WESTERN POWER
LONG TERM STRATEGIC OPTION REVIEW

Western Terminal – Area Development Report

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Contents

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
CB	Circuit Breaker
DTC	Distribution Transfer Capacity
ERA	Economic Regulation Authority of Western Australia
GIS	Gas Insulated Switchgear
NCR	Normal Cyclic Rating
NDP	Network Development Plan
NFIT	New Facilities Investment Test
NPC	Net Present Cost
NPV	Net Present Value
RRST	Rapid Response Spare Transformer
Technical Rules (DM#3605551)	Approved by ERA, the technical rules consist of the standards, procedures and planning criteria governing the construction and operation of the electricity network

▪ Table 2 Western Terminal load area 2011 substation abbreviations

Abbreviation	Substation	Operating Voltage
AMT	Amherst Street	132/22 kV
C	Cottesloe	66 kV
CK	Cook Street	132/11 kV
CTE	Cottesloe	132/11 kV
EP	East Perth	132/66 kV
HE	Herdsman Parade	66/6.6 kV
MC	Medical Centre	66/6.6 kV
N	Nedlands	66/6.6 kV
NF	North Fremantle	66/11 kV
NP	North Perth	132/11 kV
NT	Northern Terminal	330/132 kV
SP	Shenton Park	66/6.6 kV
U	University	66/6.6 kV
WD	Wembley Downs	66/11 kV
WT	Western Terminal	132/66 kV

1. Executive summary

Western Power has identified the requirement for a robust long term development plan for the electrical transmission system assets in the Western Terminal load area, to the west of the Perth Central Business District (CBD), 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 Western Terminal area 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
- Rationalisation of existing substation sites
- Customer driven connection works

Assessment of these investment drivers across the Western Terminal load area over the considered strategy period led to the development of four discrete Development Strategies:

1) Development Strategy 1 – Retain 66 kV
2) Development Strategy 2 – Shenton Park and Herdsman Parade upgraded to 132 kV
3) Development Strategy 3 – Shenton Park, Herdsman Parade, Medical Centre and University upgraded to 132 kV
4) Development Strategy 4 – full 132 kV migration

Each strategy has been evaluated against a range of financial and technical performance metrics resulting in the identification of Strategy 3 as the most suitable long term development strategy for the Western Terminal area. Strategy 3 is recommended as it balances technical performance whilst extracting the maximum lifetime from the existing 66 kV Western Terminal transmission infrastructure and hence yields an attractive capital investment phasing profile.

There are however, a number of key areas that require further analysis and assessment to confirm the superiority of Development Strategy 3 over the other strategies considered for the Western Terminal load area. This includes:

- The practicalities of uprating the existing 66 kV wooden pole overhead lines within the Western Terminal area identified under this study should be investigated to confirm that the desired line operating temperature and ratings proposed can be achieved in practice.
- Detailed conceptual designs for each substation need to be developed to confirm that the number and rating of transformers considered under this study can be achieved in practice, with specific consideration given to operational and construction issues. Particular attention is required at Medical Centre and Nedlands given the restricted site plots available.
- The technical and financial viability of replacing the existing 66 kV switchgear at Nedlands, either in situ or on a vacant part of the existing site, must be determined as well as the practicalities of installing 132 kV gas insulated switchgear.
- The capital cost building blocks used in this assessment should be reviewed in conjunction with the network design proposed under each development strategy and cost input from equipment suppliers. This should confirm the calculated strategy capital investment costs are appropriate and the financial conclusions reached are correct.

Once the above aspects have been fully researched and Development Strategy 3 confirmed as the most suitable network development strategy for the Western Terminal load area over the next 25 years, the individual transmission system projects that comprise Strategy 3 can be subjected to detailed engineering design studies to confirm design concept, engineering, specification and procurement aspects to progress implementation.

2. Scope of assessment

2.1. Background

Western Power has identified the requirement for a robust and documented strategy for future network development in the Western Terminal load area, to the west of the Perth CBD. The current lack of such a strategy 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.

Western Power has recognised the urgency for a 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 the 2011 NDPs Western Power has identified a number of emerging capacity limitations in the Western Terminal load area. Whilst the 2011 NDPs present a good high level view of these emerging constraints they are not sufficiently mature to provide detailed option analysis and subsequent strategies. Further work is required to form a robust economic proposal to address these constraints and properly stage a program of work to ensure deliverability.

Some initial investigations into this load area have been conducted and have identified 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 it is critical that all aspects of existing infrastructure be considered as part of any future network proposals.

2.2. Aim of document

2.2.1. Study scope of work

As highlighted in the previous subsection, Western Power has identified the need for a detailed and documented long term network planning strategy for the Western Terminal load area. To address this issue, and support future NFIT submissions for new facilities to the ERA, SKM were engaged by Western Power to develop a robust long term development strategy for a study horizon of 25 years.

The aim of the study was to document and assess the alternative strategies for developing the Western Terminal transmission system to meet the forecast load requirements over the next 25 years, giving consideration to financial, technology, regulatory and accompanying issues. The study was required to identify the level of capital investment for network reinforcement that would be required to develop the Western Terminal load area under three discrete network development scenarios:

- Retaining 66 kV as the underlying transmission system voltage in the area
- Partial migration to 132 kV for key substations within the Western Terminal area
- Full migration to 132 kV for all substation within the Western Terminal area

For each strategy consideration should be given to the technical, financial, regulatory, reliability, compliance and environment impacts of the following network development drivers:

1) Network reinforcement to accommodate area load growth
2) Asset replacement to address age and condition related deterioration
3) Rationalisation of existing substation sites
4) Customer driven connection works

The study should highlight the merits and associated limitations of each of the considered development strategies for the Western Terminal area as well as the recommended strategy and any factors that may impact on its selection. Of particular interest is the comparative cost-benefit assessment of the voltage migration from 66 kV to 132 kV across the Western Terminal area, this aspect having been identified previously by ERA in relation to previous Western Power NFIT submissions.

2.2.2. Exclusions and limitations

In reviewing this study report it is important to understand not only the original aim of the work performed, but also how this work fits within the wider context of the development of the Western Power transmission and distribution system in the west Perth area. It is worth highlighting a number of key aspects that have not been considered, or only given limited consideration, in this study. These include:

- The impact of Western Terminal load area developments on the bulk transmission system – beyond the 132 kV circuits supplying Western Terminal explicitly assessed under this study
- The explicit reinforcement of the Western Terminal transmission substation, either at 132 kV or potentially at 330 kV, to provide additional area supply capacity – other than reinforcements of the 132/66 kV transformer capacity
- The requirement for wider reinforcement of the Western Power transmission system to the north, east or south of the Western Terminal load area, including potential new 330 kV substations
- Consideration of the technical and financial merits of alternative distribution system voltages eg, 22 kV, 11 kV and 6.6 kV – this aspect has been covered in a previous Western Power report detailed in Section 2.3 below.

2.3. Past study reports

This study report is one of several that have been completed by Western Power in relation to the development of the transmission and distribution system in the Western Terminal load area. Previous reports that have been completed and have been considered as part of this work include:

1) Draft Western Terminal Load Area: Transmission 50 Year Strategic Development Plan, December 2009, DM#6609423v2
2) Draft Western Terminal Load Area: Long Term Strategic Plan 2009 – 2029, DM#4029988v3
3) Western Terminal Strategy Overview – 2011 to 2030, February 2011, DM#7754590v2

The first report provided, at a relatively high level, an overview of the factors that are expected to influence the development of the transmission system in the Western Terminal area over a 50 year horizon, including analysis of demand forecast trends and outline of different network development options. However, this option assessment did not consider in detail the practical issues associated with each option (including design, construction and commissioning) or indeed specific environmental factors associated with each site.

The second report provides a much more detailed review of the options available for providing additional supply capacity at each of the substations in the Western Terminal load area as well as the practical issues associated with each substation. However, this report does not provide a comparative assessment of the financial and technical merits of retaining 66 kV as the sub-transmission system voltage in the Western Terminal load area in comparison with partial and full migration to 132 kV, one of the key aims of this study.

The third report provides the background and analysis justifying the move from 6.6 kV to 11 kV as the principal distribution system voltage in the Western Terminal load area, having given consideration to retaining 6.6 kV, moving to 11 kV as well as 22 kV. This report provides useful background to the works required at substations as well as across the wider distribution system, but does not have a significant impact on this particular study.

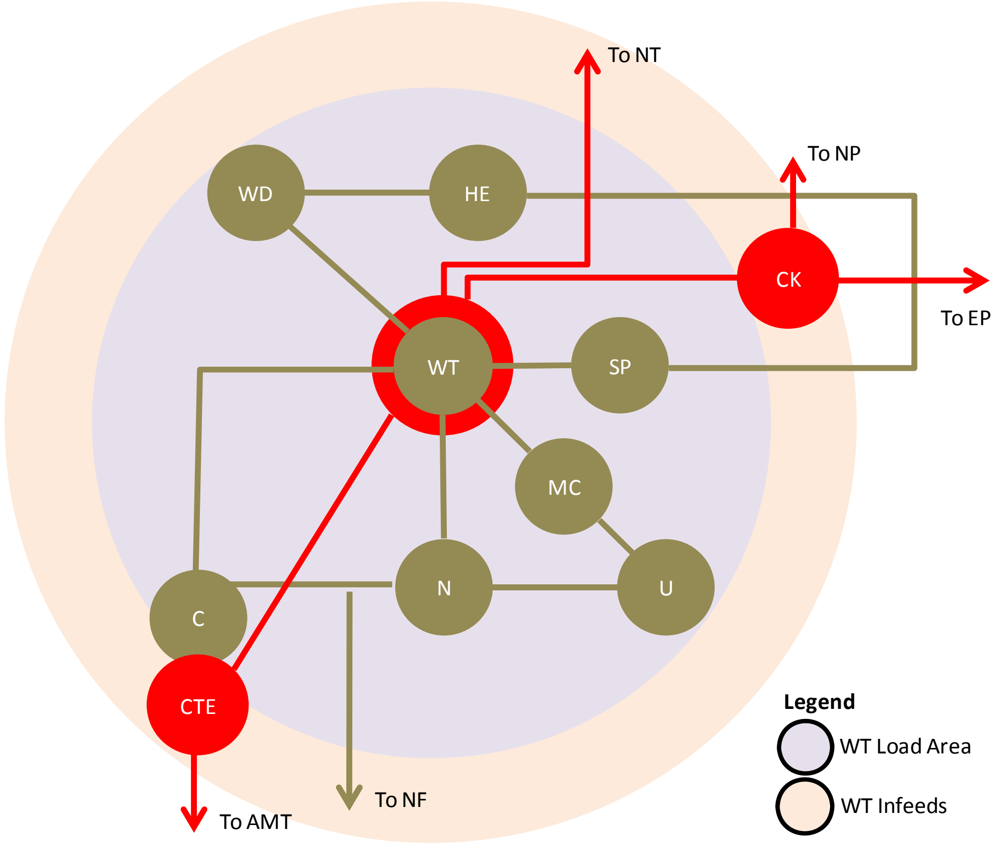
3. Background

3.1. Overview of the network area

This report outlines the cost benefit analysis of a long term strategic plan for the Western Terminal load area from 2011-2035.

Western Terminal presently supplies six substations in two distinct 66 kV rings, one to the North and one to the south as shown in Figure 1 and is the primary focus of this study. The 132 kV infeeds to Western Terminal are currently supplied via Cottesloe/Amherst, Cook Street and Northern Terminal and have been monitored throughout this study to highlight any interconnection issues as a result of the proposed development strategies. The load area covers most of the South West Inner Metropolitan area as illustrated within Appendix A - Figure 30, extending from City Beach and Wembley Downs in the north, to Mosman Park in the south, Nedlands and the Swan River in the east with the western boundary being the coastline.

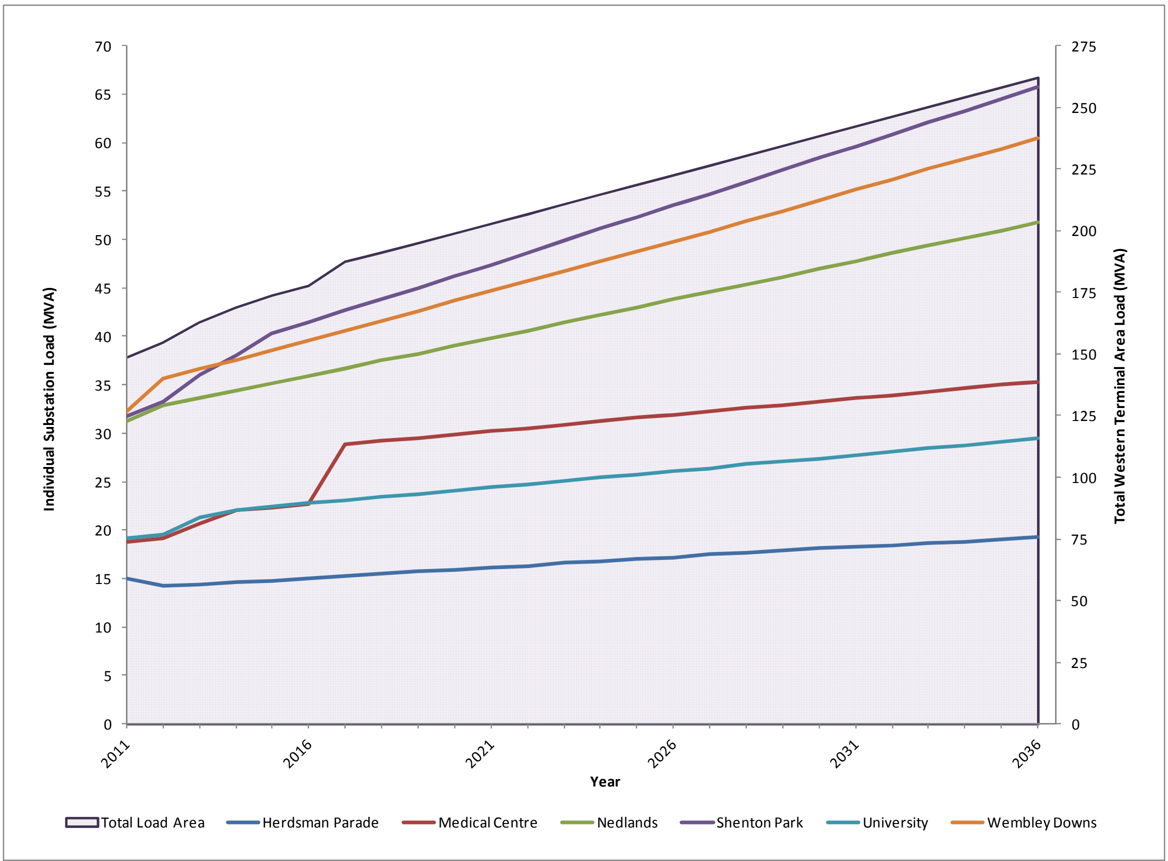
■ Figure 1 Western Terminal load area overview (2011)



The area contains mostly residential and commercial loads with some light industrial load and is a mature and well established region. All customers are supplied at 415 V with the exceptions of Sir Charles Gardiner Hospital (Medical Centre substation) and the University of Western Australia (University substation) which are currently supplied directly at 6.6 kV and Hale School and Floreat Shopping Centre (Wembley Downs substation) which are currently supplied directly at 11 kV.

