Directlink.

Phacelift has assumed that:

- any cost information provided by the Company without documentary evidence is anecdotal.
- all anecdotal cost information provided by the Company excludes GST.

[2] The maintenance cycle is made up of a range of key processes, underlying information systems (Maintenance Management Information System and FRACAS) and resources to support those processes and systems.

Where maintenance related information was provided by the Company with supporting evidence of its authenticity, the source of that information has been recorded. Where anecdotal (that is, without documentary evidence[3]) maintenance related information was provided by the Company the reasons for adopting that information (or a considered variation) are discussed in Appendix A and are identified in the O&M Model. Where Phacelift provided information that was required in the model but was not available from the Company, the reasons for adopting that information have been recorded in Appendix A and/or the O&M Model.

[3] Anecdotal cost information is information obtained from subjective sources, where the information is examined on a case by case basis for the extent of its objectivity.

2. Summary of findings – Operation & Reliability of Directlink

It was found that Directlink has had the following operating history:

- Directlink was commissioned in mid-2000 with three systems in service.
- APA took control of the asset in 2006.
- In 2007 a phase reactor failed a Bungalora.
- In 2008 the remote control room operations were moved to APA in Victoria.
- From mid-2012 the out-sourced maintenance provider (Transfield) did not renew the maintenance contract. At that point, the Company chose to source the maintenance internally.
- In July 2012 a phase reactor failed a Bungalora.
- In August 2012 one of the converter stations at Mullumbimby was destroyed. Directlink was operated on only 2 systems from that time onwards.
- In August 2013, all three systems were taken out of service to assist in the repair of the new converter station.
- Since 2000 there have been 138 cable faults (just under one per month).
- In the past 5 years there have been 195 IGBT failures (just under 40 per year)

The diagnostic review found that the reliability of Directlink was currently at a low point in its service life. This is due to the series of events mentioned above. The consequence of this finding was to recognise:

(a) that repeated faults were forcing the Company's limited maintenance resources into a reactive maintenance mode because planned maintenance schedules were constantly being disrupted; and

(b) Additional resources and processes (supported by appropriate CAPEX projects) were needed to be introduced by the Company if it was to turn around the declining reliability and restore the asset to sustainable operation.

3. Summary of Findings – maintenance cycle and associated resources

The diagnostic review examined the maintenance process and resources deployed for Directlink. Existing maintenance practices were blended with experience to identify practices that should be in place. The resulting processes and required resources are shown in Appendices D to G.

The analysis of maintenance processes and associated resources revealed that the Directlink maintenance practices were formed largely at the time of handover from the outsourced maintenance contract in mid-2012. Whilst some parts of the process have changed, the changes were mostly superficial.

For example, the preventative maintenance schedule was moved from a spreadsheet based record to an APA wide database, Maintenance Connections – however, the content of the schedules had not changed during or since that transfer.

An examination of the role of the Maintenance Management Information System (using the Maintenance Connections database) revealed:

- increased numbers of corrective maintenance work orders were being generated compared to preventative maintenance work orders due to the excessive fault conditions;
- maintenance results associated with completed work orders were not being electronically archived.
- photographic information to provide future evidence of the condition of an asset were not being collected.

An examination of the Condition Monitoring process revealed many parts of the process that were not being addressed. APA's intention to introduce a formal condition monitoring process was noted with the purchase of the FRACAS database, but the reactive maintenance environment prevented any resources from utilising that software, or introducing the culture that was needed for a condition monitoring process to flourish.

There was evidence that APA staff recognised the need for accurate and up to date maintenance documentation, but the evidence also supported the view that this task was extremely difficult when operating in a reactive mode. The preparation of quality documentation requires a skilled document writer who has an appreciation of work practices and who can facilitate and mobilise subject matter experts to create and maintain meaningful documents.

Based on the view that Directlink should be returned to sustainable operation, the Bottom Up Cost Study has been developed on the basis that the Company has adopted the maintenance practices identified in the process maps and the additional resources identified in the proposed structure. The O&M Model includes estimates of the additional resources to sustainably operate the Directlink asset.

4. Summary of Findings – O&M Direct Costs

The bottom up study examined the operational and maintenance (O&M) expenditure of the Directlink High Voltage Direct Current (HVDC) link for the 5 years July 2015 to June 2020. This study estimates the O&M cost to be $16.354 million. The breakdown of expenditure in each of the five years is shown in Figure 4.

The bottom up study analysed 60 operational and maintenance costs. The most significant contributors to O&M costs are listed in the following table.

Table 2: Most significant contributors to O&M Direct Cost in the period July 2015 to June 2020

Category	Cost (2014$)
ELECTRICITY COSTS	$3,816,967
CABLE REPAIRS	$2,030,267
CONTROL ROOM OPERATIONS	$1,111,356
OPERATIONS MANAGER	$811,138
SENIOR RELIABILITY ENGINEER	$729,617
RELIABILITY ENGINEER	$698,889
PHASE REACTOR MAINTENANCE	$570,176
WORKS PLANNER	$565,289
WORK PRACTICES SPECIALIST	$565,289
VEGETATION MANAGEMENT	$502,098
POWER TRANSFORMER MAINTENANCE	$460,285
CIRCUIT BREAKER MAINTENANCE	$398,815
TRAVEL	$394,698
SITE SECURITY	$316,026
REMOTE COMMUNICATIONS	$287,808
CONTROL SYSTEM REPAIRS	$218,097
REACTOR MAINTENANCE	$212,866
OTHER COSTS	$201,369
INCIDENTAL INVESTIGATIONS	$179,573
ENERGISED MAINTENANCE INSPECTION	$178,693
AIR BLAST COOLER MAINTENANCE	$172,301
DIAL BEFORE YOU DIG	$168,226
FIRE SPRINKER SYSTEM	$150,272

Notes:

- Costs associated with the roles of the O&M Supervisor and Maintenance Technicians are allocated across many of the identified items.
- The figures are presented in 2014$ (that is yearly escalation has been applied).

Discussion of the O&M Costs in each category

Appendix A of this report discusses the most significant contributions to the O&M Direct Costs shown in Table 2. The discussion includes assumptions used in the O&M Model. The discussions are limited to those contributions with a material impact on the final O&M Direct Cost (for example the number of cable faults per year). Where gaps in information arose that could not be substantiated with documented evidence, Phacelift estimated information to fill the gaps. The estimated data is identified and reasons / assumptions provided to justify the estimates.

Appendix B presents a summary of component counts used in the O&M Model arising from a detailed analysis of the Single Line Diagram.

The O&M Model uses Microsoft Excel. Identified maintenance tasks are entered on their own 'costed' worksheet. The costed worksheets cover all the components (as well as associated services such as vegetation management) to which the maintenance is applied. These maintenance costs are then summarised in accordance with AER requirements.

Appendix A - Bottom Up Cost Study

Discussion of Findings

The following figure plots the total O&M Direct Cost for all the studied categories in the AER period.

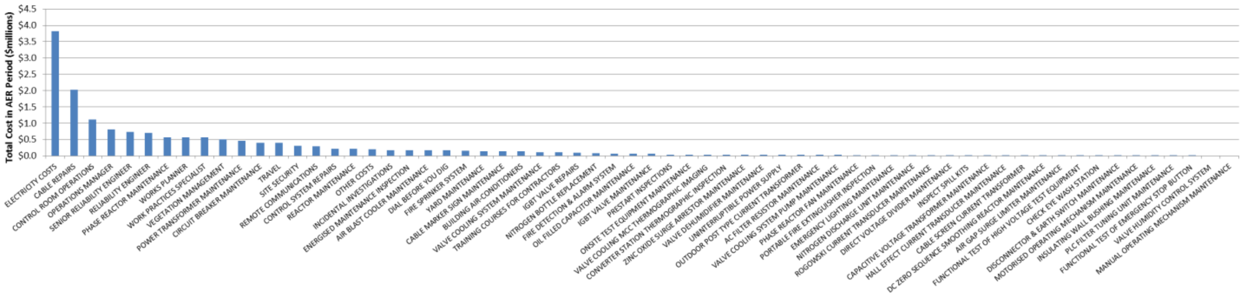


Figure 2: O&M Direct Cost contributions for each costed worksheet in the AER period

The first item in Figure 2 is Electricity Costs. Electricity Costs at the two sites contributes 23% of total O&M Direct Cost. The top twenty categories account for 87% of the total O&M Direct Cost. The following figure shows the categories with the most significant contribution to the O&M Direct Cost (figures are in $thousands).

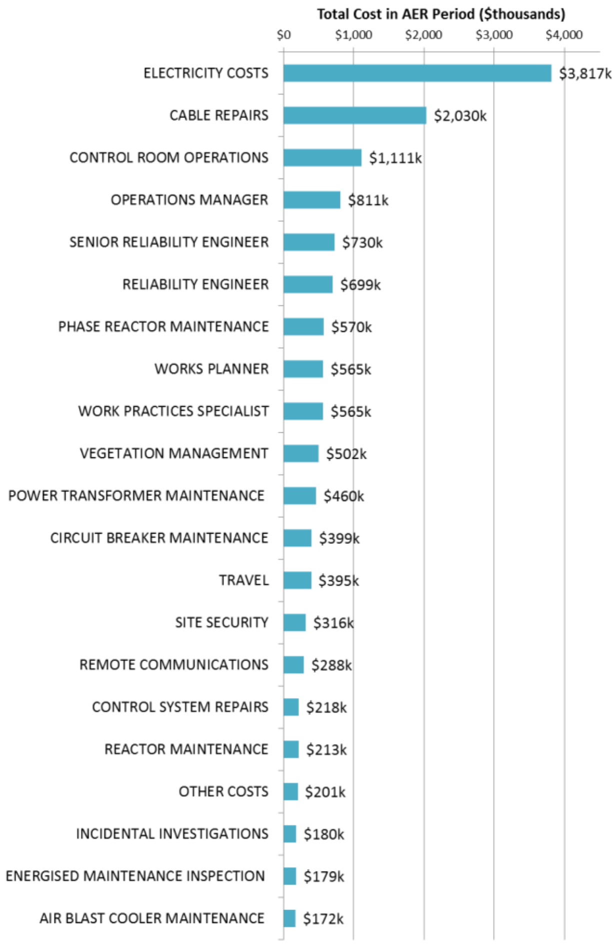


Figure 3: Plotting the O&M Direct Cost categories shown in Table 2

The following figure plots the O&M Direct Cost in each year of the AER assessment period.

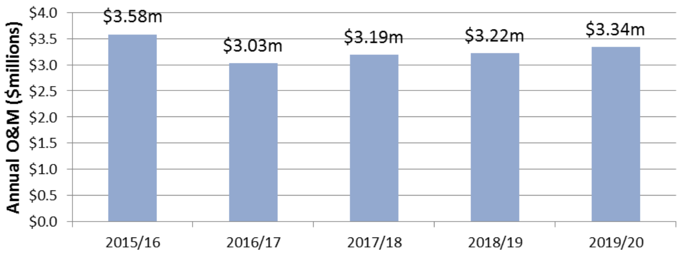


Figure 4: Total O&M Direct Cost in each year

Figure 4 shows the total expenditure in each of the AER years. While average expenditure is $3.271 million the figure shows higher expenditure in 2015/16. This higher expenditure is predominantly due to 15 year preventative maintenance being required on two components (Circuit Breakers and Reactors).

The O&M Model has broken the direct costs into four categories: APA staff costs (Labour), APA material costs, Contractor Labour and Contractor Materials. This is shown in the following figure.

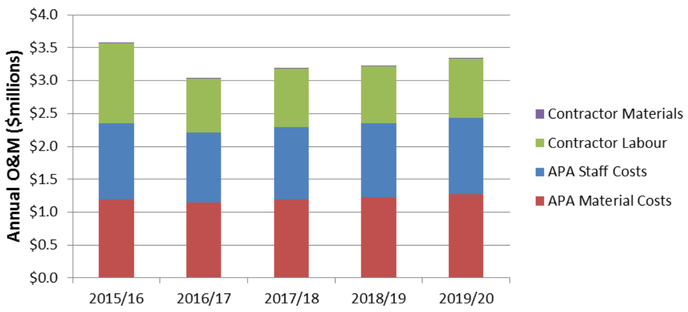


Figure 5: Total O&M breakdown

The Contractor Materials was not able to be separated from Contractor Labour in the invoices provided by APA. As a consequence costs identified under Contractor Materials are too low. At the same time the costs for Contractor Labour are too high, as they include contractor materials. The majority of these costs are Contractor Labour hence the O&M Model has applied the labour inflation rate (which is the lower rate of inflation) to both labour and materials (this is discussed in Modelling Assumptions). The inability to separate material costs means that the estimated O&M Direct Cost is slightly lower than if contractor material costs had be separately identified.

Reasons for a Bottom Up Cost study

The AER's revealed cost method requires the identification of a year of historic O&M which accurately reflects the cost to efficiently operate and maintain the asset. For a number of reasons this was not possible.

Changes to Outsourced Maintenance Arrangements

Prior to 2012 preventative maintenance on Directlink was largely undertaken by a single contractor, Transfield. When this maintenance contract was due for renewal Transfield chose not to renew. It is understood that this decision was partly due to the peaky nature of the Directlink maintenance and to the need for their staff to travel to the two remote sites. The peaky nature of the maintenance work occurs because the majority of preventative maintenance tasks are scheduled during two planned outages of around a fortnight each. During these intense periods of work Transfield were required to bring a considerable number of staff to the two sites. In contrast resource planning for the typical Transfield contract is much simpler requiring relatively constant person-hours throughout the year.

Transfields's decision not to extend the contract has meant that APA is now undertaking more active management of the preventative maintenance tasks. As a point of clarification Transfield used to outsource technically complex maintenance work. APA have formed a relationship with the same specialists that Transfield employed, for example Thearle Pty Ltd have been employed to undertake the specialist electrical maintenance work. More recently APA have signed a contract with SAE to undertake similar specialist electrical maintenance work.

After finding a number of issues with various items of equipment APA have contacted the Original Equipment Manufacturers (OEMs) and use them to undertake highly specialised maintenance. This includes the power transformers (Wilson), dehumidifiers (Munters) and circuit breakers (ABB).

Maintenance work using the new mix of contractors had not fully settled when a major fault occurred at Mullumbimby.

Changed Cable Repair Strategy

On average Directlink has experienced one cable fault each month that it has been in operation. In the second half of the first decade, the number of faults started to increase. It was observed that faults would occur in close proximity to earlier faults. As a result in July 2010 APA introduced a new cable repair strategy (which is discussed in detail under Cable Repairs). In addition an improved design of cable joint is being used during cable repairs. The two changes appear to have stabilised the number of cable faults.

Reduced Operations

In August 2012 there was a fire at one of the three Mullumbimby converter stations. The fire completely destroyed the converter station on System 1. Between August 2012 and July 2013

Directlink continued to operate however with reduced capacity. In August 2013 the decision was made to cease operation of the link until several critical maintenance tasks were undertaken[4].

As a result of the fire APA commissioned several reviews including an examination of their maintenance strategy. These reviews have led to a significant revision of several maintenance procedures, most notably around the phase reactors (these changes are discussed under Phase Reactor maintenance).

Replacement Converter Station

The replacement Mullumbimby converter station is due to be commissioned in August 2015. This is a different design to the original five converter stations. The design of this new converter station is being developed by the system designer. Once the documentation for the new station is released, its maintenance requirements will be entered into Maintenance Connection and new maintenance procedures will be documented.

Summary

The combination of new maintenance procedures on new equipment being undertaken by new contractors means that it was not possible to identify a suitable base year for the revealed cost method. Instead the Company (in consultation with the AER) chose to use a bottom up cost study.

Introduction to the bottom up cost study

An early assumption was that the majority of the maintenance costs would be identified by examining the scheduled maintenance of each component.

To date the maintenance strategy for the Directlink HVDC equipment has followed the system designer's recommendations. This recommends annual inspections much like regularly checking car tyre pressures or the oil level. Less frequently the system designer recommends performing more detailed checks, often requiring actual measurements of the components.

It is worthwhile highlighting that the system designer's recommendations were not based on well-established field experience. When commissioned in 2000 the Directlink HVDC equipment was only the second installation of a new (and at the time unproven) converter technology.

In the case of Directlink inspections often reveal the need for further work. For example the system designer recommends that the oil filled capacitors are checked annually for oil leaks. Oil leaks are an indicator of pressure build up inside the capacitor so when an oil leak is detected the capacitor must be replaced.

In addition to component failures identified during routine inspections APA have experienced other issues not envisaged by the system designer. To address these issues APA have found it necessary to undertake more frequent and/or more extensive preventative maintenance on a number of critical components.

[4] The link was turned on again in February 2014 but two cable faults have since restricted operations.

Maintenance Connection

APA uses an automated tool to help manage scheduled maintenance of all their assets. This uses a commercial software package called Maintenance Connection. Maintenance Connection stores all the components requiring maintenance along with a schedule of how often the maintenance is required.

Maintenance Connection notifies the Maintenance Coordinator[5] of required maintenance tasks 45 days before their due date. At this time, Maintenance Connection automatically assigns the maintenance request to the O&M Supervisor who determines how best to undertake (plan and schedule) the maintenance.

To reduce the number of planned system outages the O&M Supervisor groups maintenance tasks. For the Directlink asset APA plan two major maintenance periods each year around March and September. The O&M Supervisor negotiates with the contractors required to undertake the numerous maintenance tasks in the allocated time.

Figure 6 shows a Programmed Maintenance Identifier from the Maintenance Connection system and how the various fields are interpreted.

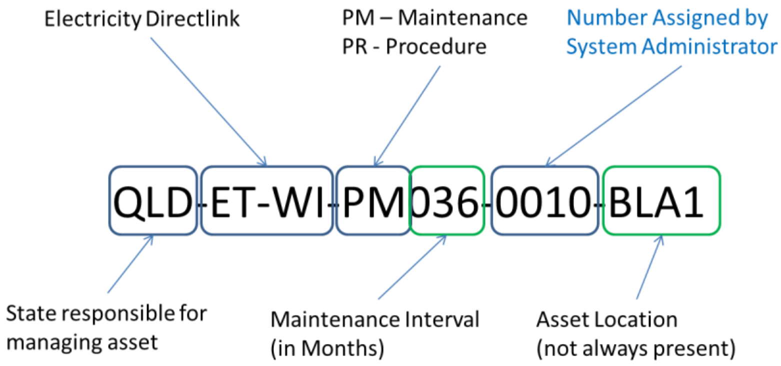


Figure 6: Decoding the Preventative Maintenance Identifiers (used in Maintenance Connection)

There are a number of advantages of using Maintenance Connection as the starting point for this analysis.

Maintenance Connection lists the frequency of each of the maintenance tasks and when the maintenance was last performed. Using these two values it is a simple calculation to determine if, and how many times, a particular maintenance task will be performed during the AER assessment period of July 2015 to June 2020.

Maintenance Connection offers a means to group individual items into similar components types. In this way Maintenance Connection is able to cover all Directlink maintenance in less than 50 component types.

Finally Maintenance Connection lists the maintenance tasks needed to operate Directlink including tasks that are not directly related to components. For example tasks related to Occupational Health and Safety.

[5] Maintenance Coordinator is the name given a person who performs System Administration duties.

In the bottom up study it was important to start with the individual components that had to be serviced under each category. Appendix B of this report analyses the Single Line Diagram of the Directlink HVDC link to reveal the number of components of each type. It is noted that the line diagram includes 750 individual components. Further several of these components actually comprise banks of individual devices, for example the oil filled capacitors, air blast coolers and IGBT valves. The number of individual devices in the Directlink HVDC system numbers well over 5000.

Modelling Assumptions

The O&M Direct Cost associated with each maintenance category is captured in within a worksheet in the Excel Workbook (referred to as the O&M Model).

Adjusting for Inflation

The O&M Model uses the Reserve Bank's inflation target to adjust the yearly figures for future years. It assumes that all labour rates (both APA and contractor) fall in the middle of the Reserve Bank's target range of 2 to 3% per annum, which is 2.5% p.a.

