CitiPower

Little Queen supply area

CP BUS 4.04 - LQ supply area - Jan2020 - Public

Regulatory proposal 2021–2026

CitiPower

July 2019

Contents

1 Overview

Business	CitiPower
Title	Little Queen supply area
Project ID	CP BUS 4.04 - LQ supply area - Jan2020 - Public
Category	Replacement
Identified need	The identified need is to address the increasing risks to safety and reliability of supply associated with the deterioration of the assets at Little Queen zone substation
Recommended option	Replace existing switchboard in the same building
Proposed start date	2022/23
Proposed commission date	2025/26
Supporting documents	CP MOD 4.03 - LQ supply area - Jan2020 - Public CP ATT105 - Ausgrid - Project justification for 11kV switchgear - Jan2019 - Public CP ATT107 - PowerWater - Berrimah substation condition - Feb2018 - Public CP ATT112 - Western Power - Network management plan - Sep2011 - Public CP ATT175 - AER - Asset replacement planning - Jan2019 - Public CP ATT225 - TasNet - Investment evaluation - Nov2018 - Public

Source: CitiPower

This business case outlines various options to maintain the safety and security of supply for customers served by Little Queen (**LQ**) zone substation.

LQ zone substation was constructed in the early 1970s and most of the original substation equipment remains in service. This includes the existing Email Westinghouse HQ compound-insulated double bus switchboard and bulk oil-filled switchgear which was designed with no arc fault containment.

Following an assessment of a range of options, and quantification of the risk associated with each option, replacement of the existing switchboard was found to meet the identified need at the least life-cycle costs.

The forecast capital expenditure requirements for the preferred option are outlined in table 1.

Table 1 Expenditure forecasts for preferred option ($ million, 2021)

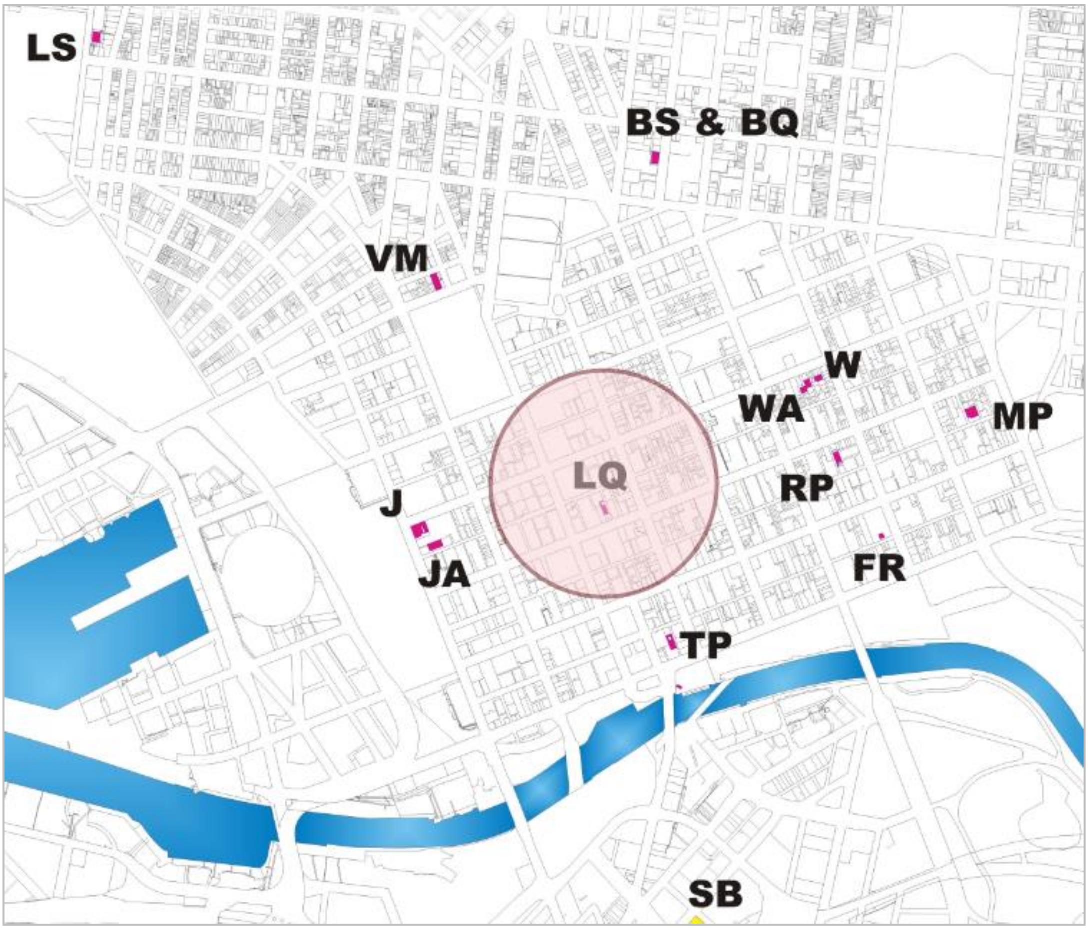
Expenditure forecast	2021/22	2022/23	2023/24	202/254	2025/26	Total
Total capital expenditure	-	0.04	2.61	6.02	10.35	19.02

Source: CitiPower

2 Background

LQ zone substation is located in the heart of Melbourne's central business district (**CBD**), as shown in figure 1. It supplies electricity to over 5,000 major commercial, industrial and domestic customers, including the headquarters of major financial institutions.