It is forecasted (as shown within Figure 2) that the load growth within the Western Terminal load area over the next 25 years will be driven organically through residential and commercial customers. 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 very few Greenfield developments. However, the area contains most of the affluent suburbs of Western Australia and it is experiencing a considerable infiltration of air-conditioning use, which is believed to be the cause of the area's significant load growth in the past few years. The re-zoning and re-development of parts of the Western Terminal load area has contributed significantly to the area's high load growth, with the re-zoning to high density residential of areas such as Mt Claremont resulting in extensive developments of many high electricity-consumption residences.

■ Figure 2 2011-2036 load forecast (10% PoE)



3.2. Overview of transmission system limitations

It is anticipated that there will be insufficient 66 kV transmission capacity in the short term, particularly as the North 66 kV transmission ring will experience the overloading of the WT-WD overhead line under contingency outage conditions of the WT-SP line by 2015. Additionally, by 2026 there will be a requirement for a new transmission circuit as the transfer limit of any reinforced 66 kV overhead line using Venus AAC conductor will be exceeded. The potential for building new overhead lines in the area is limited due to reluctance and opposition from local residents. The south 66 kV transmission ring is seen to provide adequate capacity throughout the study period.

It is seen that there is a severe lack of transformation capacity throughout the Western Terminal load area in the immediate to short term. Of the six 66 kV substations in the Western Terminal load area, Nedlands, Shenton Park and University are non compliant in terms of network reliability with the Technical Rules (NCR clause 2.5.3.2(b)) by the 2011 summer peak due to insufficient available transformer capacity. Load balancing could be employed at Nedlands and Shenton Park but would provide very short term benefits, extending compliance by one to two years. Medical Centre and Wembley Downs substations are expected to be non-compliant with NCR requirements by 2016 and 2018 respectively.

The fault level in the load area is low at all transmission substations and is not considered a limitation.

The age and condition of the load area 66 kV assets is approaching the end of its lifetime. It is expected that all 66 kV transmission lines in the load area will require replacement over the 25 year period with the majority of 66 kV transformers also requiring replacement within the next 10-15 years.

3.3. Overview of distribution system limitations

The demand for electricity in the Western Terminal load area is increasing to the point that some of the existing 6.6 kV distribution feeders have exceeded the design limits of 100% of thermal rating. A number of options have been considered to address the capacity shortfall of the distribution feeders.

Option 1 is to keep the existing Western Terminal load area operating at 6.6 kV and upgrade the exit cables and install new feeders. According to the 2011 load forecast, there will be a shortfall of approximately 112 MVA for the Western Terminal feeders by 2030 if the distribution network remains at 6.6 kV. It is estimated that a minimum of 37 new feeders are required to supply a total load of 112 MVA. Such a large number of additional feeders required will exceed the available circuits to connect, as well as increasing cable congestion issues that already exist. Consequently, the new feeders will be de-rated. Moreover, QE11 medical centre is also seeking to upgrade to 11 kV. If the Medical Centre is upgraded to 11 kV as a result of the customer request, this would denote an island of 11 kV near Medical Centre surrounded by the remaining 6.6 kV network (University, Shenton Park and Nedlands), further restricting the distribution transfer capacity and decreasing the reliability of the network. Both the load at Medical Centre, expected as 18 MVA by 2018, and the street load, 12 MVA, are considered too large to adopt a 6.6/11 kV step up transformer to provide wider network interconnection.

Option 2 is to convert the existing 6.6 kV distribution network to 11 kV operation. The upgrading to 11 kV will significantly increase capacity and according to the forecast, there will be a reduced shortfall of approximately 19 MVA for the Western Terminal feeders by 2030, down from 112 MVA if 6.6 kV operation is retained. The upgrading to 11 kV will also significantly reduce the risk of cable congestion that 6.6 kV will encounter and will resolve the potential Medical Centre islanding issues.

Cost benefit studies of the Western Terminal load area distribution network have been carried out and are documented within DMS#7754590. The studies illustrate that there is cost savings to be made by upgrading the distribution system in this area to 11 kV and when coupled with the technical advantages provided above, result in this solution being the preferred option. All development strategies proposed within this study will therefore be designed to allow the distribution network to be upgraded to 11 kV operation.

3.4. Committed investments

There are no committed transmission investments for the Western Terminal load area. It is to be noted however that at the time of writing there is a formal agreement in place for the Medical Centre substation to provide an 11 kV distribution supply and the upgrade of Shenton Park to 132/11 kV operation has been incorporated within the preliminary AA3 submission.

3.5. 132 kV enabled assets

Within the Western Terminal load area there are already assets installed that are 132 kV specification equipment but currently operated at 66 kV. Such assets include the 1.43 km double circuit overhead line between Western Terminal and Shenton Park (double circuit steel pole line) as well as the 840 m (3 x 1C 1200 mm^2 CU XLPE) and 550 m (3 x 1C 2000 mm^2 CU XLPE) 132 kV underground cables installed in the Herdsman – Wembley Downs and Western Terminal – Nedlands 66 kV single circuits.

4. Network asset condition report

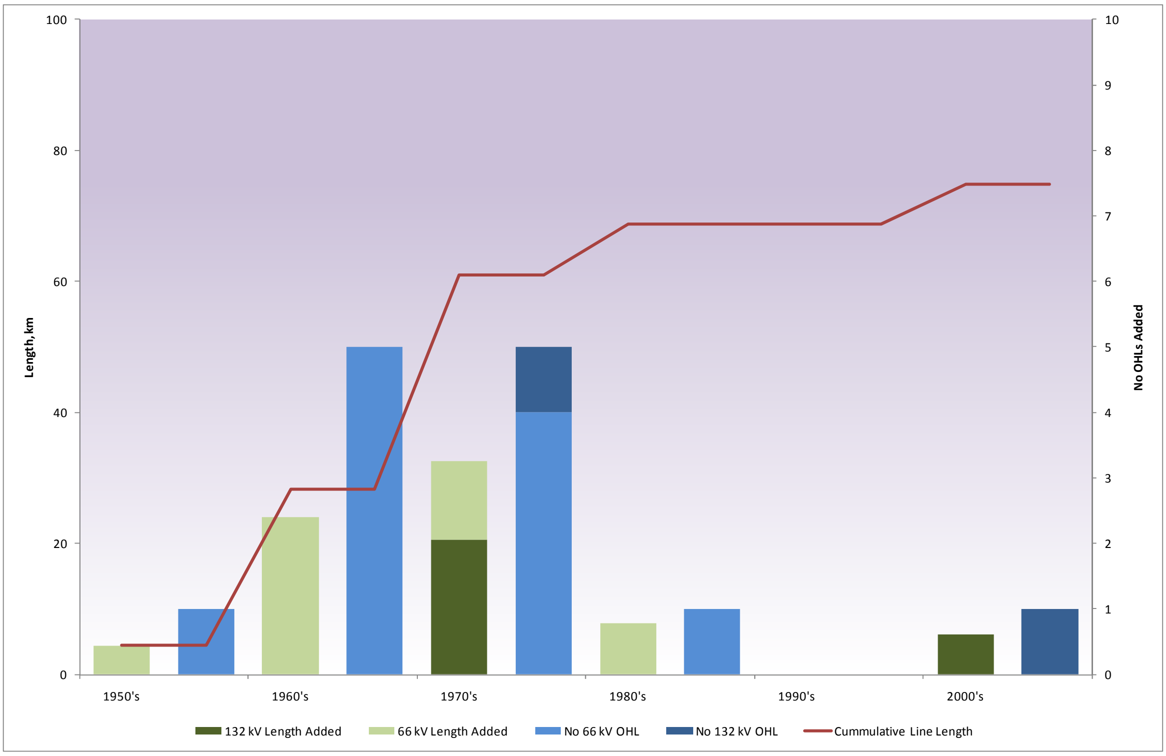
This section details the age and condition characteristics of the principal electrical transmission and distribution equipment within the Western Terminal area relevant to the development of a 25 year strategy plan.

4.1. Transmission assets

4.1.1. Overhead lines

The principal electrical transmission assets within the Western Terminal area include all 132 kV and 66 kV overhead lines and underground cables as well as all 132 kV and 66 kV switchgear. The following figure (Figure 3) demonstrates how the existing 132 kV and 66 kV overhead lines in the Western Terminal area have been added to the Western Power network since the mid twentieth century. Table 3 details the specific 132 kV and 66 kV overhead lines summarised in Figure 3.

■ Figure 3 Western Terminal transmission line installation profile



- Table 3 Western Terminal transmission line age profile

Lines	From – to substation	Age	Length, km	Rating, MVA
132 kV	WT-CTE	2009[1]	7.39	210
	WT-CK	2002[1]	6.09	210
	NT-WT	1978	20.63	243
66 kV	CK-HE	1967	8.35	80
	CK-SP	1967	4.09	80
	C-N	1955	4.4	93
	HE-WD	1969	4.8	80
	MC-U	1973	1.64	80
	N-U	1966	3.05	80
	WT-C	1980	7.76	80
	WT-MC	1973	4.12	105
	WT-SP[2]	1976	1.43	105
	WT-WD	1965	5.31	104
	WT-N	1967	3.13	105

Although Western Power has asset condition information and ratings for EHV transformers and transmission and distribution switchgear, at present a similar condition assessment methodology has not been implemented for transmission overhead lines and cables. 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 Western Terminal strategy. After discussion with Western Power engineers it was considered that an appropriate lifetime for overhead lines was 60 years, principally as most overhead lines use wooden pole structures.

From examination of Figure 3 and Table 3 it is evident that virtually all of the existing 66 kV overhead lines in the Western Terminal area will require replacing within a 25 year period, if a 60 year asset lifetime is considered, with many requiring replacement much sooner given original installation dates in the 1950's and 1960's.

It is also evident from Figure 3 that all existing 132 kV overhead lines within the Western Terminal area are much younger than the 66 kV lines with all except the Northern Terminal to Western Terminal 132 kV line (installed in 1978) being installed in the last decade.

4.1.2. Transformers and 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) and as well as transformers. For switchgear the following parameters are considered in addition to unit age:

- General deterioration
- Maintainability
- Performance

[1] The indicated age of the line has been obtained from the TLS line report and reflects the recent work undertaken to renew/upgrade line components. It is however expected that some of the line components will be older than indicated.

[2] The majority of the WT – SP line has been rebuilt as a double circuit (along with the WT – MC line) steel pole 132 kV specification overhead line, however short sections of the existing 1970's vintage wood pole line remain in service.

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

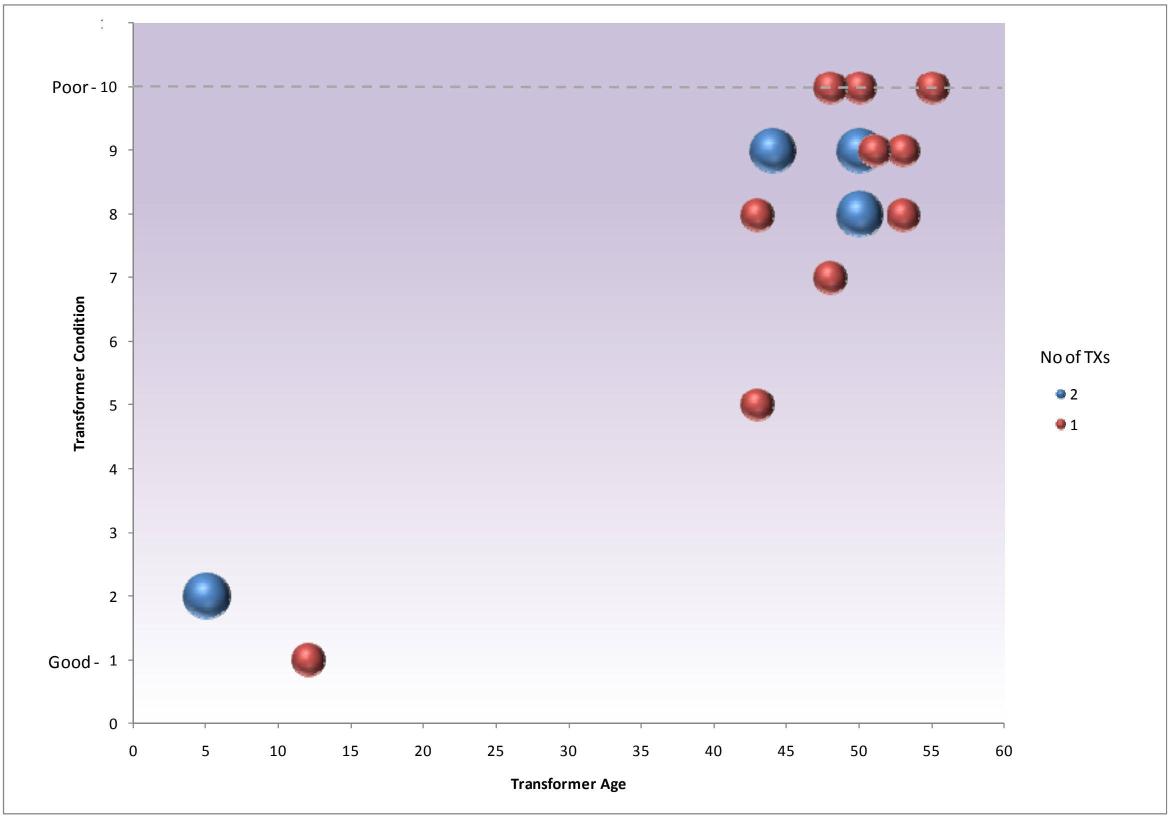
For transformers the following parameters are considered in addition to unit age:

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

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 one to 10, with 10 being unacceptable condition requiring replacement in the short term. For 132 kV and 66 kV transformers the following figure (Figure 4) outlines the distribution of transformer ages and accompanying conditions.

