PowerWater

Program Business Need Identification

Power and Water Corporation

NMP3/PRD33395

66kV HLC Circuit Breaker Replacement Program

Proposed:	Approved:
Stuart Eassie Manager Strategic Asset Engineering Power Networks Date: 15/2/2018	Michael Thomson Chief Executive Power Water Corporation Date: 23/02/2018

	Refer to email D2018/72353	Refer to email D2018/68933
Djuna Pollard Executive General Manager Power Networks Date: 15/2/2018	Finance Review Date: 06/02/2018	PMO QA Date: 13/02/2018

1 Program Summary

Program Name:	66kV HLC Circuit Breaker Replacement Program		
Program No:	NMP3 / PRD33395	SAP Ref:	
Financial Year Commencement:	2019/20		
Business Unit:	Power Networks		
Program Owner (GM):	Djuna Pollard	**Phone No:**	08 8985 8431
Contact Officer:	Stuart Eassie	**Phone No:**	08 8924 5214
Date of Submission:	23/02/18	**File Ref No:**	D2017/364601
Submission Number:		**Priority Score:**	
Primary Driver:	Renewal/ Replacement	**Secondary Driver:**	Compliance
Program Classification:	Capital Program of Works		

2 Recommendation

MAJOR PROJECT >$1M OR PROGRAM

It is recommended that Chief Executive note the proposed three year HLC 66kV circuit breaker replacement program for an estimated budget of $1.04M and approve the inclusion of this Program into the SCI for this amount, with a corresponding completion date of July 2022.

The forecast for this program of work extends beyond the current SCI period. The first two years of this program aligns with the last two years of the 2017-18 SCI. This program will be included in the 2019-24 Regulatory Proposal to the Australian Energy Regulator (AER).

Note that individual projects within the program will each be documented in a Business Case Category C to be approved by the Executive General Manager Power Networks.

3 Description of Issues

There are currently 30 [redacted] HLC 66kV circuit breakers remaining in the network, ranging from 32 to 45 years of age. These units are being targeted for replacement based on:

- Poor condition as demonstrated through consistent conditional failures and susceptibility to moisture ingress.
- High consequence of failure in terms of both safety and system security. Failures of minimum oil, porcelain tank circuit breakers are extremely hazardous and are likely to damage adjacent equipment. They are typically not repairable, as demonstrated by examples of failure both within Power and Water Corporation (PWC) and other utilities resulting in extended outages.
- Very high and increasing maintenance costs as compared with current technology SF6, CO2 or vacuum circuit breakers.

The risk of failure in terms of personnel safety, reliability and system security consequences associated with these circuit breakers and other aged oil-filled assets has driven a major substation asset replacement program over the last 7 years. This investment was triggered by the catastrophic failure of an oil-filled circuit breaker at Casuarina Zone Substation in 2008 which resulted in widespread rolling outages to Darwin and the deployment of a large fleet of temporary generators to mitigate supply reliability risks over many months while repairs were performed.

As part of this replacement program the majority of HLC circuit breakers in the PWC fleet have already been replaced. Planned zone substation replacement projects between 2018/19 and 2023/24 will result in the replacement of 8 units including Berrimah (5), Humpty Doo (1), Cox Peninsula (1) and Pine Creek (1) Zone Substations. The remaining 16 circuit breakers are installed at Palmerston (5) and Hudson Creek (11) zone substations. Action is required to address the risks associated with these 16 circuit breakers to ensure the ongoing safe and reliable operation of the network.

3.1 Asset Condition

This type of circuit breaker has a history of high failure rates in the PWC network. Routine maintenance activities over the life of these circuit breakers have not been effective at maintaining their condition. Contemporary asset management practices have been applied to these assets since the 2008 Davies Inquiry[1] into a major substation failure within PWC. However the failure modes targeted through maintenance are consistently recurring indicating major refurbishment or replacement is necessary.

