EAST PERTH AND CENTRAL BUSINESS DISTRICT NETWORK DEVELOPMENT STRATEGY

CBD Load Area Development Report

Revision 2 – Draft Final

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Foreword

This document provides a 25 year strategy for the development of the Western Power Network within the CBD Load Area. Where required, commercially sensitive information has been redacted from this publically available form of the strategy document at the request of Western Power.

References made to the development of sites are provided for the purposes of the strategy only, final decisions have not been made on specific projects and land requirements. Extensive stakeholder engagement will be sought by Western Power with regards to potential new developments and more detailed analysis will be undertaken by Western Power before investment decisions are made.

Contents

Figures

Glossary

The following table shows a list of abbreviations and acronyms used throughout this document. International System of Units (SI) have not been included.

Table 1 Abbreviations and Acronyms

Abbreviation / Acronym	Definition
AIS	Air Insulated Switchgear
AA3	Access Arrangement 3 – Planning submission to ERA for the period 2012 - 2017
Capex	Capital Expenditure
CB	Circuit Breaker
CBD	Central Business District
Perth CBD Boundary	Load within the area currently defined as Wellington Street to the North, Hill Street to the East, Swan River to the South and Havelock Street to the West which is supplied with N-2 security.
DSM	Demand Side Management
DTC	Distribution Transfer Capacity
EHV	Extra High Voltage
ERA	Economic Regulation Authority of Western Australia
GIS	Gas Insulated Switchgear
LTER	Long Term Emergency Rating
MRA	Metropolitan Redevelopment Authority
N-1	The occurrence of a contingency event during which the network experiences a loss of one transmission element.
N-1-1	The occurrence of a credible contingency event during planned maintenance of another transmission element that would otherwise result in the loss of supply to a large number of consumers.
N-2	The occurrence of a double contingency event during which the network experiences a loss of two transmission elements.
NCR	Normal Cyclic Rating
NDP	Network Development Plan
NFIT	New Facilities Investment Test
NMP	Network Management Plan
NPC	Net Present Cost
PoE	Probability of Exceedance
PTA	Public Transit Authority
QB	Quadrature Booster
RMU	Ring Main Unit
RRST	Rapid Response Standby Transformer
SLD	Single Line Diagram
SMI	System Minutes Interrupted

Abbreviation / Acronym	Definition
Technical Rules [12]	Approved by ERA, the Technical Rules consist of the standards, procedures and planning criteria governing the construction and operation of the electricity network
TNDP	10 Year Transmission Network Development Plan
XLPE	Cross-linked Polyethylene

Table 2 CBD Load Area and Associated 2011 Substation Abbreviations

Abbreviation	Substation	2011 Operating Voltage	Comments
A	Arkana	132/22 kV	
AMT	Amherst	132/22 kV	
BCH	Beechboro	132/22 kV	
BEL	Belmont	132/22 kV	
BEN	Bennett Street	-	Land Available
BTY	Bentley	132/22 kV	
CK	Cook Street	132/11 kV	
CT	Cannington Terminal	132/66 kV	
CTE	Cottesloe	132/11 kV	
EP	East Perth	132/66 kV	
F	Forrest Avenue	66/11 kV	
H	Hadfields	132/22 kV	
HAY	Hay Street	132/11 kV	
JAM	James Street	132 kV	Land available
JT	Joel Terrace	66/11 kV	Same site as JTE
JTE	Joel Terrace	132/11 kV	Same site as JT
MIL	Milligan Street	132/11 kV	
MLA	Mount Lawley	132/11 kV	Switching station
MO	Morley	132/11 kV	
MUR	Murray Mews	-	Land available
NP	North Perth	132/11 kV	
NT	Northern Terminal	330/132 kV	
OP	Osbourne Park	-	
RTN	Riverton	132/22 kV	
SF	South Fremantle	132/66 kV	
ST	Southern Terminal	330/132 kV	
SUM	Summers Street	132/25 kV	Customer Substation
TUL	Tully Road	-	Land Available
W	Wellington Street	66/11 kV	
WT	Western Terminal	132/66 kV	
Y	Yokine	132/11 kV	

Executive Summary

Western Power has identified the requirement for a robust long term development plan for the electrical transmission system assets supplying and within the East Perth and Central Business District (CBD) Load Area[1] spanning a period of 25 years. The plan is required to guide network engineering decisions along a clear, economically sound investment path and underpin future New Facilities Investment Test (NFIT) submissions to the Economic Regulation Authority (ERA) of Western Australia.

SKM was therefore engaged by Western Power to assess potential long term development strategies for the CBD Load Area and wider transmission supply network over a 25 year period, giving specific consideration to a range of network investment drivers:

- Network reinforcement to accommodate area load growth over 25 years
- Asset replacement to address age and condition related deterioration
- Customer driven connection works

and other desired objectives:

- Rationalisation of existing substation sites
- Overcome practical restrictions such as cable exit congestion
- Flexibility in future growth and expansion

Guidance on the above issues has been provided by the 'East Perth and Central Business District Network Development Strategy – Review of Planning Philosophies [1].

Each reinforcement project was assessed on the basis of a number of financial, technical and practical metrics. This included:

- Capital investment cost utilising Western Power building block costs
- NPC with agreed investment profile and discount parameters
- Ability to address asset age and condition related deterioration
- Continual compliance with Technical Rules
- Practical issues related to overhead line, cable, substation and distribution developments
- Perceived environmental and community benefits/consenting issues

From the analysis conducted and assessment performed, it is evident that:

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[1]For simplicity this is referred to only as the CBD Load Area for the remainder of this report.

- All substations in the CBD Load Area are expected to require capital investment or capacity enhancement within seven years.
- All of the existing 66 kV network within the CBD Load Area (with the exception of a limited number of 66 kV switchgear units at East Perth) will require asset replacement and capacity upgrading within the considered strategy period.
- Space restrictions at Hay Street, Milligan Street and proposed Bennett Street Zone Substations will limit the designs that can be employed, particularly if in-situ replacement of the assets at Hay Street and Milligan Street Zone Substations is considered.
- As per the Western Power TNDP a number of transmission projects are required across the wider CBD Load Area transmission network before 2020. These include the requirement to address the ST-EP 132 kV circuit thermal loading issues under contingency events, the requirement to reinforce Western Terminal for N-1-1 compliance, plus wider area reactive reserve balancing and fault level mitigation.
- Within 5 to 10 years a new transmission corridor from Cannington to East Perth is likely to be required to cater for a new 132 kV double circuit line. This can be constructed at either 132 kV or 330 kV specification, with the latter potentially being adopted if the long term benefits of migration to 330 kV are substantiated. In either case the circuit would be expected to operate at 132 kV until towards the end of the strategy period, at which time upgrading to 330 kV can be considered.

Table 3 presents the investment projects that have been identified as key future network reinforcements required to address specific limitations:

- **Table 3 Summary of Investment Projects**

Investment Project	Proposed Year in Service
Cook Street 3rd 132/11/11 kV transformer	2015
Completion of Joel Terrace 132 kV conversion	2015
New 132 kV underground cable between Hay Street and Milligan Street Zone Substations	2016
Establishment of single 132 kV transformer and distribution switchboard at James Street	2017
Installation of WT-CK 82 132 kV transmission line	2017
Load balancing at North Perth Zone Substation	2018
New Bennett Street 132 kV Zone Substation and associated transmission supply	2018
East Perth 132 kV Switchyard Extension	2018
Establishment of first CT-EP 132 kV transmission line	2020
Retirement of the existing Forrest Avenue, Wellington Street and East Perth 66 kV sites	2020
Hay Street and Milligan Street asset replacement	2018/20
Uprating of EP-HAY 132 kV underground cables (500 m on circuits 81 & 82)	2023
Installation of third transformer at Joondanna Zone Substation (NP Strategy)	2023

Investment Project	Proposed Year in Service
Construction of second CT-EP 132 kV transmission line	2025
Rebuild EP-NP 132 kV transmission line	2029
Installation of third transformer at Joel Terrace Zone Substation	2031

The practicality and deliverability of these projects has been assessed with respect to discussed planning, consenting and construction timeframes and risks within the 25 year strategy, however further detailed assessment of these aspects will be required.

A development strategy has been derived to stage these reinforcement projects to minimise system risk with consideration for the investment profile and resourcing of parallel projects. The following aspects are highlighted:

- The baseline strategy has a nominal 25 year capital cost of $347.60M and an associated NPC of $221.42M.
- Resourcing for the baseline strategy is intensive within the first 10 years with up to eight independent projects (1x zone substation construction, 3x transformer substation expansions, 3x 132 kV cable installations and 1x switchyard extension) required to be ongoing in parallel.
- Should the delivery of the Bennett Street Zone Substation reinforcement project be delayed by an arbitrary three years to reflect possible difficulties in consent/construction, the impact on NPC would be a reduction of 7%. However, the load at risk during the implementation period would be expected to increase by an additional 9.6 MW or $1M of revenue against the baseline implementation timeframe. The investment profile of such a scenario is significantly increased with a peak of $85M in 2020 alone.
- Low load growth sensitivity (half growth rate) indicated a marginal reduction on project delivery NPC (2%), but noticeable reduction in load at risk (25% based on comparative SMI with baseline strategy).
- High load growth sensitivity (provided by Western Power load forecast) indicated a marginal increase on project delivery NPC (1%), but significant increase in load at risk (additional 36% based on comparative SMI with baseline strategy).

Other aspects to note from this study include:

- Western Power standard substation configurations and transformer ratings have been utilised within this study unless explicitly noted. Other arrangements could be adopted if required, however this would not be expected to impact on the outcomes of this study.
- The development strategy presented addresses all of the limitations identified within the 25 year horizon primarily through significant asset replacement and overcoming the existing practical limitations within the CBD Load Area.
- Beyond the 25 year horizon minimal capacity expansion works are expected to be required, however Western Power owned land is available at the James Street and Wellington Street sites to expand or construct additional substations respectively based on this analysis. In

addition, land is also owned at Tully Road, Murray Mews and other locations. It is possible that through future investigations and negotiations other land may be available or traded.

- As part of Western Power's license, non-network alternatives (e.g. DSM) must be considered at the development of each business case by modelling the impact of any potential delay in investment. However, consideration of such techniques is not expected to impact significantly on the developed strategy.

Having studied the capital investment requirements of the CBD Load Area and wider transmission supply network over a period of 25 years, the following recommendations are made to Western Power:

1) Retaining the 66 kV network as part of the transmission system voltage within the CBD Load Area is not recommended as it is the least economically efficient strategy over the long term.
2) Discussions with the ERA should be continued to establish the longer term vision for the existing 66 kV switchyard at East Perth Terminal, including the potential for a 330 kV switchyard.
3) A number of projects have been identified as being required within the first 5-7 years of the development strategy period to minimise Western Power business and customer risk and provide the maximum attainable benefit. It is therefore recommended that the further analysis of the cost, practical issues, environmental impacts and other implementation/deliverability factors of the following projects be made a priority:
   - HAY-MIL 132 kV underground cable
   - Bennett Street Substation and associated transmission supply
   - Joel Terrace 132 kV conversion
   - Cook Street 3rd Transformer
   - Single 132 kV transformer and distribution switchboard at James Street
   - Staging requirements and any associated load transfers to facilitate the Milligan Street and Hay Street Zone Substation switchboard replacements
4) Develop a preliminary Stakeholder and Community Engagement Strategy for the CBD Load Area Program of Works

In addition to these recommendations, there are a number of aspects that require further analysis and assessment to fully understand their associated impact on the investment strategy. Typically this additional analysis will be completed as part of detailed planning reports. It is therefore recommended that:

1) The migration to a 22 kV distribution voltage from the existing 11 kV within the high density Perth CBD boundary is further analysed to fully understand the level of asset replacement required, the advantages that can be gained and the deployment strategy for any potential

migration. Such an analysis should be carried out as part of a distribution development strategy in conjunction with the detailed planning reports.

2) The support capability of the DTC network under contingency conditions is reviewed to understand the ability to contribute to continued compliance with the Technical Rules.

3) The long term benefits of migrating the new CT-EP double circuit line to 330 kV should be further assessed, including analysis of potential timings and cost impacts. In the short term, assessment of existing Western Power 132 kV and 330 kV tower designs should be conducted in order to determine the most appropriate line construction design to facilitate future upgrades at minimal cost and with minimal additional work.

4) The installation of a quadrature booster should be further assessed to analyse the potential impacts on timings of the identified 132 kV transmission supply reinforcement projects as well as any potential wider system benefits.

5) The mitigation measures required to manage the risks to the Western Power business (in terms of the potential occurrence of a quality of supply or legal compliance incident) and its customers' during the implementation of the proposed capital investment strategy requires further detailed analysis.

6) The feasibility of the proposed overhead line or underground cable projects should be investigated to confirm that these schemes can be achieved in practice considering environmental and community consenting concerns and other practical limitations. This should include installation techniques such as pit and duct or tunnel technologies which will be of particular importance for the proposed HAY–MIL 132 kV cable.

7) Detailed conceptual designs are developed for each new / modified substation to confirm that the number and rating of transformers considered can be achieved in practice, with specific consideration given to operational and construction issues. Particular attention is required at Hay Street, Milligan Street and Bennett Street Zone Substations given the restricted site plots available.

1. Scope of Assessment

1.1. Background

Western Power has identified the requirement for a robust and documented strategy for future network development in the CBD Load Area across a 25 year horizon. Whilst considerable work on this subject has been undertaken previously, the need for a holistic review of the CBD Load Area acknowledging recent load trends, asset condition, technology improvements and other broader strategic network drivers and business objectives has been recognised.

The absence of a refreshed strategy in the CBD Load Area continues to present uncertainty for Western Power when making capital investment decisions for new installations, customer relocations and ongoing maintenance activity. A robust network development strategy also reduces regulatory risk and increases the likelihood that new facilitates will meet the NFIT requirements as stipulated by the ERA of Western Australia [1].

Western Power has recognised the urgency for a refreshed strategic network development plan in the area to guide network engineering decisions along a clear, economically sound investment path and underpin future NFIT submissions. As part of its TNDP, Western Power has identified a number of emerging limitations in the CBD Load Area. Whilst the TNDP presents a good view of these emerging constraints, its focus on the CBD Load Area was not sufficiently mature to consider a detailed, more optimised assessment of asset condition and capacity related emerging constraints, particularly across a 25 year horizon. Western Power identified that further work is required to form a robust economic development proposal to address the emerging constraints and prepare a suitably staged program of work to ensure deliverability and mitigate risk.

This report assesses the CBD Load Area and the surrounding transmission supply network to identify emerging limitations. In turn, the derivation of a sound capital investment strategy to address these forecasted limitations over a 25 year horizon is examined. This load area development report is drawn from the SKM report 'Review of Planning Philosophies' which examines the current Western Power planning standards for the CBD Load Area, assessing their suitability for ongoing usage and relevance to future network developments based on reviews of other Australian CBD standards [2]. Relevant outcomes and recommendations from that report are referenced within this study where applicable.

Some initial investigations into this load area have been conducted previously and have identified that various substation elements and transmission lines are in excess of 50 years old, some of which are due for replacement in the AA3 period 2012-2017. Beyond this period considerable investment will be required over a 25 year horizon to ensure safety and ongoing reliability of supply. In order to optimise network development with asset management requirements it is critical that all aspects of existing infrastructure including cables, overhead lines, switchgear, transformers and structures at both transmission and distribution level be considered as part of any future network proposals.

1.2. Aim of Document

1.2.1. Study Scope of Work

The aim of this study was to document and assess alternative strategies for developing the CBD Load Area transmission (and to an extent distribution) system to meet the forecast load requirements over the next 25 years, giving consideration to financial, technological, regulatory, asset replacement and other accompanying issues. The study was required to ultimately identify and target the level of capital investment for network reinforcement that will be required to develop the CBD Load Area in a manner which is robust, flexible and efficient to sensitivities over the 25 year horizon.

In assessing different strategies, consideration was given to the aforementioned issues and their impact on the following network development drivers:

1) Network and non-network reinforcements to accommodate area load growth
2) Asset replacement to address age and condition related deterioration
3) Customer driven connection works and relocations
4) Expansion of Perth CBD boundary security standard to a wider geographical area

with extension to the following considerations:

5) Introduction and enabling of new and emerging technologies as identified in the SKM ‘Review of Planning Philosophies’ report [2]
6) Impact on community and stakeholders
7) Wider transmission network reinforcements

This study highlights the merits and associated limitations of each of the considered development projects for the CBD Load Area as well as the recommended strategy and any factors that may impact on its selection. A number of project specific studies are of particular interest following generic work carried out in the SKM ‘Review of Planning Philosophies’ report [2] including:

- Comparative cost-benefit assessment of the use of the transmission network to allow compliance with Perth CBD boundary N-2 Technical Rule over the currently utilised distribution transfer capacity network.
- Long term distribution strategy e.g. continued use of 11 kV distribution voltage, migration to a higher distribution voltage.
- Requirement for 330 kV transmission supply voltage directly into the CBD Load Area.
- Comparative cost-benefit assessment of the voltage migration from 66 kV to 132 kV in the CBD Load Area

1.2.2. Exclusions and Limitations

There are a number of aspects that have not been considered or only given limited consideration within the scope of this study. The primary limitations are noted below, with further detail in Section 4.

- Transmission network reinforcements for the wider system are only presented to support the proposed CBD Load Area development strategies. No consideration has been given to wider system reinforcements beyond the transmission supplies required for the CBD Load Area.
- Consideration has been given to the existing distribution system limitations and constraints within the CBD Load Area such as feeder exit restrictions and de-rating as well as the potential migration of one or more zone substations to 22 kV. A detailed load and feeder analysis, to quantify exact feeder capacity constraints and migration opportunities, has not been conducted as part of this work and requires further analysis.
- Load forecast data is based on 10% PoE values [8] with coincident substation peaks to provide the worst case.
- System modelling has been restricted to the CBD Load Area and the surrounding network which provides infeeds to the load area. Identified TNDP investments have been included in the analysis, but limited to those which have direct influence on the CBD Load Area and surrounding network. Further details on the modelling approach and suitability for this analysis can be found in Section 4.5.
- Summers Street substation is owned and operated by the PTA and is not considered within this study.

1.3. Past Study Reports

1.3.1. CBD Load Area

Part of the scope of work for this study was to review the work completed to date by Western Power in relation to the long term planning of the transmission and distribution system in the CBD Load Area. Previous reports that have been considered as part of this work include:

1) Perth CBD Contingency Criteria 1990, [3]
2) East Perth Load Area – Strategic Management Plan 2008 – 2026, [4]
3) CBD 50 Year Development Plan For Transmission, [6]
4) 10 Year Transmission Network Development Plan (TNDP), [7]

The first report provided a review of the Perth CBD boundary contingency criteria in 1990 and those used by other Australian power utilities. It was determined that the existing contingency criteria were not sufficient to secure the commercially and politically sensitive loads in the Perth CBD boundary to an acceptable level. An economic analysis of the implementation of a higher security standard was carried out to recommend the current N-2 (with two hour restoration time)

Perth CBD boundary security standard. It was noted that the security standard and the boundary in which it operates should be reviewed every five years. Additionally it was proposed that the low probability failure contingency of the loss of a Perth CBD boundary transmission substation due to fire, explosion etc could be restored within 4 hours. Such a stipulation is not, however, included within the Technical Rules [12].

The second report, dated March 2008, provided a 20 year strategic plan for the CBD Load Area indicating a number of proposed reinforcement strategies. The primary recommendation was for the construction of two new substations in the load area by summer 2011/12 and also illustrates the severe restrictions on distribution cable exits. The report does not however provide detailed asset condition information and consideration of the timings of asset replacement within the strategies is minimal. Several reinforcements are suggested at the transmission level within the load area, with some consideration given to the wider transmission network and reinforcements required to alleviate N-1 and N-2 contingency overloads.

The third report, dated May 2009, is similar to that of the second, but looking at a 50 year horizon for the CBD Load Area. A number of reinforcement strategies were proposed which are similar to those detailed in the second document. A brief discussion around transmission voltage was provided, i.e. 330 kV versus existing 132 kV, with a development plan for installing additional transformation capacity and transmission capacity also presented. Consideration of practical issues and interleaving with asset replacement requirements was however limited.

The fourth report, dated July 2011, provides a 10 year strategy for each of the Western Power Network load areas, including that of the CBD Load Area. Such strategies were utilised as the basis for the AA3 capital investment regulatory submission. This report also illustrates expected transmission system limitations within the 10 year horizon including commentary on the ageing condition of the existing 66 kV assets. The primary project identified is a new substation within the CBD Load Area in the year 2016/17 to provide load growth support and facilitate asset replacement works, such as the 11 kV switchboards at the Hay Street and Milligan Street Zone Substations which are in a poor condition. It is also identified that a distribution voltage migration to 22 kV may have significant merits.

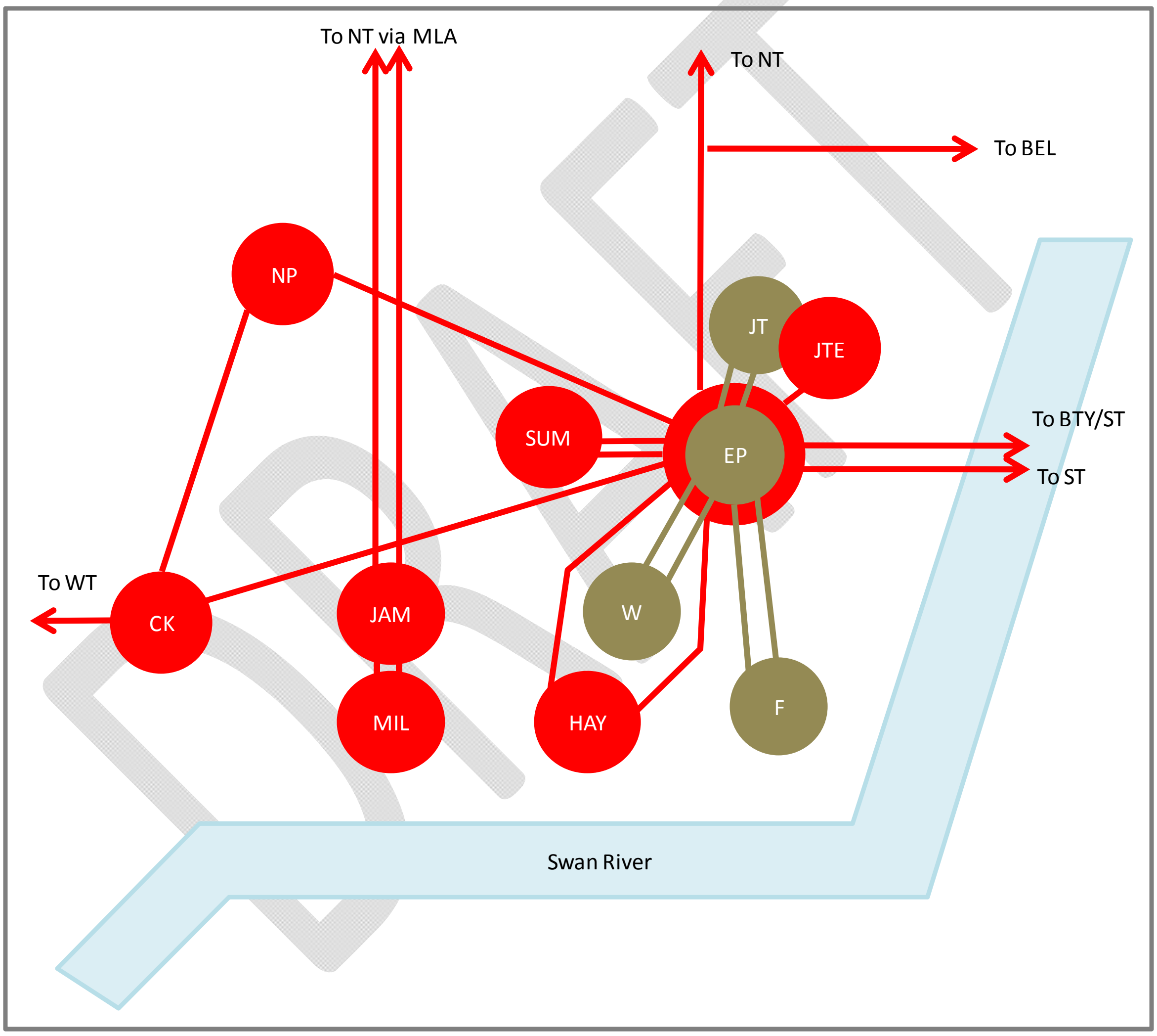
These reports provide useful background with respect to the technical limitations expected to be seen across the CBD Load Area and some of the strategies that have been proposed to date to address these limitations. Some consideration of asset replacement schemes, distribution development plans, timing, staging, practical and environmental issues of implementing the strategies is also provided, although limited. Solid financial and technical justification for the proposed network reinforcements documented within these reports is fairly limited.

In addition to these long term planning reports, a number of short term or project specific reports have been completed by Western Power. These reports will be referenced within the relevant sections throughout this study where necessary.

2. Background

2.1. Overview of the Network Area

For the scope of this report the CBD Load Area has been defined by the substations and transmission circuits as detailed within Figure 1. The load area consists of multiple radial connections from East Perth at both 66 kV and 132 kV with additional connections to loads at North Perth and Cook Street. The CBD Load Area is also supplied from Northern Terminal via the James Street to Milligan Street radial connection.



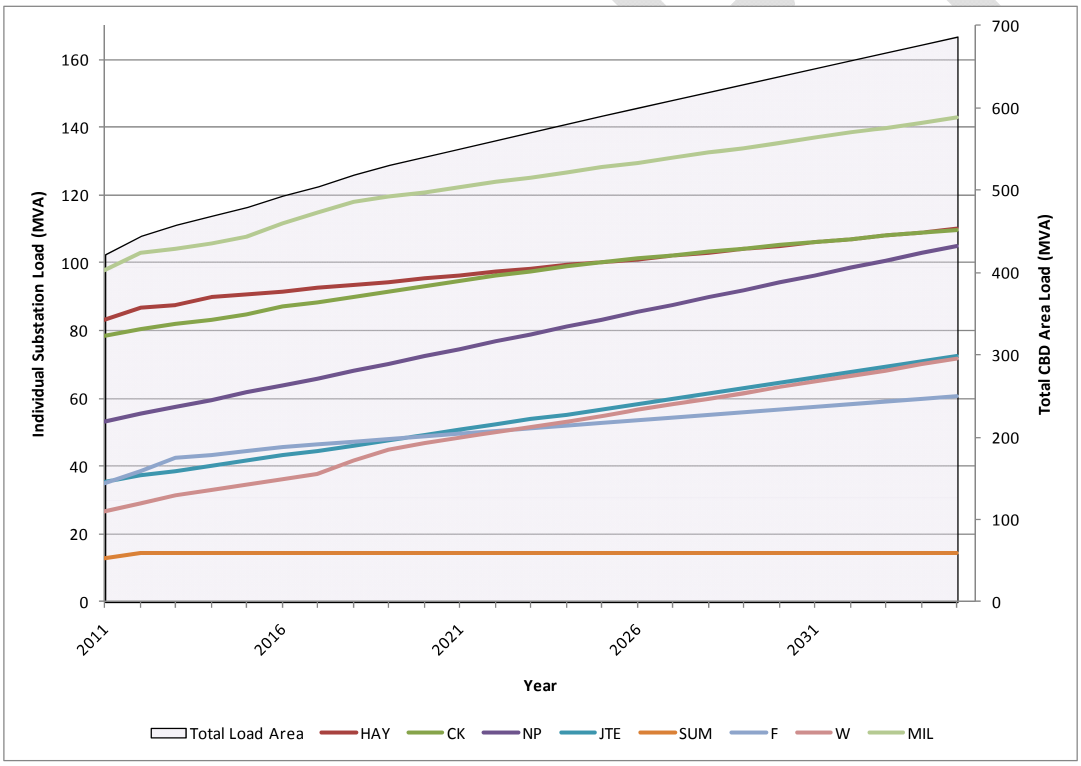
■ **Figure 1 CBD Load Area Overview (2011)**

Abbreviations in Figure 1 are provided in Table 2.

Infeeds into the area are provided by Western Terminal (1x), Northern Terminal (3x with one circuit teeing into the Belmont substation and the Cannington load area) and Southern Terminal (2x). The study of these infeeds and the wider transmission network has been assessed within Section 9.

The load area geographically covers the Perth CBD boundary with extensions primarily to the North and East. The boundaries of the CBD Load Area are seen to be the Swan River to the South and East, North Perth in the North and Subiaco in the West. The general geographic region that the CBD Load Area covers is illustrated within Appendix A - Figure 42.

The area is of high importance with sensitive financial and political customers interleaved with significant levels of commercial load. In addition, there is a growing level of high density residential load. It is forecasted (as shown within Figure 2 - [8]) that the load growth within the CBD Load Area, over the next 25 years, will be driven by a mixture of block loads (described further in Section 2.6) and organic growth from residential and commercial customers. Organic developments in the area are expected to be centred on the rationalisation of existing land uses such as higher density residential and commercial buildings, with block load developments based around new Greenfield sites generated through reclaimed land.



- **Figure 2 2011 - 2036 CBD Load Area Demand Forecast (10% PoE)**

2.2. Applicable Technical Rules Overview

The Technical Rules define the level of security required for the Western Power transmission system. Relevant aspects for the CBD Load Area are provided within this section for reference regarding both the transmission and distribution systems:

2.2.1. Applicable Transmission Technical Rules

Clause 2.5.2.2 N-1 Criterion

- For sub-networks designed to the N-1 criterion (excluding a zone substation designed to the 1% risk or NCR criteria in accordance with clause 2.5.4), supply must be maintained and load shedding avoided at any load level and for any generation schedule following an outage of any single transmission element.
- Notwithstanding the requirements clauses 2.5.2.2(b) and 2.5.2.2(c), where the failed transmission element is a zone substation supply transformer, supply may be lost for a brief switching period while loads are transferred to un-faulted supply transformers by means of distribution system switching. The Network Service Provider must maintain sufficient power transfer capacity to allow supply to all Consumers to be restored following switching.

Clause 2.5.2.3 N-1-1 Criterion

- The N-1-1 Criterion applies to those sub-networks of the transmission system where the occurrence of a credible contingency during planned maintenance of another transmission element would otherwise result in the loss of supply to a large number of Consumers. Sub-networks of the transmission system that are designed to the N-1-1 criterion include:
  - all 330 kV lines, substations and power stations;
  - all 132 kV terminal stations in the Perth metropolitan area, and Muja power station 132 kV substation;
  - all 132 kV transmission lines that supply a sub-system of the transmission system comprising more than 5 zone substations with total peak load exceeding 400 MVA; and
  - all power stations whose total rated export to the transmission system exceeds 600 MW.
- The range of operating conditions that are allowed for when planning a part of the transmission system to meet the N-1-1 criterion include any combination of maintenance and unplanned outage of two transmission elements including lines, transformers, busbars and circuit breakers.
- Under the N-1-1 criterion, each sub-network must be capable of withstanding the coincident planned and unplanned outages of transmission elements at up to 80% of the expected transmission system peak load. In determining whether the N-1-1 criteria have been met, the

Network Service Provider may assume that, during the planned outage, generation has been rescheduled to mitigate the effect of the subsequent unplanned outage.

Clause 2.5.3 Perth CBD Criterion

- The Perth CBD criterion applies to those sub-networks of the transmission system that transfer power to the Perth CBD and zone substations and the transmission lines that terminate in those zone substations that supply Perth CBD.
- Following any outage within a sub-network to which the Perth CBD criterion applies involving:
    - one or two transmission lines;
    - one or two supply transformers; or
    - one transmission line and one supply transformer,

  and irrespective of whether any single transmission element outage is planned or unplanned, there must be sufficient power transfer capacity in the transmission system to maintain supply to all Consumers within the Perth CBD without the need to reschedule generation.
- For an unplanned outage of a single supply transformer, there may be a supply interruption to some Consumers of up to 30 seconds to allow for the automatic transfer of the affected loads to other supply transformers within the same substation or to other substations using capacity that is kept available for this purpose.
- For unplanned outages of two transmission elements in accordance with clause 2.5.3(b), there may be a supply interruption to some Consumers of up to 2 hours to allow for the transfer of the affected loads to other supply transformers within the same substation or to other substations using capacity that is kept available for this purpose.

Clause 2.5.4 (b) NCR Criterion

- The NCR risk criterion permits the loss of a portion of power transfer capacity at a substation following the unplanned loss of a supply transformer within that substation.
- The portion of the power transfer capacity that may be lost is the lesser of:
    - 75% of the power transfer capacity of the smallest supply transformer within the substation; and
    - 90% of the power transfer capacity of the rapid response spare supply transformer.

2.2.2. Applicable Distribution Technical Rules

Clause 2.5.5.2 Distribution Feeders in the Perth CBD

- Distribution feeders in the Perth CBD must be designed so that in the event of an unplanned loss of supply due to the failure of equipment on a high voltage distribution system, the Network Service Provider can use remotely controlled switching to restore supply to those sections of the distribution feeder not directly affected by the fault.

2.2.3. CBD Load Area

Capacity Limitations

This section discusses the transmission capacity limitations that are expected to arise across East Perth Terminal Substation and the CBD Load Area zone substations over the next 25 years.

Within the next 10 years, EP-W 66 kV radial circuits are forecast to be non N-1 compliant by 2013. In the longer term the EP-F 66 kV radial circuits are forecast to be non N-1 compliant by 2032.

In addition, the EP-HAY 132 kV radial circuits are expected to be overloaded in 2022 following an N-2 contingency of the MLA-MIL circuits resulting in the requirement for the EP-HAY circuits to support both the Hay Street and Milligan Street substation loads[2]. The limiting factor on these circuits are the short (500 m) oil filled cable section between the cable sealing ends at Wellington Street Substation and Hay Street Substation which are rated at 110 MVA[13].

Condition Limitations

Within the CBD Load Area there are significant limitations based on known asset condition and equipment approaching the end of nominal life. These known asset condition limitations are summarised in Table 4.

- **Table 4 Load Area Asset Age and Condition Summary**

Substation/Line	Asset	Limitation[3]	Year
Milligan Street	2x 11 kV Switchboards	Poor Condition	2016
	2x 132/11 kV Transformers	Nominal Age	2023
Hay Street	2x 11 kV Switchboards	Bad Condition	2017
	2x 132/11 kV Transformers	Nominal Age	2027
Joel Terrace	2x 11 kV Switchboards	Bad Condition	2011
	2x 66/11 kV Transformers	Poor Condition	2011

[2] The current configuration at the Hay Street and Milligan Street substations can support the complete loss of one of the substations. It should be noted that such an event is not specified within the Technical Rules and the economic justification to maintain this level of security may not be justifiable. Further details are provided in Section 4.6.2.

[3] The year provided for 'Poor Condition' limitations is the year at which Western Power internal analysis indicates that the equipment concerned poses considerable risk to the reliability of the network and hence should be replaced.

Substation/Line	Asset	Limitation[3]	Year
		Nominal Age	2013
East Perth	2x 132/66 kV Transformers	Nominal Age	2017
Forrest Avenue	2x 11 kV Switchboards	Poor Condition	2011
	2x 66/11 kV Transformers	Nominal Age	2019
Wellington Street	2x 66/11 kV Transformers	Nominal Age	2016
EP-JT 71	1x Oil Filled Cable	Nominal Age	2025
EP-W 71 & 72	2x Oil Filled Cables	Poor Condition	2013
EP-F 71 & 72	2x Oil Filled Cables	Nominal Age	2020

2.2.4. Transmission Supply to CBD Load Area

The transmission system supplying the CBD Load Area consists of six 132 kV circuits, as mentioned in Section 2.1. The incoming CBD Load Area transmission supply circuits are thermally rated as follows:

- WT-CK 81 - 920 A (210 MVA)
- ST-EP 81 - 1,063 A (243 MVA)
- ST-BTY-EP 81 - 1,063 A (243 MVA)
- NT-BEL-EP 81 - 906 A (207 MVA)
- NT-MLA-MIL 81/82 (243 / 203 MVA)

Capacity Limitations

Section 8 presents details of capacity limitations expected across the CBD Load Area transmission supply network over the coming decades. Expected short to medium term limitations have been identified from the Western Power TNDP [7].Medium to long term limitations have been identified through our own analysis and assessment.

Within the next 10 years, of particular relevance to this study are the limitations identified in relation to the ST-EP, ST-BTY-EP 132 kV circuits and WT-CK 132 kV circuit which are forecast to be overloaded under contingent conditions in 2014/15 and 2015/16 respectively.

Beyond the ten year horizon, and the scope of the TNDP, it has been identified that there will be insufficient capacity in the existing transmission system to supply the CBD Load Area within the Technical Rules and a new infeed circuit or circuits are likely to be required.

Condition Limitations

In the wider transmission system supplying the CBD Load Area there are a number of assets approaching the nominal end of asset life which are summarised in Table 5. Of these the most likely to impact on the future CBD Load Area development are the NP-EP 81 circuit which approaches the nominal end of life in 2028 and the NT-BEL/EP 81 which approaches end of life in 2027.

Table 5 Transmission Supply Asset End of Life Summary

Line	Notional End of Life Year
ST-SF 81	2012
CT-RTN 81	2016
NT-BEL/EP 81	2027
NP-EP 81	2028
NT-MLA 81/82	2034
MLA-Y	2034
NT-A	2035

2.3. Overview of Distribution System Limitations

The distribution system is currently utilised within the CBD Load Area to provide significant DTC support following contingency events, particularly N-2 events at either Hay Street or Milligan Street Zone Substations. DTC is required to fully support one of these substations, should an N-2 contingency on the two incoming 132 kV feeders occur. In 2011 the maximum DTC requirement would be following a loss of the James Street to Milligan Street 132 kV feeders resulting in a DTC support requirement of 91.80 MVA (the 2011 load at Milligan Street substation). The current DTC is technically capable of supporting 107.5 MVA (see Appendix E - Figure 45) under this contingency although in reality this may be slightly reduced due to practical limitations such as de-rating factors and switching capability. This technical capacity is expected to be exceeded by 2014.

The distribution network currently operates at 11 kV throughout the CBD Load Area. With increasing load this has resulted in severe restrictions of cable exits (see Figure 11) from substations and available routes particularly within the sidewalks of the Perth CBD boundary. In order to alleviate these issues a number of options have been proposed, as detailed in the SKM 'Review of Planning Philosophies' report [2]. These include:

- Use of pit and duct or tunnel installation technologies
- Use of fewer higher capacity distribution cables for cable exits
- Migration to higher distribution voltage

2.4. Wider System Reinforcements

Though the scope of this study is to provide a detailed long term development plan for the transmission system within and supplying the CBD Load Area only, it may be necessary to consider some wider system implications for some of the proposed strategies. This is due to the interconnected nature of the Western Power Network, and also the requirement for N-1 and N-1-1 compliance. For example, a contingency event under which both circuits from Southern Terminal to East Perth are lost at up to 80% peak demand, may create power flows in other parts of the network that feed back into the CBD Load Area. This may result in overloaded transmission elements along the new supply path. Network reinforcements will be proposed in such an event.

This report serves to highlight only those network reinforcements required to maintain a stable supply to the CBD Load Area, which may include circuits not immediately evident as part of the transmission supply to the load area. This report does not, suggest any reinforcements for transmission elements found to be overloaded in remote parts of the network that do not strengthen or affect the secure and reliable supply of power to the CBD Load Area.

2.5. Committed Investments

At the time of writing there are no committed transmission planning investments for the CBD Load Area for the period of this study. For the purposes of the planning strategy, proposed investments appropriate to the load area and identified within the TNDP have been assumed to be in service. For further information on these assumed projects see Section 4.5.1.

2.6. Potential Large Scale Developments

Within the CBD Load Area there are significant proposals for new large scale developments in the short to medium term. These developments are defined within Table 6.

- **Table 6 Proposed Large Scale Developments within the CBD**[4]

Development	Estimated Demand	Expected Completion
Perth City (Northbridge) Link	53 MVA	2018/19
Elizabeth Quay (Perth Waterfront)	33 MVA	2026

In addition to these large scale developments there are a number of other smaller (<10 MVA) individual developments proposed to take place within the CBD Load Area, particularly in East Perth around the Western Australian Cricket Association (WACA) cricket ground as part of the Riverside development. The Riverside development as a collaborative is expected to be around 30 MVA once completed.

Although not committed investments, it is necessary to plan any long term CBD Load Area strategy with the connection of these potential developments in mind. Proposed connection substations have been identified by the Western Power distribution planning team based on the completion dates provided within Table 6 and are included within the load forecast shown in Figure 2 which is used as the base load forecast for this study. Further detail on the Perth City (Northbridge) Link and Elizabeth Quay (Perth Waterfront) proposed developments and distribution strategies to date can be found in the respective feasibility studies [9], [10].

2.7. Other Considerations

Western Power currently owns a significant amount of land around the East Perth Terminal as illustrated in Appendix B - Figure 44. The land along the riverside or where the existing 66 kV switchyard is located is considered to be of significant land value particularly for commercial and

[4] Estimated demand and completion as forecasted by Western Power

residential developments. This consideration should be taken into account when assessing potential strategies in the East Perth Terminal area. The MRA’s approvals for development on this land must also be considered.

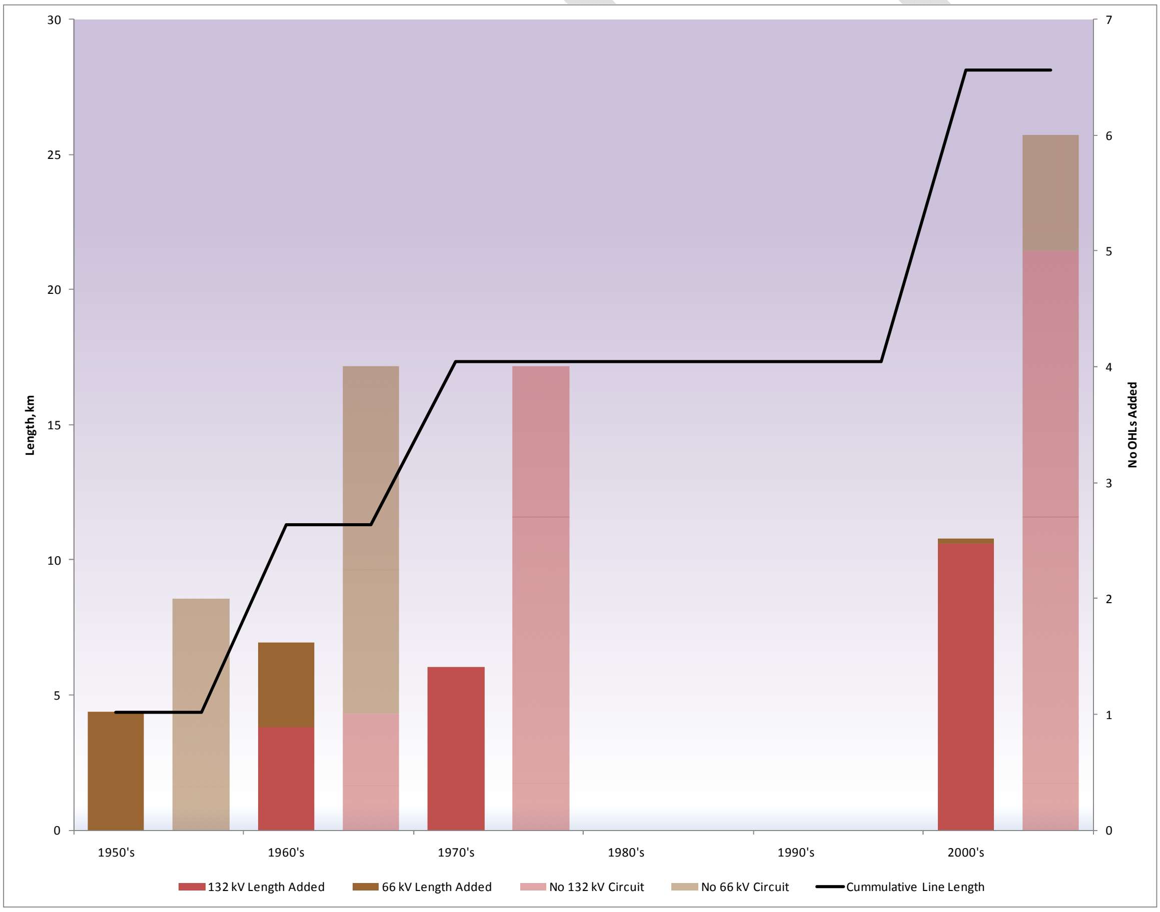
3. Network Asset Condition Report

This section details the age and condition characteristics of the principal electrical transmission and distribution equipment within the CBD Load Area and associated transmission supply network, relevant to the development of a 25 year strategy plan.

3.1. Transmission Assets

3.1.1. Overhead Lines and Cables

The CBD Load Area utilises both 132 kV and 66 kV operating voltages to transmit power. Figure 3 demonstrates how the existing 132 kV and 66 kV overhead lines and cables in the load area have been added to the network since the mid twentieth century. Table 7 details the specific 132 kV and 66 kV circuits that have been considered and summarised in Figure 3, in addition to the percentage of the circuit length which is cable and overhead line.



- **Figure 3 CBD Load Area Transmission Circuit Installation Profile**

Table 7 CBD Load Area Transmission Circuit Age Profile[13]

Lines	From – To Substation	Age	Length, km	Rating, MVA	% Cable
132 kV	EP-CK	2004	5.20	280	100%
	CK-NP	2001	3.55	210	44%
	EP-NP	1968	3.81	231	16%
	EP-HAY 81	1977	2.74	110	42%
	EP-HAY 82	1977	2.87	112	43%
	EP-EP 81[5]	1971	0.23	281	0%
	EP-EP 825	1971	0.18	238	0%
	JAM-MIL 81	2005	0.75	203	100%
	JAM-MIL 82	2005	0.77	203	100%
	EP-JTE	2010	0.32	165	100%
66 kV	EP-W 71	1950	1.80	29	100%
	EP-W 72	1951	2.56	30	100%
	EP-F 71[6]	1960	1.55	58	59%
	EP-F 72	1960	1.44	58	54%
	EP-JT 71	1965	0.15	50	100%
(132 kV Construction)	EP-JT 72	2005	0.18	105	100%

Although Western Power has asset condition information and rankings for EHV transformers and transmission and distribution switchgear, at present a similar condition assessment is not available for transmission overhead lines and cables, however this is being implemented. Therefore, whilst specific line or cable conditions assessments will be undertaken to determine ongoing asset maintenance and refurbishment requirements on an individual basis, for the purpose of this assessment an age based approach has been adopted for determining the end of life of overhead lines and underground cables to feed into the CBD Load Area strategy. After discussion with Western Power engineers and review of the NMP, it was considered that an appropriate lifetime for overhead lines and cables was 60 years, principally as most overhead lines use wooden pole structures and the cables of this era are typically of oil filled construction. This is not inconsistent with life expectations used in optimised depreciated replacement cost valuations of network facilities used in regulatory price setting across Australia.

From examination of Figure 3 and Table 7 it is evident that all of the existing 66 kV overhead lines and cables in the CBD Load Area will require replacing within the next 10 - 15 years, if a 60 year asset lifetime is considered (as provided in the NMP), given the original installation dates in the 1950s and 1960s.

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[5] Circuits from East Perth 132 kV switchyard to the 132/66 kV transformers at East Perth 66 kV switchyard

[6] Some sections of the EP-F 66 kV cable circuits were installed in the late 1990s as part of the East Perth Redevelopment.

The 66 kV cables within the load area are of a construction which utilises oil as the insulating medium. Although estimated to require replacement in the next 10-15 years, based on a 60 year lifetime, replacement may in fact be required sooner in some cases to address known condition related defects[7].

It is also evident from Figure 3 that all existing 132 kV overhead lines and cables within the CBD Load Area are generally younger than the 66 kV lines and cables with the exception of the East Perth to North Perth 132 kV line also being installed in the 1960s (1968). Furthermore, no lines or cables have been installed within the 1980s or 1990s.

Similar historical capacity additions for the wider 132 kV transmission system development around South Fremantle, Southern Terminal, Cannington, Western Terminal and the area between central Perth and Northern Terminal are presented in

Figure 4, with further details for key circuits provided in Table 8.

[7] For example, the EP-W circuits require significant levels of maintenance and investment to maintain the oil integrity of the cables and this maintenance cost burden will reduce the economic life of the cables

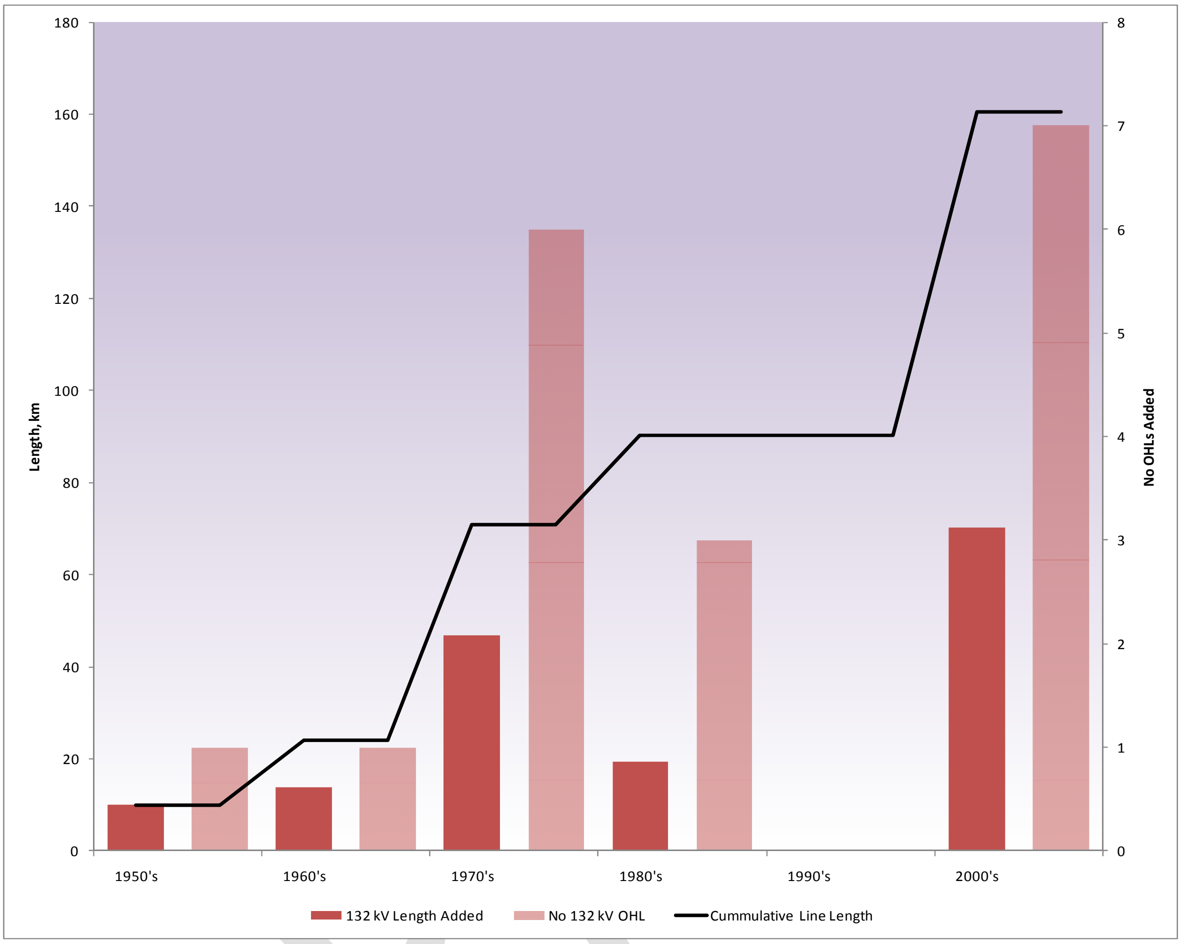


Figure 4 Wider Perth Area Transmission Circuit Installation Profile

Table 8 Wider Perth Area Transmission Circuit Age Profile [13]

Lines	From – To Substation	Age	Length, km	Rating, MVA	% Cable
132 kV	NT-WT	1977	20.63	243	0%
	WT-CK	2001	6.09	210	0%
	WT-CTE	2009	7.39	210	0%
	AMT-CTE	2009	7.84	210	0%
	SF-AMT	2001	6.34	247	0%
	ST-SF	1952	10.05	281	0%
	ST-EP	2005	21.78	243	12%
	EP-BTY	2007	8.26	246	41%
	ST-BTY	2007	12.62	243	7%

Lines	From – To Substation	Age	Length, km	Rating, MVA	% Cable
	NT-EP[8]	1967	13.9	207	0%
	NT-A	1975	6.60	281	5%
	A-OP	1980	8.28	207	0%
	OP-Y	1972	5.20	207	0%
	MLA-Y	1974	3.07	207	0%
	MLA-MO	1974	3.98	210	0%
	H-MO	1973	7.29	160	0%
	BCH-H	1981	6.09	210	0%
	NT-BCH	1981	5.00	210	0%

3.1.2. Transformers & Switchgear

Whilst age is the predominant factor underpinning the deterioration in electrical asset condition and is often therefore used as an asset replacement driver, for more complex items of electrical equipment (e.g. transformers and switchgear) specific condition assessments are often used to provide more accurate information relating to the requirement and timing of maintenance activities as well as ascertaining remaining asset lifetimes.

Western Power routinely collects asset condition information for transmission switchgear (132 kV and 66 kV) as well as power transformers. For switchgear the following parameters are considered in addition to unit age:

- General deterioration
- Maintainability
- Performance
- Contact / insulation resistance testing
- Number of successful / unsuccessful operations to date
- Availability of spare parts

For power transformers the following parameters are considered in addition to unit age:

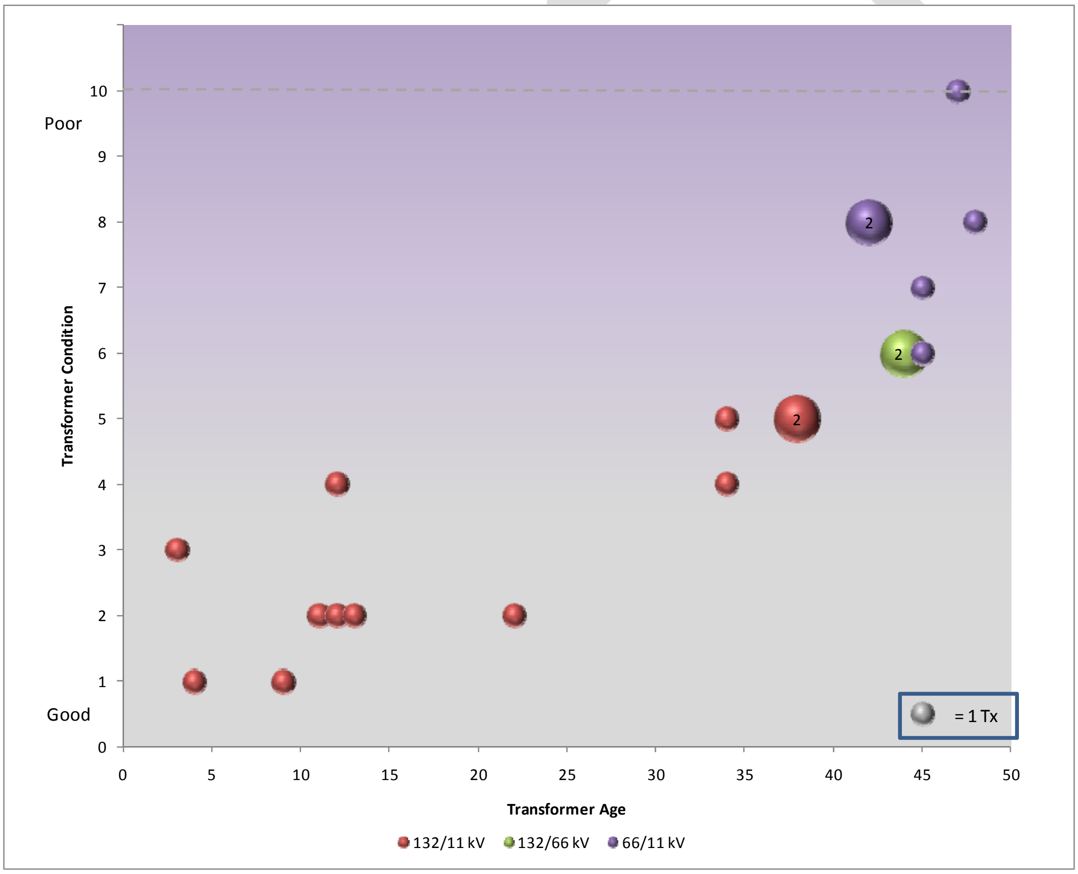
- Results of oil sample tests (e.g. acidity, electrical breakdown strength, furan level, cellulose level, total dissolved combustible gases)
- Tests of bushing insulation
- Thermal loading history
- Tap changer type

[8] Tee to Belmont Zone Substation has not been included for clarity

In both cases the collated condition parameters are used to calculate an overall condition rating for each transformer or circuit breaker on a scale of 1 to 10, with ten being particular bad condition. For 132 kV and 66 kV transformers, Figure 5 outlines the distribution of transformer ages and accompanying conditions.

Note that Figure 5 includes the East Perth 132/66 kV transformers as well as 132/11/11 kV transformers at Cook Street, North Perth (132/11 kV), Milligan Street and Hay Street plus the 66/11 kV transformers at Wellington Street and Forrest Avenue. PTA owned Summers Street equipment is not included in this asset condition assessment as stated earlier.

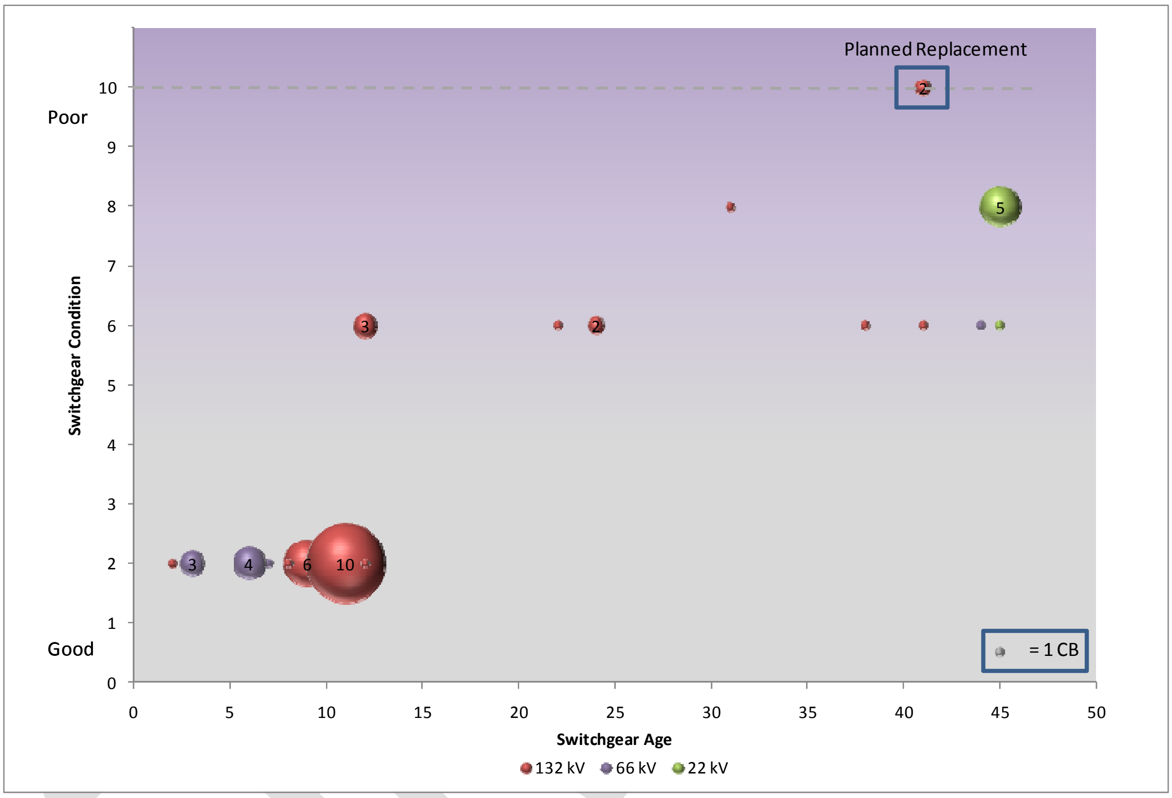
Figure 5 is interpreted by the size of the bubble denoting the number of assets with that age and condition. The majority of bubbles denote a single asset as given in the reference bubble to the lower right of the chart. Where multiple assets are of the same age and condition, a larger bubble is utilised with a proportionate scale. The number of assets in these larger bubbles is provided for clarity. The colour of the bubble denotes the asset class as defined within the legend.