Figure 1 LQ zone substation supply area



Source: CitiPower

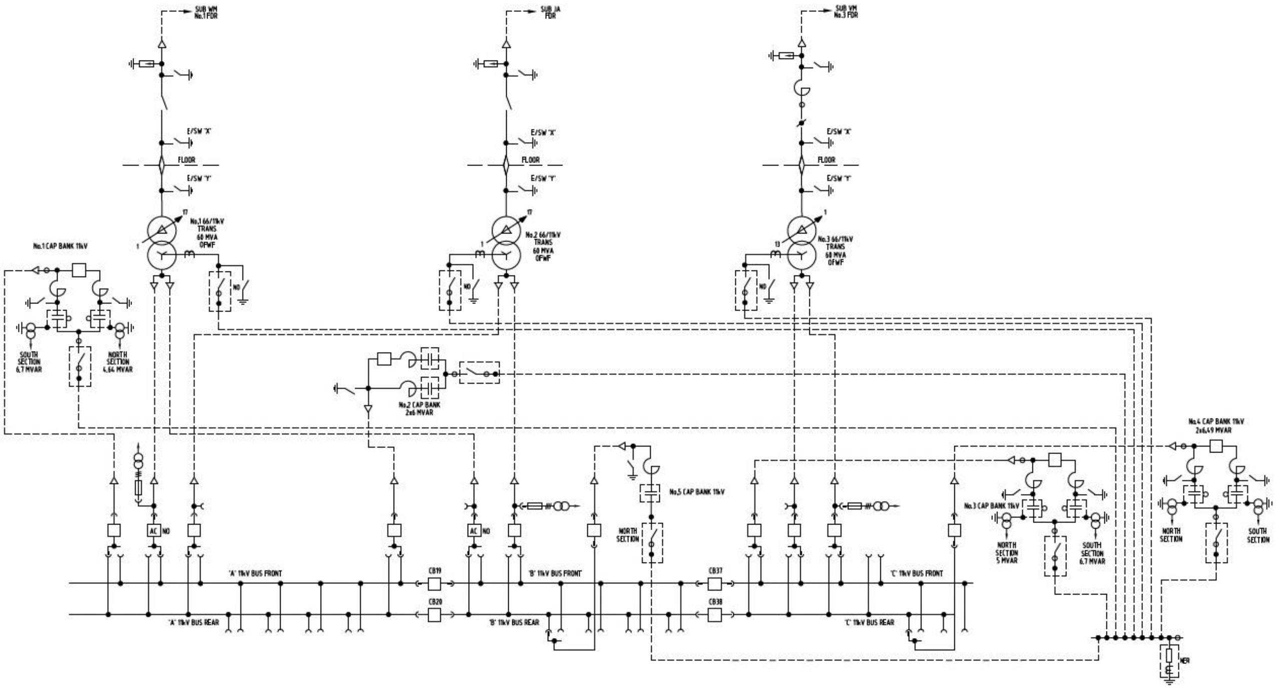
2.1 Existing network characteristics

2.1.1 Zone substation

LQ zone substation was constructed in the early 1970s and comprises multiple floors with equipment spread across all floors. Most of the original substation equipment remains in service.

An electrical schematic of the existing layout is shown in figure 2.

Figure 2 LQ zone substation: single line diagram[1]



Source: CitiPower
Note: Due to the number of circuit breakers the LQ operational single line diagram is split over two pages. The circuit breaker page is not shown here to avoid confusion.

As shown in figure 2, LQ zone substation comprises three 60MVA 66/11kV transformers, with the third transformer operated as a 'hot' stand-by. The transformers are water cooled with cooling water pumped to cooling towers mounted on the roof of the building.

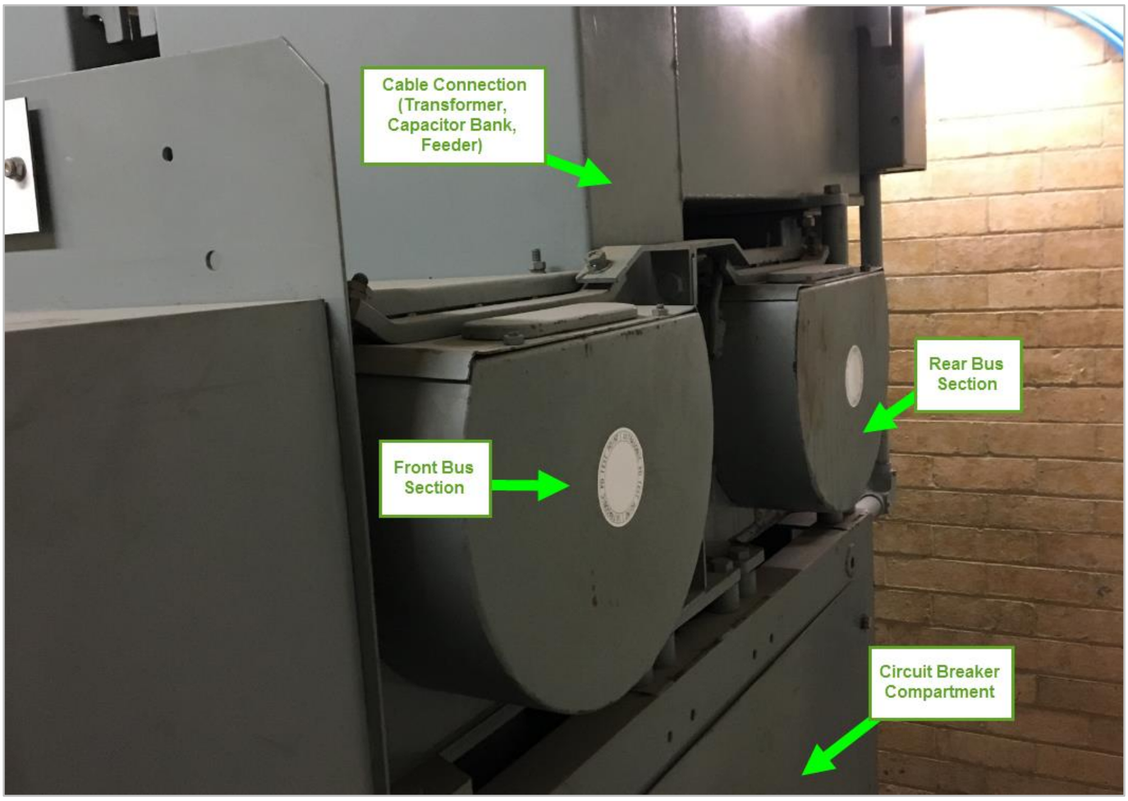
The existing switchboard is 47 years old and is one of nine compound-insulated switchboards remaining across our CitiPower and Powercor networks.[2] Of the nine switchboards, all but one is planned for replacement or decommissioning by the end of 2025 (the remaining site is currently being reviewed).