Due to exposure to overseas material prices and the recent drop in the Australian Dollar the O&M Model has assumed material prices will increase at the upper end of the Reserve Bank's target range that is 3% per annum.

Recognising that adjustment of the applicable rates may be required, both figures are entered on the Worksheet labelled 'Modelling Assumptions'. Changes made to the two values shown on this worksheet will be reflected throughout the O&M Model.

Labour Rates for APA staff

APA charge out rates for the APA staff responsible for the operation and maintenance of Directlink have been used the O&M Model. The charge out rates provided by APA are shown in Table 3.

Table 3: Charge Out Rates Provided by APA

Position	Charge Rates $/hr
Operations Manager	121
Leading Hand	100
Engineer	100
Senior Technician	86
Technician	72

Table 3 shows that the charge out rates for the two APA onsite Maintenance Technicians is $72 and $86 per hour. The O&M Model uses an average value of $79 per hour. This is based on the two technicians undertaking identical roles at each of the converter stations (the O&M Model does not differentiate between them).

Table 3 shows the charge out rate for a Leading Hand is $100 per hour. This is rate applied to the O&M Supervisor.

The other positions are discussed below under the Asset Management Team.

The APA Charge Out rates do not include overheads. APA refer to this as the Home Cost Centre (HCC) allocation. The HCC allocation assigns a percentage of head office costs (building rent, electricity, cars, etc). An early draft of the CY2014/FY2015 budget included both timesheet allocations and HCC allocations which enabled the calculation of the applicable rate. Anecdotally the figures showed the HCC allocation to be 26.9%.

The HCC allocation is included on the Modelling Assumptions worksheet of the O&M Model.

Maintenance Tasks are Cumulative

Many components specify multiple maintenance periods, for example annual maintenance and 3 yearly maintenance. When both the more frequent and less frequent maintenance tasks fall in the same year it is important to note that Directlink maintenance procedures are written so that the less frequent maintenance procedure is required to be undertaken *in addition* to the more frequent maintenance. This maintenance strategy follows the system designer’s maintenance instructions.

For example a component with 1 year and 3 year maintenance requirements is shown in the following figure:

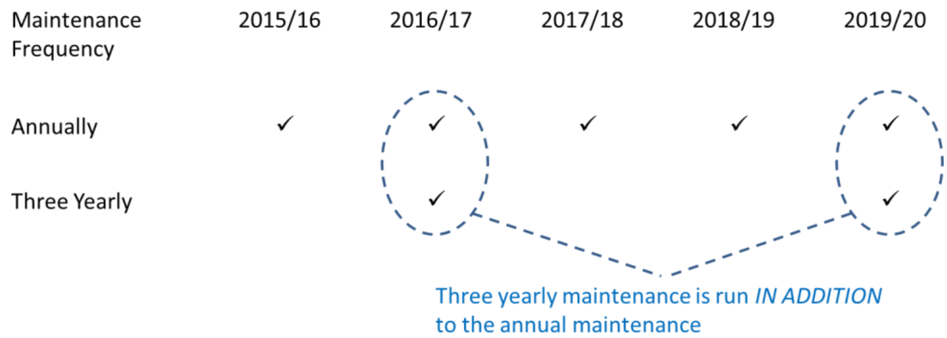


Figure 7: Less frequent maintenance is run IN ADDITION to more frequent maintenance

Figure 7 provides an example of a component for which both annual (1 yearly) and 3 yearly maintenance is required. The figure shows that every 3rd year both the 1 year and 3 year maintenance schedules are undertaken. The O&M Model includes both maintenance requirements to be undertaken in the specified year, as this is specified in the OEM maintenance instructions.

Contractor Access to the site

Whenever a contractor arrives at the site they must receive a safety briefing from the onsite APA representative (either the O&M Supervisor or the Maintenance Technician). This covers the current operational state of the site and includes reminders of the numerous dangers around the site. It was reported that this briefing and site tour takes 30 minutes. This briefing must occur at both sites hence the ‘Modelling Assumptions’ tab of the O&M Model assumes that this briefing adds 1 hour.

It was reported that the briefing must be repeated each day contractors are onsite. The O&M Model assumes that all the maintenance is undertaken on the same day and only adds one hour for each maintenance task. In practice numerous maintenance tasks actually require several days highlighting that this value under-estimates the time spent providing contractor safety briefings.

O&M Supervisor

Once a maintenance task is received by the O&M Supervisor, that person must determine when the maintenance will be undertaken and by whom. There is the need to raise Work Orders. If the maintenance is to be undertaken by contractors the O&M Supervisor is required to coordinate with the contractor to determine when they are available. They then need to raise purchase orders for the work.

Once the work is complete both the Work Order(s) and Purchase Order(s) must be closed. The review found gaps between the Maintenance System and the Accounting System used by APA. To address this gap the O&M Supervisor is required to manually enter the work order and contractor invoice into the Accounting System when closing the purchase order.

This report notes that often preventative maintenance identifies items requiring follow on corrective maintenance (for example a capacitor that must be replaced). The O&M Supervisor must then schedule this corrective work, including raising new work orders and purchase orders. The O&M Model accommodates this activity against the O&M Supervisor as explained in the Modelling Assumptions worksheet, where 8.1 hours has been allocated to each task for this person.

Costs exclude GST

To remove ambiguity it is stated that the model presents O&M costs excluding the GST.

Commercial Services Agreement

The total cost to operate the Directlink asset includes a management margin. The management margin is described in the Management Operations, Maintenance and Commercial Services Agreement (the MOMCSA). The margin outlined in section 10.1 (c) (i) of this agreement is 10%.

The MOMCSA margin is only included in figures presented on the worksheets ‘Introduction’, ‘Summary’ and ‘Summary of PMs’. Figures shown on other worksheets do not include the MOMCSA margin. The value of the MOMCSA margin is specified on the ‘Modelling Assumption’ worksheet.

Reference Year

Each worksheet in the model assembles all the costs into the year that they were accrued. For accuracy the model has used the most recent costs to perform the various maintenance tasks. Once all the costs have been assembled they are adjusted to the reference year of 2014 using the appropriate rates for labour and material costs (refer to Modelling Assumptions for more information).

In most cases the costs are from 2013/14 so no adjustment is necessary.

Relevant Technology History of the Directlink HVDC Link

HVDC transmission links have been available since the 1960’s with high power semi-conductor devices allowing numerous global installations. Two different designs are available Line Commutated Conversion (LCC) and Voltage Source Converter (VSC). Early HVDC systems used LCC and were based on Thyristers. Directlink was commissioned in 2000 making it only the second installation of a new converter technology employing VSC. VSC uses insulated-gate bipolar transistors (IGBT).

Globally the system designer only installed one other VSC based system of the same configuration as Directlink. The other system was installed shortly before Directlink in Gotland, Sweden (it also uses a different HVDC cable). VSC systems available today have addressed many of the weaknesses found in these two early installations, for example even during commissioning of the Directlink system the system designer engineers found the level of harmonics was too high requiring them to add filter reactors (U.L2). Installing the additional reactors required several other components to be relocated. Even today the U.L2 reactors are not shown on the system designer provided plant layouts.

One significant difference between VSC systems and LCC systems is the use of phase reactors in VSC systems. With no prior installations to guide the design the phase reactors are installed close to other components. Field deployments have shown that these components can fail catastrophically (one caused problems during the commissioning of Directlink). Modern VSC systems isolate the phase reactors from the rest of the converter station.

By way of analogy, Mercedes Benz is known for well above average build quality and reliability. What is often overlooked is that in 2003 JD Power's annual reliability survey saw them slip to below the industry average for the first time. The New York Times observed that this was largely due to the poor reliability of the ML-class SUV[6]. The ML-class was Mercedes Benz's first attempt at a luxury four wheel drive. Mercedes Benz learnt many valuable lessons from this first attempt and made design improvements to ensure the problems were addressed. Unfortunately this does not help owners of their first attempt who are faced with above average running costs.

Similarly the first deployments of the novel VSC technology allowed system designers to gain practical field experience. Whilst the lessons learnt have resulted in significant design improvements, APA have been faced with higher maintenance costs due to the problems with the early design.

[6] New York Times 10th July 2005 "Mercedes Quality: Back on Track?" By Cheryl Jensen

Discussion of the most significant contributions to O&M Direct Costs

Electricity Costs

Directlink does not have any onsite generation, instead they purchase all electricity used to run the conversion stations. The amount of electricity used depends on the number of circuits operating (converter stations) and to a lesser extent the ambient temperature.

To obtain typical electricity costs for Directlink it is necessary to examine historical electricity use. This analysis is restricted to the period before the Mullumbimby converter fire when Directlink was fully operational. Figure 8 shows electricity use at both sites.

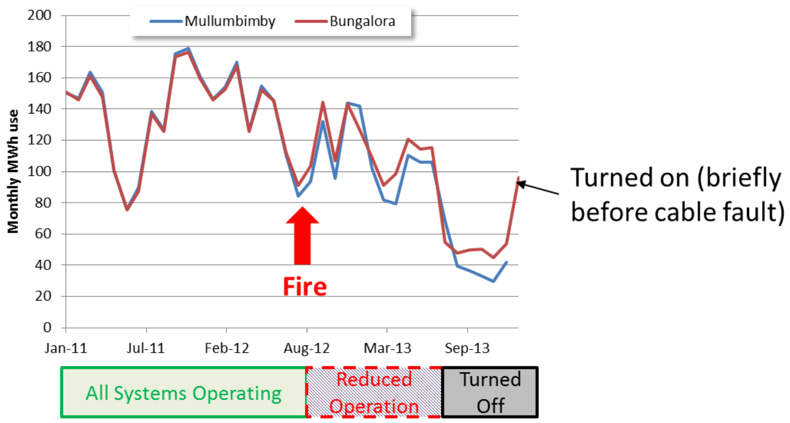


Figure 8: Monthly Electricity Use at each site (MWh)

Three areas are highlighted in Figure 8. Before the Mullumbimby fire the figure notes "All Systems Operating". After the fire energy use decreases, this is labelled "Reduced Operations". In August 2013 Directlink was "Turned Off" with a significant drop in electricity use at both sites.

Even when the HVDC link is not being operated electricity use at the two sites remains relatively high (in the order of 15% to 20%) due to continuous operation of numerous dehumidifiers (air conditioners), fans and pumps (used to keep components cool), heaters (to heat components), control systems and associated air-conditioners.

On-site electricity usage is an O&M Direct Cost hence it must be forecast for the regulatory period.

The O&M forecast uses two steps:

- Determine typical electricity use at the two sites (when operating normally)
- Apply the cost of electricity in the reference year.

Detailed invoices were provided for the financial year 2011/12. This corresponds to a period when all converter stations were available and is therefore taken as typical electricity use (the Mullumbimby fire occurred in August 2012).

The worksheet 'Electricity Costs' in the O&M model lists monthly electricity use and peak demand recorded for 12 months in 2011/12. It then applies the 2014 tariffs to calculate the cost of electricity in the reference year. The results of this analysis to electricity use at Mullumbimby and Bungalora are shown in the following figure.

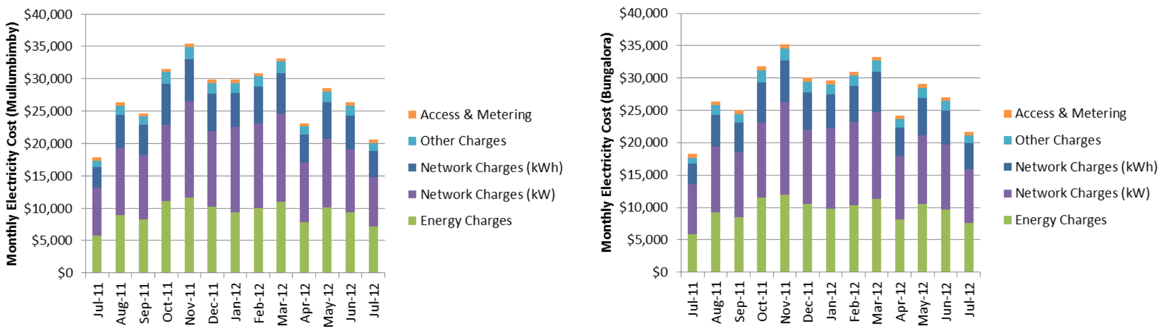


Figure 9: Analysis of Mullumbimby and Bungalora electricity costs (in 2014$)

The analysis reveals that the cost of electricity in the reference year is $684,781. The O&M Direct Cost for electricity use at both sites is modelled to be $4.128 million for the 5 year regulatory period.

The replacement Mullumbimby converter is due to be operational in August 2015. The O&M Direct Cost was not adjusted for the one month that this converter will not be operational. This is because in this month the new converter will be undergoing extensive final commissioning tests before becoming an operational asset. This testing would increase energy use at both sites. Any reduction in the total energy use would be negligibly small.

It is acknowledged that the new Mullumbimby converter station has the potential to be slightly more efficient than the one it replaces. Fundamentally the VSC technology used in the new converter station will be identical to the one that it replaces with identical energy consumption. Any energy savings in support systems (for example only running the phase reactor fans when required) would be negligibly small. No saving has been applied in the O&M Model.

Electricity Procurement

During the preparation of the O&M Direct Cost APA advised they were negotiating a new national electricity contract for all their assets. While this agreement has not been finalised it is expected to lead to lower electricity prices for Directlink. APA has advised that a 29% will apply in the first year of the regulatory period. The discount does not apply to the network charges. The discount ceases on the 30th June 2016. Negotiation for subsequent years has not commenced.

From the detailed analysis of the Mullumbimby and Bungalora invoices (refer to Figure 9) Energy Charges comprise 34% of the total bill (with the remainder comprising network and other charges). A saving of 29% on 34% of the total cost indicates that the Company could reduce the total cost of electricity by 10%.

APA advised that the contract for electricity rates applies from July 14 to June 16. This contract only covers the first year of the regulatory period. The O&M Model has applied a discount of 10% (29% of 34%) for the first year of the regulatory period (2015/16). Subsequent years require APA to renegotiate the applicable rates.

NERA prepared a report for the Australian Energy Market Commission investigating “Prices and Profit Margin Analysis for the NSW Retail Competition Review” dated 5th March 2013. This report has been used to estimate the sustainable electricity discount APA can expect in subsequent years.

On page 39 of the Profit Margin report NERA states:

> In particular, the average discounts available with market offers tend to be less than or equal to the implied margin in each distribution area.

Table 6.3 of the NERA report estimates the margin for commercial customers[7] in the Essential Energy area is 9% (for FY2008 to 2013). The report also lists the margin allowed by the NSW regulator IPART which is 5.4% (FY 2012-13 from Table 6.2 of the NERA report). It is acknowledged that IPART are probably focussed on residential customers, as NERA states:

> Retail margins to supply commercial customers were generally higher than those to supply the standard representative customer.

The NERA report indicates that the APA corporate procurement saving of 10% in FY2015/16 is probably above the retail margin. It is also noted that NERA list the margin in FY2002 – 2007 as 11% suggesting that margins are decreasing. Both NERA and IPART suggest that the discount offered in subsequent years will be lower. The O&M Model has therefore adopted a total saving of 8% in FY2017 and 2018 reducing to 6% in FY2019 and 2020.

Without the discount the cost of electricity at the two sites would be (as calculated by the O&M Model) $4.128 million. Including the above discounts in the O&M Model the electricity costs are calculated as $3.817 million for the 5 year regulatory period – this is included in the O&M Direct Cost.

Cable Repairs

The cable route between Mullumbimby and Bungalora is 59km long. There are 6 cables connecting Mullumbimby and Bungalora (a pair of cables for each 'system', with 3 converter stations per system). The cables are installed above ground in Galvanised Steel Trough (GST) or underground where they are installed in conduit or buried directly in the soil.

Background

Each cable consists of a central conductor (tightly bundled strands of aluminium) surrounded by an insulating layer. On the outside of the insulating layer is a cable screen which is connected to ground. An outer hard plastic case provides protection for the cable screen.

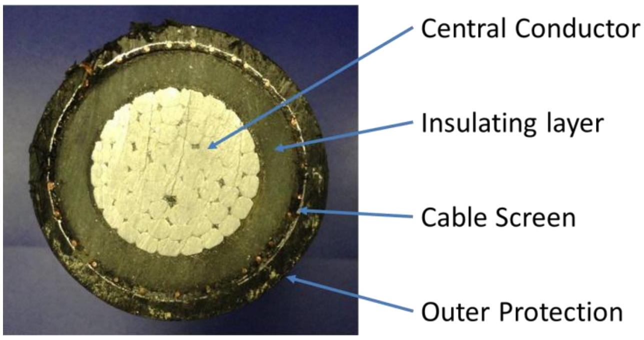


Figure 10: Cross Section of the HVDC cable

[7] The NERA report considers a commercial customer using considerably less electricity than Directlink

A cable fault occurs when a short circuit appears between the central conductor and the cable screen. An immediate consequence of the fault is that a large current flows through the short circuit until the control system at the converter station detects the fault and shuts down ("trips"). Note that because the faults are occurring in the DC section there is no circuit breaker to protect the converter station from the large currents (the control system opens circuit breakers in the AC section of the converter station).

Since the Directlink system was commissioned in 2000 there have been 138 cable faults. The root cause of the cable faults is unknown. Some possibilities include:

- Water ingress into the cable weakening the insulation (the underground cables are placed directly into the ground (not installed in conduit) exposing the cable and joints to moisture.
- The system designer originally installed cable joints designed for use on AC cables. Subsequently special cable joints for use on DC cables have been released. All cable repairs use the new DC joints.
- The soil along the cable route has a high percentage of clay. During dry months it contracts and during wet months it expands exposing the cable (and joints) to continuous flexing.
- The cable passes through populated areas where it regularly transitions from above ground to underground (e.g. to pass under a driveway). The above ground cable is exposed to temperature extremes (full sunshine, cold nights) while the underground cable is not. This subjects the cable to increased stress.
- The converter stations do not operate continuously. When operating high currents flow through the cable with inevitable heating and expansion. When not operating (e.g. while there is a cable fault) the cable will cool and contract. This results in continuous expansion and contraction of the cable.

At the time Directlink was installed the XPLE cable was a well proven cable technology for medium voltage AC cables. It was not a well proven technology for use in HVDC links. Subsequent installations of XPLE cable in HVDC links have proved reliable, including APA's other HVDC link, Murraylink. While it is known that ABB have improved the design of the cable joints, it is not known if they have also made improvements to the XPLE cable technology between the installation of the Directlink and Murraylink cables. (Murraylink was installed 2 years after Directlink).

It must be stated that at many of the cable faults there is evidence of water inside the cable core. What is unclear is how water penetrates the cable. While cable joints are high on the list of possible points of entry it is also important to note that the outer plastic cover is not completely waterproof. Instead the cable relies on the metal cable screen to provide a solid metal barrier. Being made of metal the cable screen can be damaged by excessive bending of the cable.

Cable Repairs

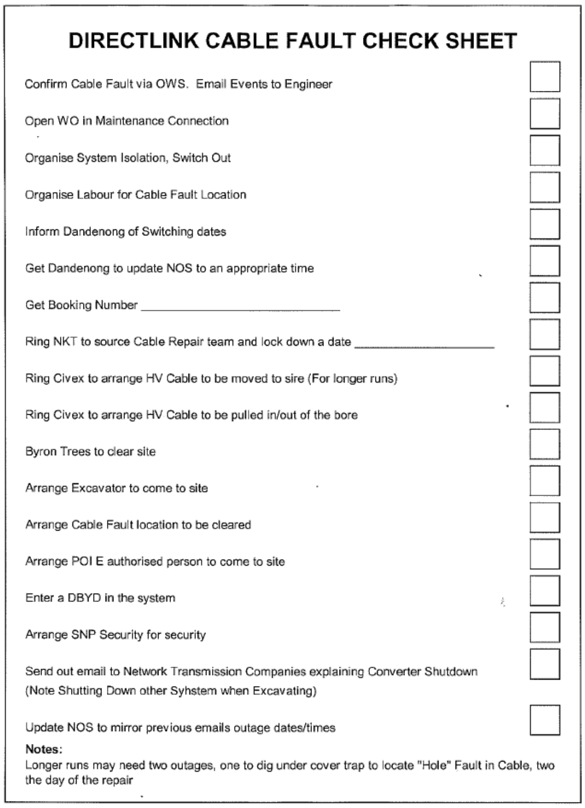
Once a cable fault has occurred it is necessary to locate the fault. The first step is to attach the Hiptronics fault path burner ('test equipment') to the failed cable. This test equipment injects a high voltage pulse into the cable which propagates down the cable to the fault where it is shorted to ground through the original fault. At the fault location the pulse causes an audible thump which can be used by the operator to identify the location of the fault.