■ **Figure 5 CBD Load Area Transformer Asset Condition and Age Profile**

It is evident from Figure 5 that the existing transformers in the CBD Load Area are of varying age and condition, although those supporting the 66 kV network (bubbles coloured purple and green) are of the oldest and worst condition. It is expected that the transformers in this load area could expect to have a notional 50-60 year life (as defined in the NMP [19]). As a result, it is evident from Figure 5 that the 66 kV transformers in the CBD Load Area will require replacement within 5 to 10 years, with a number of 132 kV transformers to be replaced between 10 to 20 years.

For 132 kV, 66 kV and 22 kV[9] switchgear, the distribution of asset age and associated conditions is illustrated in Figure 6. The interpretation of this chart is as per Figure 5.



▪ **Figure 6 CBD Load Area Switchgear Asset Condition and Age Profile**

Examination of Figure 6 shows a slightly different age and condition distribution to that of the transformers, the main difference being that much of the 66 kV rated equipment is younger than the 132 kV equipment. It can be seen that much of the switchgear is young (<15 years), with only small isolated amounts of switchgear of an older age and in worse condition. The 22 kV switchgear is related to the reactive compensation located on the tertiary winding of the East Perth 132/66 kV transformers and is seen to be some 45 years old which aligns with the age of the associated transformers as seen in Figure 5.

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[9] 22 kV switchgear relates to the reactive compensation located at the tertiary winding of the 132/66 kV transformers at East Perth.

Collectively Figure 3 and Figure 5 highlight that much of the existing CBD Load Area 66 kV assets, including overhead lines, cables and transformers will require replacement within the next 10 years. The anomaly being the 66 kV switchgear at East Perth is of a younger age as shown in Figure 6.

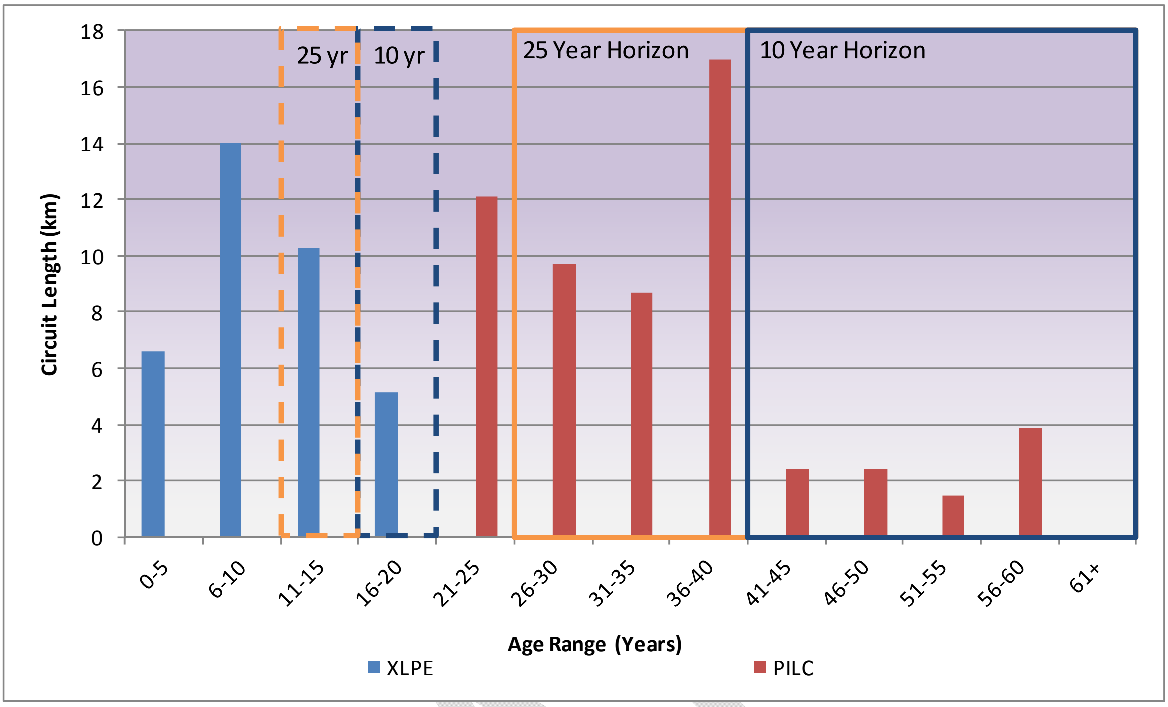
The requirement for near wholesale replacement of the 66 kV network assets over the coming years presents a potential opportunity to rationalise the transmission voltage in the CBD Load Area. Such an approach could provide benefits in rationalising substation locations, overhead transmission lines and increased substation capacity to better accommodate modern and future distribution customer load densities in the area. Should such a rationalisation be seen to be an economic strategy, there are opportunities to reuse the existing 66 kV switchgear at East Perth in Country areas where upgrades to 132 kV from the existing 66 kV networks is potentially less attractive due to lower forecast load levels in these regions. In addition, a small proportion of the existing 132 kV rated equipment, including overhead lines, cables, transformers and switchgear will require replacing within the period considered for this strategy document, which is before 2036.

3.2. Distribution Assets

3.2.1. Cables

The CBD Load Area utilises 11 kV as the operating voltage to distribute power. However recently installed XLPE 11 kV cables across the CBD Load Area are suitable for 22 kV operation as described in the SKM 'Review of Planning Philosophies' report [2]. Detailed data of the specific age or condition of Perth CBD boundary distribution cables was not available at the time of writing other than for the construction type and circuit length. Therefore, an assumption was made that the trending of the age of distribution cable assets across the Western Power Network, as illustrated in Figure 7.16 of Western Power's 2011 NMP, be applied to the known circuit lengths within the CBD to provide an indicative view as to the age distribution of these assets.

Figure 7 demonstrates how the existing distribution cables in the load area have been added to the network since the mid twentieth century, with a breakdown of the cable technology. The highlighted blue box indicates the cable length expected to require replacement over a 10 year horizon, whilst those in the orange box indicate the expected cable length to be replaced over a 10-25 year horizon. This is based on the nominal age of the distribution cabling shown in the NMP. It should however be noted that in practice, distribution cabling will generally be replaced on failure and not on the basis of notional end of life.



- **Figure 7 CBD Load Area Distribution Circuit Installation Profile**

For transmission lines and cables, an age based approach to end of life has been applied in the absence of condition based data. After review of the NMP it was noted that Western Power's view for the appropriate lifetime for distribution cables is 50 years for PILC construction and 30 years for XLPE.

The shorter lifetime attributed to XLPE cables is due to the first generation of this technology installed in the 1970s and 80s. It is expected that later generations of this technology will have a nominal lifetime comparable to that of PILC construction. For the purpose of this analysis, it has been assumed that those XLPE cables between 16-20 years old will need replacing in the 10 year horizon, with those 11-15 years old to be replaced in the 25 year horizon as shown in the dotted blue and orange boxes respectively in Figure 7.This allows for the expected improving life expectancy of XLPE cabling with more recent generations of the technology.

XLPE cables are fast becoming the preferred technology across all voltage ranges with Cigré reporting that 87% of AC cables installed since 2000 have been of XLPE technology. In comparison, no PILC cables have been installed since 2000 [20]. The remaining 13% of AC cable types are of a mass impregnated construction.

Examination of Figure 7 shows that the installation of XLPE cable at a distribution level has been restricted to the past 20 years with PILC technology utilised before this time. In the 10 year horizon, relatively short lengths of distribution cabling are expected to be required to be replaced(approximately 16% of the population); however this dramatically increases in the 10-25 year horizon (additional 50% of the population). This indicated over the 25 year horizon, it is expected that 66% of the distribution cable population, primarily PILC cables, will require replacement.

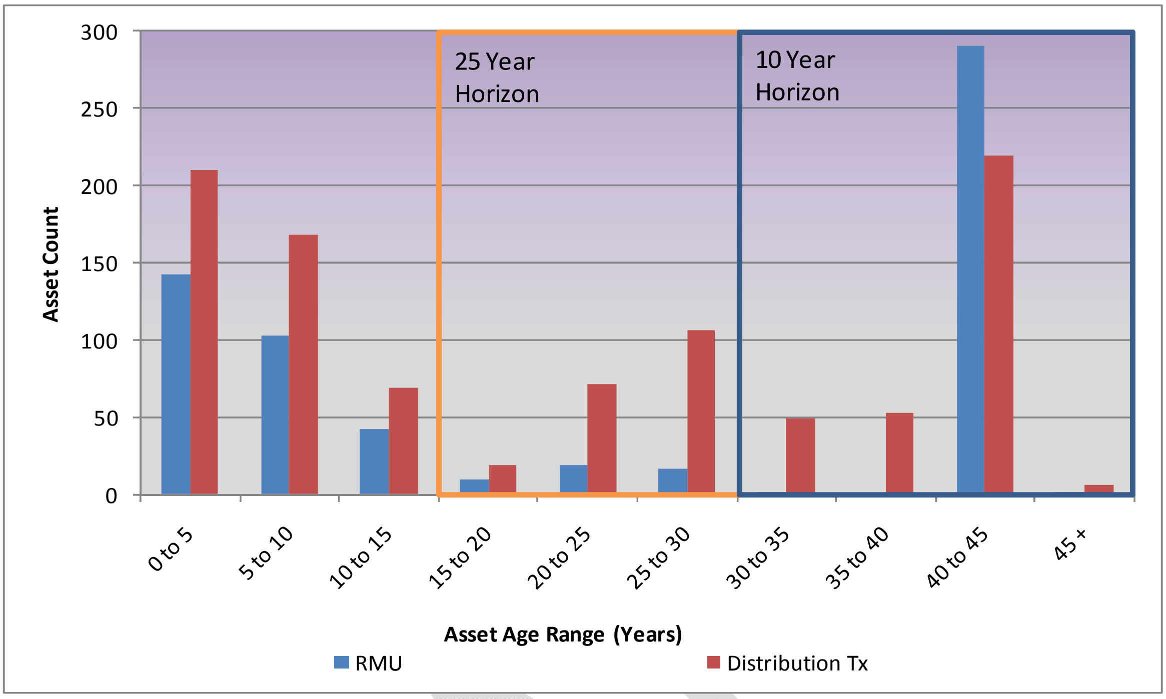
It has been assumed as part of the SKM 'Review of Planning Philosophies' studies that all XLPE installed distribution cables are suitable for 22 kV [2]. Therefore it can be seen, using the assumptions made in Figure 7, that by the end of the 25 year horizon being studied, some 13% of the current population would not be suitable for 22 kV operation (of PILC construction installed between 21-25 years ago), with the remainder being of Western Power standard XLPE distribution cable construction which is 22 kV capable. This is through 21% of the cable population being installed within the past 10 years of XLPE construction and some 66% of the cable population expected to be replaced over the 25 year horizon.

This is difficult to substantiate however, considering that distribution cabling is run to failure and is not replaced based purely on a nominal age. In addition, this assumption relies on the statement that all currently installed XLPE cables are capable of 22 kV. Detailed investigative works would be required to determine if this is indeed the case. It can be concluded however that over the 25 year horizon it is expected, through natural asset replacement, that some 87% of the existing distribution cable population will be suitable for 22 kV operation.

3.2.2. Transformers and Switchgear

Distribution Transformers and RMUs

Asset condition ranking data is unavailable for distribution transformers and RMUs; therefore an age based approach has been applied to provide an indication of the installation profile of these assets. After review of the NMP it is considered that the expected lifetime of distribution transformers and RMUs, appropriate for this study, is 35-45 years. Figure 8 illustrates the age profile for distribution transformers and RMUs in the CBD Load Area.

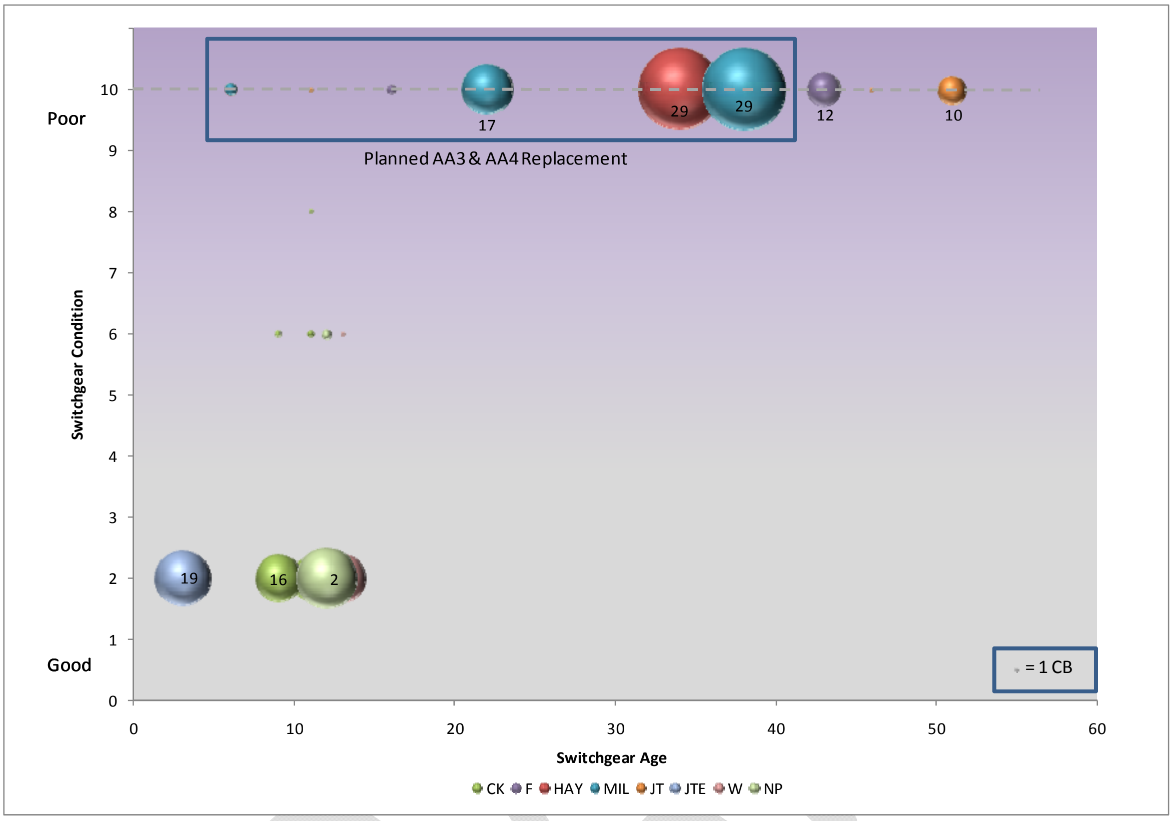


▪ **Figure 8 CBD Load Area Distribution Transformers and RMU Age Profile**

Examination of Figure 8 reveals an asset age profile dominated by significant asset installation around 40 to 45 years ago and also over the last 10 years, for both distribution transformers and RMUs. Assuming an indicative lifetime of 40 years for both asset classes, it is expected that over the 25 year horizon some 54% of existing RMUs and distribution transformers will require replacement due to age drivers. In the shorter 10 year timescale it can be seen that some 47% of RMUs and 34% of distribution transformers will require replacement.

11 kV Indoor Switchgear

For indoor 11 kV switchgear, asset condition information is available in addition to the age of the assets. The condition ranking for the 11 kV switchgear is derived from the same parameters outlined in Section 3.1.2. Figure 9 outlines the profile of distribution switchgear age and accompanying condition. It should be noted that none of the existing 11 kV indoor switchgear is 22 kV capable. The interpretation of the figure is as per that described for Figure 5.



■ **Figure 9 East Perth and CBD 11 kV Switchgear Asset Condition and Age Profile**

Examination of Figure 9 shows a distinct disparity in the condition profile with the vast majority of assets at the extremes of poor or good condition. A proportion of the poor condition assets are also of a relatively young age, reflecting the other factors that are taken into consideration in the condition assessment e.g. maintainability, performance history, etc (see Section 3.1.2). It is indicated that some 57% of the existing 11 kV switchgear in the CBD Load Area is of the poorest condition. These assets are located at Forrest Avenue, Joel Terrace (66 kV), Hay Street and Milligan Street with the latter two sites currently proposed for AA3 and AA4 replacement of the 11 kV switchgear. Further details regarding the bad condition of the Hay Street and Milligan Street 11 kV switchgear can be found in Appendix C.

4. Assumptions

4.1. Load

4.1.1. Load Forecast

This study has utilised the Western Power 2011 APR release [8]load forecast with all non-committed load transfer schemes and other projects omitted. The load forecasts for each site are based on a 10% PoE consistent with the Western Power Transmission Planning Guidelines [5]. The load forecast is utilised as a guide to the triggers and staging of developments described within the strategies. It is noted that these triggers will vary year on year as more refined forecasts are provided, however the comparative assessment of a preferred solution will be largely unaffected.

Diversity of peak load across substations has not been included within this assessment and it is assumed that all substations will peak together to provide a worst case scenario development study. This is considered to be a fair assumption due to the load in the CBD Load Area being primarily residential and light commercial and concentrated within a compact metropolitan area such that load peaks will naturally occur at comparable times. In addition, many of the substations within the CBD Load Area are fed through radial transmission circuits which make the peak loading assessment appropriate.

CBD Load Area load forecast table analysing each of the substations can be found in Appendix K - Table 37 and is shown in graphical format within Figure 2.

4.1.2. Customer Connections (Load and Generation)

At present there are no customer projects regarding the connection of generation within the CBD Load Area.

Much of the load is residential and light commercial with organic load growth primarily driven by the further uptake of air conditioning systems and is applied within this study as per the 2011 forecast. Although not all committed, the block loads seen for proposed developments such as Elizabeth Quay (Perth Waterfront), Perth City (Northbridge) Link and other individual loads have been incorporated into the high load forecast. Further details on this load forecast and the methodology for incorporating block load developments is described in the CBD Load Development Report [11] and Annual Planning report [22].

The impact of embedded Photovoltaic (PV) generation is included in the 2011 load forecasts on a Western Power Network wide basis but not at an individual substation level at this time. It is expected that in future forecasts this will available. It is anticipated that the impact on an individual substation basis would be minimal with the size of PV units being approximately 1.5-2 kVA, particularly within the CBD Load Area. The potential impact of embedded generation has been addressed as part of a low load forecast sensitivity; see Sections 4.1.4 and 11.5.2 for further information and analysis respectively.

4.1.3. Non Network Solutions

The implementation of non network solutions such as Demand Management and Smartgrid technologies will have an impact on the load forecast in that it may alter the shape of the system and customer demand profiles and serve to offset otherwise increases in Western Power Network electrical demand. As relevant for this report, this could result in the delay of capital investment projects, potentially by a number of years depending on the location and extent of the technology adopted. Demand management becomes an attractive investment if reinforcement works can be significantly delayed, as the NPC would then be more favourable than upfront reinforcements. It is important to note, however, that this will not forgo the need for investment as it will not eliminate the increasing load demand expected over time or the requirement for network investment for asset management purposes

As this study is concerned with the development of a 25 year strategy it does not incorporate demand management techniques explicitly as options to defer investment. It should be noted, however, that Western Power's regulatory regime stipulates that non-network alternatives such as demand management must be considered. Such alternatives should be considered prior to the development of individual projects within the CBD Load Area and may be the subject of a specialist study. Further details on DSM can be found in the SKM 'Review of Planning Philosophies' report [2].

The sensitivity study of a low load growth scenario as shown in Section 11.5.2 indicates the financial impact that a reduced growth rate, potentially implicated by DSM, may have on the overall strategy.

4.1.4. Load Sensitivities

The central forecast has been utilised as the basis for this study. In addition, high load growth and low load growth scenarios have been considered as sensitivities to the strategy. The high load forecast is taken from the Western Power OPAL system and represents an accelerated rate of load growth, particularly for the block loads of Elizabeth Quay (Perth Waterfront) and Perth City (Northbridge) Link, which are not currently in the central forecast.

For a low load growth scenario, the annual central forecast growth rates for each substation in the load area have been halved. Whilst it is accepted that this is a significant reduction in growth, it is nonetheless useful to illustrate a number of load reduction measures such as the introduction of DSM, improved customer efficiency and cancellation of large block loads, and the potential impact they could have on the resulting capital investment projects identified through this study.

4.2. Plant

4.2.1. Transformers

Throughout this analysis the LTER of transformers is utilised as provided by Western Power within the load forecast documentation [8]. The LTER is based on the hot spot temperature limit calculation as defined in Australian Standard AS2374-7. For substations with multiple transformers, the lowest LTER is utilised to represent the firm capacity of the site. For clarity and reference, the nameplate and LTER ratings of existing transformers is provided in Table 9.

Table 9 Transformer Nameplate and LTER Ratings [8]

Site	Tx	Voltage Ratio	Nameplate (MVA)	LTER (MVA)
Cook Street	T1	132/11/11	40 / 60	84.80
	T3	132/11/11	40 / 60	80.70
East Perth	T3	132/66	50 / 75 / 100	100.00
	T5	132/66	50 / 75 / 100	100.00
Forrest Avenue	T1	66/11	20 / 27 / 35	38.90
	T2	66/11	20 / 27 / 35	38.90
Hay Street	T1	132/11/11	36 / 45 / 60	71.40
	T2	132/11/11	40 / 40 / 60	76.20
	T3	132/11/11	36 / 45 / 60	71.40
Joel Terrace	T0	132/11/11	40 / 50 / 60	76.20
	T2	66/11	15 / 24	23.80
	T3	66/11	15 / 24	23.80
Milligan Street	T1	132/11/11	36 / 45 / 60	71.60
	T2	132/11/11	36 / 45 / 60	63.00[10]
	T3	132/11/11	36 / 45 / 60	71.40
North Perth	T1	132/11	19 / 33	34.30
	T2	132/11	19 / 33	34.30
	T3	132/11	19 / 33	34.30
Wellington Street	T1	66/11	20 / 27	28.60
	T2	66/11	20 / 27	28.60

This study has considered a principal rating for substation transformers as part of the costing for each project. For 132 kV, Western Power already use 60 MVA nameplate rated 132/11/11 kV transformers with dual LV windings at Cook Street as well as Hay Street and Milligan Street substations. Typically the LTER of these transformers is in the order of 75 MVA.It is this large rated dual LV winding 132/11/11 kV transformer that has been adopted for this study with an associated assumed LTER of 75 MVA. Detailed financial analysis will be required to confirm this transformer is the most economic size given the load growth, transformer costs and transformer bay costs (including land and circuit costs).

It is noted that the size selection of transformers has been the subject of scrutiny by the ERA in recent NFIT decisions. It is recommended that as part of any specific NFIT business case an NPC analysis be undertaken to confirm the economic prudency of the transformer size selection. This analysis would include load growth, transformer costs and circuit costs (including value of land for each transformer circuit) to determine the economically prudent size of the transformer.

[10] Restricted due to transformer design and air forced cooling only.

Standardisation of transformer designs, ratings and standards can provide significant efficiencies in substation design, asset procurement, maintenance and the availability of spares. Western Power is currently investigating the benefits of alternative transformer sizes and configurations for use in zone substations.

As noted within the SKM 'Review of Planning Philosophies' report, migration to a 22 kV distribution voltage is seen to have significant advantages [2]. The movement to this voltage may require reconfigurable transformers to be installed at zone substations or alternatively the installation of a limited number of 22/11 kV transformers to facilitate the migration. For the purposes of this study, and to provide a fair cost comparison across all cost-benefit analysis of projects, the single cost of the 75 MVA 132/11/11 kV dual LV winding transformer has been utilised throughout. Following further detailed analysis into a potential 22 kV distribution architecture within the CBD Load Area, such assumptions will need to be reviewed as single winding transformers could be utilised once this level of detail is known.

4.2.2. Switchgear

When considering the cost of replacing switchgear as part of a cost-benefit analysis of projects, it has been assumed that the existing protection and switching arrangement, and therefore volume of switchgear assets, is maintained. For new sites, it is assumed that switchgear will be applied to each circuit, i.e. line incomer, transformer, and bus section unless specifically noted otherwise due to constraints such as space availability. It is assumed that new 132 kV switchgear be rated for 40 kA for zone substations and 50 kA for terminal substations as is typically standard for Western Power.

It has been assumed that new or replacement switchgear will be of AIS technology, as is Western Power standard, unless specifically stated due to restrictions within the CBD Load Area environment. As indicated in the SKM 'Review of Planning Philosophies' report, GIS technology can provide significant advantages, particularly in reducing the required substation footprint. However, despite this equipment having been installed across utility networks for many years GIS equipment still carries a cost premium and additionally such equipment is rare on the Western Power Network with currently no indoor GIS [2] employed. That said, due to the restricted space available within CBD Load Area substations it is likely that GIS technology may need to be employed to economically facilitate growth of the network and where this is seen as necessary, it has been costed as such within the project comparison studies. The economic prudency of this decision will need to be justified in detailed studies and should consider land cost, maintenance and installed switchgear cost on an NPC basis.

4.3. Environmental Constraints

4.3.1. Substations

All substations for the CBD Load Area are located within or adjacent to established residential and commercial areas and the visual impact of any new substations or modifications will need to be adequately addressed with significant community involvement. A potential solution to ease opposition is through the use of architecturally designed substation façades or the use of low profile GIS equipment. The application of such designs or technical variations requires assessment on a project by project basis. The SKM 'Review of Planning Philosophies' report has reviewed some of the emerging technologies available which may assist in minimising environmental and community impact [2].

4.3.2. Transmission Overhead Lines/Cables

All potential new transmission line routes into the CBD Load Area would involve establishing lines within mature residential and commercial areas. There will be a strong push externally for any new transmission lines within this area to be underground cable to mitigate traffic hazards, mitigate visual impacts, and reduce opposition from the community. It is however assumed that any in-situ replacement of overhead lines would meet less resistance than the installation of new transmission lines.

Depending on the location of any new transmission circuits required to supply the CBD Load Area, circuit routes may pass through environmental constraints of State and Commonwealth interest. This should be given due consideration when planning line routes, as areas such as these will also require State or Commonwealth approval which may have additional mitigation costs associated. New overhead transmission lines in the verge of roadways will likely require safety barriers to be installed around poles to meet new road safety standards.

Within the CBD Load Area, new transmission cable routes near existing sites are limited due to the large number of distribution cables and other utility services installed underground. This study has assumed that any new 132 kV underground cable will be of 2000 mm^2 XLPE copper construction with an operating capacity of 280 MVA, similar to the recently installed EP-CK 132 kV cable circuit within the CBD Load Area. Where this is not suitable, it has been noted within the report.

4.3.3. Distribution Cables

Within the CBD Load Area power distribution is achieved through cables with no overhead distribution lines. Typically distribution cables have been installed within the pathway with short cable tunnels at substation exits. The availability of space within footpaths and substations is becoming restricted (see Section 6.1.2) which has resulted in the installation of cables within the roadway in recent times. The cables are currently installed in a direct buried technique; however the City of Perth council has recently requested a minimisation of disruption when installing cables. As such, new installation techniques may be required such as pit and duct or a greater level of tunnelling. Further details are provided within the SKM 'Review of Planning Philosophies' report [2].

4.3.4. Known Community, Environmental & Approval Issues

A number of known environmental and community related consenting issues exist in relation to the electrical transmission network supplying the CBD Load Area. The principal known issues which are considered in the assessment of CBD Load Area supply reinforcement options include:

- Many areas in and around the CBD Load Area contain acid sulphate soil content which will require careful excavation and management.
- Numerous areas surrounding the CBD Load Area contain Bush Forever designated land, protected wetlands and rare native and endangered flora all of which will require permits and approval before developing. In some cases approvals are expected to be required at national level.
- Swan River Trust Development control area. Appropriate engagement must occur with Swan River Trust and the lodgement of development applications as required.
- Aboriginal Heritage assessments in Aboriginal Heritage Sites. Section 18 referral may be required if an identified site is to be disturbed through construction (up to one year)
- Numerous areas of Land Potentially Subject to Native Title within the CBD Load Area
- Priority flora located within the CBD Load Area. It is likely that this can be avoided through forward planning of construction.
- Several wetland and drainage areas within the Swan River Management Area.
- Area of System 6 Reserve above East Perth Terminal.
- Heritage Register of National Estate, Heritage Council Sites (WA) and Heritage Commonwealth Public sites are located in the CBD Load Area.
- Utilities including rail, water, gas and communications are located in the area. Location of these services, engagement with stakeholders and the potential relocation of services may be required.
- Fremantle – the Fremantle area contains many heritage sites and lobby groups are active in protecting them increasing the difficulty to consent any new transmission lines in the area.
- Perth Airport – new transmission lines in the vicinity of the Perth Airport may present issues with pole heights depending on proximity.

4.3.5. Land Availability

Western Power currently owns a number of potential substation sites within the CBD Load Area as described within Table 10 and illustrated within Appendix B - Figure 43. It should be noted that even though this land is owned by Western Power, significant stakeholder and community engagement is required before utilisation of the land.

Table 10 Western Power Owned Land within the Load Area

Plot Name	Plot Size	Notes
Tully Road	2000 m^2	-
Bennett Street	592 m^2	-
Murray Mews	802 m^2	Adjacent to No.2 Electric Light Substation
No.2 Electric Light Substation	326 m^2	Site is of cultural heritage significance [17]
Roe Street	1206 m^2	Currently leased by Charity Link
James Street	3041 m^2	Partially utilised as cable transition location for MLA-MIL double circuit overhead line
James Street (Wilson Car park)	1826 m^2	-
James Street (Bakery Site)	1372 m^2	-

In addition to the sites indicated in Table 10, there is additional space available at both the Wellington Street and East Perth existing substations. There is also the ability to install a third transformer and associated equipment within the existing Cook Street Zone Substation. Land in front of Hay Street Zone Substation is Crown owned and may be available if required, however access to the existing substation will need to be kept is utilised.

No further land in the CBD Load Area is owned by Western Power and for this study it is assumed that all substation works will be completed on existing Western Power owned land in the first instance. It is recognised that Western Power may identify more appropriate sites to procure as part of subsequent detailed feasibility studies for each of the key projects. However, it is envisaged that any new sites will be aligned with the development strategy presented in this report. Whether existing land holdings are sold off or retained will be determined as part of the investigations.

4.4. Costs

4.4.1. Capital Costs

The transmission capital cost estimates utilised in this assessment have been derived from the Western Power AA3 estimating building blocks. This provides a library resource for cost forecasting for network planning activities associated with the AA3 program and beyond.

The original Western Power building block cost estimates were developed using the Estimating Centre's Success Estimator software and database for standard design and typical engineering parameters as well as by investigating historical cost figures and typical expenditure. The Estimating Centre's Cost Reconciliation Analysis Breakdown, was a key reference resource. Historical estimating and actual cost details were available for comparison and value engineering in order to establish benchmarks and expenditure trends [14].

Engagement was also sought with the Estimating Community to gain expert knowledge on design specific and engineering specific items, where required. The basic building block cost items are located in the Western Power central database [15].

Due to the specialised and compact nature of the CBD Load Area environment, costs are likely to escalate above those included in the basic building block database. As such a [redacted] CBD Load Area multiplier has been applied to building block costs to factor in these complexities as discussed and agreed with Western Power cost estimators. Additional civil costs have also been included where applicable such as multi-storey buildings and substation cable exit tunnels.

The building block costs factor for procurement and construction only, with consenting, surveying and other such costs omitted. The elapsed time of these key tasks has however been included within the indicative timeframes required for different types of projects when deriving the overall strategy as seen in Section 11.1.

4.4.2. Net Present Cost

Where NPC analysis has been conducted, the following parameters have been utilised as agreed by Western Power planning engineers:

- Escalation Rate [redacted]%
- Pre Tax Nominal Discount Rate [redacted]%
- Investment Period [redacted] Years

In addition, an investment profile has been applied to NPC analysis for varying types of capital investments. This indicates the percentage of total project investment to be applied in the years up to and including the project in service date. These profiles have been discussed and agreed with Western Power planning engineers and are summarised in Table 11. The expenditure profile timeframe for new substation works is extended to illustrate the level of complex civil works likely to be required for this type of construction within the CBD Load Area, particularly within the Perth CBD boundary.

Table 11 Investment Profile

Investment	ISY -4	ISY -3	ISY -2	ISY -1	ISY*
New Substation	[redacted]%	[redacted]%	[redacted]%	[redacted]%	[redacted]%
Partial Substation Works	[redacted]%	[redacted]%	[redacted]%	[redacted]%	[redacted]%
Line/Cable Works	[redacted]%	[redacted]%	[redacted]%	[redacted]%	[redacted]%

* In Service Year

4.4.3. Operations and Maintenance Costs

Operations and maintenance costs have not been explicitly included within the assessments unless such aspects will materially affect the outcome. This stance has been adopted as such costs are likely to be of second order in comparison with equipment / project capital costs. Where necessary, commentary is provided on a comparative basis as to the number of assets to be maintained and the potential advantage of standardising equipment through the system.

4.5. Power System Analysis

4.5.1. Model and Data Set

Load flow analysis to determine required future transmission system capacity investments has been carried out using DIgSILENT PowerFactory software. The base system model has been developed from the Western Power AA3 model using the ROAM scenario 20 generation planting schedule[11] with Western Power derived projects for the year 2020. The Western Power derived projects assumed to be in service as part of this study are summarised in Table 12 with further detail provided in Section 8.

- **Table 12 Assumed Western Power Derived Projects**

Project	In Service Year	Status
WT-CK 82	2017	Not Committed
NT-BEL/EP Special Protection Scheme	2012	Not Committed
Establish 330 kV Switchyard at CT	2020	Not Committed
South Metro Reconfiguration	2016	Not Committed
Convert ST-SF 81 Split Phase to Double Circuit	2018	Not Committed
Convert ST-CT 81 to Double Circuit	2020	Not Committed
String Second Side of ST-CT 330 kV	2020	Not Committed

The model used is a simplified version of the full network, taking care to model the CBD Load Area to the greater level of detail present in the full Western Power Network model. It does not take into account legacy 66 kV networks outside the CBD Load Area, instead lumping load from these networks onto the 132 kV busbar. The 132 kV network has been modelled as far as Northern Terminal in the North; Kwinana and Southern Terminal in the South; and Cannington Terminal and Guildford Terminal to the East. All other 132 kV substation loads and generation have been lumped onto an appropriate 132 kV busbar. The 330 kV network has been modelled in detail in order to better understand flows around the network and how best to utilise the existing capacity on those circuits.

It should be noted the load forecast figures used at each substation and included in the analysis were the peak substation loads in each year throughout the considered strategy period – no diversity was considered. This assumption is considered appropriate given the very similar customer profile and small geographical area supplied within the CBD Load Area. The results will yield worse case reinforcement timings for consideration in the subsequent strategy evaluation. In addition, within the CBD Load Area, much of the transmission network is of a radial design, meaning there will be no diversity on these feeders; this further supports the appropriateness of this approach.

[11] This new entrant generation planting schedule provides a bias towards generation in the North. Sensitivity analysis of a bias to Southerly generation has also been carried out.

4.5.2. Methodology

Load flow analysis has been utilised to illustrate loading of transformers and lines under normal and contingency (N-1 and N-2) conditions and to monitor voltage levels throughout the CBD Load Area to ensure these are within acceptable limits.

N-1-1 security is a requirement for East Perth infeeds as East Perth is a 132 kV terminal substation within the Perth metropolitan area as defined in clause 2.5.2.3 of the Technical Rules [12]. There is also an additional requirement for N-2 transmission security standard for the infeeds to load within the Perth CBD boundary outlined within clause 2.5.3 of the Technical Rules.

All substations within the CBD Load Area operate to an N-1 standard with a few exceptions. North Perth Zone Substation currently operates at an NCR security standard as identified within clause 2.5.3.2(b) of the Technical Rules. The NCR criteria is seen to allow greater utilisation of total transformer capacity in the short term and is therefore deemed suitable for the deferral of new installed capacity. It does, however, increase the level of customer risk in comparison to N-1 designs. It should also be noted that NCR substations require sufficient land to accommodate an RRST under contingency conditions. Hay Street and Milligan Street in comparison operate to an N-2 standard which provides a higher level of security to the customer and reflects the significant importance of the load within the Perth CBD boundary.

It is assumed for the purpose of this analysis that future substation capacity upgrades will be completed to an N-1 security standard, unless they are a specific replacement of Hay Street or Milligan Street Zone Substations which will be designed to retain the existing N-2 standard. This ensures that each proposed strategy is consistent with the existing level of network security. It is possible that the Technical Rules Perth CBD boundary criteria may extend beyond the existing Perth CBD boundary in future. For this reason, proposed new substations will be assessed for the ability to operate to an N-2 security standard and the additional expected works (if any) required in achieving this will be defined. Further details surrounding the potential expansion of the N-2 Perth CBD boundary is provided in the SKM ‘Review of Planning Philosophies’ report [2].

4.5.3. Study Horizon

Load forecast data is provided to the study horizon of 2036. Where additional foresight is required beyond this horizon, the load forecast has been extended using Western Power’s forecasting tool OPAL, providing a forecast up to 50 years into the future.

Studies have been divided into two distinct components, namely 1-10 years and 11-25 years. This allows coordination with the two distinct Western Power planning teams which are defined by the 10 year development planning team and the long term transmission planning team respectively. In addition, those strategies deemed necessary within the 10 year horizon are of high priority and probability, those beyond the 10 year horizon are primarily for guidance and will require review in future years to ensure their continued relevance based on new developments, load forecasts, condition data and other factors. Sensitivity analysis has been provided within this study to assess uncertainties at this time.

4.6. Other Assumptions

4.6.1. Distribution Voltage

Previous studies conducted by Western Power have illustrated that there are economies to be had in converting the distribution voltage from the current 11 kV operation to 22 kV [16]. The SKM 'Review of Planning Philosophies' report [2] has also indicated the benefits such a migration may provide. Although some advantages have been identified, a number of assumptions were made as part of the generic analysis in these documents, which does require revisiting on a site specific, detailed basis before application can be considered further. The introduction of 22 kV would alleviate many of the cable exit and route issues currently encountered within the CBD Load Area, however the overlaying required with the existing 11 kV network may bring forward investments and add cost.

A level of appreciation for this potential conversion has been provided within this report with an assessment of 11 kV asset condition and the 22 kV rated equipment currently installed and operated at 11 kV within the load area. Limited consideration is provided as to the benefits which reinforcement projects can provide in facilitating a potential migration.

4.6.2. Loss of Substation

At present, the full loss of either the Hay Street or Milligan Street Zone Substations can be recovered through the distribution network. The capability to support the loss of the entire substation is not prescribed within the current Technical Rules to which Western Power operate. It is therefore assumed that this level of security is not specifically required to be maintained for future development strategies.

Further detailed techno-economic studies will be required to be undertaken by Western Power to identify the cost and benefit involved with continuing to fully support this security level. Alternatives could see the increase in the use of physical substation security methods such as cameras and fencing to minimise vandalism risk or improved fire suppression systems to protect electrical equipment in the event of a potential complete substation failure. A number of the emerging technologies discussed within the SKM 'Review of Planning Philosophies' report [2] are focussed on minimising the probability of a full loss of a substation.

4.6.3. DTC

The base case analysis within this report has not included the use of the DTC network unless specifically required as part of a comparative assessment. The capability of the DTC network is constantly changing with the addition of new load and interconnections between substations. With significant developments within the CBD Load Area, it is not certain as to the continual level of DTC support that may be available throughout the strategy period, particularly if a migration to a 22 kV distribution voltage was adopted. A further issue includes the ability for the DTC to support an N-1 outage within 30 seconds as dictated in the Technical Rules.

It is however recognised that DTC provides a material contribution to firm capacity at many substations within the CBD Load Area. As such sensitivity on the base case strategy has been carried out within Section 11.4 to illustrate the potential impact including the DTC network would have on increasing firm capacity ratings based on the 2011 DTC capability as seen in Appendix E - Figure 45.

4.6.4. Strategy Sensitivities

In addition to the load sensitivity analysis indicated in Section 4.1.4, a number of further sensitivities have been performed to illustrate the impact of these variables on the base case strategy. Such sensitivities include:

- Power flow control through the CBD Load Area
- Generation dispatch
- Project staging
- DTC capability

5. Strategic Development Vision

This section briefly looks at how developments in the CBD Load Area will influence and align with the wider strategic vision of the Western Power Network. The primary strategic concepts considered in this study involve the introduction of 330 kV into the area and the removal of time expired 66 kV networks for more system wide standard 132 kV assets.

5.1. Utilising 330 kV Assets Efficiently

It is a primary strategic vision to unlock available 330 kV capacity in the Western Power Network and to utilise these assets more effectively. In the wider transmission network it is proposed within Western Power's TNDP to establish a 330 kV switchyard at Cannington Terminal to better utilise the existing 330 kV transmission network [7]. Within the CBD Load Area it is not currently proposed to use 330 kV infeeds through the 25 year horizon. However, it has been noted, with further detail provided in the SKM 'Review of Planning Philosophies' report [2], that it may be desirable to transition to 330 kV once the CBD Load Area demand increases to a level such that this voltage is the most efficient transmission solution and consideration has been given for this within the development of the strategy.

5.2. 66 kV Networks Legacy

Across the Western Power network there are a minimal number of 66 kV substations and network assets, most of which were installed within the 1960/70s and approaching the end of their economic life. Specific 66 kV rated equipment is no longer widely available and as a result many individual components (e.g. switchgear and underground cables) operated at 66 kV are typically supplied by manufacturers with a 132 kV rating. Consequently, it is Western Power's view that any new 66 kV lines installed within the Western Power Network should be of a 132 kV construction if a future network upgrade to 132 kV has been identified. There may also be benefits in procurement and maintenance regimes if Western Power standardised away from 66 kV.

5.3. Management of Load Area Through Flows

The present Western Power Network accommodates generation located to the North and South of the CBD Load Area. Generation to the South can under certain circumstances lead to 132 kV power flows through the CBD Load Area to Northern Terminal. This typically occurs under lower demand periods.

Over the coming years and decades it is expected that this generation capacity and location may change and currently there is significant uncertainty as to how this could develop. It will therefore be necessary to manage the level of power flowing through the CBD Load Area, which would otherwise use up capacity in existing transmission circuits that should be available for dedicated Perth CBD boundary supply, recognising the difficulties in reinforcing this part of the network.

Consideration for managing CBD Load Area through flows under varying generation sensitivities has been given in the development of the strategy.

6. Emerging Limitations – Load Area

This section details the emerging limitations within the CBD Load Area in the periods 1-10 years and 11-25 years, particularly focussing on capacity shortfalls in the transmission system and substations. A summary of all the emerging limitations within the CBD Load Area, including asset condition related limitations described in Section 3, is provided at the end of this section.

6.1. 1-10 Years

6.1.1. Transmission Network

The existing CBD Load Area transmission network consists of a number of radial circuits to single substations at both 132 kV and 66 kV as shown previously in Figure 1. The transmission infeeds into the load area, including the lightly meshed arrangement around North Perth, Cook Street and East Perth are studied in Section 8. The 66 kV radial networks consist of connections to Forrest Avenue, Wellington Street and Joel Terrace Zone Substations through a total of 5.98 km of cable and 1.70 km of overhead line. The 132 kV networks consist of radial connections to Joel Terrace, Hay Street, Milligan Street[12] and Summers Street Zone Substations[13] through a total of 3.14 km of cable and 3.24 km of overhead line.

All CBD Load Area connections are made from East Perth Terminal, with the exception of Milligan Street which is connected to Mount Lawley and in turn to Northern Terminal. The ratings and condition of the transmission assets vary due to the technology of equipment such as oil filled or XLPE cables, de-rating factors associated with ground conditions and the age of the assets, as summarised in Table 7.

The majority of these radial transmission circuits support N-1 secure substations with the exception of Hay Street and Milligan Street substations which are N-2 secure. At present, DTC systems are in place to assist in providing N-2 security to these substations, the limitations of the distribution system are outlined in Section 6.1.2. As previously noted, it is the load within the Perth CBD boundary which must be secured to N-2 to comply with the Technical Rules. This load can be supplied from any substation, however to minimise significant investment in N-2 security of multiple sites, this has been focussed at the Hay Street and Milligan Street Zone Substations. Other substations which supply Perth CBD boundary load are interconnected to either Hay Street or Milligan Street to provide this security.

Figure 10 illustrates the load growth on each of the radial circuits within the CBD Load Area on a biannual basis for a 10 year horizon. Markers are utilised to indicate potential restrictions based on exceeding the existing level of DTC support and N-1 or N-2 thermal ratings.

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[12] Considered from the James Street cable sealing ends only

[13] Summers Street substation is not considered due to the customer owned assets

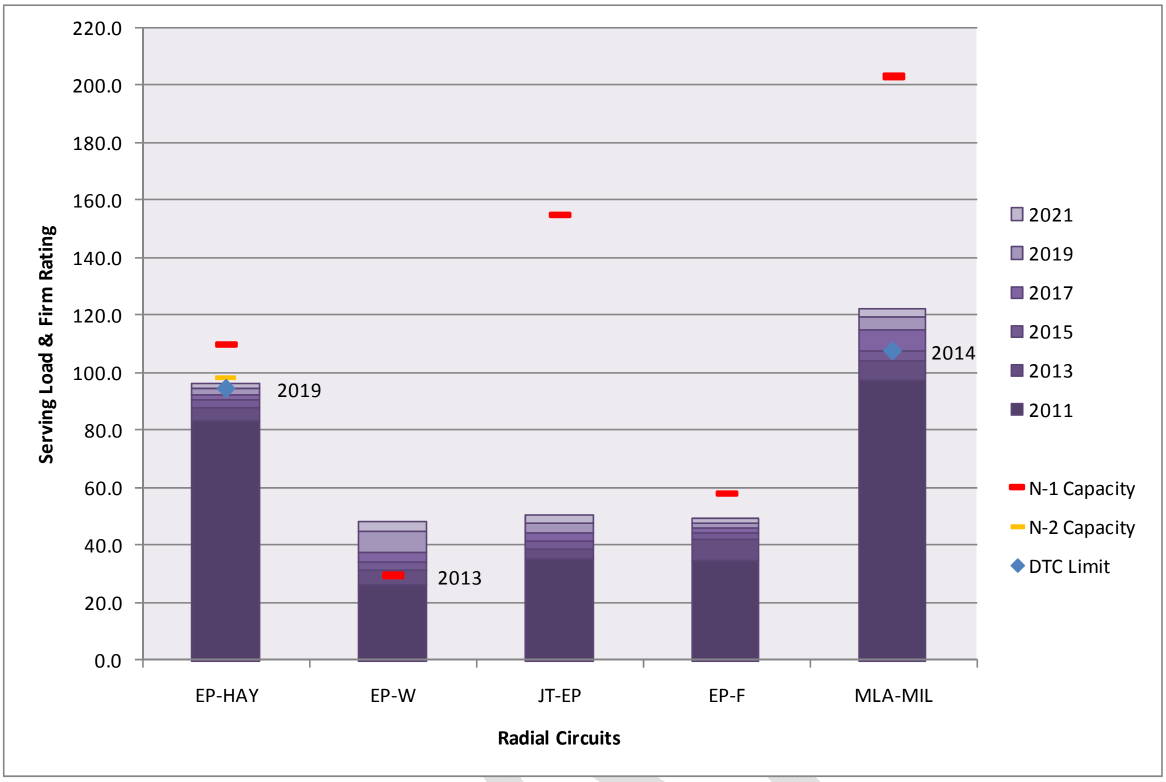

Figure 10 Transmission Network Emerging Limitations: 2011 - 2021

It can be seen from Figure 10 that the EP-W 66 kV circuits are identified as the primary transmission element limitation during this period, requiring mitigation action in the short term. The orange dash indicates an N-2 capacity limitation in 2022 for the EP-HAY circuits which is discussed further in Section 6.2.1.

It can also be seen that there are significant limitations in the DTC network for an N-2 event at Hay Street and Milligan Street in 2019 and 2014 respectively. This occurs when an N-2 contingency event on the EP-HAY or MLA-MIL double circuits removes the transmission infeed into that substation entirely, requiring the DTC connectivity to fully support the substation. Although not a direct transmission system limitation, if DTC support cannot be increased further, a transmission network solution may be required to provide the N-2 security at these sites. This DTC technical and practical restriction at the Hay Street and Milligan Street Zone Substations is described further in Section 6.1.2.

Joel Terrace Zone Substation is currently operated at both 132 kV and 66 kV voltage levels through a single 132 kV XLPE cable, a single 66 kV oil filled cable, and a single 132 kV XLPE cable which is currently operated at 66 kV. Although operated at two different transmission voltages, under N-1 contingencies the distribution switchboard can be operated in a fully interconnected mode without reverse power flows in the transformers to allow N-1 security. This provides a significant level of secure transmission circuit capacity to this site.

6.1.2. Distribution Network

Practical Limitations

The distribution network within the CBD Load Area operates at 11 kV and is an entirely undergrounded system. Some significant practical limitations have become apparent within the distribution system which are expected to deteriorate further over the next 10 years and beyond without appropriate innovation and strategy.

There is significant congestion in the cable routes along streets, and particularly at substation exits, as shown in Figure 11. At present there are minimal routes available which will allow installation within the sidewalks as is standard practice for Western Power. There is the potential to expand into the roadways; however this would likely require a different installation method so as not to disturb the road surface for cable installation for a further 15 years[14]. Further to the restriction of cable routes in the streets, are the severely congested cable exits at each of the CBD Load Area substations. Currently the cable exits are achieved through short cable tunnels, however the quantity of 11 kV cables required within the Perth CBD boundary has meant that congestion is still high in this region.

- **Figure 11 Substation Cable Exit Congestion – Wellington Street**

The congestion in the sidewalks and cable exits has resulted in significant de-rating of the distribution cables due to the thermal restrictions introduced by the close proximity installation. This

[14] The City of Perth has made this request based on a history of utilities in the area removing road surfaces multiple times a year without a clear strategy for future installation works. Although not an official restriction, it is a guideline which could have potential political and social ramifications if not addressed directly or through improved strategies on cable installation programmes which is not always possible.

has exacerbated the congestion with the requirement for additional cables for customer connections, which in turn are de-rated further due to the close proximity installation resulting in an ever increasing reduction in capacity as load growth in the area continues. Further evidence of the cable exit congestion and the impact of cable de-rating is shown in SKM's 'Review of Planning Philosophies' report [2].

Further to the general congestion of distribution cables within sidewalks and substation exits, there is a lack of remaining spare 11 kV feeder circuits available at all substations within the CBD Load Area. Of the few remaining spare feeder circuits, many of these are reserved for near future projects. Table 13 provides an overview of the current situation of feeder circuits in the CBD Load Area. It can be seen that the net number of actual spare feeder circuits is 0, indicating that all available circuits have been reserved for near future developments[15].

- **Table 13 Remaining Spare Distribution Feeder Circuits**

Substation	Total No. of Feeder Circuits (inc. spares)	Spare Feeder Circuits	Reserved for Future Projects	Actual Spare Feeder Circuits
Hay Street	52	7	7	-1*
Milligan Street	54	2	2	-2*
Cook Street	32	2	0	2
Wellington Street	26	6	5	1
Forrest Avenue	16	0	0	0

*Hay Street and Milligan Street currently have spare capacitor banks which are reserved for future projects

In order to address these practical limitations, a mixture of innovation and strategy could be utilised for the future development of the 11 kV distribution network in this area. The use of a higher voltage, such as 22 kV would assist in reducing congestion as less cables will be required than the 11 kV system to transfer the same amount of power. Alternative or further improvements to reduce congestion could be achieved through the use of a pit and duct systems or more extensive use of tunnelling. Further details on these potential solutions are discussed within the SKM 'Review of Planning Philosophies' report [2]. It should be noted that at the Hay Street and Milligan Street Zone Substations, there are sizeable levels of N-1 transformation capacity available which cannot be realised due to the distribution cable restrictions.

Taking into consideration the expected cable exit restrictions at Hay Street and Milligan Street, it is assumed that the ability to connect new feeders to these substations will to be restricted by 2017 due to the severe level of congestion. It is therefore necessary to consider reinforcements which will assist in alleviating this congestion to allow load to grow and to better realise the existing installed capacity at Hay Street and Milligan Street Zone Substations.

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15 It is expected that half of the future projects are expected in the next 3-4 years with the remaining expected within 5-10 years based on the major developments of the Perth City (Northbridge) Link and Elizabeth Quay (Perth Waterfront)

Technical Limitations

Within the CBD Load Area there is significant interconnection of the 11 kV distribution network due to the close proximity of the substations and to provide support and security during outages. The Hay Street and Milligan Street Zone Substations operate to an N-2 security standard to supply load within the Perth CBD boundary as dictated within the Technical Rules. The significant interconnection of the distribution network allows for support to be provided to these sites during contingency events via DTC.

At present the DTC is relied upon to support N-2 contingency events at both these sites. The most onerous of these outage events is the dual loss of the 132 kV infeeds into one of the substations at peak load. Under this event, the DTC is required to support the entire substation's load within 2 hours. In 2011 this relates to some 83.2 MVA and 97.6 MVA at Hay Street and Milligan Street respectively. Currently, the assumed maximum DTC capability support for these substations is determined to be 94.5 MVA and 107.5 MVA for Hay Street and Milligan Street (as shown in Appendix E - Figure 45), resulting in a forecasted DTC shortfall for N-2 support in 2019 and 2014 respectively.

Increasing the DTC capability to overcome this forecasted shortfall is difficult due to the practical restrictions in the distribution network as previously discussed. Furthermore, the level of additional interconnection necessary considering an average 2.5 MVA available per feeder and forecasted growth at the substations in the next 10 years of 13.1 MVA and 21.8 MVA at Hay Street and Milligan Street respectively would be substantial. An alternative to utilising substantial levels of DTC support during N-2 contingencies at these substations would be to utilise the transmission network. A generic analysis of these options has been provided in the SKM 'Review of Planning Philosophies' report [2] with further project specific detail provided within Section 7.3.5 of this report.

6.1.3. Substation Capacity

Figure 12 illustrates the substation capacity for the next 10 years and the load expected to be seen by these substations. The red dash indicates the capacity of the substation under a single contingency event, with the orange dash indicating a dual contingency event which is explicitly planned for at the Hay Street and Milligan Street Zone Substations. It can be seen that in the next 10 years the majority of substations in the CBD Load Area will be over their firm rating, with the exception being the East Perth Terminal Substation. Forrest Avenue, Wellington Street and Cook Street are all over their firm capacity in the immediate future (2012).

The Hay Street and Milligan Street Zone Substations are currently over firm rating for an N-2 contingency when two of the three transformers are out of service. Under this contingency the DTC network would support the substation similar to that described in Section 6.1.2; however the level of support required is much lower than that of an N-2 transmission line contingency (some 75 MVA less).

DTC network support is also available for all other substations in the CBD Load Area to varying amounts. The forecasted maximum capability of the existing DTC network, discounting any potential new interconnections and growth in DTC capability is shown in Appendix E - Figure 45.However, for N-1 contingencies the DTC support cannot be utilised as cannot be switched quickly enough to meet the 30 second switching time indicated within the Technical Rules for Perth CBD boundary load.

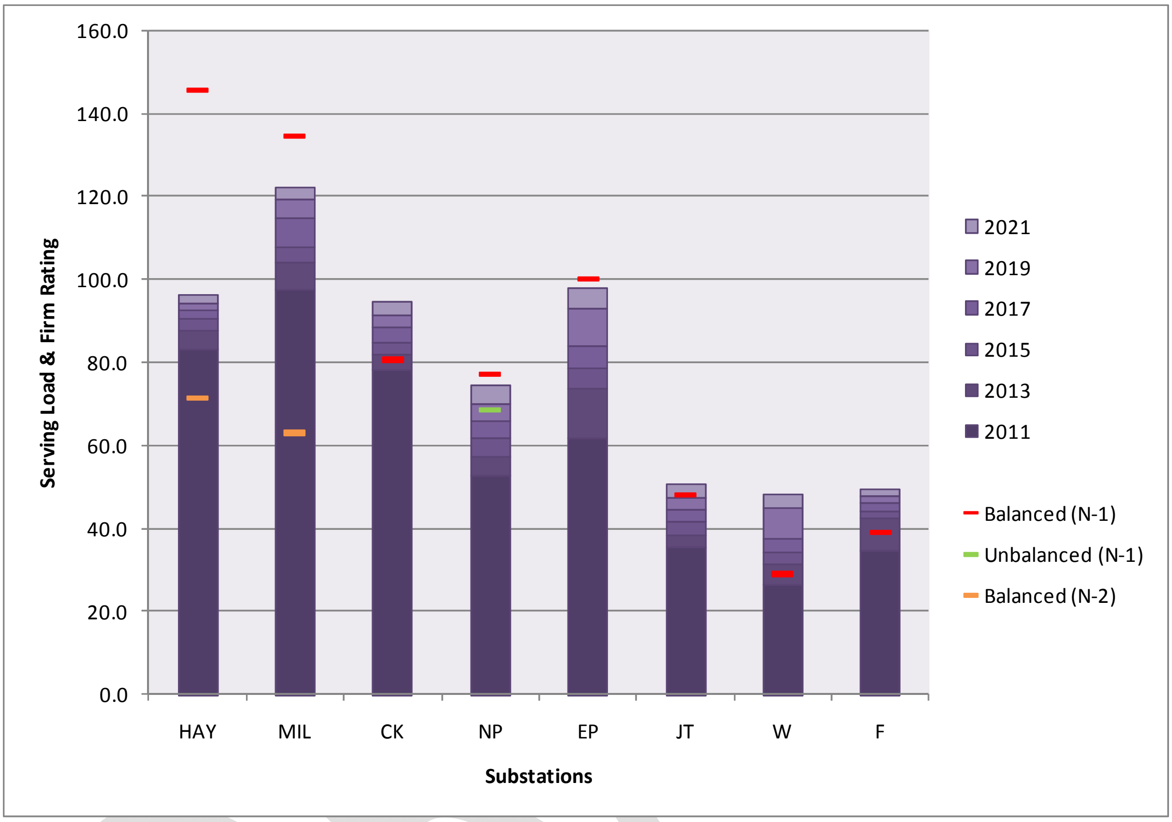


Figure 12 Substation Capacity Emerging Limitations Summary: 2011 - 2021

At North Perth Zone Substation there is the potential to balance the load on the transformers to further enhance the substation capacity as this is an NCR site. It is expected that at this site an enhancement of some 8.6 MVA could be achieved which would extend the emerging limitation from an indicative year of 2018 to 2022. Joel Terrace, which is currently split between 132 kV and 66 kV transmission voltages, is forecasted to be over firm in 2019 based on an N-1 firm capacity of 48 MVA (loss of the 132 kV transformer).

Fault Level

Transmission system fault levels in the CBD Load Area for the year 2020 are illustrated in Table 14. The fault levels are seen to be within the ratings of the existing switchgear. Furthermore it is not expected that any significant generation connections will occur in the load area.

Analysis of the impact on fault levels of new infeeds and connections are discussed where relevant in the development of the strategy noting that any reinforcements will be designed appropriately for the fault level.