The switchboard consists of double bus bar sections; the layout of the double bus is shown in figure 3.

[1] Due to the number of circuit breakers the LQ operational single line diagram is split over 2 pages. The circuit breaker page is not shown here to avoid confusion.

[2] The term 'compound' refers to the insulating medium used to cover bare conductor components and reduce the electrical clearance distances required compared to when insulated by air.

Figure 3 Arrangement of double bus at LQ substation



Source: CitiPower

There are three of these sections, with each section located in a separate switch room. The front and rear bus ties for the adjacent sections are housed together in a separate room from the main bus and associated circuit breakers (transformer, capacitor bank and feeder).

The switchgear at LQ zone substation includes 56 panels of 11kV switchgear (Email HQ type, primarily with J18 oil circuit breakers). There are retrofitted Siemens 3AH vacuum circuit breakers on the capacitor bank positions.

A section of the No.1 11kV bus is displayed in figure 4.

Figure 4 11kV switchgear installed at LQ zone substation

Source: CitiPower

3 Identified need

The identified need is to maintain a safe and reliable supply of electricity to customers in the LQ supply area, recognising the risks associated with the existing switchboard, including:

- the increased risk of failure posed by the deterioration of the existing switchboard
- site-specific factors exacerbating potential adverse consequences of failure
- the higher risk of arcing posed by compound-filled switchboards, as recognised by the shift away from these asset types by the broader energy industry.

These factors are discussed in further detail below, and a monetisation of these risks and consequences is provided in section 5.

3.1 Risk of failure from the switchboard at our LQ zone substation

The LQ zone substation is heavily loaded and the compound-filled bus-sections are older than their original technical life of 40 years. This puts the switchboard at increased risk of deterioration.

The deterioration of compound insulation—such as leaks, degradation or the development of internal voids due to repeated melting and cooling of the compound over time—can change the dielectric properties of the insulation, and result in the inception of partial discharge activity. This increases the probability of arc-faults occurring.

Deterioration in compound-filled assets is typically monitored by measuring partial discharge activity, with changes in partial discharge activity providing early warnings of impending failure.[3]

In November 2017, on-line partial discharge monitoring equipment was installed at LQ zone substation after partial discharge activity was detected during routine maintenance. Partial discharges have since been detected at multiple locations within the switchboard, including the compound-filled cables and cable boxes, circuit breaker spouts, and the B-C bus tie area that includes the compound-filled busbars. The detection of partial discharge in the busbar area of a switchboard is particularly concerning as an arc-flash in this area is likely to result in the loss of a complete busbar section or the whole switchboard.

Examples of compound-filled switchboard failures and internal voids in compound insulation are shown in appendix A.

3.2 Consequences of failure from the switchboard at our LQ zone substation

The potential consequences of a switchboard failure at our LQ zone substation are largely driven by the likely reliability and safety impacts. These impacts reflect the characteristics of the switchboard (i.e. compound-filled) and the zone substation design.

During the 1960s and 1970s, compound-filled indoor switchboards were a common technology and widely used. Compound-filled switchboards, however, have since been found to pose material safety and reliability risks.

In particular, compound-filled switchboards are not designed to contain arc-faults, creating the potential for adverse safety outcomes. An internal arc fault occurs where an electric arc is sustained, either between phase conductors or between a phase conductor and earth, following a breakdown in the insulation. The extreme heat

[3] Partial discharge refers to localised electrical flashovers within part of an electric insulation that does not completely bridge the overall insulation integrity.

caused during an arc can vaporise the metal of the conductors involved and create a significant pressure rise. This can have explosive effects and increase the intensity of equipment failures.

This presents a serious risk to operators in the vicinity of a failure and can result in significant injuries leading to long-term disability or death.

Explosive failures can also create further damage to the building and adjacent circuit breakers, resulting in greater reliability consequences. This is a real risk as Email/Westinghouse J18 circuit breakers have previously failed within our network.

The configuration and loading of our LQ zone substation are such that a fault would be expected to impact our ability to supply load to the central business district. For example:

- the normal operating condition of the LQ switchboard is to supply customers from the front and rear bus sections, and as such, there is no bus reserved solely for operational contingency
- due to the layout of the switchboard and the presence of compound insulation, there is a high probability that a fault on one bus would also result in damage to the other adjacent bus
- for failures close to the bus tie, the damage would impact two of the double bus sections, as the arrangement of the busbars would allow the spread of arc products and smoke; the presence of compound insulation will increase the likelihood that a failure will result in a fire.

3.3 Industry shift away from compound-filled switchboards

Broader industry experience supports the view that compound-filled and non-arc fault contained switchboards pose an increasing safety and reliability risk. For example:

- Ausgrid's regulatory proposal and revised regulatory proposal for its 2019–2024 regulatory period indicates their intention to replace compound-filled switchboards as a commitment to implementing current industry best practice[4]
- Western Power experienced four catastrophic failures of compound-filled switchboards in the 10-year period to 2010[5]
- TasNetworks have proposed to continue their program, initiated in 2014, to replace non-arc rated HV metal-clad switchgear installed on their transmission network due to safety and operational risks associated with these assets[6]
- Power and Water Corporation are replacing their non-arc contained switchboards due to safety concerns following an incident at their Berrimah substation in 2017, in which an operator suffered second degree burns.[7]

As noted in section 2.1, the existing switchboard at LQ zone substation is one of only nine remaining compound-filled switchboards in operation across our networks. We have plans to replace all but one of these switchboards in the next five years.

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4 CP ATT105: Ausgrid, *Revised Proposal, Attachment 5.14.1 Project Justification for 11kV Switchgear*, January 2019.

5 CP ATT112: Western Power, *Appendix L – Network Management Plan*, September 2011, p. 7–55.

6 CP ATT225: TasNetworks, *Investment Evaluation Summary*, November 2018

7 CP ATT107: PowerWater, *Berrimah Zone Substation Condition Assessment Report*, February 2018.

4 Options analysis

We considered several options to address the risks posed by the ageing compound-filled switchboard at our LQ zone substation. These alternatives are shown in table 2.