The test equipment also provides an indication of the distance to the fault. A field crew is therefore sent to the approximate location but must then walk along the cable route trying to hear the precise location of the fault. Sometimes the fault is found quite quickly and other times the search is more involved and may even require digging pilot holes to validate the position. Throughout the manual search the test equipment must continue to inject pulses regularly into the cable.

Once the test equipment is disconnected a visual inspection of the cable is required to find the actual location of the fault in the cable. The following figure shows the small size of the hole in the cable. This hole is created by the test equipment to pinpoint the location of the cable fault. The location of the cable fault is only confirmed once this hole has been located (for underground faults this will require excavation when the cable will be covered in mud).

Figure 11: Hole that must be located in the cable to find the fault location

Cable repairs are a major undertaking. An APA employee is assigned full time to coordinate all the contractors needed to undertake the repair. A checklist is provided to ensure that all required contractors are notified and equipment located and taken to the site.



DIRECTLINK CABLE FAULT CHECK SHEET

- Confirm Cable Fault via OWS. Email Events to Engineer ☐
- Open WO in Maintenance Connection ☐
- Organise System Isolation, Switch Out ☐
- Organise Labour for Cable Fault Location ☐
- Inform Dandenong of Switching dates ☐
- Get Dandenong to update NOS to an appropriate time ☐
- Get Booking Number ________________ ☐
- Ring NKT to source Cable Repair team and lock down a date ________________ ☐
- Ring Civex to arrange HV Cable to be moved to sire (For longer runs) ☐
- Ring Civex to arrange HV Cable to be pulled in/out of the bore ☐
- Byron Trees to clear site ☐
- Arrange Excavator to come to site ☐
- Arrange Cable Fault location to be cleared ☐
- Arrange POI E authorised person to come to site ☐
- Enter a DBYD in the system ☐
- Arrange SNP Security for security ☐
- Send out email to Network Transmission Companies explaining Converter Shutdown (Note Shutting Down other Syhstem when Excavating) ☐
- Update NOS to mirror previous emails outage dates/times ☐

Notes:
Longer runs may need two outages, one to dig under cover trap to locate "Hole" Fault in Cable, two the day of the repair

Figure 12: APA checklist for Cable Fault repairs

NKT are the specialist contractors who install the cable joints. Their services are in high demand and the checklist requires the responsible person to “lock down a date”. For faults located in the underground sections of cable this provides time for heavy earth moving equipment to be brought to the site and careful excavation to expose the cable.

Roughly 50% of the cable is underground with slightly more faults occurring in underground sections.

Figure 13: Photograph taken during an underground cable repair

The original repair strategy was to locate the fault and remove a small section of the cable. The length of cable was just enough to allow the two new cable joints to be installed. This repair strategy proved ineffective, with more failures often occurring shortly afterward near the original failure. Each repair added more cable joints and it is reported that the number of cable faults was starting to climb.

The amount of cable that is replaced is assessed on a site by site basis. If there are other cable joints close to the new fault (particularly the old joints) then the amount of cable to be installed is increased to allow these joints to be removed. It is also based on an assessment of the terrain and whether it is similar to other areas in which grouped cable faults have occurred.

An observation is that the new cable repair strategy takes advantage of the considerable effort to install the cable joints. It is only incrementally more expensive to replace a larger section of cable. At this point it is worth highlighting that each cable joint costs $14,348 while the cable is ‘only’ $168 per meter (both of these costs are capitalised and are not included in the O&M forecast).

This new strategy has reduced the rate of increase in the number of cable failures, but to date has not been proven to reduce the number of cable failures.

Figure 14: Covering the cables with barrier tape after a cable repair

While undertaking the cable repair it is necessary to shut down the link. The six cables lie next to each other making it unsafe to work on one cable while energised cables are in such close proximity. Cable repairs therefore impact the availability of the entire inter-connector, not just the affected circuit.

Calculating the O&M cost requires an estimate of the number of cable faults that will occur during the forecast period. The most reliable figure uses the historical cable fault data. In the 12 years that

Directlink has been operating (allowing a year for outages) there have been 138 cable faults. This gives the average number of cable faults per year as 11.5. With the new cable repair strategy the O&M Model estimates that this annual failure rate remains constant throughout the AER period.

The contractor costs for a cable repair varies depending if the fault is located in above ground or underground cable. The O&M Model has used anecdotal costs of $9,180 to repair an above ground fault and $29,701 when the fault is located underground (both figures are anecdotal as provided by APA).

Discussions with Directlink staff indicate that cable faults occur in roughly equal numbers above and underground. The O&M Model uses these anecdotal values to arrive at an O&M of $2.030 million for the 5 year regulatory period.

Control Room Operations

Remote control room operations for Directlink are provided by APA Group's Dandenong Control Room. This part of the business also provides all the IT infrastructure needed to interface Directlink to the Australian Energy Market Operator (AEMO). AEMO set the dispatch targets for Directlink and the Dandenong Control Room remotely control the converter stations to meet these dispatch targets.

A services agreement for the provision of these services was signed in 2008 detailing the terms of the agreement. At the time the contract was for $140,000 per annum (exclusive of GST). A clause in the agreement allows the contracted fee to be increased annually. The O&M Model has taken the value from the CY2014/FY2015 OPEX budget which shows the current monthly fee is $15,500 . Control room operations therefore add $1.111 million to Directlink's O&M for the 5 year regulatory period.

APA provided invoices from the period when control room services where provided by Country Energy. The four invoices where from the period Oct 2007 to Jan 2008 and showed the average monthly cost was $19,314. Using the modelled rate of inflation this equates to $22,398 in the reference year, almost $7,000 a month more than the cost of using the APA Group's Dandenong Control Room.

Phase Reactor maintenance

As discussed in the Relevant Technology History the Directlink HVDC link was one of the first practical installations of VSC technology. While HVDC links using LCC were field proven there was very little practical field experience for VSC designs at the time it was installed in Directlink. One of the significant differences between the two technologies is that converters using VSC contain phase reactors. Directlink has experienced issues with the phase reactors which were not foreseen by the system designers.

Clearly the system designers realised that under load the phase reactors would run hot, hence fans were installed to circulate air. These fans continuously circulate air, even when the reactors are only lightly loaded (and do not actually require cooling). The system designers now recognise that this is an inefficient design and modern HVDC designs use a thermostatically controlled fan to only circulate air when cooling is actually required (estimated to be less than 20% of the time).

It is also relevant to note that the Directlink design does not include any air filters. The rural setting of the two converter stations means that the air is typically full of dust (and insects). During the cooler wetter months the air can be very moist. Some designs of phase reactor cooling fans include air filters to circulate predominantly contaminant free air.

Modern HVDC converters physically isolate the phase reactors from the rest of the station. This is not the case with Directlink with the phase reactors located close to other components. Instead of physical isolation shielding is installed around the Directlink phase reactors.

After the Mullumbimby converter fire an inspection of the phase reactors (in the remaining converter stations) revealed an accumulation of dust on the inside of the phase reactors. Previous issues with the phase reactors combined with this analysis have led to a decision to remove the layer of dust from the phase reactors annually.

Removal of this layer of dust from the phase reactors is a challenging operation. There is very little space between the reactor windings (in the order of several millimetres). Blasting with air proved ineffective. Liquid cleaning using steam or water blasting risks leaving residual moisture, with catastrophic consequences on system re-energisation. Aggressive abrasive blasting was not considered practical due to concerns it would damage the reactors (and leave residual dust).

A gentle abrasive was required which would leave no trace once the treatment was completed. After researching the problem the final solution was to use finely ground dry ice as the abrasive. Blocks of dry ice are fed into a special machine which progressively grinds the block and feeds the fine particles to the air-stream. The advantage of using dry ice is that it evaporates completely leaving no residue or moisture.

A contractor supplies and operates the specialist equipment. The initial treatment cost of $25,000[8] per building (note 3 reactors per building) in the reference year includes dry ice.

The revised maintenance procedures require the phase reactors to be cleaned annually. The original treatment removed over 10 years of accumulated dust. Removing only one year of dust will be simpler so the O&M Model has taken the cost to be $12,500 per building (50% of the original cost).

Fibreglass ducts are used to direct the air to the phase reactors. Inspection has revealed the inside surface is starting to craze. It has been decided to apply a special electrical grade insulating silicone grease to the inside of the ducting so that the cracks don’t contribute to a lower level of insulation.

The annual maintenance task first requires the old grease to be removed before the new grease is carefully applied. The removal and reapplication of fresh insulating grease requires close attention to detail. The task occupies both technicians for a full-day. Each reactor uses just under 22 kg of the insulating grease (at a cost of $440 per 22 kg tub).

The replacement Mullumbimby converter will use a modern design. It is understood that the modern design will address the above faults. The O&M Model therefore only applies the above maintenance to the 15 phase reactors of the original design. There will be some annual maintenance

[8] Anecdotal, as provided by APA.

of the phase reactors in the new converter station. The O&M model uses the standard Reactor Maintenance (as described in worksheet '0104 (1)') for this maintenance.

The O&M Direct Cost to undertake this maintenance is $570,176 over the 5 year regulatory period.

Pre-start Inspections

While not an expensive item in the overall O&M forecast it is highlighted that APA have enhanced pre-start inspections to address potential issues with the phase reactors.

As discussed the phase reactor fans run continuously and in the cooler damper months the concern was that a layer of condensation may have formed on the cold phase reactors. To avoid this happening in the future APA have enhanced the pre-start inspection to include visual inspection of the original phase reactors. This requires each of the phase reactors and ducts to be carefully inspected for any signs of dampness and any ingress of vermin. Due to limited access and the size of the reactors APA has advised anecdotally that inspections will take 15 minutes for each building.

Pre-start inspections add $41,033 over the 5 year regulatory period. It is mentioned here as a reminder that APA's maintenance requirements are higher due to the significant issues they have experienced with an early implementation of VSC converter technology.

The modelling assumes that pre-start inspections will continue for the full 5 year regulatory period. It is acknowledged that the Reliability Engineer is likely to review the results of these inspections. This review may lead to a reduction in the number of inspections in later years. Reducing the number of inspections would make a minor (non-material) difference to the O&M cost.

Vegetation Management including Yard Maintenance

Part of the cable route was deliberately chosen to follow a now disused railway line. There were a number of benefits from this decision however one significant advantage was that the rail authority undertook vegetation management along the rail corridor.

The rail line was shut down in 2003 at which time the rail authority stopped their vegetation management. Along the track the rail authority used to completely remove all vegetation hence it has taken a number of years for the vegetation to regrow. The result is that each year APA finds more vegetation management is required along the cable route. Today the rail corridor is significantly overgrown.

The cable route also passes through national park making it necessary to physically walk the cable route (this is discussed below in Cable Marker Maintenance).

APA undertake a scheduled monthly inspection of a section of the cable route. After the inspection the vegetation contractor is alerted to areas requiring maintenance.

Vegetation management is undertaken by the contractor Byron Bay Trees. An analysis of invoices for the reference year reveals that in the first seven months the cost is $49,000. This indicates that the total cost in the reference year will be $84,000.

An analysis of the invoices for financial year 2011/12 showed several invoices listing additional work for cable repairs. The majority of the reference year invoices correspond to the period when

Directlink was non-operational and would therefore not include this additional work. The O&M Model has taken the cost of additional vegetation management needed for cable repairs to be $3,000 (around 2 to 3 hours of additional work a month).

The provided invoices did not allow Yard Maintenance to be separated from Vegetation Management (along the cable route). The O&M model assigns 10% of vegetation management to yard maintenance (shown in worksheet '0010 (1)' Yard Maintenance).

Vegetation management along the cable route and in the yard therefore contribute $643,000 over the 5 year regulatory period.

Power Transformer Maintenance

Both sites use three Wilson Power Transformers. These large power transformers require specialist maintenance which has been contracted to the OEM. Anecdotally the annual maintenance is covered under a contract with Wilson for $32,472 per site.

There is also a spare transformer located at Bungalora. This is also maintained by Wilson Transformers for an anecdotal additional fee of $10,824 per year.

The contracted transformer maintenance adds $460,285 to the 5 year regulatory period.

The above figure also includes a small allowance for APA staff to take additional oil samples from the transformers and send them off for independent testing. This adhoc maintenance occurs roughly every second year and takes 2 hours per site. The material cost to test the 7 samples is $1,000.

Circuit Breaker Maintenance

In 2015 several components will require 15 year maintenance. One of these is the Circuit Breakers. The maintenance of circuit breakers is an involved and specialist operation. APA have chosen to use ABB since they are arguably the only specialist able to undertake the work and have a high degree of familiarity with the system.

The 15 year maintenance has not been previously performed so the following anecdotal information was advised by APA.

Each Circuit Breaker consists of several contacts. The following table lists the Circuit Breakers requiring maintenance. It uses the Single Line Diagram (Appendix B) to reveal the number of each Circuit Breaker and details of each Circuit Breaker to determine the total number of Contacts requiring maintenance.

Table 4: Contacts per Circuit Breaker

Circuit Breaker	Number of Circuit Breakers in Directlink	Number of Contacts	Total Number of Contacts
WT.Q1	1	3	3
WT1.Q1	6	3	18
WT1.Q2	6	3	18
Total	13		39

Each Circuit Breaker consists of several mechanisms. The following table lists the Circuit Breakers requiring maintenance and the number of mechanisms in each to arrive at the total number of mechanisms requiring maintenance.

Table 5: Mechanisms per Circuit Breaker

Circuit Breaker	Number of Circuit Breakers in Directlink	Number of Breaker Mechanisms	Total Number of Mechanisms
WT.Q1	1	3	3
WT1.Q1	6	3	18
WT1.Q2	6	1	6
Total	13		27

There is only one Circuit Breaker (WT.Q1) located at Bungalora. Mullumbimby relies on a Circuit Breaker per system located in the nearby Essential Energy substation. The other Circuit Breakers are located at both Bungalora and Mullumbimby.

The estimated maintenance costs are based on a quote from ABB to undertake similar work. This was the replacement of a single pole which came to $9,500 in 2012.

The mechanisms used in Circuit Breakers are delicate and require precise adjustment. Anecdotal evidence assigns 80% of the cost to the maintenance of each mechanism. The remaining 20% is allocated to maintenance of the contacts.

As shown in Table 4 and Table 5 the 13 Circuit Breakers contain 27 mechanisms and 39 contacts. Using the anecdotal contractor costs the 15 year maintenance will cost just over $293,000 in the reference year.

In the quote to undertake similar work the contractor requested two APA staff must be available at all times throughout the maintenance to provide assistance. This quote also required that APA were required to hire the necessary elevated work platform and cranes required to access the elevated circuit breakers.

Including the APA personnel and platform hire in the O&M Model indicates that the total cost to undertake the 15 year maintenance of the circuit breakers comes to $398,815 in the 5 year regulatory period.

Travel

The Mullumbimby and Bungalora converter sites are located remotely from the Brisbane office. This requires frequent travel to the sites by the Brisbane based staff along with accommodation and meals.

There is one technician located at each site. Several times per month both technicians are required at the same site requiring them to travel to the other site.

APA's internal CY14/FY15 Budget allocates $60,000 for travel (in the reference year). Using this figure in the modelling suggests O&M costs for the 5 year regulatory period will total $394,698.

Site Security

Despite regular night time security patrols, Directlink was experiencing a number of break-ins at the remote sites. It was reported that many of these break-ins were by scavengers trying to locate any copper. The initial solution was to place a security guard at the site. The long term solution was to upgrade fencing around the sites. After upgrading the fencing the onsite security guard has been removed early in 2013 and night time security patrols were resumed. Invoices after this time do not include the on-site security guard.

The model estimated the cost of site security by averaging the cost shown on invoices from Jul-2013 to Feb-2014. These invoices suggest that the average cost of site security is $4,316 per month.

By July 2015 a monitored alarm system will also have been installed at the two sites (this is only awaiting the installation of additional telephone lines at each site). The CY14/FY15 OPEX budget allocates $200 per month for the provision of this remote monitoring.

In total the O&M Modelling reveals that Site Security comes to $316,026 for the 5 year regulatory period.

Note that the O&M Model only considers security at the two converter station sites. Security guards needed to provide public safety during underground cable repairs is captured in the cost of Cable Repairs.

Remote Communications

The two converter stations are operated remotely by APA Group’s Dandenong Control Room. Remote control room operations require reliable data communications. The O&M Model has used the figure from the APA’s internal CY2014/FY2015 Budget. This showed the cost as $3,920 per month. The provision of Remote communications therefore comes to $287,808 over the 5 year regulatory period.

No allowance has been included for the additional telephone lines required by the remotely monitored alarm system to be installed at each site.

Reactor Maintenance

Inspection of several reactors has revealed major cracks are appearing in the protective outer cover. The cracking risks exposing the windings used in each reactor and must be repaired. Many of the reactors are located outside where the system designer had probably not anticipated the effects of long term exposure to harsh Australian sunshine.

After contacting the OEM the recommended maintenance involves applying a new coating. This has been added to the 15 year preventative maintenance which is scheduled to be performed in 2015. High voltages across the reactors mean that the coating must be non-conductive. The OEM is able to provide the original coating which can be painted on. Anecdotal advice by APA indicates that the special coating costs $16,000 per 25 kg tin.

The reactors are a coil of wire forming a tube. The coating must be applied on both the outside and inside surfaces. For each reactor the area to be treated is:

$$Area = \pi \times Diameter \times Length \times 2$$

The following table lists the reactors that must be treated with their size and total number of each. These values are used to calculate the total area to be treated.

Table 6: Reactors requiring reapplication of protective coating

	Diameter (m)	Length (m)	Number
WT.L1	1.155	1.355	6
WT.L2	1.155	1.355	6
WT.L3	1.155	1.355	6
Z1.L1	0.796	0.93	18
Z11.L1	0.935	0.84	18
Z12.L1	0.57	0.63	18
U.L2	1.035	1.53	6
WP1.L1	1.125	1.495	6
WP2.L1	1.125	1.495	6
Total Area	577 m^2	Number of Reactors	90

Table 6 shows that the total area to be painted is 577 m^2. The data sheet for the coating indicates the coverage is 6 m^2/kg. Using the total area, coverage and tin size reveals that APA must purchase 4 tins. The total cost of materials is therefore $64,000.

Anecdotal advice by APA indicates that it will take 10 hours to apply the coating to each reactor. The 15 year maintenance is incurred in 2015/16 only. Reapplication of the protective coating should last another 15 years.

At a contractor labour rate of $85/hour applying the coating to the 90 reactors will cost $76,500 in the reference year. Reactor Maintenance for the 5 year regulatory period totals $212,866.

Other Costs

A number of costs were identified from line items on the CY2014/FY2015 budget

- Vermin control at the two converter sites of $2,000 per quarter
- There is no permanent toilet at the Mullumbimby site, instead a Portaloo is hired costing $400 per month
- Waste removal is shown as $110 per month
- General Consumables are shown as $1,000 per month

Other Costs therefore add just over $201,000 to costs in the 5 year regulatory period.

Incidental adhoc investigations

The Directlink asset is exposed to miscellaneous incidents (such as noise complaints, environmental complaints or accidents) where a breach in regulations may have occurred. Each of these incidents requires investigation, and in some cases an assessment of the extent to which a regulation has been breached. For example, APA have advised that they regularly receive noise complaints from households in the vicinity of the converter stations. The CY2014/FY2015 OPEX budget allocates

$30,000 per year for external service provider costs (including $10,000 for legal costs). The O&M Model has assigned these costs to incidental adhoc investigations. The costs are anecdotal.