There are currently fault level limitations on the distribution network which are mitigated through operational restrictions. At present 11 kV bus section circuit breakers are run normally open to keep fault levels within the capabilities of the switchgear. Should a failure occur at a transmission level, the 11 kV bus section circuit breaker can be closed to allow compliance with the N-1 or N-2 security criteria. For N-1 compliance this operation must be carried out within 30 seconds and within the 2 hours provided for N-2 events as prescribed in the Technical Rules.

The fault level on the distribution network is high in this load area due to the contribution provided from the low impedance (typically 12%) transformers which are installed across the CBD Load Area, particularly at the Hay Street and Milligan Street Zone Substations. If the 11 kV switchboards were required to operate with bus couplers closed, without the operational restriction and associated switching time, the installation of higher impedance transformers could provide assistance in reducing fault levels to potentially allow this operation to occur.

- **Table 14 Transmission System Short Circuit Currents: 2020**

Substation	Voltage (kV)	Single Phase Fault Current (kA)	Three Phase Fault Current (kA)	Existing Switchgear Rating (kA)
CK	132	22.58	22.22	40
F	66	-	-	-[16]
HAY	132	23.00	21.68	34.6 / 40
MIL	132	19.12	17.87	31.5 / 40
W	66	-	-	-[16]
EP	132	26.55	23.59	31.5 / 40 / 50
EP	66	13.39	10.74	25 / 31.5 / 40
NP	132	20.24	20.46	40
JTE	132	25.60	23.27	-[16]
JT	66	13.34	10.72	13.4 / 31.5

6.2. 10-25 Years

6.2.1. Transmission Network

Figure 13 below illustrates the emerging transmission network limitations for the CBD Load Area in the longer term following further forecasted load growth beyond 2021. It is now evident that the EP-F double circuit is expected to exceed firm capacity by 2032.

[16] No transmission switchgear is installed at these sites

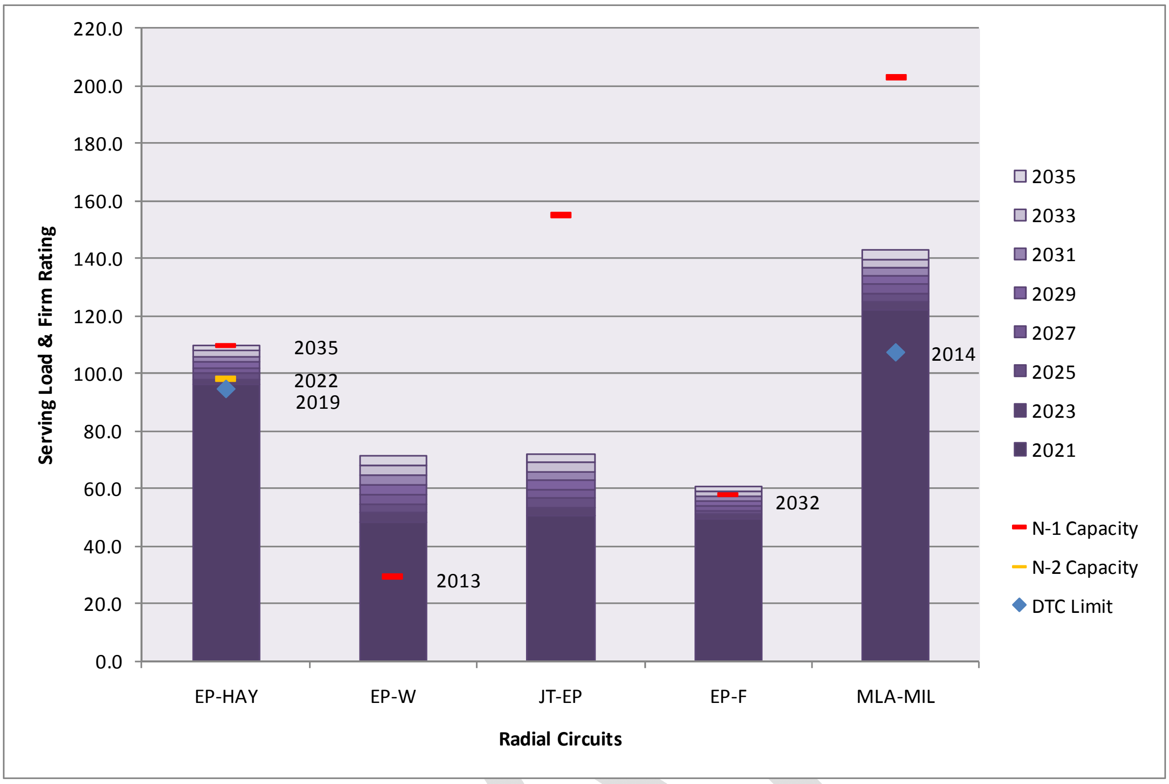


Figure 13 Transmission Network Emerging Limitations: 2021 - 2036

In addition to this is the EP-HAY double circuit which will exceed capacity following an N-1 contingency in 2035 (red marker) and N-2 in 2022 (orange marker). The N-2 contingency arises from the loss of the double circuit from MLA-MIL which requires the EP-HAY circuits to support both the load of Hay Street and potentially that of Milligan Street (total of 221 MVA in 2022). It is noted that it is only the short oil filled section of cable (0.62 km) between the Hay Street Zone Substation and the cable sealing ends at Wellington Street Zone Substation which restrict the EP-HAY double circuit's total capacity to 220 MVA. The remainder of the double circuit is rated to 420 MVA, providing similar capacity to that seen on the MLA-MIL double circuit.

6.2.2. Substation Capacity

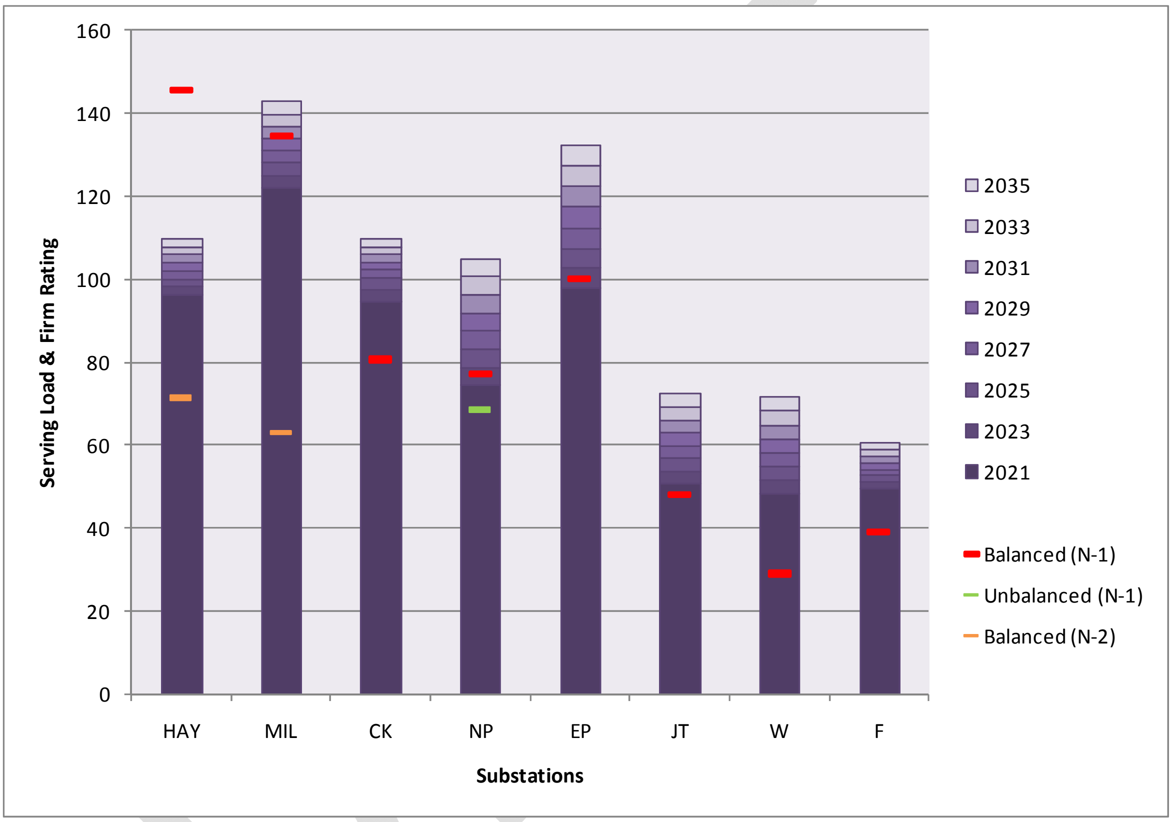
Appendix I provides details of the individual substation capacity and nominal age of transformer assets over the period of 2011 – 2036 with Figure 14 summarising substation capacity in the load area for the period 2021 – 2036.

Further to the substations identified in Section 6.1.3 for the period 2011 – 2021, it can now be seen that East Perth Terminal and North Perth Zone Substation with load balancing carried out are also expected be over firm in 2022. This illustrates that all substations[17] in the CBD Load Area are

[17] Hay Street and Milligan Street substations are over N-2 firm (currently supported by DTC)

expected to be over firm within the next 11 years, indicating a substantial level of investment is required in the short to medium term to provide suitable substation capacity. Furthermore, Milligan Street substation is forecast to be over N-1 firm in 2029.

It can also be seen that the level of DTC support required for N-2 transformer contingency events at Hay Street and Milligan Street has increased substantially above the firm capacity by approximately 35 MVA and 75 MVA respectively. It should be noted however, that this is lower than the present DTC support provided to the substations during an N-2 transmission network contingency at these sites.

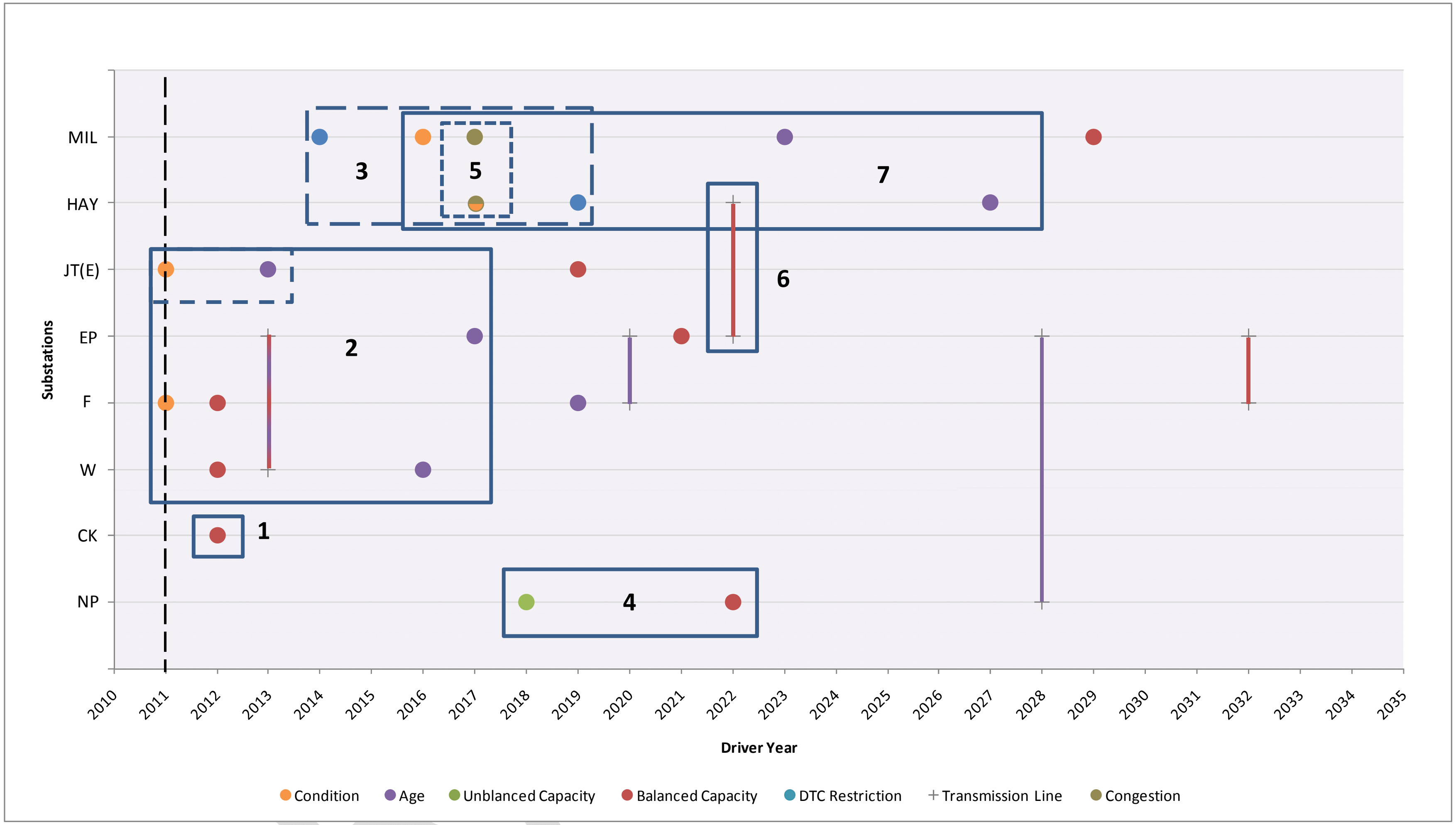


■ Figure 14 Substation Capacity Emerging Limitations Summary: 2021 - 2036

6.3. Summary of Load Area Emerging Limitations: 2011 – 2036

In addition to the capacity limitations that have been discussed within this section, the asset age and condition limitations discussed within Section 3 are also emerging limitations for the CBD Load Area. Figure 15 provides a summary of these limitations and demonstrates the drivers and timings for reinforcements across the load area.

Each capacity limitation marker within Figure 15 has been derived from the markers indicated on Figure 10, Figure 12, Figure 13 and Figure 14 within this section. Similarly, each condition based marker is derived from the oldest or poorest condition asset at each of the substations as derived in Section 3. Where the asset is identified as a condition driver (orange), this is generally the 11 kV switchboards with age drivers (purple) relating to power transformers at the substation. Lines between substations correspond to the relative cables or overhead lines and are coloured based on the limitation. Congestion markers, as seen at Hay Street and Milligan Street Zone Substations, relate to the physical distribution cable restrictions discussed in Section 6.1.2.



■ **Figure 15 Summary of Load Area's Emerging Limitations: 2011 - 2036**

It can be seen from Figure 15 that there are numerous emerging limitations and hence new reinforcement requirements, covering all substations in the CBD Load Area over the 25 year horizon, particularly in the next 10 years.

It is possible to group zones of limitations based on the aligned timeframes of limitations and the potential interactions of reinforcements. Figure 15 indicates seven potential zones:

1) Cook Street Zone Substation under firm capacity[18]
2) Existing 66 kV networks at Forrest Avenue, Wellington Street, Joel Terrace and East Perth coming to the end of life with under capacity issues also present
3) Existing levels of DTC support for Hay Street and Milligan Street Zone Substations under N-2 contingencies is exhausted
4) North Perth Zone Substation under firm capacity
5) Congestion of distribution cabling exits and 11 kV switchgear exhausted
6) EP-HAY cable section under N-2 capacity
7) Hay Street and Milligan Street 11 kV switchgear poor condition and transformer end of nominal life[19]

These seven zones of limitations form the basis for developing reinforcement projects and ultimately a development strategy to address these restrictions, allowing future load growth and asset management within the CBD Load Area.

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[18] Firm capacity limitations illustrated in Figure 15 omit DTC capability as noted in section 4.6.3, with the exception of the Hay Street and Milligan Street substations regarding N-2 support.

[19] It is assumed that protection upgrades indicated within the TNDP have been implemented at Milligan Street substation to facilitate the increased firm capacity.

7. Projects Considered – Within Load Area

7.1. Overview of Project Analysis

Section 6 has illustrated that the CBD Load Area is presently experiencing a significant number of restrictions in all areas with capacity, asset age, condition and physical limitations as the primary drivers. These restrictions are likely to be compounded with expected load growth in the future.

Significant levels of asset replacement and reinforcement are expected to be required over the study period to cater for equipment condition, insufficient transformation capacity as well as distribution system voltage migration plans. Furthermore, previous studies undertaken by Western Power and generic analysis within the SKM 'Review of Planning Philosophies' report has demonstrated that upgrading the distribution system voltage in sections of this area to 22 kV operation would provide significant practical benefits over the existing 11 kV operation [2].

It has been highlighted within Figure 15 that there are a number of primary discreet asset replacement zones around the load area which are comparatively independent from each other. Each zone has therefore been studied independently with capital investment option analysis of potential reinforcement projects. The preferred reinforcement project for each of the zones are then carried forward and consolidated into a coherent 25 year strategy with assessment of the timing of the reinforcement projects and any additional enabling works required.

The asset replacement zones on which the capital investment projects have been derived are summarised within Section 6.3.

7.2. Evaluation Criteria

The projects developed and considered within this study were evaluated on the basis of a number of key tangible metrics, including capital cost and capacity benefit, as well as less tangible metrics such as expected environmental impact and social perception. The initial evaluation criteria of each project will be the capital cost, system capacity increase and risk in implementation as these metrics allow for the simplest identification of the projects that will, when implemented in a holistic strategy, deliver the lowest 25 year NPC. Following the definition of the most favourable project options, a consolidated 25 year strategy will be assessed, with the primary evaluation criteria being the most favourable NPC. Such an analysis allows the identification of the strategy with the greatest net benefit after considering a number of alternative options in line with the Electricity Networks Access Code[20].

Project delivery timescales and associated risk have been considered including the unique complexities and difficulties of construction within the CBD Load Area. Opinions from Western Power environmental, distribution, operations, substation design and asset management teams sought have been sought to understand the duration of a project from planning, through consenting

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[20] Electricity Networks Access Code, 2004, pg. 98

and engagement to construction and commission. Where applicable this project delivery risk has been highlighted between projects as part of the optioneering analysis.

All projects are designed to be compliant with the Technical Rules. Newly installed substation capacity is designed to the security standard relevant for the load which it supplies. Consideration has been given to the potential future expansion of the Perth CBD boundary and where appropriate the flexibility of reinforcements to react to such a change, if it was to occur, has been incorporated into the evaluation as recommended in the SKM 'Review of Planning Philosophies' report [2].

7.3. Primary Limitations and Project Optioneering

7.3.1. Capacity Restrictions at Cook Street Substation

Cook Street Zone Substation is located to the West of the CBD Load Area and primarily supplies loads in the City of Subiaco with support to the Western Perth CBD boundary and Milligan Street Zone Substation. Figure 15 illustrates that the load at Cook Street is expected to grow above the firm capacity of the site in 2012, providing the trigger to address a capacity restriction.

The existing Cook Street substation has two 81 MVA 132/11/11 kV transformers resulting in 81 MVA of firm capacity. Load is forecast to grow to 110.5 MVA by 2036 at a rate of approximately 1.5 MVA per annum resulting in some 29.5 MVA of load over the firm capacity at the end of the period. There is currently some 17 MVA of DTC capability to Milligan Street (see Appendix E - Figure 45).

Due to the restrictions of connecting new N-2 load to the Hay Street and Milligan Street Zone Substations, it is noted that two existing feeders from Milligan Street to Cook Street currently supplies N-1 load. It is possible that these feeders could be transferred to Cook Street to free two feeder circuits for new N-2 load to be connected to Milligan Street substation. Although this may allow new N-2 load to be connected in the short term, it would marginally reduce the DTC support between Cook Street and Milligan Street. At Milligan Street this would not be of significant issue if support was provided by the transmission network as discussed in Section 7.3.5.

There are currently only two spare 11 kV feeder circuits available at the Cook Street site which will not be sufficient to allow the forecasted growth. In addition, it would not be possible to transfer this load growth to other substations in the CBD Load Area due to the congestion discussed in Section 7.3.5. Additionally, much of the Cook Street load is located in the Subiaco area to the West of the CBD Load Area so there would be inefficiencies in supplying this load from Milligan Street. Similarly, any new load connected at Cook Street will require N-1 security at a distribution level. With the insufficient availability of circuit breakers at surrounding substations, new feeders will likely be required to loop back to another bus section at Cook Street, therefore using the remaining two feeder circuits during installation of the next feeder.

Although a new switchboard at Cook Street would allow new load to be connected, there is insufficient firm capacity at the substation to secure the new load. Although DTC is currently available, this cannot operate fast enough (within 30 seconds) to support the loss of a single transformer in an N-1 contingency event.

It is therefore recommended that a third transformer and switchboard be installed at Cook Street Zone Substation. This would facilitate the load growth in West of the CBD Load area and Subiaco whilst providing flexibility for the connection of new Perth CBD boundary load in the short term. Furthermore, a third transformer would assist future CBD Load Area asset replacement and potential required load transfers in the medium to long term. Sufficient land is available within the existing substation site to allow the installation of a third 81 MVA 132/11/11 kV transformer to be in line with those currently installed, however it is noted that the existing 132 kV GIS equipment will need to be extended to allow for the connection of the transformer[21].

7.3.2. Existing 66 kV Network End of Life

This section focuses on the 66 kV network restrictions within the CBD Load Area which Figure 15were highlighted in Figure 15.These restrictions, expected to materialise within the next 5-7 years, include:

- Transformer capacity restrictions in the short term (2013) at Forrest Avenue and Wellington Street Substations followed by expected end of asset life (2016-2019)
- Capacity restrictions seen on the EP-W 66 kV cables (2013) in addition to end of asset life and poor condition resulting in high maintenance
- The poor condition of the Joel Terrace 66 kV transformers, assets approaching the end of asset life in the short term and capacity restriction in the medium term (2019)
- East Perth 132/66 kV transformers expected end of asset life in 2017

Based on the above it is evident that the entire 66 kV network within the CBD Load Area is approaching the expected end of asset life in the next 5-10 years in addition to capacity restrictions. A strategy is therefore required to allow the replacement of these 66 kV assets.

The SKM 'Review of Planning Philosophies' report has provided a generic analysis that illustrates that there are economic efficiencies and other advantages to be made in the replacement of end of life 66 kV assets with an upgrade to 132 kV operation rather than a like for like replacement at 66 kV [2]. Such efficiencies are primarily provided as specific 66 kV rated equipment (i.e. cables, overhead line designs, etc) are no longer commonly installed across electrical networks and are instead replaced by 132 kV rated equipment energised at 66 kV[22]. Additional efficiencies are made by minimising the volume of equipment to be replaced, such as terminal substation 132/66 kV

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[21] The extension of the GIS equipment may introduce some added complexity in acquiring compatible equipment types in addition to potential operational issues or restrictions during the extension's construction and commissioning.

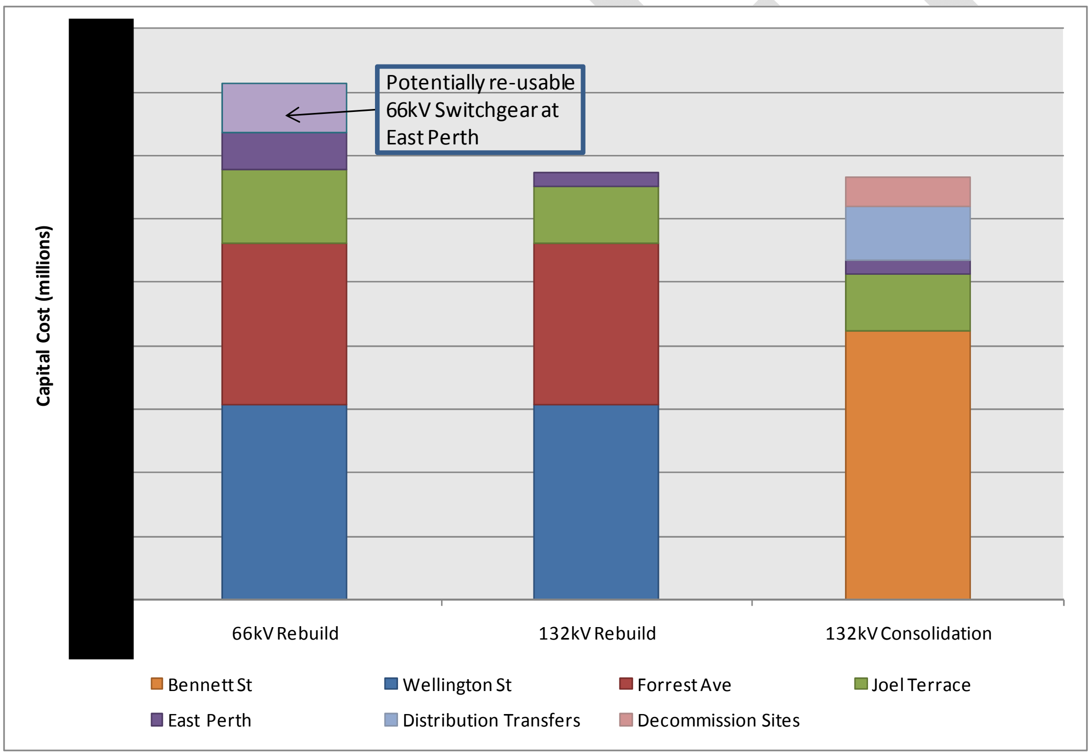
[22] [redacted]

transformers and associated switchgear, as well as reducing losses and potentially providing greater transmission capacity.

Although upgrading to 132 kV is shown as being efficient from a generic analysis, it is necessary to carry out a project specific analysis for the replacement of the 66 kV assets in the CBD Load Area. Figure 16 illustrates this project specific cost assessment for the replacement of 66 kV assets at Joel Terrace, Wellington Street, Forrest Avenue and East Perth with a 66 kV and 132 kV solution.

In addition, a project specific option to the CBD Load Area would be to utilise existing land at another site to create a consolidated solution, minimising the number of substations required to be upgraded to 132 kV. This option is also shown in Figure 16. Details are provided within Appendix D as to the assumed design utilised for a consolidated substation with the costing developed on this design.

In the interests of a fair and comparable assessment, it has been assumed that all existing switchgear arrangements are retained and a minimum firm capacity of 60 MVA (nameplate) is provided.[23]



- **Figure 16 Capital Cost for 66 kV Asset Replacement by Substation**

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[23] In practice it is noted that alternative switchgear or transformer arrangements and other design variables may be utilised.

It can be seen from Figure 16 that a 66 kV rebuild of each of the four sites is more costly than a 132 kV rebuild solution, even taking into account the recently installed 66 kV switchgear at East Perth which is not suitable for 132 kV operation. In contrast a consolidation of the Wellington Street and Forrest Avenue Substations to a new substation[24], for example at Bennett Street, provides a comparable cost (3% variance) with a 132 kV rebuild of these sites.

A consolidated site in isolation would provide significant savings to a 132 kV rebuild, however the requirement to transfer load to the new site and the decommissioning costs of the old sites make these options comparable on cost alone. Furthermore, this project specific analysis has assumed that the consolidated site would be at Bennett Street as a complex multi-storey building which adds significant ($10M) cost.

A 132 kV solution over an equivalent 66 kV solution brings a number of other advantages such as reduced power losses and efficiencies in operations and maintenance strategies with a minimised number of assets and a lower variety in spares requirement across the Western Power Network. Further efficiencies can be gained from utilising a consolidated substation on new land by assisting the staging and minimising the outages during the strategy to replace the ageing 66 kV assets. Also, following the construction of the new substation, the subsequent decommission of the old substations will provide land for potential future developments. It is therefore not recommended for the sites to be rebuilt at their current 66 kV operation.

Analysis in Figure 16 has shown that the cost differential between a 132 kV rebuild of the sites in question against a consolidation of the Wellington Street and Forrest Avenue sites is marginal. Table 15 provides a comparison of these solutions under a number of other metrics which are of importance.

- **Table 15 Comparison of 132 kV Rebuild Against Consolidated Site Solution**

	132 kV Rebuild	**Consolidated Site**
Security of Supply	Outages and load transfers will be required to continue supply during construction.Risk increase if load is secured to N only during these times.	New substation can be constructed offline with load continuing to be secure from other sites.
N-2 Capability	Additional cost to secure two smaller capacity sites to N-2 capability to support Perth CBD boundary load	Lower cost to upgrade single large site to N-2 capability similar to existing Hay Street and Milligan Street substations
Construction timeframe, complexity and safety risk	Required to work on a live site adjacent to aged at risk equipment.Work likely to be restricted to periods of low demand to minimise risk during outages resulting in extended timeframe and complexity	Substation can be constructed offline at an increased rate and minimised safety risk.

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[24] Cost for new consolidated substation is provided for Bennett Street [redacted] as described in Appendix D.

It can be seen from Table 15that the rebuilding of the sites in-situ introduces complexity and risk during the construction process. Mitigation of these load supply risks through standby transformers, emergency generation or other methods will introduce additional costs. Furthermore, the construction complexity and restrictions may also introduce additional cost not captured within Figure 16. An example could be that the rebuilding of Forrest Avenue in situ is not feasible and the land at Bennett Street would be used for this redevelopment adding load transfer and decommissioning costs.

In comparison, a consolidated site allows the substation to be built offline, minimising construction and load supply risk whilst also introducing other advantages such as a lower cost and preferred capability to upgrade to N-2 operation to support load within the Perth CBD boundary. It is therefore proposed that to address the multiple asset expiry and capacity shortfalls across the 66 kV network within the CBD Load Area a new substation is constructed at an operating voltage of 132 kV. This project will consolidate the existing Wellington Street and Forrest Avenue Substations whilst preventing the renewal of the 132/66 kV transformers at East Perth Terminal.

Currently Western Power has land at holdings across the CBD Load Area on which a new consolidated substation could be constructed and further analysis on the merits of each site is now detailed.

Bennett Street, Tully Road and James Street

Land is available at Bennett Street, Tully Road and James Street for the construction of a new zone substation (as illustrated in Appendix B - Figure 43). Land is also available at Murray Mews; however this site is subject to significant environmental restrictions as indicated in [17] and was deemed inappropriate for this type of development.

Bennett Street is located to the East of the CBD Load Area and is in a strategic geographical position to support existing loads in this area as well as potential future growth of the Perth CBD boundary and proposed new developments such as the East Perth Riverside. Tully Road is located some 2 km to the Northeast of the CBD Load Area, in close proximity to Joel Terrace Substation and East Perth Terminal. James Street is located North of the PTA railway to the North of the CBD Load Area, approximately 1.2 km from Wellington Street and 2.4 km from Forrest Avenue. James Street is also the current site for the cable termination structures for the MLA-MIL 132 kV circuits and the CK-EP 132 kV cable routes within 100 m of the site.

The new zone substation is proposed to offload Forrest Avenue Substation and Wellington Street Substation to allow their respective decommission. Although it may be possible for other substations to assist in this transition it would mean approximately 40 distribution cables (26 to Wellington Street and 14 to Forrest Avenue) would need to be installed from the new substation to the existing substations to pick up the existing loads. Table 16 details the distances that have been assumed for distribution cabling to collect Wellington Street and Forrest Avenue load to a new consolidated site

Table 16 Estimated Distribution Cabling Lengths for New Consolidated Substation

New Zone Substation Options	Forrest Avenue Feeders	Forrest Avenue Distance	Subtotal	Wellington Street Feeders	Wellington Street Distance	Subtotal	Total
Tully Road	14	1 km	*14.0 km*	26	1.8 km	*46.8 km*	**60.8 km**
Bennett Street	14	0.5 km	*7.0 km*	26	1.2 km	*31.2 km*	**38.2 km**
James Street	14	2.4 km	*33.6 km*	26	1.2 km	*31.2 km*	**64.8 km**

Based on the approximate distances between substations, it is assumed that Bennett Street would require 38.2 km, Tully Road 60.8 km and James Street 64.8 km of distribution cabling to be installed to collect the Wellington Street and Forrest Avenue load. Present costs for the supply and installation of distribution cable within the footpath of a metropolitan area such as the CBD Load Area are approximately $[redacted]/km as provided by Western Power engineers; this cost may be higher if installation is required in the road or in a pit and duct or tunnel system.

Table 17 Tully Road, Bennett Street and James Street Cabling Costs

	Elements	Tully Road	Bennett Street	James Street
Distribution	Cable Length	60.8 km	38.2 km	64.8 km
	Cable Unit Cost		$[redacted] per km[25]	
	Total Cable Cost	**$[redacted]M**	**$[redacted]M**	**$[redacted]M**
Transmission	Cable Length	0.7 km x2	2.5 km x2	0.1 km x2
	Cable Unit Cost[26]	$[redacted] per km	$[redacted] per km	$[redacted] per km
	Total Cable Cost	**$[redacted]M**	**$[redacted]M**	**$[redacted]M**
Combined	Total	**$[redacted]M**	**$[redacted]M**	**$[redacted]M[27]**

Taking the assumed transmission and distribution circuit lengths required it can be seen that the total cabling costs for Tully Road is $[redacted]M with Bennett Street $[redacted]M and James Street $[redacted]M. This is the estimated cabling cost to collect the existing load from the Wellington Street and Forrest

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[25] 240 mm^2 11 kV cable (urban) building block cost.

[26] Includes line length scaling factor

[27] A James Street solution could utilise the EP-CK 132 kV circuit which routes in close proximity to the site for a small cut in cost. It would not however be suitable for a consolidated site to be connected solely to this single circuit due to load restrictions. The existing MLA-MIL 132 kV double circuit which has existing cable terminations within the James Street site could also be utilised. Extensive switchgear works would likely be required to allow auto-switchover schemes and isolation between the circuits which would add significant cost to the value indicated for cable costs only.

Avenue Substations only and can be seen to be marginal in difference between all potential new sites, particularly considering the cable length assessments and costing tolerances used.

This analysis does not include the supply of future loads in the CBD Load Area which would currently be supplied from Forrest Avenue or Wellington Street substations, but now require to be supplied from the new proposed substation. It is likely that the ongoing cost of a Tully Road or James Street substation would be higher, with significantly longer distribution cables being required to feed the East of the CBD Load Area in comparison to Bennett Street. For instance, should distribution cable costs increase by some 20%, James Street would have a higher total cost than that of Bennett Street. Such a scenario is not unlikely considering the complexities and congestion of installing cables within the CBD Load Area, particularly within the Perth CBD boundary. It is also expected that there would be significant environmental and social disruption due to the installation of multiple distribution cables over a long length should a Tully Road or James Street substation be selected. Any loads in the near vicinity of Tully Road would likely be supplied by the existing Joel Terrace substation. A James Street substation may have restrictions in serving significant amounts of new CBD Load Area load, particularly to the East of the Load Area where the Forrest Avenue and Wellington Street Substations are located, due to the limited number of crossings available across the PTA railway.

In comparison a Bennett Street substation would have reduced ongoing cost to supply new load due to the close geographic location with the existing Wellington Street and Forrest Avenue Substations and expected growth in the East Perth area. In turn, the reduction of distribution cabling works is likely to minimise construction and social disruption.

In summary, this analysis has shown that the cost differential between the potential consolidated sites is marginal; however the strategic location of Bennett Street going forward to support the East Perth area of the CBD Load Area provides significant tangible benefits. It is therefore recommended that Bennett Street is the preferred site for a new zone substation to consolidate the existing Forrest Avenue and Wellington Street loads required to facilitate the respective decommission of these sites. Analysis and justification for a proposed design of a new Bennett Street substation is provided in Appendix D. Concept civil designs for a multi-level substation at this location have been carried out by Western Power which indicates its feasibility [21].

Joel Terrace

A consolidated site is proposed to accept the load from the Wellington Street and Forrest Avenue 66 kV substations only. As such, the cost of rebuilding the 66 kV assets at Joel Terrace is illustrated in Figure 16 as separate items under all scenarios. It can be seen that cost savings can be made if the existing, poor condition, 66 kV assets are rebuilt at 132 kV rather than 66 kV at this site. This is primarily due to the requirement for only one 60 MVA 132/11/11 kV transformer in comparison to two 33 MVA 66/11 kV transformers. These transformer sizes have been utilised as they are standard Western Power specifications.

Furthermore it has been seen throughout this analysis that there are significant cost savings to be made in migrating the CBD Load Area 66 kV network to 132 kV. If Joel Terrace was to remain at

66 kV, cost savings seen from the removal of 132/66 kV transformers and switchgear at East Perth would diminish or if attributed to Joel Terrace, make this solution significantly more expensive.

It is therefore recommended that the currently partial conversion of Joel Terrace to 132 kV operation is completed, no later than the date for decommissioning of the Forrest Avenue and Wellington Street Zone Substations. This would be achieved by replacing the two existing 66/11/11 kV transformers which are in extremely poor condition with a single 132/11 kV transformer[28] and associated cabling and switchgear works. Furthermore, it should be noted that forecasted continual load growth at Joel Terrace may result in a third transformer being required towards the end of the 25 year horizon in order to maintain N-1 firm capacity, unless supported by DTC. It is possible, due to direct land constraints on the Joel Terrace site, that this third transformer may be required to be installed on other land currently owned by Western Power in the East Perth Terminal area as shown in Appendix B - Figure 44.

7.3.3. East Perth Switchyard Extension

As a result of the uprating of the 66 kV network to 132 kV, the existing 132 kV switchyard at East Perth will be required to accommodate the new feeders proposed for the new Bennett Street substation and Joel Terrace. In turn the 66 kV switchyard at East Perth can be retired following the removal of 66 kV assets from Wellington Street, Forrest Avenue and Joel Terrace.

It is therefore expected that three new 132 kV circuits will be required to supply the CBD Load Area from East Perth. This relates to a single new circuit to Joel Terrace and a double circuit to the new Bennett Street substation. In addition, it is seen (see Section 10) that the preferred future support from the wider transmission network to supply the CBD Load Area is through two new circuits from Cannington Terminal to East Perth Terminal. The East Perth 132 kV switchboard is therefore expected to require an extension to allow the connection of five[29] new circuits within the 25 year horizon.

Appendix B - Figure 44 illustrates the current location of the East Perth 132 kV switchyard, 66 kV switchyard and Joel Terrace Zone Substation. It is evident that Western Power currently owns a significant amount of land in this area; however the existing East Perth 132 kV switchyard, has limited potential for extension in its current form due to the orientation of the busbar structures and the Swan River. The switchyard extension is therefore likely to be required to be located in a new area of land and linked through cable connections or busbar rerouting.

[28] Dependant on future detailed analysis of the distribution network this transformer may be 132 / 22 kV.

[29] It is recommended that Bennett Street substation be designed for potential future N-2 operation. A third circuit will therefore be required at such a time. In order to accommodate such a future expansion, it would be anticipated that design works and foundations for a sixth connection would be completed without the installation of the associated switchgear until the N-2 operation of Bennett Street substation.

The timing of the 132 kV switchyard extension is likely to be such that the 66 kV switchyard will still be in operation to allow the staging of load transfers, particularly to the new Bennett Street substation. It is therefore proposed that the switchyard extension be constructed to the North of the existing East Perth 132 kV switchyard, on land currently owned by Western Power. This extension of a minimum of five circuit connections could be constructed of AIS or GIS technology as suitable land is available for both designs. It is assumed that the extension will be of AIS technology to minimise cost and simplify any future expansion unless a suitable case can be made that a portion of the land is of more value for resale than the increased cost of GIS equipment. The voltage upgrade of Joel Terrace from 66 kV to 132 kV is likely to occur before this East Perth switchyard extension. This may require the new 132 kV circuit to Joel Terrace to be banked onto one of the existing East Perth circuit breakers in the short term.

Although the existing 66 kV switchyard is proposed to be removed following the upgrade of this voltage in the CBD Load Area to 132 kV operation, it is not proposed that this land be sold. The SKM 'Review of Planning Philosophies' report has indicated that the potential for 330 kV into the CBD Load Area, albeit towards the end of the 25 year planning horizon, is likely to be required in the more distant future [2]. The current 66 kV switchyard is of suitable size to accommodate a potential future 330 kV AIS substation at East Perth[30] – see Section 10.3. It is understood that the MRA has an interest in this land holding for redevelopment opportunities. It is therefore advised that Western Power begin discussions on the potential future use of this site to determine the best solution for the city, whilst considering potential future energy requirements.

Should it be operationally feasible, it may be possible to bank the three new 132 kV circuits to the CBD Load Area onto the existing 132 kV switchgear arrangement at East Perth and defer the requirement for the switchyard extension. Section 10 indicates that two new transmission infeeds to the CBD Load Area (East Perth) from Cannington are expected to be required within the next 5 to 10 years and further that these circuits may be of 330 kV specification suitable for later uprating to 330 kV operation. These circuits could be connected to a new 330 kV rated GIS[31] switchyard operated at 132 kV at East Perth without the requirement for the existing 132 kV switchyard to be extended. Such an approach however has a number of development dependencies, will advance the construction of a 330 kV rated switchyard and would require the new 330 kV rated 132 kV switchyard to be connected to the existing switchyard via the redundant 132 kV circuit breakers made available by the decommissioned 132/66 kV transformers, circa 2020. Hence it is proposed that the 132 kV switchyard be extended to accommodate five AIS 132 kV circuit breakers in such a time as to accommodate the new Bennett Street circuits.

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[30] The viability of using re-using this land for this purpose requires further assessment

[31] An AIS switchyard arrangement can be implemented at 330 kV if a transformer feeder design is adopted. However, if the switchyard is to first operate at 132 kV then a full double busbar switching scheme will be required which cannot be constructed using AIS on the land expected to be made available at East Perth through decommissioning the 66 kV switchyard, hence GIS will be required.

Further analysis is required to determine the feasibility and suitability of a banked solution of the CBD Load Area circuits in the short to medium term which may defer this investment until the introduction of the CT-EP circuits.

7.3.4. North Perth Capacity Restrictions

North Perth Substation is an NCR secure site approximately 2 km due North of the Perth CBD boundary. The site currently has three 33 MVA 132/11 kV transformers installed resulting in a maximum NCR capacity of 77.2 MVA. Due to load imbalance on the transformers, the current available NCR capacity is reduced to 68.6 MVA. Load growth at this substation is forecasted to result in peak substation demand being greater than the unbalanced NCR capacity in 2018 and greater than the balanced NCR capacity by 2022 as illustrated in Figure 15.

North Perth substation currently supplies a large distribution catchment area (as illustrated in Appendix F-) which is resulting in approximate load growth of 2.2 MVA per annum and a 50% increase in load over the next 25 years to 107.2 MVA in 2036.

A number of solutions could be adopted to manage the forecast capacity restriction at North Perth:

1) Reinforce North Perth Substation directly
   - Install a fourth transformer
   - Replace existing transformers for dual winding 75 MVA capacity
2) Construct a new Mount Lawley substation
3) Connect new load to surrounding substations
   - James Street[32]
   - Joel Terrace
   - Cook Street
   - Joondanna[33]

Each potential solution has been analysed to determine the preferred project option.

[32] Future substation as indicated by this report

[33]Future substation identified by Western Power as part of its Northern Terminal 25 Year Development Strategy

Reinforce North Perth Substation Directly

North Perth Substation could be reinforced directly through the installation of a fourth transformer or by replacing the existing transformers with those of a larger capacity. The replacement of the existing transformers would not be favourable due to the relatively young age of the assets, unless it was possible to reuse these transformers elsewhere in the Western Power Network.

There is suitable available land within the existing North Perth Zone Substation land holding for a fourth transformer to be installed. However, it has been noted by Western Power distribution planning engineers that the installation of further capacity at the substation could result in congestion restrictions (cable exits from the substation) similar to that seen at the Hay Street and Milligan Street Substations. Furthermore, the potential installation of a 132 kV transmission cable at this site for a future PTA supply may restrict busbar access for a fourth transformer and should be considered. Outages required to install and maintain a fourth transformer at this site would require further analysis to ensure the feasibility of this option.

It is therefore proposed that additional capacity is not installed at North Perth substation directly to prevent this congestion restriction occurring, however further assessment by Western Power will be required to ensure this is not a viable solution.

Construct a New Mount Lawley Substation

At present the Mount Lawley site is a switching station for the Northern Terminal 132 kV transmission circuits supplying Milligan Street in the Perth CBD boundary as well as the Northern Terminal circuits supplying Yokine and Morley. The site is located some 4 km North of the Perth CBD boundary and has an area of approximately 3366 m^2. The existing 132 kV switchgear at Mount Lawley (six line circuit breakers and one bus section circuit breaker) are contained within an area approximately 38 x 21 m (~800m^2), with AIS switchgear arranged with a North-South busbar.

The MLA-MO and MLA-Y transmission circuits are connected to circuit breakers at the North and South ends of the busbar system respectively. These circuit breakers could be re-used to supply two 132/11(22) kV transformers if the MLA-MO and MLA-Y transmission circuits are removed from the switchgear system and connected together outside of the Mount Lawley site perimeter. An 80 m section of overhead line would be required to connect the two circuits, with modifications being required to the MLA-Y terminating pole to cater for the near 90 degree turn required to make the connection.

Given that the rating of the incoming Northern Terminal circuits is 243 MVA and the outgoing circuits to James Street are rated at 203 MVA, in order not to impact on the available transfer capacity for Perth CBD boundary loads, as supplied by Milligan Street, no more than 40 MVA of new load could be connected to the NT-MLA circuits in the first instance. However, around 2034 it is expected that these transmission circuits will require rebuilding due to age and condition related deterioration and hence they could be rebuilt to a higher Venus AAC specification line which would yield approximately another 37 MVA of additional capacity.

Given the above, a new Mount Lawley substation would be feasible from a practical perspective, in addition to yielding some 77 MVA of load without significantly impacting on the capability of the supply to the Perth CBD boundary. As such, a considerable level of North Perth load, or future load in this area designated for North Perth, could be fed by a Mount Lawley substation.

Connect New Load to Surrounding Substations

The distribution catchment area of the North Perth Substation is extensive. A potential solution to overcoming forecasted capacity restrictions may be to utilise the surrounding substations to collect new load as it emerges.

In terms of CBD Load Area substations, Joel Terrace, James Street and Cook Street are the closest geographically to North Perth. In discussions with Western Power distribution planning engineers, it is deemed that Cook Street is located at too great a distance to provide any level of suitable support. The James Street substation is proposed to be of minimal size (see Section 7.3.5) to assist in alleviating the limitations seen at the Hay Street and Milligan Street Substations in the Perth CBD boundary. It may be possible to expand the site, however the distances involved again make any North Perth support from this location undesirable. In terms of Joel Terrace Substation, it is proposed that assistance of around 5-10 MVA may be possible, should new load appear to the East of the North Perth substation. Overall, potential for new North Perth load to be connected to the CBD Load Area substations is limited; particularly if a different distribution voltage is deemed to be preferred in the Perth CBD boundary or wider CBD Load Area following more detailed assessment.

Alternatively, new load in the North Perth distribution catchment area could be supplied via the Northern Terminal Load Area. The Northern Terminal Load Area report[18] has indicated Yokine Substation is to be retired with its load migrated to a new substation at Joondanna and potentially operated at 22 kV. This migration is expected to be completed by 2021 [18]. With a 22 kV distribution operating voltage, it is possible for feeders to be routed over longer distances, allowing significant potential to supply new North Perth load once the substation has reached firm capacity. It is currently proposed that Joondanna be constructed of 2x75 MVA 132/22 kV transformers in 2021, with a third transformer forecasted to be required by 2027. It is expected that the installation of the third transformer would be brought forward to 2022, should Joondanna be utilised to route new feeders to supply emerging North Perth load. Such an approach would not be so suitable to directly transfer existing load from North Perth Substation due to the 11 kV operation, unless interim 22/11 kV transformers were utilised.

Option Analysis

It has been demonstrated that a number of potential solutions are available to allow the growth of load in the North Perth distribution catchment area following the expected realisation of firm capacity at this site in 2022. These potential solutions are defined as the installation of a fourth

transformer at North Perth Zone Substation, construction of a new Mount Lawley substation or the utilisation of the proposed new Joondanna Substation.

An NPC analysis has been carried out to illustrate the capital expenditure required for the three proposed options. The NPC of a fourth transformer at North Perth Substation in 2022 is $[redacted]M, with a new Mount Lawley Substation in 2022 is $[redacted]M, in comparison to the Joondanna transformer advancement cost of $[redacted]M, a difference of $[redacted]m. Distribution costs have not been included within this assessment as these would be determined by the location of the emerging load in North Perth and its vicinity to any of the proposed substations. Furthermore, any additional costs required to overcome potential distribution cable congestion restrictions, particularly for a North Perth solution, such as tunnels, have not been included within this analysis.

Considering the reduced capital expenditure, it is proposed that Joondanna substation be utilised to feed new load in the North Perth area once firm capacity is reached. In addition, surrounding CBD Load Area substations, particularly Joel Terrace should assist in this supply of new load where the opportunity arises. Furthermore, the construction of a Mount Lawley substation connected via the NT-MLA-MIL 132 kV double circuit is not attractive as this may erode CBD Load Area transmission capacity should the limiting sections of this circuit be uprated in the future.

Although such a solution may appear preferred at this time, review should be taken of the location of future load to ensure suitability of this approach. Options to overcome 11 kV distribution congestion at North Perth which could restrict a fourth transformer solution at this site should be further investigated. In addition, the likelihood of a new 132 kV supply for the PTA from this substation and the implications this may have on busbar access for a fourth transformer should also be further investigated.

It is worth noting that although North Perth Substation is supplied by East Perth and currently located within the CBD Load Area, it is likely that the ongoing future strategy employed for North Perth will have significant interaction with the Northern Terminal Load Area.

7.3.5. Hay Street and Milligan Street Cable Exit Congestion

The Hay Street and Milligan Street Substations are currently experiencing significant congestion in terms of both distribution cable exits and remaining switchboard capacity (further detail on these limitations is provided in Section 6.1.2). It is expected that as the load grows within the Perth CBD boundary that this congestion will worsen to a point where new load cannot be directly connected at these substations. Based on the forecasted customer connections in the next 10 years, it is expected that this restriction could occur around 2017. At this time no remaining 11 kV circuit breakers are expected to be available and the existing cable exit tunnel at each substation will be at full capacity. There will be remaining transformer capacity at the substations; however this cannot be realised due to the physical restrictions of the distribution system. Furthermore, the 11 kV switchboards at the Hay Street and Milligan Street Substations are noted to be in bad condition (further details provided in Appendix C) and requiring replacement in 2018 and 2017 respectively. In order to overcome this congestion and to facilitate the 11 kV switchboard replacements, three options have been considered:

- Substation rebuild to 22 kV distribution operation
- Tee into existing 11 kV interconnections between Hay Street and Milligan Street Substations
- New distribution switchboard and transformer at an external location

22 kV Migration

It has been proposed within the SKM 'Review of Planning Philosophies' report [2] that there are potential significant benefits which can be obtained through migrating the distribution voltage to 22 kV, particularly in highly dense and restricted areas of the Perth CBD boundary. The use of a voltage higher than 22 kV(such as 33 kV) was seen within that report [2] to be less attractive, primarily due to the standard installation of 22 kV capable assets by Western Power over the last ten years. Therefore, in order to alleviate congestion within the Perth CBD boundary now and in the future it may be preferred to migrate to a 22 kV distribution voltage to minimise the number of cables installed. Such a migration would potentially require the rebuilding of the Hay Street and Milligan Street substations. The age and condition of the assets at these sites indicates that the transformers will be 50 years old in 2023 and 2027 respectively. Such an approach would result in the bringing forward of the Hay Street and Milligan Street substation rebuilds (excluding switchboards) by some six years.

Based on a capital cost of $[redacted]M for the rebuilding of Milligan Street Substation, the advancement costs seen by bringing forward this project by six years are in the region of $[redacted]M. Significant distribution works will also be required to move load away from the substation while the rebuilding works are ongoing. This is likely to introduce significant risk to the security of supply as further discussed in Section 7.3.7. Further costs associated with the advanced 22 kV distribution conversion should also be considered, including the replacement of customer owned assets.

Tee into existing 11 kV interconnections between Hay Street and Milligan Street Substations

A short term solution which could be adopted should congestion become a restriction sooner than expected would be to tee into existing interconnecting 11 kV distribution cables. Such an approach could allow the loading of an interconnection to increase from the existing 50% to 67% from a single feeder teeing into an existing feeder pair. This could allow load to continue to grow at the Hay Street and Milligan Street substations by not requiring additional circuit breakers and cable exits, assuming that the tee point is created outside of the substation and from a substation other than Hay Street or Milligan Street.

Such an approach, however, has a number of potential drawbacks. These include:

- A detailed knowledge of the distribution assets and condition is required, particularly the size and rating of all cable sections in the feeder and the capability of the RMUs. This is necessary to enable a suitable tee point location to be selected which will allow the increased loading required of the cable sections, particularly under contingency events. This is of particular importance where tapered feeder designs are used; however this is not likely to be an issue with the Perth CBD boundary where interconnection feeders are fully rated for N-2 support.
- Asset replacement may be required if cable sections or RMUs are not of a suitable capacity.

- The further addition of load to substations requiring asset replacement in the short to medium term (such as Hay Street and Milligan Street substations) will further increase the difficulty and complexity of moving or resupplying load to allow asset replacement to be carried out.
- Fault detection will become more complex with the addition of a tee point which could increase repair or restoration times.
- Distribution fault levels will increase should the parallel operation of two of the three feeders in the tee configuration be used. It is currently known that the distribution fault level in the CBD Load Area is high due to the installation of low impedance transformers.

This strategy may be suitable in the short term, particularly if congestion worsens faster than expected. However, this is not deemed as a suitable long term strategy to alleviate the cable congestion within the Perth CBD boundary for the reasons noted above and is therefore not considered further in this analysis.

Additional Switchboard and Transformer

Currently, numerous feeder pairs are installed between Hay Street and Milligan Street Substations and others in the surrounding area to provide DTC capability (see Appendix E - Figure 45). Feeders between Hay Street and Milligan Street Substations are generally loaded to 5 MVA, effectively resulting in each substation seeing 2.5 MVA of load (dependant on the normally open point) so that should an N-2 contingency occur at one of the sites, the full 5 MVA can be supplied from the other site. Such a design effectively means that feeders which exit Milligan Street Substation (for instance) are only loaded to 2.5 MVA (50%), instead of the potential full 5 MVA to which they are rated.

The installation of a new switchboard and transformer at an external site can assist in maximising the capacity of the Hay Street and Milligan Street substations by overcoming the existing cable congestion. Re-routeing interconnecting cables to the new switchboard and transformer[34] allows the load on each of these cables to be increased from the effective 2.5 MVA to the full 5 MVA. Figure 17 graphically illustrates the significant effectiveness of such a project to release more distribution capacity.

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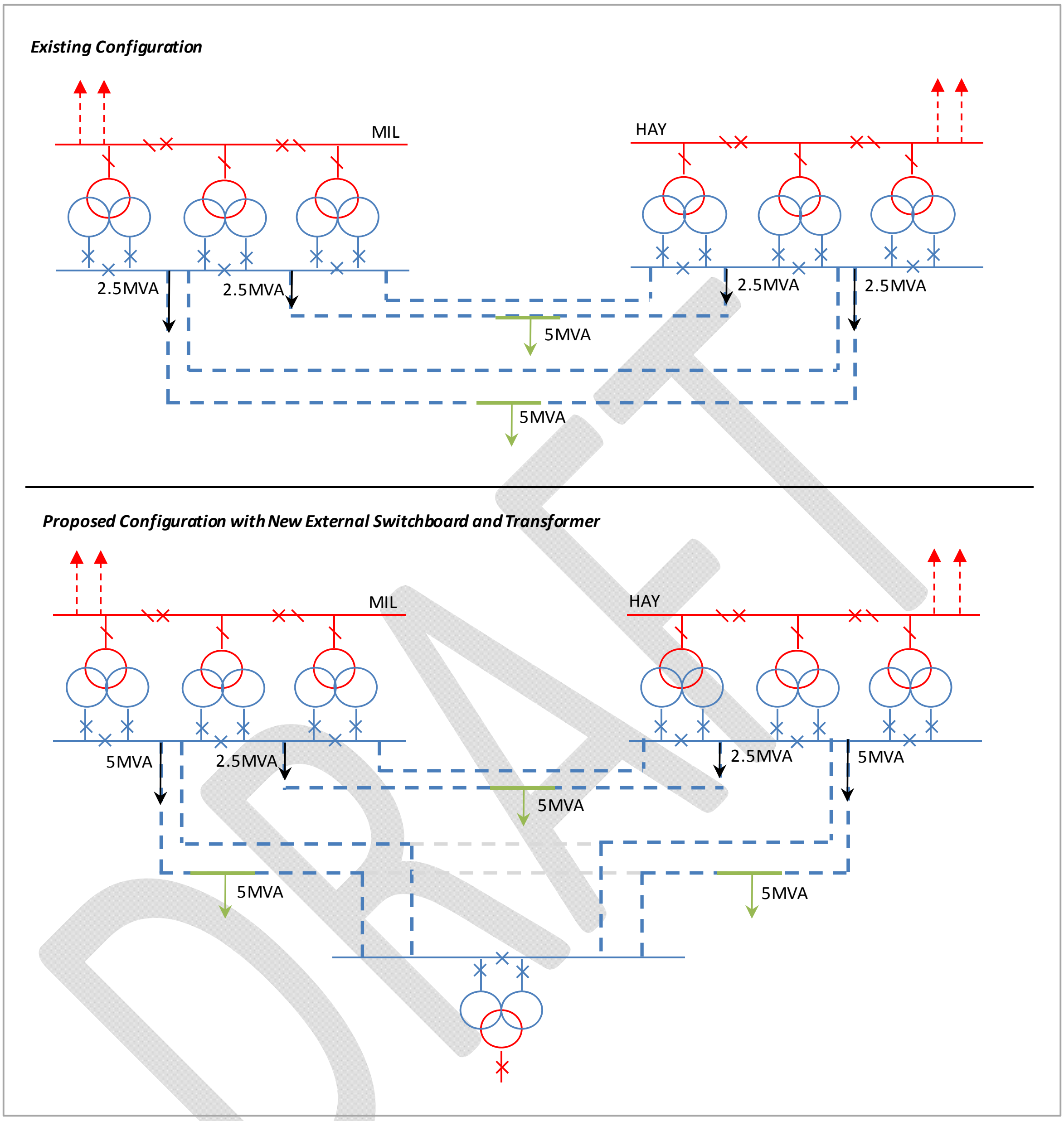
[34] This assumption assumes that transmission connection to the HV winding for the transformer is available nearby



- **Figure 17 Release of Capacity Through Additional External Switchboard**

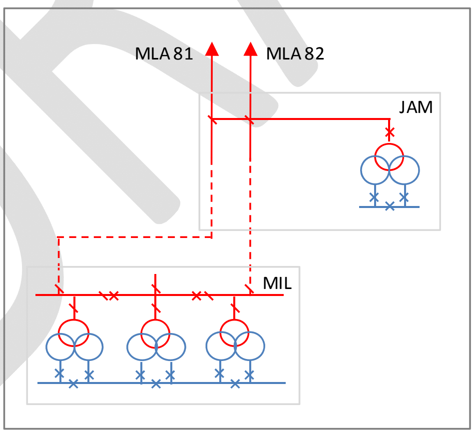
It is evident from Figure 17 that such an approach allows the Hay Street and Milligan Street Substations to be more heavily loaded without utilising additional 11 kV circuit breakers or installing more 11 kV feeders at these sites, thereby overcoming the congestion restrictions. In addition, the remaining transformer capacity at the substations can be further realised, allowing deferral of transformer investment at these substations until they are required on condition grounds.

Comparison

The installation of a new switchboard and transformer at an external location from the Hay Street and Milligan Street substations allows the potentially stranded capacity to be realised by overcoming the cable exit and circuit breaker congestion restrictions. The alternative to such an approach would be to bring forward the reconstruction of the Milligan Street substation by some 6 years at an advancement cost of $[redacted]M in addition to the capital cost of $[redacted]M. In comparison the capital cost of a new switchboard and transformer is estimated as some $[redacted]M.

It is therefore proposed that a new switchboard and transformer be installed at an external site to Hay Street and Milligan Street Substations once congestion becomes a full restriction (expected 2017). The switchboard would be 22 kV rated, as is Western Power standard, but operated at 11 kV until the reconstruction of the substations at the end of asset life when a migration to 22 kV distribution voltage could be considered to limit the level of future congestion across the Perth CBD boundary. The location of the switchboard and transformer could be installed at any of the Western Power owned land with suitable 132 kV infrastructure. This includes James Street or Wellington Street with the final site likely to be selected based on the longer term strategy for managing the end of life of the Hay Street and Milligan Street Substations.