Table 2 Summary of option costs ($ million, 2021)

	Option	Costs
1	Maintain status-quo	-
2	Replace existing switchboard in the same building	19.0
3	Establish new switchboard at Gallagher Place switching station	27.2
4	Non-network solution	N/A

Source: CitiPower

The two network options we assessed are expected to equally reduce the risk at the zone substation. As such, our preferred option—option two, replace the existing switchboard—is that with the lowest cost.

The efficient timing of our preferred option is determined relative to the maintain status-quo option, based on our risk monetisation approach (set out in section 5).

For the reasons outlined below, we do not expect a non-network solution to be economic.

4.1 Option one: maintain status-quo

Option one involves managing the risk posed by the existing switchboard at LQ zone substation without major intervention. This option is expected to result in a deterioration of reliability performance, as the increasing risk of catastrophic failure results in interruptions to customer supply for extended periods of time. These risk costs have been monetised in our attached model, and as noted previously, are compared to the preferred option to determine the efficient timing of any intervention.

In assessing the potential risk costs, we have used the cost of replacement on a planned basis. This provides a conservative assessment of the potential risk-cost of maintaining the status-quo, as the costs of responding to a catastrophic failure are greater than those for a planned intervention.

4.2 Option two: replace existing switchboard in the same building

Under this option, the LQ switchboard would be temporarily off-loaded, and then replaced in its existing location. The scope of works required under this option would include the following:

- install a transportable switchboard, and transfer distribution feeders and transformer incomers from the existing switchboard to the portable switchboard
- relocate the transformer protection, communications and pilot wires
- decommission and remove the existing switch room and indoor plant
- rebuild switch room according to current technical standards for design and layout, including three double busbar switchboards with a total of 56 circuit breakers, six bus sections and all relevant protection and communications
- transfer distribution feeders to the new switchboard
- re-instate the building and surrounding area affected by the work.

This option would enable the existing substation layout to be retained and remove the compound-type switchboard from the network. The costs of this option are shown in table 4.

Table 3 Option two costs ($ million, 2021)

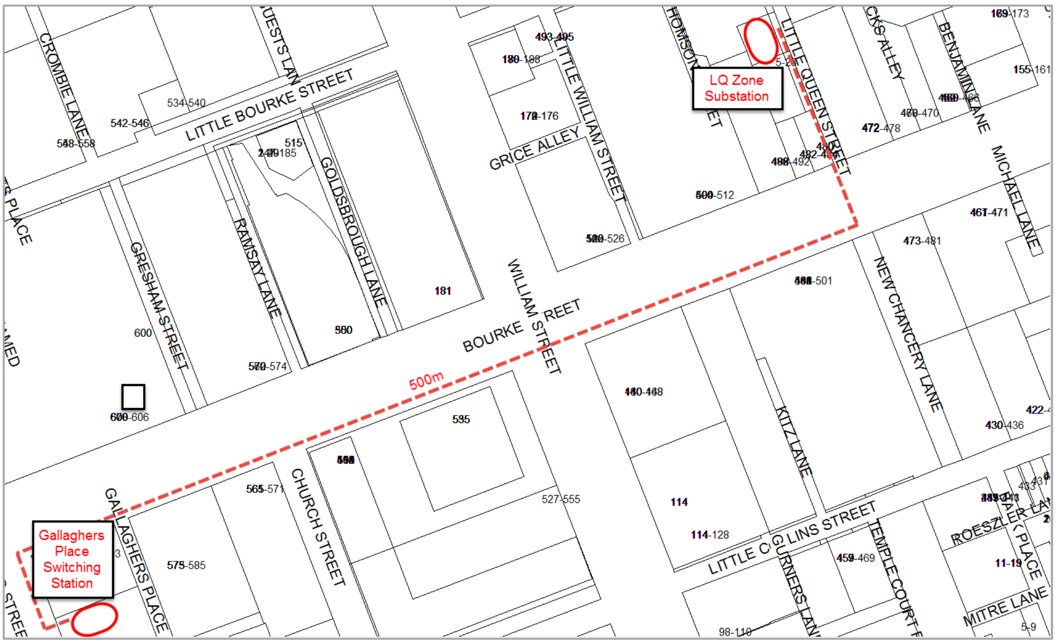
Option	Costs
Replace existing switchboard in the same building	19.0

Source: CitiPower

4.3 Option three: establish new switchboard at an alternate site

An alternative to replacing the existing switchboard on site is to establish a new switchboard at Gallagher Place switching station (**GPSS**). GPSS is located approximately 500m from LQ zone substation, as illustrated in figure 5.

Figure 5 Location of Gallagher Place switching station



Source: CitiPower

The switching station already has multiple connections to LQ zone substation at the 11kV level and would be a suitable site to establish a new switchboard. The scope of works required under this option would include the following:

- establish a 35 circuit breaker switchboard:
  - 5 x capacitor bank breakers and associated capacitor bank
  - 3 x transformer breakers
  - 3 x bus tie breakers
  - 24 x feeder circuit breakers
  - 3 x transformer cable extension from LQ to GPSS (500m)
- reconnect underground feeders:

- – 500m extension of 13 feeders
- – 350m extension of 26 feeders
- – 250m extension of 6 feeders

- building modifications to accommodate new equipment
- decommission and remove the existing switch room and indoor plant
- establish new cable joints and terminations
- establish new protection schemes.

This option will resolve the risks associated with the existing switchboard condition. However, the cost associated with underground cable installations and extensions in the CBD make the project more expensive than replacing the switchboard in the existing building.

The costs of this option are shown in table 5.

Table 4 Option three costs ($ million, 2021)

Option	Costs
Establish new switchboard at GPSS	27.2

Source: CitiPower

4.4 Option four: load transfers and non-network solutions

Option four considers the use of load transfers and non-network solutions to defer the need to replace the existing switchboard at LQ zone substation.