[1] September and October 2008, a series of power outages occurred in the vicinity of the Casuarina Zone Substation. In response to these outages, and growing concerns for the continued security of supply to the northern suburbs of Darwin, the NT Government commissioned this independent inquiry.

One of the primary causes of failure is contamination of the oil interrupting medium with water. The HLC circuit breaker is a “free-breathing” design. In the humid and wet environment of the Darwin region, significant amounts of moisture can enter the breaker and build up over time. This is exacerbated by oil leaks, which are becoming more frequent as a result of ageing seals and sealing surfaces perishing or being damaged over time. As a result significant volumes of “free” water (i.e. water below the oil) must be drained from the circuit breaker stacks at each maintenance outage. The presence of free water considerably increases the risk of the circuit breaker failing to break fault currents when required, since it lowers the dielectric strength of the oil.

Insulation resistance testing is performed during routine maintenance to ensure the integrity of the circuit breaker insulation, and is a useful indicator for the presence of moisture and degraded oil. The failure rate for “as-found” insulation resistance is approximately 30% since testing began in 2008. By comparison, the failure rate for non-HLC circuit breakers is approximately 7%. A summary of the HLC results is given in Figure 1.

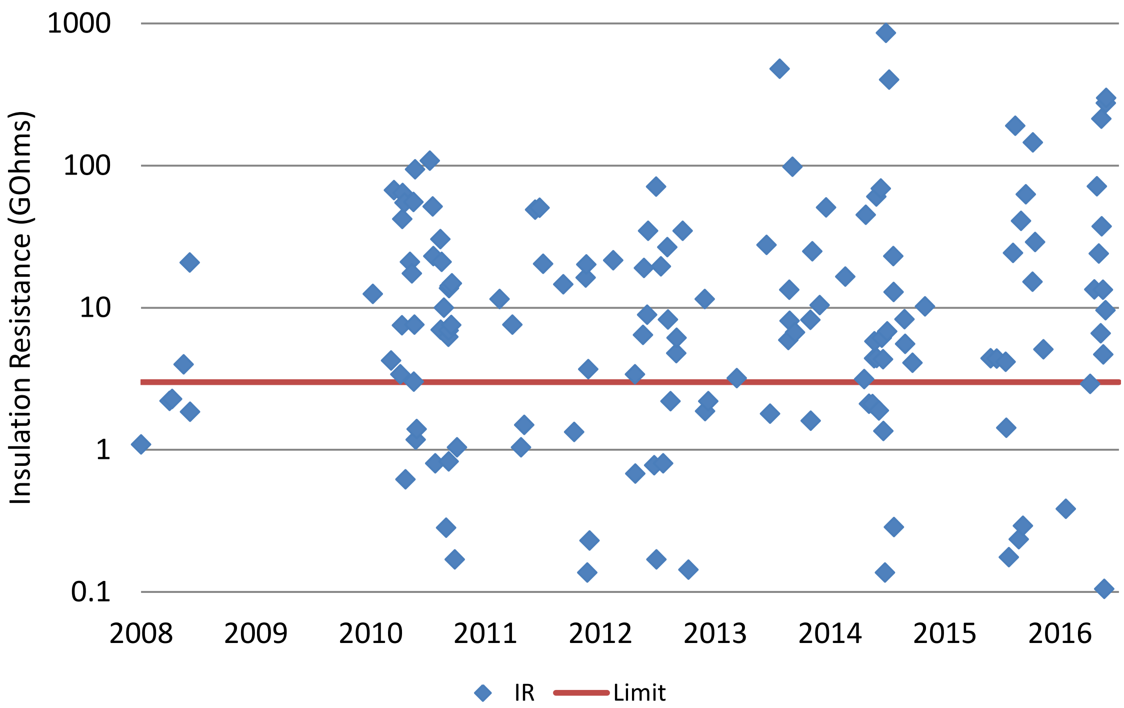

Figure 1 – HLC As-found insulation resistance test results

A failure occurred during switching operations in 2011 on one of the Hudson Creek units due to water ingress. Despite only load current being interrupted, oil was expelled from the circuit breaker and posed a serious risk to the safety of operations staff. If the operation occurred under fault conditions the failure would likely have been catastrophic due to the significantly higher fault energy, and could have resulted in further risks to operator safety and damage to adjacent assets.