It is noted that the Milligan Street 11 kV switchboards are expected to be replaced sooner than those at Hay Street Substation. Based on geographical location to Milligan Street, the immediate availability of 132 kV network and the immediate availability of Western Power owned land, it is proposed for the purpose of this strategy that the new transformer and switchboard be located at James Street. The proposed connection arrangement is through the transformer onto one of the existing MLA-MIL 132 kV circuits with a potential switch capability onto the adjoining circuit as shown in Figure 18.



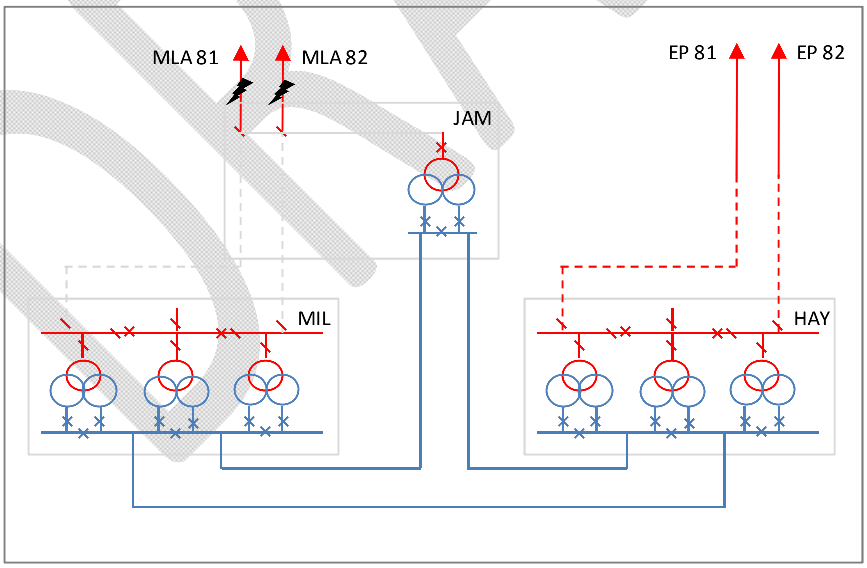
- **Figure 18 Proposed James Street Single Transformer and Switchboard Arrangement**

This approach minimises switchgear requirements and minimises site size. In effect the James Street site will become an extension of the Milligan Street substation (by being fed from the same 132 kV connection)to allow the transfer of load for asset replacement and to allow existing distribution feeders to be loaded greater to realise the potentially stranded substation capacity. Such an approach is suitable for N-1 contingencies, however it is not N-2 secure under specific contingencies - as further discussed in Section 7.3.6. The practicalities and restrictions in the ducting through Perth City (Northbridge) Link and location of Hay Street to Milligan Street distribution cabling that can be accessed also requires further investigation by Western Power.

7.3.6. N-2 Security of Infeeds

Load within the Perth CBD boundary is required to be N-2 secured at a transmission level in accordance with the Technical Rules. Much of the load within this boundary is supplied from the Hay Street and Milligan Street Substations which have significant interconnections at a distribution level as seen in Appendix E. Presently, each of these substations is supplied through a 132 kV double circuit to East Perth and Mount Lawley respectively. Under an N-2 contingency of one of these double circuits, the 132 kV busbar and 132/11/11 kV transformers at the respective substation will become unsupplied. Under this condition, the load is supplied from the interconnected distribution network, primarily from the opposing Hay Street or Milligan Street Substation. The Technical Rules allow two hours for this transfer to be carried out.

In order to allow the greater loading of existing 11 kV distribution feeders to combat congestion and also to facilitate the asset replacement of the Hay Street and Milligan Street Substations it is proposed that a single transformer and switchboard be installed at an external site, suggested as James Street. The advantages provided by such a solution in addressing these limitations are seen in Section 7.3.5 with the proposed connection arrangement seen in Figure 19. Such an arrangement is suitable for N-1 contingencies and N-2 contingencies of transformers or the EP-HAY double circuit, but is not secure for an N-2 contingency of the MLA-MIL double circuit as shown in Figure 19.



▪ **Figure 19 N-2 Contingency of MLA-MIL with James Street Proposal**

As the direct DTC has been broken between Hay Street and Milligan Street in order to allow load to grow on existing feeders and also facilitate switchboard replacements, an N-2 contingency of the MLA-MIL 132 kV circuits under this connection arrangement would result in load between James

Street and Milligan Street being unsupplied where the majority of which is likely to be within the Perth CBD boundary. It is assumed that the feeders from Hay Street to Milligan Street and James Street are fully loaded under these conditions and cannot feed any of the loads between Milligan Street and James Street.

In order for the load within the Perth CBD boundary to be secured to N-2 at a transmission level an alternative connection arrangement is required such as:

- James Street Substation connected to an alternative 132 kV infeed
- 132 kV cable between the Hay Street and Milligan Street Substations

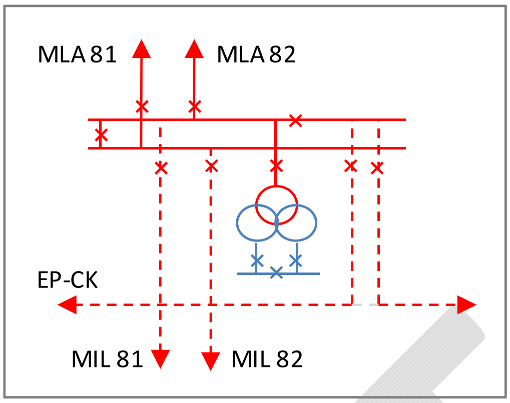
Alternative James Street Substation connection arrangement

It is evident that the proposed connection arrangement shown in Figure 19 is not suitable for fully supporting N-2 load within the Perth CBD boundary. An alternative connection arrangement is required which is not an existing connection to the Hay Street or Milligan Street substations.

One solution could be to cut into the existing EP-CK 132 kV cable which routes along the James Street substation boundary. There are however restrictions on the utilisation of this circuit due to its support of Western Terminal during N-1-1 contingencies. Load from the James Street transformer should not therefore be directly applied to this circuit under normal operation so as to prevent an overload of the circuit under an N-1-1 contingency of SF-AMT and NT-WT (seen in 2022)[35].

A potential solution would be for the transformer at James Street to be connected to the MLA-MIL 132 kV circuits as shown in Figure 19 under normal conditions. Should an N-2 event occur on these circuits, the transformer is switched over to the EP-CK circuit cut in. Such a solution would require an extended busbar structure to be constructed with multiple switchgear elements and the reliance of an auto-switching protection and operation scheme if the scheme was to be fully automated. The capital cost of a fully switched arrangement including structures, associated switchgear and cable cut in with the highlighted arrangement shown in Figure 20 (excluding the direct transformer costs) is some $[redacted]M.

[35] Should reinforcement of the SF-WT circuits occur, the N-1-1 loading of the EP-CK circuit will reduce which may make this solution more attractive.



- **Figure 20 EP-CK Cut in Arrangement for Costing**

Alternatively a new 132 kV feed to James Street Substation could be constructed which would be sourced from East Perth Terminal due to proximity and the minimised impact on existing circuits in the CBD Load Area. Such a connection would however require some 3.3 km of 132 kV cable to be installed at a cost of approximately $[redacted]M in a transformer feeder arrangement.

132 kV cable between Hay Street and Milligan Street Substations

An alternative to supporting the transmission connection at the James Street site is to support the Hay Street or Milligan Street substations from another location. The most efficient and effective approach to this would be through the installation of a 132 kV cable between the two sites due to their proximity. The SKM report 'Review of Planning Philosophies' has indicated the efficiencies of this type of solution [2]. Such an approach would overcome the isolation of distribution feeders between Milligan Street and James Street Substations under an N-2 contingency of the incoming double circuit to Hay Street or Milligan Street substations by providing an additional infeedthrough the transmission network rather than the distribution network with DTC, as is currently employed.

The Hay Street and Milligan Street substations currently have the structures and disconnectors in place to accept a 132 kV cable resulting in the requirement for the cable and installation only. The distance between the substations is approximately 1.2 km; however the length of cable required will be dependent on the route taken.With an assumed route length of 1.2 km, the capital cost of the cable is some $[redacted]M.

To confirm the technical viability of a HAY-MIL 132 kV cable load flow studies have been carried out and have illustrated that no significant or problematic through flows are seen under intact conditions up to expected load growth in 2036. Further analysis of the effect of this cable for the wider transmission network and the performance under generation and load sensitivities is provided within Section 10. A potentially detrimental effect of the cable on the transmission network is an increase in fault level contribution, particularly at the Hay Street and Milligan Street substations as illustrated inTable 18. Review of the potential increase in fault levels at these substations has indicated that fault levels are not expected to become excessive or reach equipment ratings as a result of the HAY-MIL 132 kV cable.

- **Table 18 Fault Level Impact of HAY-MIL 132 kV Interconnection: 2020/21**

Substation	Voltage (kV)	New Three Phase Fault Current (kA)	Approximate Increase in Fault Contribution (kA)	Existing Switchgear Rating (kA)
HAY	132	24.1	2.4	34.6 / 40
MIL	132	23.5	5.6	31.5 / 40
EP	132	25.0	1.4	31.5 / 40 / 50

Additionally, an interconnecting cable between these substations has significant wider system advantages relating to managing power flow through the CBD Load Area. This is particularly effective if a quadrature booster is installed with the cable to control the power flows with a potential deferral of East Perth infeed reinforcements. Further details of these advantages are provided in Section 10.4.2.

Summary

This section has assessed a number of options to allow the continued N-2 security of the Perth CBD boundary load following the installation of a transformer at the proposed James Street site to combat distribution feeder congestion and facilitate asset replacement at the Hay Street and Milligan Street substations. This has included utilising the EP-CK 132 kV cable circuit which routes in front of the James Street site, a new 132 kV infeed to the James Street site or an interconnecting 132 kV cable between the Hay Street and Milligan Street substations.

It has been identified that an interconnecting HAY-MIL 132 kV cable is the least cost solution primarily due to the existing structures in place to accept such a connection at both substations. This solution is also the simplest from an operations perspective, without the requirement for an auto-switch scheme or extensive manual switching. Other significant advantages regarding the control of power through the CBD Load Area have also been identified in Section 10.4.2. Although fault levels will increase with the installation of such a 132 kV cable, the resultant fault levels will still be within the existing equipment ratings.

With these technical and economic advantages it is proposed that an interconnecting 132 kV cable between the Hay Street and Milligan Street substations be installed in conjunction with the transformer works proposed for the James Street site as described in Section 7.3.5. As such, the interconnecting 132 kV cable is proposed in service in 2016/17 to allow continuous N-2 security to Perth CBD boundary load.

7.3.7. Hay Street and Milligan Street End of Life

The Hay Street and Milligan Street substations were constructed in the mid 1970s. It is therefore expected that the end of transformer asset life at these sites will occur in the mid 2020s. It is already noted that the 11 kV switchboards at these sites are of poor condition and a strategy is therefore required to facilitate the reconstruction of these substations as the transformers also approach the end of life. For the Milligan Street substation this is expected in 2023 and 2027 for the Hay Street substation.

A number of strategies have been considered to facilitate the end of life of these substations:

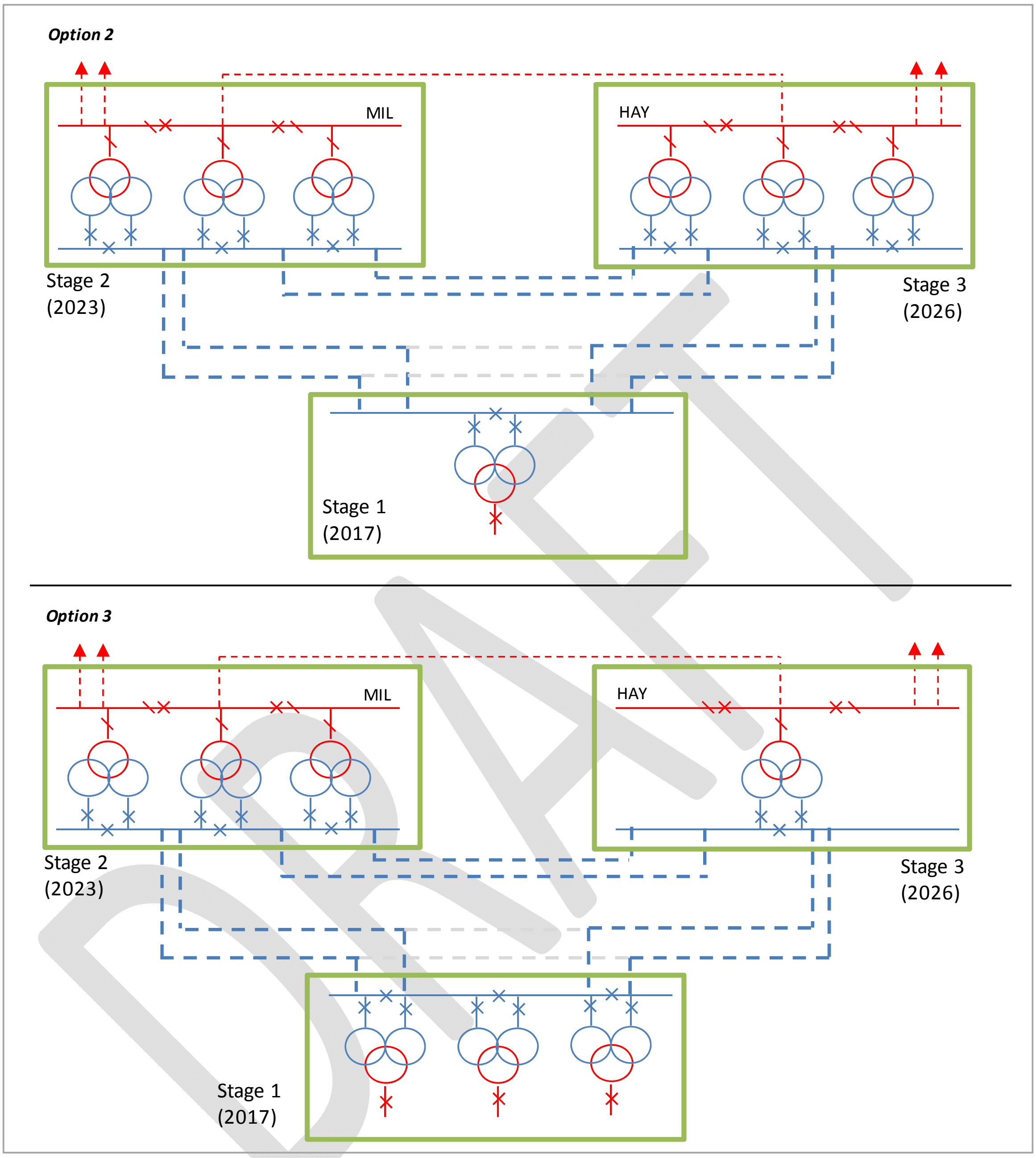
1) Rebuild Hay Street and Milligan Street Substations in-situ
2) Rebuild Hay Street and Milligan Street Substations in-situ with new switchboard and single transformer at other Western Power owned land
3) Build new zone substation at other Western Power owned land, in-situ rebuild of Milligan Street Substation and partial rebuild of Hay Street Substation

It has been outlined in Section 7.3.5 that the significant advancement costs of Option 1 make this an unattractive solution, particularly compounded with the likely level of risk involved during construction in securing supply of load. It has already been demonstrated that a new switchboard and transformer at a new location will provide significant assistance in relieving distribution congestion with minimal cost. In conjunction with an interconnecting 132 kV cable between the Hay Street and Milligan Street Substations, the N-2 security of the Perth CBD boundary can be retained whilst the reconstruction of Milligan Street Substation is carried out. With this in mind, Option 1 has been discounted from further analysis with Options 2 & 3 carried forward for further study.

Option Analysis

Option 2 utilises the new switchboard and a single transformer to provide support to the full reconstruction of Milligan Street Substation. Following these works a full reconstruction of Hay Street Substation would be carried out.

In comparison, Option 3 constructs a new zone substation of equal capacity to Milligan Street Substation offline to allow the full reconstruction of this substation. Following these works only a single transformer and associated switchboard would be installed at the new Hay Street substation. The three stages of each of these options are illustrated in Figure 21.



▪ **Figure 21 Hay Street and Milligan Street – End of Life Options**

An estimated capital cost of both developments as calculated from the building block costs is $[redacted]M. Based on the timings illustrated in Figure 21, Option 2 has an NPC of $[redacted]M, whilst Option 3 has an NPC of $[redacted]M. Therefore, from an NPC perspective, Option 2 is preferred over Option 3, with the difference in Net Present Cost being $[redacted]M. Note that this does not include any distribution transfer costs which are expected to be comparable in both options.

In addition to a reduced NPC, Option 2 is preferred on a number of other metrics as indicated in Table 19.

- **Table 19 Comparison of Hay Street and Milligan Street Reconstruction Options**

Metric	Option 2	Option 3
NPC	$[redacted]M	$[redacted]M
Deliverability	Single transformer and switchboard installation in the short term	Full N-2 three transformer substation required in the short term
Strategy	Full rebuild of Hay Street and Milligan Street substations which are in strategically advantageous locations to serve existing and expected new load	New N-2 three transformer substation to be constructed in a new location which is likely to be in a less advantageous location to serve Perth CBD boundary load
Transmission Network Security Requirements	Single transformer is likely to be backed up primarily from the distribution network so minimal transmission network infeeds required	New N-2 three transformer substation to be constructed in a new location which will require three transmission infeeds. This may require new transmission circuits to be installed
Distribution Transfers	Minimal transfers required to new single substation site	Full N-2 substation load to be transferred to new three transformer site
Construction Difficulty	Requires the full rebuild of the Hay Street substation which is a constricted site	New N-2 substation constructed on a cleared site with much reduced construction difficulty

For the reasons noted above it is proposed that Option 2 is selected to facilitate the reconstruction of the Hay Street and Milligan Street Substations. This option involves the installation of a single transformer and switchboard at a new site as detailed in Section 7.3.5. It also addresses the congestion restrictions at these substations in the shorter term.

Site Location

As noted in Section 7.3.5, land is currently available at James Street and prospectively Wellington Street following decommission of the 66 kV assets at that location as described in Section 7.3.2. Both sites are currently the location of double circuit 132 kV cable sealing ends with those at James Street feeding Milligan Street and those at Wellington Street feeding Hay Street.

It is assumed that the Milligan Street substation assets are to be replaced before those at Hay Street due to the poorer condition at this site. Based on the location of the James Street and Wellington Street sites, it would appear at first pass that James Street is most appropriate for the single transformer site to facilitate this initial support to Milligan Street. Table 20 provides a further high level comparison of the James Street and Wellington Street sites for their suitability to support the rebuild of the Milligan Street substation with the installation of a single transformer and switchboard.

Table 20 James Street vs. Wellington Street

Metric	James Street	Wellington Street
Land Availability	Significant cleared land available	Minimal cleared land available at the front[36] and rear of the site until the removal of the 66 kV assets
Distribution Cabling	Assumed 16 ducts available across the railway, through the Perth City (Northbridge) Link development	Restriction on future cabling across the railway
Existing Transmission Structures	Busbar not present	Busbar not present
Existing Transformer Circuits	No existing structures	66/11 kV transformers being decommissioned. Structures not suitable for 132/11(22) kV

From a high level perspective James Street is the preferred site for the single transformer and switchboard. This is principally a result of proximity of James Street to the existing Milligan Street substation which is proposed to be replaced before the Hay Street substation. Other advantages of the James Street location include the existing availability of land and the proximity to forecasted new load at Perth City (Northbridge) Link.

7.3.8. EP-HAY 81 & 82 132 kV Cables: Limiting Element

The existing EP-HAY 132 kV double circuit has a significantly reduced capacity limiting section between the cable sealing ends at Wellington Street Substation and terminations at Hay Street Substation. The 132 kV cables are some 34 years old, of an oil filled construction with a conductor cross-sectional area of 625 mm^2 and a combined length of 1 km. Currently these cables are the limiting component in the EP-HAY circuits with a maximum capacity of some 110 MVA each, whilst the remainder of each circuit to East Perth is rated to some 240 MVA.

These circuits are required to support both the Hay Street and Milligan Street substation load following an N-2 contingency of the MLA-MIL circuits. It is forecasted that by 2022, the combined load at these substations will exceed 220 MVA and subsequently the combined capacity of the EP-HAY cables in question. It is therefore proposed that this short length of limiting component cable be replaced with 2000 mm^2 XLPE 132 kV cables to increase capacity of each cable to 240 MVA to match that of the remainder of the circuit[37]. Such a replacement will allow the N-2 transmission circuit support of the Hay Street and Milligan Street substations to be in excess of the N-1 capacity of 150 MVA at each substation.

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[36] It should be noted that the use of a quad booster on the proposed HAY-MIL 81 cable has been seen to provide wider system benefits (see Section 10.4.2). It is currently proposed that such an asset would be installed in the land at the front of Wellington Street substation as the cable is likely to route in this vicinity.

[37] Studies have illustrated the suitability of such cables.

With the current load forecast it is proposed that this cable uprate is implemented by 2022 at an estimated capital cost of $[redacted]M.

7.4. Summary of Load Area Projects

The expected limitations in the CBD Load Area over the next 25 years have been identified and a number of projects proposed and analysed to overcome each limitation. This has resulted in the derivation of preferred projects based on a number of analysis metrics including cost, deliverability, technical benefits achieved plus other tangible and intangible factors. The favoured individual projects are summarised as:

- Installation of a third transformer at Cook Street
- Complete the conversion of Joel Terrace to 132 kV operation
- Construct a new Bennett Street substation and associated double 132 kV circuit to East Perth
- Extend the East Perth 132 kV Switchyard
- Install a single transformer and switchboard at James Street
- Install a 132 kV cable between the Hay Street and Milligan Street Substations
- Balance load at North Perth and utilise Joondanna for future load growth
- Uprate the EP-HAY 81 & 82 132 kV cables
- Rebuild Milligan Street Substation
- Rebuild Hay Street Substation
- Installation of a third transformer at Joel Terrace

The combination of these projects over the 25 year horizon has been demonstrated to provide an effective approach to alleviating the forecasted limitations. The deployment of such projects will provide significant long term benefits to the security and demand growth of the CBD Load Area.

Currently these favoured projects have been assessed in a relatively independent approach with little consideration of the impact of each project on another. It is however necessary to consider the full staging and deliverability over the 25 year strategy period which will tie these projects together. Section 11 provides this analysis whilst illustrating project risks, potential mitigation measures and enabling works. In addition the impact of sensitivities, such as changes in load demand and deliverability, are assessed to illustrate the robustness of the strategy.

8. Emerging Limitations – CBD Load Area Supplies

This section details the emerging limitations associated with the transmission system supply to the CBD Load Area over the periods 1-10 years and 11-25 years, with particular focus on transmission system underground cable and overhead line circuits supplying the CBD Load Area. Substation capacity and asset limitations within the CBD Load Area have been discussed within Section 6.

8.1. 1-10 Years

The short to medium term limitations associated with the existing Western Power Network transmission system supplying the CBD Load Area across a 10 year outlook are detailed in Western Power's TNDP. This section summarises the limitations that have been identified in relation to transmission supplies to the CBD Load Area.

8.1.1. Transmission Network Capacity

Referencing the current 2011/12 TNDP there are a number of network limitations that are expected to occur over the period 1 to 10 years that impact on CBD Load Area transmission supplies. These include:

- ST-EP 132 kV circuit (81 or 82) for the loss of the other (82 or 81) as well as the loss of the SF-AMT 132 kV circuit
- SF-AMT 132 kV circuit following loss of either ST-EP 132 kV circuit (81 or 82)
- WT-CK 132 kV circuit for the loss of the SF-AMT 132 kV circuit whilst the NT-WT 132 kV circuit is undergoing maintenance, or vice versa, at 80% system loading
- 132 kV sub-transmission network North of Cannington Terminal, following the loss of a number of 132 kV circuits in the same network. Through power flows from Belmont to East Perth, and to Northern Terminal, under low northern generation conditions exacerbates this problem
- Various ST-CT 132 kV circuits including both the direct and indirect connections, following loss of a number of transmission elements that make the ST-KNL 330 kV connection, as well as the KNL-CT 132 kV connection overload. Issues arise under N-1 and N-1-1 conditions from 2016/17 onwards
- NT-BCH 132 kV circuit following loss of the MLA-MO 132 kV circuit and vice versa
- NT-MLA 132 kV circuit following loss of a parallel circuit.

Of particular relevance to this study are the limitations identified in relation to the ST-EP 132 kV circuits and the WT-CK 132 kV circuit expected around 2014/15 and 2015/16 respectively.

8.1.2. Transmission Substation Issues

In addition to the CBD Load Area transmission network limitations identified in the TNDP a number of substation issues are also identified. These include:

Substation voltage limits

- There is expected to be a deficit in reactive power reserve at East Perth Terminal from summer 2014/15 onwards due to forecast area demand growth.
- Similar to the issues at East Perth, Southern Terminal, Cannington Terminal, Northern Terminal and Western Terminal are all expected to have a deficit of reactive power reserve by summer 2013/14, 2014/15, 2014/15 and 2017/18 respectively.

Substation fault levels

- 132 kV fault levels are high at the Northern Terminal substation and forecasted to exceed switchgear ratings around 2014/15 without concomitant action.
- 132 kV fault levels are also high at the Southern Terminal substation. Although series reactors are connected between 132 kV busbar sections, fault levels have risen to excessive levels.

Of the above issues, the potential deficit of reactive power reserve at East Perth is the most relevant for this study as any such deficiencies in relation to meeting load area requirements (for reactive power) will result in this being imported to East Perth from neighbouring terminal substations. This will depress the East Perth Terminal 132 kV voltage and restrict MW power flow transfers across incoming transmission circuits, potential accelerating the need for capacity augmentation.

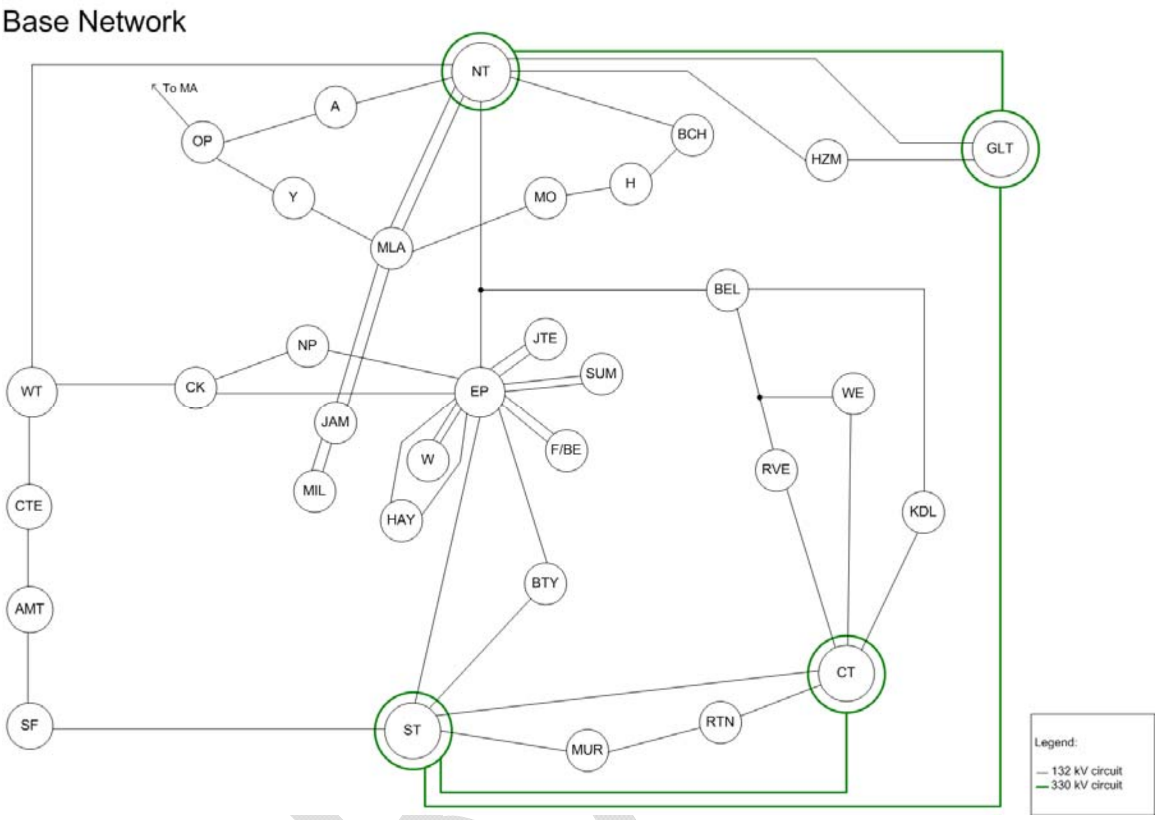
The identified high system fault levels at Southern Terminal and Northern Terminal are of less significance in this study although careful consideration will need to be given to potential fault level impacts at these substations of any further transmission circuits linking these terminal substations with neighbouring substations.

8.2. 10-25 Years

At present time there are no detailed longer term plans for capital expenditure and network reinforcement for the Western Power transmission network supplying and surrounding the CBD Load Area. As a result, for the purpose of this study analysis has been undertaken with a smaller focussed sub-network in order to identify potential future network limitations for the period up to 25 years. The results of this analysis are presented and commented on in this section.

8.2.1. Transmission Network Modelling

In order to identify potential future network limitations, a sub-network of the entire Western Power Network was developed in DIgSILENT power system analysis software focussing on the key 132 kV transmission network supplying the CBD Load Area and the immediate vicinity. The broader 330 kV network was also modelled given the limited extent of that transmission system across the Western Power Network. A summary of the key terminal substations and transmission circuits of interest in this study is shown in Figure 22. The full extent of the DIgSILENT developed model covers more of the Western Power Network where required.



■ **Figure 22 SLD for Reduced Western Power Network Model**

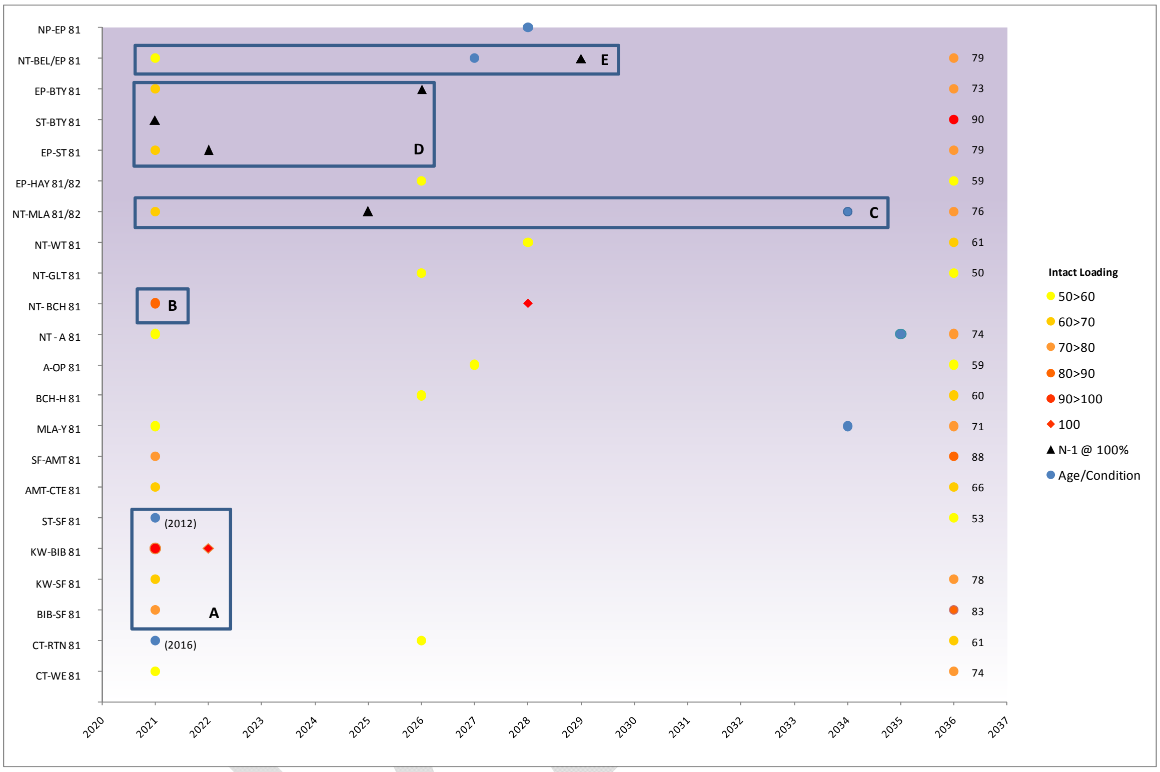
It should be noted that although Wellington Street and Forrest Avenue Substations are presently supplied at 66 kV, for the purpose of this study, as they are radially fed from East Perth, they have been added as equivalent 132 kV loads and hence are shown as such in Figure 22 and within the DIgSILENT model.

Using the reduced model the existing Western Power 25 year demand forecast was adopted to undertake load flow studies for key future years of 2021, 2026, 2031 and 2036, the end horizon year for this study. The ROAM Consulting Scenario 20 [23]was used as the base generation scenario for this analysis.

By taking the base network model (as used for year 2020 analysis under AA3, but without AA3 modifications) the potential loading on key transmission circuits in and around the CBD Load Area was determined under N and N-1 conditions (key CBD Load Area supply circuits only). The results are shown in Figure 23for all circuits with a loading of 50% or more.

Note that line loadings for intermediate years not studied were obtained by interpolation.

N-1-1 and N-2 investment drivers for CBD Load Area transmission circuits are also not studied here but are considered for the preferred subset of reinforcement options in the sensitivity analysis presented in Section 10.



- **Figure 23 Expected Loading of Key Transmission Circuits in Vicinity of CBD Load Area**

From review of Figure 23and the grouped loading / condition drivers (boxes A to E) a number of conclusions can be made:

1) The BIB-KW 132 kV circuit is approaching its thermal rating in 2021 under intact system conditions. Additionally, the neighbouring 132 kV circuits (KW-SF, BIB-SF and ST-SF) are also likely to need replacement / upgrading to cater for expected demand growth and asset condition (Box A) around 2020.

2) The NT-BCH 132 kV overhead line (Box B) is expected to reach 100% of its thermal rating (210 MVA) around 2028 under intact network conditions. Under line outage conditions, specifically an outage of the MLA-MO circuit, the NT-BCH line will exceed 100% of its thermal rating pre-2021.

3) The NT-MLA 132 kV overhead lines (Box C) are expected to reach 76% of their thermal rating by the end of the strategy period, 2036. Each circuit is expected to be overloaded for an outage of the other at peak demand from 2025 onwards.

   Additionally, both circuits are expected to reach the end of nominal asset lifetime towards the end of the strategy period, by 2034.

4) The existing ST-EP 132 kV double circuit overhead line (Box D) is expected to be loaded to around 67% by 2021, with the ST-BTY line section loaded to 77%. Crucially, this is under intact system conditions. For an outage of the ST-EP circuit the loading of the ST-BTY circuit is expected to exceed 100% of thermal rating by 2021 with the loading of the ST-EP and EP-BTY circuits exceeding 100% of rating under line outage events within the subsequent five years.

5) The NT-BEL/EP circuit (Box E) is expected to exceed the circuit thermal rating (207 MVA) under N-1 conditions by 2029, around a few years later than the notional end of useful life for this circuit (being 60 years old) in 2027.

   It should be noted that the NT-BEL/EP line is expected to be the final CBD Load Area circuit to exceed its thermal rating under N-1 conditions, all four other CBD Load Area circuits (from Southern Terminal and Mount Lawley) exceed their corresponding thermal rating much earlier without additional transmission capacity.

6) Asset age and condition is not expected to be a significant driver for asset replacement over the considered strategy period, as would be expected based on the asset age profile outlined in Figure 4.

7) The exception are the seven transmission circuits shown in Figure 23 with a blue dot indicating the expected end of asset life before 2036. Of these, the most relevant for this study are the NT-MLA 132 kV circuits and the NT-BEL/EP 132 kV and NP-EP 132 kV circuits, expected to reach end of nominal asset life in 2034, 2027 and 2028 respectively.

8.3. Previously Identified Transmission Reinforcement Projects

In addition to the current Western Power TNDP outlining known and expected transmission network limitations across the Western Power Network going forward, the TNDP also outlines potential solution options to address the identified limitations. In relation to the network limitations presented in Sections 8.1 and 8.2 Western Power have identified the following capital investment projects, although not yet committed, that will directly impact on this study. These include:

Cannington Terminal

- Establish 330 kV switchyard with 2x 490 MVA 330/132 kV transformers with one relocated from Kenwick Link – 2019/20
- Install 120 MVAr capacitor bank – 2014/15
- Northern Terminal – Belmont / East Perth overhead line reconfiguration and special protection scheme – 2012/13

East Perth

- Install 120 MVAr capacitor bank – 2014/15

Northern Terminal

- Installation of a special protection scheme to allow Northern Terminal 132 kV busbar sections to operate independently under normal system conditions – 2014/15
- Installation of a 330 kV Static VAr Compensator – 2015/16
- Establish new 132 kV circuit between Northern Terminal and Hadfields Substation – 2018/2019

Southern Terminal

- Install 120 MVAr capacitor bank – 2013/14
- Establish Southern Terminal to Bibra Lake 81 & 82 circuits as part of the South Metro Reconfiguration Project – 2015/16
- Convert Southern Terminal to South Fremantle 132 kV split phase circuit to double circuit – 2017/18
- Convert Southern Terminal to Cannington 132 kV circuit to double circuit using high temperature conductor – 2019/20
- String second Southern Terminal to Cannington 330 kV circuit – 2019/20
- Installation of a special protection scheme on Southern Terminal 132 kV busbar sections – 2014/15

Western Terminal

- Install 90 MVAr capacitor bank – 2017/18

Additionally, the long term strategy report developed for Western Terminal [24] identified that reinforcement of the transmission supply to Western Terminal would be required to maintain N-1-1 compliance around 2017/18. Although a detailed assessment of all options has not yet been completed the preliminary assessment has indicated the lowest cost solution to achieve long term N-1-1 compliance at Western Terminal will be a second WT-CK (82) 132 kV circuit. It is considered for this analysis that this capital investment project will be implemented in preference to the second SF-CTE 132 kV transmission circuit proposed in the TNDP which is likely to be significantly more expensive and harder to achieve planning and consenting for given the coastal locations.

The recently completed Northern Terminal long term strategy report [18] identified reconfiguration and network reinforcement requirements for this load area over the coming years. Relevant to this CBD Load Area strategy report are two key recommendations:

1) A new NT-MO 132 kV transmission circuit, circa 8 km, would be constructed between in 2015.

   Note that the end point for this circuit (Morley) identified from the Northern Terminal study is different from the Hadfields location indicated in the TNDP due to the later completion of the former study.

2) Consideration should be given to reconfiguring the MO-Y 132 kV circuit which forms part of the BCH-A 132 kV ring out of Northern Terminal to by-pass the NT-MLA-MIL 132 kV circuits. This will free up the NT-MLA 132 kV circuits to provide a dedicated transmission infeed to the CBD Load Area.

   Further study and analysis is however required in order to confirm that this recommendation is practical and can be delivered without undue impact on the Yokine / Arkana / Beechboro 132 kV ring system.

The impact of the proposed special protection schemes proposed to be installed at Northern Terminal and Southern Terminal (along with accompanying area network reconfigurations in both cases) to address high fault levels is also shown in Table 21.

- **Table 21 Projected 2015/16 CBD Load Area & Surrounding Terminal Substation Short Circuit Currents**

Substation	Voltage (kV)	Single Phase Fault Current (kA)	Three Phase Fault Current (kA)	Existing Switchgear Rating (kA)
East Perth	132	25.1	22.5	31.5 / 40 / 50
East Perth	66	8.0	6.6	25 / 31.5
Northern Terminal	132	31.2	27.4	40 / 50
Western Terminal	132	22.3	19.9	31.5 / 40 / 50
Southern Terminal	132	31.0	27.2	40 / 50
South Fremantle	132	21.9	22.6	31.5 / 40 / 50
Cannington Terminal	132	30.1	26.7	31.5 / 40 / 50

Table 21 details the estimated 2015/16 132 kV fault levels at East Perth and surrounding terminal substations after the proposed investment projects have been implemented. It is evident that once these projects have been implemented the expected fault levels (post-2016) at terminal substations across the wider CBD Load Area are not likely to be problematic. The exception is at Cannington where it is expected that a number of the 132 kV circuit breakers (three oil filled units) rated at 31.5 kA will need to be replaced as part of the establishment of a 330 kV switchyard with accompanying 330 / 132 kV transformers at Cannington expected in 2019/20. However, other terminal substations in the area surrounding the CBD Load Area are not expected to be significantly affected by the potential changes to circuit configurations and impedance values resulting from this work.

8.4. Summary of CBD Load Area and Surrounding Network Limitations

Based on the network limitations outlined in Sections 8.1 and 8.2 for the periods up to 10 years and 11 – 25 years, the key transmission network limitations and reinforcement projects considered within this strategy are as detailed in Table 22.

- **Table 22 Summary of CBD Load Area and Surrounding Network Transmission Supply Limitations & Proposed Solutions**

Network Limitation	Expected Year	Reinforcement Project Proposed
ST-EP 81/82, N-1	2014/15	Further details in commentary below
SF-AMT 81, N-1	2017/18	Further details in commentary below
WT-CK 81, N-1-1	2017/18	New WT – CK 82 132 kV circuit
132 kV network North of CT	2011/12 onwards	Opening Belmont line breaker and special protection scheme
ST-CT 132 kV circuits, N-1 & N-1-1	2016/17 onwards	ST-CT 81 double circuit conversion New ST-(KNL)CT 92 330 kV circuit
NT-BCH 81, N-1	2018/19	New NT – H (MO) 132 kV circuit
MLA-MO 81, N-1	2018/19	New NT – H (MO) 132 kV circuit
Reactive Reserve Deficit	2013/14 to 2017/18	Installation of shunt capacitor banks at various locations
Substation 132 kV fault levels (KW / ST)	2015/16	South Metro Reconfiguration Project
Substation 132 kV fault levels (NT)	2014/15	Installation of special protection schemes on 132 kV busbars at NT to allow unparalleled operation
KW-BIB, KW-SF, BIB-SF and ST-SF 132 kV circuits,	2015/16	South Metro reconfiguration project ST-SF 132 kV split phase conversion
NP-EP 81, age	2028	See commentary below
NT-BEL/EP, age & N-1	2027/29	See commentary below
NT-MLA 81/82, N-1 & age	2025/34	New NT – H (MO) 132 kV circuit & MLA reconfiguration – see NT strategy report

From review of Table 22 it is evident that there are four specific network limitations that are expected to occur over the period 2011 to 2036 that are not addressed by the capital investment projects already highlighted. These are:

1) ST-EP 81/82, N-1 limitations 2014/15

2) SF-AMT 81, N-1 limitations 2017/18

3) NP-EP 81, end of nominal asset life 2028

4) NT-BEL/EP, end of nominal asset life in 2027 & N-1 limitations 2029

ST-EP 81/82 132 kV Circuits

Of the above limitations the expected overloading of the ST-EP 132 kV circuits under various N-1 outage conditions is potentially the most problematic. The TNDP highlights how these circuits are expected to be overloaded under N-1 contingencies from 2014/15 onwards under certain generation operational conditions (high southerly generation dispatch). Our own analysis with the central Roam Consulting Scenario 20 demand and generation profile (mid-high northern generation scenario) have identified that these circuits will also be expected to be overloaded by 2021 under N-1 contingencies. Collectively this indicates that, depending on generation developments and dispatch requirements, the ST-EP 81 & 82 132 kV circuits could need reinforcement as soon as within the next three or four years, i.e. 2015/16.

There are a number of potential options available to defer the need for significant reinforcement / upgrade of the existing ST-EP 81 & 82 132 kV circuits, including the installation of the Belmont substation special protection scheme in 2012/13 as outlined in the TNDP. Western Power engineers have also identified benefits to upgrade part of the 66 kV network in the Cannington Load Area around the Clarence and Collier substations to 132 kV as part of an aged asset and capacity reinforcement strategy. This strategy uses Bentley Substation, together with a new substation site at Kensington to consolidate load from various substation sites. The strategy involves resupplying Bentley via 132 kV from Cannington and extending circuits from Bentley to Kensington to supply the new substation. This would remove the Bentley load (circa 30 MVA) from the ST-EP 132 kV circuits. This would be sufficient to cater for increased CBD Load Area demand for approximately another two years, to around 2016/17 under high southerly generation dispatch conditions or potentially to around 2023 under more Northerly generation (as per the Roam 20 Scenario).

An alternative option is to upgrade the capacity of the existing ST-BTY-EP 132 kV circuits – see Appendix G. This option would also yield a circa 30 MVA increase in line thermal capacity. However, uprating the double circuit overhead line would result in numerous and lengthy outages of each, and sometimes both main circuits to yield the increased line rating. This would result in significant disruption and would also leave East Perth, including Hay Street, Wellington Street and Forrest Avenue substations supplied from Northern Terminal and via Western Terminal for extended periods.

Therefore, for the period up to 2020 in this strategy development it is considered that the proposed Belmont special protection scheme (as outlined in the TNDP) plus the reconfiguration of the Kensington and Bentley supplies within the Cannington load area will be sufficient to defer the need for reinforcement of the ST-EP 132 kV circuits until around 2020. For the period 11-25 years (from 2021 onwards) consideration will be given to the augmentation of the CBD Load Area supply capacity with one or more additional 132 kV circuits from another terminal substation e.g. Northern Terminal, Western Terminal, Southern Terminal, Cannington Terminal. This will be one of the principal aims of the CBD Load Area transmission supply option development discussed in the following sections of this report.

SF-AMT 81 132 kV Circuit

One of the projects identified in the current Western Power TNDP is the reinforcement of the SF-WT 132 kV circuit, essentially developing a second 132 kV circuit using the aged and redundant 66 kV overhead line routes between the two terminal substations. This project is intended to have two purposes. Firstly, it will provide an additional 132 kV infeed to Western Terminal in order to maintain N-1-1 compliance (see Section 8.1.1) and secondly it will reinforce the existing SF-WT 132 kV circuit route in conjunction with the Belmont special protection scheme, which is expected to become overloaded under outages of one of the ST-EP 132 kV circuits in future years.

As outlined in Section 8.3, an alternative and preferred option to providing N-1-1 compliance at Western Terminal is to install a second CK-WT 132 kV circuit. This means that the only requirement for the second SF-WT 132 kV circuit will be to address the potential future overload of the existing circuit routes between the two substations under network outages conditions (particularly under high southern generation dispatch). However, as additional transmission infeeds to the CBD Load Area will be explicitly assessed to alleviate the expected future overloading of the ST-EP 132 kV circuits, it is no longer necessary to continue with consideration of the second SF-WT circuit, at least until such time as additional transmission supply options to the CBD Load Area have been appropriately considered and assessed as these are likely to address the issues identified on the SF-WT 132 kV circuit route over the short to medium term. Reinforcement along this route, i.e. between South Fremantle and Amherst Substation, may still be necessary over the long term, however this will not be considered further in this CBD Load Area transmission strategy document.

NP-EP 81 & NT-EP/BEL 81 132 kV Circuits

Both of these circuits are expected to reach the end of nominal asset life within twenty years, i.e. around 2027/28. Additionally, the NT-EP/BEL 132 kV circuit is also expected to exceed its thermal rating under N-1 contingencies around 2029.

In relation to the development of a long term strategy for the CBD Load Area it is assumed that the NP-EP 132 kV circuit will be replaced around 2028.

For the NT-EP/BEL 132 kV circuit, as consideration will be given in the subsequent sections of this document to potential new transmission supply options for the CBD Load Area, a sensitivity analysis will be carried out to determine if this circuit actually requires to be rebuilt once a preferred subset of CBD Load Area transmission supply options have been developed and assessed.

Summary of Baseline Transmission Network Projects

Based on the review detailed above, and for the avoidance of doubt, we have considered that the following CBD Load Area transmission network reinforcement projects will be in service by 2021.

1) Belmont Special Protection Scheme
2) South Metro Reconfiguration (as applicable to the reduced Western Power Network study model)
3) New WT-CK 82 132 kV circuit

4) ST-CT 132 kV double circuit conversion
5) New ST-KNL 92 330 kV circuit and new KNL-CT 91/92 330 kV cables
6) New 330 kV switchyard at Cannington Terminal with relocated Kenwick Link 330/132 kV transformer
7) New NT-H (MO) 132 kV circuit

These reinforcements will form the baseline 2021 network configuration from which solutions to address the medium to long term CBD Load Area network limitations identified in Figure 23 can be developed.

It should be noted that the proposed new HAY-MIL 132 kV underground cable will not be considered as a baseline 2021 network modification in the development of transmission supply options to reinforce the CBD Load Area. This new cable circuit will however be given specific consideration as part of the subsequent sensitivity analysis presented in Section 10 in relation to the preferred CBD Load Area supply reinforcement options.

9. Development of Supply Options

The previous section of this report detailed the transmission network limitations that are expected to arise in relation to the supply to the CBD Load Area over the coming years.

For the short to medium term (1 to 10 years) a range of specific network limitations and associated capital investment projects have been presented, largely obtained from the Western Power TNDP plus other supporting studies and documents. However, as the TNDP does not cover the medium to long term period of this development strategy (11 to 25 years) we have conducted our own review of network limitations for the period 2021 to 2036. This has identified the following development drivers and network limitations that require to be addressed:

1) ST-EP 132 kV double circuit overhead line, exceeds thermal rating under N-1 contingencies circa 2020
2) NP-EP 132 kV overhead line and underground cable circuit, expected end of asset life circa 2028
3) NT-EP/BEL 132 kV overhead line, expected end of asset life and exceeds thermal rating under N-1 contingencies circa 2027 & 2029 respectively

This section focuses on network solutions to address the above outlined, longer term limitations, and complement the capital projects already identified and presented for the short to medium term as well as the inner CBD Load Area capital investment projects presented in Section 7. Of these, development of solutions to address the ST-EP 132 kV circuit limitations is considered the principal aim of this section, with the other two circuits being considered for like for like asset replacement unless specifically identified otherwise.

The approach adopted in developing solutions to address the ST-EP 132 kV circuit limitations was as follows:

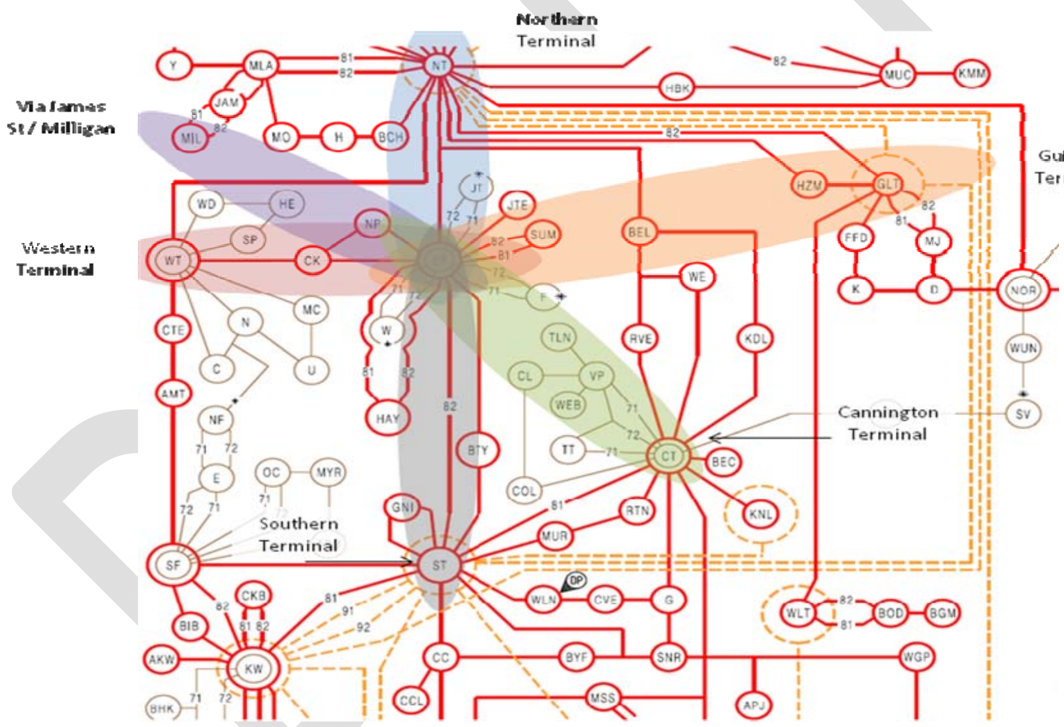
- Generate a range of alternative transmission network reinforcement options to augment the existing CBD Load Area supplies up to 2036
- Identify and develop a range of evaluation criteria to measure the desirability of each option
- Carry out studies and analysis to determine the performance of each supply reinforcement option at 2036
- Rank order and assess the desirability of the developed solutions against the considered evaluation criteria
- Determine a subset of ‘preferred’ options for detailed study of reinforcement project timings, including N-1-1 and N-2 investment drivers, as well as other key sensitivities

These activities are discussed in the following sub-sections.

9.1. Generation of Alternative Supply Options

As outlined, in order to address the expected future thermal loading limitations of the ST-EP 132 kV transmission circuits a range of network reinforcement options for the CBD Load Area were identified. This included direct reinforcements following routes similar to the existing ST-EP 132 kV circuits as well as reinforcement from other terminal substations and even higher voltage supply options.

As part of this process reference was made to the reduced Western Power Network model developed and discussed in Section 8 to identify post-2020 baseline network reinforcements. Using this model and the 2021 network flows a number of alternative transmission supply options for the CBD Load Area were developed based on the principals outlined in the Transmission Architectures section of the SKM ‘Review of Planning Philosophies’ report [2]. For reference, the figure presented in the SKM ‘Review of Planning Philosophies’ study report highlighting potential CBD Load Area transmission supply options is reproduced here as Figure 24.



■ **Figure 24 Outline of Potential Future CBD Load Area Supply Options**

As discussed in the SKM ‘Review of Planning Philosophies’ report [2], Figure 24 highlights the principal transmission corridors available to provide augmentation and reinforcement of the CBD Load Area transmission supply. Using these six key routes eleven potential CBD Load Area transmission supply options were developed to address the identified limitations in relation to the ST-EP 132 kV circuits – see Figure 25. These are described now at a high level, with single line diagrams and detailed commentary for each option present in Appendix H.

It should be noted that transmission assets that are expected to require asset replacement for age or condition related deterioration are assumed to be replaced on a like for like basis unless explicitly stated otherwise.

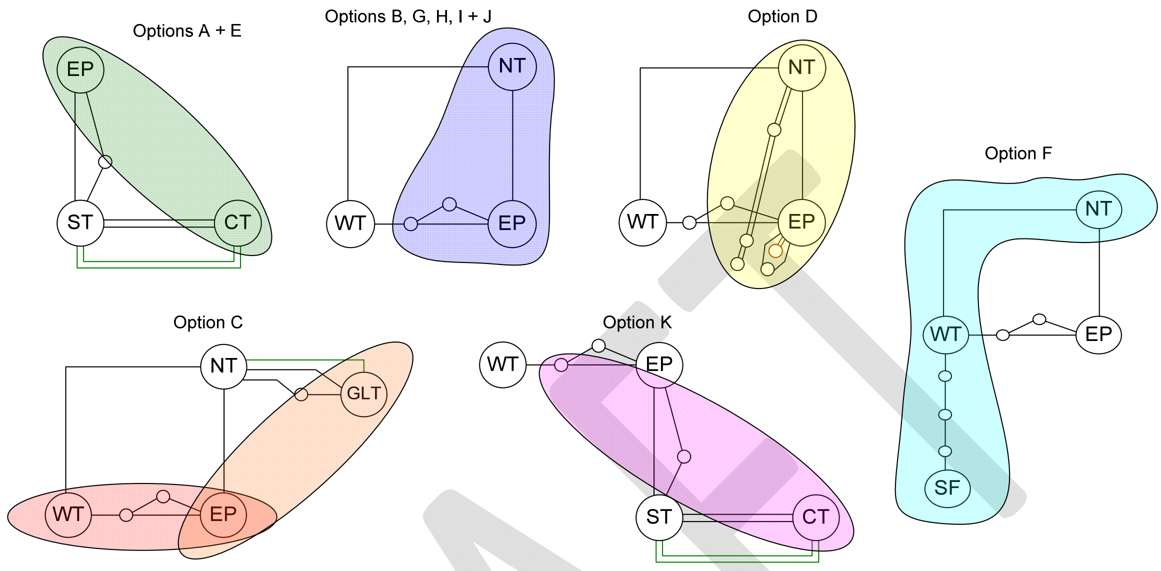


Figure 25 High Level Illustration of CBD Load Area Transmission Supply Options

Option A – East Perth Southern Feed

The principal reinforcement under this option is a new 13.5 km 132 kV double circuit transmission line between Cannington Terminal and East Perth Terminal.

Option B – East Perth Northern Feed

A new 132 kV 15 km transmission line would be installed between Northern Terminal and North Perth Substation under this option, with accompanying reconfiguration of the East Perth Terminal 132 kV switchyard.

Option C – James Street Terminal

Under this option a new CBD Load Area supply substation would be established at James Street with a new 18 km 132 kV transmission circuit from Guilford Terminal. Additional 132 kV interconnection would be provided between East Perth Terminal and Cook Street Substation.

Option D – 220 kV Supply

This option would see the CBD Load Area substations Wellington Street, Hay Street, Milligan Street and James Street supplied at 220 kV from a new 220 kV switchyard established at Northern Terminal. Interconnection to the existing 132 kV transmission system would be provided by step-down transformers at Wellington Street Substation.

Option E – Forrest Avenue / Bennett Street Southern Feed

This option is very similar to Option A except that the new 132 kV transmission circuits from Cannington Terminal would be connected to a new Forrest Avenue or Bennett Street substation in the East Perth Terminal area.

Option F – Western Terminal Reinforcement

This option would see transmission supplies to Western Terminal reinforced at 132 kV from Northern Terminal and South Fremantle to supply the CBD Load Area from the West and complement the existing supply from East Perth substation.

Option G – New Morley 330 kV Substation

This option considers the development of a new 330 kV terminal substation at Morley with accompanying 132 kV transmission infeeds to East Perth Terminal.

Option H – Resupply North Perth

This option is similar to Option B and Option A and would see new 132 kV transmission infeeds to North Perth Substation and one new 132 kV transmission circuit from Cannington Terminal to East Perth Terminal.

Option I – Osborne Park Ring Reinforcement

The principal transmission system reinforcements implemented under this option would be a new 132 kV transmission circuit from Northern Terminal to James Street via Mount Lawley. This would be accompanied by reconfiguration and uprating of sections of the NT-BCH-MLA-OP 132 kV ring.

Option J – Northern Terminal – James Street Loop

This option is a variation of Option H with North Perth supplied directly from a new Northern Terminal (via Mount Lawley) 132 kV transmission circuit. This would result in Cook Street and North Perth moving from the CBD Load Area to the Northern Terminal Load Area.

Option K – Cook Street Supply from Cannington Terminal

This option is similar to Option A except that the new 132 kV circuits from Cannington Terminal would be taken to Cook Street via the Collier and Clarence Street supply area – presently supplied at 66 kV.

9.2. Preliminary Evaluation of Options

Having generated eleven different transmission system options to reinforce the CBD Load Area by 2036 these options were assessed using the reduced transmission system model discussed in

Section 8.2.1. The aim of this assessment was to confirm that the options generated resulted in acceptable 2036 transmission circuit loadings and substation voltages under intact system conditions, as well as key N-1 and N-1-1 / N-2 outage conditions. If any option could not be made to perform satisfactorily against these key metrics without requiring significant additional network reinforcement / augmentation, then such options would be discounted from further consideration. Of the eleven options developed, four were discounted at this stage:

- *Option C – James Street Terminal*

  This option was discounted as fundamentally it did not perform much better than the 2036 base system model with no additional reinforcements (beyond those reinforcements already outlined in Section 8.4) in terms of reducing the loading of key circuits (e.g. ST-EP, ST-BTY, BTY-EP). As a result, significant additional network reinforcement would be required in order to elicit meaningful improvements in network power flows and associated circuit thermal loadings.