Load transfers

Load transfers could be used at LQ zone substation to transfer approximately 20MVA to our Little Bourke (**JA**) zone substation, and a further 25MVA to our Southbank (**SB**) zone substation. Implementing these transfers, however, would restrict the existing switching and contingency transfer capability within the CBD.

These adjacent substations also have emerging capacity and asset condition constraints that would be exacerbated by transferring load from LQ zone substation.

Residual energy at risk

With summer peak demand of around 100MVA, the use of 45MVA of load transfers would leave residual demand of 55MVA to be met during the summer peak load. Meeting this level of demand through a non-network solution(s) is expected to be prohibitively expensive (e.g. it would likely require additional at-call generation capacity).

Based on the expected service life of existing generator, photo-voltaic cell and battery storage solutions an overall period of 20-years is expected before replacement will be necessary.

The implementation of this option includes the decommissioning of the existing switchboard at LQ and associated reparations to the building, including proper disposal of hazardous materials such as asbestos and PCBs.

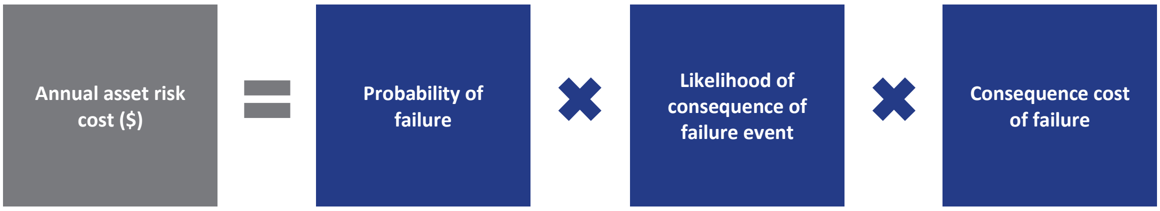
The direct (up-front) cost for this option is considered excessive, with additional ongoing annual running and tariff reduction costs required over the life the solution. It is therefore not considered a viable option.

5 Asset risk monetisation

This section explains our risk monetisation process and how it has been used to inform the timing of our preferred LQ zone substation investment. Our risk monetisation model is attached with our regulatory proposal.[8]

We monetise risk when assessing investment decisions by determining the annual asset risk cost (as shown in figure 6). This approach is applied to all identified failure modes for an asset, and the sum of the annual asset risk cost for all of failure modes is compared to the annualised cost of the preferred option to determine the economic timing for any intervention. This approach is consistent with the AER's recent asset replacement guidance practice note.[9]

Figure 6 Calculation of annual asset-risk cost



Source: CitiPower

Our approach to risk monetisation employs CBRM to provide a robust methodology for the preparation and application of the required input information (i.e. the probability of failure, and the likelihood and consequence cost of failure).[10] CBRM enables us to use current asset information, engineering knowledge and practical experience to predict future asset condition, performance and risk for our assets. It is a comprehensive management methodology.

5.1 Probability of failure

Asset performance is measured in terms of probability of failure and, for each asset category, is determined by matching the 'health index' profile with recent data on failure rates.

Health indices are derived for individual assets by combining information on age, environment, duty and specific condition information. These indices are then projected forward to reflect the asset's ageing rate, which is dependent on its condition and operating environment.

5.1.1 Determination of health index

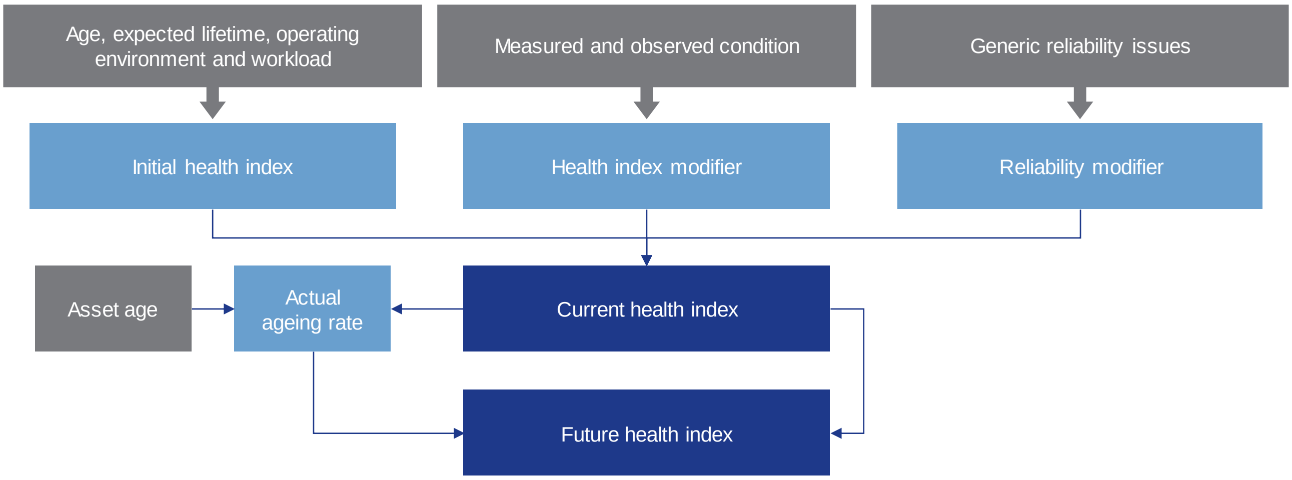
The detail of the health index formulation is different for each asset class, reflecting the asset-specific information and degradation processes. There is, however, a consistent approach to determining the health index for all asset classes as shown in figure 7.

8 CP MOD 4.03 - LQ supply area - Jan2020 - Public

9 CP ATT175: AER, *Industry practice application note: asset replacement planning*, January 2019.

10 The CBRM is a proprietary model developed by EA Technologies. The model is an ageing algorithm that takes into account a range of inputs to produce a health index for each asset in a range from zero to 10 (where zero is a new asset and 10 represents end of life). The health index provides a means of comparing similar assets in terms of their calculated probability of failure.