HLC circuit breakers have also failed catastrophically at Berrimah zone substation circa 2002 and Snell St zone substation in 2006. Other utilities in Australia have had catastrophic failures of HLC circuit breakers due to similar failure modes, including at least three failures out of less than 100 installed at a utility[2] in a similar climate zone to PWC.

Figure 2 below shows the aftermath of the 2006 failure at the Snell Street zone substation in Darwin.

Figure 2 – Failed HLC circuit breaker at Snell Street zone substation

Other condition issues regularly found with HLC circuit breakers include:

- Mechanism malfunction – there have been multiple instances of mechanisms seizing, operating slowly, or tripping through (tripping immediately after closing). The failure rate for "as-found" opening time during routine maintenance is approximately 15%. Mechanism failures can usually be restored by maintenance crews, however there have been instances where restored mechanisms have failed again shortly afterwards, requiring multiple outages and visits to correct. The mechanism failures are thought to be caused by the build-up of dirt and corrosion, failed dampers and inadequate lubrication over long periods. To resolve these issues a complete refurbishment of the mechanisms is required.
- Oil leaks – as described above, the ageing seals and sealing surfaces on these circuit breakers regularly fail resulting in oil leaks and subsequent moisture ingress and increased maintenance costs to repair and often require multiple repair attempts.

[2] HSE Alert – [redacted] 66kV Circuit Breaker Failed in Service May 2010

3.2 Maintenance

HLC circuit breakers impose a large burden on the maintenance resources of the business. The routine maintenance costs for an HLC circuit breaker is approximately $5.5k per annum. Emergency and non-routine maintenance is expected to be approximately $2k per annum per HLC circuit breaker based on historical records, but this expected to increase in line with the failure rate as the fleet continues to age. By comparison, an equivalent SF_6 circuit breaker in the PWC network has routine maintenance costs of approximately $1.5k per annum and negligible emergency and non-routine costs.

Maintenance can only be effectively performed during the limited dry season due to weather conditions affecting both the availability for maintenance due to high system loads, and the inability to perform high voltage testing when humidity is extremely high. Wet season weather conditions often restrict any work being performed due to heavy rain and lightning.

A major review of maintenance strategies based on industry benchmarking in 2009 indicated intrusive maintenance for minimum oil circuit breakers is typically performed every eight years. The HLC circuit breakers in PWC typically required this level of maintenance every two years to deal with the consistent moisture ingress issues. The equivalent SF_6 circuit breakers are only functionally tested every six years, with diagnostic maintenance performed every 12 years.

The high failure rates also means that maintenance crews often spend additional time on site troubleshooting and re-testing to get the circuit breaker back into service. Failures during the wet season are extremely challenging due to the impact on system security, poor weather conditions and high voltage testing issues. Extended outages during the wet season also increase the likelihood of a second contingency event due to severe weather.

3.3 Obsolescence

Oil-filled high voltage switchgear is considered an obsolete technology due to the high maintenance costs and the risks involved with large quantities of flammable mineral oil. All utilities in Australia are phasing out this type of equipment from zone substations. OEMs no longer offer new devices with this technology - SF_6 and CO_2 are currently the preferred interrupting media. [redacted] continues to support its legacy minimum-oil circuit breakers, but as increasing numbers are retired worldwide it is likely that [redacted] will reduce its support for the range, reducing the availability and increasing the cost of spare components. This will make continued maintenance of the circuit breakers more uneconomic.