- *Option E – Forrest Avenue / Bennett Street Southern Feed*

  Although this option was discounted, it was not because it was considered to offer little benefit over the 2036 base system with no reinforcements (as per Option C). Rather, once the loadings on key transmission circuits were identified under 2036 N-1 conditions, a second 132 kV cable circuit between East Perth and Forrest Avenue / Bennett Street would be required. Essentially this option would become very similar to Option A, albeit with an additional 1.5 km of 132 kV transmission line or cable per CT-EP circuit. As this would increase the capital cost of this option over that of Option A, with little discernable benefit other than diversifying CBD Load Area infeeds to another substation (other than East Perth) this option was discounted.

- *Option I – Osborne Park Ring Reinforcement*

  This option was discounted due to the excessive number of transmission system reinforcements and upgrades necessary to make the option perform adequately from a circuit thermal loading perspective under N-1 and N-1-1 / N-2 contingencies. Required reinforcements included the need for a third JAM-MIL 132 kV cable in addition to the third NT-JAM 132 kV circuit required, plus capacity upgrades of transmission circuits supplying Western Terminal from South Fremantle.

- *Option J – Northern Terminal – James Street Loop*

  Although this option would relocate Cook Street and North Perth substation loads onto a new James Street – Mount Lawley ring, which would reduce the load at East Perth by around 200 MW (2036), it has been discounted on the basis of the results of an initial N-1 analysis. This indicated that a significant number of transmission circuits would require to be upgraded or augmented under N-1 conditions as well as under N-1-1 events in addition to automated transmission system switching for network reconfiguration at several locations e.g. Mount Lawley, James Street, Cook Street and East Perth. As a result of the capital investment required and the potential complexity of the required switching schemes, which offer no benefit over other options considered, it has been discounted from further consideration.

9.3. Detailed Evaluation of Options

The remaining seven options were subjected to a range of technical, economic and environmental assessments in order to determine the desirability and robustness of each option. The metrics developed were then used to rank the options in terms of desirability with a view to selecting a sub-set of options for more detailed analysis, including specific assessment of timing and staging requirements of individual investment projects. The evaluation criteria adopted in this assessment are now briefly outlined.

9.3.1. Option Capital Cost Include condition costs

The estimated capital cost for each option was calculated using Western Power AA3 building block costs for the new transmission system equipment associated with each option, including transmission system overhead lines, underground cables and substation switchgear [15]. Substation transformer costs were also included for options that considered transmission system voltages higher than 132 kV. Other transmission system equipment, e.g. reactive compensation, substation building, civil and structure costs, etc was not included here as the primary focus of this work was the transmission infeeds to the CBD Load Area.

Rebuild costs for the NT-BEL/EP and NP-EP 132 kV transmission lines were also included with all options. Note for the latter only the cost of the overhead line element was included – the underground cable section is not expected to require replacement within this strategy period.

9.3.2. Electrical Losses

To gain an appreciation of the technical efficiency of the resulting CBD Load Area transmission system developed under each option, the electrical losses (MW) at peak load were calculated for the strategy horizon year, 2036.

9.3.3. N-1 System Loadings

The seven remaining CBD Load Area reinforcement options are quite different in operating configuration and resulting power flows. In order to ascertain which of the developed options has the most desirable 2036 network power flows with respect to transmission circuit thermal ratings, a full N-1 assessment was performed for each option.

The results of N-1 analysis are often used to determine the extent of further network reinforcements required to maintain compliance with the Technical Rules, and hence additional capital investment requirements. In this instance a different approach was adopted as it was felt there was little use in optimising the design and configuration for options that did not intrinsically perform well against a broad range of evaluation criteria. As a result, the N-1 study data was used to develop a weighted value representing the overall loading across transmission circuits in each option. This had the benefit that the desirability of each solution with respect to N-1 system power flows and concomitant thermal loading issues could be assessed without necessitating further iterations of solution option development and assessment.

The analysis was undertaken in DIgSILENT using the reduced Western Power Network model for 2036 with the Roam 20 Scenario outlook with all transmission circuits subjected to N-1 contingency outages. The loadings on all other network circuits were monitored during each contingency and all circuits with a post-event thermal loading of 85% or above identified. Further thermal rating thresholds of 90%, 95% and 100% were also considered.

Collectively the four rating thresholds were used to calculate a weighted average loading for all circuits above 85% in each option, expressed relative to the option with the greatest number of circuits over the 85% threshold[38]. This approach enables options with a smaller number of highly loaded circuits or options with a higher number of more lightly loaded circuits to be appropriately assessed and not unduly discriminated against. Such as would be the case if an average loading figure over all circuits in an option was considered or even simply the number of circuits with loading greater than 85%.

For all options a number of N-1 circuits over the 85% loading threshold were identified in 2036. It should be noted that these circuits are restricted to the periphery of the developed Western Power Network model, with no overloads seen in the immediate infeeds to the CBD Load Area to which the options relate. This N-1 loading metric allows an additional evaluation criterion to illustrate the wider advantages that CBD Load Area related infeed options have on the extended Western Power Network.

9.3.4. Environmental & Community Assessment

Recognising the significant issues inherent in constructing new transmission circuits in developed and urban areas, as part of the option appraisal consideration was given to the potential environmental and community impact associated with each CBD Load Area transmission supply option. Whilst detailed comments were received from the Western Power Environment,

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[38] As an example, Option A has 5 circuits between 85% & 90% (average loading of 86.8%), 2 circuits between 90% & 95% (average of 93.0%), 8 circuits between 95% & 100% (average of 97.0%) and 13 circuits above 100% (average of 121.6%). Option H has the highest number (68) of circuits above 85%. Thus, the weighted average load for Option A is: (5 x 86.8) + (2 x 93.0) + (8 x 97.0) + (13 x 121.6) / 68 = 43.8.

Community and Approvals (ECA) team on a number of the options and their preference for several of the options recorded, to perform a full option appraisal and comparison it was necessary to supplement the ECA view with a quantitative evaluation of the performance of each option.

Of the transmission system components identified under each option one in particular, overhead lines, is considered the most likely aspect to give rise to objections from community groups and vocal lobbying against new developments. As such, to provide a measure of desirability of each of the developed options from an environment and community perspective each option has been graded with respect to the transmission overhead line work required.

Based on input from the Western Power ECA team a rank order has been developed for different overhead line types and construction, including rebuilds following existing line routes, that reflects the relative impacts of each line type and construction. This rank order considers:

- Overhead structure height
- Width of line corridor
- Extent of line structure foundations and required clearance

The rank order developed has been derived relative to the upgrade of a 132 kV single circuit steel pole overhead line to a double circuit steel pole construction, which is considered to have the lowest incremental impact. The rank order placement for each line type was then used as a weighting value expressed as a value per circuit km, with the single 132 kV steel pole to double steel pole upgrade considered to have an environmental and community rating of 1 per circuit km. The weighting applied to other circuit types are as outlined in Table 23.

It should be noted that Table 23 also includes a weighting for new underground cables recognising that whilst they do not have a direct visual amenity impact, there are environmental impacts during construction as well as future restrictions on development within corridors or cable easements.

- **Table 23 Environmental Rating Applied to New Circuit Types**

Transmission Line Type	Relative Impact (per km)
Rebuilt 132 kV single steel pole line to double circuit steel pole	1
Rebuilt 132 kV single wood pole line to double circuit steel pole	2
New 132 kV wood pole single circuit line	3
New 132 kV steel pole double circuit line	4
New 220 kV steel pole double circuit line	5
New 330 kV steel pole double circuit line	6
New underground cable (132-220-330 kV)	0.4

9.3.5. Project Risk & Dependency

Although the preceding evaluation criteria (e.g. capital cost, environmental impact, losses, N-1 performance) provided a measured summary of the relative performance of each option when fully constructed and delivered, all of the options considered have inherent project implementation risks and dependencies on other network reinforcement projects. To provide a measure of assessment and weighting of the relative delivery risks associated with each option in this appraisal, the seven considered options have been ranked in relation to their perceived impact, taking account of:

- Dependency on wider system reinforcement projects, particularly where funding has not yet been secured
- Practical issues related to construction and project delivery which have not been incorporated within the other evaluation criteria (i.e. ability to lay cables in narrow bridge ways, expand GIS switchgear, etc)
- Ability to obtain environmental consent and planning approval for new overhead lines and underground cables through specific geographical areas (i.e. river crossing)

9.3.6. Summary of Option Performance

Based on the five evaluation criteria outlined, the performance of each of the seven considered CBD transmission supply options is shown in Table 24.

- **Table 24 Summary of Option Performance**

	Capital Cost	2036 Losses, MW	N-1 Rating	Environmental	Project Risks
Option A	$[redacted]M	87.3	52.7	79.9	3
Option B	$[redacted]M	99.2	53.9	111.5	1
Option D	$[redacted]M	116.6	78.5	104.7	7
Option F	$[redacted]M	98.5	67.9	141.0	2
Option G	$[redacted]M	91.3	56.5	122.8	5
Option H	$[redacted]M	90.7	105.1	97.5	3
Option K	$[redacted]M	99.6	36.4	74.9	5

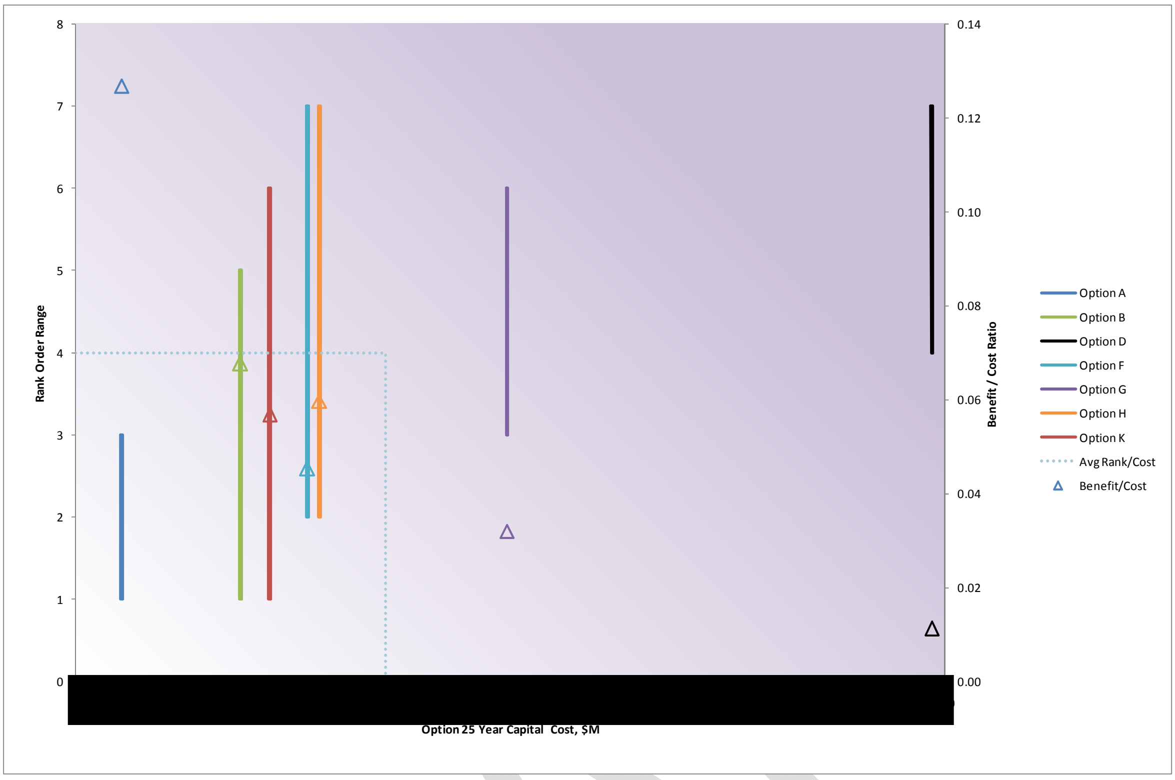
■ **Table 25 Summary of Option Rank Order Preference**

	Capital Cost	Rank Order				Benefit / Cost	
		2036 Losses	N-1 Rating	Environmental	Project Risks	Ratio	Rank Order
Option A	$[redacted]M	1	2	2*	3	0.127	1
Option B	$[redacted]M	5	3	5	1	0.068	2
Option D	$[redacted]M	7	6	4	7	0.011	7
Option F	$[redacted]M	4	5	7	2	0.045	5
Option G	$[redacted]M	3	4	6	5	0.032	6
Option H	$[redacted]M	2	7	3*	3	0.060	3
Option K	$[redacted]M	6	1	1*	6	0.057	4

* Western Power Environment & Community Assessment Team Preferred Options

Additionally, Table 25also shows the performance of each option, with a rank order applied to the Technical Criteria (losses, N-1, ECA and Project Risks). The Technical rank order is also converted to a score (inversely proportional to the average rank order across all criteria[39] - referred to as "Ratio") which is then used to rank order the options according to benefit presented by each option for a given cost. This effectively weights all criteria equally. The range of the technical rank order, capital cost and benefit / cost ratio (shown on the secondary Y-axis) of each of the seven options is also illustrated in the chart shown in Figure 26.

[39] For example, Option A has an average technical rank order of (1+2+2+3)/4 = 2. With seven points awarded to an average score of 1 and 1 point to a score of 7, Option A receives a score of 6. This score divided by the option capital cost ($[redacted]M) yields a cost / benefit ratio of = [redacted] / $M.



- **Figure 26 Graphical Illustration of Option Performance**

It is evident from review of Table 24, Table 25 and Figure 26 that there is a considerable spread of option performance across the technical and economic evaluation criteria. Some immediate comments are:

- Option A (East Perth Southern Feed) – performs well across all of the evaluation criteria and has the lowest estimated capital cost, lowest estimated losses and the highest benefit / cost ratio.
- Option B (East Perth Northern Feed) – has a reasonably good performance in two criteria but a poorer performance in relation to estimated electrical losses and environmental impact.
- Option D (220 kV Supply) – performs poorly across all financial and technical metrics and has no notable benefits over any of the other options.
- Option F (Western Terminal Reinforcement) – has a middling performance across most of the evaluation criteria with the exception of the Project Risk criteria. However, although the projects required to be implemented under Option F are not highly dependent on other network reinforcement projects or enabling works (hence the score of 2) the individual projects themselves still contain a high degree of risk, particular for the proposed reinforcement between Amherst and Cottesloe.

- Option G (New Morley 330 kV Substation) – is the second most expensive option and other than a reasonable performance under the losses criteria has little other merit.
- Option K (Cook Street Supply from Cannington Terminal) – has a split performance, performing very well in relation to expected N-1 performance and environmental consideration, but performing poorly in relation to estimated capital cost, estimated electrical losses and associated project risks.

Based on the above it is considered that the Options D, F and G should be discounted.

With regards to Options H and K:

- These options have broadly similar capital costs and benefit / cost ratios although this is around 12% lower than Option B and more than 50% lower than Option A.
- Option H is in effective a hybrid of Option A& B however it performs worse than either across almost all criteria.
- Option K has the best environment rating however this is a consequence of the significant length of 132 kV underground cable required to provide the double circuit connection between Cannington Terminal and Cook Street, As a result, Option K is the third most expensive option and could potentially become more expensive than Option G (330 kV option) if the 132 kV double circuits are required to be cabled significantly further than already anticipated. This could take the potential capital cost of this option to nearly double that of Option A.

As a result, it is considered that Options H and K should also be discounted at this stage due to their individual performance across the evaluation criteria being considered poor whilst offering little positive tangible or intangible benefits.

10. Subset Supply Option Evaluation

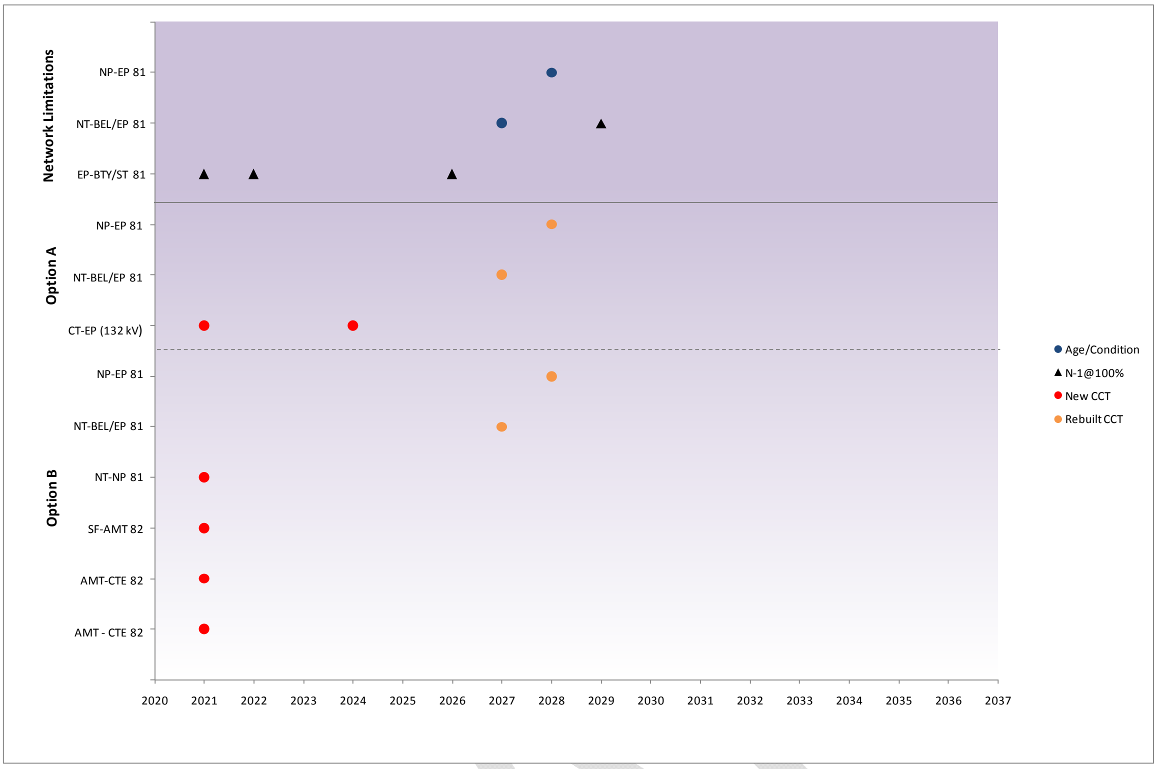
10.1. Overview of Subset Options

Following the option evaluation and consolidation process detailed in Section 9, of the eleven options considered, two, Option A and B were identified as being the best performing options across the considered technical and economic evaluation criteria. Having identified these as the preferred options it is necessary to identify the approximate timings that the individual network reinforcement projects would be required under each option.

The timings for the individual investment projects that make up each option were determined using the DIgSILENT sub-network model for the Western Power Network, focussing on the CBD Load Area, with the ROAM 20 Outlook generation and demand scenario. Power system analysis studies (including N-1, N-1-1 at 80% load and N-2) were undertaken for the four key study years first (e.g. 2021, 2026, 2031 and 2036) to narrow the focus. Further studies for additional years were undertaken to identify more accurately which year individual projects were required where necessary.

Consideration was also given as to whether the NT-BEL/EP 132 kV transmission circuit is required to be rebuilt in 2027 or whether it could be removed once the assets reach the end of nominal asset life at this time.

The result of the analysis is shown in Figure 27.



▪ **Figure 27 Summary of Problem Drivers and Option A & B Projects**

It is evident from Figure 27that for Option A, the first CT-EP 132 kV circuit is required in 2021 to address the N-1 limitations associated with the existing ST-EP double circuits. The second CT-EP 132 kV circuit is required in service by 2024, again as a result of N-1 contingencies involving the ST-EP 132 kV circuits, although in this case the requirement is due to the unequal power sharing of the remaining ST-EP and CT-EP circuits which exceeds the thermal rating of the latter.

Additionally, for Option A, the NT-BEL/EP 132 kV circuit does not require to be rebuilt in 2027 once the second CT-EP 132 kV circuit is in service, as the four southern CBD Load Area infeeds (from Cannington Terminal and Southern Terminal) plus the interconnection through Western Terminal provide more than sufficient network capacity to cater for expected N-1 and N-1-1 network power flows until beyond 2036. Not rebuilding the NT-BEL/EP transmission line will result in a cost saving of around $5.5M. Potentially more significant is the fact that the redundant circuit route could then be reconfigured for use in supplying other existing or future substations.

For Option B all of the new 132 kV transmission circuits are required in service by 2021, again as a result of the limitations on the ST-EP 132 kV circuits under N-1 contingencies. The NT-BEL/EP 132 kV circuit is also required to be rebuilt in 2027 once the assets have reached the end of the nominal life.

Consideration of 330 kV Construction

As outlined in Section 8.2, Western Power has plans to upgrade the existing Cannington substation to a terminal substation with 330 kV transmission line circuits and associated 330 kV switchyard pre-2020. Therefore, one of the potential benefits of Option A not explicitly discussed in the previous section is the ability of Option A to provide a future 330 kV transmission supply to East Perth. Although there is no requirement to provide a direct 330 kV transmission supply to the CBD Load Area in the short to medium term, as discussed in the SKM 'Review of Planning Philosophies' report it is considered that such supply reinforcement will likely be required over the medium to long term as the demand continues to grow [2].

The potential future option to upgrade the East Perth transmission supply to 330 kV provides an opportunity to consider the merits of adopting 330 kV transmission equipment as an alternative to the normal Western Power standard at 132 kV. As part of this assessment we have explicitly included a sub-option of Option A (Option A2) that would be constructed using Western Power 330 kV specification equipment and operated at 132 kV for the short to medium term (i.e. up to 20 years). The details of Option A2 that differ from Option A already discussed are:

- The 7 km double circuit overhead transmission line (CT – EP) would be a combination of the existing Western Power Metro and Country specification, that is Metro transmission towers and line profile would be adopted but using twin Silicon AAC line conductors per phase as per the country specification. The use of twin Silicon AAC line conductor per phase (required at transmission voltages of 220 kV or higher to minimise radio interference) would still result in a circuit rating of 2,000 A per phase.
- The 6.5 km section of the CT-EP route that is assumed to be undergrounded would use 330 kV 3x 1C 2,000 mm^2 XLPE[40] cables per circuit. These are the largest size that Western Power commonly use and would be rated at approximately 330 MVA when operated at 132 kV and laid in flat formation.
- The estimated total capital cost of Option A2 would be around $[redacted]M higher than Option A.
- The first CT-EP 81 transmission circuit would be required by 2021 as per Option A. However, due to the higher capacity rating of the 330 kV specification overhead line, which would allow the maximum underground cable rating (330 MVA) to be achieved, then the CT-EP 82 circuit would not be required until 2025.
- The trigger for the second CT-EP circuit is an N-1-1 event involving the existing ST-EP 81 circuit and the new CT-EP 81 circuit. This is why the apparent (CT-EP) circuit capacity gain of circa 50 MVA only achieves a year deferral for the CT-EP 82 circuit over Option A.

10.2. Option Net Present Cost

In addition to the capital cost of each of the three preferred options, the cost phasing of each option is also an important factor. Using the project timings identified and outlined in the previous sub-

[40] Modern XLPE technology has a notional asset life of 50-60 years in comparison to younger generations of the technology seen in the 1970s installed distribution cabling.

section as a basis plus a generic project phasing the NPC value for each option has been determined. The results are shown in Table 26.

Note that this includes the cost for the NT-EP/BEL and NP-EP 132 kV overhead line rebuilds expected in 2027 and 2028 (Option A, A2 and B) and the NP-EP 132 kV line rebuild only in 2028 in Option A-2 and A2-2.

- **Table 26 Capital and Net Present Cost of Option Subset**

Option	Capital Cost	Net Present Cost
A	$[redacted]M	$[redacted]M
A2	$[redacted]M	$[redacted]M
B	$[redacted]M	$[redacted]M
A-2	$[redacted]M	$[redacted]M
A2-2	$[redacted]M	$[redacted]M

10.3. Practical & Operational Issues

In addition to the financial evaluation of preferred option subset there exist a number of practical and operational considerations associated with both options that are worthy of comment.

Practical Issues

Under Option A2 there is the potential to upgrade the transmission system voltage to East Perth to 330 kV. To achieve this it will be necessary to develop a 330 kV terminal switchyard at East Perth, as a minimum to include 330 / 132 kV transformers and potentially also 330 kV switchgear if a connection arrangement other than a transformer feeder design is to be adopted.

The existing Northern Terminal 330 kV switchyard has an approximate area of 25,400 m^2 and contains two 490 MVA 330 / 132 kV transformers plus four 330 kV overhead transmission lines. Reviewing the existing East Perth site, there is currently no available spare land approaching this size. However, the existing 66 kV switchyard which contains outdoor AIS switchgear is expected to be redundant around 2020 following the proposed upgrade of the ageing 66 kV network in the load area to 132 kV operation (see Section 7.3.2). This land is around 11,000 m^2 and is of sufficient size to accommodate a pair of 330/132 kV transformers and either GIS switchgear or limited outdoor AIS switchgear.

Operational Issues

As detailed in Section 10.1, it is expected that the two new CT-EP 132 kV circuits (constructed at 330 kV in the case of Option A2) could be installed over two phases with the first circuit being energised by 2021 and the second circuit energised by 2024 or 2025. This potentially provides an opportunity to defer the investment of the second circuit by three or four years, which would result in a more attractive Net Present Cost.

However, consideration needs to be given to potential system operational requirements before determining that the deferral of the second circuit is a prudent course of action as it is likely that once the first circuit enters service it will not be able to be removed from service a few short years later in order to facilitate the upgrade. This may be required, depending on the transmission line design adopted, to enable safe working practices to be followed whilst insulating, stringing and tensioning the second circuit. Given the length of the transmission line section of the CT-EP circuits, estimated at around 7 km, the first circuit may need to be out of service for six months or more to enable the second circuit line works to be completed. During this period it may be necessary to re-dispatch generation, including dispatching lower merit order northern generation, in order to provide a work around solution and reduce power inflows to the CBD Load Area from the South. This would avoid exceeding the thermal rating of the existing ST-EP circuits, particularly under outage conditions.

An alternative solution to the transmission line construction issue could be to construct both circuits together and operate only one circuit, leaving the other de-energised. Such an option would not however result in as a great a capital deferral as the first, however it may be considered eminently more practical.

A similar approach could be taken when installing the 6.5 km of cable that is expected to be required to complete the circuits. During the installation of the first cable circuit, ducts could be installed in preparation for the second circuit. This would allow the deferral for the supply of the second cable circuit and would have minimal impact on the operation of the first circuit during installation.

For Option B the principal new circuits being installed, NT-NP and SF-WT (by way of SF-AMT, AMT-CTE and CTE-WT), can all be installed individually with little impact of one on the other. That said, the construction of the second circuit from SF-WT, via Amherst and Cottesloe, may require outages of the existing circuit depending on the final line construction and route adopted – the existing single circuit sections may be combined with a new second circuit. Depending on the duration of any such outages it may be necessary to re-dispatch northern generation in preference over Southern generation. This would be required during times when one of the main power corridors supplying Western Terminal (from SF) is not available and hence more of the Western Terminal and CBD Load Area will need to be supplied from the North.

10.4. Sensitivity Analysis

A range of sensitivity analyses have been conducted as part of this study to ascertain the impact on the technical and financial viability of the options. The key sensitivities assessed were:

- Impact of high demand forecast
- Potential quadrature booster at Wellington Street
- Variation in future generation location and capacity

These aspects are now discussed.

10.4.1. Impact of High Demand Forecast

A sensitivity analysis was undertaken to assess the impact of increased loading in the CBD Load Area. The study analysed the difference in load demand and growth between System Forecasting's Central and High Forecasts. The differences were evaluated to determine if the increased loading in the High Forecast would bring forward any of the proposed network reinforcements.

The forecast shows an increase of 30 MW across the CBD Load Area in the High Forecast over the Central Forecast, with an increase of approximately 12 MW at Milligan Street Substation. As the load at Milligan Street is supplied from Northern Terminal, the overall impact on the East Perth load area was found to be marginal, especially if the HAY-MIL 132 kV cable circuit is not in service. Actual differences in circuit loadings in comparison with the Central Forecast used in this study were less than 2.5%, with the exception of the circuits shown in Table 27.

- **Table 27 Comparison of 2036 Circuit Loadings under Alternative Demand Forecast**

Circuit Name	High Forecast Loading, %	Central Forecast Loading, %	Difference, %
CT-EP 81	71.8	68.9	2.9
CT-EP 82	71.8	68.9	2.9
EP-HAY 81	62.5	59.0	3.5
EP-HAY 82	62.5	59.0	3.5
JAM-MIL 81	29.0	25.6	3.4
JAM-MIL 82	28.9	25.6	3.3

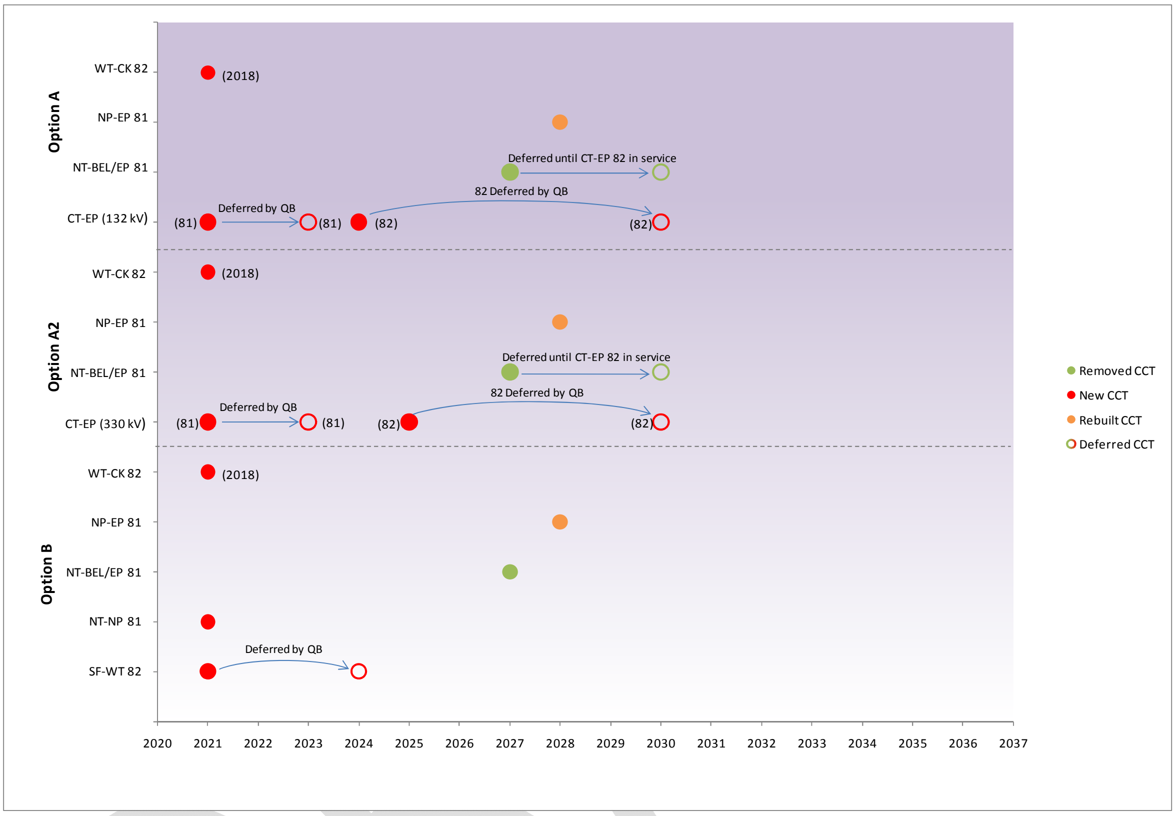
In light of the above, it is concluded that any potential increase in CBD Load Area demand associated with the High Forecast will not be expected to materially impact on the timings of the network reinforcements identified and proposed under this study.

10.4.2. CBD Load Area and QB

The proposed HAY-MIL 132 kV underground cable will create a new transmission link (via the Perth CBD boundary) between Northern Terminal and Southern Terminal / Cannington Terminal. Preliminary load flow studies have indicated that the expected power flow through the HAY-MIL 132 kV cable under normal or outage conditions is expected to be low, i.e. less than 50 MW in either direction in most cases.

The new HAY-MIL 132 kV cable along with the relatively low utilisation of the existing NT-MLA-JAM 132 kV transmission circuits presents an opportunity to provide another source of power into the CBD Load Area. This could potentially reduce the loading on the existing ST-BTY-EP transmission circuits and defer the need for the new CT-EP circuits, if the power import to the CBD Load Area can be controlled. This could be achieved through use of a phase shifting (QB) transformer. As the HAY-MIL 132 kV underground cable will potentially be routed up towards Wellington Street, one potential location for a QB could be the car park of the existing Wellington Street Substation. This has suitable space to accommodate such a transformer.

In order to determine the potential impact of a QB[41] on the timing for the new CT-EP transmission circuits additional power system studies have been performed for each of the three considered CBD Load Area supply options (Option A, A2 and B). The results of the assessment are shown in Figure 28. The new investment triggers are shown in Table 28.



[41] Rating 250 MVA, electrical parameters as per the existing Kemerton 225 MVA unit. Capital cost obtained from Western Power Building Block cost estimates as $[redacted]M.

- **Figure 28 Impact of QB on Option Project Timings**
- **Table 28 Revised Investment Triggers with QB & HAY-MIL 132 kV Cable**

Option	HAY – MIL UGC & QB	1st CCT	2nd CCT	Contingency Driver for 2nd Circuit(s)	NT-BEL/EP Required?
A	N	CT-EP 81 2021	CT-EP 82 2024	N-1: EP-ST 81 / ST-BTY 81	No
A	Y	CT-EP 81 2023	CT-EP 82 2030	N-2: MLA-JAM 81 & 82	Yes, to 2030
A2	N	CT-EP 81 2021	CT-EP 82 2025	N-1-1: EP-ST 81 & CT-EP 81	No
A2	Y	CT-EP 81 2023	CT-EP 82 2030	N-2: MLA-JAM 81 & 82	Yes, to 2030
B	N	NT-NP 81 2021	SF-AMT-CTE-WT 82 2021	N-1: EP-ST 81 / ST-BTY 81	Yes
B	Y	NT-NP 81 2021	SF-AMT-CTE-WT 82 2024	N-1: EP-ST 81 / ST-BTY 81	Yes

It is evident from Figure 28 that a (QB) located within the CBD Load Area and able to control the power flow along the proposed HAY-MIL 132 kV cable could have a potentially significant impact on the timing of the new network projects developed under all options.

The QB would be of least benefit for Option B where the deferral of the new WT-CTE, CTE-AMT and AMT-SF 132 kV circuit would be for three years. The greatest benefit in terms of deferring investment would either be Option A, in terms of number of deferred years obtained, or Option A2 in terms of the NPC savings. The revised NPC values for each of the options are shown in Table 29.

Note that with both Option A and A2 the NT-BEL/EP 132 kV circuit would have to remain in service for an additional three years beyond its schedule decommissioning date (2027) until the second CT-EP 82 circuit is installed to enable N-2 requirements to be met across the Perth CBD boundary. It is assumed that this would be achievable with additional maintenance / management of the NT-BEL/EP circuit.

- **Table 29 2036 NPC Estimates with QB**

Option	Original NPC	NPC with QB	Original – QB Difference	
A	$[redacted]M	$[redacted]M	$0.2M	0.8%
A2	$[redacted]M	$[redacted]M	$2.1M	5.2%
B	$[redacted]M	$[redacted]M	-$0.6M	-1.5%
A-2	$[redacted]M	$[redacted]M	-$0.2M	-0.9%
A2-2	$[redacted]M	$[redacted]M	$1.6M	4.2%

It is clear from reviewing Table 29that the additional capital cost associated with providing the QB (circa $[redacted]M for QB and 132 kV switchgear) would be largely offset by the gains in NPC for all options, even Option B.

For Option A the scheme is largely cost neutral regardless of whether the NT-BEL/EP 132 kV transmission circuit is rebuilt, the difference in NPC being <1%.

For Option A2 there would be expected to be a NPC benefit of around $2M after accounting for the cost of the QB, again largely regardless of whether the NT-BEL/EP transmission circuit is rebuilt. This benefit would be expected to increase if the cost of the CT-EP circuits increases further i.e. if there is a requirement to underground a greater proportion of the circuit.

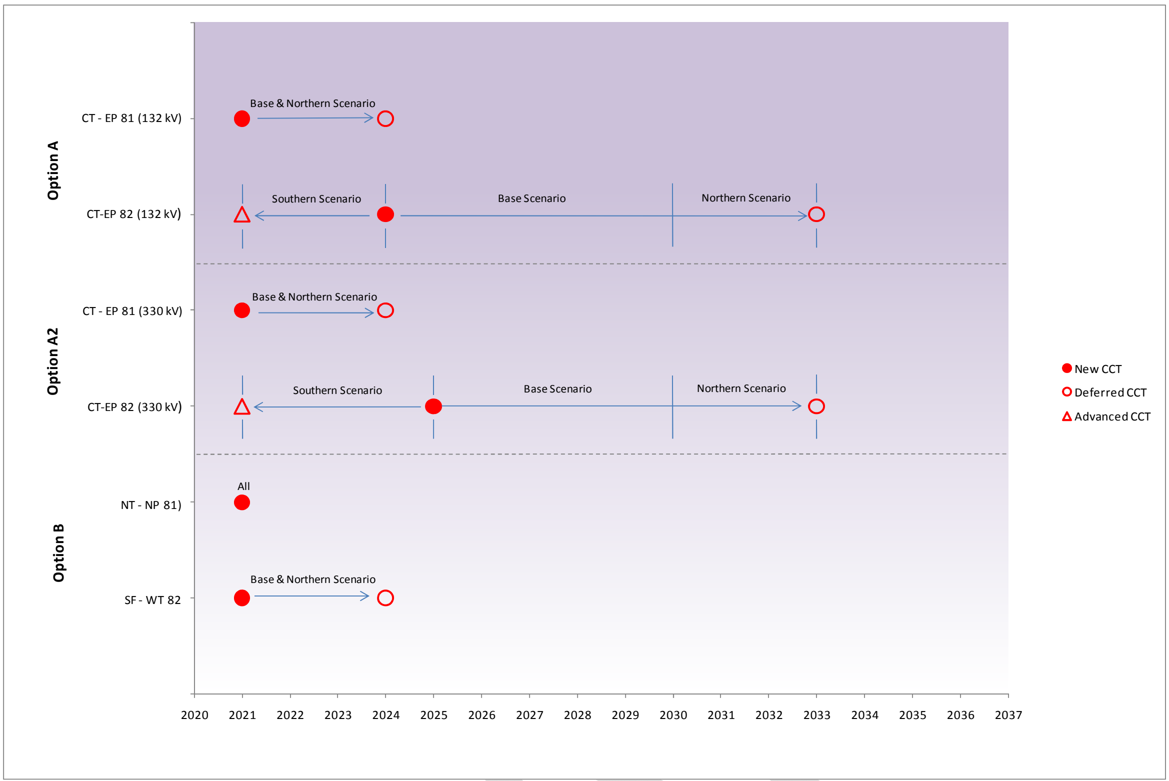
There would also be additional non-financial benefits associated with the QB, in terms of operational flexibility and planning, which could also support the installation of such a transformer in the CBD Load Area.

10.4.3. Variation in Generation Location and Capacity

The base generation locations and capacity considered in this analysis has been obtained from the ROAM Consulting Scenario 20. The ROAM 20 Scenario essentially corresponds to a largely high northern generation scenario with significant new wind and gas generation in the northern areas of the Western Power Network.

As an alternative to the base scenario two further generation scenarios have been considered, a high northern scenario and a high southerly generation scenario. Both scenarios were created using the same total additional generation capacity at 2036 as per ROAM 20 [23](2,343 MW over the 2020 generation capacity) used in the base scenario but with all of this new generation located in either the Neerabup area or the southern Western Power Network areas. For the purpose of this latter assessment the additional generation was assumed to be split equally between Muja in the far South and Kwinana, around 30 km South of Perth.

The timing of the principal circuits to be installed under each of the three main supply options (CT-EP 81 & 82 for Option A & A2, NT-NP 81 and SF-WT 82 for Option B) have been reassessed for the two additional generation scenarios. The results are shown in Figure 29.



- **Figure 29 Impact of Generation Scenarios on Project Timings**

It is evident from review of Figure 29and the detailed results used to create this figure that:

- The timing of the first CT-EP circuit (81) (Option A & A2) is expected to vary depending on the origin of the power flows into the CBD Load Area i.e. from the North or South. In the case of a northern generation dispatch the CT-EP 81 circuit could be deferred by around three years over the central scenario (ROAM 20 Outlook). Although not explicitly studied, we would expect a similar degree of advancement under a southern generation bias to around 2017/18.
- The second CT-EP circuit (82) (Option A & A2) is even more heavily dependent on the future generation location that the CT-EP 81 circuit. A variety of contingency events could drive the requirement to augment the CT-EP 81 circuit including N-1, N-1-1 and N-2 contingencies depending on the generation bias. The CT-EP 82 circuit could be required as late as 2033 under a high northern scenario or potentially as early as 2020 (around three years after the CT-EP 82 circuit) under a Southern generation scenario.
- The maximum deferral of CT- EP 82 under any option / scenario is nine years with Option A under the high northern scenario using a quad booster to control power flows along the HAY-MIL 132 kV cable
- The QB has little impact on the timing of either CT-EP circuit under the Southern generation scenario due to the larger voltage angle difference between the Northern Terminal and

Southern Terminal substations under high South to North power flows, which reduces its effectiveness

- The timing for the new circuits required under Option B are not likely to change significantly (more than 3 years) under a high northern generation dispatch, being similar to the central scenario (ROAM 20 Outlook). Under a high southern generation dispatch it is expected that all new circuits required under Option B would be advanced by around three years – as per Option A

Collectively this assessment of alternative generation scenarios and dispatch highlights how the requirement for, and the timing of both CT-EP 132 kV circuits could vary significantly over the duration of the strategy period. This is particularly true for the CT-EP 82 circuit which could be required within the next ten years or potentially deferred to beyond 2030 depending on future generation dispatch and locations.

10.5. Summary of Subset Option Evaluation

Based on the analysis conducted and reported on here it is evident that of the two main options carried forward from the initial assessment and evaluation (Section 10), Option A (East Perth Southern Feed) is the most desirable.

Option A has been further developed into an Option A2, essentially the same as Option A but constructed using 330 kV transmission line equipment to enable East Perth to be upgraded to 330 kV at some point in the future. Option A2 has a capital cost penalty over Option A of approximately $[redacted]M.

Having assessed both Option A and A2 against a range of sensitivity assessments it is clear that:

- Potential variations in CBD Load Area demand growth are not expected to alter the requirement for, or the timing of the CT-EP 132 kV circuits.
- The timing of both CT-EP 132 kV circuits is however dependent on future generation location and dispatch across the Western Power Network, with a Southern bias to the generation potentially requiring the first circuit to be installed around 2017/18 and the second circuit a few years later.
- In the case of a northern generation bias, the first CT-EP circuit could be delayed until around 2023, with the second CT-EP circuit potentially delayed to beyond 2030 if a QB is installed to control power flows across the new MIL-HAY 132 kV cable.

At the present time no decision needs to be made as to whether Option A or A2 is implemented. The first CT-EP 132 kV circuit will be required under both options at the same time, likely driven by N-1 contingency events of the existing ST-EP 132 kV circuits. The timing will however be dependent on the generation dispatch across the Western Power Network, with the first CT-EP circuit under both options potentially being required before 2020 under a southern generation dispatch.

Further analysis is required in order to fully assess the cost, practical and environmental aspects associated with the 330 kV design (Option A2) to confirm that this is the best long option for supplying the CBD Load Area.

Similarly, analysis has suggested that a QB installed in the CBD Load Area to control power flows across the proposed HAY-MIL 132 kV can be cost effective in deferring the requirement for the second CT-EP circuit. Further analysis of the practical issues and wider system benefits is however required before confirming the suitability of this project – which is also dependent on a new HAY-MIL 132 kV cable being confirmed.

Therefore, for the purpose of this assessment Option A (without quad booster) will be taken forward in the next section for consideration of staging and deliverability issues alongside the CBD Load Area projects already identified and discussed in Sections 7 & 8.

11. Development Strategy

11.1. Staging of Projects

With the identification of the preferred projects, it is necessary to stage these projects to ensure suitable deliverability within a coherent strategy. The strategy is required to overcome the limitations summarised in Figure 15 whilst considering the deliverability of the projects. It is therefore necessary to identify the likely timescales for each of the favoured projects to be implemented.

Discussions with Western Power environmental, construction and planning teams have provided indicative timeframes for different types of projects. These timeframes are from planning to commissioning including environmental studies, community engagement, procurement, construction and other activities. At a high level basis these are provided as:

- Cable route 4-5 years
- Substation expansion works 3-4 years
- New CBD Load Area substation construction 5-7 years

With the above high level timeframes taken into consideration, Table 30 illustrates the indicative timeframes applied to each of the projects for the purpose of developing the 25 year strategy. Typically the worst case timeframes have been selected, particularly those projects needed within a short time frame, to provide the worst case risk analysis.

- **Table 30 Indicative Timeframes for All Projects**

Project	Timeframe
Cook Street 3rd Transformer	4 years
Joel Terrace 132 kV Conversion	4 years
Bennett Street Substation	7 years
New EP-BEN 81 & 82 132 kV Cables	5 years
East Perth Switchyard Extension	4 years
New HAY-MIL 81 132 kV Cable	5 years
North Perth Load Balancing	1 year
EP-HAY 81 & 82 Cable Section Uprate	2 years
James Street Single Transformer and Switchboard	4 years
Milligan Street and Hay Street Switchboard Replacements	2 years per site[42]
Milligan Street and Hay Street Transformer Replacements	2 years per site
Joel Terrace 3rd Transformer	4 years

[42] Asset replacement is deemed to require a shorter timeframe to substation expansions due to the minimised planning and design works

Project	Timeframe
EP-NP 81 132 kV Circuit Rebuild	5 years
New WT-CK 82 132 kV Circuit	5 years
New CT-EP 81 132 kV Circuit	4 years
New CT-EP 82 132 kV Circuit	4 years

It is evident from Table 30 that the sum of the timeframes for all projects is some 68 years. Significant parallel working will therefore be required, particularly considering the majority of limitations within the CBD Load Area are expected to occur within the next 10 years. The parallel project delivery and hence resourcing for the baseline strategy, is illustrated within Section 11.2.3 - Figure 34.

Throughout the analysis of the projects, it has been seen that there are interdependencies between the projects to enable future projects to go ahead. Table 31 illustrates these project interdependencies which are considered within the strategy.

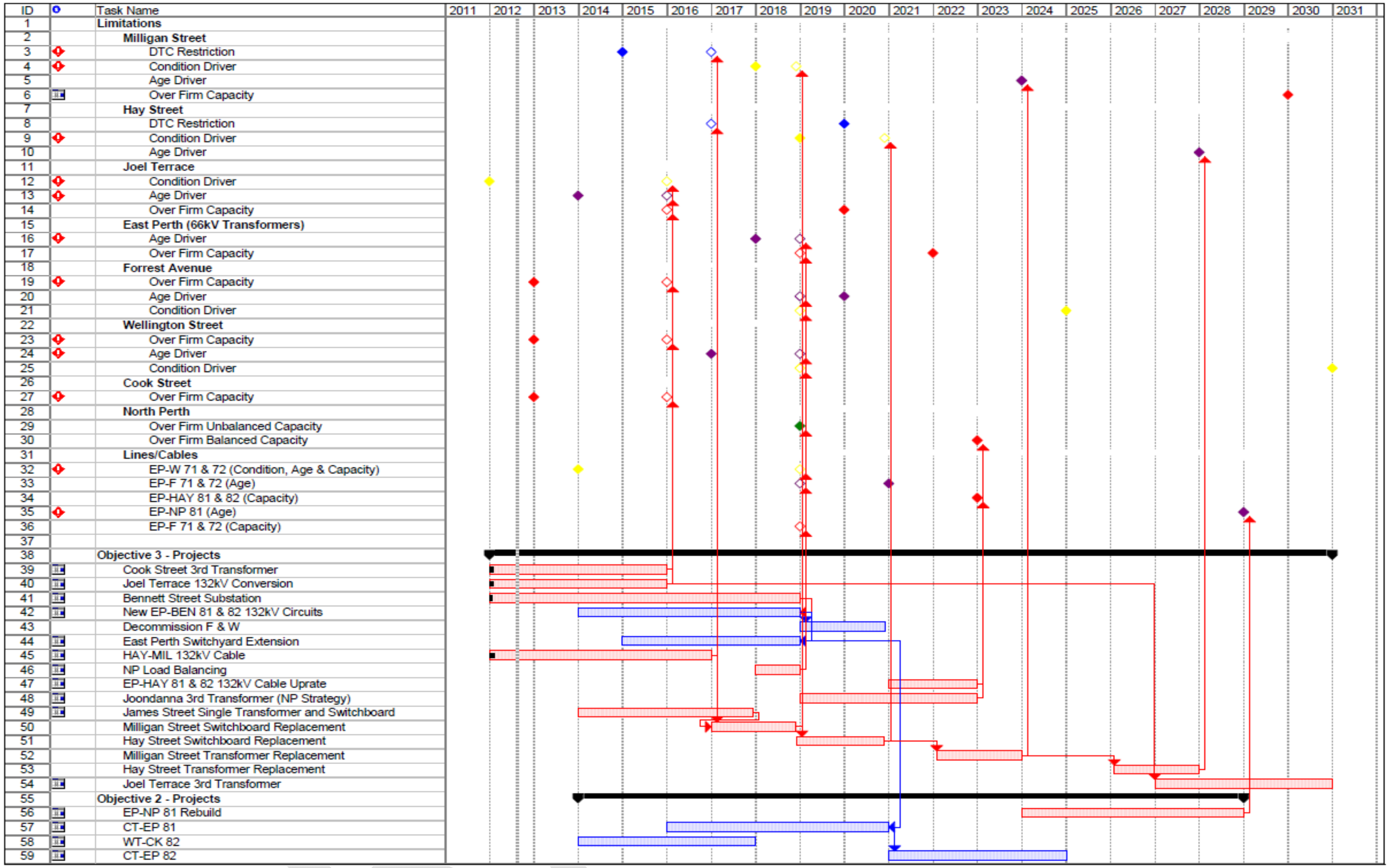
- **Table 31 Primary Project Interdependencies**

Project	Dependencies	Comments
Bennett Street Substation	▪ New EP-BEN 132 kV Double Circuit ▪ East Perth Switchyard Extension	Required for 132 kV connection of new Bennett Street Substation to East Perth
Milligan Street Switchboard Replacement	▪ James Street Single Transformer ▪ New HAY-MIL 132 kV Cable	James Street required to allow transfer of load from Milligan Street switchboard. HAY-MIL cable required for continued N-2 security
Hay Street Switchboard Replacement	▪ Milligan Street Switchboard Replacement	Replacement of switchboards at Milligan Street required to be completed to free James Street capability

Based on Table 31 it is evident that there are a number of projects that will be key to the progression of the overall strategy, particularly for the construction of the new Bennett Street substation and for the rebuilding of the Milligan Street substation.

11.2. Baseline Strategy

The baseline strategy has been derived by taking the indicative timeframes from Table 30 and applying this to each of the projects with due consideration given to the limitations for which they have been developed. Figure 30 (and Appendix L) illustrates the limitations and baseline strategy based on the deliverability and interdependency of the projects.



- **Figure 30 Baseline Strategy: Timings**

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The legend for the limitations follows that described in Figure 15 with the year illustrated as the coloured rhombus. The outlined rhombus indicates when a project has been commissioned which addresses the associated limitation. Taking this into consideration it can be seen from Figure 30 that the majority of limitations are addressed beyond their proposed deadline (further highlighted by the red warning marker in the far left column). This indicates that there will be some level of mitigation works required during the period between the limitation deadline and the project addressing the limitation in order to minimise risk to customer supply. This is highlighted by the four projects which are required to address immediate limitations[43]. Due to the deliverability timeframes, risk mitigation measures will be required until these projects are commissioned. Furthermore, due to the interdependency of future projects on these initial projects, it can be seen that future limitation deadlines may also not be met, primarily due to the deliverability timeframes of the initial projects.

11.2.1. Baseline Strategy: Risk

A view of the system risk presented by the baseline strategy due to the deliverability timeframes has been calculated with details of this process and detailed analysis of the results provided in Appendix J. The risk matrix for the baseline strategy is shown in Figure 31.

The risk matrix highlights the substations which are forecast to be over firm, illustrating the likelihood and consequence of a failure occurring and the impact of that failure. The primary projects derived to eliminate these risks are shown. Taking the baseline strategy timings, the over firm risks of each of the substations will fall away once the reinforcement is commissioned. The ‘ghosted’ markers indicate how the risk would move, should these projects be delayed, increasing the risk to the system.

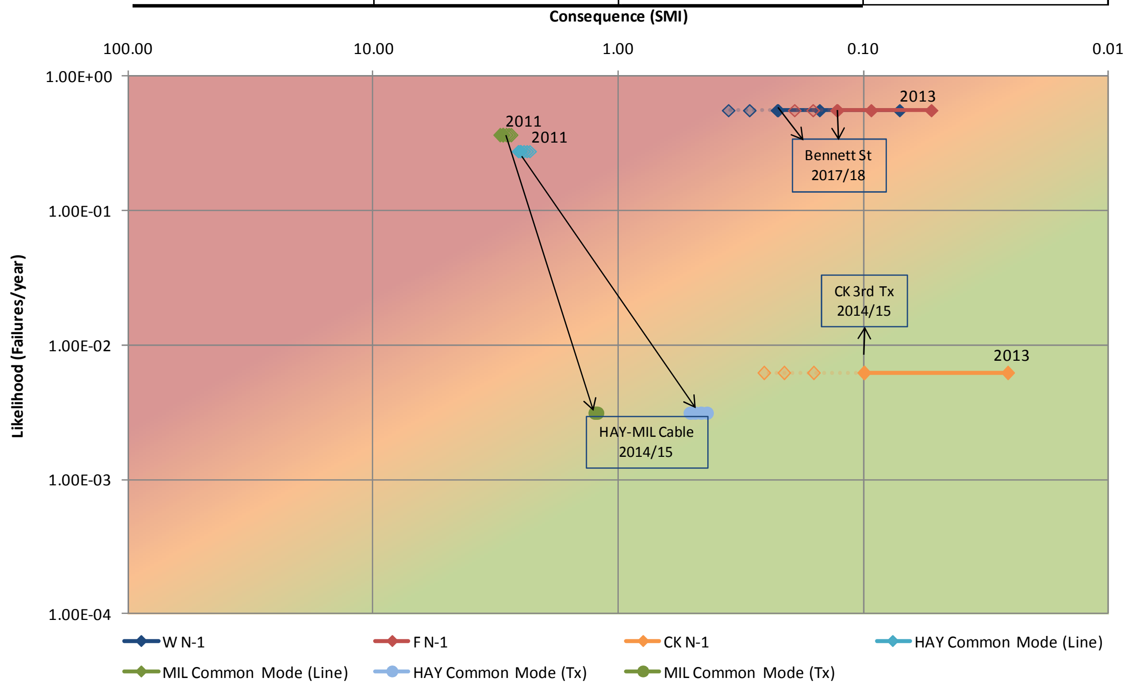
Figure 31 shows the key projects associated with overcoming load at risk limitations. In the case of the Bennett Street substation project, this will provide suitable firm capacity to accommodate both Forrest Avenue and Wellington Street load. Once commissioned, the over firm risk at these substations will not be present. Similarly, the installation of a third transformer at Cook Street will overcome the over firm risk at this site once commissioned.

In the case of the HAY-MIL 132 kV cable, this would overcome the current worst case common mode failure at these sites whereby the full substation load would be unserved for up to 2 hours. With the introduction of this project the worst case common mode failure would fall to a loss of two transformers at these sites. Figure 31 illustrates how this significantly reduces the likelihood (approximately 100x) of a failure at these substations as transformer failures are rarer than those of overhead lines/cables. The consequence is also reduced as three transformers are present,

[43] Cook Street third transformer, Joel Terrace 132 kV conversion, Bennett Street Zone Substation and HAY-MIL 132 kV cable

meaning if two were to fail, some 63 MVA of load at Milligan Street, or 71 MVA of load at Hay Street substation could be immediately served from the remaining transformer[44].

Catastrophic	Critical	Marginal	Negligible
Quality of Supply – SMI >=10 for single event E@R MWh >= 500 for a single event System or revenue loss / damage => $50,000,000 Reputation – severe and damaging series of media reports, trigger for parliamentary inquiry, several senior officers leave immediately as a result Regulation / Licence – severe threat of losing operating licence irrespective of remedial plans	Quality of Supply – 1 <= SMI < 10 for single event 50 <=E@R MWh < 500 for a single event System or revenue loss / damage =>$5,000,000 but < $50,000,000 Reputation – Damaging media reports which require extensive efforts to mitigate, several senior officers move posts Regulation / Licence – significant threat to operating licence if remedial plans not implemented	Quality of Supply – 0.1 <= SMI < 1 for single event 5 <=E@R MWh < 50 for a single event System or revenue loss / damage => $500,000 but < $5,000,000 Reputation - Adverse media reports on the performance of the company, however they disappear within weeks Regulation / Licence – adverse comments from ERA linked to capital investment programme	Quality of Supply – SMI <0.1 for single event E@R MWh <5 for a single event System or revenue loss / damage <$500,000 Reputation – No significant impact on WP business Regulation – No significant regulatory issues



■ **Figure 31 Baseline Strategy Risk Matrix**

Risk Mitigation Measures

Although each of the projects proposed significantly reduces, or eliminates, over firm risk, it can be seen from Figure 30 and Figure 31 that under the baseline strategy there is still a significant level

[44] Lowest rated transformer at each of the Hay Street and Milligan Street Zone Substations

of risk in terms of substations being over firm capacity prior to the project being commissioned. Mitigation measures will therefore be required to be in place to minimise this risk, particularly in the first 10 year period. Consideration must also be given to the risk provided from assets surpassing nominal age and/or of known poor condition and therefore at a greater likelihood of failure. As such, a number of mitigation measures to overcome the risk posed in these interim periods is summarised in Table 32.