Figure 7 Overview of health index determination



Source: EA Technology

An initial health index for our switchboard is calculated using knowledge and experience of the asset's performance and expected lifetime, taking account of factors such as original specification, manufacturer, operational experience and operating conditions (e.g. duty and location).

The initial health index is then adjusted by the health index modifier, which is based on the known condition of the asset. It includes information on condition that is gathered by inspecting the asset, together with information relating to asset defects and failures, and condition information obtained through diagnostic tests.

A reliability modifier can also be applied to modify the current health index to reflect generic issues affecting asset health and/or reliability associated with a manufacturer or model type, or a specific asset performance issue. It can also be used where a specific material or treatment has been applied to the asset. The reliability modifier should be used where there is evidence to show that a sub-group of assets has a materially different probability of failure compared to other assets with the same health index in that asset category.

The current health index, therefore, is derived by modifying the initial health index by the health index modifier and the reliability modifier, subject to upper and lower thresholds derived from the condition and reliability data. Information on the degradation of each asset is then used to 'age' the current health index and thus derive the future health index of each asset.

For our LQ zone substation, individual health indices for each bus section have been calculated in our CBRM. The individual health indices are set out in table 5.

Table 5 LQ switchboard: current health indices

Switchboard section	Health index
11kV bus front: A	3.57
11kV bus rear: A	3.86
11kV bus front: B	5.50
11kV bus rear: B	5.50
11kV bus front: C	5.50
11kV bus rear: C	5.50

Source: CitiPower (CBRM)

5.1.2 Determination of probability of failure

The probability of failure is determined by assessing the current condition of the asset and how it will continue to degrade over time. For switchboards, the condition related failure modes that have been derived by considering actual failure data are listed in table 6.

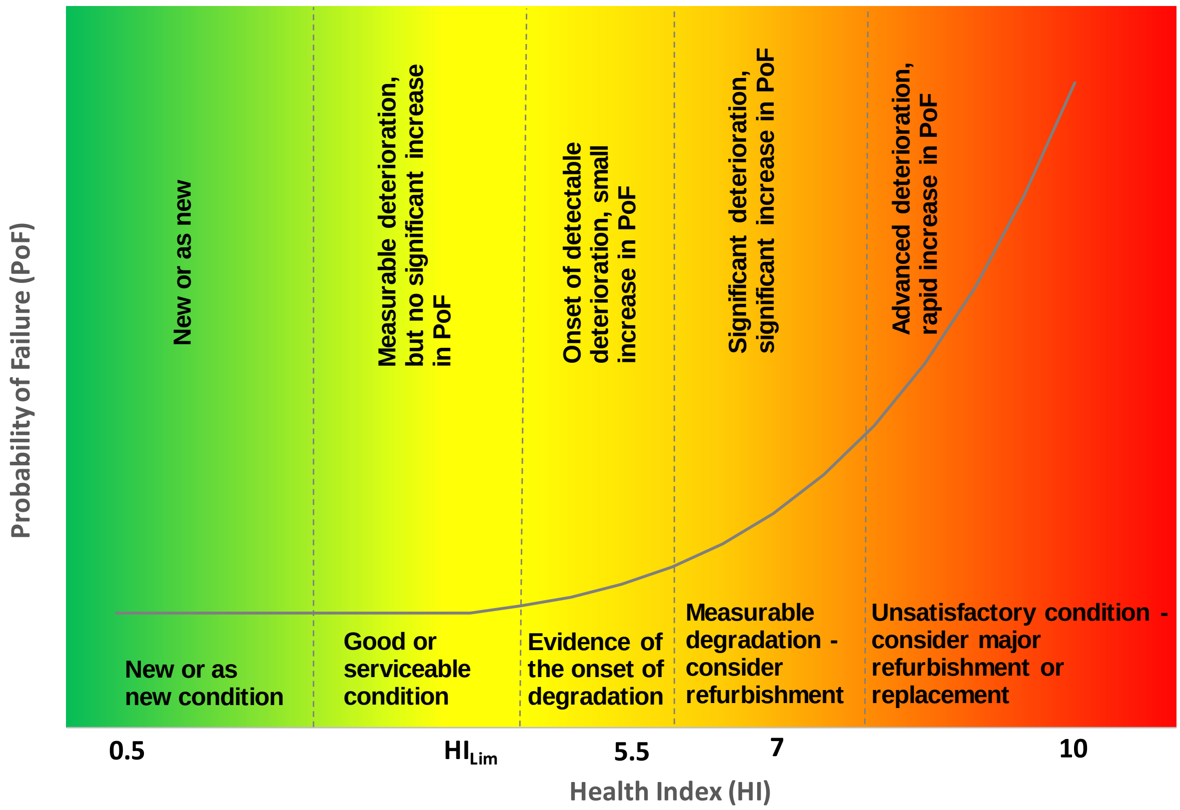
Table 6 Failure mode definitions for switchboards

Failure Mode	Description
Significant	A significant failure which will result in damage to a single bus section and will cause an unplanned outage and require a replacement unit(s) to be installed to restore supply and/or network security
Major	A major failure will which will cause damage to multiple bus sections cause an unplanned outage and require a replacement unit(s) to be installed to restore supply and/or network security

Source: CitiPower

The specific relationship between asset health index and probability of failure is determined by matching the health index profile with the recent failure rate for the asset category. This relationship is not linear. An asset can accommodate significant degradation with very little effect on the probability of failure. Conversely, once the degradation becomes significant or widespread, the risk of failure rapidly increases. The probability of failure of an asset is a function of its health index, as shown in figure 8.

Figure 8 Relationship between health index and probability of failure



Source: EA Technology

Mathematical modelling techniques carried out by EA Technology suggest that a cubic relationship (3rd order polynomial) is appropriate to define the health index and probability of failure relationship as follows:

$$PoF = k \cdot \left(1 + (HI \cdot c) + \frac{(HI \cdot c)^2}{2!} + \frac{(HI \cdot c)^3}{3!}\right) \qquad \text{Equation 1}$$

where:

PoF = probability of failure per annum

HI = health index

k & c = constants

The value of c fixes the relative values of the probability of failure for different health indices (i.e. the slope of the curve) and k determines the absolute value; both constants are calibration values.