Additionally, only small parts and consumables are available for purchase through the OEM – in the event of a major pole or mechanism failure PWC has historically had to seek parts from salvaged decommissioned assets or other utilities. These assets are in a similar condition and are barely suitable for repair or require significant refurbishment to restore to an acceptable condition.

3.4 Network Risk

Network risk is the combination of the health and criticality of the circuit breaker. Health and criticality are measured from 1-3 where a lower score indicates better health or lower criticality.

It should be noted that the network risk relates to the reliability, stability and security of the power network; it does not consider other risk domains such as safety and compliance which are major drivers for this program.

The health index, criticality index and resulting network risk for the 16 HLC circuit breakers are shown in the table below.

Circuit Breaker	Health Index	Criticality Index	Network Risk
CB66HC205	H3	C2	High
CB66HC206	H3	C1	Moderate
CB66HC208	H3	C2	High
CB66HC210	H3	C1	Moderate
CB66HC407	H3	C1	Moderate
CB66HC507	H3	C1	Moderate
CB66HC704	H3	C1	Moderate
CB66HC705	H3	C3	Extreme
CB66HC706	H3	C3	Extreme
CB66HC708	H3	C3	Extreme
CB66HC711	H3	C1	Moderate
CB66PA203	H3	C2	High
CB66PA204	H2	C1	Moderate
CB66PA205	H3	C1	Moderate
CB66PA503	H3	C1	Moderate
CB66PA504	H3	C1	Moderate

As outlined above, all circuit breakers score poorly on health apart from CB66PA204, and there are a range of criticality outcomes. As a result the network risk is Moderate (10), High (3) and Extreme (3). Due to the safety consequences of a circuit breaker failure, units with a Moderate health and criticality rating require action.

3.5 Project Drivers

a. Safety
High voltage switchgear generally performs well; however, when failures occur, the consequences can be catastrophic. The HLC circuit breakers are ageing and have a history of moisture entering the active parts significantly increasing the risk of the circuit breaker failing to operate when required to isolate a fault, thereby causing equipment, personnel and public safety risk. Replacement of the ageing HLC circuit breakers with modern equivalents will significantly mitigate, if not eliminate these risks.
b. Reliability (if not compliance obligation)
The failure risk associated with ageing HLC circuit breakers increases the likelihood that reliability targets will not be met. Failure of circuit breakers with a C2 or C3 criticality rating directly affect system security by radicalising a large proportion of the transmission network. Replacement with modern equipment will significantly reduce this risk. Additionally, HLC circuit breaker routine maintenance is performed at a high frequency, reducing the availability of the transmission network.
c. Compliance
The objective of this project is to ensure that PWC meets its obligations under the Power Networks Technical Code and Planning Criteria to operate a reliable network. The system security consequences associated with a catastrophic failure of a 66kV circuit breaker, particularly at Hudson Creek, is considered high due to the potential for damage to multiple other 66kV feeders. Failure is also more likely during poor weather conditions in the wet season when transmission line faults due to lightning or debris require more frequent operation of the circuit breakers under fault conditions. During the wet season the time required to repair a failure is significantly longer than other times of the year or what would be considered typical for other network businesses.

4 Potential Solutions

Option 1 – Run to Fail

Continue to maintain and repair the 16 HLC circuit breakers, with units replaced as they fail. The ongoing routine maintenance cost of HLC circuit breakers is expected to remain high and continue to increase as the fleet ages.

This option is not preferred as the consequence of failure is high due to the nature of oil switchgear failures. The likelihood of a failure is also high demonstrated by the history of catastrophic failures and the frequency of condition failures identified during maintenance.

Due to the high ongoing operational costs and unplanned nature of the replacements, this is the highest cost option.

Option 2 – Refurbishment / Life Extension

Perform a refurbishment on the 16 HLC circuit breakers to extend their life. This will require that the circuit breakers be completely stripped down and mechanisms and seals restored to an acceptable condition to reduce the frequency of condition failures. External contract support from the OEM will be required as the skills to perform this level of refurbishment reliably do not exist in Power Networks.