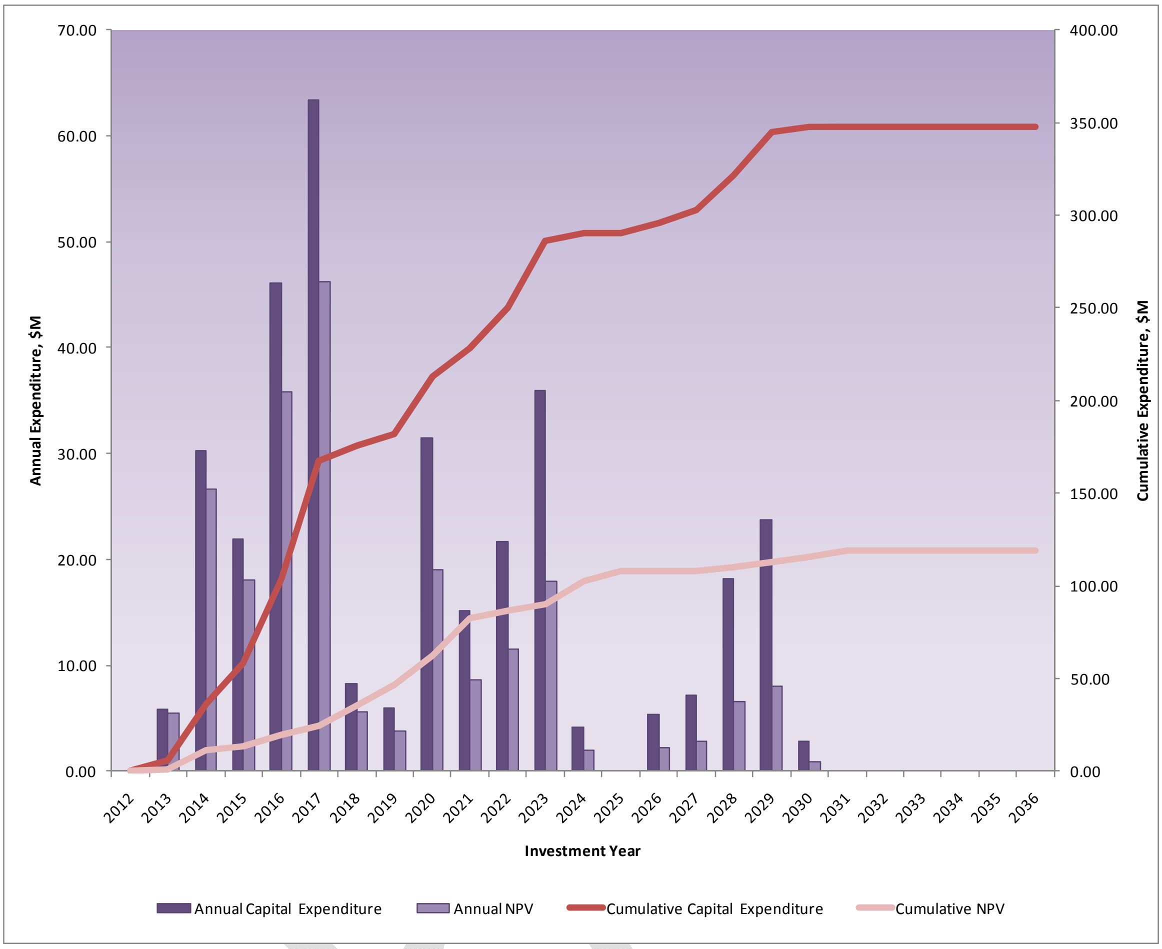
- **Table 32 Summary of Potential Risk Mitigation Measures**

Mitigation Measure	Risk Mitigation	Comments
RRST[45]	Asset Condition Over Firm Capacity	Replace a failed transformer asset in the short term Temporary additional transformation capacity
Intensive O&M	Asset Condition	Extend the life of existing assets
Derogation	Over Firm Capacity	Temporary modification of substation security standard
Distributed Generation	Over Firm Capacity	Supply over firm load under contingency events

11.2.2. Baseline Strategy: Cost

The baseline cost profile is illustrated in Figure 32 for both capital cost and NPC on an annual and cumulative basis. In addition, Figure 33 illustrates the breakdown of the capital cost per asset group. The costs indicated within the baseline strategy and associated sensitivities are provided for transmission assets and associated civil works only, including 11 kV switchboards.

[45] Suitable for Cook Street and North Perth Zone Substations in the CBD Load Area only



▪ **Figure 32 Baseline Strategy: Investment Profile**

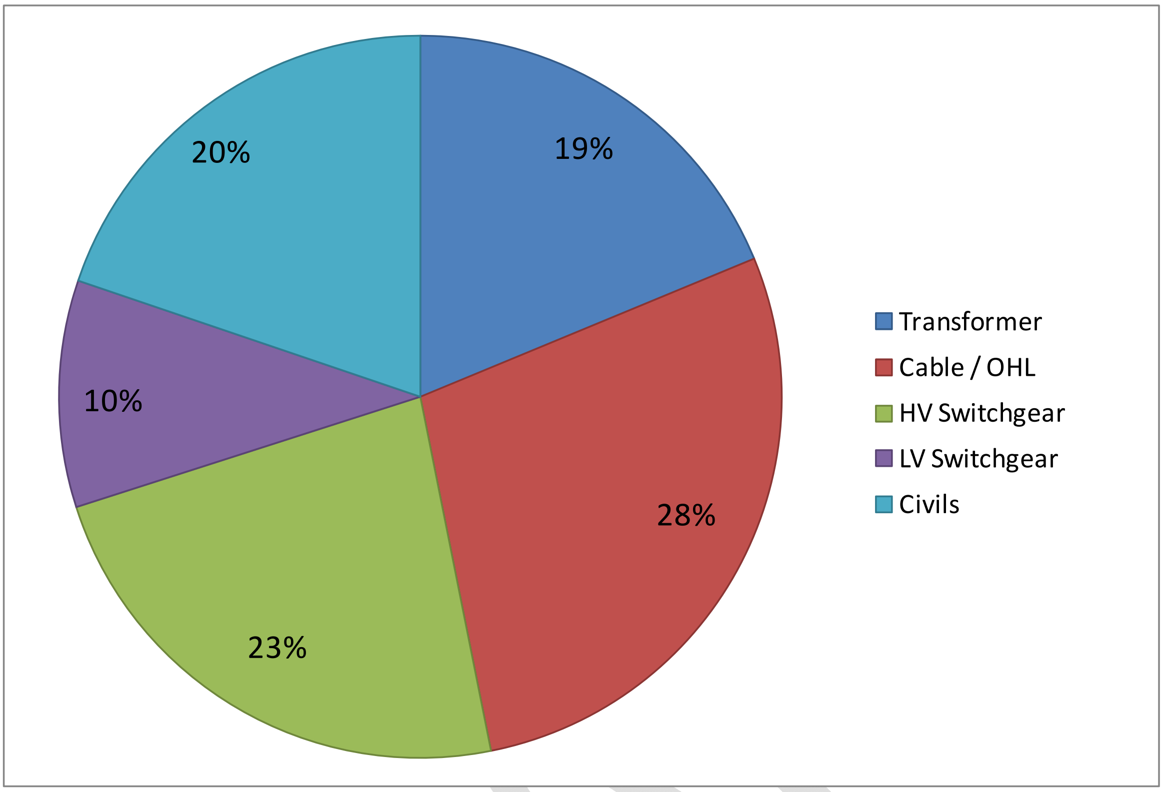


Figure 33 Baseline Strategy : Capital Cost Breakdown

The capital cost of the baseline strategy is calculated as $347.60M as shown in Figure 32 with an NPC cost, based on the staging illustrated in Figure 30, of $221.42M. It is evident that the investment required is primarily focussed within the first 5 year period with a more subsequent scattered profile. It should also be noted that no investment is indicated post 2030 up to the 25 year horizon year of 2036. This is due to the significant long term benefit provided by the proposed strategy and projects, in terms of suitable transmission capacity for load to grow and the considerable renewal of assets within the load area.

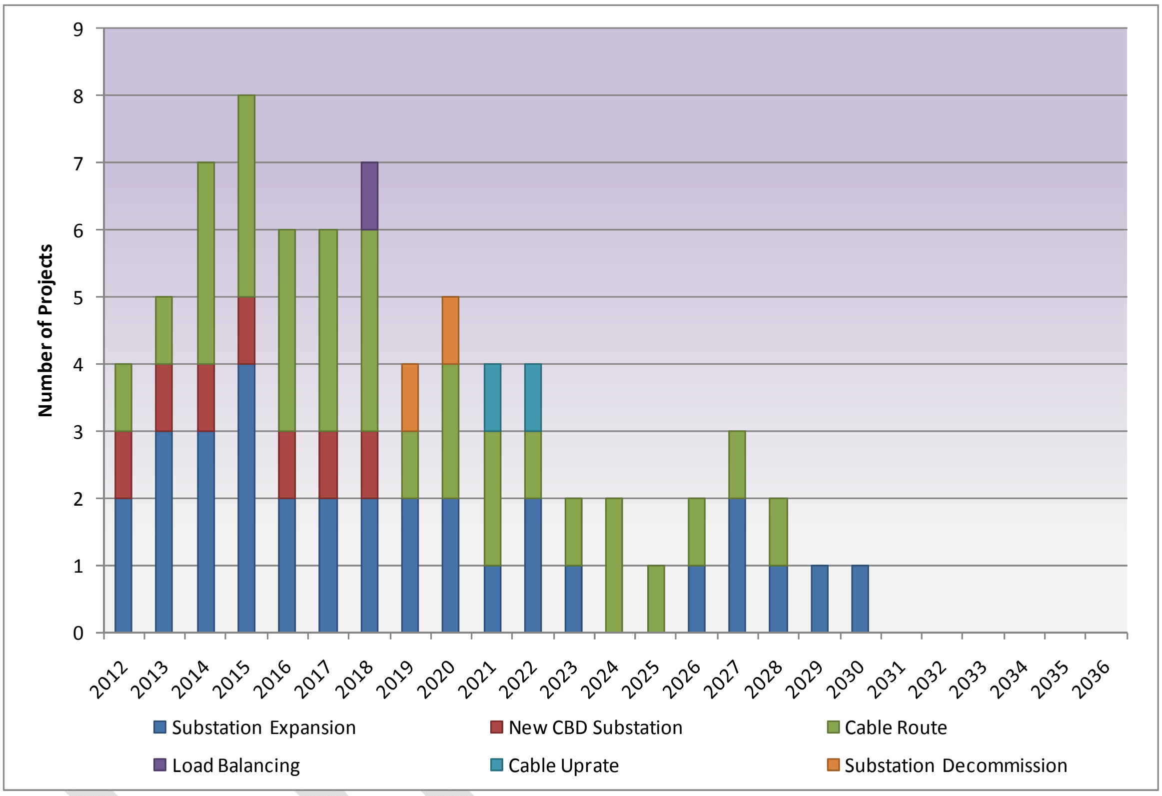
Figure 33 indicates that almost a third of the capital cost is attributed to cable and overhead line works, whilst over 20% is ascribed to 132 kV switchgear costs. Although there is proposed minimal transmission circuit works within the CBD Load Area, it is seen that some significant routeing is required to supply the load area from the wider transmission system. It is therefore the costs associated with supplying the CBD Load Area in the medium to long term that are a primary factor in relation to the high overhead line capital cost.

Similarly, the high 132 kV switchgear percentage is attributed to a number of factors in the reinforcement of the CBD Load Area. Where new transformers are installed, associated switchgear and potentially bus section switchgear is required. In the case of the Cook Street and proposed Bennett Street substations this would be of GIS technology which, although provides significant benefits in reduced footprint, does have a cost premium. In addition, the proposed East Perth switchyard extension introduces a number of 132 kV switchgear assets in isolation.

Civil costs are also seen to be some 20% of the total, primarily attributed to the construction of a multi-storey substation and associated cable tunnel at Bennett Street.

11.2.3. Baseline Strategy: Resources

The staging of projects required to deliver the baseline strategy is shown in Figure 30 and indicates a high level of parallel working will be necessary. Figure 34 illustrates the number of parallel projects ongoing for each year of the baseline strategy and subdivided into project type.



▪ **Figure 34 Baseline Strategy: Resources**

It is evident from Figure 34 that for the baseline strategy there are a significant number of projects ongoing in parallel, particularly within the next 10 years. The workload is expected to peak in 2015 with eight projects likely to be operating in parallel. Substation and transmission circuit works are shown to be ongoing over the next 20 years with a combination of the project types throughout the strategy period. Figure 34 highlights the significant level of resource effort required, particularly within the next 10 years to deliver the baseline strategy.

11.3. Bennett Street Substation: Delayed Deliverability Sensitivity

In order to assess the suitability of the baseline strategy, a deliverability sensitivity has been considered to assess the impact on system risk, investment profile, NPC and resourcing. The sensitivity relates to the delayed delivery of the Bennett Street Substation Project which could occur due to the complex nature of the project in consenting, design and construction.

The Bennett Street substation is identified as a key project due to the significant number of limitations which it addresses, but also the numbers of projects on which interdependencies are associated.

The Bennett Street substation project has been identified as providing significant benefits in the strategy surrounding the 66 kV assets in the CBD Load Area (see Section 7.3.2). In turn this results in the project being a key driver to address limitations seen at Forrest Avenue, Wellington Street, East Perth 66 kV switchyard and indirectly to Joel Terrace and Hay Street. The project is also required to facilitate the rebuild of the Milligan Street Substation by providing load transfer support to Hay Street Substation. Due to the key nature of the project it is deemed prudent to analyse the impact to the strategy should the Bennett Street substation be delayed by three years.

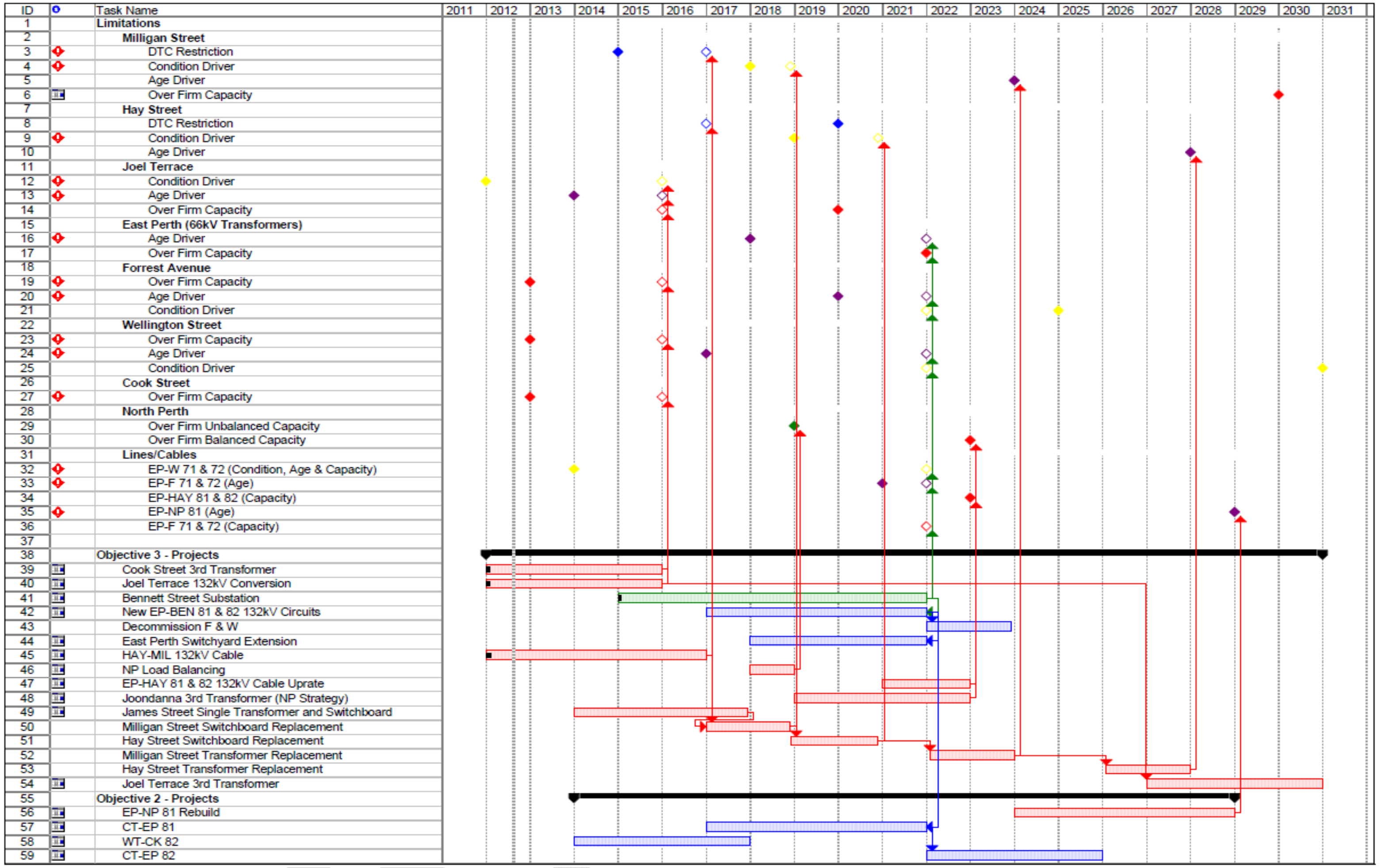
Revised Strategy

The revised strategy incorporating the delay of the Bennett Street substation by some three years is illustrated in Figure 35. The Bennett Street project has been highlighted in green and can now be seen to be completed by 2021 rather than the baseline timing of 2018. The deferral of this project has impacted on the risk surrounding the asset condition at the Forrest Avenue and Wellington Street substations.

Bennett Street dependant projects which have no other dependencies have also been delayed as part of this strategy which includes:

- EP-BEN 132 kV double cable circuit
- East Perth switchyard extension[46]
- Decommission of the Forrest Avenue and Wellington Street substations.

[46] This can be deferred until 2021, at which point the dependency of the CT-EP 132 kV circuit will override



- **Figure 35 Bennett Street Delayed: Revised Strategy**

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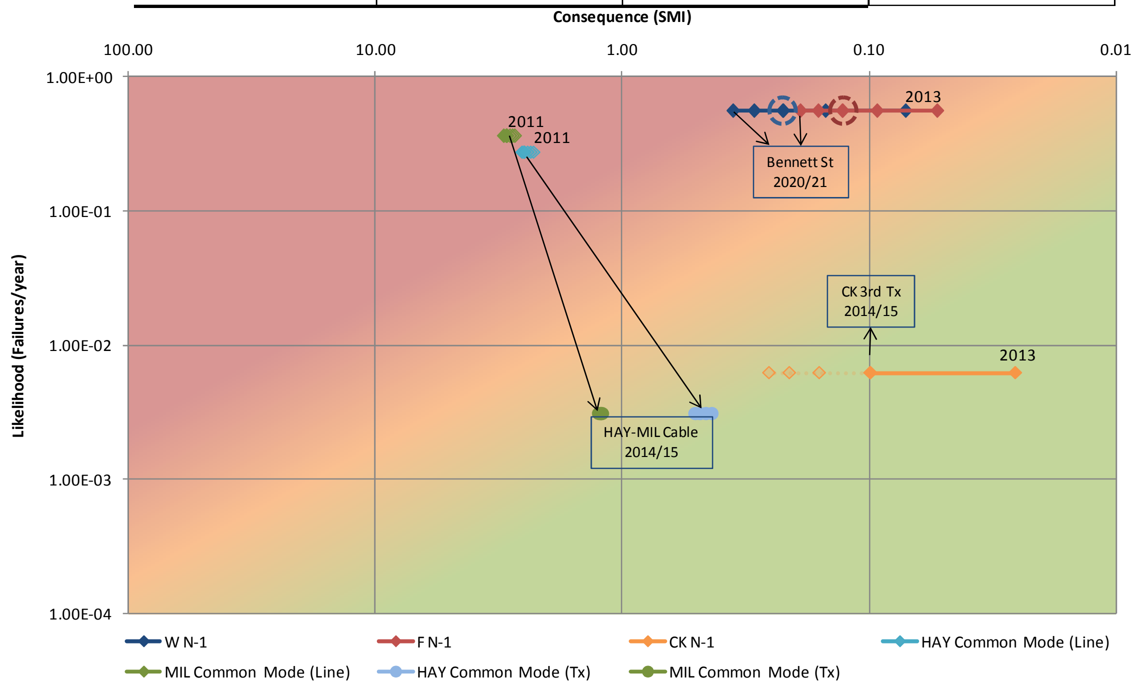
Revised Risk

The deferral of the Bennett Street substation project has resulted in the addressing of numerous limitations being extended by some 3 years. Of most significance is the over firm and asset condition risks seen at Forrest Avenue and Wellington Street substations as shown in Figure 36.

Catastrophic	Critical	Marginal	Negligible
Quality of Supply – SMI >=10 for single event E@R MWh >= 500 for a single event System or revenue loss / damage => $50,000,000 Reputation – severe and damaging series of media reports, trigger for parliamentary inquiry, several senior officers leave immediately as a result Regulation / Licence – severe threat of losing operating licence irrespective of remedial plans	Quality of Supply – 1 <= SMI < 10 for single event 50 <=E@R MWh < 500 for a single event System or revenue loss / damage =>$5,000,000 but < $50,000,000 Reputation – Damaging media reports which require extensive efforts to mitigate, several senior officers move posts Regulation / Licence – significant threat to operating licence if remedial plans not implemented	Quality of Supply – 0.1 <= SMI < 1 for single event 5 <=E@R MWh < 50 for a single event System or revenue loss / damage => $500,000 but < $5,000,000 Reputation - Adverse media reports on the performance of the company, however they disappear within weeks Regulation / Licence – adverse comments from ERA linked to capital investment programme	Quality of Supply – SMI <0.1 for single event E@R MWh <5 for a single event System or revenue loss / damage <$500,000 Reputation – No significant impact on WP business Regulation – No significant regulatory issues



▪ **Figure 36 Bennett Street Delayed: Revised Risk Matrix**

Figure 36 illustrates that the consequence of a failure at both Wellington Street and Forrest Avenue has increased from the baseline strategy (circled markers indicate original risk value from baseline strategy). Collectively, the impact of the delayed commission of the Bennett Street substation project results in an approximate increase of 9.6 MW of load at risk or 0.20 SMI across Wellington Street and Forrest Avenue Zone Substations. Based on the broad conversion technique indicated in Appendix J, this could relate to an additional $1M revenue at risk during the delayed implementation of the project from the baseline strategy.

It is noted that this analysis has indicated risk in terms of load which is over the firm capacity of the site and with a static failure rate however, much of the limitations are of an asset age or condition nature. Therefore, for each year a poor condition asset is retained in service or beyond its nominal lifetime, the risk of failure is more exponential than proportional[47]. Consequently, it is suggested that the risk that would be carried in such a case is likely higher than that stated and will continue to increase at an exponential rate for each year of delay.

Revised Cost

The revised investment profile for the 25 year strategy incorporating the Bennett Street substation delayed completion is provided in Figure 37.

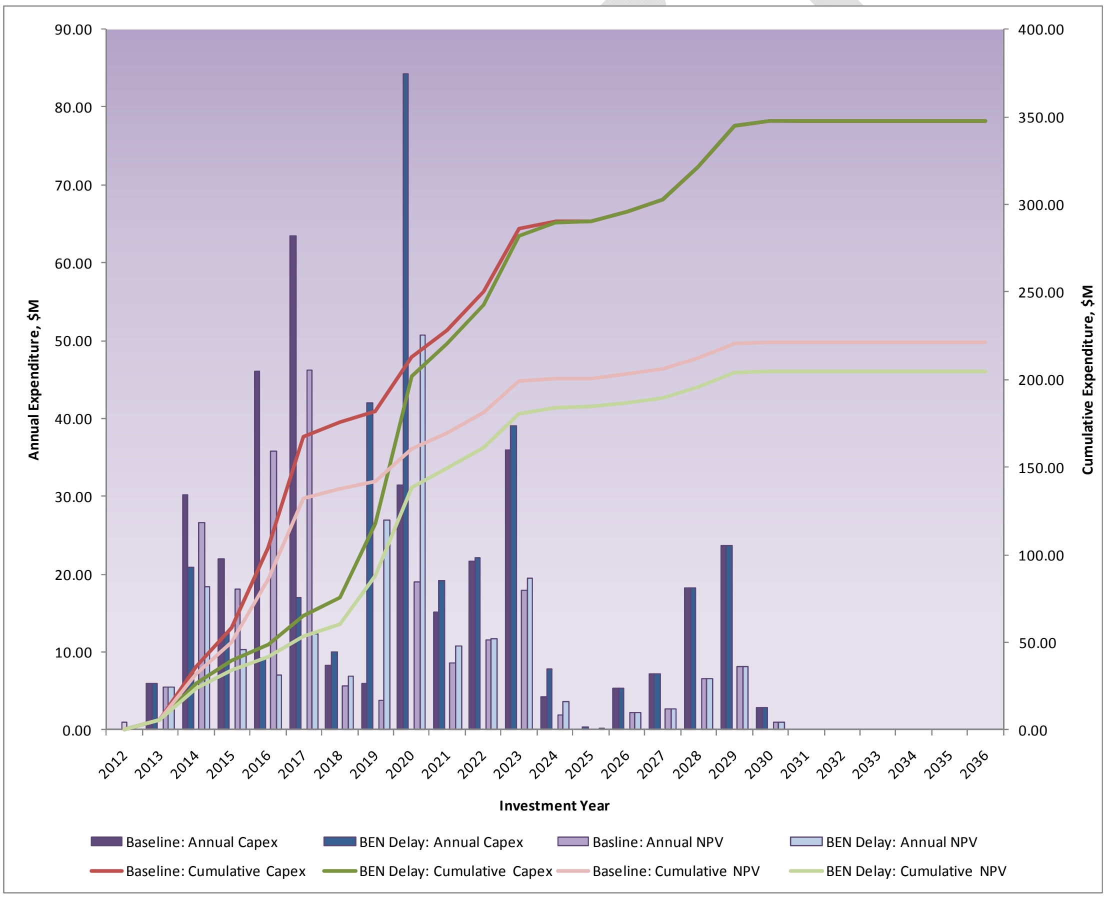


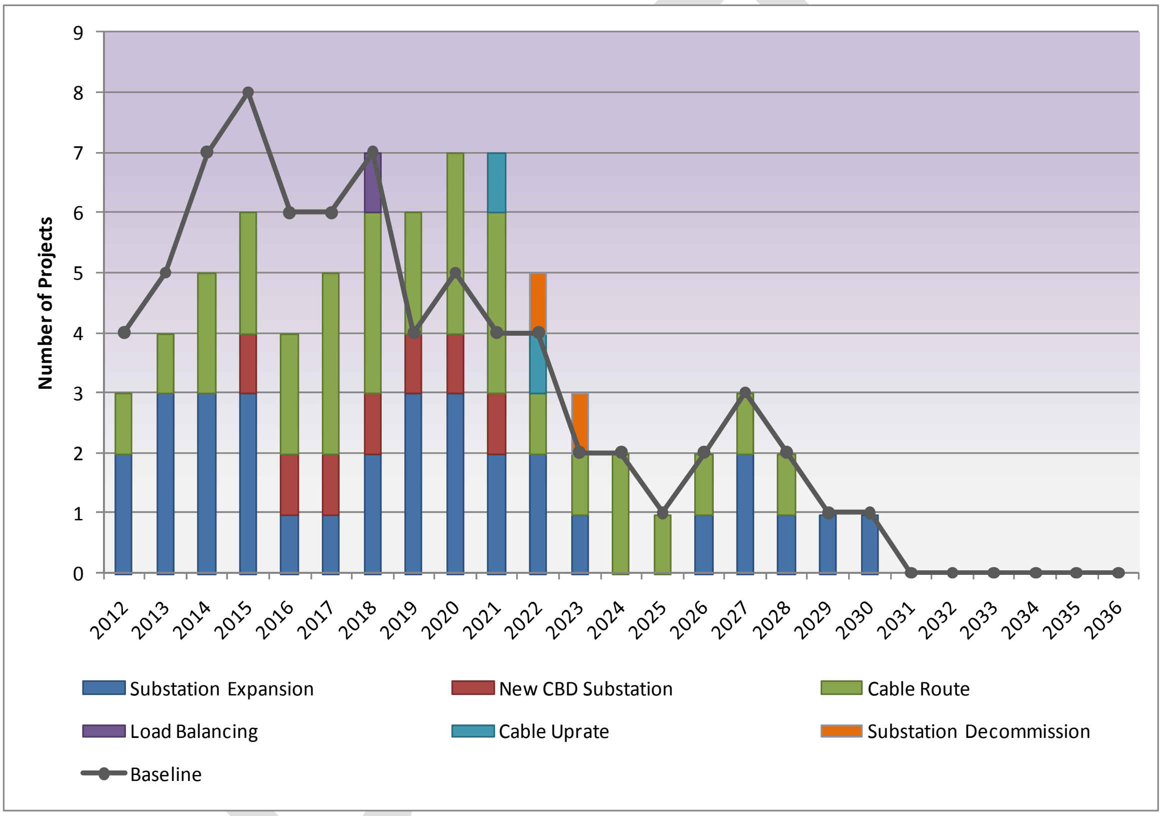
Figure 37 Bennett Street Delayed: Investment Profile Comparison

47 As illustrated in Figure 4.8 of the Western Power 2011 Network Management Plan

It is evident from Figure 37 that the delay of the Bennett Street substation has resulted in a lower NPC due to the deferral of the investment by three years. The revised NPC is seen to be $205M, some $16m or 7.5% less than the baseline strategy of $221M. The revised investment profile can now be seen to have a significant investment of some $85M in 2020. The $20M increase from the peak in the baseline strategy is attributed to the parallel works of the delayed Bennett Street substation with the CT-EP 132 kV circuit. The delivery of such an investment could be questioned and emphasises the importance of suitable staging of projects.

Revised Resourcing

The revised resourcing of the strategy considering the delay of the Bennett Street substation project is illustrated in Figure 38.



- **Figure 38 Bennett Street Delayed: Revised Resourcing**

It can be seen from Figure 38 that the delay of the Bennett Street substation has resulted in the significant reduction of parallel projects within the first six years of the strategy. There is now a greater level of parallel project work between 2019 and 2024. The movement in resourcing to later in the period reflects the reduced NPC seen against the baseline strategy as a result of the delayed implementation of this project.

Summary

The sensitivity of the three year delay of the Bennett Street substation project has illustrated a number of impacts on the 25 year strategy. Namely:

- Load at risk has increased by some 9.6 MW equating to some potential $1M revenue. The likelihood of a failure incident is also likely to increase due to continued deterioration of age expired assets at the Wellington Street and Forrest Avenue substations.
- 25 year NPC has reduced by some 7%
- Significant investment peak in 2021, circa $85M
- Parallel resourcing has been delayed from the beginning of the strategy towards the middle

The increased risk illustrates the wide ranging limitations which this project addresses directly and the future projects that rely on the construction of the substation to address other limitations. Although the NPC has been seen to reduce, it could be assumed that the mitigation measures required to manage the increased risk could potentially outweigh the savings made. Similarly, although immediate resourcing has been reduced, an increased number of smaller projects are likely to be required to implement the mitigation measures required to manage the increased risk.

11.4. DTC to Minimise Risk Exposure

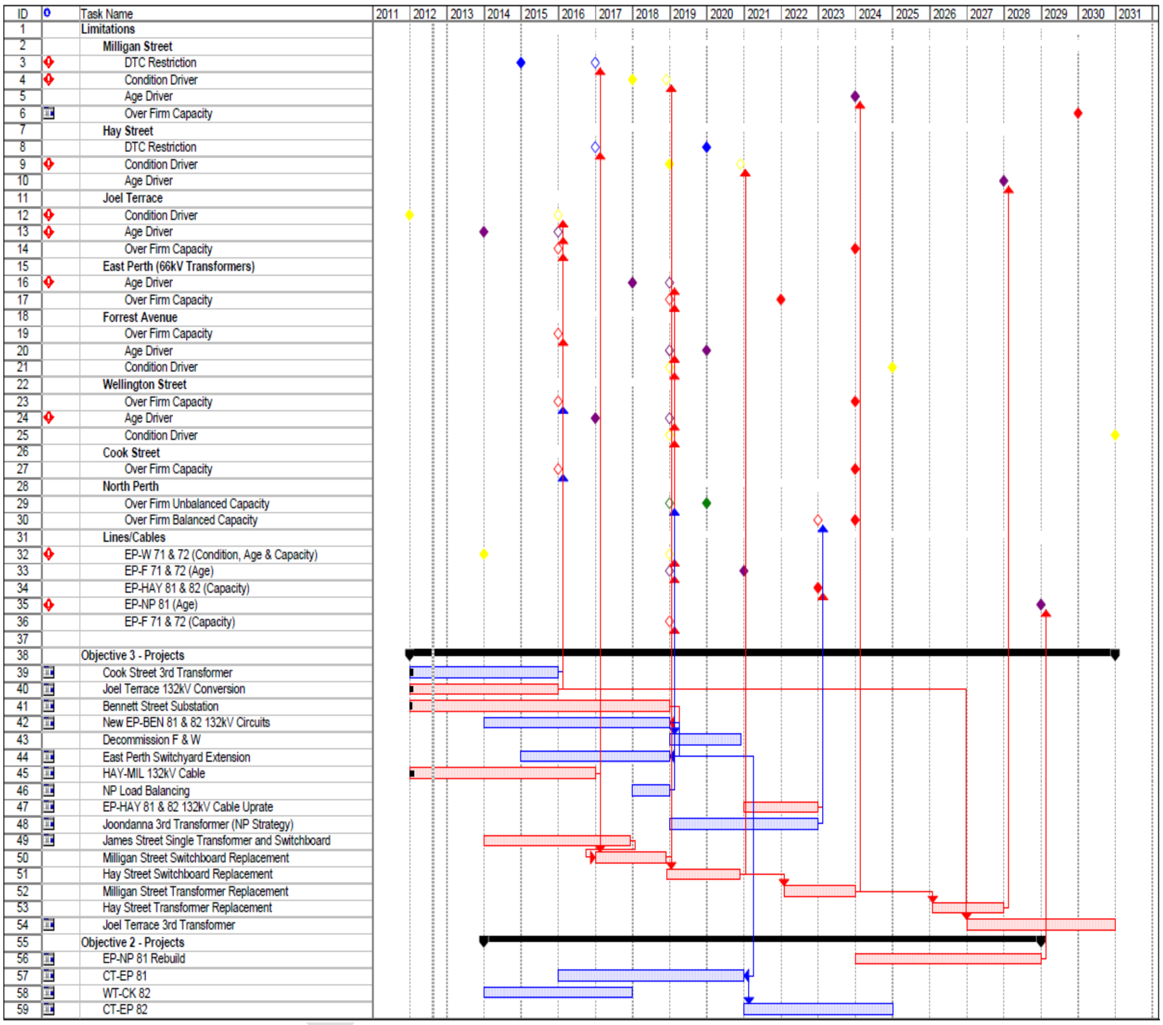
When defining the limitations seen within the CBD Load Area (as summarised in Figure 15), the capability of the DTC network has not been considered. The DTC network can potentially provide additional support during an outage event by transferring load to neighbouring, interconnected substations. The 2011 installed capacity of this DTC capability is shown in Figure 45.

The capability of the DTC network to support over firm substation outages has not been previously considered due to a number of factors:

- The Technical Rules dictate that for an N-1 outage within the Perth CBD boundary, it is required that the load be supplied within 30 seconds of the outage occurring. Such a timeframe could only be met with the DTC system if auto-switching systems are available. Without detailed studies of the distribution system capability, it is not possible to define the level of DTC capable of meeting the Technical Rules in an over firm N-1 outage. Furthermore, should a bumpless N-1 approach be adopted, no switching time would be allowed which would restrict the use of DTC from providing firm capacity support.
- It has been proposed that a migration to a 22 kV distribution voltage may have significant benefits in alleviating distribution restrictions and other advantages. In migrating to this voltage from the existing 11 kV system it is highly likely that there will be significant disruption to the DTC network.

With this in mind, it is proposed that the DTC capability is not utilised to defer projects within the CBD Load Area due to these uncertainties, however in the short term there is the potential to mitigate risks associated with over firm capacity operation. This is of particular importance where the system is at increased risk due to a delay in project implementation to address defined limitations.

Figure 39 illustrates the baseline strategy with over firm limitations augmented to include the 2011 DTC capability. It is evident that with the inclusion of DTC, no over firm capacity limitations are expected within the 10 year period. This does not however consider the large number of limitations within the CBD Load Area which are associated with asset age and condition issues rather than a wholly under capacity restrictions.



■ **Figure 39 Utilising DTC Capability to Minimise Risk Exposure**

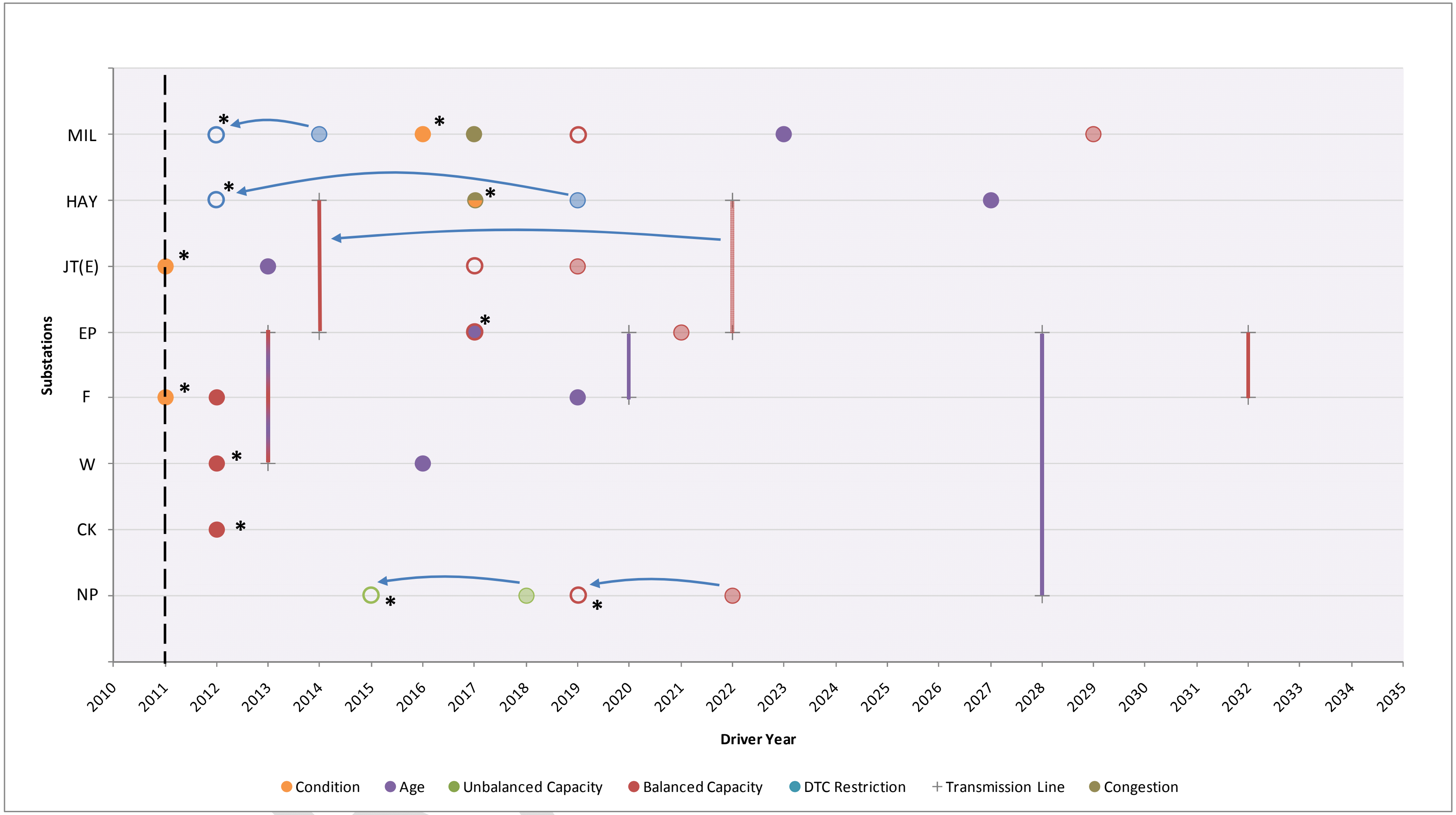
11.5. Load Demand Sensitivities

11.5.1. High Load Growth Forecast

A high load forecast sensitivity for the wider transmission network has been carried out as part of Section 10.4.1 which indicated a minimal impact to the loadings of the incoming circuits. The high load forecast has been provided through Western Power's OPAL forecasting system, primarily indicating an accelerated growth of the block load developments at Elizabeth Quay (Perth Waterfront) and Perth City (Northbridge) Link. Figure 40 illustrates the impact of this increased load forecast across the full baseline strategy.

Figure 40 is a revision of the summary of emerging limitations chart shown in Figure 15. Due to the increased load growth, a number of these emerging limitations have been brought forward. The revised limitations are shown as unfilled circles with the original limitations illustrated as filled circles for reference. In addition, limitations with an asterisk indicate the first driver seen at that substation. For the Hay Street and Milligan Street substations there are two asterisks indicated, one for the DTC restriction and another for the asset condition restrictions which require different reinforcements to be implemented.

It can be seen from Figure 40 that in some instances the increased load growth results in the driver for reinforcement to be brought forward, as indicated by the blue arrows. In other instances, although the limitation has been brought forward, a prior limitation still overrides it. An example of this is the balanced capacity at Joel Terrace which has been brought forward by some 2 years to 2017; however the primary driver at this site is the poor condition of the assets which has reached a critical level in 2011. Therefore the reinforcement is still required from 2011 and the load growth has no impact in altering the required project.



▪ **Figure 40 High Load Growth: Revised Limitations Summary**

Overall from Figure 40 it is evident the general impact across the load area from an increased load growth scenario is relatively small. The Forrest Avenue, Wellington Street and Cook Street substations see no change as the capacity restrictions are emerging immediately. Similarly, although the capacity limitation has been brought forward at Joel Terrace and East Perth, it is still not before the existing asset age or condition limitation and hence has no impact.

The primary impact of the high load growth scenario is the advancement of the DTC restriction at both Hay Street and Milligan Street Substations to 2012. In addition, the capacity restriction seen on the cable sections of the EP-HAY circuits has been advanced by some 8 years. These advancements occur as much of the accelerated load growth is attributed to Milligan Street Substation which impacts on these drivers. It should also be noted that the congestion seen at Milligan Street Substation would be significantly advanced in accommodating the increased load. Further advancements are seen at North Perth in both the balanced and unbalanced capacity by some 3 years each.

The impact of these driver advancements in the emerging limitations is the resulting advancement of reinforcement projects and where this is not possible, a consequential increase in system risk. Table 33 summarises the impact on the reinforcements required to address the highlighted limitations and the additional system risk expected.

- **Table 33 High Load Growth Scenario: Impact on Baseline Projects**

Limitation	Project	Project Advancement	Increased NPC	Additional Risk From Baseline
North Perth Unbalanced Capacity	North Perth Load Balancing	3 Years	Negligible	-
North Perth Balanced Capacity	Joondanna Third Transformer Advancement	3 Years	$0.18M	-
EP-HAY Capacity	EP-HAY 81 & 82 132 kV cable uprate	8 Years	$1.20M	-
DTC Restrictions	HAY-MIL 132 kV Cable	Not possible	-	0.62 SMI
Cook Street Balanced Capacity	Cook Street Third Transformer	Not Possible	-	0.17 SMI
Wellington Street & Forrest Avenue Balanced Capacity	Bennett Street Substation	Not Possible	-	0.38 SMI

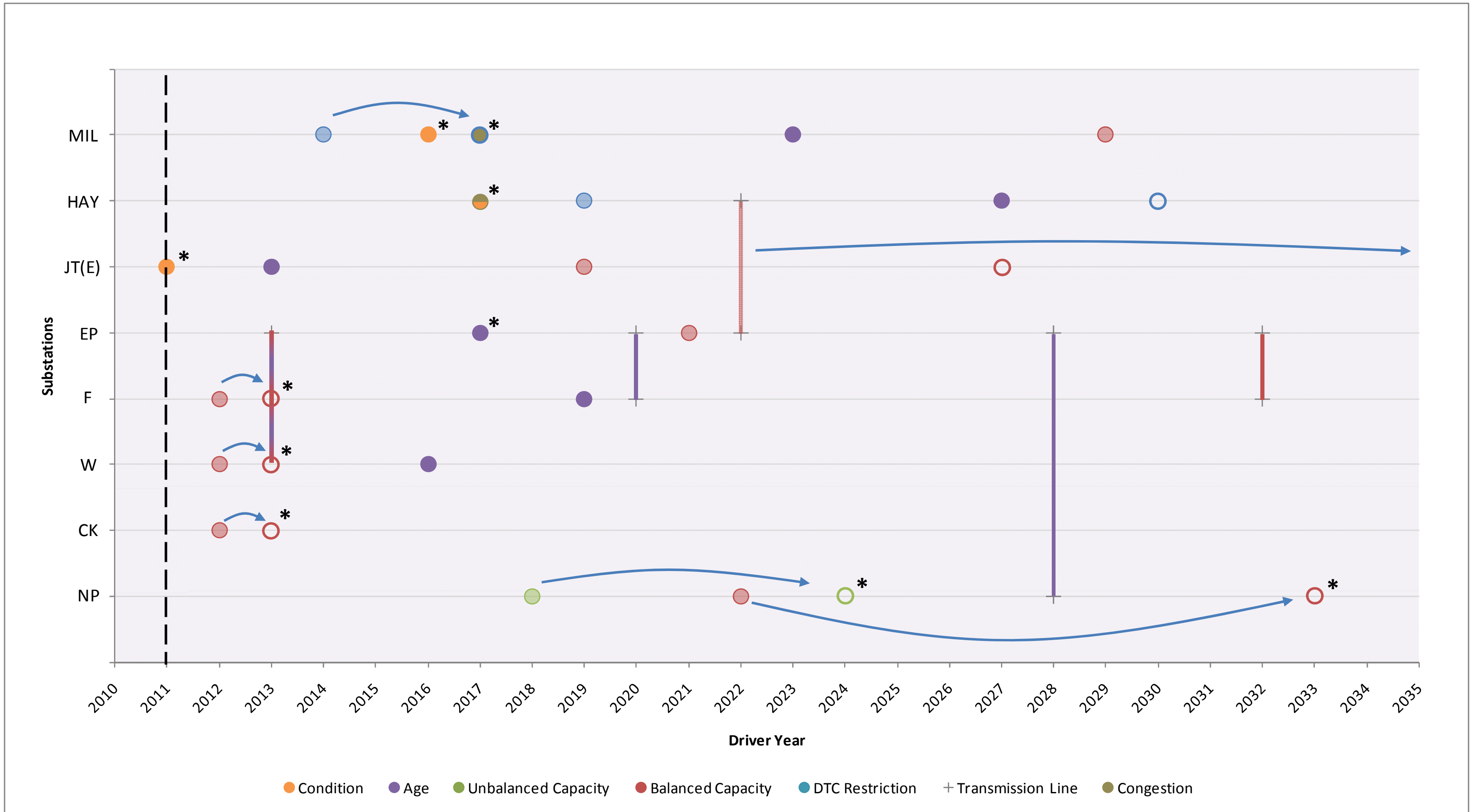
Should a high load growth scenario occur it is evident that the impact on the overall baseline strategy in terms of project requirements will be minimal. This is primarily due to the number of asset age and condition drivers in conjunction with the immediate nature of many of the capacity restrictions which are less susceptible to load sensitivities. The advancement of projects is however seen to increase the NPC of the baseline strategy by some $1.4M (~1%). Furthermore, as the HAY-MIL 132 kV cable, Cook Street third transformer and Bennett Street Substation projects cannot be advanced further; there would be an additional 36% of system risk over the baseline strategy during the project implementation period. This is due to an increased level of load being over the firm capacity of the impacted substations for a greater period of time and of a greater magnitude.

11.5.2. Low Load Growth Forecast

In addition to the consideration of a high load growth scenario, it is possible that the load growth within the CBD Load Area could be slower than that forecasted. Drivers for this reduction in growth could be attributable to:

- Introduction of Demand Side Management
- Customer education of energy efficiency
- Delay or cancellation of commercial connections, particularly block loads.

It is therefore necessary to assess the baseline strategy against the potential of a lower load growth. For the purpose of this study, it has been assumed that the load at each substation grows at half its current forecasted rate. The limitations summary illustrated in Figure 15 has been updated in Figure 41 to illustrate the deferral of under capacity drivers due to this reduced load growth. The interpretation of this chart is as per that described in Section 11.5.1.



■ **Figure 41 Low Load Growth: Revised Limitations Summary**

The impact of the low load growth scenario can be seen to be a reflection of that illustrated by the high load growth scenario shown in Figure 41. Again, the main impacts are at North Perth Substation, the EP-HAY circuits and DTC restrictions. Minimal deferral is expected for the short term capacity restrictions of Forrest Avenue, Wellington Street and Cook Street. All other substations are not impacted by a low load growth scenario as the limitations are based around asset replacement requirements.

The primary deferral due to the low load growth scenario is that of EP-HAY circuits which is now seen to be beyond the 25 year horizon. In addition, the DTC restriction at Milligan Street Substation has been deferred by some 3 years. It is also noted that the congestion restriction expected at Milligan Street Substation may also be deferred as the requirement for new feeders is delayed. Further deferrals are seen at North Perth in both the balanced and unbalanced capacity by some 6 and 11 years respectively.

The impact of the deferral in the emerging limitations is the associated deferral of the reinforcement projects and a subsequent potential reduction in system risk. Table 34 summarises the impact on the reinforcements required to address the revised limitations.

- **Table 34 Low Load Growth Scenario: Impact on Baseline Projects**

Limitation	Project	Project Deferral	Reduced NPC	Reduced Risk from Baseline
North Perth Unbalanced Capacity	North Perth Load Balancing	6 Years	Negligible	-
North Perth Balanced Capacity	Joondanna Third Transformer Advancement	11 Years	$0.67M*	-
EP-HAY Capacity	EP-HAY 81 & 82 132 kV cable uprate	Beyond Horizon	$1.84M	-
DTC Restrictions	HAY-MIL 132 kV Cable	0 Years	-	0.22 SMI
Cook Street Balanced Capacity	Cook Street Third Transformer	Not Possible	-	0.09 SMI
Wellington Street & Forrest Avenue Balanced Capacity	Bennett Street Substation	Not Possible	-	0.23 SMI

*At this deferral the Joondanna third transformer will have been installed due to limitation drivers from the Northern Terminal Load Area and not specifically the requirements of North Perth. The project deferral noted is that with respect to the CBD Load Area.

Should a low load growth scenario occur it is expected that the impact on the overall baseline strategy will again be minimal. This is due to the number of asset age and condition drivers in conjunction with the immediate nature of many of the capacity restrictions which are less susceptible to load sensitivities. The deferral of projects would however be expected to reduce the NPC of the baseline strategy by $2.5M (~2%) over the 25 year horizon. Furthermore, as the DTC, Cook Street and Wellington Street capacity restrictions have been marginally deferred, there would be an approximate 25% reduction in system risk (based on SMI to in comparison with the baseline strategy) wholly from these substations not being over firm for as long before identified projects are commissioned.

11.5.3. Economic Value of Demand Side Management Options

As previously discussed Western Power is required to consider DSM and other Network Control Service (NCS) options when producing a business case for network investment. These options have not been specifically considered in this analysis as their value and availability is expected to change significantly over time. These options must however be considered at the time of developing project specific business cases.

DSM options effectively act by reducing demand growth and as such this analysis can provide a guide to the competitive economic value of the DSM in the context of the baseline strategy. This will provide a comparison for use in future business cases. From the results of the low load growth sensitivity study reducing the prospective demand growth across the CBD Load Area by 50% results in a lowering of the estimated 2036 demand by broadly 100 MW for a reduction in NPC of $[redacted]M. Consequently, the NPC value generated by 1 MW of DSM implemented today is $[redacted].

12. Summary & Recommendations

12.1. Summary

This report has considered the potential network limitations and capital investment drivers for the Western Power transmission and distribution system in the CBD Load Area over the next 25 years. The key network and asset limitations have been identified covering the following investment drivers:

- Network reinforcement to accommodate area load growth over 25 years
- Asset replacement to address age and condition related deterioration
- Customer driven connection works

and other desired objectives:

- Rationalisation of existing substation sites
- Overcoming practical restrictions such as cable exit congestion
- Flexibility in future growth and expansion

Each reinforcement project has been assessed on the basis of a number of financial, technical and practical metrics. This included:

- Capital investment cost utilising Western Power building block costs
- NPC with agreed investment profile and discount parameters
- Ability to address asset age and condition related deterioration
- Continual compliance with Technical Rules
- Practical issues related to overhead line, cable, substation and distribution developments
- Perceived environmental and community benefits/consenting issues

From the analysis conducted and assessment performed, it is evident that:

- All substations in the CBD Load Area are expected to require capital investment or capacity enhancement within seven years.
- All of the existing 66 kV network within the CBD Load Area (with exception of a limited number of 66 kV switchgear units at East Perth) will require asset replacement and capacity upgrading within the considered strategy period.
- Space restrictions at Hay Street, Milligan Street and proposed Bennett Street Zone Substations will limit the designs that can be employed, particularly if in-situ replacement of the assets at Hay Street and Milligan StreetZone Substations is considered.
- Reinforcement of the transmission supply into the CBD Load Area is expected to be required towards the end of the first ten years, including both the installation of second WT-CK 132 kV

circuit plus a new transmission connection from Cannington. The exact timing for the new CT-EP circuit(s) will be influenced by developing generation capacity and operational dispatch, a Southerly bias to which is expected to accelerate the requirement for these circuits.

- Beyond 10 years further CBD Load Area transmission supply investment is likely to be required to develop the new CT-EP 132 kV transmission circuits (if not installed earlier due to generation developments) as well as replace the existing NP-EP 132 kV circuit.
- Towards the end of the 2020s the CT-EP circuits may be uprated to 330 kV operation if this is considered technically and economically justifiable.

The following investment projects have been identified as key future network reinforcements being required to address specific limitations:

- **Table 35 Summary of Reinforcement Projects**

Reinforcement Project	Primary Limitation	Proposed In Service Year
Cook Street 3rd Transformer	Cook Street Substation – over firm capacity	2015
Joel Terrace 132 kV conversion	Bad asset condition	2015
HAY-MIL 132 kV Cable	Continued N-2 security and control of power flows through the CBD Load Area	2016
James Street single 132 kV transformer and switchboard	Distribution system congestion restrictions and facilitation of asset replacement	2017
Install WT-CK 82 132 kV transmission circuit	Transmission supply network N-1-1 compliance (Western Terminal Load Area)	2017
Load balancing	North Perth substation – over firm capacity	2018
Bennett Street Substation with associated transmission connection works	66 kV network (Wellington Street, Forrest Avenue, Joel Terrace and East Perth 66 kV) approaching end of nominal life, poor asset condition and emerging capacity restrictions	2018
East Perth 132 kV switchyard extension	Lack of available circuit breakers for new transmission connections	2018
Hay Street and Milligan Street asset replacement	Hay Street and Milligan Street substation assets approaching end of nominal life and poor asset condition	2018/20
EP-CT 81 & 82	Transmission supply network N-1 and N-1-1 compliance	2020/25
Uprate EP-HAY 81 & 82 cable sections	EP-HAY 81 & 82 – over firm capacity	2023
Joondanna 3rd transformer	North Perth Substation – over NCR capacity	2023
Rebuild EP-NP 132 kV transmission line	End of nominal life	2029
Joel Terrace 3rd transformer	Joel Terrace Substation – over firm capacity	2031

A development strategy has been derived to stage the reinforcement projects to minimise system risk with consideration for the investment profile and resourcing of parallel projects. The following aspects are highlighted:

- The baseline strategy has a nominal 25 year capital cost of $347.60M and an associated NPC of $221.42M
- Resourcing for the baseline strategy is intensive within the first 10 years with up to eight independent projects (1x zone substation construction, 3x transformer substation expansions, 3x 132 kV cable installations and 1x switchyard extension) required to be ongoing in parallel.
- Should the delivery of the Bennett Street Zone Substation reinforcement project be delayed by an arbitrary three years to reflect possible difficulties in consent/construction, the impact on NPC would be a reduction of 7%. However, the load at risk during the implementation period would be expected to increase by an additional 9.6 MW or $1M of revenue against the baseline implementation timeframe. The investment profile of such a scenario is significantly increased with a peak of $85M in 2020 alone.
- Low load growth sensitivity (half growth rate) indicated a marginal reduction on project delivery NPC (2%), but noticeable reduction in load at risk (25% based on comparative SMI with baseline strategy).
- High load growth sensitivity (provided by Western Power load forecast) indicated a marginal increase on project delivery NPC (1%), but significant increase in load at risk (additional 36% based on comparative SMI with baseline strategy).

Other aspects to note from this study include:

- Western Power standard substation configurations and transformer ratings have been utilised within this study unless explicitly noted. Other arrangements could be adopted if required, however this would not be expected to impact on the outcomes of this study.
- The development strategy presented addresses all of the limitations identified within the 25 year horizon primarily through significant asset replacement and overcoming the existing practical limitations within the CBD Load Area.
- Beyond the 25 year horizon minimal capacity expansion works are expected to be required, however Western Power owned land is available at the James Street and Wellington Street sites to expand or construct additional substations respectively based on this analysis. In addition, land is also owned at Tully Road, Murray Mews and other locations. It is possible that through future investigations and negotiations other land may be available or traded.
- As part of Western Power's license, non-network alternatives (e.g. DSM) must be considered at the development of each business case by modelling the impact of any potential delay in investment. However, consideration of such techniques is not expected to impact significantly on the developed strategy.

12.2. Recommendations

Having studied the capital investment requirements of the CBD Load Area and wider transmission supply network over a period of 25 years, the following recommendations are made to Western Power:

1) Retaining the 66 kV network as part of the transmission system voltage within the CBD Load Area is not recommended as it is the least economically efficient strategy over the long term.
2) Discussions with the ERA should be continued to establish the longer term vision for the existing 66 kV switchyard at East Perth Terminal, including the potential for a 330 kV switchyard.
3) A number of projects have been identified as being required within the first 5-7 years of the development strategy period to minimise Western Power business and customer risk and provide the maximum attainable benefit. It is therefore recommended that the further analysis of the cost, practical issues, environmental impacts and other implementation/deliverability factors of the following projects be made a priority:
   - HAY-MIL 132 kV underground cable
   - Bennett Street Substation and associated transmission supply
   - Joel Terrace 132 kV conversion
   - Cook Street 3rd Transformer
   - Single 132 kV transformer and distribution switchboard at James Street
   - Staging requirements and any associated load transfers to facilitate the Milligan Street and Hay Street Zone Substation switchboard replacements
4) Develop a preliminary Stakeholder and Community Engagement Strategy for the CBD Load Area Program of Works

In addition to these recommendations, there are a number of aspects that require further analysis and assessment to fully understand their associated impact on the investment strategy. Typically this additional analysis will be completed as part of detailed planning reports. It is therefore recommended that:

5) The migration to a 22 kV distribution voltage from the existing 11 kV within the high density Perth CBD boundary is further analysed to fully understand the level of asset replacement required, the advantages that can be gained and the deployment strategy for any potential migration. Such an analysis should be carried out as part of a distribution development strategy in conjunction with the detailed planning reports.
6) The support capability of the DTC network under contingency conditions is reviewed to understand the ability to contribute to continued compliance with the Technical Rules.
7) The long term benefits of migrating the new CT-EP double circuit line to 330 kV should be further assessed, including analysis of potential timings and cost impacts. In the short term, assessment of existing Western Power 132 kV and 330 kV tower designs should be conducted in order to determine the most appropriate line construction design to facilitate future upgrades at minimal cost and with minimal additional work.

8) The installation of a quadrature booster should be further assessed to analyse the potential impacts on timings of the identified 132 kV transmission supply reinforcement projects as well as any potential wider system benefits.

9) The mitigation measures required to manage the risks to the Western Power business (in terms of the potential occurrence of a quality of supply or legal compliance incident) and its customers' during the implementation of the proposed capital investment strategy requires further detailed analysis.

10) The feasibility of the proposed overhead line or underground cable projects should be investigated to confirm that these schemes can be achieved in practice considering environmental and community consenting concerns and other practical limitations. This should include installation techniques such as pit and duct or tunnel technologies which will be of particular importance for the proposed HAY–MIL 132 kV cable.

11) Detailed conceptual designs are developed for each new / modified substation to confirm that the number and rating of transformers considered can be achieved in practice, with specific consideration given to operational and construction issues. Particular attention is required at Hay Street, Milligan Street and Bennett Street Zone Substations given the restricted site plots available.