Note that Figure 4 includes the Western Terminal 132/66 kV transformers as well as Cottesloe 132/11 kV transformers plus the 66/6.6 kV transformers at Nedlands, Medical Centre, Shenton Park and Herdsman Parade. Wembley Downs is not included as asset condition data was not available at the time of writing for the refurbished 66/11 kV transformers.

- Figure 4 Load area 132 kV and 66 kV transformer asset condition and age profile

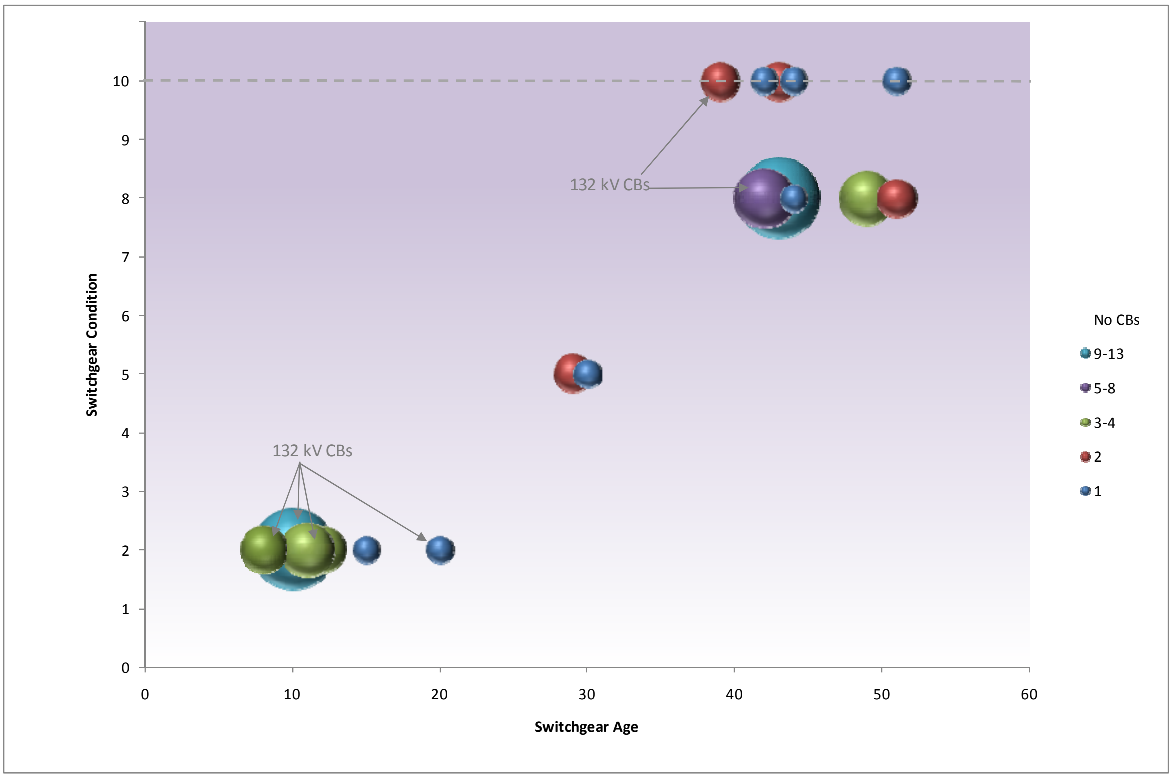


It is evident from Figure 4 that the majority of the existing transformers in the Western Terminal area are more than 40 years old and have condition ratings of eight out of 10 or higher. From discussions with Western Power engineers it was considered that an appropriate lifetime for 11 kV and 6.6 kV supplying transformers was 50 years, with larger 132/66 kV transformers having a notional 60 year life reflecting the lower average loading experienced under N-1 operating conditions.

As a result, it is evident from Figure 4 that the majority of transformers in the Western Terminal supply area will require replacement within 10 to 15 years.

For 132 kV and 66 kV switchgear the distribution of asset age and associated conditions is illustrated in the Figure 5.

- Figure 5 Load area 132 kV and 66 kV switchgear asset condition and age profile



Examination of Figure 5 shows an asset age and condition distribution similar to that of transformers, albeit with a greater number of younger (132 kV) assets reflecting replacement/extension works to facilitate ongoing network reconfiguration and modifications.

Collectively Figure 3, Figure 4 and Figure 5 highlight that virtually all of the existing Western Terminal 66 kV assets, including overhead lines, transformers and switchgear will require replacement within the period considered for this strategy document, which is before 2035. The wholesale replacement of a significant proportion of the Western Terminal electrical transmission assets over the next 20 years or so presents an opportunity to consider revising the operating configuration and transmission voltage of the Western Terminal sub-system. This will allow rationalisation of the number of substation locations, overhead transmission lines and increase substation capacity to better accommodate modern and future distribution customer load densities in this area.

4.2. Distribution assets

Although the principal focus of this long term strategy document is the Western Terminal transmission system, consideration has however been given to relevant distribution system assets that may influence the developed strategy. Distribution system assets of main interest here include substation LV switchboards as well as LV (6.6 kV and 11 kV) feeder line and cabling. It is further recognised that Western Power have long term plans to migrate the secondary distribution system voltage from 6.6 kV to 11 kV, analysis showing that this is the preferred voltage for the long term (DMS#7754590).

At present a number of the existing substation LV boards are the original 6.6 kV boards installed more than 40 years ago (Medical Centre, University and Herdsman primary substations). Other substations have seen LV switchboard replacements due to asset condition in anticipation of subsequent LV voltage migration (Nedlands and Shenton Park substations have

22 kV rated LV switchboards operated at 6.6 kV less than five years old) whilst Wembley Downs has already been converted to 11 kV in recent years. There will be opportunities to reuse these recently replaced assets.

For distribution system feeder circuits, there are no plans for wholesale or widespread line/cable replacement in the AA3 regulatory period or beyond, either for asset replacement or to enable voltage migration – the majority of 6.6 kV feeder circuits are already capable of operating at 11 kV. That said, where options are considered to merge two existing primary substations as part of the long term Western Terminal strategy, consideration will be given to LV feeder requirements and the associated capital investment necessary to transfer existing feeder loads to new substation locations.

5. Assumptions

5.1. Load forecast

This study has utilised the Western Power, May 2011 release, load forecast with all non-committed load transfer schemes and other proposed developments omitted. The load forecasts for each site are based on a 10% probability of exceedance (PoE) this is consistent with the Western Power Transmission Planning Guidelines. 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 Western Terminal area being primarily residential and concentrated within a relatively compact metropolitan area such that load peaks will naturally occur at comparable times.

5.1.1. Customer connections (load and generation)

At present there are no customer projects regarding the connection of generation within the Western Terminal load area. Much of the load is residential with organic load growth primarily seen through the further uptake of air conditioning systems and is applied within this study as per the 2011 forecast. The Charles Gardner Hospital is proposing a combined heat, cooling and power installation within the hospital but this has been included within the load forecasts. The impact of embedded photovoltaic (PV) generation is included in the 2011 load forecasts on a SWIS wide basis.

5.2. Environmental constraints

A high level summary of environmental constraints is given here with further detail as provided by the Western Power environmental team on specific substations and line issues presented in Appendix E.

5.2.1. Substation

All substations for the Western Terminal load area are located within or adjacent to established residential areas and the visual impact of any new substations or modifications will need to be adequately addressed with significant community involvement. A solution to ease opposition is through architecturally designed substation façades.

This study has considered two principal ratings of substation transformers as part of the development of each strategy. For 66 kV substations it has been assumed that conventional 2 x 66/11 kV transformers would be adopted, each with a 35 MVA rating. This is a slightly higher unit rating than the typical 33 MVA rated transformer normally installed by Western Power at this voltage, but is nonetheless considered an appropriate size of unit. Given the higher demand at Shenton Park it has been assumed that 3 x 35 MVA transformers would be adopted.

For 132 kV, Western Power already use 60 MVA rated 132/11 kV transformers with dual LV (30 MVA) windings at Cook Street. Additionally, Western Power have also initiated discussions with transformer manufacturers who have confirmed that larger 75 MVA (dual 37.5 MVA LV windings) are also available for 132/11 kV transformers. It is this larger rated dual LV winding 132/11 kV transformer that has been adopted for this study, with 2 x 75 MVA 132/11 kV transformers being installed at each substation where migration to 132 kV is considered. The exception is Shenton Park when amalgamated with Herdsman where 3 x 75 MVA transformers are considered.

The sensitivity of the resulting study conclusions to these substation capacity and configuration assumptions is considered further in Section 8.9.1.

5.2.2. Overhead lines

All potential new line routes would involve establishing lines within mature residential areas. There will be a strong push for any new transmission lines within this area to be underground cable due to space constraints, mitigation of earth potential rise (EPR) and low frequency induction (LFI), mitigation of traffic hazards and opposition from the community. It is however expected that any in-situ replacement of overhead lines will meet less resistance.

This study has assumed that newly constructed or uprated 66 kV or 132 kV lines in the Western Terminal load area will be of Venus conductor type, strung for 85°C operation resulting in a capacity of 141 MVA at 66 kV or 282 MVA at 132 kV energisation. Such an assumption allows the greatest capacity conductor to be realised whilst accounting for installation restrictions resulting in an 85°C operating temperature only. A sensitivity analysis of this assumption is considered further in Section 8.9.4, which addresses different conductor sizes and maximum operating temperatures.

5.2.3. Land availability

Western Power currently owns a small potential future substation site at Montgomery Avenue, Mt. Claremont. DMS#4029988 states that there is potential for this site to be moved to an alternative location at the corner of Alfred Road and West Coast Highway through discussions with the City of Nedlands Council. No further available land in the Western Terminal 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. If further land requirements are identified new sites have been identified in conjunction with Western Power.

5.3. Costs

The 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.

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 DM#5358272, 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.

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 DM#7426252.

5.4. Power system analysis

5.4.1. Model and data set

Load flow analysis has been carried out with DIgSILENT PowerFactory software. The base system model is that utilised as part of the AA3 development studies, specifically the ROAM scenario 20 generator dispatch with Western Power derived projects for the year 2020.

The Western Terminal load area can be isolated from the rest of the network with three infeeds from Northern Terminal, Cook Street/East Perth and Cottesloe/Amhurst. Load forecast data for each of the Western Terminal load area substations from 2011-2035 were created to produce a complete data set using the Western Power 2011 forecast.

It should be noted that the load forecast figures used at each substation and included in the analysis studies 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 relatively small geographical area supplied from Western Terminal. The results will, in any case, yield worse case reinforcement timings for consideration in the subsequent strategy evaluation.

5.4.2. Methodology

Load flow analysis has been utilised to illustrate loading of transformers and lines under normal and contingency (N-1) conditions and to monitor voltage levels throughout the Western Terminal load area.

N-1-1 security is a requirement for Western Terminal infeeds as it is a 132 kV terminal substation within the Perth metropolitan area as described by the Technical Rules. Although not explicitly required within this scope, where potential infeeds have been identified, N-1-1 studies have been carried out to provide a high level commentary on the advantages gained.

66 kV substations in the Western Terminal load area, excluding Medical Centre, currently operate to 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, however it does increase the level of customer risk in comparison to N-1 designs. It is assumed for the purpose of this analysis, and has been modelled as such, that future substation capacity upgrades will be completed to an N-1 security standard. This ensures that each proposed strategy is developed with a consistent level of network security. It has also been assumed that the bus section circuit breaker will be operated closed at future N-1 substations.

Further analysis will be undertaken by Western Power at a later date to confirm the practically and applicability of the existing NCR and alternative N-1 substation design philosophies on a case by case basis.

5.4.3. Study horizon

Load forecast data is available to the study horizon of 2035. Where additional foresight is required beyond this horizon, the load forecast has been extrapolated using a linear regression to provide a guide on future trigger years.

Studies have been divided into two distinct components, namely one to 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 long term transmission planning team respectively.

5.5. Other

Previous studies conducted by Western Power[3] have illustrated that there are economies to be had in converting distribution voltage from the current 6.6 kV operation to 11 kV. Part of this upgrade has been seen at the Wembley Downs substation. The costs involved in this conversion process have not been accounted for within this study; however the reinforcements proposed would allow this work to be carried out concurrently. The costs for these works will however be common to each investment strategy.

[3] DM# 4029988 and DM#7754590

6. Strategic development vision

This section briefly looks at how developments in the Western Terminal load area will influence and align with the wider strategic vision of the Western Power network. The primary strategic ideas concerned with this study involve the introduction of 330 kV into the area, removal of time expired 66 kV networks for more system wide standard 132 kV assets and future N-1-1 compliance of Western Terminal through infeeds from adjacent parts of the Western Power transmission system.

6.1. Utilising 330 kV assets efficiently

It is a primary strategic vision to unlock trapped 330 kV capacity in the Western Power network and to utilise these assets more effectively. It is however not expected in the 25 year period for the Western Terminal load area to be a part of this strategy. This is in part due to the 132 kV infeed capacity being suitable for the load area and therefore no immediate requirement for higher capacity 330 kV infeeds. There is the potential to reinforce Western Terminal directly or indirectly from a 330 kV reinforcement in the CBD which would subsequently increase the utilisation of the 330 kV system and offload the 132 kV sub-transmission network.