The above figures suggest that incidental adhoc investigations add just under $180,000 to costs incurred during the 5 year regulatory period.

Energised Monthly Inspection

Each month the two onsite technicians are required to visually inspect the whole converter station. The inspection focusses on four main areas, the power transformers, valve cooling, switch yard and converter buildings.

In addition to visual checks the work instruction also requires the Maintenance Technician to perform several checks and to note readings from various monitors located around the sites. The following figure is the table of contents from the relevant work instruction (DL-WI-17) and is included to show the scope of the inspection.

APA Group	Directlink Monthly Energised Maintenance Inspections DL-WI-17	*Commercial In Confidence*

TABLE OF CONTENTS

Figure 15: Table of Contents showing the scope of the Energised Monthly Inspection

The energised inspection takes each technician a full day. An additional 2 hours has been allocated to ensure that the maintenance log is correctly entered and sent to APA supervisors.

The forecast O&M to undertake the inspection is therefore $178,693 over the 5 year regulatory period.

Dial Before You Dig

APA are alerted when anyone contacts Dial Before You Dig either via the website or the phone number (1100).

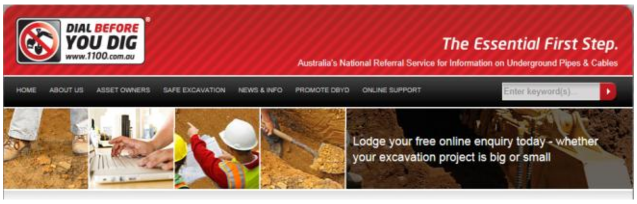


Figure 16: Dial Before You Dig Website

Each dial before you dig (DBYD) request that has the potential to affect the Directlink cable is forwarded to APA for checking. In the past 12 months there have been 265 such requests.

The first step is to check the location against the known cable route. There are three levels of response:

- If it is clear that the work does not affect the cable then it is immediately given approval.
- If the location is near the cable then a follow up call is made to the person making the request to discuss the intended work.
- If the phone discussions indicate that there is the potential to affect the cable a site visit is planned to coincide with the actual dig. APA advised that their technician is to remain onsite while the digging is in progress.

Depending on the level of response the O&M Model assigns different times. In all cases the reported location must be compared against the known cable route, the model has taken this time to be 10 minutes. If more information is required then the APA technician will call the person lodging the DBYD request and increase the total time to 30 minutes. If the phone call indicates that the proposed earth works may impact the cable then a site visit is required. Currently the APA technician must be onsite while the earth works is undertaken, hence supervision and travel time increases the total time to 6 hours.

The O&M modelling has used anecdotal evidence of actual DBYD requests received in the past 12 months (to March 2014). Of the 265 DBYD requests, 152 found the cable was not affected. Of the remaining 113 requests it is estimated that 20% required a site visit. Using these figures reveals that DBYD requests require 5 weeks of full time work for the APA technicians. These requests add nearly $90,000 to the 5 year regulatory period.

The CY2014/FY2015 budget also indicates that there are annual fees for the X-info Landholder Database ($6,000) and for DBYD ($500). The total for DBYD is therefore $168,226 for the 5 year regulatory period. This value is considered to be conservative as the population growth and continued developments in the Directlink area suggest that the number of DBYD requests will actually increase each year.

Control System Repairs

Background

Each converter building has two MACH 2 control systems (a total of 12 systems). The MACH 2 system was developed by the system designer and comprises three main parts:

- Proprietary external racks of equipment measuring and controlling signals around the converter station

- Proprietary interface cards plugged into the host Personal Computer which connect to external racks of equipment
- A generic Personal Computer (PC) running a proprietary control system program

The PC runs a proprietary application developed by the system designer. This application combines all the measurements to generate the control signals required to run the converters.

While the system designer can provide all the proprietary interface cards they do not support the generic host PC. The PC is an old Pentium based design and is no longer available. Approaching 15 years old the PC is proving unreliable. Unable to source spare PCs APA staff have resorted to sourcing old personal computers from second hand stores however even this unreliable source is drying up.

The majority of PCs are consumer goods. The PC market remains highly cost competitive with suppliers continuously attempting to improve performance and reduce costs. To obtain these savings a specific design of personal computer is only available for a short time period typically between 6 to 12 months. Then the design is replaced with one using faster and cheaper components. Unfortunately the proprietary program will not run properly on new PC hardware.

A further complication is that the proprietary interface cards are designed to use the superseded Peripheral Component Interconnect (PCI) standard. Today most PCs use USB ports to simplify the connection of external peripherals[9]. Put simply PCs with the required number of PCI slots are no longer available.

The proprietary nature of the PC application and the interface cards means that it is not possible to replace the PC with a new model. Upgrading the host computer requires a major CAPEX project. Changing the computer requires the system designer to completely rewrite their proprietary control program. Then because the PCI interface cards are no longer supported all these cards must be replaced. Each of these cards contains specific software to interface between the PC and the racks of equipment so all this proprietary software must also be rewritten. It was reported that the racks of equipment would also have to be significantly upgraded as part of the replacement program.

APA are therefore required to treat the control system very carefully. This includes the installation of Line Filters, Uninterruptable Power Supplies and Air-conditioning. Even with these precautions the control system still reports regular faults that must be diagnosed and repaired.

Control System Repairs

Anecdotally APA advised that each control system reports a fault every 2 ½ months. There are a total of 12 control systems (System A and System B for each building) resulting in 60 control system faults each year. The diagnosis and repair of Control System Faults is quite involved and is discussed in Appendix H.

[9] It is acknowledged that a few modern computers still offer PCI Express. PCI Express superseded PCI in 2004 and is not backwards compatible with PCI. To remove doubt the proprietary interface cards cannot be connected to a computer offering PCI Express since PCI Express uses a totally different connector.

Due to the delicate nature of the control systems APA have added line filters and uninterruptable power supplies to protect the electronics from mains-bourne interference. The rooms containing the controllers are also air-conditioned to maintain a constant and controlled temperature. Despite these efforts there are still a considerable number of faults requiring analysis and repair.

Discussions with APA staff indicated that the time to analyse and rectify a fault varies widely. From 30 minutes to quickly check the cards, perform a system reset and confirm that the reset has fixed the problem; through 5 hours to locate a faulty card, reprogram the card (refer to Appendix H), commission and run diagnostics; to several days when multiple cards have failed, there are issues with the host PC or a tricky combination of card faults and loose connections. The O&M Model uses 6 hours as the average time taken to diagnose and repair each fault in the control system.

As noted there are a range of different interface cards, costing from $700 to $14,000. The most common faults occur in the relay cards which are the least expensive at $700. As discussed reprogramming the card often rectifies the fault, hence the O&M Model assumes that in most cases the faulty cards is reused. As such the O&M model only includes the cost of a replacement card for 10% of the faults.

The O&M Model assumes that the new Mullumbimby converter will be supplied with an improved control system which will not generate as many faults as the current system. Hence while there are 12 control systems the modelling has only applied the repair time to the remaining 10 original control systems. The two new control systems (installed with the replacement Mullumbimby converter) will also generate faults, however the model has not captured any cost for these repairs in the next 5 year regulatory period.

While this discussion has highlighted that the control system is arguably approaching end of life any decision to replace the control system would require a major CAPEX investment. There is no allowance in the capital budget to replace the control system so Control System Repairs are forecast to continue for the full 5 years of the analysis. It is noted that APA have advised they may add a CAPEX project to replace the control system in the FY2020. This implication has not been accommodated in the O&M Model.

In summary, the total cost for these repairs is $218,097 over the 5 year regulatory period.

Air-Conditioner Maintenance

There are 36 split system air-conditioners installed across the two sites. These are predominantly installed to protect the delicate system controllers. They run continuous (24 x 7) to keep the delicate electronics at a constant and controlled temperature. A failure of an air-conditioner invariably leads to failures of the interface cards. Due to the critical role of the air-conditioners maintenance has been contracted to a specialist company. The specialist company regularly maintains all the units and replaces any unit approaching end-of-life.

Despite choosing high end consumer grade units the air-conditioners are not really suitable for continuous operation in harsh conditions. Each unit is around 2kW and the specialist maintenance company has indicated that industrial grade air-conditioning units are not available in these small sizes.

Invoices provided by APA for the period November 2012 to February 2014 show $20,000 was spent on the maintenance of these air-conditioners. Converting this to a monthly figure (the maintenance is undertaken monthly) reveals that air-conditioner maintenance would incur O&M Direct Costs of $137,349 in the 5 year regulatory period.

The O&M Model also considered reducing the maintenance and simply replacing the units every 3 years. This modelling suggests the current strategy of ongoing specialist maintenance is half the cost of regular replacement.

Uninterruptable Power Supplies

As noted above the control systems are fitted with Uninterruptable Power Supplies (UPS) and line conditioners to remove voltage spikes and provide a stable operating voltage. Each of the 12 control systems is fitted with its own UPS.

UPSs are tested every 6 months. The testing requires the power to the UPS to be removed with power for the computers and interface cards now supplied from the UPS battery. For the next 15 minutes the UPS is regularly checked to ensure that the battery is still showing full capacity. If capacity falls within the 15 minute test period it indicates that the UPS battery is degraded and the battery must be replaced.

The batteries are sealed lead acid batteries and replacement is relatively straight forward. The replacement batteries are only commercial grade which have a typical service life of 2 to 3 years. The O&M Model considers that the commercial batteries will cost $50 each and has taken the mid-point considering them to last 2 ½ years.

Testing and battery replacements incur an O&M Direct Cost of just over $34,000 in the 5 year regulatory period.

Air Blast Cooler Maintenance

The Air Blast Coolers are a critical component. The air blast coolers are fans designed to pull air through water filled radiators thereby cooling the water. This water is circulated to cool the IGBTs. A failure of the air blast coolers reduces the effectiveness of the radiators potentially shortening the life of the IGBTs (especially if the link was under load).

Each converter building is fitted with 7 banks with each bank comprising 5 fans. Across the two sites the air blast cooler comprise 210 individual fans each of which must be maintained.

Due to failures of fan blades a 3 monthly inspection has been added requiring the technician to listen carefully to each fan to detect is it operating smoothly. If the fan is not running smoothly then it is likely that the fan blades are damaged and need to be replaced. Replacement fan blades cost $100 and discussions suggest they will last 5 years.

The annual inspection requires the technicians to measure the current to each fan motor. A significant imbalance in the motor currents indicates that the motor needs to be replaced. Each fan motor costs $250 and discussions suggest they will last 5 years.

The O&M Model considers that replacement of faulty fans and motors occurs as part of the annual maintenance. Replacing a fan or fan motor requires 2 hours of contract labour.

The large number of fans means that the O&M Direct Cost forecast for Air Blast Cooler maintenance is $172,301 in the 5 year regulatory period.

Fire Sprinkler System

The Mullumbimby converter fire has led to a decision to install a fire sprinkler system in all converter buildings. The original system designer had not foreseen the catastrophic failure of a single component leading to the total destruction of converter building. As such the system designer did not specify the installation of a fire sprinkler system.

The fire suppression system comprises a number of components: Water Tanks, Valves, Control System(s), two Diesel Powered Pumps, fuel storage and the reticulation pipework. Maintenance of these critical components will be performed by specialist contractors. Preliminary discussions with APA have indicated that the monthly maintenance will be three times more expensive than the current Fire System Maintenance.

Assuming that the fire sprinkler system is installed in all converter buildings before July 2015 and that the monthly maintenance will be $300 per building indicates that maintenance of the sprinkler system will be $150,272 over the 5 year regulatory period.

The O&M Model has only included maintenance of the sprinkler system. Currently there are also discussions in train to install a gaseous fire suppression system. However, no date for commissioning is available and consequently the O&M Model does not include the cost of maintenance of the gas suppression system.

Cable Marker Maintenance

Every month a section of the cable route is walked. Due to the remote nature of much of the route and the difficult terrain (especially through the national park) it is necessary for the technicians to jointly perform the inspection. The primary activity is to inspect the route and alert the vegetation contractor to areas requiring maintenance. A different section of the cable route is selected each month with the goal being to inspect the entire route at least once per year.

The inspection takes a full day. Two technicians for 8 hours each, every month contributes $140,065 to the O&M forecast over the 5 year regulatory period.

While walking the route any signs marking the cable route which have been damaged or removed are replaced. The modelling has included a small allowance ($100 per month) for the replacement of signs.

IGBT Repairs

A single IGBT failure will not prevent the HVDC system from operating. Technically each failed IGBT becomes a short circuit allowing the rest of the IGBTs in the stack to operate. One consequence of a failed IGBT is that all remaining IGBTs in the stack are exposed to a proportionally higher voltage. This higher voltage appears negligible with 148 IGBTs in each stack – a single failure only exposes the remaining IGBTs to a 0.7% voltage increase.

While the voltage increase appears negligible the system designer's control system will shut down the converter when it detects more than 4 failed IGBTs in a single stack. Shutting down the converter when the voltage across each IGBT has increased by more than 2.7% implies that the IGBTs are operating near their maximum ratings.

Detected IGBT failures are shown in the system log. Extracted information from the logs have been recorded in Table 7.

Table 7: Historical annual IGBT replacements

Year	IGBT Replacements
2009	35
2010	44
2011	38
2012	35
2013	43
Average failures per year	39

Table 7 lists historical IGBT replacements. The number is consistently around 39 each year which has been used in the modelling.

The major cost for the O&M Model comprises two stages: firstly locating failed IGBTs in the valve stacks and then replacing the failed IGBTs.

While the control system notes that an IGBT has failed and in which stack, it does not give its specific location in the stack. The first step of the IGBT repair is to test the valve stacks to find the IGBTs which need replacing. The control system is put into the appropriate mode and then special test equipment is used to probe each (of the 148) IGBT.

Replacing the IGBTs involves:

- Disconnecting the water cooling pipes
- Disconnecting the fibre optic cable (control signal).
- Removing the old IGBT
- Fitting the new IGBT Reinstalling all the water pipes
- Reinstalling the fibre optic cable.

Finally the new IGBTs must be commissioned. A total of 5 hours has been allocated to each IGBT replacement.

IGBTs are replaced during the two scheduled outages and must also be replaced when more than 4 IGBTs fail in one stack. APA staff time for IGBT replacement during scheduled outages has already been captured hence it is only necessary to include APA staff time for unscheduled replacement. This time comprises nominal hours for the Maintenance Technicians to provide safety briefings to the contractors doing the replacement and the O&M Supervisor opening and closing work orders and purchase orders for the contractors to undertake the work. Anecdotally most years see two unscheduled IGBT maintenance periods each year which has been used in the model.

The O&M Model shows that IGBT repairs add $93,725 to costs over the 5 year regulatory period.

For completeness it is noted that each IGBT costs $5,000. The O&M Direct Cost only includes the labour and contractor costs needed to locate and replace failed IGBTs. APA capitalise the cost of the IGBTs.

Nitrogen Bottle Replacement

Nitrogen gas bubbling is used to reduce the oxygen content in the valve cooling circuit. The bubbling equipment uses bottled nitrogen. Each converter building has four bottles, with two bottles in service and two bottles on automatic standby. A drop in pressure causes the system to switch to the standby bottles.

While the system will automatically switch between the two banks, manual checking of a pressure gauge is used to determine when the bottles must be replaced. The size and weight of the bottles means it takes an hour to change the bottles.

Each month APA pay for the nitrogen gas they use and to rent the bottles. Anecdotally Directlink require 26 bottles per year with the current cost to refill the nitrogen stated as $33.04. Anecdotally the rental fee is $51.27 per month. The cost of nitrogen is therefore $8,242 in the reference year.

In addition to the time to change the bottles the O&M Model includes technician time to induct the BoC technician, accept the onsite exchange of nitrogen bottles and to update the log. It also includes an allowance for the O&M Supervisor to enter invoices into the accounting system. The total cost of nitrogen adds $87,121 over the 5 year regulatory period.

Miscellaneous Costs

A number of items were identified which would incur O&M Direct Costs. While the items were easily identified it was only possible to obtain indicative costs.

Training Courses

A large percentage of the Directlink maintenance is undertaken during two scheduled shutdowns. During this period the O&M Supervisor must coordinate sufficient resources to ensure all the maintenance is undertaken in the available period. Any work not completed during the outage must be rescheduled requiring additional outages. The only way to economically meet the high personnel requirements during these two short periods each year is to rely on contractors.

Due to the specialist nature of several maintenance tasks APA has agreed to pay for some contractors to receive Directlink specific specialist training. As a point of clarification, APA only pays for specialist training. Any training which the contractor could reasonably be expected to undertake themselves is not covered (for example electrical trade certificates).

It is also worthwhile noting that APA is required to maintain a strong working relationship with many of the contractors. The specialist high voltage skills used by Directlink are usually also required by large distribution businesses who offer a steady stream of work. In comparison Directlink only requires two intense periods of work per year. The relatively remote location of the two stations also combines to reduce the number of contractors prepared to offer their services to APA.

In passing it is also noted that APA must continuously maintain the skills of the contractors. To achieve this maintenance tasks are often shared between contractors and the APA technicians.

Sharing the work ensures that APA are able to access the high level of expertise across all required maintenance tasks.

APA provided a 'training matrix' to cover the training for all relevant people. The O&M Model has used the costs shown on the APA's internal CY2014/FY2015 Budget totalling $15,000 per year. Training therefore contributes just under $107,000 over the 5 year regulatory period.

Asset Management Team

This section of the Bottom Up Cost Study discusses the suitability of the Asset Management Team to service Directlink and provides the reasons for assigning costs of the Team to the O&M Model.

Current arrangement

APA currently has an Asset Management Team ('the Team') that in the main is required to multi-task across a range of assets. Three key Team members (Operations Manager, O&M Supervisor and Reliability Engineer) are shared across Directlink, Murraylink and other minor assets. Another three Team members are shared across all APA assets, including gas assets, and consequently their contribution to Directlink is minimal. Another two Team members are deployed 100% on Directlink.

The contribution of the Team to Directlink is presented in Section 5 of DL-DO-06 'Asset Management Plan'. The structure of the team has been redrawn in Diagram G1 of Appendix G to better represent the structural arrangement. Diagram G1 shows the following features:

- The Maintenance Technicians (2 people) are allocated 100% to Directlink. One is located a Mullumbimby and the other at Bungalora. The cost of these people is included directly in the O&M Model in accordance with their contributions to Preventative Maintenance Work Orders.
- Three key positions are shared between Directlink and Murraylink on a notional 50/50 basis[10]. The cost of these people in the O&M Model is explained below including a view on the capacity of the resources to service the Directlink reliability performance. These positions are:
  - Operations Manager.
  - O&M Supervisor.
  - Reliability Engineer.
- Three positions are shared across all of the APA assets, including gas assets. The cost of these services is included in the O&M Model through the Home Cost Centre allocation. Their contribution to Directlink is estimated (anecdotally) to be:
  - Maintenance Coordinator: ~1%, as System Administrator for the Maintenance Management Information System.
  - Technical Compliance Officer: ~5%, associated with regulatory compliance obligations.

[10] These positions were planned on the notional basis of a 50/50 split between Directlink and Murraylink, with a small dilution required to attend to the other minor assets. For the purpose of the diagnostic review, the allocation of time to Directlink is assumed to be based on the notional 50/50 split.

  - Document Control and Records Officer: ~5%, associated with correspondence administration.

- Outsourced services are utilised for the following requirements – the cost of these services is included directly in the O&M Model:
  - The Control Room – a shared service across all APA assets.
  - Maintenance Contractors – external specialists in their field of endeavour.

These two contributions are also shown in Diagram G1.