13. References

[1] Reference 1

[2] Reference 2

[3] Reference 3

[4] Reference 4

[5] Reference 5

[6] Reference 6

[7] Reference 7

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[9] Reference 9

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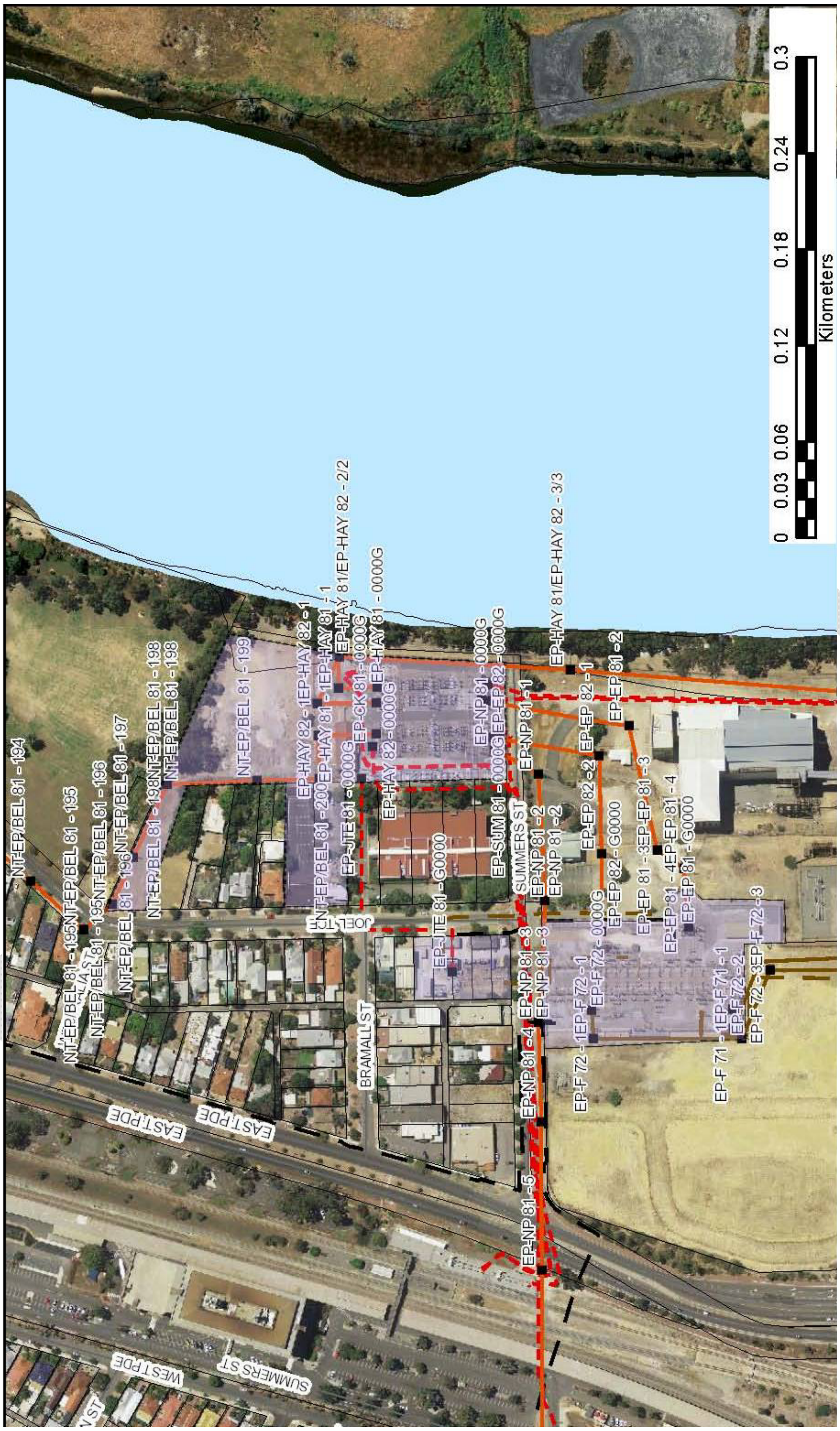
Appendix A CBD Load Area

■ **Figure 42 CBD Load Area - Geographic**

Appendix B Land Ownership

- **Figure 43 CBD Load Area - Land Ownership**



■ **Figure 44 East Perth Switchyard: Land Ownership**

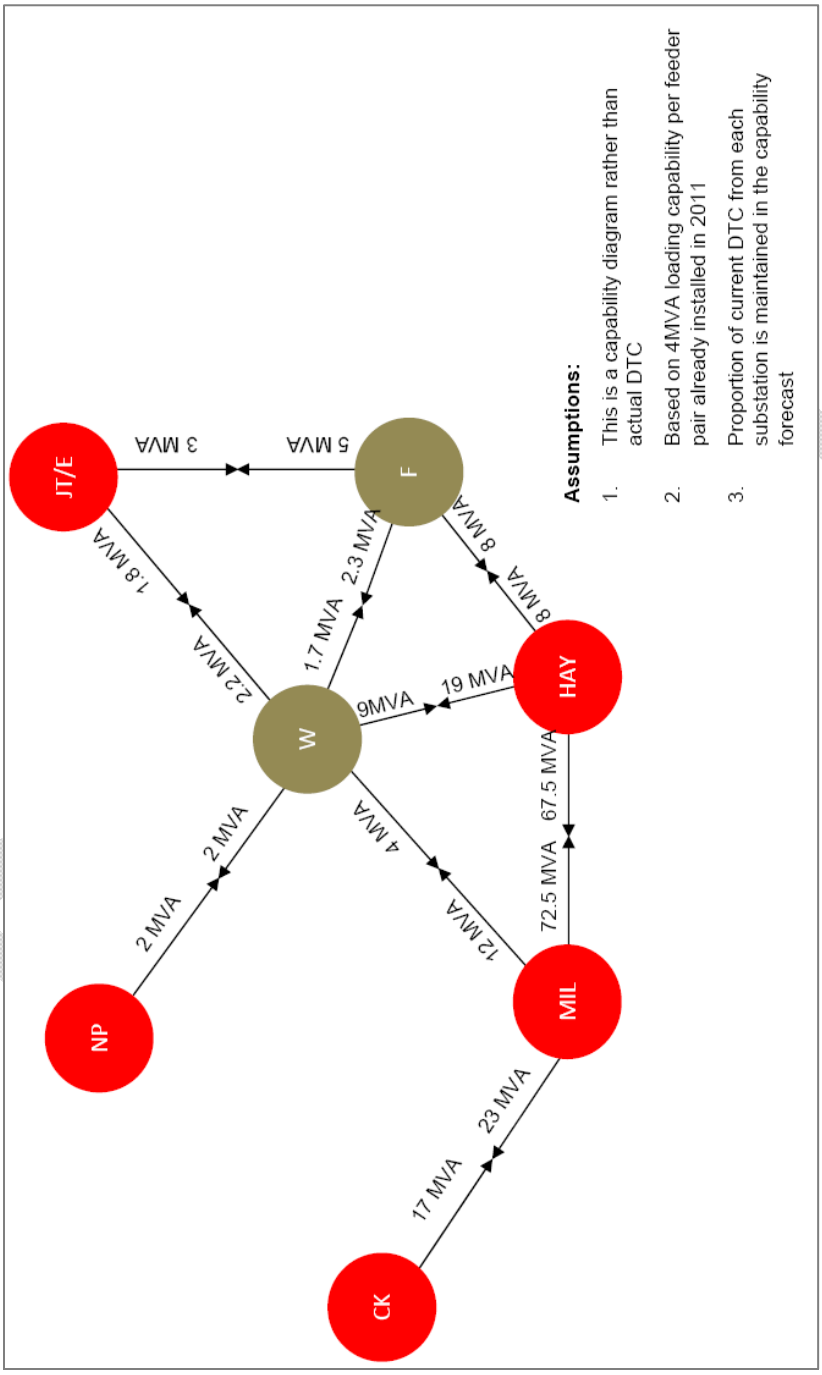
Appendix C Hay and Milligan Street 11 kV Switchboard Condition

Commercially confident.

Appendix D Bennett Street Substation

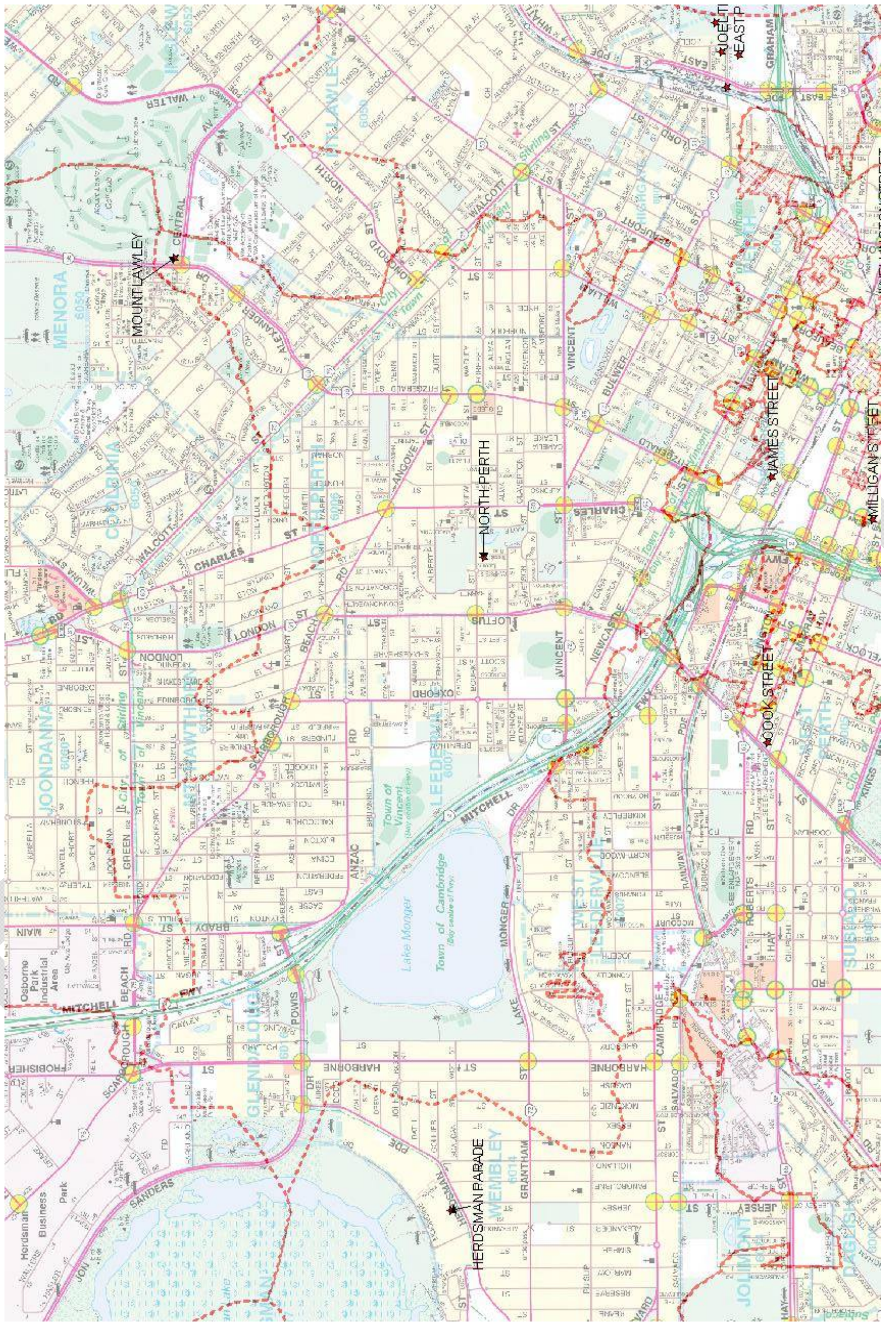
Commercially Confident

Appendix E DTC Capability



- **Figure 45 CBD Load Area – November 2011 DTC Capability Diagram**

Appendix F Distribution Catchment



- **Figure 46 North Perth and Surrounding Substations: Distribution Catchment Area**

Appendix G ST- EP Line Uprating Information

The information was provided by Transmission Primary Engineering in response to questions raised by Transmission Planning concerning the ability of the Southern Terminal – Bentley – East Perth 132 kV circuits to be increased to a higher thermal rating.

G.1 ST-BTY-EP Circuit Background

The two circuits (after converting the original split phase line to double circuit construction with new sections of underground cable) ST-EP 81 and 82 consist of underground cable, wide and narrow base lattice steel towers and wood pole sections with various types of conductor. The required ratings of the new circuits were to match Triton at 100°C (1,063 A, 243 MVA at 132 kV) which was the predominant conductor used on the circuits at that time.

The ACSR conductor sections (on wide based towers with limited strength) were restrung with high temperature low sag conductor (HTC). The HTC (R-XTACIR of 210 mm^2 cross sectional area) had to replicate the existing ACSR conductor loading and ground clearances and has a rating of 1,063 A at 172°C. The HTC conductor has a maximum operating temperature of 230°C, which offers a current rating of 1,195 A (273 MVA at 132 kV).

G.2 General Related Comments

The transmission line strung information for the overhead lines and underground cables are taken as correct and have been interpreted correctly. In view of the complicated and expensive methods of marginally increasing the present ratings of any of the three circuits, it would be prudent to investigate other methods of reinforcing the electrical supplies to the CBD Load Area. Other methods of increasing the circuit ratings could be reviewed, but the results may be somewhat limited.

The existing HTC sections form the majority lengths of the three circuits. It is assumed that maximising the current rating of these sections will be the limiting factor, otherwise the line will have to be rebuilt with new structures and conductors or installing underground cable.

It should be noted that the wide and narrow based towers were installed in the 1960s and there is very little information of the structure, foundation design and as-constructed information. Extensive structural design studies will have to be carried out to validate the potential solutions noted below.

Most of the sections of the circuits are on double circuit structures. Care has to be taken not to double up the modification costs, so while the individual costs per circuit are indicated below, the summary indicates the individual and total costs.

G.3 Uprating ST-EP 82, ST-BTY 81 and EP-BTY 81

The three circuits are reviewed in turn to establish the sections that would require uprating, the proposed method and an indicative cost. The maximum uprated current is taken as 1,195 A.

1. ST-EP 82

- Replace the existing Triton conductor section with Venus and one wood pole at Southern Terminal at an estimated cost of $[redacted]k.
- Structures 6 to 49 consist of narrow base towers with Triton conductor. Due to limited structure and foundation loading capacity, any uprating will have to be limited to replacing the existing Triton conductor with a HTC such as ACCC. Estimated cost for the 7 km length is in the order of $[redacted]M.
- Structures 49 to 95 consist of wide base towers with HTC operated at a maximum of 172°C. The conductor may be run at 230°C, but will require the structures to be raised approximately 0.5m. Investigations and a line survey will be required to confirm that these structures can be modified. Estimated costs are $[redacted]M based on $[redacted]k and $[redacted]k for suspension and tension tower respectively. Note that there are a number of narrow based and steel pole structures that may have to be entirely replaced for the uprate and therefore the line would require a survey regarding structural and foundation design.
- Structure 102 to East Perth is an underground 1,200 mm^2 132 kV cable. Rating restrictions are seen due to the various ducted sections along the route and some short parallel sections with the EP-BTY 81 circuit. Estimated cost for installing Bentonite into the ducts (this method will have to be fully assessed and the duct will remain as the critical limiting section) are $[redacted]k to $[redacted]k based on $[redacted]k per duct and $[redacted]k to $[redacted]k/m excavating and relaying cables.

2. ST-BTY 81

- Replace the existing Triton conductor section with Venus and three wood poles at Southern Terminal at an estimated cost of $[redacted]k.
- Structures 6 to 49 consist of narrow base towers with Triton conductor. Due to limited structure and foundation loading capacity, any uprating will have to be limited to replacing the existing Triton conductor with a HTC such as ACCC. Estimated cost for the 7 km section is in the order of $[redacted]M.
- Structures 49 to 66 consist of wide base towers with HTC operated at a maximum of 172°C. The conductor may be run at 230°C, but will require the existing structures to be raised approximately 0.5m. Investigations and a line survey will be required to confirm whether these structures can be modified to this level. Estimated costs are $[redacted]k based on $[redacted]k and $[redacted]k for suspension and tension tower respectively. Note that there are a number of narrow based and steel pole structures that may have to be entirely replaced for

the uprate and therefore the line would require a survey regarding structural and foundation design.

- Structure 66 to Bentley substation is an underground 2,000 mm^2 132 kV cable. Although a cable with a potential rating of 1,480 A (330 MVA at 132 kV) was used, the cables were laid in trefoil which limited the rating to 1,058 A. An estimated length of 250 to 300m will have to be excavated and re-laid in flat formation. Estimated costs based on $[redacted]k to $[redacted]k/m are $[redacted]k to $[redacted]k.

3. EP-BTY 81

- East Perth to structure 1 is an underground 1600 mm^2 132 kV cable. Maximum circuit rating is restricted by ducted installation and parallel cable circuit sections. Similar costs to ST-EP 82 circuit for the 1200 mm^2 cable uprating of $[redacted]k to $[redacted]k would be required.
- Structures 7 to 38 consist of wide based towers with HTC conductor. This section rating can be uprated to 1195 A by raising the towers by 0.5m. Estimated cost based on similar parameters of the above circuit sections are in the order of $[redacted]k. Note that there are a number of narrow based and steel pole structures that may have to be entirely replaced for the uprate and therefore the line would require a survey regarding structural and foundation design.
- Structure 38 to Bentley substation is an underground 2,000 mm^2 132 kV cable. See comments on ST-BTY 81 cable section above. Similar costs if this circuit only is uprated to 1195 A.

G.4 Summary

Estimated costs to uprate the individual and combined circuits (where two circuits are supported on the same line structure) to 1,195 A are shown in Table 36.

Table 36 Estimated Costs for ST-EP Line Uprating Options

Circuit	Individual Circuit Costs	Combined Circuit Costs
ST-EP 82	[redacted]	[redacted]
ST-BTY 81	[redacted]	[redacted]
EP-BTY 81	[redacted]	[redacted]

1) The cost summary does not include additional costs such as planning and council approvals, traffic management, survey, structural design and other associated costs.
2) New overhead line routes will be difficult to obtain. Underground cable routes are more feasible with the estimated costs being $[redacted]M/km for 132 kV 2,000 mm^2 cable laid in flat formation at an approximate rating of 1,480 A (330 MVA).

3) Excavating and relaying existing underground cable circuits expose the cables to additional risk of damage through this process as the cement backfill has to be removed and is therefore not recommended.

Appendix H Single Line Diagrams for Supply Options

H.1 Option A - East Perth Southern Feed

The first option requires construction of a new double circuit CT-EP 81 & 82 approximately 13.5 km in length. This option takes advantage of the South Metro Reconfiguration project by increasing utilisation of the 330 kV network between Southern Terminal and Cannington Terminal before transforming back to 132 kV and supplying the CBD Load Area. As Cannington Terminal is electrically closer to East Perth than Southern Terminal, it is expected that a significant amount of power should flow along these new circuits.

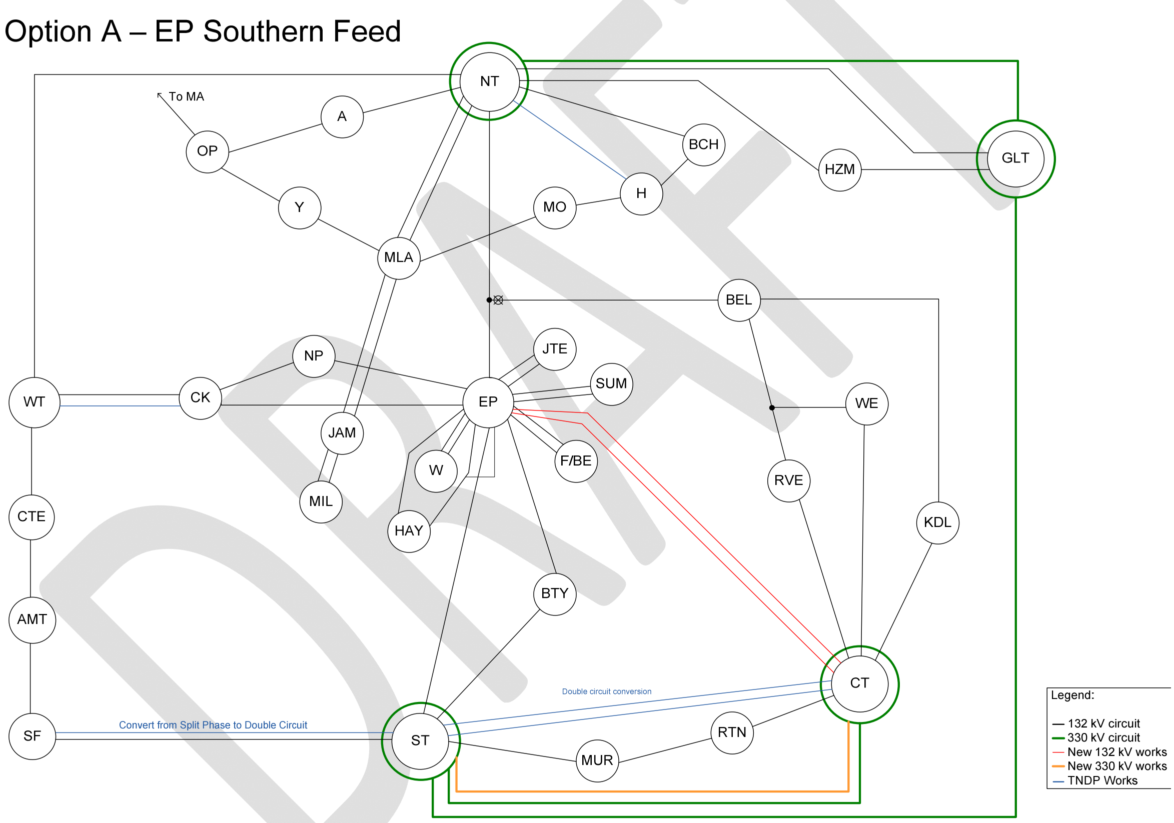


Figure 47 CBD Load Area Supply Option A SLD

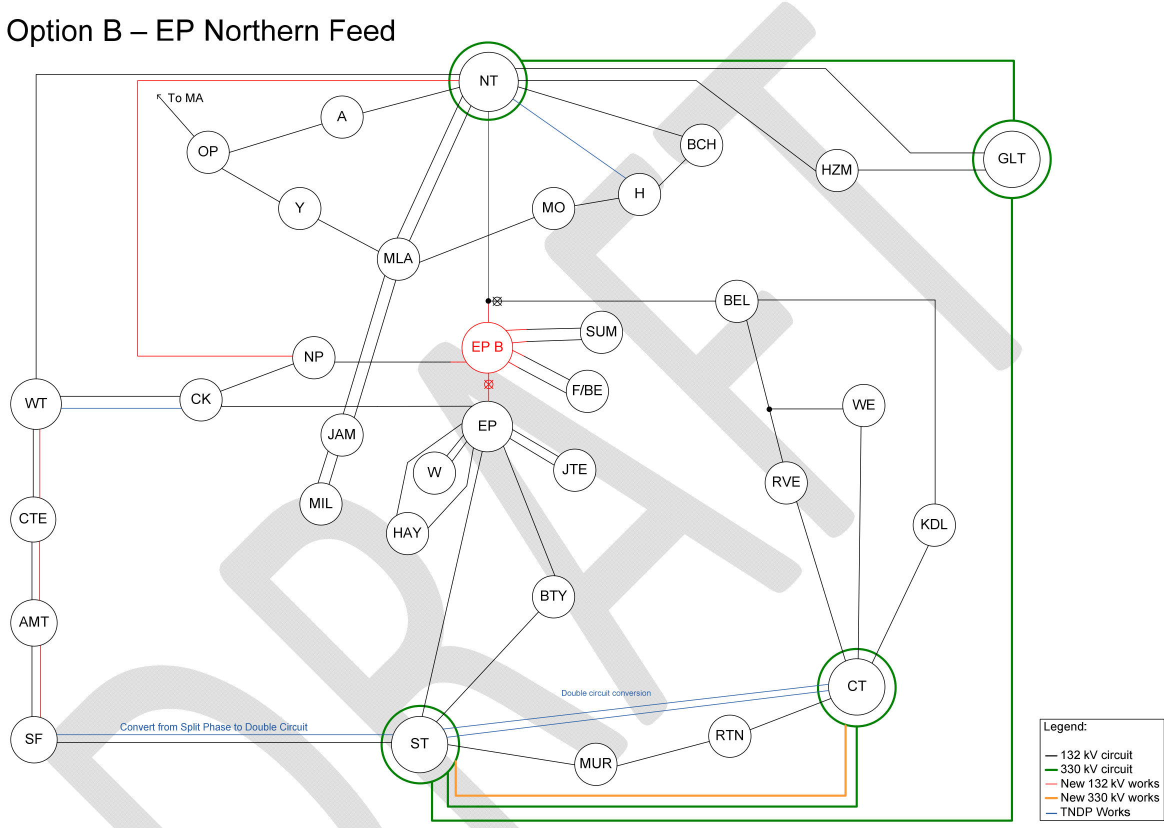
H.2 Option B - East Perth Northern Feed

This option looks to increase supply to the CBD Load Area via a new circuit from the North. The existing East Perth Terminal would be split into an East Perth 'A' and East Perth 'B' 132 kV switchyard in order to limit fault levels and potential through power flows. A bus section breaker, operated normally open, would connect the two sites. The circuits connected to East Perth would be reconfigured to have the NP-EP 81 and NT-EP/BEL 81 circuits connected to the new East Perth

'B' switchboard with North Perth, Joel Terrace, Summers Street and Forrest Avenue/Bennett Street Substations supplied from this switchboard.

A new circuit between North Perth and Northern Terminal would be installed, NT-NP 81, approximately 15 km in length.

Additional wider system reinforcements required for this option include new double circuits AMT-CTE 82 and WT-CTE 82.



▪ Figure 48 CBD Load Area Supply Option B SLD

H.3 Option C - James Street Terminal

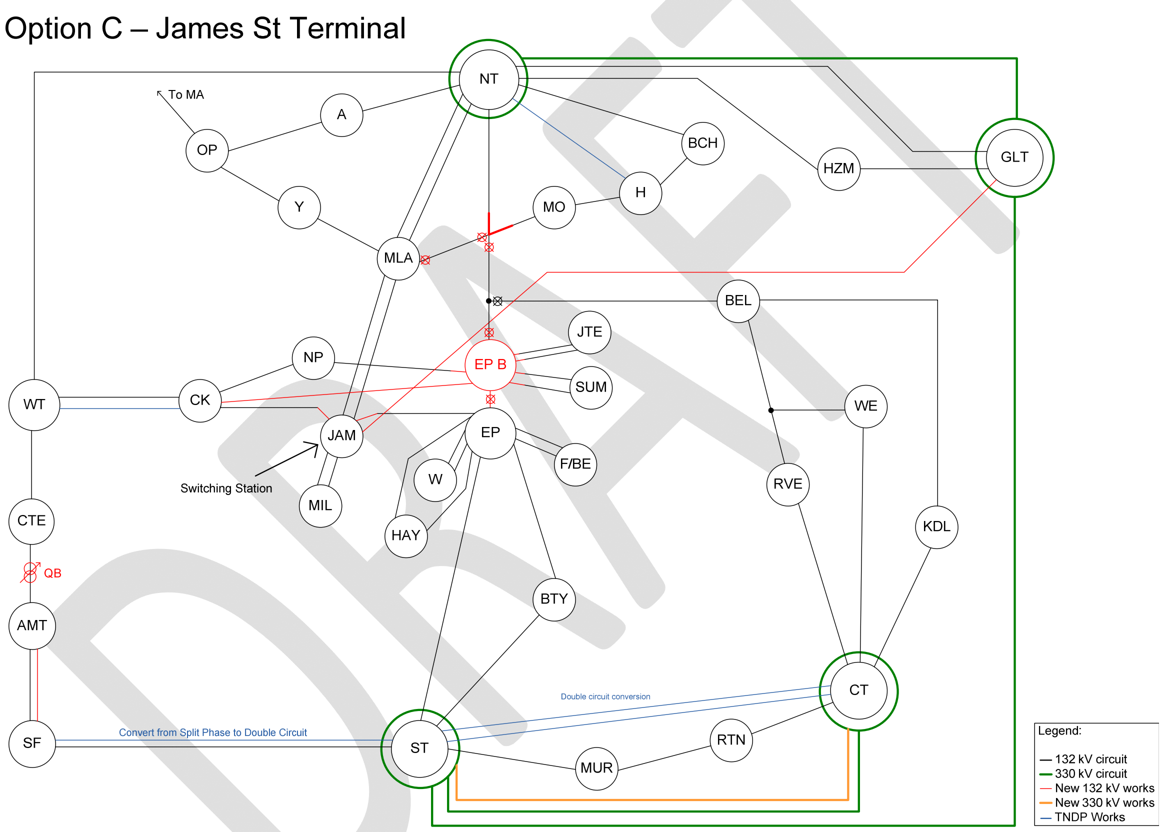
Guilford Terminal is located Northeast of the CBD Load Area and is considered as another option to supply the CBD Load Area. Under this option, the James Street site would become a switching station and a new circa 18 km circuit GLT-JAM 81 circuit would be installed. This would potentially increase utilisation of the 330 kV network as power would flow from Southern Terminal to Guilford via the existing 330 kV circuit before flowing along the new 132 kV circuit to James Street to supply the load demand.

The East Perth switchyard would again be split into an 'A' and 'B' site with some circuit reconfiguration and a bus section breaker between the sites operated normally open. A new circuit CK-EP 'B' 81 would be installed to allow supply from Western Terminal to the new switchyard.

The existing circuit CK-EP 81 would be turned in at James Street, installed on its own bus section with the section breaker operated normally open. This would allow the Cook Street load to be transferred onto Northern Terminal via the MLA-JAM-MIL circuits, if required.

The existing NT-BEL/EP 81 circuit would cut into MLA-MO 81 circuit, operated normally open between the new tee point and East Perth and between Mount Lawley and the new tee point. This would create a NT-MO 81 circuit and serve to create a load ring NT-MO-H-BCH.

This option would also require installation of a phase-shifting transformer on the AMT-CTE 81 132 kV circuit to control flows during contingency events.



■ **Figure 49 CBD Load Area Supply Option C SLD**

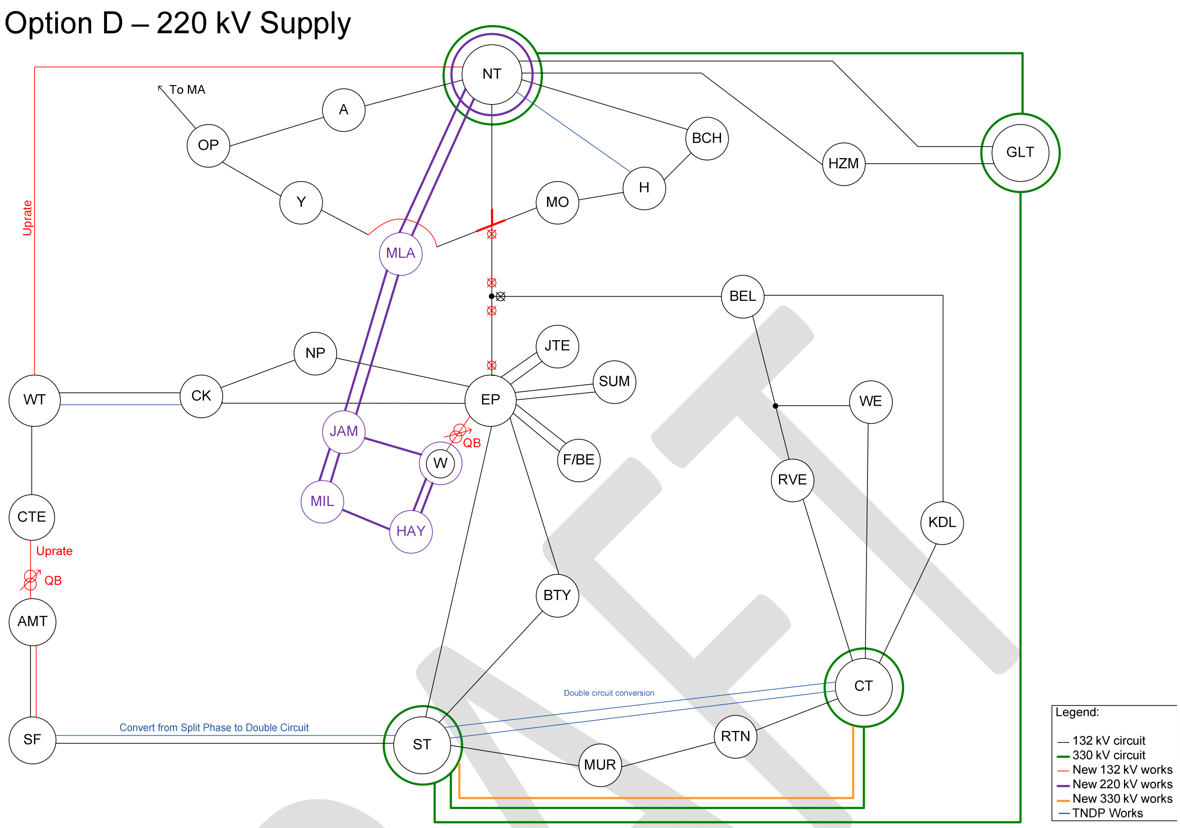
H.4 Option D - 220 kV Supply

A more radical approach to supplying the CBD Load Area is to introduce an entirely new operating voltage, albeit one already used elsewhere on the Western Power Network and utilise 220 kV. This voltage level is used elsewhere in the Western Power Network although it is limited to the Muja and the Eastern Goldfields load areas.

For this option, a new 220 kV switchyard would be established at Northern Terminal taking advantage of the higher 330 kV voltage already present. Two 490 MVA, 330/220 kV transformers would be installed and the existing NT-MLA-JAM-MIL circuits would be converted to 220 kV. Hay Street and Wellington Street would also be converted to 220 kV substations, forming a strong ring in the CBD Load Area. One circa 300 MVA, 220/132 kV phase-shifting transformer would be installed at Wellington Street to connect the ring back to the 132 kV network at East Perth and provide the required level of N-2 support for loss of transmission infeeds, both at East Perth and also for Hay Street and Milligan Street Substations.

The existing NT-BEL-EP 81 circuit would cut into the MLA-MO 81 circuit to form a tee point. The circuit section South to East Perth would be operated normally open. The MLA-Y 81 and MLA-MO 81 circuit would be reconfigured to bypass Mount Lawley, forming Y-MO 81. This would create a 132 kV ring in the Northern Terminal Load Area.

Other wider system reinforcements for this option would include uprating the NT-WT 81 and AMT-CTE 81 circuits, and installation of a phase-shifting transformer at Amherst to control power flows across the 132 kV circuit to Cottesloe.



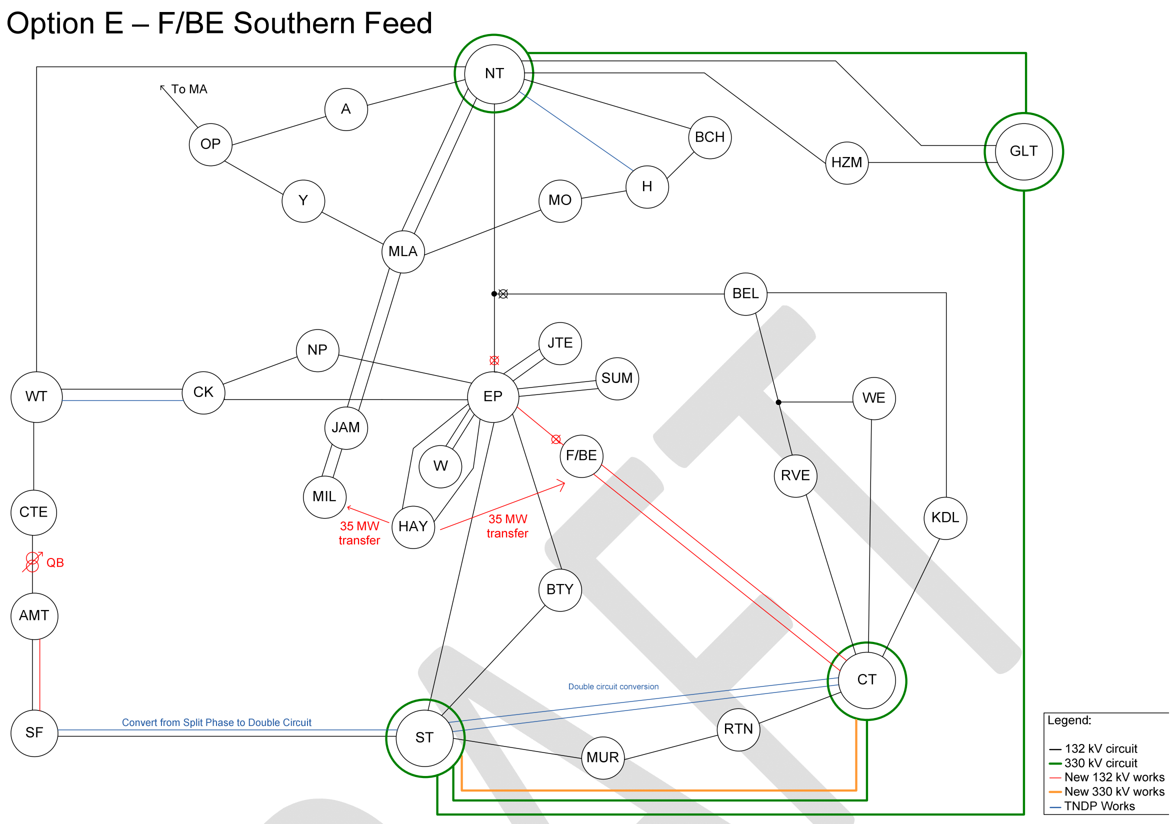
▪ **Figure 50 CBD Load Area Supply Option D SLD**

H.5 Option E – Forrest Avenue / Bennett Street Southern Feed

This option is a variation of Option A, the difference being the new circuits from Cannington Terminal would be installed at the new Forrest Avenue/Bennett Street substation instead of East Perth. Only one 132 kV circuit would potentially be required from East Perth to Forrest Avenue/Bennett Street for N-2 compliance, but would be operated normally open, moving the Forrest Avenue/Bennett Street load on to Cannington Terminal.

Additionally, the circuit NT-BEL/EP 81 would be opened at East Perth, used only during N-2 operating scenarios. The load at Hay Street would be transferred to Forrest Avenue/Bennett St and Milligan Street to further de-load East Perth.

All other works are the same as in Option A except for the inclusion of installing a phase-shifting transformer on the AMT-CTE 81 circuit.



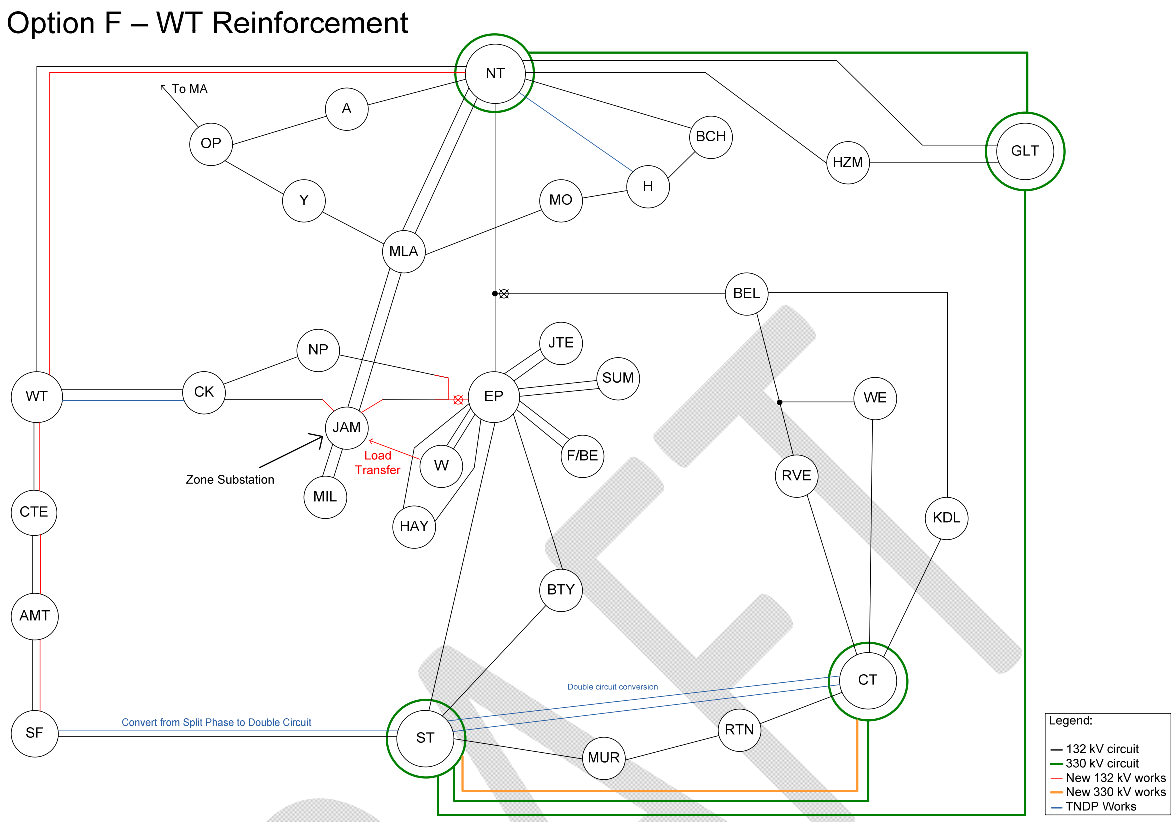
- **Figure 51 CBD Load Area Supply Option E SLD**

H.6 Option F – Western Terminal Reinforcement

Along a different theme, this option looks to de-load the CBD Load Area by reinforcing the Western Terminal load area and reconfiguring circuits to be supplied from Western Terminal instead of East Perth.

This option would require construction of four new circuits; NT-WT 82, WT-CTE 82, AMT-CTE 82 and AMT-SF 82. The existing NP-EP 81 circuit would be reconfigured to connect to the CK-EP 81 circuit, operated normally open at the East Perth end to form a loop back to Western Terminal. The CK-EP 81 circuit would be turned in at the new James Street Zone Substation, installed on its own bus section with the section breaker normally open.

Load at Wellington Street (around 35 MW) would be transferred to James Street to further de-load East Perth.



- **Figure 52 CBD Load Area Supply Option F SLD**

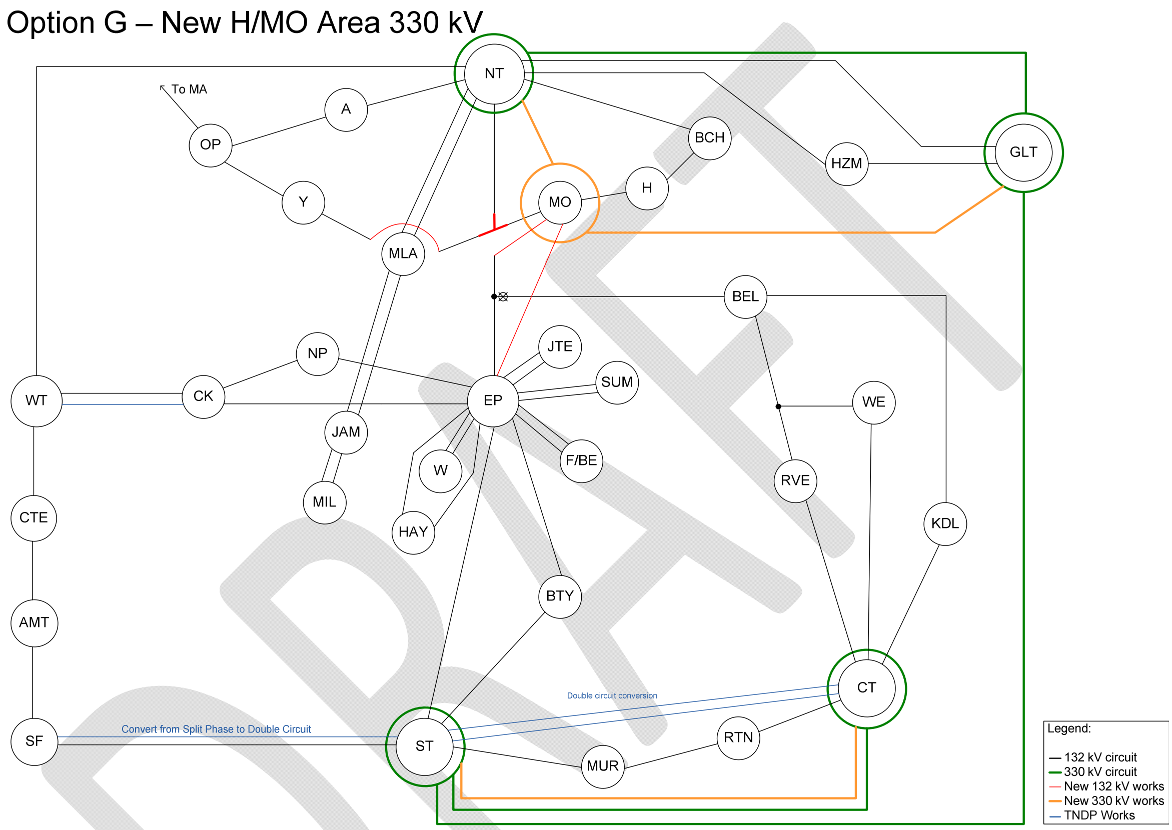
H.7 Option G - New Morley 330 kV Substation

An operating voltage of 330 kV was also considered for supply to the CBD Load Area.

This option, however, would only be brought forward if a new 330 kV circuit was expected to be installed between Northern Terminal and one of the southern 330 kV terminal substations, in this example considered as Guilford although Cannington Terminal, Southern Terminal or Kwinana could also be options. This would provide an opportunity to divert the circuit which would otherwise take as direct a route as possible between Northern Terminal and the chosen end terminal substation. The capital cost of this option would not therefore have to consider the full cost of the 330 kV transmission line, only the diversion cost to the new Terminal substation.

In this example it is considered that a new Northern Terminal to Guilford Terminal 330 kV overhead line would be diverted by approximately 10 km to Morley to establish a new 330 kV Terminal substation closer to the CBD Load Area. The new substation would not be required within the CBD Load Area itself as there is no immediate need directly in the load area at this time.

Two 490 MVA, 330/132 kV transformers would be installed at Morley in order to tie the 330 kV network into the 132 kV network. The existing MLA-Y 81 and MLA-MO 81 circuits would be reconfigured to bypass Mount Lawley, forming Y-MO 81 and creating a 132 kV ring in the Northern Terminal load area. The existing NT-BEL/EP 81 circuit would cut into the new Y-MO 81 circuit and a new 132 kV circuit would be constructed from Morley to the tee point creating MO-BEL/EP 81. This would effectively eliminate supply to the CBD Load Area from Northern Terminal, but introduce a new supply from Morley. A second 132 kV circuit MO-EP 82 would be constructed, establishing a second supply into the CBD Load Area from Morley



■ **Figure 53 CBD Load Area Supply Option G SLD**

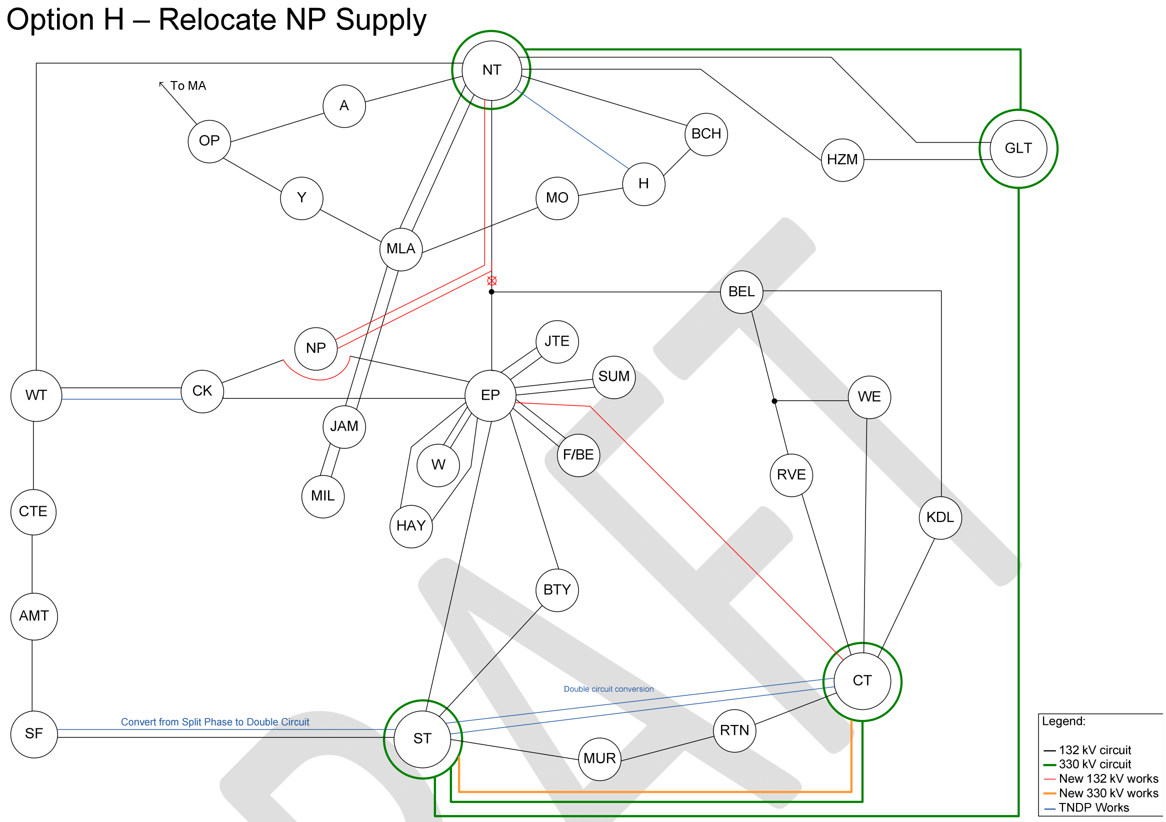
H.8 Option H - Relocate North Perth to Northern Terminal Load Area

This option considers transferring zone substations supplied by East Perth to other load areas, thereby de-loading East Perth and reducing the need for new circuits. North Perth Substation transmission supply would be reconfigured to supply the zone substation from Northern Terminal.

The existing NT-BEL/EP 81 circuit would be cut into to make a NT-NP 81 circuit and opened on the Belmont end of the NT-BEL section. A second NT-NP 82 circuit would be required to provide N-1 compliance as the North Perth Zone Substation does not require N-2 compliance.

The existing CK-NP 81 and EP-NP 81 circuits would be reconfigured to form CK-EP 82.

This option would also require uprating the AMT - CTE 81 132 kV circuit to a Venus AAC conductor and associated 274 MVA thermal rating.



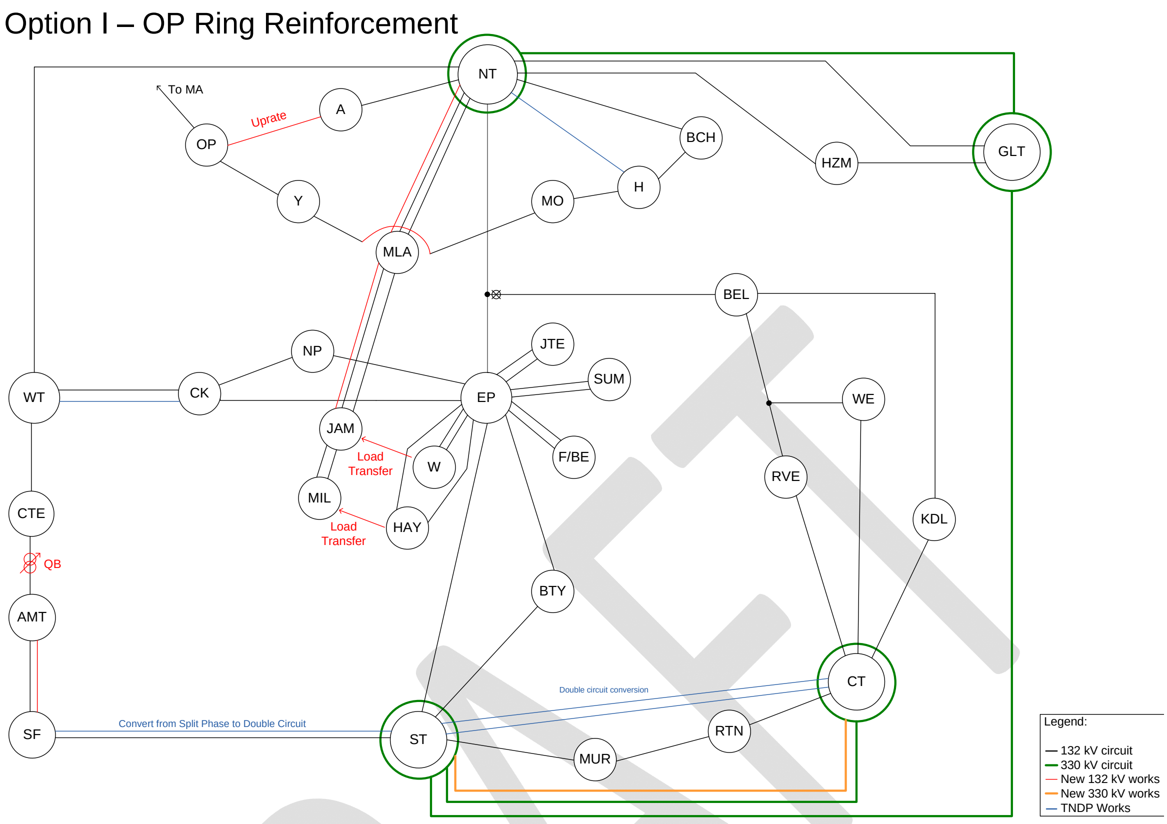
- **Figure 54 CBD Load Area Supply Option H SLD**

H.9 Option I - Osborne Park Ring Reinforcement

This option considers reinforcing the Northern Terminal Load Area including the two 132 kV rings NT-A-OP-Y-MLA and NT-BCH-H-MO-MLA. To accomplish this, the MLA-Y 81 and MLA-MO 81 circuits would be reconfigured to bypass Mount Lawley, forming Y-MO 81 and creating one larger 132 kV ring in the Northern Terminal Load Area. The existing A-OP 81 circuit would then need to be uprated to support the western side of the ring.

These works would provide a dedicated double circuit from NT-MIL. The load at Wellington Street and Hay Street could then be transferred to James Street and Milligan Street, respectively, using the increased capacity on the NT-MIL circuits. A third circuit NT-MLA 83 and MLA-JAM 83 would also be required to support the total load on James Street.

This option would also require installation of a phase-shifting transformer on the AMT-CTE 81 circuit to control flows during contingency events.



- **Figure 55 CBD Load Area Supply Option I SLD**

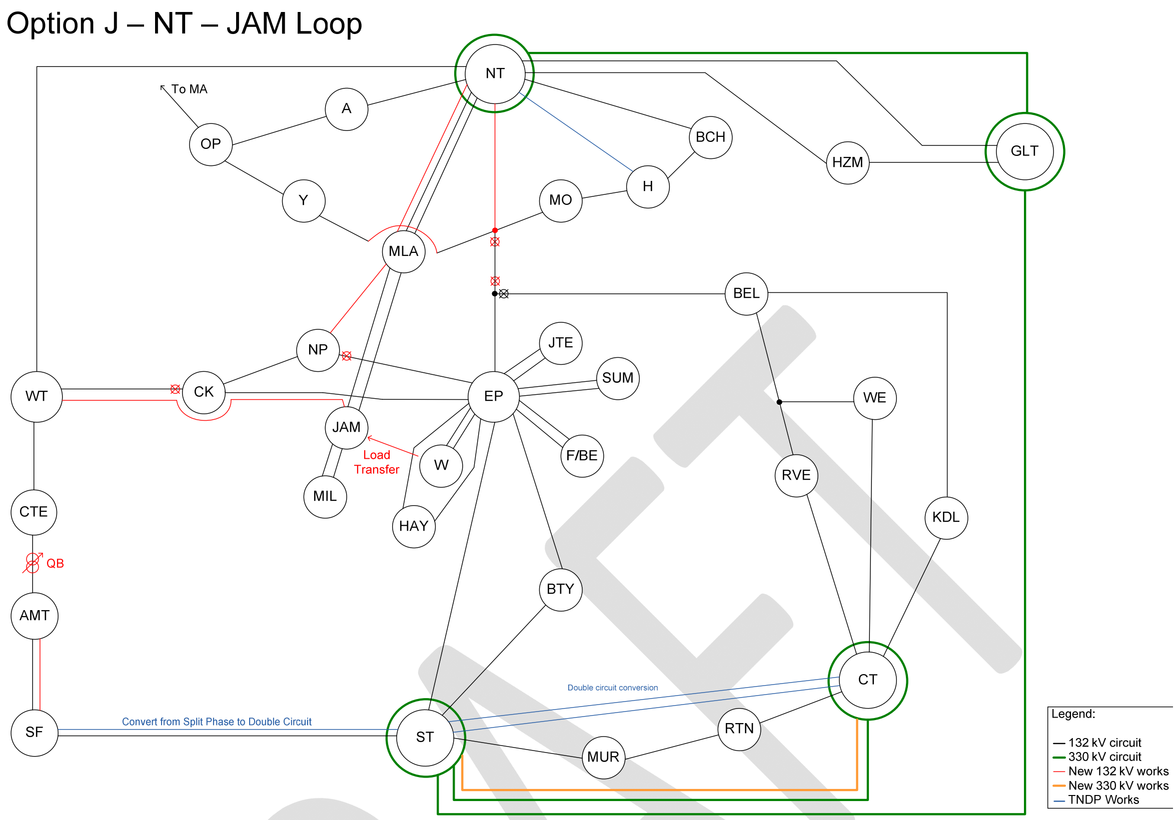
H.10 Option J – Northern Terminal – James Street Loop

This option is a variation of Option H. Instead of supplying North Perth directly from Northern Terminal, a new 132 kV MLA-NP 81 circuit would be constructed and the existing EP-NP 81 circuit would be operated normally open. This would serve to move North Perth into the Northern Terminal Load Area and enable supply of Cook Street from Northern Terminal as well. A third circuit NT-MLA 83 would be required to support the additional load from MLA to NT.

The existing NT-BEL/EP 81 circuit would cut into the existing MLA-MO 81 circuit and be run normally open on the East Perth side. The MLA-Y 81 and MLA-MO 81 circuits would be reconfigured to bypass Mount Lawley, forming Y-MO 81 and creating a 132 kV ring in the Northern Terminal Load Area.

The existing WT-CK 81 circuit would be disconnected in order to supply Cook Street from Northern Terminal. A new circuit WT-JAM 81 would be constructed, turning in at Cook Street to be used during contingency events.

This option would also require installation of a phase-shifting transformer on the AMT-CTE 81 circuit to control flows during contingency events.