This option is not preferred since it does not reduce the consequence of a failure, and there is a risk of a maintenance induced failure. There is also a high likelihood that difficulties will be encountered disassembling these units, and as a result some units will need to be fully replaced. This option is expected to reduce the unplanned and emergency maintenance costs; however routine maintenance costs will remain high since the underlying technology has not changed.

The refurbishment option has a lower net present cost than option 1, but higher than option 3.

Option 3 – Planned Replacement

Replace the 16 HLC circuit breakers in a planned fashion on a substation by substation basis.

In general the circuit breakers at Hudson Creek are in worse condition and have higher network risk than those at Palmerston. Therefore it is planned to prioritise the replacements at Hudson Creek over those at Palmerston. The Hudson Creek replacements will occur over two consecutive years to reduce impact on contractor and PWC resources.

This is the preferred option since it eliminates the safety risks associated with oil switchgear, improves the stability and reliability of the network and significantly reduces the maintenance burden on substation crews, high voltage operators and controllers. The removal of the HLC asset class also provides other un-modelled benefits such as a reduction in spares holdings, simplified maintenance planning and increased network availability.

Option 3 has the lowest net present cost of the three options assessed.

4.2 Comparative Cost Analysis

A comparative cost analysis of the three options has been undertaken. The net present cost of each option including Opex and Capex over a 40 year period is detailed in the table below.

Option	Capital cost ($M)	Net Present Cost ($M)	Comments
1 – Do nothing	1.1	2.4	Assumes one failure replacement every 5 years then remainder replaced in 25 years.
2 – Refurbishment / Life Extension	0.4	2.2	Refurbishment occurs over three years. Opex reduced to 75% historical HLC cost.
3 – Planned Replacement	1.0	2.0	Replacement occurs over three years. Opex reduced to historical SF6 cost

As outlined above, option 3 has the lowest net present cost of the three options.

4.3 Non-cost attributes

An analysis of the non-cost attributes for each option has been completed using the multi-criteria analysis method. The attributes are selected considering major risks and priorities to achieve Project Objectives. A weighting is allocated to each, totalling 100%. Each attribute is given a score out of 5 (from 1 – Fails to satisfy, to 5 – exceeds requirements); the score is then multiplied by the relevant weighting to give the weighted score that is summarised in the table below.

	Technical & System Risk	Stakeholder Risk	Environment Risk	Commercial	
Criteria	Reliability	Safety	Oil Leaks	NPC	Weighted Scores
Weighting (%)	20	30	10	40	100
Option 1	0.2	0.3	0.1	1.2	**1.8**
Option 2	0.6	0.6	0.2	1.6	**3.0**
Option 3	0.8	1.2	0.5	2.0	**4.5**

4.4 Preferred Option

As outlined above, option 3 is the preferred option based on lowest NPC and best overall qualitative assessment.

4.5 Non Network alternatives

There are no feasible non-network options to be considered. The assets are required for ongoing operation of the transmission network.

4.6 Capex/Opex substitution

The business-as-usual option results in an annual Opex of approximately $120k. The preferred option is expected to reduce the annual Opex to approximately $44k.

4.7 Contingent Project

The expenditure does not meet the criteria for a contingent project as outlined in the Northern Territory National Electricity Rules, section 6.6A.1.

5 Strategic Alignment

This program aligns with the Asset Objectives defined in the Strategic Asset Management Plan (SAMP) and Asset (Class) Management Plans (AMP). The capital investment into 66kV circuit breakers outlined in this program will contribute to the Corporation achieving the goals defined in SCI Key Result Areas of Health and Safety and Operational Performance.

6 Timing Constraints

There are no critical timing constraints; however, deferral of this replacement work increases the safety and reliability risks to the business, particularly for those circuit breakers assessed as presenting a high network risk.