Suitability of the Asset Management Team key positions

The capacity of the three key positions in the Team to perform Directlink maintenance was assessed in the diagnostic review. Their capacity was examined in part by drawing out the implied maintenance practices deployed by the Team. These practices were mapped to a high level maintenance process ('Maintenance Cycle'), a sub-process involving the Maintenance Management Information System and Work Orders, and a sub-process for performing Condition Monitoring. These process maps are shown in Appendices D, E and F respectively. The process maps contain both current practices and desired future practices.

These process maps, coupled with published position duties (DL-DO-06), an understanding of the current state of the reliability of Directlink (arising from the diagnostic review) and an understanding of the actual practices deployed to address the current state of performance (also arising from the diagnostic review) were used by Phacelift to form a view on the suitability of the Asset Management Team to service the maintenance of Directlink to and at its sustainable level of performance.

An assessment of these contributions revealed the following significant matters:

- Excessive forced outages of Directlink (an average of approximately 1 per month) have diverted the Operations Manager, the O&M Supervisor and the Reliability Engineer away from fulfilling published duties to the point where those duties are not able to be undertaken.
- The O&M Supervisor required more time on site (due to the excessive forced outages) to supervise multi-party maintenance / repair contractors. In this regard the following points are noted:
  - The Plan Works step in the Maintenance Cycle had to be resourced for continuity of maintenance work. To service both the 'Plan Works' step and the on-site supervision, the practical outcome was to allocate the Reliability Engineer to the on-site supervision and retain the O&M Supervisor to perform the Plan Works step.
  - Undertaking Quality Assurance of the information contained in the Maintenance Management Information System is given a low priority when confronted by excessive forced outages. The Preventative Maintenance 'procedures' in the System were in need of a comprehensive review (alignment with the published maintenance strategy and data cleansing).
- The Reliability Engineer has a duty to "review and update work instructions, operational procedures, operating forms and safety procedures specific to the assets". This duty had

defaulted to the Operations Manager due to the diversion of the Reliability Engineer to forced outages requiring urgent corrective maintenance.

- The compliance regime associated with Directlink's Network Connection Agreement and the NER requirements was formalised in a Compliance Plan (DL-DO-07) during FY2014. This Plan prioritises existing duties of the Operations Manager and Reliability Engineer to the point where there is a clash in the ranking of those published duties. The Asset Management Team does not have adequate resources to address multiple duties that are given equal ranking – as a consequence, published duties are required to be re-ordered to attend to the most urgent matters, with the consequence that many duties will not be attended to, or will be given only brief attention.
- The current capital works forward program will take a number of years before the impact on the Asset Management Team will be materially noticed. In regard to reliability performance, which is primarily measured by the number and duration of the forced outages caused by cable faults and IGBT failures, Phacelift has formed a view that the capital works program will not make a material impact on the utilisation of Directlink resources during the 5 year regulatory period. Consequently, any supplementary resources required at the commencement of the 5 year regulatory period will be required at the end of that period. In each subsequent regulatory period, the composition of the Asset Management Team should be reviewed to assess the level of support required for that period.

The following points relate to each of the key Team members that are shared between Directlink and Murraylink:

Operations Manager

The Operations Manager is a shared resource with a notional 50/50 split between Directlink and Murraylink.

For Directlink, the Operations Manager has the implied role of oversighting the effective operation of the Maintenance Cycle, as shown in Appendix D. In addition, this position:

- Has a part supervisory and part direct role in the Maintenance Planning step;
- Has a direct role in the OPEX Budget step;
- Has a direct role on the Management Reporting step;
- Has a sponsor's role in the Maintenance Review step;
- Has a direct role in the Compliance Plan (DL-DO-07), with 8 of the 17 compliance tasks assigned to this role.

The Operations Manager has advised of the proportions of time spent on Directlink and Murraylink tasks, as shown in the following Table:

Table 8: Proportion of time spent on Directlink and Murraylink tasks

#	Task description	Directlink[1]	Murraylink[1]
1	Cable repairs	5%	0%
2	Control system repairs	10%	0%
3	Control room with operational issues	10%	5%
4	Leadership, management and supervisory duties: Audits, compliance	75%	95%

	requirements, management reporting, safety issues, communications, leadership, revenue submissions, and other corporate overheads.		

Note [1]: estimated proportion of time spent on each task for that asset.

From this assessment, and based on the notional 50/50 split of duties between Directlink and Murraylink, it can be concluded that the lower reliability of Directlink has consumed 20% of the available time (5% cable repairs, 10% control system repairs and 5%[11] control room operational issues) when compared to Murraylink.

The balance of the time (80%) is not share evenly between the assets because the lower reliability of Directlink brings with it additional overheads. For the purpose of the O&M Model, Phacelift has allocated (based on a conservative view) 45% of that balance to Directlink and 35% to Murraylink.

This analysis indicates that the Operations Manager spends 65% (=20% + 45%) of available time on Directlink and 35% of available time on Murraylink. Phacelift is of the view that this outcome is not sustainable as good practice. Either the Murraylink asset will suffer (on the basis that 15% less attention is currently being given to published duties) or the management culture will deteriorate (due to the additional time being applied to manage reactive events which have moved from being one-off to much more frequent).

Phacelift contends that in this current unusually situation, good practice dictates that the Operations Manager must be given additional support to enable the duties to be returned to the notional 50/50 split so that quality leadership can be exhibited. This implies that the Operations Manager's costs should be included in the O&M Model on the notionally 50/50 split for the full duration of the next 5 year regulatory period. It also implies that the additional time that would have otherwise been aligned to the Operations Manager can be costed and allocated to specialist support staff[12] who can relieve the Operations Manager from some duties. In particular, it is noted that the Operations Manager had become the default 'document writer' to allow the Reliability Engineer to attend to other duties. This duty should be removed from the Operations Manager by the specialist support staff (see discussion of the Reliability Engineer below).

From this analysis, the O&M Model assigns a notional 50% of the Operations Manager's time directly to Directlink (55.2% in the first year and 50% in the remaining 4 years). The APA's charge out rate for the Operations Manager is $121 per hour (listed in Table 3).The contribution of this position to the O&M Direct Cost is shown in the summary table at the end of this section.

O&M Supervisor

The O&M Supervisor is a shared resource with a notional 50/50 split between Directlink and Murraylink.

For Directlink, the O&M Supervisor has the implied role of oversighting the effective operation of various steps in the maintenance process. These are:

- From the Maintenance Cycle process map: Plan Work, Schedule Work, Perform Work, Complete and Close Work, as shown in Appendix D.

[11] The balance remaining when the 5% Murraylink is subtracted from the 10% Directlink.
[12] The annual funds available to support an additional resource is 30% (=65% - 35%) times the hourly rate of the Operations Manager for a 12 month period (approximately $63,000). This resource would be assigned to the preparation of documentation and its renewal based on good work practices.

- From the Maintenance Management Information System process map: Create Work Orders, Issue Work Orders, Complete and Close Work Orders, as shown in Appendix E.
- From the published duties (Section 5.3.2 of Work Instruction DL-DO-06): examples include:
  - Ensuring all high voltage switching activities are performed safely by suitably qualified and authorised personnel.
  - Increase public safety awareness of the hazards presented by the underground cables.
  - Work with customers and team members to identify opportunities to improve the operational performance and reduce costs of the assets.
  - Supervise to ensure personnel and contractors complete their work to an acceptable standard.

In summary, once a preventative maintenance task is initiated by the Maintenance Management Information System, the O&M Supervisor (as the only available person) must determine when the maintenance will be undertaken and by whom (that is, a works planning task is initiated), requiring the raising of one or more Work Orders. If the maintenance is to be undertaken by contractors the O&M Supervisor is required to coordinate with the contractor to determine when they are available. A purchase order is then required to be raised for the work.

Through the modelling, the Bottom Up Cost Study found that the 'supervision time' provided by the O&M Supervisor was close to the 50% mark in each year, confirming the notional 50% split. However, through the diagnostic review, the Bottom Up Cost Study found that the Directlink reliability issues were (without additional support) consuming significantly more of the O&M Supervisor's time than the notional 50% split. To relieve the O&M Supervisor, the Reliability Engineer was assigned to undertake the on-site supervision, as mentioned above .

The O&M Supervisor has a set of published duties (DL-DO-06) which includes "supervise to ensure personnel and contractors complete their work to an acceptable standard". This duty has been assigned largely to the Reliability Engineer who was required to manage the logistics of having multiple contractors work on site at the one time and supervise the quality of their work. This released the O&M Supervisor to perform the Works Planning step in the Maintenance Cycle, which is essential for maintenance work to proceed.

The Reliability Engineer was also assigned to carry out works planning for approved CAPEX projects. Time wise, this task would normally be assigned to the O&M Supervisor. Consequently the Reliability Engineer was being used 'out of character' to fill in for the O&M Supervisor due to the excessive work that was being thrust upon that role due to the reliability state of the Directlink asset.

The diagnostic study found that the time available to the Reliability Engineer for Directlink was mostly assigned to carrying out O&M Supervisor published duties rather than Reliability Engineer published duties and that this had significantly impacted on the 50/50 split – to the point where the Reliability Engineer was almost 100% on Directlink, with minimal time on Murraylink. By returning the Reliability Engineer to its published duties, a gap of approximately 1 person (applied on a 50% notion split) for the O&M Supervisor was evident. Consequently, the Bottom Up Cost Study has recognised this gap as the cost of 1 additional person (on a notional 50/50 split between Directlink and Murraylink) who would undertake planning duties (the Planned Work and Complete Work steps) for the O&M Supervisor. Note that for QA purpose, the O&M Supervisor would be required to perform the Close Work step after the Complete Work step was performed.

For the purpose of the Bottom Up Cost Study, and to service the Directlink preventative and corrective maintenance work based on a notional 50/50 split between Directlink and Murraylink, Phacelift has adopted the following allocation of work:

- 50% (notional 874 hrs) of the O&M Supervisor's time for all Directlink maintenance work. Note that this is required to ensure this person also has time to perform the published Murraylink duties; and
- 50% (notional 874 hrs) of another person's time for assistance with Directlink maintenance work. This person is required to supplement the O&M Supervisor in the Plan Work and Complete Work steps of the maintenance cycle.
- 200% (notional 2 x 1,748 = 3,496 hours) to the Maintenance Technicians to recognise their full time roles on Directlink.

The obvious use of the additional employee under the O&M Supervisor is to undertake the Plan Work and to assist with the Complete & Close Work steps in the Maintenance Cycle (refer to Appendix D). This new position ('Works Planner') is shown in Diagrams G2 and G3 in Appendix G.

From this analysis, the O&M Model assigns 50% of the O&M Supervisor's time, 50% of a new position (Works Planner), and two Maintenance Technician times directly to Directlink. The APA's charge out rate for the O&M Supervisor is $100 per hour, $86 per hour for the Works Planner and an average value of $79 per hour for the technicians (listed in Table 3). The contribution of this position to the O&M Direct Cost is shown in the summary table at the end of this section.

Reliability Engineer

The Reliability Engineer is a shared resource with a notional 50/50 split between Directlink and Murraylink.

For Directlink, the duties of the Reliability Engineer are well documented by APA[13]. Of these duties, twelve relate to matters of conduct and are not relevant to the diagnostic review, and seventeen relate to areas for which this role was responsible – for example, "analysis of maintenance activities to determine future maintenance needs". Of the seventeen relevant areas, the review assessed that only a few areas were being addressed, being:

- Provide electrical engineering and technical support for the assets as required;
- Liaise with asset control rooms to interpret operational alarms and diagnose malfunctions of the assets;
- Liaise with on-call maintenance personnel to assist diagnosis of equipment failures;
- Attend asset sites for emergencies and maintenance periods to supervise contractors onsite and provide technical support.

The last dot point mentions the duty of supervising contractors during maintenance periods. Phacelift considers that it is reasonable practice to allocate 2% (38 hrs – 1 week) of the Reliability Engineer's time for onsite supervision of Directlink Corrective Maintenance work (as distinct from

[13] See Section 5 'Asset Management Resources' in document DL-DO-06 'Directlink Asset Management Plan' – S5.3.3 'Reliability Engineer'.

on-site advice during fault repairs and on site presence during fault investigations). Some exposure to Corrective Maintenance supervision work will be relevant to the Reliability Engineer. This will allow the Reliability Engineer to be refocused on published duties relating to that role.

The remaining duties were not being undertaken due to the reactive environment associated with the forced outages of the Directlink asset.

This situation was assessed in the diagnostic review from a different viewpoint. An assessment of the condition monitoring process was undertaken (refer to the process map in Attachment F). The assessment was performed to: (a) understand the key steps of a condition monitoring process that would be applicable to the Directlink assets, and (b) assess the proportion of those steps currently being undertaken within that process. The review found that four of the six steps (Data Entry QA, Failure Mode & Corrective Actions, Asset Recommendations, and Lifecycle Cost Projects) were not being resourced by the Reliability Engineer due to Directlink reliability issues. A fifth step Data Collection was being performed to a limited degree, partly due to limited measurement facilities. Elsewhere, the diagnostic review found that there was an average of one cable fault a month, indicating that the Reliability Engineer was being permanently distracted from the published duties, as explained above.

The Condition Monitoring process maps identify steps that are capable of being assigned to people with different skill levels. In particular, the following split in skills is available:

- Level 1 steps (senior skill): Asset Maintenance Strategy, Asset Recommendations, and Lifecycle Cost Projects. A senior skill set is required as these steps require the person to produce business cases of a quality suitable for presenting to the Company's Board for approval. The business cases need to explain the existing asset maintenance strategy and the changes that would be made to that strategy once the lifecycle project was commissioned and operational[14]. The person needs to act as a project manager any approved projects to ensure their effective implementation. And the person needs to ensure that the maintenance strategy is changed as a result of the commissioning of the project.
- Level 2 steps (junior skill): Data Collection, Data Entry QA, Failure Mode & Corrective Actions. This person needs to analyse the current poor state of data availability and prepare a data specification to support APA's failure mode analysis software (including the provision of a suitable data warehouse), develop workarounds to provide a transitional pathway towards good condition analysis techniques, introduce sound data cleansing techniques, develop a practical life cycle model in which to place the data, and build up a useful database of failure mode scenarios.

It is noted that the Condition Monitoring process ends up producing Lifecyle Cost Projects, which implies that the process whilst costed as an O&M Direct Cost, produce outputs that feed into the Capital Expenditure program and hence the CAPEX budget.

[14] Directlink has experienced a number of issues which are specific to its unique design and to the environment in which it is operating. The unique design means that APA must develop their own improvements to the system designer's recommended maintenance (as noted previously the unique design of the early VSC converters used in Directlink limits APA's ability to draw on experience from other HVDC operators).

It is also noted from the above analysis of the O&M Supervisor that the current role of the Reliability Engineer on Directlink 'supervision' duties is almost 100%. Separately, and as with the Operations Manager, a prioritisation of duties has recently occurred within APA with the introduction of a formal Compliance Plan[15]. Whilst the duties of the Reliability Engineer also cover the "preparation of technical incident reports as required" these reports were not currently being prepared due to the distractions with forced outages. The Compliance Plan places six formal obligations on the Reliability Engineer, for example:

- Undertake an analysis of fault events external to the Directlink system, resulting in an 'Applicable Event Report' for each 'Applicable Event'.
- Identify protection trips of Directlink and fault clearing times, resulting in an 'Applicable Event Report' for each 'Applicable Event'.

Given that there is on average 1 cable fault each month, these compliance reporting requirements need the Reliability Engineer to be readily available and not assigned to other duties.

When the Condition Monitoring Process map, the Compliance Plan and the published duties are taken together, Phacelift considers it reasonable to assign one person full time on Directlink reliability matters going forward, at least for the duration of the next 5 year regulatory period. A modification of this view is to assign two people to fulfil reliability engineer duties for Directlink for 50% of their time. This later view would be translated into a Level 1 skill and a level 2 skill for 50% on Directlink and 50% on Murraylink so as to apply the notional 50/50 split to these roles.

In addition, the current duty of the Reliability Engineer is "review and update work instructions…" as noted above. By default these documentation skills are currently being performed by the Operations Manager. It is Phacelift's view that this duty should be resumed by the Reliability Engineer position, but with a different focus. The focus going forward should be on good work practices and fit for purpose document writing to record those work practices. This would naturally be coupled with the increasing need (under WHS National Uniform Legislation) to prepare safe work documents for the workforce. In addition, the duty should perform reviews of the Maintenance Management Information System to ensure that Preventative Maintenance practices are aligned with either the OEM recommendations or the Company's asset maintenance strategy, whichever has precedence. The duty should also undertake QA of the 'Close Work' data in the Maintenance Management Information System to ensure:

- it is adequately recorded;
- where recorded it is fit for purpose; and
- where fit for purpose is able to be retrieved.

This would include ensuring that the process of taking and archiving maintenance photos supported good maintenance practices. The cost of this position would be funded from the reduction in current duties undertaken by the Operations Manager, as indicated above. The APA charge out rate of $79/hour has been used to model this resource.

Consequently, and as shown in Appendix G, diagrams G2 and G3, a Senior Reliability Engineer would be employed for 50% of the time on Directlink, likewise a (junior) Reliability Engineer would be

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[15] DL-DO-07 "Directlink Compliance Plan for Connection Agreement and NER Chapter 5"

employed for 50% of the time on Directlink, and a Work Practices Specialist would be employed for 50% of the time on Directlink.

The three positions (two new and one existing) have been included in the O&M Model for 2.5 days a week at $111/hr, $100/hr and $86/hr respectively (listed in Table 3) for the duration of the 5 year regulatory period. It is recommended that a review of these positions be undertaken in the next regulatory submission due in 2019. The contribution of this position to the O&M Direct Cost is shown in the summary table at the end of this section.

Summary for Asset Management Team

In summary, the Bottom Up Cost Study has found the need to strengthen the Asset Management Team for Directlink by adding 3 new positions, and modifying one position, these being:

1. O&M Supervisor – limit to a notional 50% on Directlink.
2. Works Planner – new 50% position under O&M Supervisor.
3. Senior Reliability Engineer – new 50% position under the Operations Manager.
4. Work Practices Specialist – new 50% position under the Senior Reliability Engineer.

These positions, along with the role of the Operations Manager (a notional 50% of the time on Directlink), the Reliability Engineer (returned to a notional 50% on Directlink) and the roles of the Maintenance Technicians add $5.291 million to the 5 year regulatory period, as shown in the following table.

Table 9: Summary of modelling outcomes for Asset Management Team – Directlink only

Position	Year 1	Total for 5 year regulatory period
Operations Manager	$151,911	$737,398
O&M Supervisor	$117,442	$589,491
Works Planner	$97,768	$513,899
Technicians x 2	$384,397	$1,675,212
Senior Reliability Engineer	$126,189	$663,288
Reliability Engineer	$113,683	$597,557
Work Practices Specialist	$97,768	$513,899
Total Asset Management Team	**$1,089,157**	**$5,290,745**

Table 10 has been provided as a summary of the annual hours assigned to each role in Table 9.

Table 10: Asset Management Team – summary of hours per annum – Directlink only

Position	Year 1 (hours)[1]	Year 2 (hours)	Year 3 (hours)	Year 4 (hours)	Year 5 (hours)
Operations Manager	965	874	874	874	874
O&M Supervisor[2]	903	826	875	864	845
Works Planner	874	874	874	874	874
Technicians x 2[2]	3,741	2,948	2,954	2,952	2,951
Senior Reliability Engineer	874	874	874	874	874
Reliability Engineer	874	874	874	874	874
Work Practices Specialist	874	874	874	874	874

Note [1]: there are 1,748 work hours available in a full year

Note [2]: these hours are a result of task modelling.

Appendix B Component Counts

Counting components using the Single Line Diagram

The two converter stations used in the Directlink High Voltage DC link are located at Mullumbimby and Bungalora.

A Single Line Diagram for both sites is shown in Figure 17. This diagram is included to show the one difference between the two sites.

- The Bungalora converter station is connected to the 110kV line through an AC Circuit Break (WT.Q11) to provide protection for the underground cable.
- In contrast the Mullumbimby converter station relies on a Circuit Breaker in the nearby Essential Energy sub-station to connect it to the 132kV line.