Practical experience has indicated that this cubic relationship is appropriate for assets with higher health indices. However, at low values it has been found that even modest increases in probability of failure defined by the cubic relationship do not fit with actual experience. Therefore, it has become standard practice to adopt a hybrid relationship. Up to a limit value (HI_{Lim}), the probability of failure is set at a constant value; above HI_{Lim} the cubic relationship applies. Experience suggests that HI_{Lim} be set at 4; this is the value that has been used in our evaluation of the transformer replacement program.

Determination of c

The value of c in equation one can be determined by assigning the relative probability of failure values for two health index values (generally HI = 10 and HI = HI_{Lim}). Where reasonably complete information is available that directly relates to the critical degradation processes, there is a fairly high level of confidence in the health indices and, consequently, the relative PoF between the two assets is expected to be high. However, where health indices are predominantly derived from indirect condition related information, leading to a lower level of confidence in the health index, the relative PoF between the two assets is expected to be lower.

In practice, with the use of the hybrid HI / PoF relationship, the value of c is typically set to 1.086, which corresponds to a PoF for an asset with a health index of 10 that is ten times higher than the PoF of a new asset.

Determination of k

The value of k in equation one is determined on the basis of:

- the total observed number of functional failures per annum;
- the health index distribution for the asset category; and
- the volume of assets in the asset category.

The asset group can have a different curve shape and height for each failure mode if it is considered appropriate.

For each asset category, k is calculated as follows:

$$k \cdot \sum_{i=1}^{n} \left(1 + HI_i \cdot c + \frac{(HI_i \cdot c)^2}{2!} + \frac{(HI_i \cdot c)^3}{3!}\right) = (\text{Average no. of failures per annum})_I \qquad \text{Equation 2}$$

where:

n = the number of assets in asset category I

HI_i = Health index of asset i

The total experienced failure rate for each failure type is allocated across the asset population based on each asset's health index. Each asset will have a calculated probability for minor, significant and major failures.

Having calculated the health index for each asset, the projected ageing curve can be determined. This projected ageing rate is used to determine the future health index in each year and the resulting probability of failure value for each year.

For our LQ switchboard, the probability of failure for each failure mode, determined based on the above method, is shown in table 7.

Table 7 LQ switchboard: probability of failure values (%)

Failure mode	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030
Major	1.1	1.2	1.3	1.4	1.5	1.7	1.8	2.0	2.1	2.3	2.5	2.8
Significant	10.2	10.9	11.7	12.6	13.7	14.9	16.2	17.6	19.2	20.9	22.7	24.8

Source: CitiPower

5.2 Consequences of failure

Our risk monetisation approach identifies four consequence categories that capture the potential impact on electricity customers of asset failures relating to switchboards. Table 8 shows these risk categories and the associated consequences, each of which can be quantified in dollar terms.

Table 8 Consequence of failure categories and inputs

Consequence category	Consequence inputs
Network performance	• Unserved energy
Safety	• Minor injuries • Serious injuries • Fatality
Financial	• Repair and replacement costs (operating and capital expenditure) • Generation support • Fire brigade attendance
Environmental impact	• Fire starts • Volume of waste produced • Level of disturbance

Source: CitiPower

The calculation of the consequence of failure in our CBRM uses the same failure modes as the probability of failure. For each of these consequence categories, any actual consequences of failure are considered and used to produce a reference cost of failure, which represents the ‘typical’ impact of a failure based on historical data.

Each of the consequence categories are discussed in further detail below.

5.2.1 Network performance: consequence cost and likelihood

The expected average unserved energy costs are based on the energy at risk, the time at risk, and the value of customer reliability (**VCR**) per megawatt hour. The time at risk is based on the time taken to install generators to restore supply. A weighted average of the 50th and 10th percentile expected unserved energy estimates is calculated by applying weightings of 70% and 30% (respectively).

The unserved energy is initially that which cannot be transferred to alternate supplies following the significant or major failure. This reduces once the generators start to come on line taking account of the number of generators which may be brought on line each day until sufficient generation support has been installed to meet the demand unserved following the initial incident.

The likelihood of consequence is set to 100% on the basis that when a particular failure type occurs it is known to have a particular consequence. For example, as the definition of a significant or a major failure is a failure that results in an outage, and the consequences are determined using actual values of load and capacity, then the likelihood of the consequence occurring must be set to 100%. By definition, these failure modes could not occur without causing loss of the asset and some consequences must occur if there is a significant asset failure.

5.2.2 Safety: consequence cost and likelihood

The safety consequences of failure represent the quantification of the societal value of preventing an accident, serious injury or fatality. The safety consequence for each failure is derived from the reference safety cost of failure used in the CBRM, modified by the probability of a safety consequence occurring.

The safety consequences are estimated with reference to minor, serious and fatal injuries by applying a dollar value that reflects the seriousness of the incident. A 'disproportion factor' is also applied, which recognises that serious and fatal injuries should be avoided even if the costs of doing so outweighs the actuarial value of the loss incurred.

The safety consequence represents the risk that the asset presents to the workforce and public by its characteristics and particular situation. The safety consequence incorporates a measure of the likelihood that someone would be in the vicinity of the asset at the time of failure. The assessment of the safety consequence recognises that staff may be present for routine activities or in response to alarms from monitoring or protection equipment (e.g. partial discharge events or Buchholz relay operation) prior to the asset failure.

The value of the safety consequence of asset failure takes into account the likelihood that a failure of each type would result in injury or death. As the likelihood of the consequence is included in defining the value of consequence, the likelihood of consequence value is set at 100% (otherwise the likelihood of consequence would be double-counted in calculating the expected safety risk).

5.2.3 Financial: consequence cost and likelihood

The financial consequence of failure of an asset is the cost of repair or replacement to return the network to its pre-fault state, and the cost of temporary generation support. As the financial consequences are based on repair or replacement cost, and the failure modes are defined as the need to repair or to replace one or more assets, the likelihood of the defined consequence occurring is 100%.