6.2. 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 1960/70's and approaching the end of life. Specific 66 kV rated equipment is no longer widely available and many individual components (eg, switchgear and underground cables) operated at 66 kV are already constructed by manufacturers and rated for 132 kV. Consequently it is considered that any new 66 kV lines installed within the Western Power network will be of a 132 kV construction if a future network upgrade to 132 kV has been identified. There is therefore merit in looking to standardise equipment operating voltages throughout the network, potentially to the more common 132 kV voltage if seen to be economic, to allow network wide efficiencies in procurement and maintenance regimes.

6.3. Emerging requirement for additional Western Terminal 132 kV infeed

The Technical Rules for N-1-1 compliance apply to 'all 132 kV terminal stations in the Perth metropolitan area' within which Western Terminal is located and therefore 132 kV infeeds to the site must meet this requirement. It is seen that by 2015, the infeeds will be non N-1-1 compliant with an overload of the Western Terminal – Cook St circuit following a loss of the Western Terminal – Northern Terminal and Western Terminal – Cottesloe circuits. As part of the wider network strategy there is a requirement for an additional 132 kV infeed into Western Terminal. Although not explicitly considered within the scope of this report it is important to recognise the wider network issues and potential solutions that can be developed based on the development strategies considered in this study.

7. Emerging limitations

This section details the emerging limitations in the Western Terminal load area in the periods one to 10 years and 11-25 years, particularly focussing on capacity shortfalls in the transmission system and substations through transformation capability.

7.1. One to 10 years

7.1.1. Transmission network

The existing 66 kV transmission network consists of two distinct electrical rings, namely one to the north and one to the south of Western Terminal. The northern ring supplies Shenton Park, Herdsman Parade and Wembley Downs substations through a total of 23.98 km of single circuit overhead line. The southern ring consists of the existing Medical Centre substation, University and Nedlands substations through a total of 11.94 km of single circuit overhead line. The southern ring is further connected from Western Terminal to Nedlands via the recently deloaded Cottesloe 66 kV substation through 4.4 km of single circuit overhead line and 430 m of underground cable (from Nedlands to Cottesloe) and a further 7.76 km single circuit overhead line (from Cottesloe to Western Terminal). The first line section out of Western Terminal for each ring is rated at 105 MVA, with subsequent line sections rated for 80 MVA.

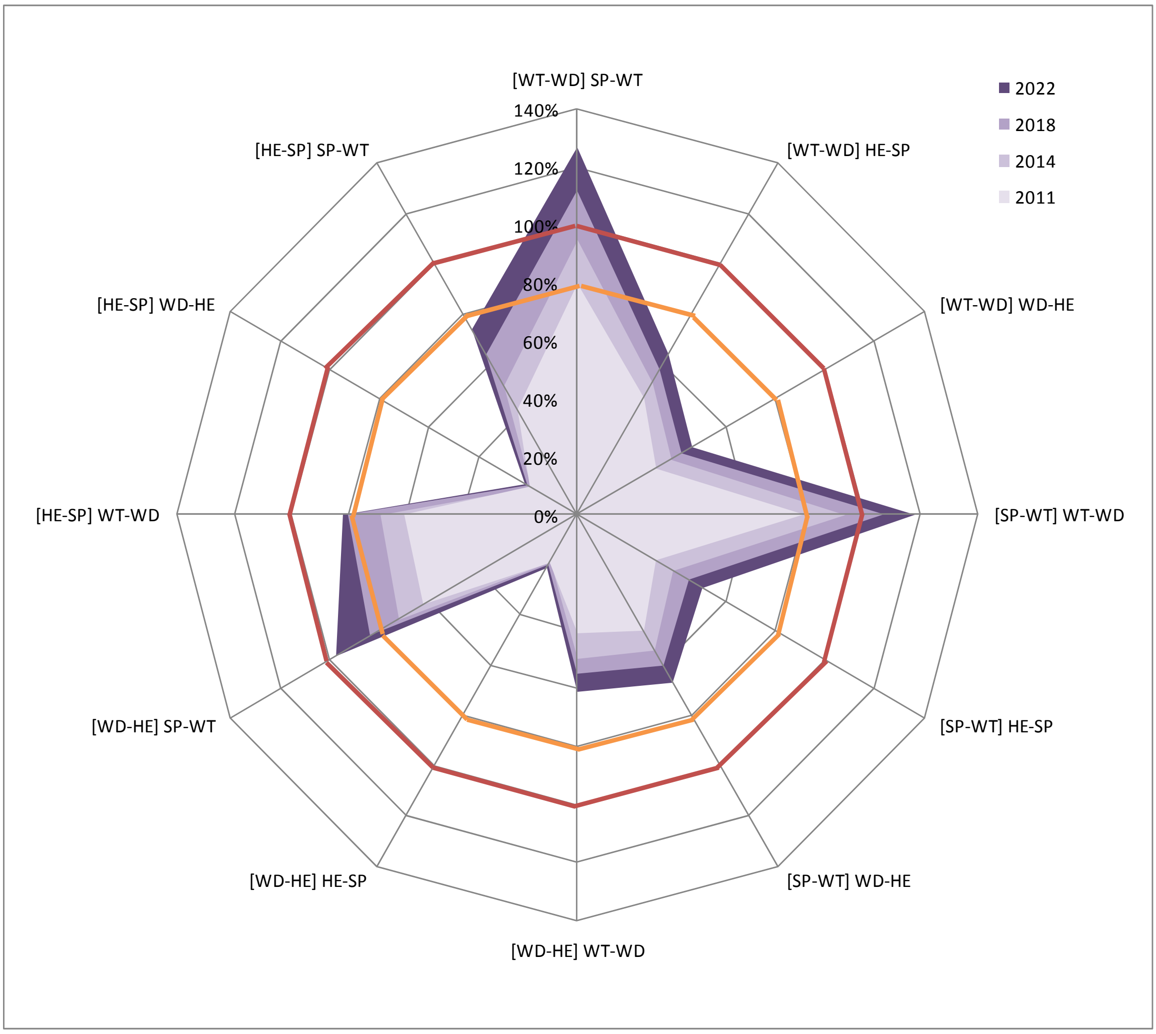
Figure 6 and Figure 7 show transmission line loading, and hence available capacity, under contingency (N-1) conditions for the next 10 years on the north and south rings respectively. Transmission lines indicated in brackets are monitored lines following the loss of the subsequently displayed line. An example of this is [WT-WD] SP-WT which illustrates the percentage loading of the WT-WD line following the loss of SP-WT for each studied year (80% 2011, 95% 2014, 112% 2018, 127% 2022).

Figure 6 illustrates that within the next five years there will be insufficient capacity available on the existing WT-SP and WT-WD lines following a contingency event involving these lines. Within ten years the WD-HE line will also experience insufficient capacity following a contingency event involving WT-SP. It can also be seen that the HE-SP line is over 80% loaded for a contingency of WT-WD within this period and expected to hold insufficient capacity in the medium term.

The primary driver for the reduction in transmission capacity on the north 66 kV ring is the substantial load and growth of Shenton Park substation, expected to increase by some 35%[4] in the period 2011-2022.

[4] 31.8MVA in 2011 to 48.6MVA in 2022 based on the 2011 load forecast

- Figure 6 North 66 kV ring transmission capacity: 2011-2022

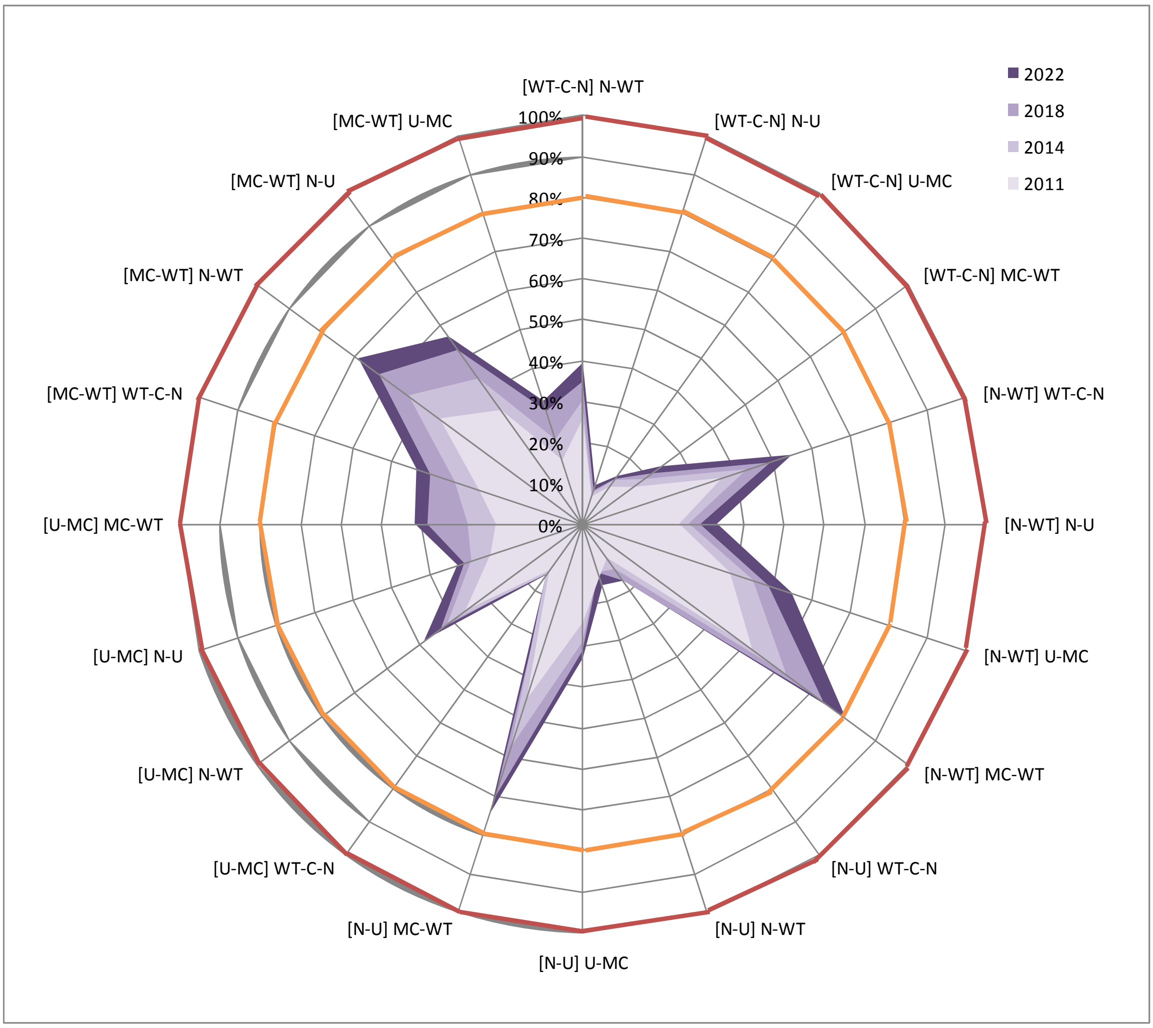


In order to increase the transmission capacity of the north ring as required to maintain N-1 compliance, a number of solutions could be implemented. This could include:

- Removal of Shenton Park substation load from the 66 kV ring by upgrading to 132 kV operation. Sufficient transmission capacity is expected to be available until 2026 following this upgrade.
- Uprating WT-SP, WT-WD and WD-HE 66 kV overhead lines to a higher capacity, a total of 11.54km. The load growth of Shenton Park and Wembley Downs would restrict the longevity to which a solution would provide. It is expected that if the lines are uprated to the maximum conductor size of Venus (subject to existing poles being able to support conductors of this dimension and statutory line clearances being achieved), capable of providing a maximum 141 MVA at 66 kV, the WT-SP line would experience insufficient capacity before 2030.
- Additional 66 kV circuit construction from WT-WD or WT-SP. This would still require the uprating of the WD-HE 66 kV line.

Figure 7 illustrates that there is sufficient transmission capacity in the south 66 kV ring within the next ten year period whilst it is noted that WT-N and N-U are greater than 75% loaded for contingencies of WT-MC.

■ Figure 7 South 66 kV ring transmission capacity: 2011-2022



7.1.2. Substation capacity

Zone substation capacity for the Western Terminal load area is currently based on the NCR criteria as described within the Technical Rules, with the exception of Medical Centre which is operated to a reduced firm security standard. There are a total of thirteen 66/6.6 kV (10-15 MVA) and two 66/11 kV (27 MVA) transformers in the load area, supplied by three 100 MVA 132/66 kV transformers at Western Terminal which are operated to N-1 criteria.

Figure 8 illustrates the substation capacity for the next four year period and the load expected to be seen by these substations. At selected sites there is potential to balance the load on the transformers to further enhance the substation capacity and is shown as the extended maroon bar. The existing capacity, with no load balancing applied is illustrated in green. The NCR criterion is currently undergoing wind back to 75% at a rate of 1.5% per year over 10 years (starting in 2004) and therefore can be seen to reduce the capacity of the substations over the next four years. The capacity shown in 2014 is based on a 75% NCR criteria and is not expected to wind back further.