The Single Line Diagram only shows one of three ‘systems’ (refer to Figure 1). Given the identical and independent nature of the other two ‘systems’, it can be used as an indications of the electricity equipment that makes up the total Directlink asset. From the Single Line Diagram, it can be seen that:

- Each converter station contains an AC section and a DC section.
- Individual components are replicated across each phase in the AC Section, meaning that there are 3 components of an asset type for the three phase circuit.
- Individual components are replicated in the DC Section (one for each cable leg), meaning that there are 2 components of an asset type for the two cable circuit.
- Each of the component counts must be tripled for each system.
- Each of the component counts must be doubled to account for the two sites (excluding WT.Q11 discussed above).

A first step in undertaking the scope of the maintenance required is to count the number of components. A quick summary reveals that the Single Line Diagram identifies over 60 different components totalling over 750 individual items.

The following sections of this Appendix use the Single Line Diagram to count the number of each component.

Note that approach still underestimates the actual number of components requiring maintenance. For example while this analysis shows that there are 36 “IGBT Valves”, each Valve comprises 8 stacks each containing 148 individual IGBTs. In the Directlink system there are 5328 IGBTs each of which must be individually checked and tested.

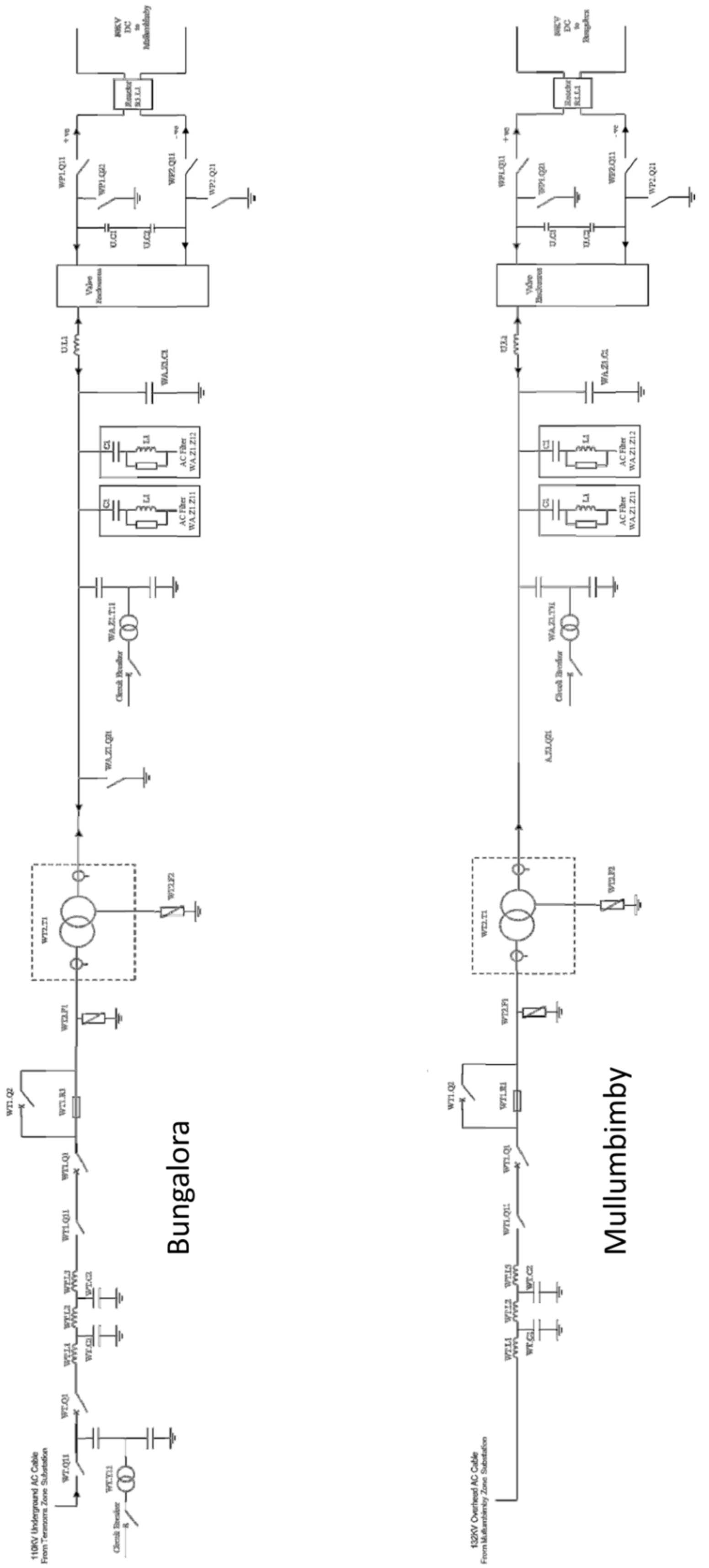


Figure 17: The Single Line Diagram of the two Directlink converter stations (showing only one system)

Single Line Diagram provided by the OEM

The following section uses the nomenclature outlined in the Single Line Diagram provided by the OEM.

The two sites are referred to as S1 (Mullumbimby) and S2 (Bungalora).

Each site is then further divided into the areas WT, WT1, WT2, WA, U, WP1, WP2 and R1.

Several of these areas are internally divided into sub-areas.

The Single Line Diagram contains in part only one of the three Directlink circuits, known as 'systems'. The other two systems are replicas of the first system, and accordingly are not shown on the Single Line Diagram). To avoid confusion, each circuit is given a 'system' number. Consequently, Directlink consists of System 1, System 2 and System 3. The Single Line Diagram also contains common AC three phase assets at both Mullumbimby and Bungalora.

Interpreting the equation giving the component counts

The following sections use an equation to show how the number of each component is derived. An example is shown in Figure 18.

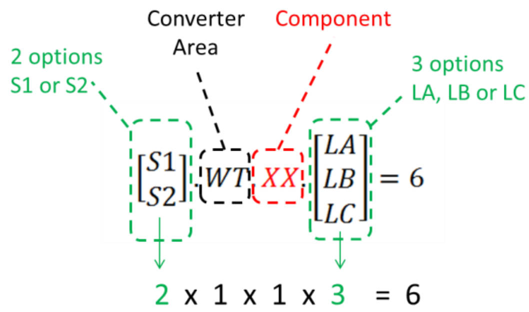
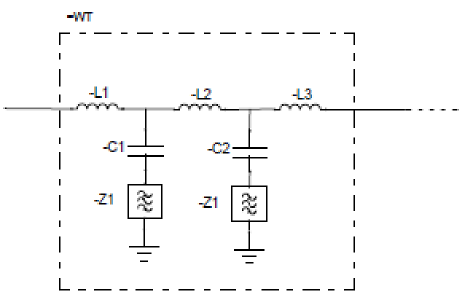


Figure 18: Example of the component counts

Referring to Figure 18 the items shown in [ ] are options. The number of items in these brackets are multiplied together to arrive at the total number of components.

WT Area (three phase AC)



WT Area (Bungalora Only)

Multiplier:

$$S2.WT.QX = 1$$

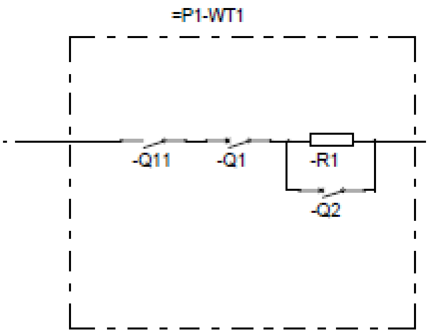
Component	Description	Number	
Q1	AC Circuit Breaker	1	Bungalora Only 3 contacts and 3 mechanisms
Q11	AC Disconnector	1	Bungalora Only 3 contacts and 3 mechanisms

Multiplier (for components shown in the system designer's diagram):

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix}.WT.XX.\begin{bmatrix} LA \\ LB \\ LC \end{bmatrix} = 6$$

Component	Description	Number	
L1	AC Reactor	6	DL-WI-29
L2	AC Reactor	6	DL-WI-29
L3	AC Reactor	6	DL-WI-29
C1	AC Capacitor	6	DL-WI-30
C2	AC Capacitor	6	DL-WI-30
Z1	AC Tuning Circuit	12	

WT1 Area (three phase AC)



Multiplier for R1:

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix}.\begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix}.WT1.R1.\begin{bmatrix} LA \\ LB \\ LC \end{bmatrix} = 18$$

Multiplier for Circuit Breakers:

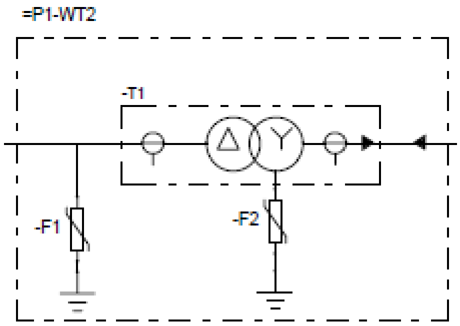
$$\begin{bmatrix} S1 \\ S2 \end{bmatrix}.\begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix}.WT1.QX = 6$$

Component	Description	Number	
Q11	AC Disconnector	6	Manually operated 3 contacts and 3 mechanisms

Q1	AC Circuit Breaker	6	3 contacts and 3 mechanisms
Q2	AC Bypass Breaker	6	3 contacts and 1 mechanism
R1	AC Resistor	18	AC Filter Resistor

While not shown on the line diagram the above table lists the number of “contacts” and “mechanisms” in each of the Circuit Breakers. This is used to estimate maintenance requirements.

WT2 Area (three phase AC)



Multiplier (for surge arrestor F1):

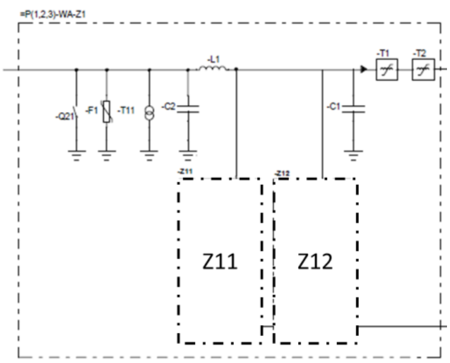
$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . WT2.FX. \begin{bmatrix} LA \\ LB \\ LC \end{bmatrix} = 18$$

Multiplier (for Transformer and surge arrestor F2):

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . WT2.T1 = 6$$

Component	Description	Number	
F1	AC Surge Arrestor	18	DL-WI-34
F2	AC Surge Arrestor	6	DL-WI-34
T1	AC Transformer	6	+ Spare Transformer at stored a Bungalora

WA.Z1 Area (three phase AC)

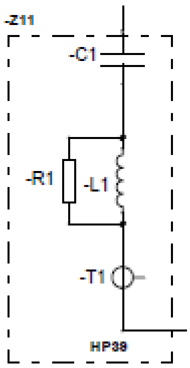


Multiplier:

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . WA.Z1.XX. \begin{bmatrix} LA \\ LB \\ LC \end{bmatrix} = 18$$

Component	Description	Number	
Q21	AC Earth Switch	18	DL-WI-45
F1	AC Surge Arrestor	18	DL-WI-34
T11	Capacitive Voltage Transformer	18	DL-WI-37
C1	AC Capacitor	18	DL-WI-30
C2	AC Capacitor	18	DL-WI-30
L1	AC Reactor	18	DL-WI-29
T1	Hall Effect Current Transformer	18	DL-WI-31
T2	Hall Effect Current Transformer	18	DL-WI-31

WA.Z1.Z11 (three phase tuning circuit)

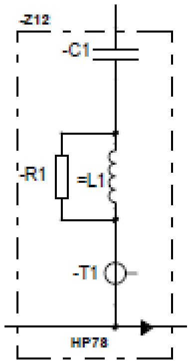


Multiplier (for components):

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . WA.Z1.Z11.XX. \begin{bmatrix} LA \\ LB \\ LC \end{bmatrix} = 18$$

Component	Description	Number	
C1	AC Capacitor	18	DL-WI-30
R1	AC Resistor	18	DL-WI-35
L1	AC Reactor	18	DL-WI-29
T1	Outdoor Post Type Current Transformer	18	DL-WI-32

WA.Z1.Z12 (three phase tuning circuit)

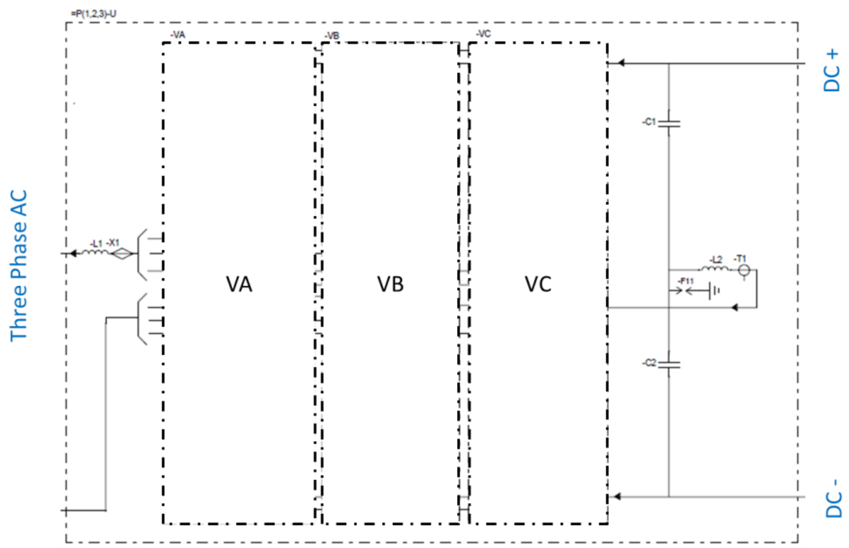


Multiplier (for components):

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . WA.Z1.Z12.XX. \begin{bmatrix} LA \\ LB \\ LC \end{bmatrix} = 18$$

Component	Description	Number	
C1	AC Capacitor	18	DL-WI-30
R1	AC Resistor	18	DL-WI-35
L1	AC Reactor	18	DL-WI-29
T1	Outdoor Post Type Current Transformer	18	DL-WI-32 (although referred to as T2)

U (Converter section)



Multiplier (for three phase AC components):

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . U.XX. \begin{bmatrix} LA \\ LB \\ LC \end{bmatrix} = 18$$

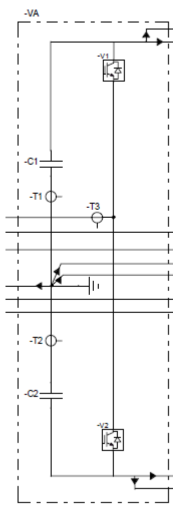
Component	Description	Number	
L1	AC Reactor	18	
X1	Insulated Wall Bushing	18	

Multiplier (for DC components):

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . U . XX = 6$$

Component	Description	Number	
L2	DC Reactor	6	DL-WI-29
C1	DC Capacitor	6	DL-WI-30
C2	DC Capacitor	6	DL-WI-30
T1	Outdoor Post Type Current Transformer	6	DL-WI-32
F11	Air Gap Surge Limiter	6	DL-WI-34

U.Vx (IGBT Stacks)



Multiplier (for DC components):

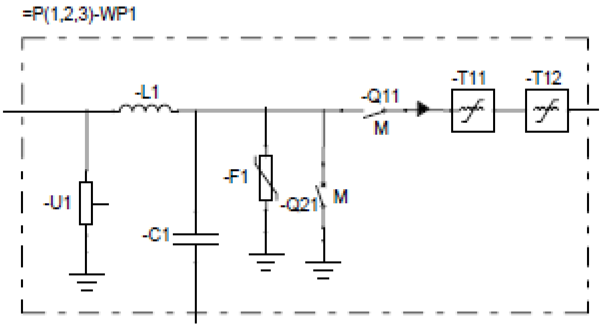
$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . U . \begin{bmatrix} VA \\ VB \\ VC \end{bmatrix} . XX = 18$$

Component	Description	Number	
C1	DC Capacitor	18	DL-WI-30
C2	DC Capacitor	18	DL-WI-30
T1	Rogowski Current Transformer	18	DL-WI-28
T2	Rogowski Current Transformer	18	DL-WI-28
T3	Rogowski Current Transformer	18	DL-WI-28
V1	IGBT Stack	18 (*)	DL-WI-26

V2	IGBT Stack	18 (*)	DL-WI-26

(*) Each stack consists of XX individual IGBTs

WP1 and WP2 (DC Sections)

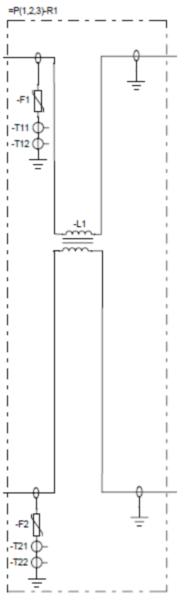


Multiplier (for components):

$$\begin{bmatrix} S1 \\ S2 \end{bmatrix} . \begin{bmatrix} P1 \\ P2 \\ P3 \end{bmatrix} . \begin{bmatrix} WP1 \\ WP2 \end{bmatrix} . XX = 12$$

Component	Description	Number	
U1	DC Voltage Divider	12	
L1	DC Reactor	12	DL-WI-29
C1	DC Capacitor	12	DL-WI-30
F1	DC Surge Arrestor	12	DL-WI-34
Q11	DC Disconnector	12	DL-WI-45 (Manual)
Q21	DC Earth Switch	12	DL-WI-45 (Manual)
T11	Hall Effect Current Transformer	12	DL-WI-31
T12	Hall Effect Current Transformer	12	DL-WI-31

R1 (DC section)



Multiplier (for DC components):

$$\begin{bmatrix}S1\\S2\end{bmatrix}.\begin{bmatrix}P1\\P2\\P3\end{bmatrix}.R1.XX = 6$$

Component	Description	Number	
F1	DC Cable Screen Arrestor	6	DL-WI-34
T11	Cable Screen Current Transformer	6	DL-WI-33
T12	Cable Screen Current Transformer	6	DL-WI-33
F2	DC Cable Screen Arrestor	6	DL-WI-34
T21	Cable Screen Current Transformer	6	DL-WI-33
T22	Cable Screen Current Transformer	6	DL-WI-33
L1	DC Zero Sequence smoothing reactor	6	

Appendix C – Worksheets in the O&M Model

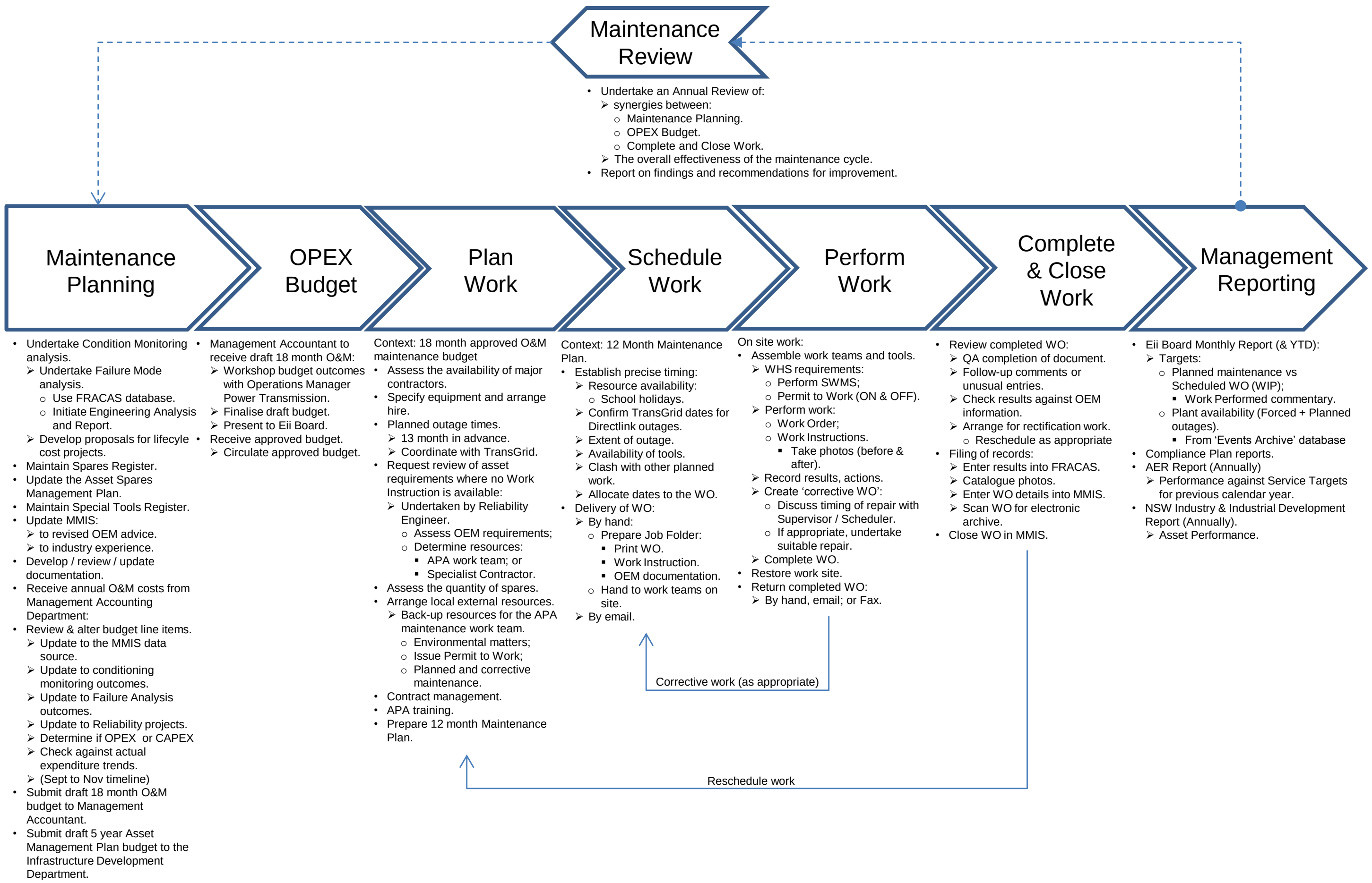
The following table lists the worksheets in the O&M Model.