Consideration has been given to the deliverability of the replacement works over several years due to the limited dry season period and the completion of other preventative maintenance on transmission assets and generation outages affect the availability for major substation works.

7 Expected Benefits

Driver	Benefit	Measure
Growth / Demand	NA	NA
Renewal / Replacement	Network safety	Health and Safety Index

Driver	Benefit	Measure
Compliance	Reduce System Security Risk	Availability of transmission lines.
Service Improvement	Network reliability maintained	Performance against SAIDI and SAIFI targets
Commercial / Efficiency	Opex reduction	Financial performance
Social / Environmental	Avoid uncontrolled oil spills	Environment incidents Customer complaints

8 Milestones (mm/yyyy)

Investment Planning	Project Development	Project Commitment	Project Delivery	Review
01/2018	NA	07/2019	06/2022	09/2022

The program delivery is scheduled to run over 3 years from July 2019 to June 2022. A program review will be held at the end of the 3 year program as well as interim reviews at the end of each Financial Year.

9 Key Stakeholders

Stakeholder	Responsibility
Internal governance stakeholders	Executive General Manager Power Networks
	Group Manager Service Delivery
	Chief Engineer
Internal design stakeholders	Senior Manager Asset Management
	Manager Test & Protection Services
	General Manager System Control
External – Unions and public	Local Residents
	ETU
	Ministers
External regulators	Utilities Commission

Stakeholder	Responsibility
	Australian Energy Regulator

10 Resource Requirements

Not applicable. Resourcing requirements for this program are considered Business as Usual and will be incorporated into the development of Category C Business Cases for each batch of replacements that will be signed off by the Executive General Manager of Power Networks.

11 Delivery Risk

Capital estimates are based on budget pricing received from OEM of suitable replacement equipment and may be subject to change if the equipment does not meet design standards.

Capital estimates are based on replacement circuit breakers being a relatively simple like-for-like replacement requiring minimal rework to foundations, secondary equipment, or substation layout. Effects of any site-specific changes can only be defined following additional detailed investigation.

12 Financial Impacts

12.1 Expenditure Forecasting Method

Capital costs have been estimated from a combination of budgetary pricing provided by OEM of suitable like-for-like replacement equipment and estimates for PWC design, development and project management, using a planned replacement approach.

Operating and maintenance costs have been forecasted by extrapolation from historical average costs associated with the class of equipment concerned.

12.2 Historical and Forecast Expenditure

No replacements of 66kV circuit breakers have been completed in recent years, other than as part of major substation replacement works. As described above, forecast costs have been estimated from OEM budgetary pricing. Refer to 12.4 Capex Profile for forecast expenditure.

12.3 Validation

Capital costs have been estimated from a combination of budgetary pricing provided by OEM of suitable replacement equipment and benchmark uplifts for PWC design, development and project management, using a planned replacement approach.

Operating and maintenance costs have been forecasted by extrapolation from historical average costs associated with the class of equipment concerned.

12.4 Capex Profile

The capex in the table below is in $2017-18, and is excluding capitalised overheads and cost escalation.

Phase	2019-20 ($'000)	2020-21 ($'000)	2021-22 ($'000)	2022-23 ($'000)	2023-24 ($'000)	Total ($'000)
Investment Planning						
Project Development						
Project Commitment						
Project Delivery	$325	$390	$325	$0	$0	$1,040
Review						
Total	$325	$390	$325	$0	$0	$1,040

12.5 Opex Implications

The preferred option results in a forecast reduction in Opex of $76k from the completion of the project in 2020-21. There are also expected to be un-modelled Opex efficiencies gained from the removal of the live tank minimum oil circuit breakers as an asset class –e.g. reduction in spares holdings, simplified maintenance planning and improved network availability.

12.6 Variance

The forecast for this program of work extends beyond the current SCI period. The first two years of this program aligns with the last two years of the 2017-18 SCI.