▪ Figure 8 Substation capacity summary: 2011-2014

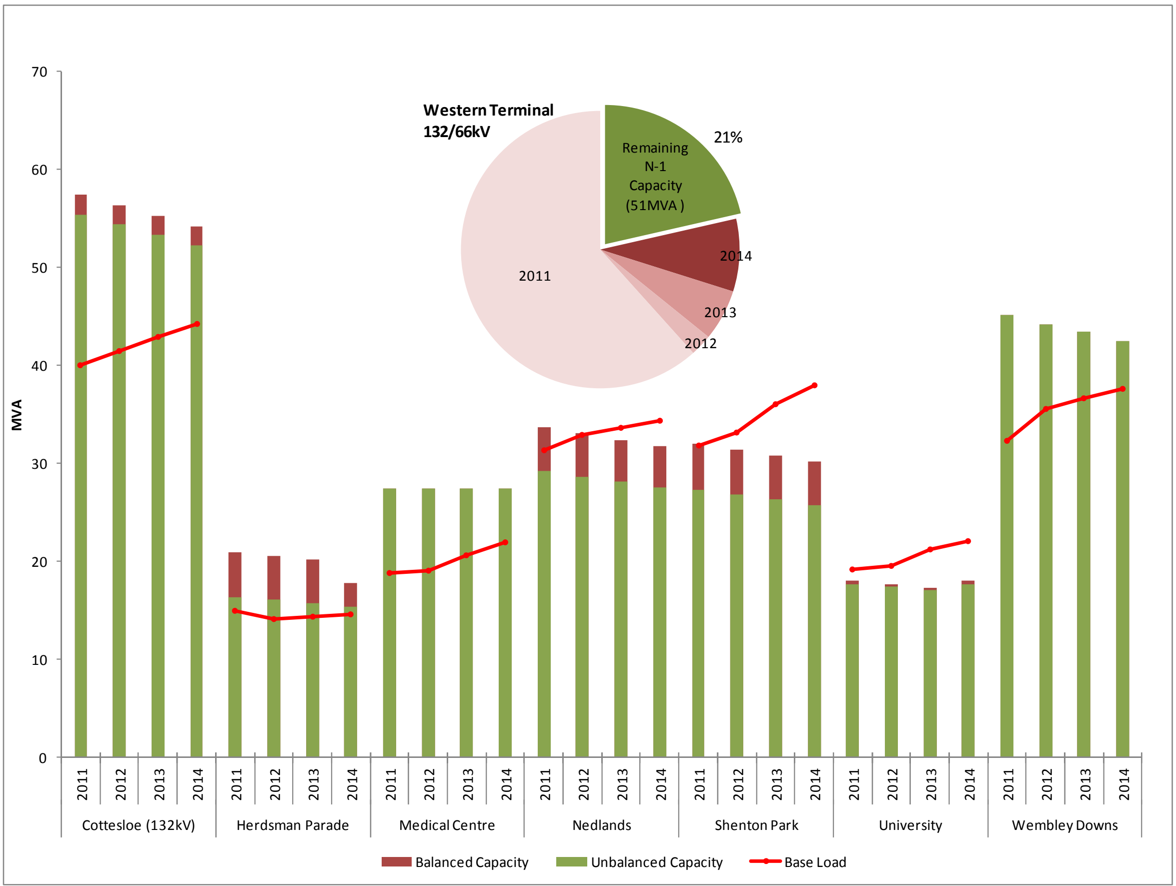


Figure 8 illustrates that there is currently insufficient capacity available at University substation to be NCR compliant and that by 2013 there will be insufficient capacity available to meet forecasted maximum demand (see Appendix B - Figure 36). Nedlands and Shenton Park substations require significant load balancing to be NCR compliant in 2011, although the benefit obtained from this is short-lived in both instances with non-compliance by 2013 and 2012 respectively. It is expected that Shenton Park will have insufficient capacity available to meet forecasted maximum demand by 2015 (see Appendix B - Figure 35) and at Nedlands by 2025 (see Appendix B - Figure 34).

Appendix B extends the study period for each substation to 2035 to highlight capacity limitations or asset condition trigger points. In the period to 2020 it can be seen that in addition to those substations with short term capacity limitations, Medical Centre will not be reduced firm compliant by 2016 and Wembley Downs not NCR compliant by 2018. This results in all 66/11 kV substations, with the exception of Herdsman Parade, within the Western Terminal load area being non compliant with planning standards by 2018.

Transformer condition at these sites is seen to be reaching the end of its life primarily within the period 2011-2020 as described in Section 4.1 and further illustrated in Appendix B. At Shenton Park it can be seen that the existing transformers have exceeded their asset lifetime and condition by some years. The majority of transformers in the load area will therefore require asset replacement measures in the short term due to condition.

The total growth of the load area is illustrated by the transformer loading at the Western Terminal 132/66 kV transformers which are required to operate to an N-1 security standard. The pie chart shown in Figure 8 illustrates the reduction in available capacity as load increases from 2011-2014 with a remaining capacity of approximately 51 MVA (21%) post 2014. Appendix B illustrates that there will be insufficient capacity to maintain N-1 compliance by 2020.

In order to increase the substation capacity in the short term a number of strategies could be employed.

- Load balancing at sites to extend NCR compliance.

- Load transfers to other substations in the load area could assist in the short term whilst alternative strategies are employed but cannot be a long term solution as insufficient capacity is seen across the load area.
- Install greater capacity 66/11 kV transformers. Limited to approximately 35 MVA per transformer.
- Upgrade substation to 132 kV operation to allow greater capacity 132/11 kV transformers. Limited to approximately 75 MVA per (duel LV winding) transformer.

Transmission system fault levels in the load area (as shown in Table 4) are seen to be low and within the ratings of existing switchgear with extensive headroom available. It is not expected that any significant generation connections or multiple infeeds to the load area, beyond the 132 kV infeed required to resolve the N-1-1 requirement, will occur which would drive the fault level in the load area higher and any new developments or reinforcements will be designed appropriately for the fault level. It is therefore concluded that transmission system fault levels will not be a limitation in the Western Terminal load area throughout the period studied. There will be fault level limits on the operation of 11 kV bus section circuit breakers closed and this will require uprating of distribution networks to ensure this parallel transformer operation is possible.

- Table 4 Western Terminal load area short circuit currents

Substation	Voltage (kV)	Single Phase Fault Current (kA)	Three Phase Fault Current (kA)	Existing Switchgear Rating (kA)
CTE	132	16.0	18.16	40.0
HE	66	6.8	8.44	25.0
MC	66	9.6	10.33	25.0
N	66	10.8	11.02	25.0
SP	66	13.1	11.56	25.0
U	66	9.3	10.18	25.0
WD	66	8.1	9.64	25.0
WT	66	16.5	13.19	25.0
WT	132	22.0	21.35	40.0

7.2. 10 to 25 years

7.2.1. Transmission network

Figure 6 illustrated that within the next ten years, it is expected for sections of the Northern 66 kV ring to be over capacity under contingency outage conditions. Figure 9 extends this study for the period 2022-2035 and demonstrates the further level of growth of demand on these circuits. All circuits within the ring are now seen to be overloaded under contingency conditions with SP-WT some 167% loaded for a loss of WT-WD in 2035. A loading of 167% on this line equates to some 175 MVA, the maximum conductor size of Venus being strung for 85°C operation provides a maximum capacity of 141 MVA and therefore illustrates the requirement for an additional 66 kV circuit to be installed in the long term as restringing of the lines will not provide sufficient capacity.

▪ Figure 9 North 66 kV ring transmission capacity: 2022-2035

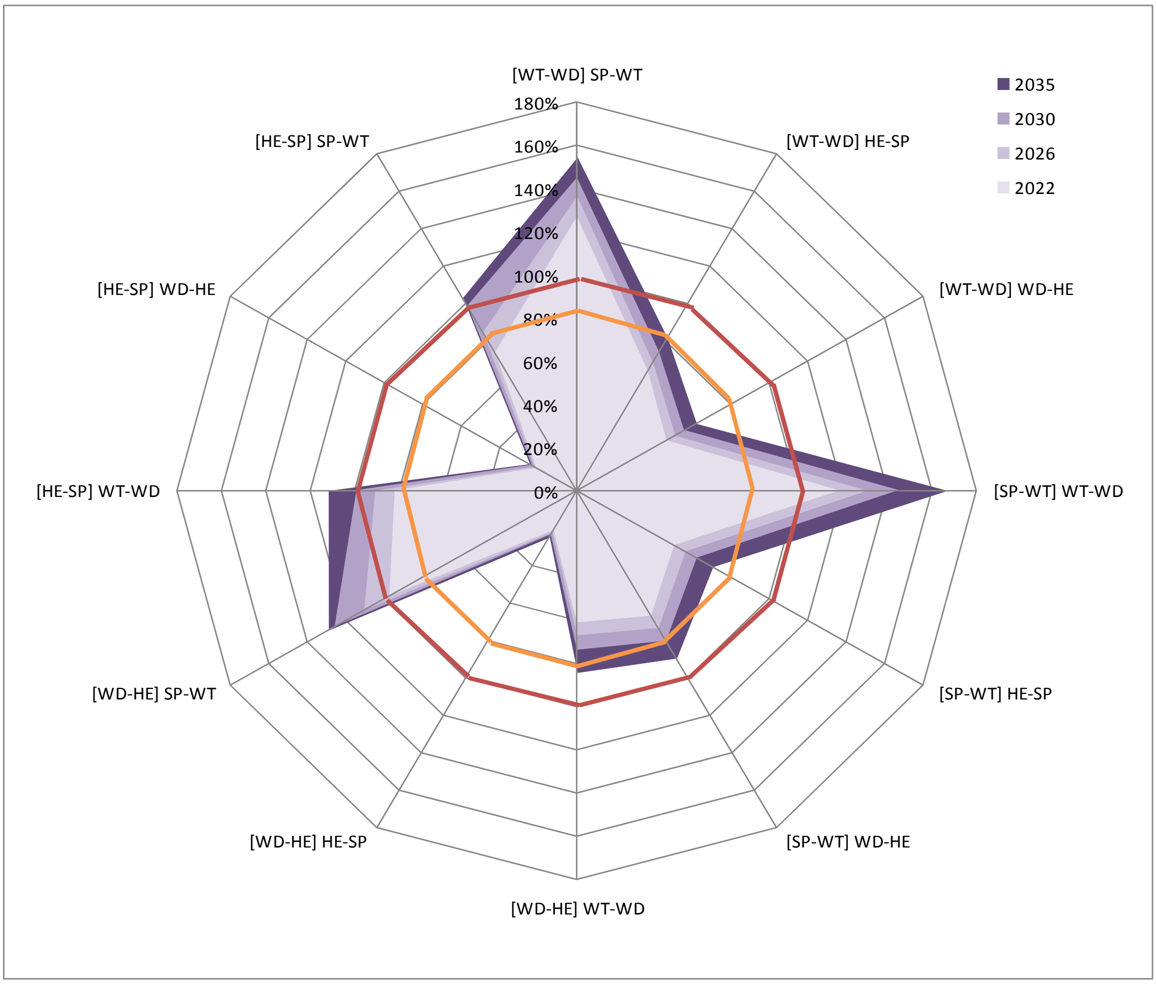
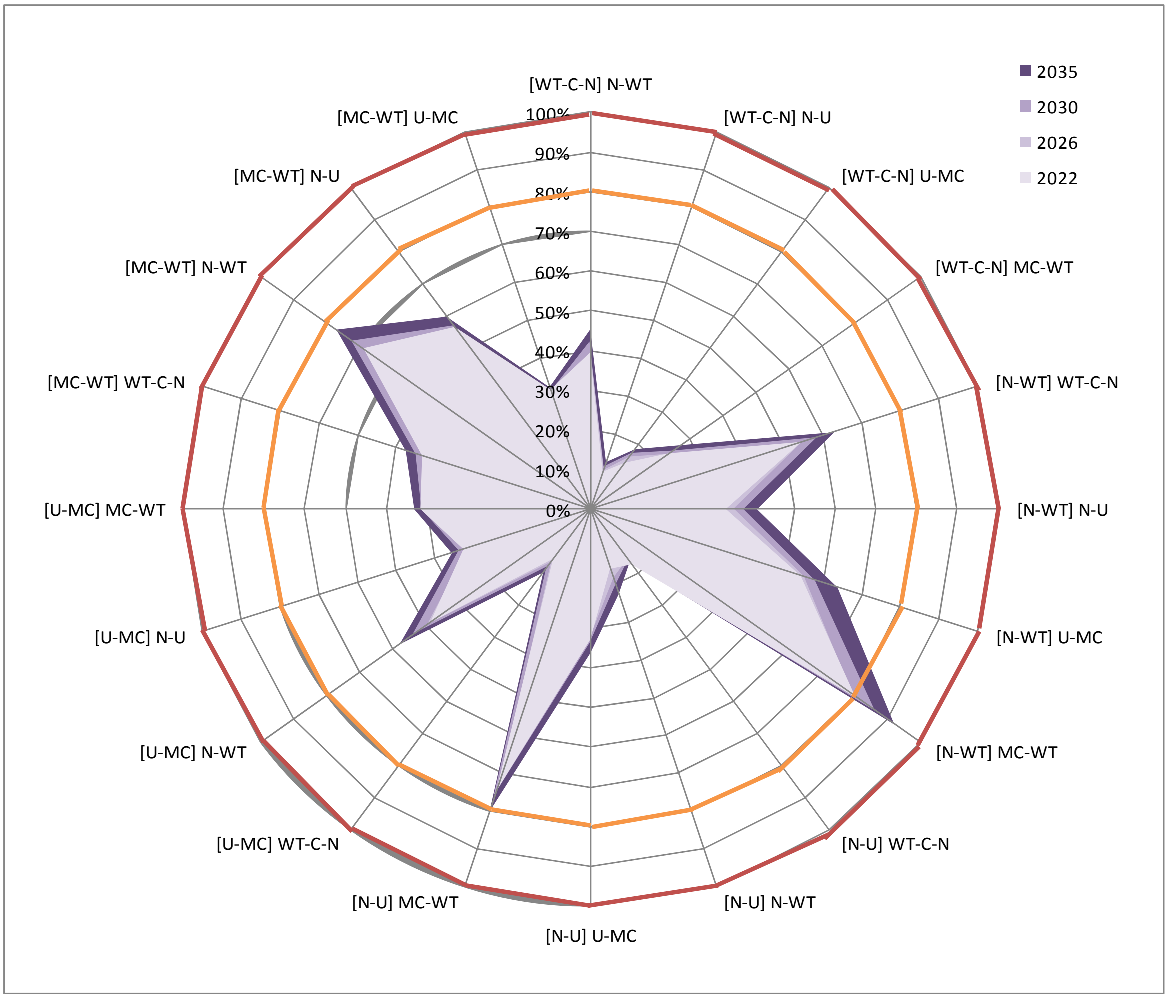


Figure 10 illustrates the southern 66 kV ring does not experience such over capacity, primarily due to the additional circuit provided via Cottesloe to Nedlands. It can be seen however, that restringing of some elements for higher capacity will be required in the long term to allow future growth, particularly N-WT and MC-WT lines.