▪ **Figure 56 CBD Load Area Supply Option J SLD**

H.11 Option K – Cook Street Supply from Cannington Terminal

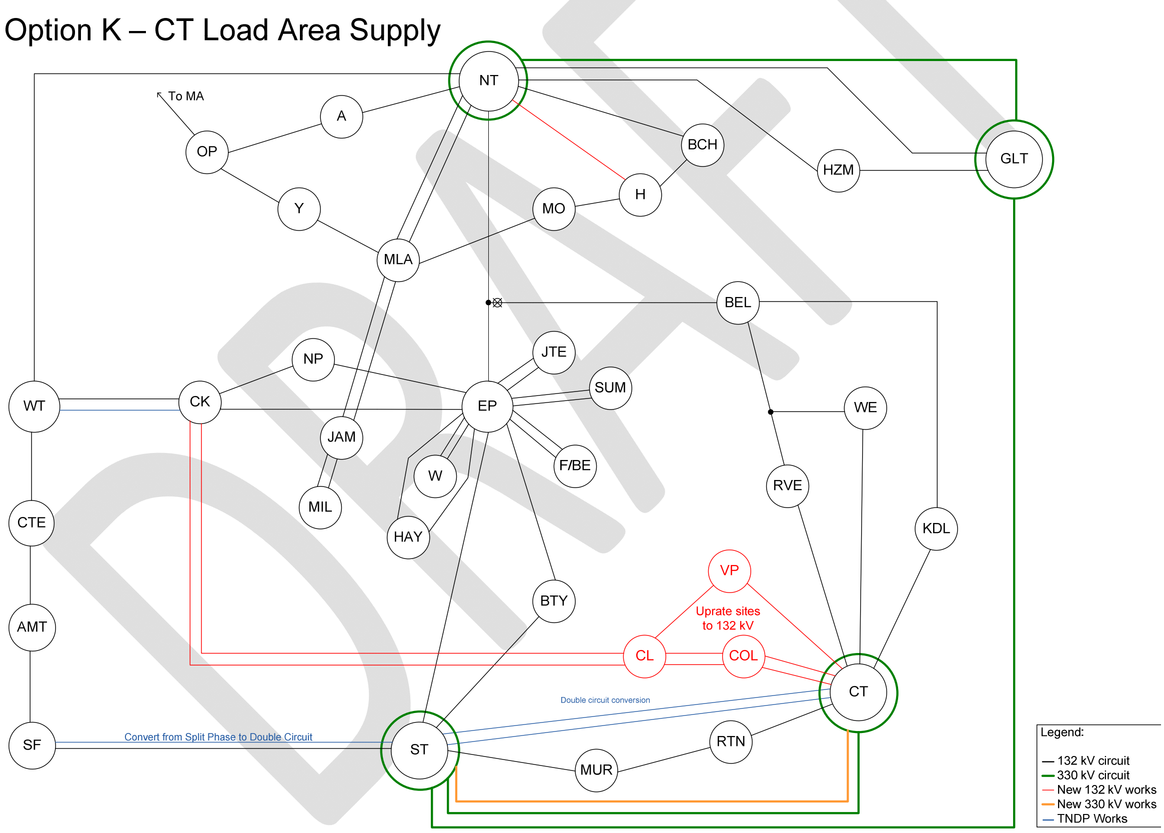
As a variation on Option A, this option looks at the possibility of uprating the Cannington Load Area to 132 kV from the existing 66 kV operation.

Collier Street, Clarence Street and Victoria Park would all require uprating to 132 kV, with new 132 kV circuits between them. A double circuit would be required from Cannington – Collier – Clarence Street, ultimately connecting to Cook Street via a double circuit due to geographical proximity.

Western Power has already developed a statement of intent for the longer term direction of the Collier Street and Clarence Street substations within the Cannington load area. This outlines a number of alternative options for supplying this load area (presently at 66 kV) over the longer term, with the preferred option being the removal of Collier Street, Clarence Street and Victoria Park substations and the establishment of a new 132 kV substation at Kensington supplied from two new circuits running to Bentley, which would be removed from the ST-EP circuits. Given the total load in this area

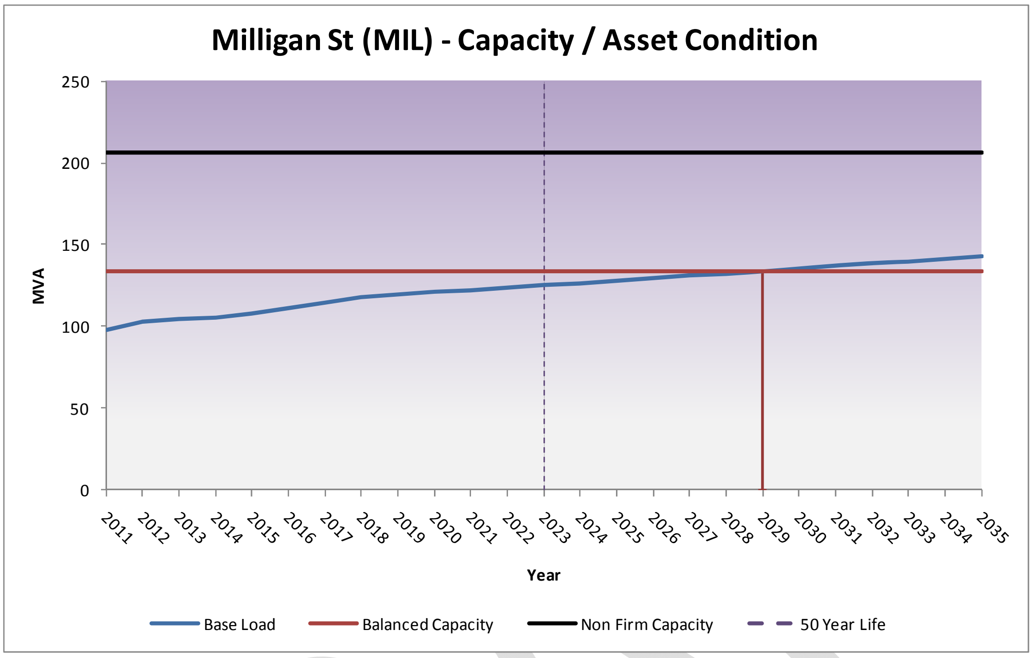
One aspect that is apparent from this early work is the potential difficulty in routing new transmission circuits through the South Perth (Kensington) load area. Therefore, it is likely that any new transmission circuits from Cannington Terminal to Cook Street would need to adopt underground cable construction for a significant proportion of the circuit length (potential 80% or more). Additionally, the Clarence Street and Collier Street area demand is likely to exceed 150 MW in the medium term (by 2020) when combined with Bentley which is likely to be removed from the existing ST-EP 132 kV transmission circuits.

As a detailed 132 kV migration or consolidation plan for this 66 kV load has not yet been developed, for the purpose of this assessment it is considered, as a worst case, that a new 132 kV double circuit would be required from Cannington Terminal to Clarence Street and from Clarence Street to Cook Street, a total distance of circa 18 km.

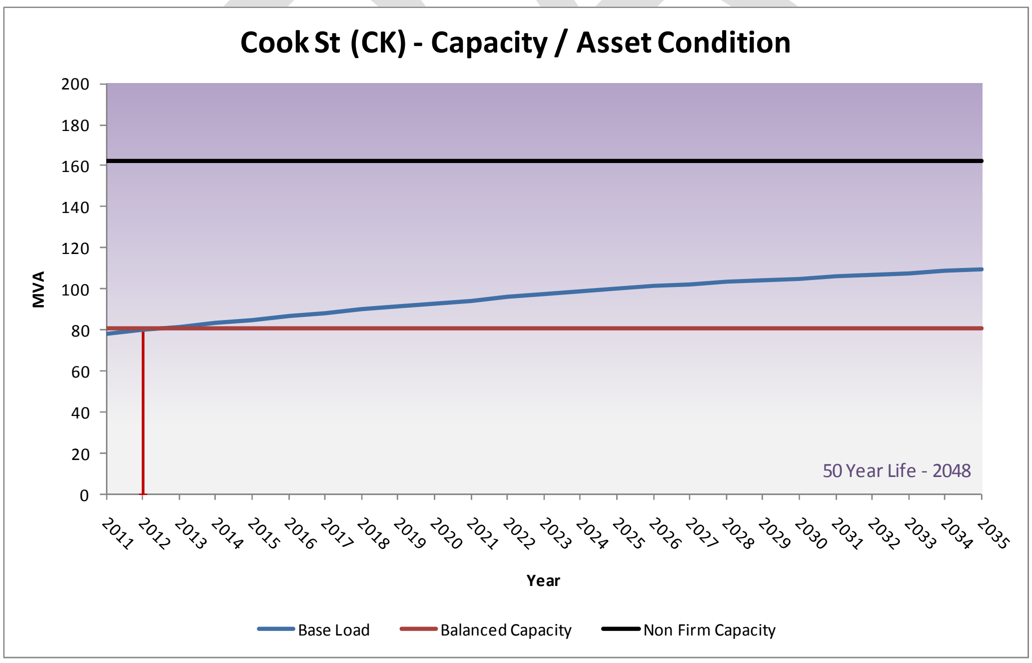


▪ **Figure 57 CBD Load Area Supply Option K SLD**

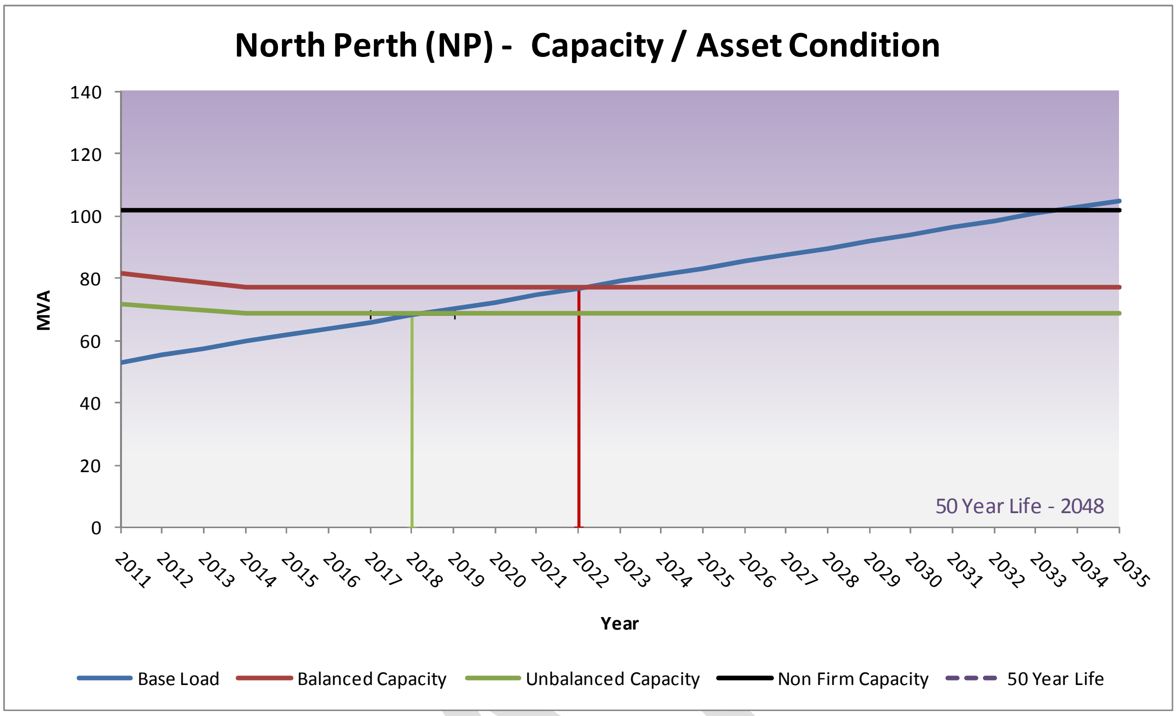
Appendix I Substation Transformer Capacity / Nominal Age Triggers



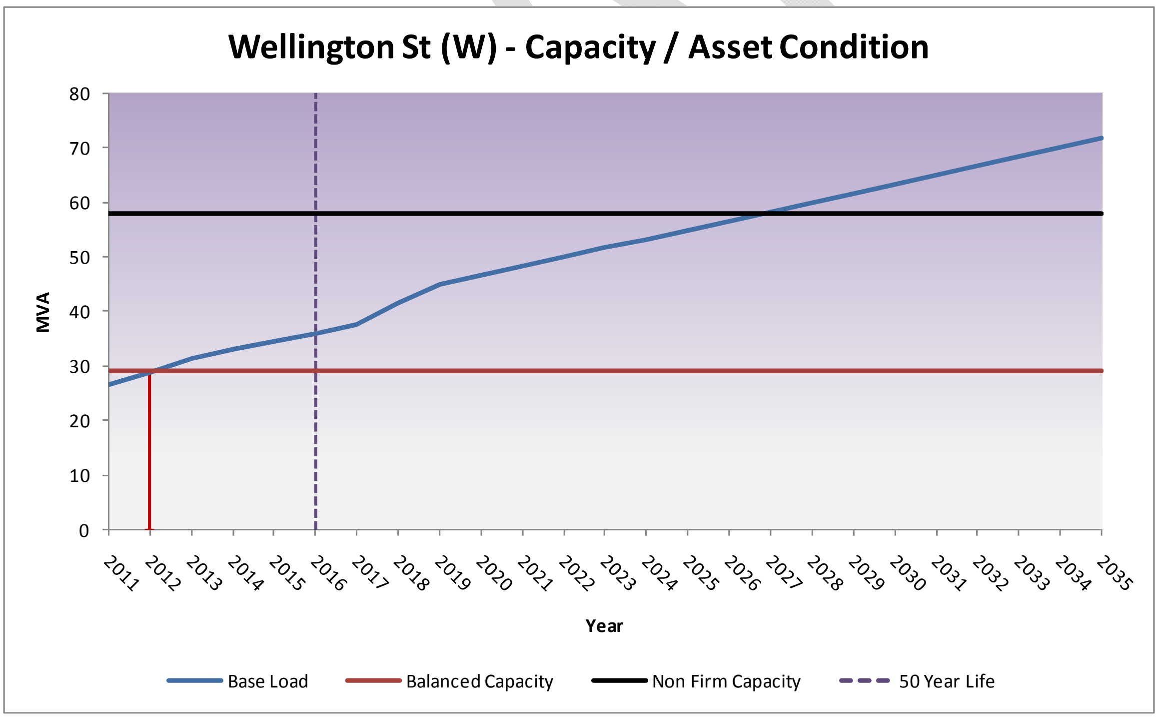
- Figure 58 Milligan Street – Transformer Capacity / Condition Triggers



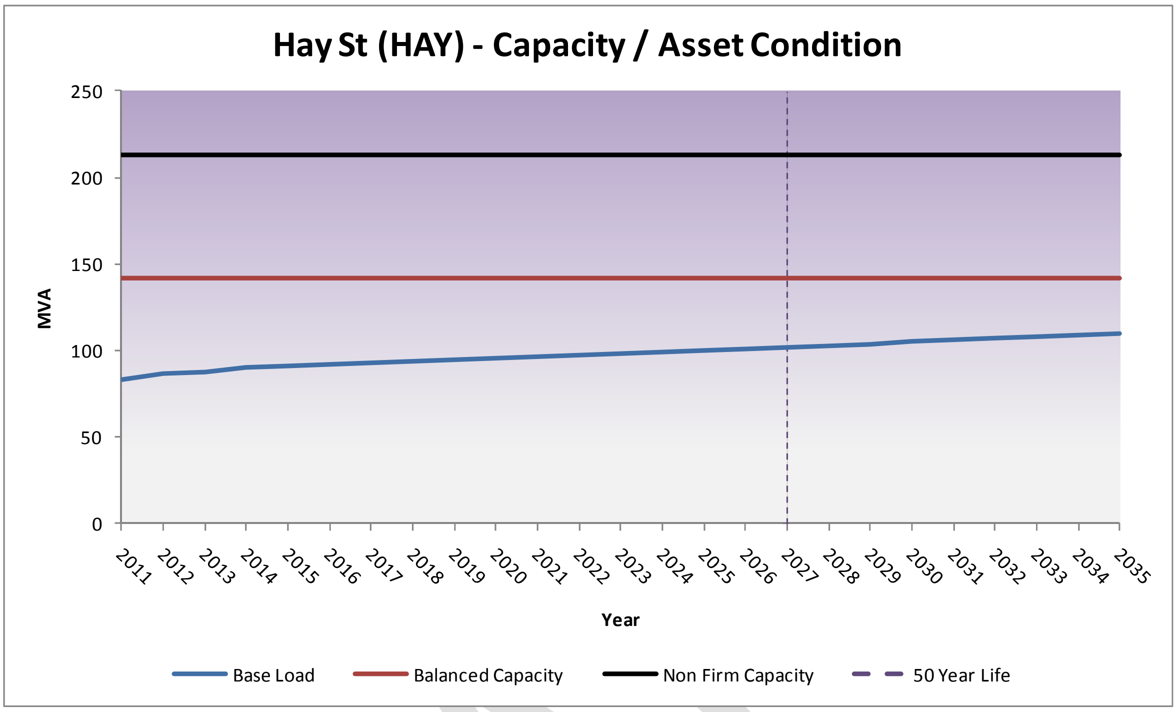
- Figure 59 Cook Street – Transformer Capacity / Condition Triggers



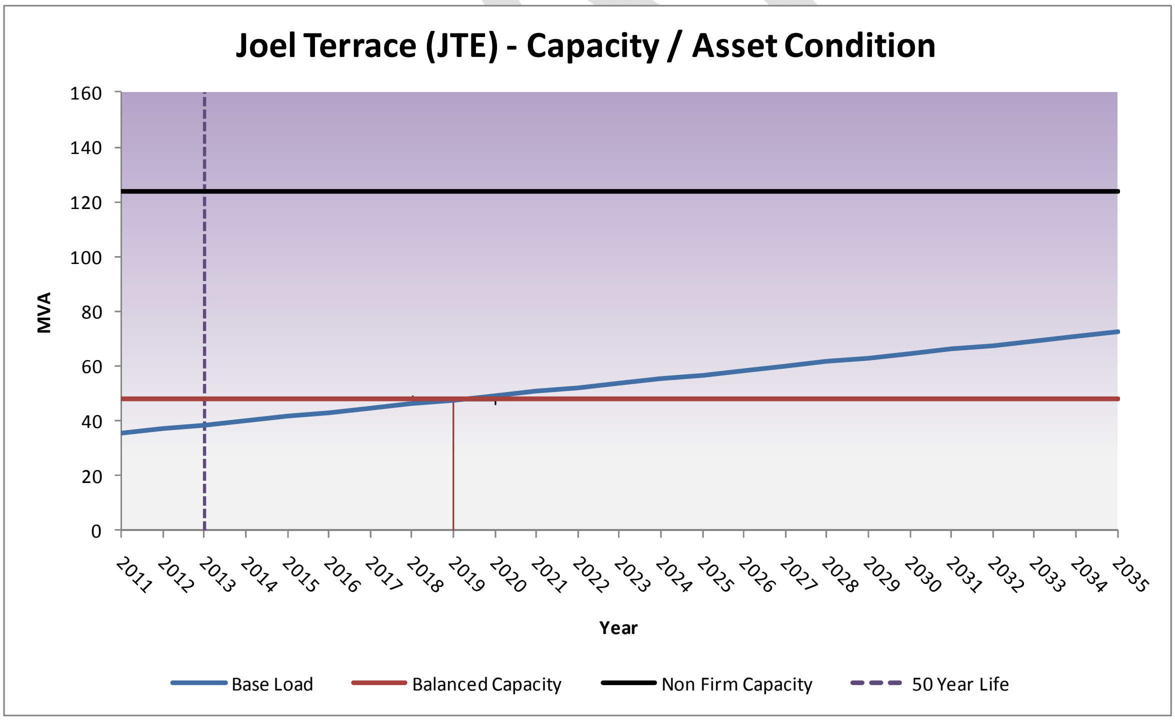
- Figure 60 North Perth – Transformer Capacity / Condition Triggers



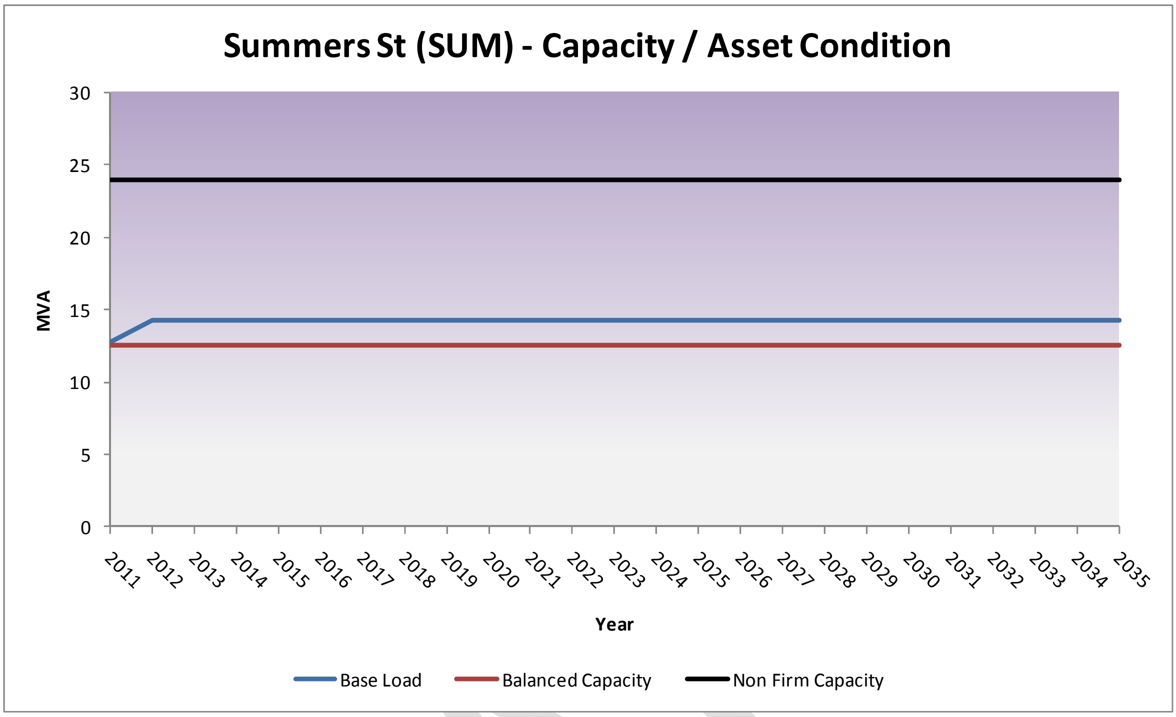
- Figure 61 Wellington Street – Transformer Capacity / Condition Triggers



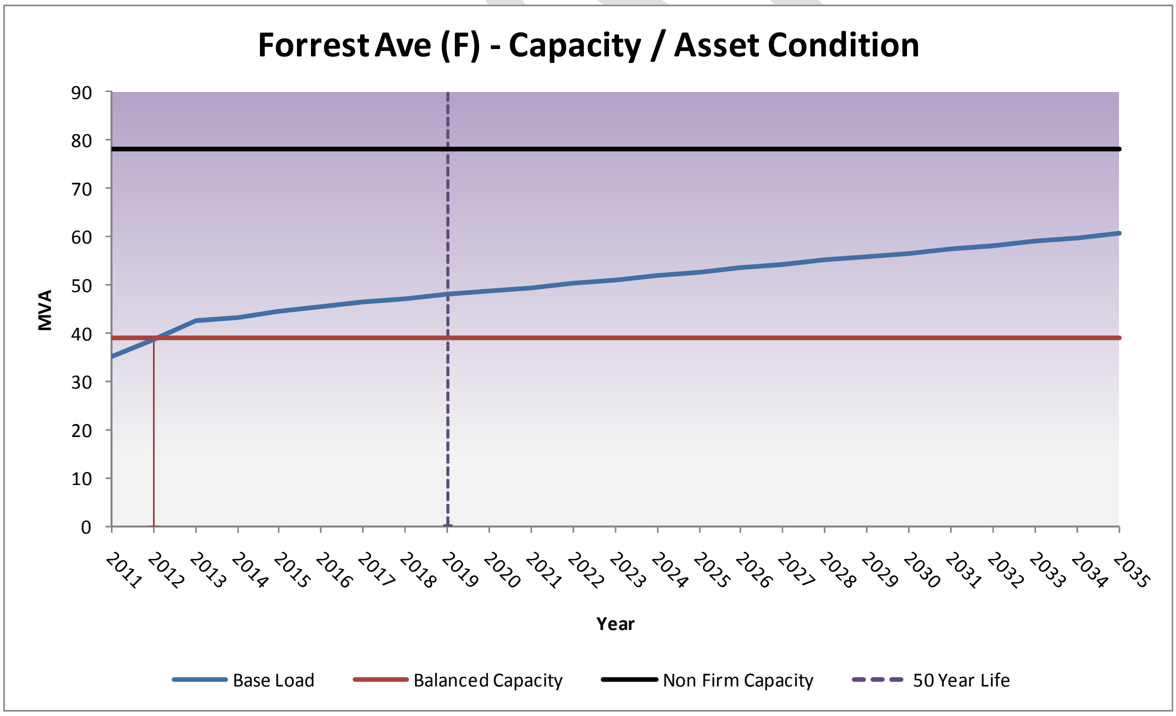
▪ **Figure 62 Hay Street – Transformer Capacity / Condition Triggers**



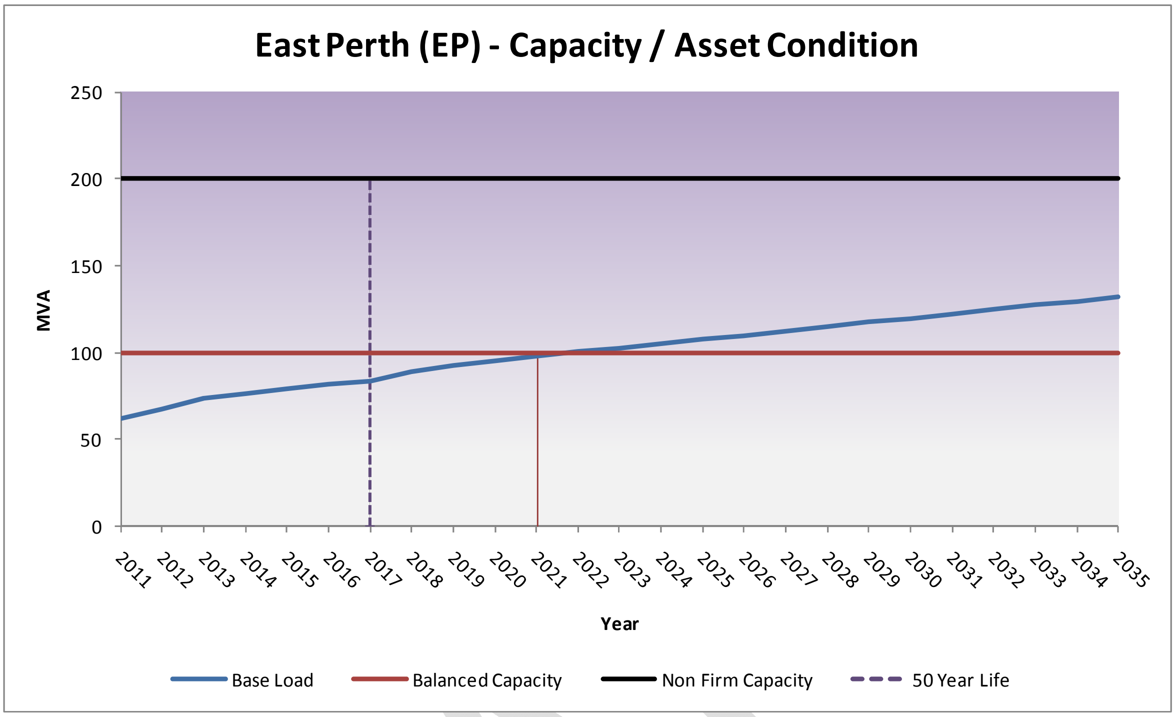
▪ **Figure 63 Joel Terrace – Transformer Capacity / Condition Triggers**



▪ **Figure 64 Summers Street – Transformer Capacity / Condition Triggers**



▪ **Figure 65 Forrest Avenue – Transformer Capacity / Condition Triggers**



- **Figure 66 East Perth – Transformer Capacity / Condition Triggers**

Appendix J Risk Analysis

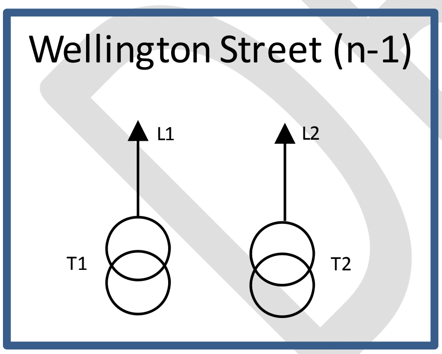
As part of the 25 year strategy it is necessary to assess the level of system risk within the CBD Load Area, prior to the proposed projects being commissioned. The risks to the system are present due to the timescales required to implement projects, which in many cases is after the limitation has been identified. A deterministic assessment of the system risk has been calculated as per required to meet the Technical Rules. In addition, a probabilistic assessment has been calculated to accommodate the likelihood of an event occurring that would put the system at risk.

J.1 Study Basis

The study basis is to illustrate the system risk to the CBD Load Area for substations when they are forecasted to be over firm capacity. The analysis calculates this risk on two axes, factoring the likelihood of component failure and the consequence of the failure.

Calculation of Failure Likelihood

The likelihood of equipment failure is calculated through a sequence of series and parallel computations of substation assets and their associated failure rates. An example is provided for Wellington Street Substation which has a transformer feeder design with two transformers and no HV switchgear structure as shown in Figure 67. In effect, each transformer and its associated feeder can be isolated from its partner for this analysis as there is no busbar structure to allow isolation of faulted assets. As such, the likelihood of a failure at the substation is the sum of T1 and L1 failure rate, multiplied by 2 (assumes L2 and T2 have the same likelihood of failure). More complex arrangements such as the Hay Street and Milligan Street substations require parallel failure assessments to be incorporated as power can be transferred along the busbar structure. The fault likelihood for each substation is plotted on the y-axis of the logarithmic risk matrix.



▪ **Figure 67 Wellington Street SLD**

Advanced deterministic analysis could include condition of assets at the substation, such as increasing the failure rate as aged assets progress beyond their nominal life. Such detail has not been included in this investigation.

For the deterministic analysis it is assumed that the fault occurs at peak load, as is the requirement stipulated in the Technical Rules. This is the worst case assessment.

A probabilistic analysis of the consequence has also been calculated in this assessment. This analysis takes into account the likelihood of the fault occurring when the substation is over firm. The forecasted load duration curves of each of the substations have been analysed to obtain the number of over firm events (over firm for greater than 40 minutes to remove short periods of over firm risk) which are expected to occur during the year. This is then taken in parallel with the likelihood of the fault occurring based on the above failure rate computations to provide a probabilistic likelihood based on both events occurring (over firm and failing).

Calculation of Fault Consequence

The consequence indicates the impact that a fault would have on a number of metrics. For the purpose of this analysis, the consequence was calculated on an SMI basis with a matrix provided to allow this metric to be converted to a number of other consequences (discussed further below).

The SMI is calculated by taking the forecasted MW which are above the firm capacity of the substation, multiplying by an assumed restoration time of 2 hours (over firm load is switched to surrounding substations) and dividing by the Western Power Network peak load in MW.

Consequence Matrix

The consequence matrix allows the plotting of the consequence and likelihood on a logarithmic scale to provide a visual representation of the risk. For this analysis, SMI has been the basis of the consequence calculation and although a useful measure, it is also valuable to consider this in a number of other metrics. The consequence matrix provides an indicative broad conversion from SMI to the following metrics:

- Energy at risk in MWh
- System or revenue loss/damage
- Reputation impact
- Regulation/license impact

Furthermore, the consequence matrix allows further dissemination of the consequence by providing four approximate risk ranges:

- Catastrophic
- Critical
- Marginal
- Negligible

These risk ranges can also be applied to the likelihood axis to provide a sliding scale within the matrix of low risk in the lower right up to high risk in the upper left.

The standard Western Power risk matrix was not suitable for this type of computational analysis as a linear (logarithmic) scale is required. It was identified that some of the risk boundaries in the Western Power matrix were not linear and suited to a more qualitative approach. It is possible however to cross compare the metrics in this risk matrix with those seen in the Western Power matrix if required.

Derivation of Equivalent Metrics

As noted, the consequence matrix allows cross comparison with a number of other metrics. This section provides details on the derivation of the broad equivalent metrics of energy at risk and revenue loss. The calculation for SMI is shown in Equation 1.

- **Equation 1 Calculation of SMI**

$$SMI = \frac{60\ (mins) * Demand\ Off\ Supply\ (MW) * Duration\ Off\ Supply\ (hours)}{4000\ (Peak\ System\ Demand\ (MW))}$$

For the energy at risk calculation it is assumed that the shape of the demand profile lost during the outages is a parabola (to reflect the normal demand variation during the outage period).Taking this assumption into consideration the calculation of energy at risk can be seen in Equation 2.

- **Equation 2 Calculation of Energy at Risk**

$$Energy\ at\ Risk = \frac{2}{3} * Demand\ Off\ Supply\ (MW) * Duration\ Off\ Supply\ (hours)$$

As an example, consider a demand of 75 MW, off for 1 hour. Each SMI is valued at $[redacted] as provided in and the value of lost load is given as $12,500[48] per MWh, although other values could be used.

- **Equation 3 Example Calculation of SMI and Energy at Risk**

[redacted]

It can be seen from Equation 3 that in this example, the sum of the SMI penalty and value of lost load equates to some $[redacted]M. However, other factors could also be included in a system loss / damage calculation e.g. asset replacement costs, operational costs associated with system reconfiguration / restrictions, hence the total upper revenue limit for the Marginal consequence rating is set higher to $[redacted]M.

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[48]The National Electricity Amendment (NEM (National Electricity Market)) Reliability Settings: Value of Lost Load, CPT and Future Reliability Review) Rule 2009 No. 13 commenced operation on 28 May 2009. This Rule was made by the Commission in response to a Rule change proposed by the AEMC (Australian Energy Market Commission) Reliability Panel. The main impacts of the Rule were that:

- the term “Value of Lost Load (VoLL)” was renamed the “Market Price Cap”;
- the Market Price Cap is to increase from $10,000/MWh to $12,500/MWh, with effect from 1 July 2010;

In summary, an SMI of 1 is broadly equivalent to an energy at risk value of 50 MWh (factor of 50 between 1 SMI and 1 MWh), with the total system revenue cost / impact considered as up to $5M, which is sufficient to cover the cost of value of lost load, the SMI penalty plus other associated system cost / impacts. All of these impacts are rated as Marginal within the consequence matrix.

J.2 Risk Matrix

The deterministic and probabilistic analysis of the risks seen by the CBD Load Area substations, Hay Street, Milligan Street, Wellington Street, Forrest Avenue and Cook Street over the next ten years is shown in Figure 68. Each substation has been analysed for every other year from 2011 to 2021. The first incidence of a consequence (over firm event) occurring has been indicated on the first point of each series. The next point on the series is two years after this date.

The average likelihood of an N-2 event occurring at Hay Street or Milligan Street Substation was seen to be greater than 1 in a million. Therefore the worst case impact of a common mode failure of either the two infeeds or of two transformers has been plotted.

The deterministic analysis can be identified by the horizontal series as the likelihood does not increase with time as it is assumed that the failure occurs when the substation is over firm. The probabilistic likelihood for Cook Street, Hay Street and Milligan Street Substations was below 1 in a thousand and has not been plotted. The probabilistic analysis of Forrest Avenue and Wellington Street Substations can be seen for both peak load and average over firm load.

The analysis is designed to provide a view on the level of risk for each substation and how this progresses through time as load continues to grow and projects are not commissioned. It is not advised that specific SMI numbers (or other metrics) be extracted as these values have been obtained through a number of assumptions such as equipment failure rates and load forecasts. Instead the trends through time and for each substation are of most interest and value.

Catastrophic	Critical	Marginal	Negligible
Quality of Supply – SMI >=10 for single event E@R MWh >= 500 for a single event System or revenue loss / damage => $50,000,000 Reputation – severe and damaging series of media reports, trigger for parliamentary inquiry, several senior officers leave immediately as a result Regulation / Licence – severe threat of losing operating licence irrespective of remedial plans	Quality of Supply – 1 <= SMI < 10 for single event 50 <=E@R MWh < 500 for a single event System or revenue loss / damage =>$5,000,000 but < $50,000,000 Reputation – Damaging media reports which require extensive efforts to mitigate, several senior officers move posts Regulation / Licence – significant threat to operating licence if remedial plans not implemented	Quality of Supply – 0.1 <= SMI < 1 for single event 5 <=E@R MWh < 50 for a single event System or revenue loss / damage => $500,000 but < $5,000,000 Reputation - Adverse media reports on the performance of the company, however they disappear within weeks Regulation / Licence – adverse comments from ERA linked to capital investment programme	Quality of Supply – SMI <0.1 for single event E@R MWh <5 for a single event System or revenue loss / damage <$500,000 Reputation – No significant impact on WP business Regulation – No significant regulatory issues

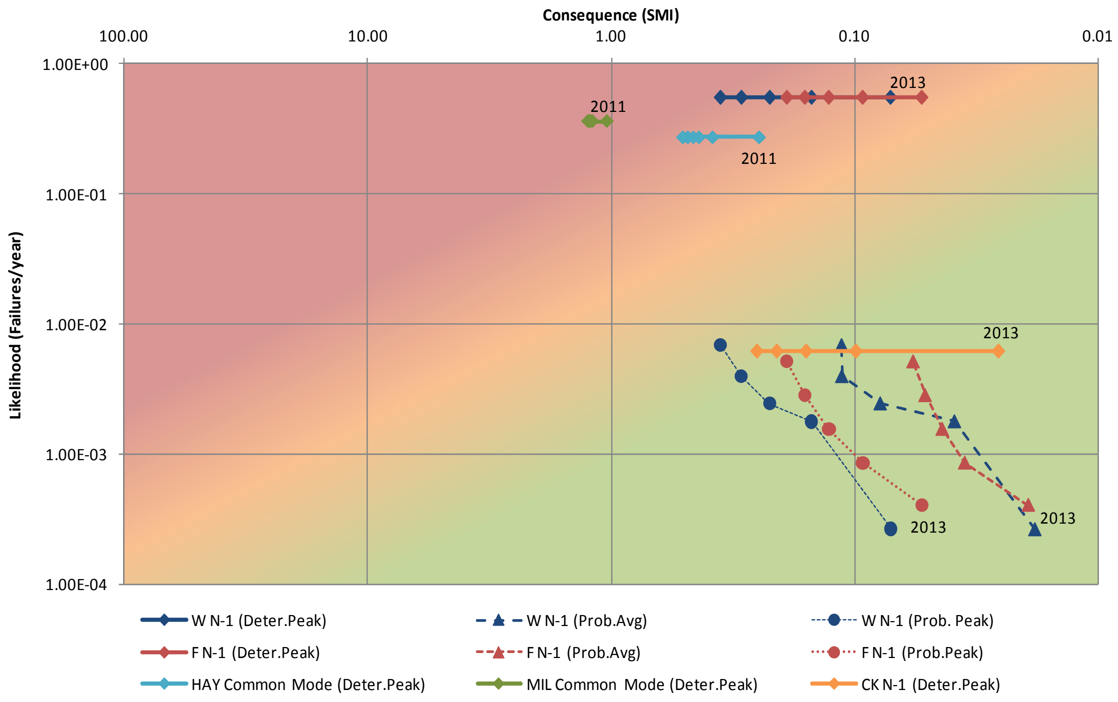


Figure 68 Risk Matrix

It can be seen from Figure 68 that the highest risk in terms of consequence should a failure occur is that of the Milligan Street substation for an N-2 common mode failure of the infeeds. This analysis has been based on a two hour restoration time, as is provided for N-2 failures in the Technical Rules. This shows that although compliant with the Technical Rules, such an event would have significant impact on customers during the outage.

The highest risk in terms of the most likely failure to occur is at the Forrest Avenue or Wellington Street Substations. This is primarily due to the basic design of these sites. In comparison, the least at risk in terms of failure likelihood is Cook Street which has a more secure design with busbar structures and multiple infeeds.

It should be noted however, that Cook Street substation sees the greatest growth in consequence as time progresses. This is due to the significant increasing load above firm capacity at this substation projected beyond 2013.

The probabilistic assessment of the Wellington Street and Forrest Avenue substations indicates the significant reduction in likelihood from the deterministic approach. Year on year, the likelihood can be seen to increase, reflecting that as more load is over the firm capacity limit of the substation, the substation as a whole is over firm for a longer period of time and the likelihood of a failure occurring whilst over firm is greater. The consequence of a failure at peak is the same for both deterministic and probabilistic approaches.

Summary

In summary, this risk analysis study allows the potential consequence of a failure occurring whilst CBD Load Area substations are over firm capacity (as is forecasted) to be illustrated. This is provided through the use of a risk matrix which allows the progression of risk to be tracked as time increases for each substation against the likelihood of a failure and the consequence of that failure. The consequence is derived on SMI, however as part of the risk matrix, a number of other metrics are provided to allow a broad cross comparison,

It is seen that the most likely failure to occur is at the Forrest Avenue and Wellington Street Substations with a marginal consequence. The most at risk substation in terms of the consequence is Milligan Street should a common mode failure of the two incoming circuits or two of the transformers occur. Although this at risk load is assumed to be recovered in 2 hours as per the Technical Rules under such an event, there would still be a significant system and customer impact during this time.

Although at a low likelihood and consequence due to the more secure design of Cook Street substation, it can be seen that year on year; this substation's consequence is forecast to increase considerably from negligible to marginal.

Appendix K Load Growth Table

- **Table 37 CBD Load Area Organic Load Growth Table**

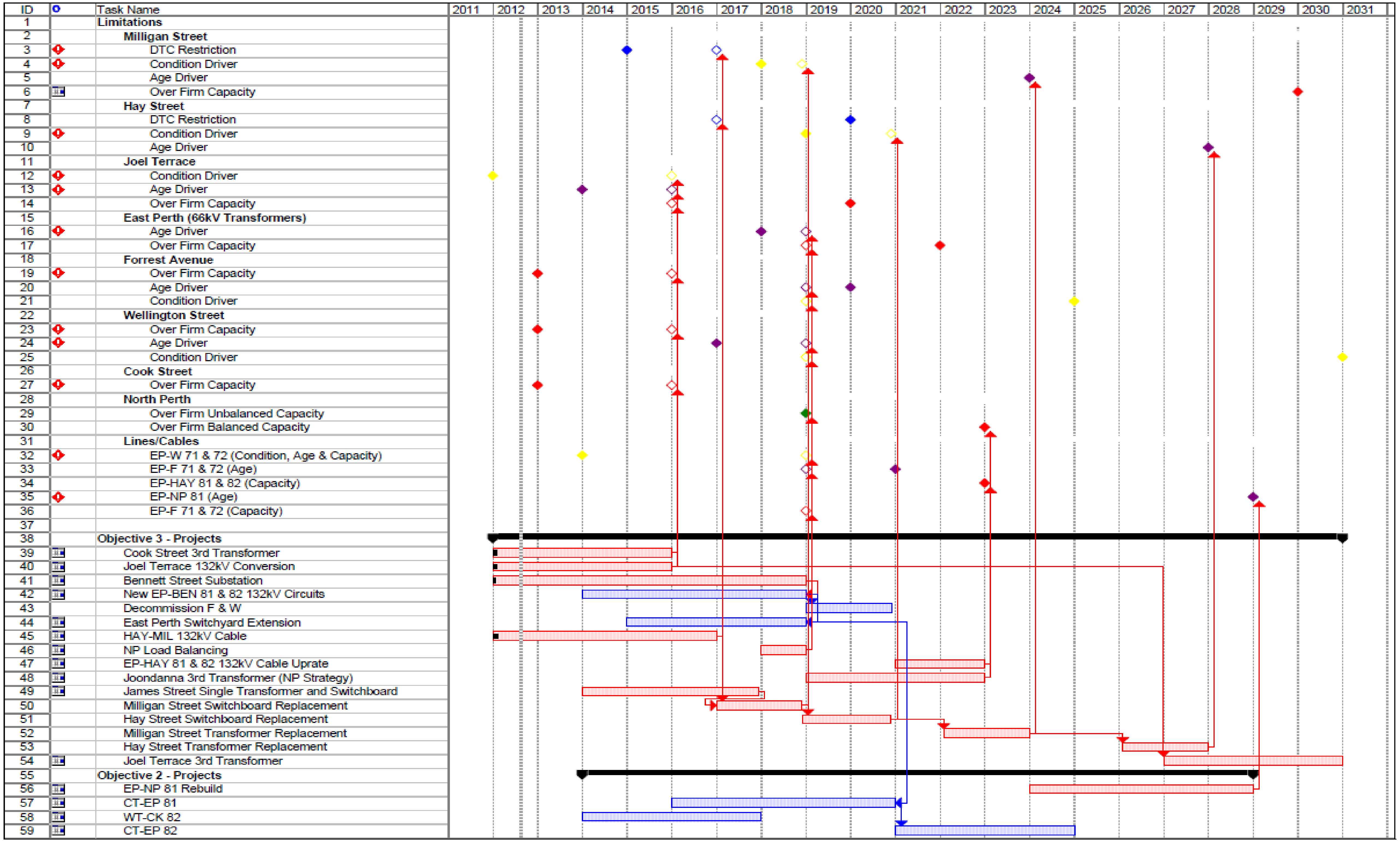
Substation	Configuration	Firm Capacity (MVA)	Power Factor	2011	2012	2013	2014	2015	2016	2017	2018	2019	2020	2021	2022	2023	2024	2025	2026	2027	2028	2029	2030	2031	2032	2033	2034	2035	2036
East Perth 132 and 66 kV	132/66/22 kV, 2x100/75/50 MVA	450.0	0.89	324.4	341.5	353.8	363.2	371.7	381.6	389.8	400.7	411.1	419.6	428.2	436.7	445.3	453.8	462.3	470.5	478.6	486.7	494.8	502.9	511.0	519.1	527.2	535.3	543.4	551.5
Hay Street 132 kV	132/11/11 kV, 3 x 71 MVA	142.0	0.88	83.2	86.7	87.6	89.8	90.7	91.6	92.6	93.5	94.4	95.4	96.3	97.3	98.2	99.2	100.1	101.1	102.1	103.0	104.0	105.0	106.0	106.9	107.9	108.9	109.9	110.9
Cook Street	132/11/11 kV, 2 x 81 MVA	81.0	0.89	78.4	80.4	81.9	83.3	84.6	87.2	88.4	90.0	91.5	93.1	94.6	96.1	97.5	98.9	100.3	101.3	102.3	103.3	104.2	105.2	106.1	107.0	107.9	108.8	109.7	110.5
North Perth	132/11/11 kV, 3 x 34 MVA	55.0	0.90	52.9	55.4	57.5	59.6	61.7	63.8	66.0	68.1	70.2	72.4	74.5	76.7	78.8	81.0	83.2	85.4	87.5	89.7	91.9	94.1	96.2	98.4	100.6	102.8	105.0	107.2
Joel Terrace	132/11/11 kV, 1 x 76 MVA, 66/11 kV, 2X 24 MVA	48.0	0.92	35.5	37.2	38.6	40.1	41.6	43.1	44.6	46.1	47.6	49.2	50.7	52.2	53.8	55.3	56.8	58.4	59.9	61.5	63.0	64.6	66.1	67.7	69.2	70.8	72.3	73.9
Summer Street	132/22, 2 X 12 MVA	12.5	0.84	12.7	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3	14.3
Forrest Avenue	66/11 kV, 2 X 39 MVA	39.0	0.87	35.0	38.6	42.5	43.2	44.4	45.6	46.4	47.2	48.0	48.7	49.5	50.3	51.1	51.9	52.7	53.4	54.2	55.0	55.8	56.6	57.4	58.2	59.0	59.8	60.6	61.4
Wellington Street	66/11 kV, 2 X 29 MVA	29.0	0.92	26.7	29.0	31.5	32.9	34.5	36.0	37.6	41.6	45.0	46.6	48.3	49.9	51.6	53.2	54.9	56.6	58.2	59.9	61.6	63.2	64.9	66.6	68.3	70.0	71.7	73.3
Milligan Street	132/11/11 kV, 3 x 71 MVA	134.0	0.89	97.6	102.8	104.1	105.5	107.8	111.6	114.7	118.0	119.4	120.8	122.3	123.7	125.2	126.6	128.1	129.5	131.0	132.5	133.9	135.4	136.9	138.4	139.9	141.3	142.8	144.3

*- Indicates load exceeding 95% of firm (N-1) capacity
*- Indicates load exceeding 100% of firm (N-1) capacity

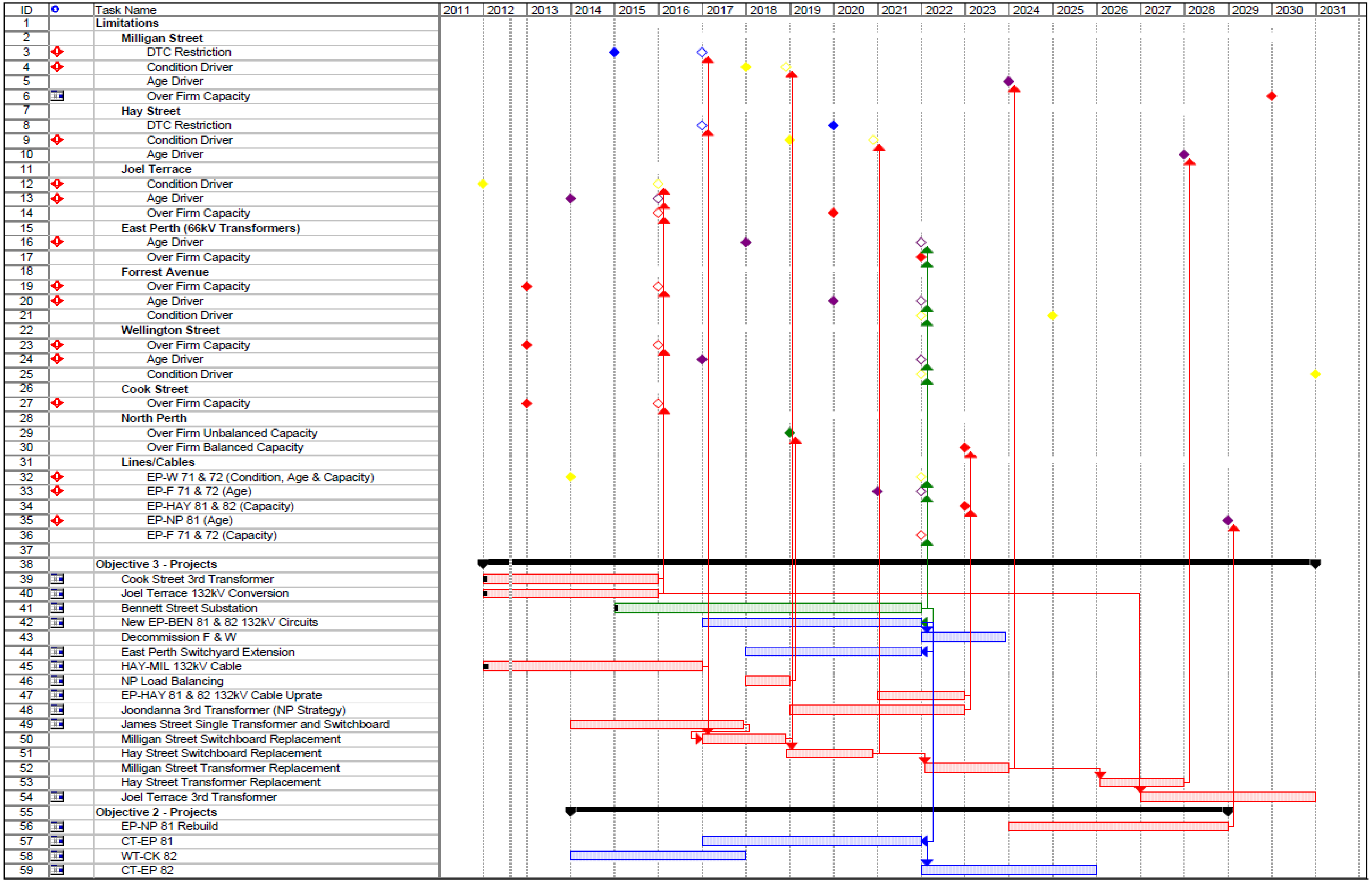
This load growth table has been prepared using Western Power's forecasting tool OPAL. All load transfers have been removed and any site due to be decommissioned has been left in service to give an overall view of the organic or natural growth of load demand in the CBD Load Area. Individual site power factors have been assumed based on an average power factor over the 25 year period from 2011-2036.

Though located geographically within the boundaries of the CBD Load Area, it is important to note that Milligan Street is supplied from Northern Terminal. The load demand at Milligan Street is therefore excluded from the total load growth figure shown for East Perth

Appendix L 25 Year Strategy Charts

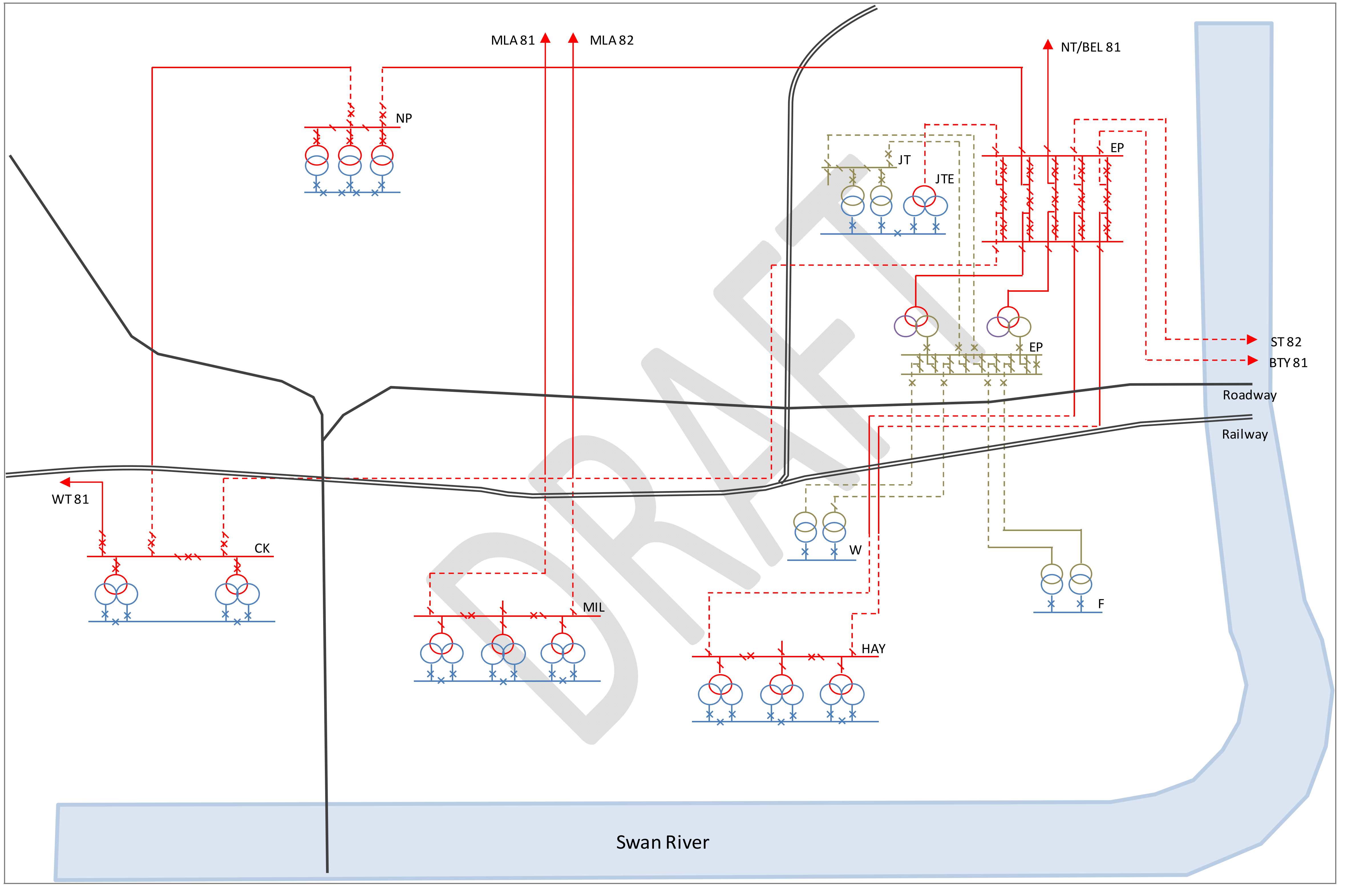


■ **Figure 69 Baseline Strategy: Timings (A3)**

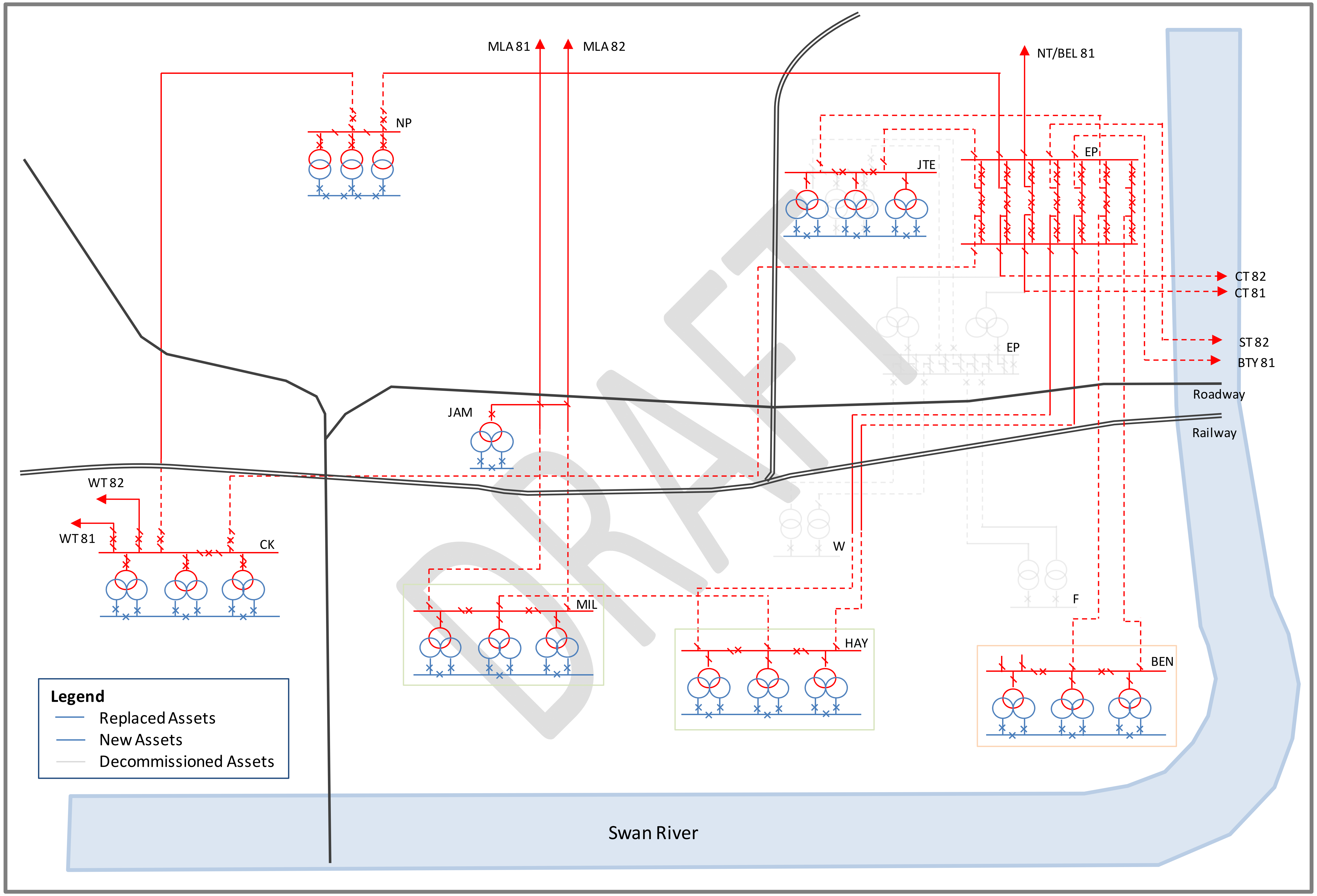


- **Figure 70 Bennett Street Delayed: Revised Strategy (A3)**

Appendix M CBD Load Area – Single Line Diagrams



▪ **Figure 71 CBD Load Area – 2011 Single Line Diagram**



■ **Figure 72 CBD Load Area – 2036 Vision Single Line Diagram**

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