Replacement costs

The replacement costs of a switchboard are based on recent, observed replacement works on our network. The replacement cost for an asset under failure conditions is assumed within the model to be the same as the planned asset replacement unit cost.

Repair costs

The model also provides for repair costs where the replacement of a switchboard is not considered necessary. The repair costs are most likely to arise for a significant failure mode, rather than major or catastrophic.

Generation costs

The operating costs for generation to supply load when failed assets are replaced or repaired is also considered in the financial consequences.

Generation costs are based on the load at risk and take account of the time to install and remove generators and step-up transformers, the fuel used whilst supplying the load that is not able to be supported within the network, and the costs to supervise and maintain the generators during the period they are deployed.

5.2.4 Environmental: consequence cost and likelihood

The environmental consequences of failure represent the quantification of the potential environmental impacts of failure for each specified failure mode. For each asset, the environmental consequence is derived from the reference environmental cost of failure used in the CBRM, modified by an asset-specific environmental consequence modifier.

A failure has a single outcome and will have 100% likelihood of consequence.

5.2.5 Summary of consequence costs and likelihoods

A summary of the consequence of failure for each failure mode for the LQ switchboard is set out below.

Table 9 Major failure risk: consequence of failure ($ million, 2021)

Description	Risk value	Likelihood of consequence	Cost of consequence
Expected average unserved energy	10.80	100%	10.80
Safety consequence	0.03	100%	0.03
Generators supplying lost load for duration	15.13	100%	15.13
Install new switchboard and protection	18.91	100%	18.91
Environmental consequence	0.10	100%	0.10
Fire brigade attendance	0.05	100%	0.05

Source: CitiPower

Table 10 Significant failure risk: consequence of failure ($ million, 2021)

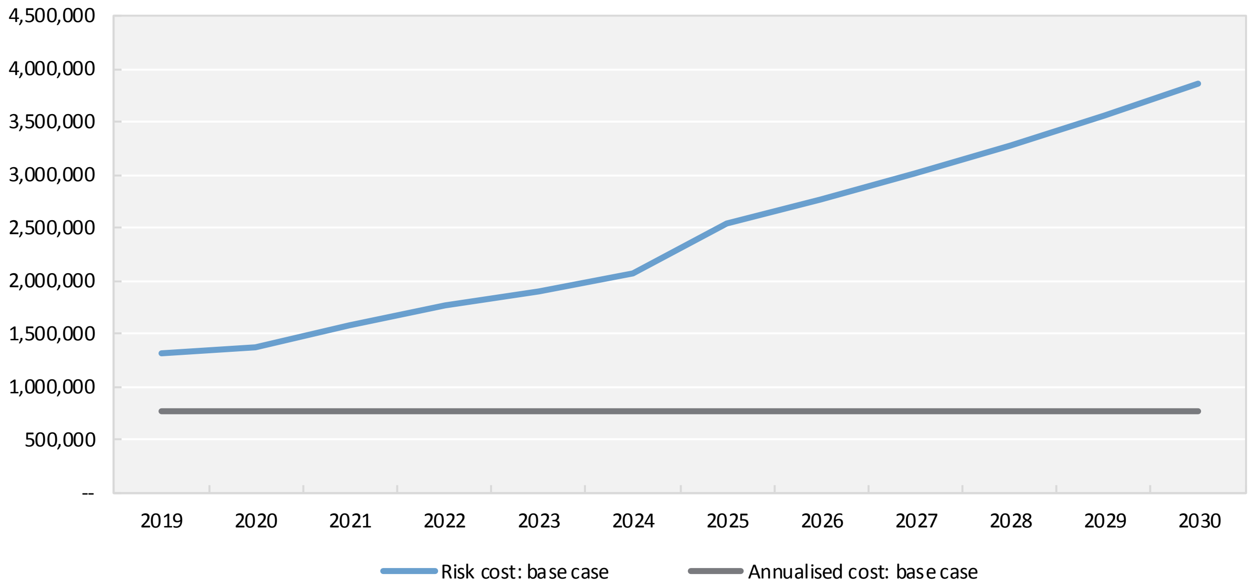
Description	Risk value	Likelihood of consequence	Cost of consequence
Expected average unserved energy	0.88	100%	0.88
Safety consequence	0.01	100%	0.01
Repair	6.30	100%	6.30
Environmental consequence	0.01	100%	0.01
Fire brigade attendance	0.05	100%	0.05

Source: CitiPower

5.3 Optimal timing of asset replacement

The optimal timing for asset intervention is based on a comparison of the asset risk and the annualised cost of the preferred option. Figure 9 shows this comparison for the base case scenario, which reflects our central input assumptions. Further sensitivity analysis is provided in our risk monetisation model.

Figure 9 LQ switchboard: comparison of asset risk and annualised cost for base case ($ million, 2021)



Source: CitiPower

Under the base case scenario, the annual asset risk cost is higher than the annualised replacement cost from 2019. We are currently monitoring these risks, but given the rising probability and consequence of failure (as shown by the increase in annualised risk costs over time), asset management intervention is required in the 2021–2026 regulatory period.

6 Recommendation

The preferred option, as set out in section 4, is to replace the existing switchboard. This approach meets the identified need at the least life-cycle cost.

The forecast capital expenditure requirements for the preferred option for the 2021–2026 period are outlined in table 11.

Table 11 Recommended option: expenditure profile ($million, 2021)

Expenditure forecast	2021/22	2022/23	2023/24	202/254	2025/26	Total
Total capital expenditure	-	0.04	2.61	6.02	10.35	19.02

Source: CitiPower

A Switchboard failures

This appendix shows example images of failures and near-misses in compound-filled switchboards.

Figure 10 Example: before and after pictures of an 11kV switchboard incident (2007)

Figure 11 Example: before and after pictures of an 11kV switchboard incident (2009)

Figure 12 **Example: near miss incident: compound filled switchboards inspected following risk assessment highlighted potential catastrophic failure (2015)**

Figure 13 **Example: void in compound insulation in bare busbar highlighting failed integrity of electrical insulation (2015)**