As described in Section 4.1, many of the Western Terminal 66 kV lines are presently 40-50 years old and would be expected to be replaced or refurbished within the period 2022-2035. Coupled with significant insufficient capacity seen in the short term this will result in an extensive replacement of 66 kV transmission assets for both condition and capacity requirements throughout the strategy period.

■ Figure 10 South 66 kV ring transmission capacity: 2022-2035



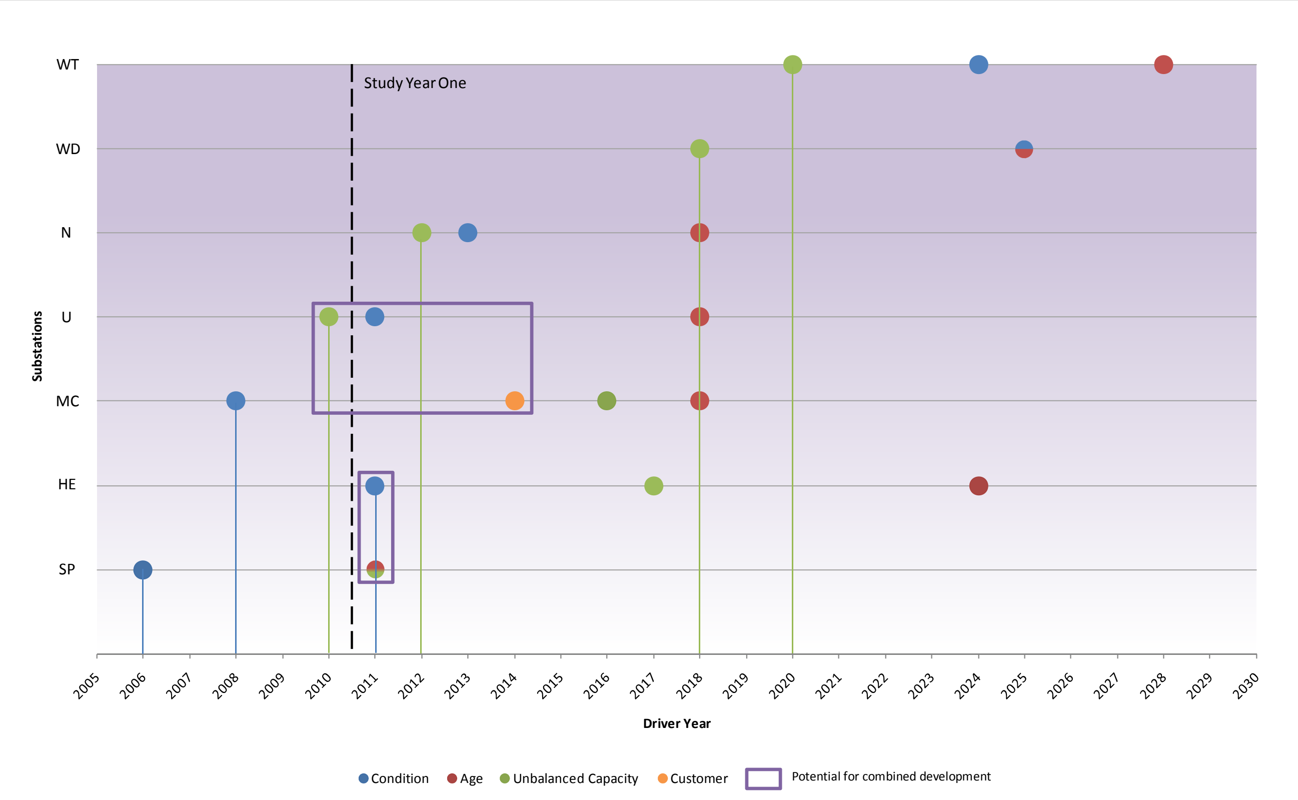
7.2.2. Substations capacity

Appendix B illustrates individual substation capacity and condition of transformer assets over the period of 2011-2035. This provides a view on the triggers for reinforcements that are required for capacity or asset condition issues. As has been described in Section 7.1.2; Nedlands, Shenton Park, University, Medical Centre and Wembley Downs will have insufficient capacity to comply with the technical rules within the next 10 years. Of the other sites in the load area, it can be seen that load balancing may extend the substation capacity lifetime of these sites; however by 2020 Cottesloe 132 kV substation will have insufficient capacity, as will Herdsman Parade by 2028.

Figure 11 summarises the capacity and condition limitations of each substation within the Western Terminal load area to illustrate the driver and the date of the replacement or reinforcement works required. Line drop downs show the first factor to impact on the substation with this seen to be evenly split between condition and capacity limitations. There are a number of limitations that have been surpassed to date, some over five years ago, which will add pressure to the timing and staging of developments in the short term and is reflected within the monetary spend profile of respective proposed strategies that have been analysed.

Figure 11 further illustrates a potential for combined developments which may provide economic/technical efficiencies due to the geographical locations of the substations and the timings of limitations experienced. Examples of this are Shenton Park and Herdsman Parade with limitations seen in 2011 as well as Medical Centre and University in the period 2011-2014.

■ Figure 11 Summary of substation capacity and condition limitations



With the insufficient level of substation and transmission capacity identified in the load area, combined with the age and condition of all transformers and 66 kV lines, it is noted that an extensive replacement of assets will be required in the Western Terminal load area within the next 25 years.

8. Strategies considered

8.1. Overview of strategies

Section 7 has illustrated that the Western Terminal load area is presently experiencing a significant lack of capacity in both the 66 kV transmission system as well as individual substation sites. This will be compounded with expected load growth in the future. In addition, the age and condition of the 66 kV transmission system and substation assets is also seen to be a driver for asset replacement, the existing equipment expected to reach the end of its useful economic life throughout the strategy period. Furthermore, previous studies undertaken by Western Power have demonstrated that upgrading the distribution system voltage in this area to 11 kV operation would provide economic benefits over the existing 6.6 kV operation.

With the expected level of asset replacement required over the strategy period for equipment condition, thermal capacity limitations, as well as distribution system voltage migration plans, there is a significant opportunity to co-ordinate the assessment of existing system design limitations and potential future capital works across the load area. The requirement for wholesale asset replacement across the considered strategy period also provides an opportunity to investigate potential alternative approaches for the transmission system design in this area, rather than just considering like-for-like asset replacements or assets with marginally increased thermal capacity.

A number of capital investment development strategies for the Western Terminal load area have therefore been considered as part of this study. These strategies have been developed to assess the suitability of maximising the lifetime of the existing 66 kV design, strategic migration of specific substations in the area to 132 kV operation to further extend the lifetime of the existing 66 kV system and complete migration of all 66 kV assets to 132 kV operation.

It should be noted that in the latter strategies (partial and full migration to 132 kV) migration of 66 kV electrical assets to 132 kV has been considered to be required when an age/condition or demand growth driver is reached. It is accepted that there may be alternative staging and timing of 132 kV upgrades that could be considered to defer other 132 kV asset investments[5], possibly for a number of years, which would result in a more attractive financial investment. It is further accepted that there will inevitably exist alternative designs that could be adopted in each strategy which may lead to the rationalisation/co-ordination of network assets and lead to a lower total capital cost. However, these considerations only serve to provide another degree of uncertainty surrounding the timing and scale of capital investment required under each strategy and is not expected to unduly influence the outcome of this assessment.

It should be noted that the capacity limitations identified at Cottesloe 132 kV substation throughout the strategy period are common amongst all the development strategies considered. Therefore, whilst capital costs are provided in the financial assessment for increasing the capacity at Cottesloe substation to allow a view on the total cost of the development strategy across the load area to be obtained, the additional capacity provided by such investments has not been explicitly incorporated into the calculation of load area capacity.

8.2. Evaluation criteria

The strategies developed and considered in this study were evaluated on the basis of a number of key metrics, including capital cost and Net Present Value (with trigger points for projects derived from the 2011 load forecast) as well as on the basis of cost-benefit. This latter metric is an important factor as it allows identification of the design strategy which delivers the greatest benefit (remaining substation capacity) for the associated capital investment. Further capital investment in the Western Terminal load area is required beyond 2035 to cater for long term demand growth. More specifically, the benefit to be assessed will be the remaining substation capacity that each design strategy provides and the longevity of this capacity throughout this strategy period and beyond.

[5] One example could be investment in 132 kV specification lines, initially operated at 66 kV, taking place before accompany substation switchgear and transformers were upgraded to 132 kV.

Deliverability of projects has been addressed at a high level and all strategies are deemed deliverable within the timescales proposed. Opinions from Western Power environmental, distribution, operations, substation design and asset management teams have been sought to provide assistance in the derived timescales. The cost of deliverability, through load transfers and other required interim works have been included in each respective strategy. General distribution system upgrade costs have not however been incorporated as these are expected to be common with all strategies. In addition, the constructability of developments has been assessed with assistance from Western Power, specifically in relation to substation design, with concept drawings provided within Appendix F.

Operations and maintenance costs have not been explicitly included in the evaluation criteria, however commentary is provided on a comparative basis including the number of assets required to be maintained in each strategy and the potential advantages of standardising equipment throughout the system.

Electrical losses through transformers and lines are assessed at a high level to give an economic comparison between the transmission efficiency of the strategies.

All strategies are designed to be compliant with the Technical Rules. New installed substation capacity is being designed for an N-1 security standard. As stated previously this is to allow a comparison of all options on an equal basis. Further work is required on a case by case basis to determine the most efficient option at each site.

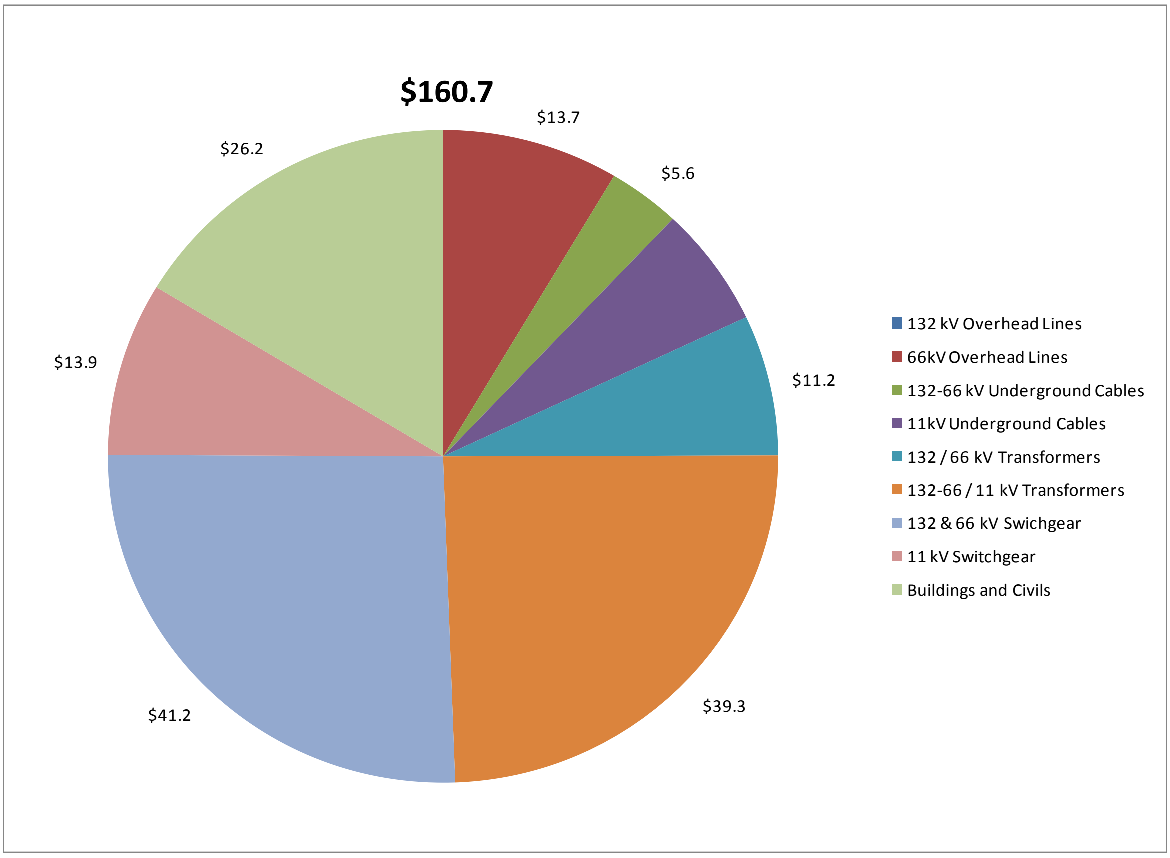
In addition to the base financial and technical assessment of each development strategy a sensitivity analysis has also been performed on a number of key aspects, including: variations in area demand growth; alternative transformer ratings; variations in building block costs; and the impact of alternative overhead line conductors.

8.3. Strategy 1 – Retain 66 kV

The first development strategy to be considered is designed to utilise the existing 66 kV network and improve the capacity and condition of the assets with in-situ replacements where possible. This provides a view on the operational ceiling that the existing 66 kV design has, and provide a benchmark on which to assess alternative designs involving the introduction of 132 kV operation into the Western Terminal load area.

The drivers for the strategy are due to insufficient capacity and asset condition throughout the load area substations and 66 kV transmission system over the 25 year period. In order to increase capacity in the substations it is proposed that all transformers will be replaced in-situ with the larger 35 MVA 66/11 kV transformers to provide the greatest benefit over the long term and allow N-1 operation. All 66 kV lines are proposed to be uprated in-situ to the largest permissible capacity Venus conductor (132 kV specification), assuming that the existing poles can support the larger conductor, once the asset condition has sufficiently deteriorated. A second 66 kV circuit will be required to be constructed between Western Terminal and Shenton Park due to further capacity restrictions in the long term and is proposed to be of cable construction due to the limitation of over-ground land available with the existing WT-NT, WT-SP and WT-MC circuits utilising this route (see Appendix E.3.1). The WT-C-N 66 kV circuit is proposed to be removed once the asset condition has sufficiently deteriorated and the North Fremantle link has been separated to reduce non-essential uprating costs. The strategy is proposed, for the year of 2035, to be of the design illustrated in Appendix C – Figure 39. The staging and description of developments is provided in Appendix D.1.