Worksheet Name	Description
INDEX	Index to all worksheets in the model
Summary	Sorted summary of all the O&M costs
Team Hours	Summary of hours for each member of the Asset Management Team
Summary of PMs	List of all the O&M costs with broken down into cost categories
Chart Summary	Chart of the most significant O&M costs
Modelling Assumptions	Worksheet allowing global parameters to be set
0000 (1)	FIRE DETECTION & ALARM SYSTEM
0000 (2)	FIRE SPRINKER SYSTEM
0001	CHECK EYE WASH STATION
0003	PORTABLE FIRE EXTINGUISHER INSPECTION
0004	EMERGENCY LIGHTING MAINTENANCE
0005	ENERGISED MAINTENANCE INSPECTION
0006	UNINTERRUPTIBLE POWER SUPPLY
0010 (1)	YARD MAINTENANCE
0010 (2)	OIL FILLED CAPACITOR MAINTENANCE
0011	INSPECT SPILL KITS
0013	FUNCTIONAL TEST OF HIGH VOLTAGE TEST EQUIPMENT
0014	HALL EFFECT CURRENT TRANSDUCER MAINTENANCE
0016	ROGOWSKI CURRENT TRANSDUCER MAINTENANCE
0017	VEGETATION MANAGEMENT
0019	CABLE MARKER SIGN MAINTENANCE
0022	OUTDOOR POST TYPE CURRENT TRANSFORMER
0024	CABLE SCREEN CURRENT TRANSFORMER
0026	CAPACITIVE VOLTAGE TRANSFORMER MAINTENANCE
0028	POWER TRANSFORMER MAINTENANCE
0038 (1)	ZINC OXIDE SURGE ARRESTOR MAINTENANCE
0038 (2)	AIR GAP SURGE LIMITER MAINTENANCE
0042	AC FILTER RESISTOR MAINTENANCE
0050 (1)	VALVE COOLING SYSTEM MAINTENANCE
0050 (2)	NITROGEN BOTTLE REPLACEMENT
0052	VALVE COOLING SYSTEM PUMP MAINTENANCE
0054	VALVE COOLING MCC THERMOGRAPHIC IMAGING
0056	AIR BLAST COOLER MAINTENANCE
0060	VALVE DEHUMIDIFIER MAINTENANCE
0062	VALVE HUMIDITY CONTROL SYSTEM
0104 (1)	REACTOR MAINTENANCE
0104 (2)	PHASE REACTOR MAINTENANCE
0104 (3)	PHASE REACTOR FAN MAINTENANCE
0104 (4)	DC ZERO PHASE REACTOR MAINTENANCE
0110	IGBT VALVE MAINTENANCE

Worksheet Name	Description
0120	DIRECT VOLTAGE DIVIDER MAINTENANCE
0124	NITROGEN DISCHARGE UNIT MAINTENANCE
0126	CONVERTER STATION THERMOGRAPHIC INSPECTION
0128	FUNCTIONAL TEST OF EMERGENCY STOP BUTTON
0140	CIRCUIT BREAKER MAINTENANCE
0142	INSULATING WALL BUSHING MAINTENANCE
0150	PLC FILTER TUNING UNIT MAINTENANCE
0160 (1)	DISCONNECTOR & EARTH SWITCH MAINTENANCE
0160 (2)	MOTORISED OPERATING MECHANISM MAINTENANCE
0180	MANUAL OPERATING MECHANISM MAINTENANCE
Prestart Inspection	PRESTART INSPECTIONS
Cable Repairs	CABLE REPAIRS
IGBT Repairs	IGBT VALVE REPAIRS
Control System Repairs	CONTROL SYSTEM REPAIRS
Building ac	BUILDING AIR-CONDITIONERS
Electricity Costs	ELECTRICITY COSTS
Control Room Costs	CONTROL ROOM OPERATIONS
Remote Comms	REMOTE COMMUNICATIONS
DBYD	DIAL BEFORE YOU DIG
Site Security	SITE SECURITY
Training Courses	TRAINING COURSES FOR CONTRACTORS
Onsite Test Equipment	ONSITE TEST EQUIPMENT MAINTENANCE
Incidental Investigations	INCIDENTAL INVESTIGATIONS
Travel	TRAVEL
Other Items	OTHER COSTS
Operations Manager	OPERATIONS MANAGER
Senior Reliability Engineer	SENIOR RELIABILITY ENGINEER
Reliability Engineer	RELIABILITY ENGINEER
Works Planner	PLAN WORKS AND COMPLETE WORKS
Work Practices Specialist	WORK PRACTICES SKILLS AND DOCUMENT WRITER
Blank	Blank sheet (used to mark the end of the items included in O&M costs)
DL PMs	Listing from Maintenance Connection of all the Directlink PM IDs
OnSite Contractors	Extract from the accounting system showing onsite contractors
DL OPEX Budget	Directlink CY2014/FY2015 OPEX Budget
Schematics	Single Line Diagrams for the two Directlink sites
Components in Schematic	Counting components shown in the Single Line Diagram
Grouped Components	Grouping similar components
ABB Maintenance	Initial list of recommended preventative maintenance tasks
Byron Bay Trees	Analysis of invoices from Byron Bay Trees (used in Vegetation management)
Electricity Invoices	Detailed analysis of electricity use and demand from electricity invoices before the Mullumbimby fire
Maintenance Documents	List of Directlink documents provided for this study

Appendix D – Directlink Maintenance Cycle

Directlink maintenance cycle

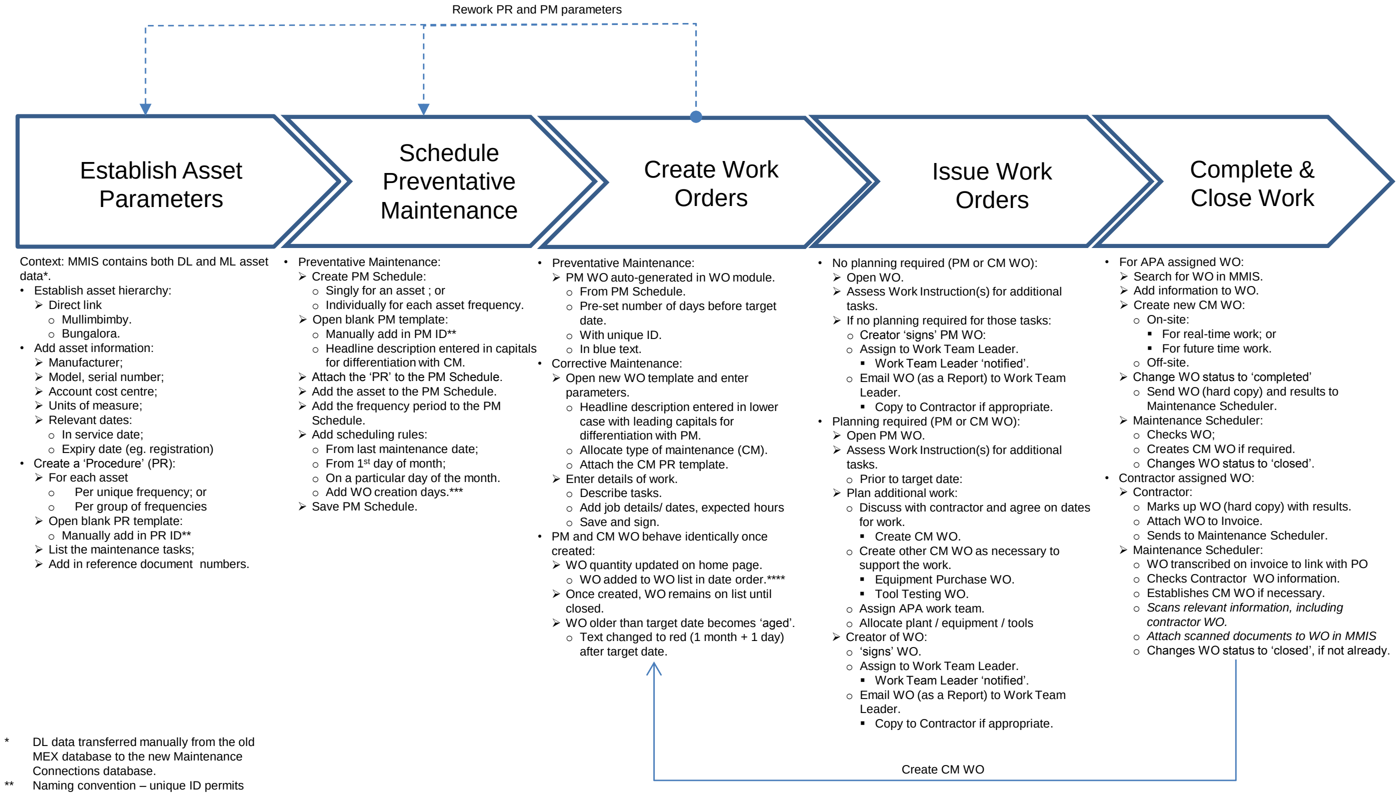


Legend:
Purple highlight ➔ new text
FRACAS ➔ Failure Reporting Analysis and Corrective Action System
MMIS ➔ Maintenance Management Information System ('Maintenance Connections')
WO ➔ Work Order

Diagram D1 – Directlink Maintenance Cycle

Appendix E – Directlink Maintenance Management Information System process map

Maintenance Management Information System



* DL data transferred manually from the old MEX database to the new Maintenance Connections database.

** Naming convention – unique ID permits System Administrator sorting.

*** The number of days prior to the target date at which the WO is created.

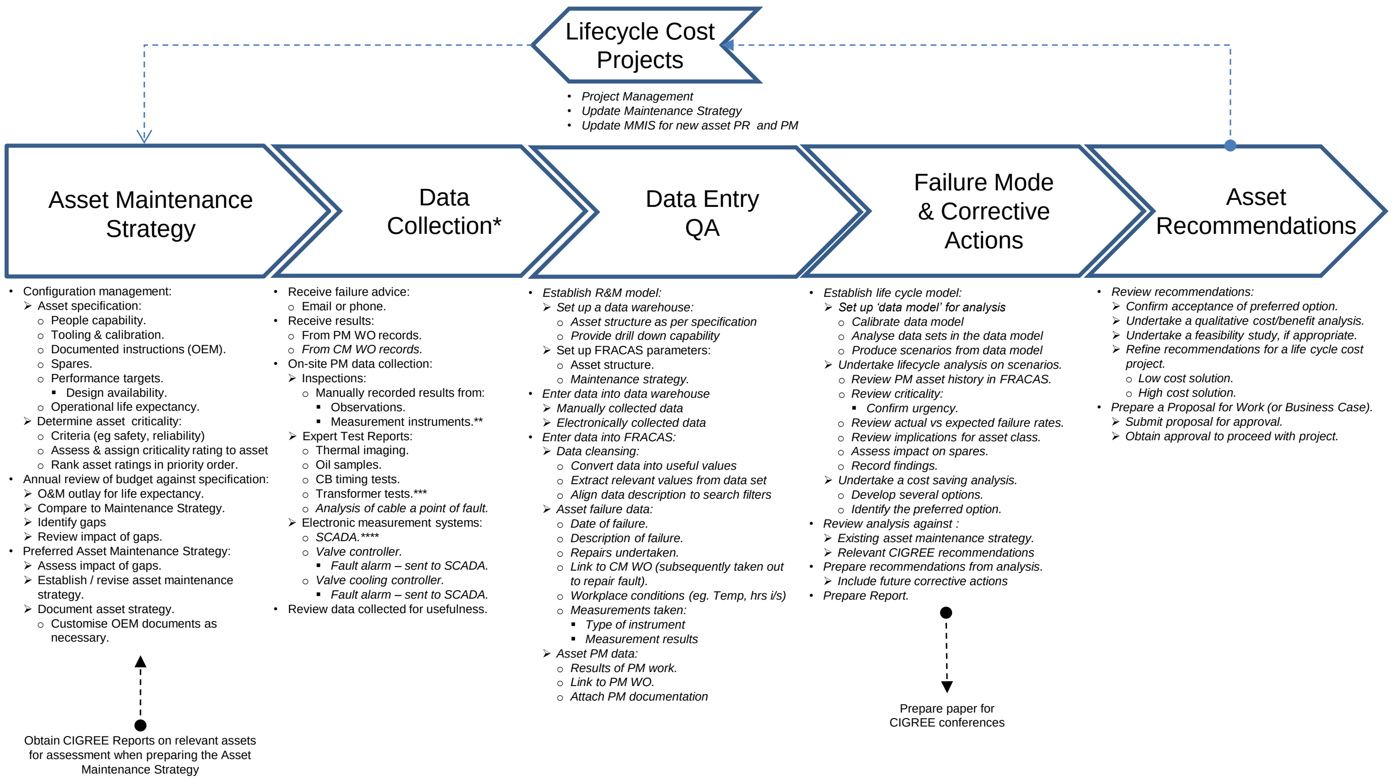
**** WO list maybe configured from top to bottom in two ways – either newest WO at top or oldest WO at top.

Legend:
Purple highlight ➔ new text
Italics ➔ future action
Asset ➔ means an asset or a service, depending on the situation
CM ➔ Corrective Maintenance
DL ➔ DirectLink
ML ➔ MurrayLink
MMIS ➔ Maintenance Management Information System ('Maintenance Connections')
PM ➔ Preventative Maintenance
PR ➔ 'Procedure'
PO ➔ Purchase Order
WO ➔ Work Order

Diagram E1 – MMIS process map

Appendix F – Directlink Condition Monitoring process map

'Condition monitoring'



*	Collect data on the operation of equipment.
**	Measurement instruments include: → Multimeter. → Temperature probe. → Humidity checks. → Oscilloscope. → Gauges (eg. oil, flow meter, lightning, temperature)
***	Transformer tests include: wining resistance, bushing (DLA).
****	Examples of SCADA records include: → alarm on fault or threshold value, but no trending data. → real time measurement values (eg. volts, amps) → trip event recorder (fault recorder) [note: no database of SCADA records currently held]

Legend:
Purple highlight → new text
Italics → future action
Asset → means an asset or a service, depending on the situation
CM → Corrective Maintenance
FRACAS → Failure Reporting, Analysis and Corrective Action System
MMIS → Maintenance Management Information System ('Maintenance Connection')
PM → Preventative Maintenance
R&M → Reliability & Maintainability
WO → Work Order