■ Figure 12 Capital cost breakdown for Strategy 1

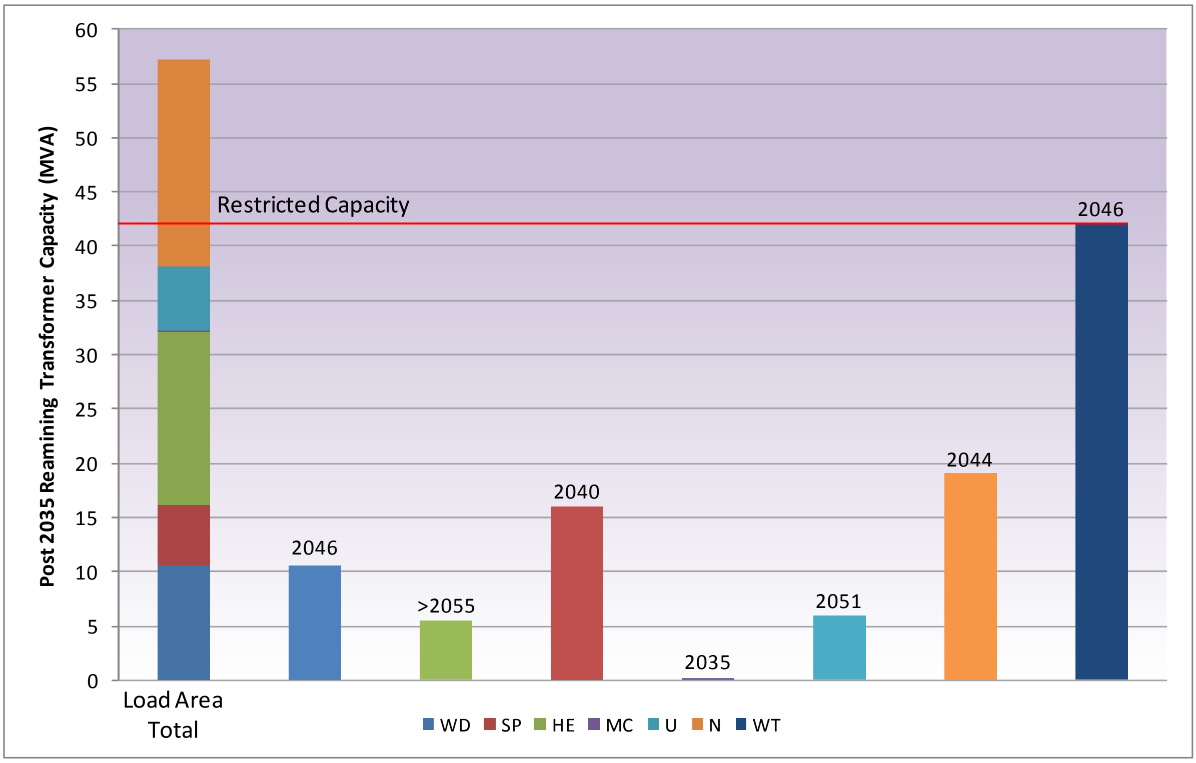


The capital cost of this strategy design is calculated as $160.7M as shown in Figure 12, with an NPV cost based on the staging described in Appendix D.1 of $117.7M. Further detail on these costs is provided in Appendix D.1.

By retaining the 66 kV network in the design proposed allows compliance to the year 2035. Line capacity is seen to be appropriate for N-1 compliance post 2035 until approximately 2040, when a second circuit out of Western Terminal to Medical Centre or Nedlands will be required based on an extrapolated load forecast.

Figure 13 illustrates the remaining transformer capacity forecast to be available at each substation in 2035. The year at which substation capacity is expected to be insufficient is denoted, based on an extrapolation of the 2011 load forecast. It can be seen that Medical Centre substation is expected to have no capacity available post 2035 and will require some investment through an additional transformer, load transfers or a new substation site to permit future load growth at this location.

■ Figure 13 Development Strategy 1 – remaining transformer capacity



The total load area capacity available in 2035 with this strategy is expected to be 57 MVA, however the available capacity remaining at Western Terminal will restrict the amount of capacity that can be unlocked within the load area until another 132/66 kV transformer is installed at the Terminal substation. The amount of load area transformer capacity that can therefore be realised is some 42 MVA. It is also worth noting that any additional transformer capacity installed at Medical Centre will increase the load area available transformer capacity, but this cannot be fully realised until additional transformer capacity is installed at Western Terminal.

66 kV overhead lines are not considered a restriction under this strategy (assuming that rebuild to Venus conductor 132 kV specification can be achieved) with all lines having sufficient capacity until circa 2040.

This strategy therefore provides 42 MVA of remaining transformer capacity given the capital investment cost of $160.7M. This equates to a remaining transformer capacity/capital cost ratio of $3.83M/MVA. If an additional (fifth) 132/66 kV 100 MVA transformer was installed at Western Terminal by 2035 this would allow the remaining residual area capacity to be increased to 57 MVA at a cost of an additional circa $7M. This would reduce the remaining transformer capacity/capital cost ratio to $2.94M/MVA.

8.4. Strategy 2 – Shenton Park and Herdsman upgraded to 132 kV

Development Strategy 1 has illustrated that although the existing 66 kV network design could continue to be utilised for the next 25 years, an extensive overhaul of transformers and lines will be required with limited available capacity beyond this timeframe. This would result in migration of load to 132 kV operation or the establishment of new substations and 66 kV rings at this time to allow additional capacity into the load area. Development Strategy 2 looks at reducing the load on the 66 kV network in the short term to prevent significant additional investment post 2035 through the migration of existing Shenton Park load to a new Shenton Park 132 kV substation and transferring load from Herdsman substation.

Shenton Park substation has been selected for migration for a number of reasons, namely:

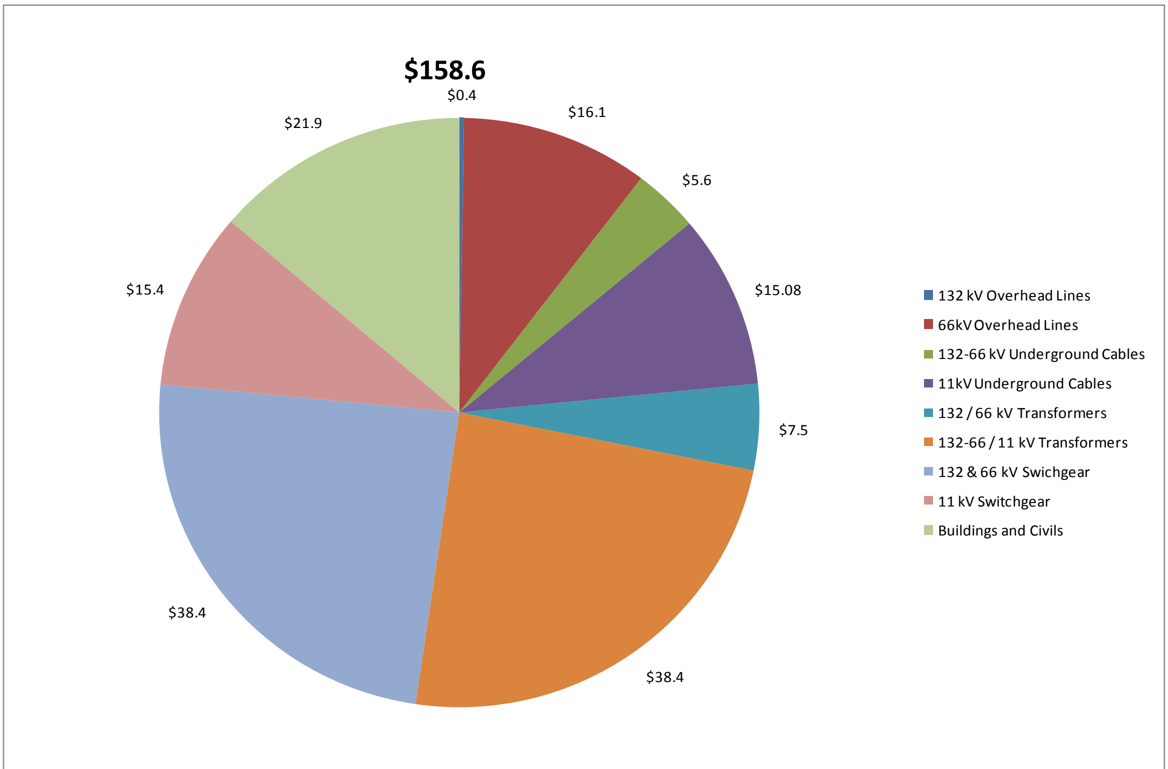
- Existing assets at this substation have far surpassed their condition limitation
- The substation is seen to have insufficient capacity to be NCR compliant in 2011

- The load at this substation is expected to grow at the greatest rate in the load area
- The North 66 kV transmission ring experiences N-1 overloading in the short term primarily due to the magnitude of the Shenton Park load
- The WT-NT 132 kV line passes by the substation which can be used to facilitate the upgrade to 132 kV at Shenton Park
- Existing distribution switchboard is rated for 11 kV operation

It is proposed that the Shenton Park 132 kV substation would be constructed on Western Power owned land adjacent to the existing substation with 2 x 75 MVA transformers and the potential to add a third at a later date when required. This capacity would allow the Herdsman Parade substation to be abandoned with the load transferred into the new Shenton Park substation to reduce the level of asset replacement required as the condition of the Herdsman transformers is seen as a limitation in 2011 also.

The remaining developments for this strategy will be as per Development Strategy 1 with the design in the year 2035 to be seen as that given in Appendix C – Figure 40. The staging and description of developments is provided in Appendix D.2.

Figure 14 Capital cost breakdown for Strategy 2



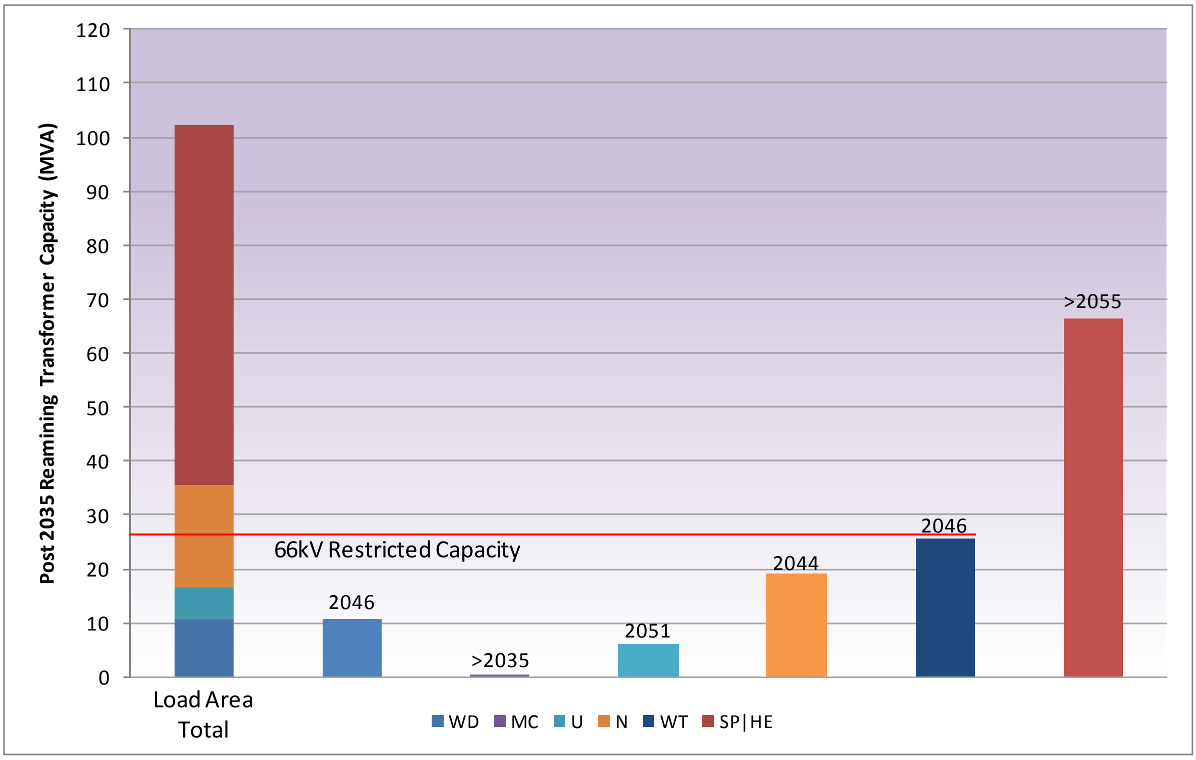
The capital cost of this strategy design is calculated as $158.6M with an NPV cost based on the staging described in Appendix D.2. of $114.8M. Further detail on these costs is provided in Appendix D.2.

This development strategy is seen to remove the requirement for an additional circuit to be installed within the North 66 kV ring and the driver for replacement will be purely age/condition related. The South 66 kV ring's performance is the same as that seen in Development Strategy 1.

Figure 15 illustrates the remaining transformer capacity forecast to be available at each substation in 2035. As the southern 66 kV ring has been unaffected in this development strategy it can be seen that Medical Centre substation is expected to have no capacity available post 2035 and will require some investment through an additional transformer, load transfers or a new substation site to permit future load growth at this location. The requirement for a fourth transformer at Western

Terminal has been pushed back from 2020 in Strategy 1 to approximately 2046 due to the deloading of Herdsman Parade and Shenton Park from the 66 kV network.

Figure 15 Development Strategy 2 – remaining transformer capacity



The total load area transformer capacity available has risen to 102 MVA with over 66 MVA located at the new Shenton Park 132 kV substation. Of the 66 kV transformer capacity, some 10 MVA of the 35 MVA available is restricted by the Western Terminal transformers resulting in a total unrestricted load area transformer capacity of 92 MVA.