Diagram F1 – Condition Monitoring process map

Appendix G – Organisational Structure

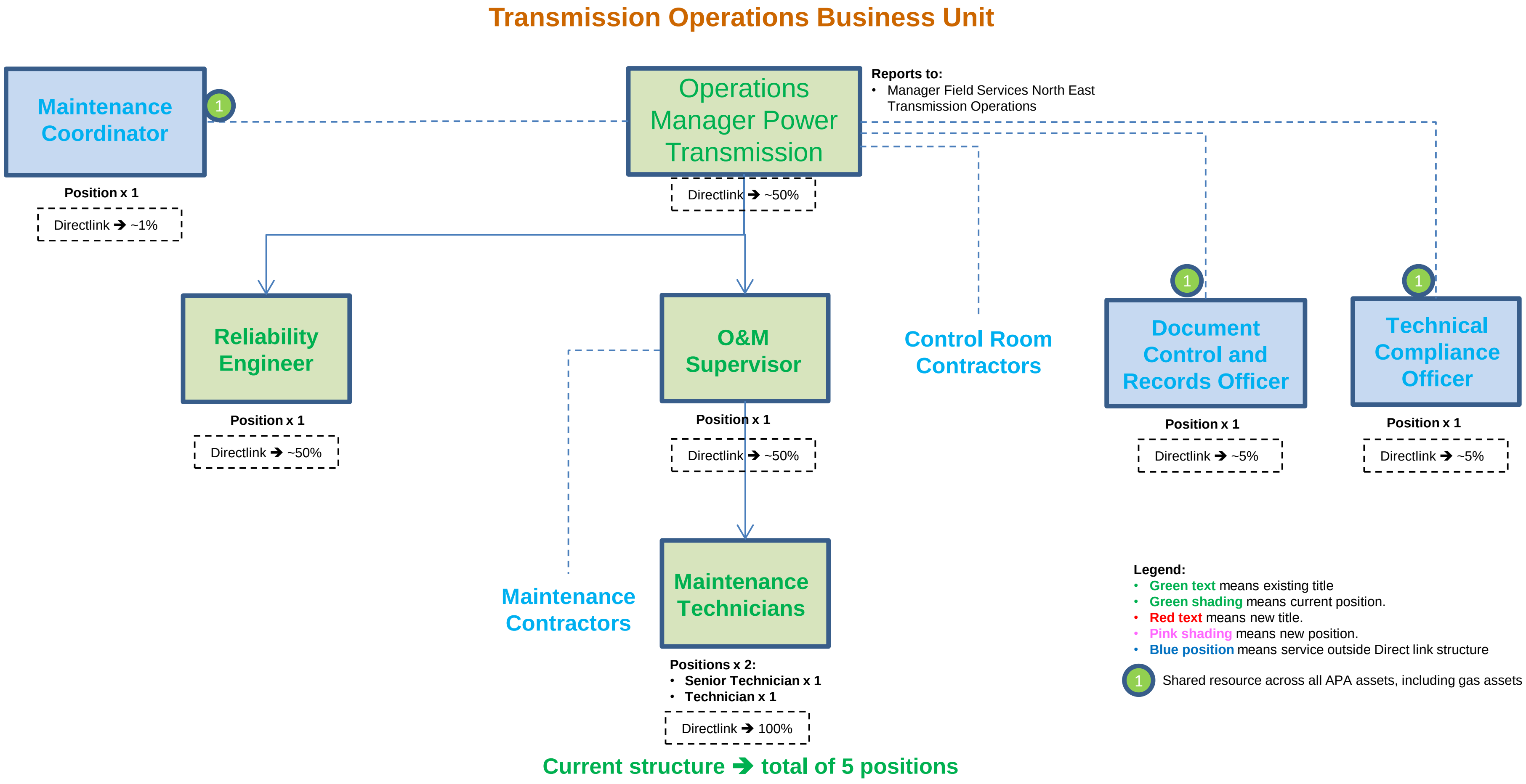


Diagram G1 – Current organisational structure 2014

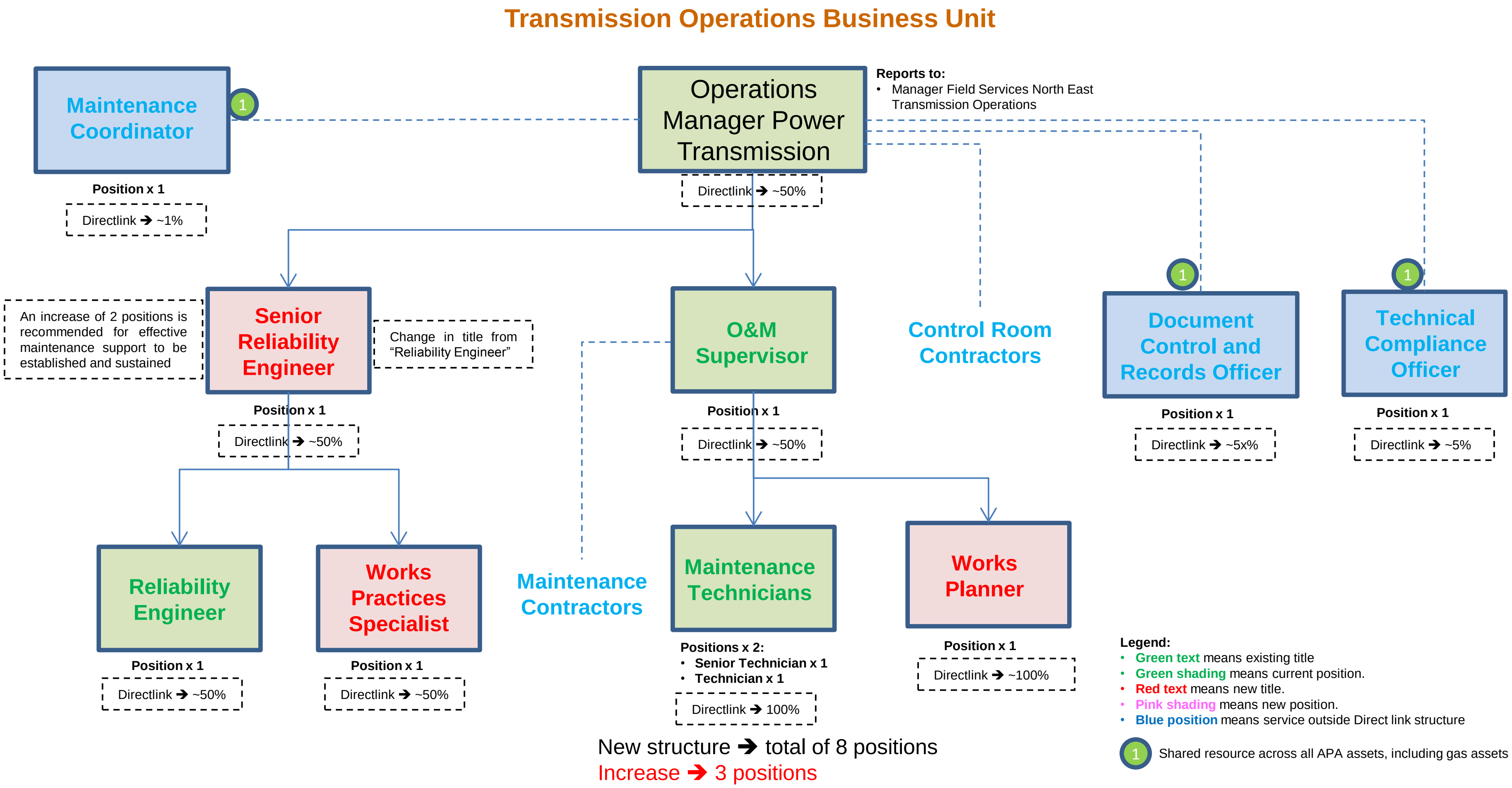


Diagram G2 – Proposed organisational structure 2015 to 2020

Transmission Operations Business Unit

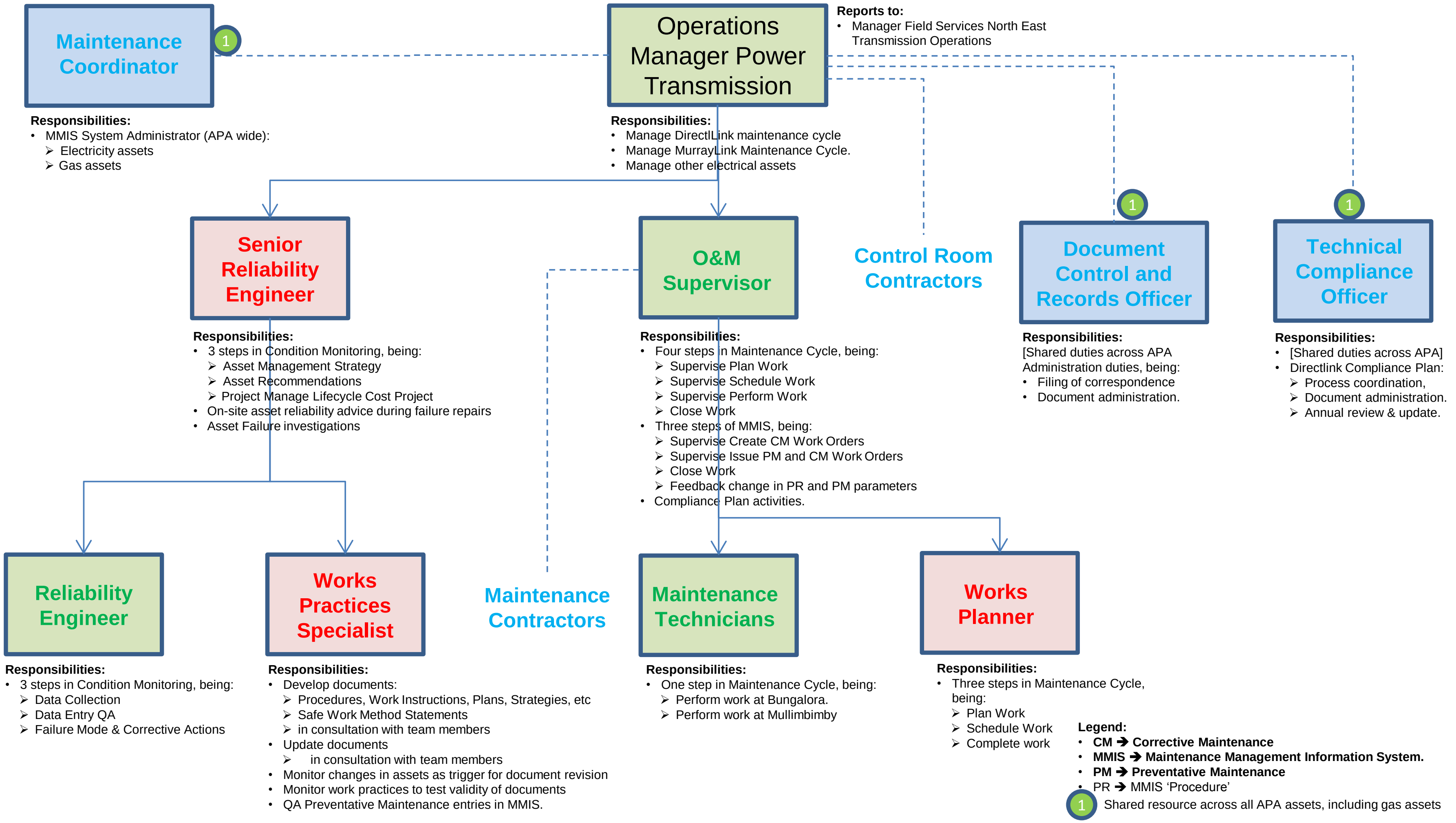


Diagram G3 – Role responsibilities 2015 to 2020

Appendix H – Control System Repairs

Control system repairs are required when the operator notes that the control system is not in the correct state. The first step is to identify which card has registered the fault.

Sometimes this is relatively easy. Going to the equipment racks an inspection of the interface cards reveals one showing a fault light. As with most predominantly software based systems the first attempt at a repair is to reset the card and control system. It is when this does not fix the problem that more detailed analysis is required.

If a software reset does not fix the problem then it is necessary to undertake diagnostic tests to help identify the faulty card(s). The first complication is that not all card faults will be identified by a “fault LED”. The interface racks contain a number of different cards including relay cards, power supply cards and CPU cards. It is also necessary to check the PCI cards (discussed above) plugged into the host PC.

Having identified a likely faulty card it is visually inspected for damage. If the card is appears faulty then it is replaced. If there is no visible issue with the card then the technician will attempt to reprogram the card to correct the fault.

Each card is individually configured with both specific software and configuration details which changes depending on the area of the converter station it is controlling. The specific program and the configuration data is stored in permanent memory known as Erasable Programmable Read Only Memory (EPROM). This allows the system designer to provide spare cards which users can configure as required (using special programming tools). The disadvantage is that the programming takes additional time.

The technician undertaking the repairs identifies the specific program to be loaded into the card and the configuration data for that card’s location. Using the special programming tools they write the required program and configuration data to the EPROM on the card. It is reported that this step alone takes 2 hours.

Once the card is programmed and configured it can be installed in the control system. To complete the repair the card is commissioned, the control system is reset and diagnostics are run to confirm that it is working correctly.

Unfortunately this may not always fix the problem. In this case further diagnostics must be run to determine the next card which will be replaced and reprogrammed.

It is not only cards that cause problems. With so many connections the cables can also work loose leading to intermittent issues.

As discussed in the Background to this section the host computer is arguably at (or even beyond) end of useful life. When problems are detected in the host computer spares are no longer available. This forces the APA staff to undertake “heroic efforts” to return the computer to correct operation.

Appendix I – Curriculum Vitae

Peter Egger
Chairman

Peter has over 15 years of experience as an advisory consultant in business administration[16]. Since April 1997, he has worked across a wide range of energy market related assignments in Australia, in electricity market development assignments in the Asia-Pacific region, and in general business administration activities in the electricity and natural resource sectors.

Relevant experience

- **Market regulatory design (Australia):**
  Peter has provided advice on metering regulation in the NEM, including changes for Full Retail Competition, design of NEM procedures, harmonisation of metering practices across jurisdictions, preparation of a jurisdictional code of metering practice, and business processes to accommodate the introduction of new metering technology.

  Between April 2009 and June 2011, Peter led a team of industry participants from multiple jurisdictions in the examination of a prescribed smart meter specification and relevant business processes to accommodate that specification. This work identified working issues confronting retailers and distributors, and common requirements that met the unique needs of those businesses.

  During 2012 Peter provided metering advice to the AEMC on their Power of Choice and Electric Vehicle Reviews. Peter is currently providing advice to the AEMC on Open Access and Common Communication Standards in regard to smart metering.

- **Climate change and Emissions trading**
  Between 2003 and June 2013, Peter was a member of the Delegated Committee of IPART acting as the Scheme Administrator for the NSW Greenhouse Gas Reduction Scheme (GGAS) and the Compliance Regulator for that scheme. In this role, Peter was one of three people (including the Chief Executive Officer) who approved, amended and terminated applications for participation in GGAS. The role involved understanding and applying the GGAS Rules (as approved by the NSW Minister) so as to maintain the integrity of the scheme over its life time. The role also involved ensuring that Benchmark Participant complied with the scheme.

- **Audits, appraisal and reviews (Australia):**
  Peter has undertaken a large range of audits, appraisals and reviews within the Australia electricity industry (retailers and distributors and metering providers). This work includes compliance audits, performance audits, business plan reviews, business fault rectification action plans and post-implementation reviews.

  Between January 2007 and July 2009, Peter performed the role of part-time Assistant Commissioner with the NSW Natural Resources Commission. In this role, Peter provided (to the Commissioner) audit advice in regard to auditing of Catchment Action Plans of NSW Catchment Management Authorities and business administration advice regarding the governance of the Commission.

  In 2012, Peter conducted a Metering Services Strategy Review for the NT Power and Water Corporation (NTPWC). In 2012/13, Peter performed a post implementation review of the engineering design of several 66/11kV substations and other major contracts for the Power Networks business unit of NTPWC. In 2013 Peter undertook a review of the NTPWC 2012 Safety Management and Mitigation Plan.

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[16] Prior to 1997, Peter worked for Pacific Power (a NSW electricity generation and transmission company, with generation capacity of 12,000MW) as an engineering specialist, engineering manager, and senior manager in business administration activities, gaining wide experience in the electricity industry and government reform programs. Functional experience at the engineering level included System Development, System Operation, substation and T/L design, substation construction, technical services including protection, metering, communications and HV testing, power station maintenance. This background provided a sound platform for entry into business and management consulting activities.

- **Business strategy, business planning and IT business requirements (Australia):**
  Peter has provided advice on a range of business related matters, for example: the preparation of a conceptual project plan for a future generator site, advice on metering business strategies, assistance with negotiation contract breaches, identification of business requirements for electricity market full retail competition, the design of customer surveys for network companies, project management for achieving network pricing submissions, and business process and procedure design and implementation.

  Peter has provided process reform advice to the NTPWC over the period August 2009 to date in the area of System Control, Asset Management, capital investment practices, Work Practices & Training, business unit Service Level Agreements, Remote Operations contractor pricing model, and advice on Safety processes, including the preparation of a Safety Management and Mitigation Plan. Peter is currently providing advice to NTPWC in metering strategy under NEM conditions, System Control arrangements under NEM conditions and the redesign of their Safety Management System.

  During 2013 following the review of engineering design projects for the Power Networks business unit, Peter facilitated a revision to the Capital Investment Process Maps and develop a purpose designed Project Management Manual for Power Networks in consultation with stakeholders.

- **Pool trading and risk management (Australia):**
  Peter lead the establishment of a market trading team for a NEM generator, provided advice on an energy trading strategic and policy framework for a new coal fired power station, lead the Back Office reform of a generator trading in the NEM, and provided advice on retailer energy trading strategy, policy and procedures.

- **Contribution to Principal consultants (Australia and Asia Pacific Basin):**
  Over the 15 years of consulting, Peter has provided a regular contribution to assignments won by Principles Consultants, including PricewaterhouseCoopers and KPMG. These assignments were related to the electricity industry and drew on knowledge of good business practices, government reform programs, regulatory compliance obligations and team cooperation.

- **Energy market design in Asia Pacific Basin**:
  Peter is currently providing electricity market design to the World Bank for the Inner Mongolian Province in China. Peter has provided market design and business administration advice to power companies in the Asia Pacific Basin, including:
  - China – Hunan province. Conceptual design for a power market in the Zhejiang Province.
  - China – World Bank: Market reviews and education program.
  - China – Hebei province. Review conditions for the development of a pumped storage power plant.
  - China – South China region. Review reform of transmission and distribution in Southern China.
  - South Korea – Assistance with the design of the Korean wholesale electricity market.
  - Philippines – World Bank: Desktop review of the electricity market IT specification.
  - Philippines – Assistance with financial risk management design of the spot electricity market.
  - Indonesia – Assistance with a functional specification for the Java-Bali competitive electricity market.
  - Singapore – SP Services: Identify business requirements for a redesign of IT systems associated with full retail competition.
  - New Zealand – Transpower: Assist in the review of the System Operator function, including the preparation of a stakeholder survey.
  - Solomon Islands – AusAID. Assist in the early stages of procurement of a management contract for the Solomon Island Electricity Authority and Solomon Islands Water Authority.

Qualifications: BE (Electrical) (UNSW 1964-1969); MBA (AGSM 1983-1984)

Other Education: Marketing Principles (AGSM); Risk Management (Monash Uni); Company Director duties; Corporations Law; Company Secretary practices.

Dr Martin Gill (PhD)
General Manager – Technology Perspective

Martin has 15 years of experience in the area of Smart Metering and Smart Grid. His innovative Smart Meter developments have been externally recognised with the Green Globe Award, Premier's Award and Best New Product. While working for the NSSC[17] he facilitated the development of the Australian Smart Metering Infrastructure Minimum Functionality Specification.

Relevant Experience

Smart Metering Planning

- Developed and deployed domestic and commercial electricity meters through to grid level power quality analysers
- Developed the first smart metering system to be deployed to domestic consumers in Australia (for Country Energy's Home Energy Efficiency Trial)
- Developed first smart metering system deployed to domestic customers combining electricity, gas and water metering (for South East Water)
- Prepared functional specifications for field service tools and supporting software needed to support smart meter deployments

Smart Grid Planning

- Assisted companies to understand the advantages of Smart Grid technology
- Developed fault monitoring equipment and prepared functional specifications
- Calculated benefits delivered to various parties by Smart Grid technology

Data Analysis

- Researched available information to prepare a costing model and final report to be submitted to the Australian Energy Regulator justifying costs to change the chosen communications technology mid-program
- Reviewed all available information on relevant market products, then developed and implemented the mathematical models needed to direct future product development efforts.
- Developed tools needed to convert meter data into an estimate of the solar system size giving households the highest financial return from their investment

Technical Translation

- Prepared numerous papers presenting technical topics to non-technical audiences. Recent examples are:
    1) The Consumer and Domestic PV Series (available from www.phacelift.com.au/library/)
    2) Describe smart meter functionality for NSSC workshop participants (including benefits) (link.aemo.com.au/sites/wcl/smartmetering/Pages/BRWG.aspx)
    3) Develop a framework describing Access and Interoperability for the contestable provision of smart meters (www.aemc.gov.au/Market-Reviews/Open/framework-for-open-access-and-communication-standards.html)
- Facilitated discussions between technical specialists and economists during the preparation of cost benefit analyses
- Developed visualisation tools allowing NSSC workshop participants to understand the communications performance levels being proposed in the Functional Specification.

Cost Benefit and Net Present Value (NPV) Analysis

- Prepared several CBAs estimating societal benefits delivered by Smart Grid technology
- Calculated NPV benefits delivered by a major communications upgrade
- Presented Return on Investment calculations for customers installing solar systems

[17] the National Stakeholders Steering Committee (NSSC) was established by the Ministerial Council on Energy in 2008

Due Diligence Reviews

- Due diligence review of a communications company for a venture capitalist
- Technical audit of major smart metering programs (for Victorian distribution businesses)
- Detailed technical comparisons of tender responses for clients

Research

- Prepared discussion papers presenting possible future energy scenarios (including the UK Government)
- Developed product roadmaps to meet future market requirements

Documentation

- Prepared (and assessed) Request for Tender documentation
- Prepared product documentation for publication and use by sales

Workshop Facilitation

- Coordinated meetings for the Australian Energy Market Commission's advice into Open Access and Common Communication Standards
- Over a two year period conducted approximately 20 workshops defining Smart Meter functionality acceptable to electricity retailers, distributors and consumer advocates. The final specification defined both meter functionality and communications performance levels.
- Conducted Smart Grid training sessions (Thailand)

Wired and Wireless Communications

- Prepared and assessed a Request for Information to select the open communications standard for the Home Area Network in the Smart Meter Functional Specification
- Deployed cost effective modern communications systems supporting smart meter rollouts (including RF Mesh, DLC, low speed PLC and commercial cellular 2G/3G)
- Review of communications standards used in international smart meter rollouts

Qualifications

- Doctor of Philosophy (PhD) in Information Technology, University of South Australia
- Master of Science (MSc) in Military Electronic Systems Engineering, Royal Military College of Science, Shrivenham, UK
- Post Graduate Diploma in Electronic Systems, University of South Australia
- Post Graduate Certificate of Management. Management and Resource Centre, Salisbury Campus of the University of South Australia
- Bachelor of Engineering (BE Honours), Electrical and Electronic Engineering, University of Adelaide
- Bachelor of Science (BSc) Applied Mathematics and Computing, University of Adelaide