The 66 kV and 132 kV overhead lines refurbished/upgraded under this strategy are generally not expected to result in any restrictions in available substation capacity. The exception is the Western Terminal to Medical Centre or Nedlands circuits which will require to be augmented with an additional circuit around 2046 based on an extrapolated load forecast.

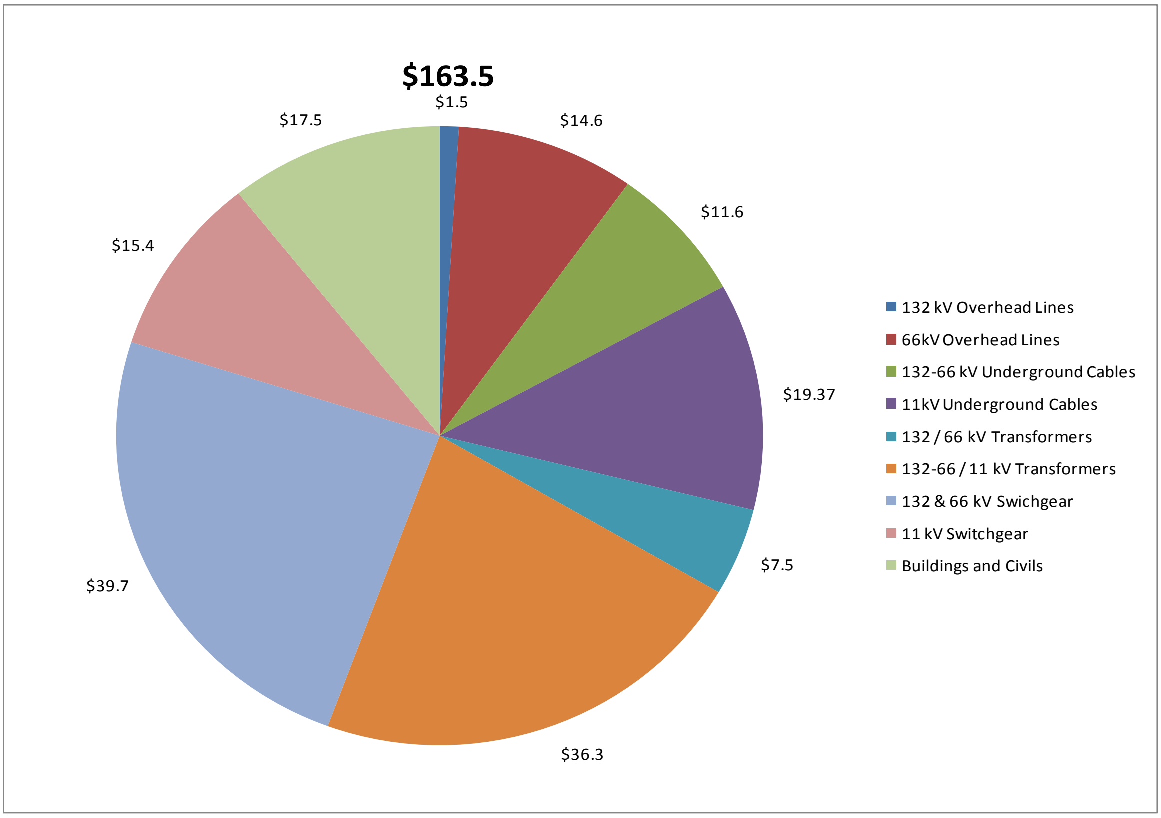
This strategy can therefore be seen to provide 92 MVA of remaining transformer capacity given the capital investment cost of $158.6M. This equates to a remaining capacity/capital cost ratio of $1.724M/MVA.

8.5. Strategy 3 – Shenton Park, Herdmans Parade, Medical Centre and University upgraded to 132 kV

Development Strategy 2 has been seen to provide significant benefits by providing additional available capacity post 2035 and delaying required investments at Western Terminal and the North 66 kV ring significantly. Capacity issues are however still seen in the southern 66 kV ring, particularly at Medical Centre where investment will be required in 2035 to allow further growth in this area. This could be through distribution system transfers to Shenton Park to extend the Medical Centre site life. However, this should not be seen as a long term solution and additional capacity will eventually be required at the Medical Centre substation should the load continue to grow. Development Strategy 3 is designed to provide further capacity in this region and delay future investments by further deloading the Western Terminal transformers and the southern 66 kV ring. This is proposed to be achieved by upgrading the Medical Centre substation to 132 kV operation[6] and abandoning the University substation following the transfer of this load to the new Medical Centre 132 kV substation. These works are an extension of those described within Development Strategy 2.

The customer requirement for an 11 kV distribution supply voltage in 2014 means that a transformer change will be required at this site by this time. The land provided by the Medical Centre is expected to be suitable for two transformers only and it has been seen that 2 x 35 MVA 66 kV transformers at this site will be suitable only until 2035. This development strategy provides greater capacity in this location by installing higher capacity 132 kV 75 MVA transformers, relieving the requirement for further investment in 2035. The system under this development strategy is proposed as per Appendix C – Figure 41 for the year 2035. The staging and description of developments is provided in Appendix D.3.

■ Figure 16 Capital cost breakdown for Strategy 3



The capital cost of this strategy design is calculated as $163.5M with an NPV cost based on the staging described in Appendix D.3 of $112.1M. Further detail on these costs is provided in Appendix D.3.

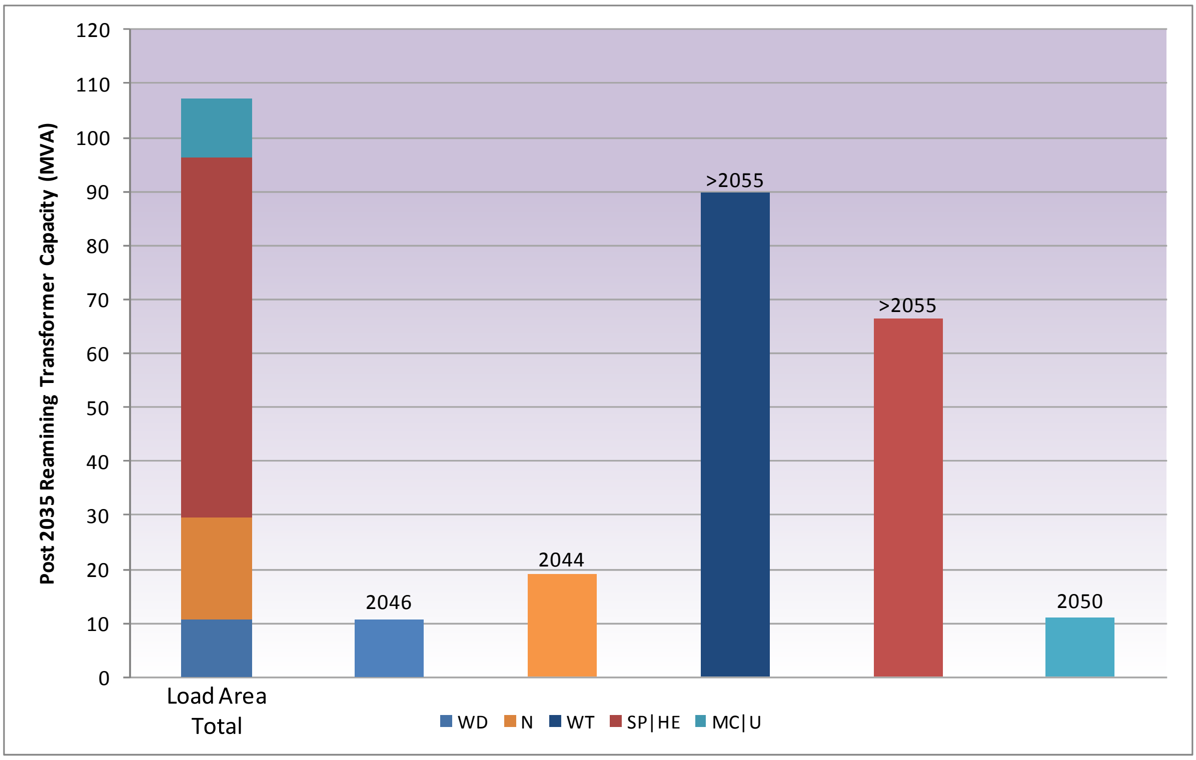
As per Development Strategy 2, this strategy is seen to remove the requirement for an additional circuit to be installed within the North 66 kV ring. The South 66 kV ring has been deloaded further with only Nedlands being supplied and it is therefore proposed that the N-C-WT line be uprated when required for condition drivers to minimise costs. The 66 kV lines from Nedlands to University, University to Medical Centre and Medical Centre to Western Terminal can then be decommissioned.

Figure 17 illustrates the remaining transformer capacity forecast to be available at each substation in 2035. As the northern 66 kV ring has been unaffected in this strategy from that given in Development Strategy 2 it can be seen that Shenton Park substation has sufficient available capacity. The requirement for a fourth transformer at WT has been pushed back for

[6] A sub-option also exists with Strategy 3 and 4 to allow Medical Centre to remain supplied at 66 kV once University load transfers are complete, instead of moving immediately to 132 kV. This would defer the installation of the Shenton Park to Medical Centre 132 kV overhead line and cable double circuits plus additional 132 kV switchgear at Western Terminal.

capacity limitation indefinitely due to the deloading of Herdsman Parade, Shenton Park, University and Medical Centre from the 66 kV network.

■ Figure 17 Development Strategy 3 – remaining transformer capacity



The total load area capacity available has risen to 107 MVA with a combined 77 MVA located at the new Shenton Park and Medical Centre 132 kV substations. Of the 66 kV capacity, none of the 30 MVA available is restricted by the Western Terminal transformers resulting in an unrestricted load area total capacity of 107 MVA.

The 66 kV and 132 kV overhead lines refurbished/upgraded under this strategy are not expected to result in any restrictions in available substation capacity with all lines having sufficient capacity until post 2050.

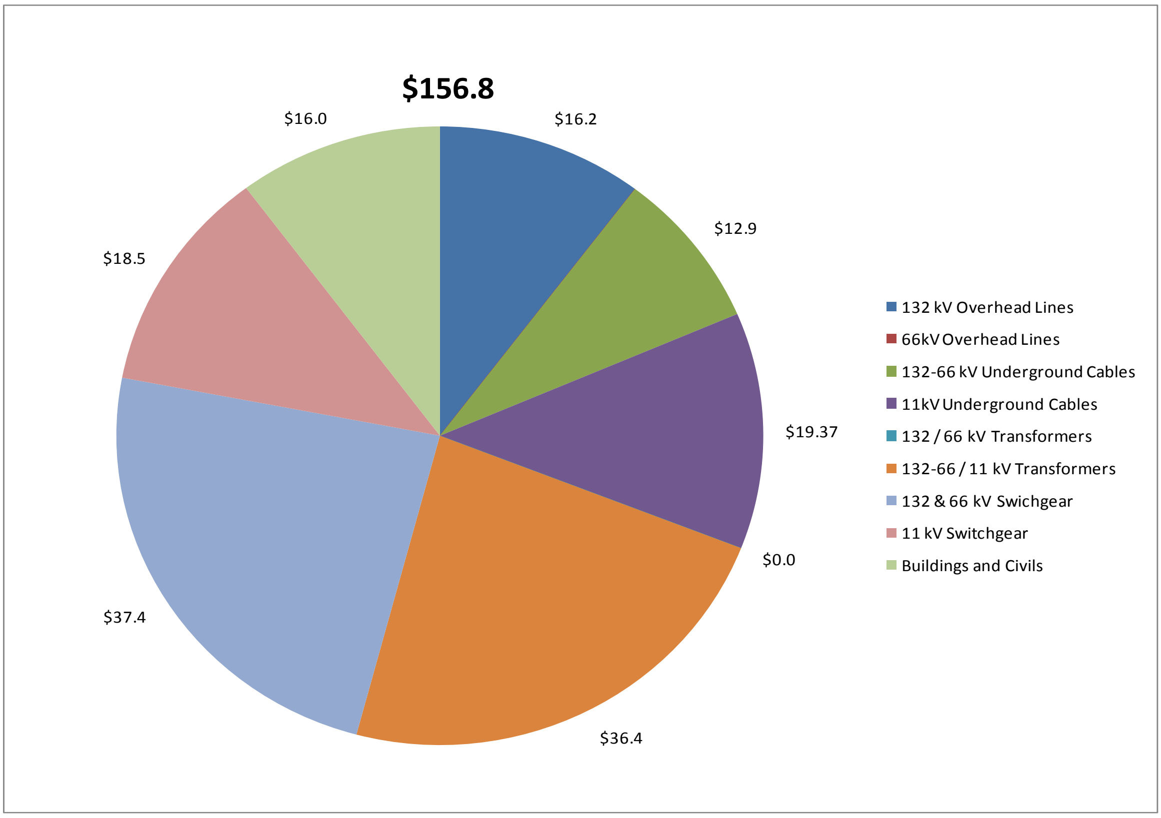
This strategy can therefore be seen to provide 107 MVA of remaining capacity given the capital investment cost of $163.5M. This equates to a remaining capacity/capital cost ratio of $1.53M/MVA. It can be seen that the requirement for future investment beyond 2035 has been further extended from that seen in Development Strategies 1 and 2.

8.6. Strategy 4 – Full 132 kV migration

The final development strategy to be proposed involves all substations and transmission lines in the load area to be upgraded to 132 kV operation as a final extension to Development Strategy 3. Following Development Strategy 3, only Wembley Downs and Nedlands are operated at 66 kV from the North and South rings respectively. This results in the continued requirement for 132/66 kV transformers at Western Terminal to supply these two sites. By upgrading Wembley Downs and Nedlands to 132 kV operation, the requirement for transformers at Western Terminal can be removed entirely with all sites in the load area operating at 132 kV and is the basis for Development Strategy 4. It is noted that in order to upgrade Nedlands to 132 kV operation, a GIS solution will be required and has been costed as such.

The system under this development strategy is proposed as per Appendix C – Figure 42 for the year 2035. The staging and description of developments is provided in Appendix D.4.

■ Figure 18 Capital cost breakdown for Strategy 4



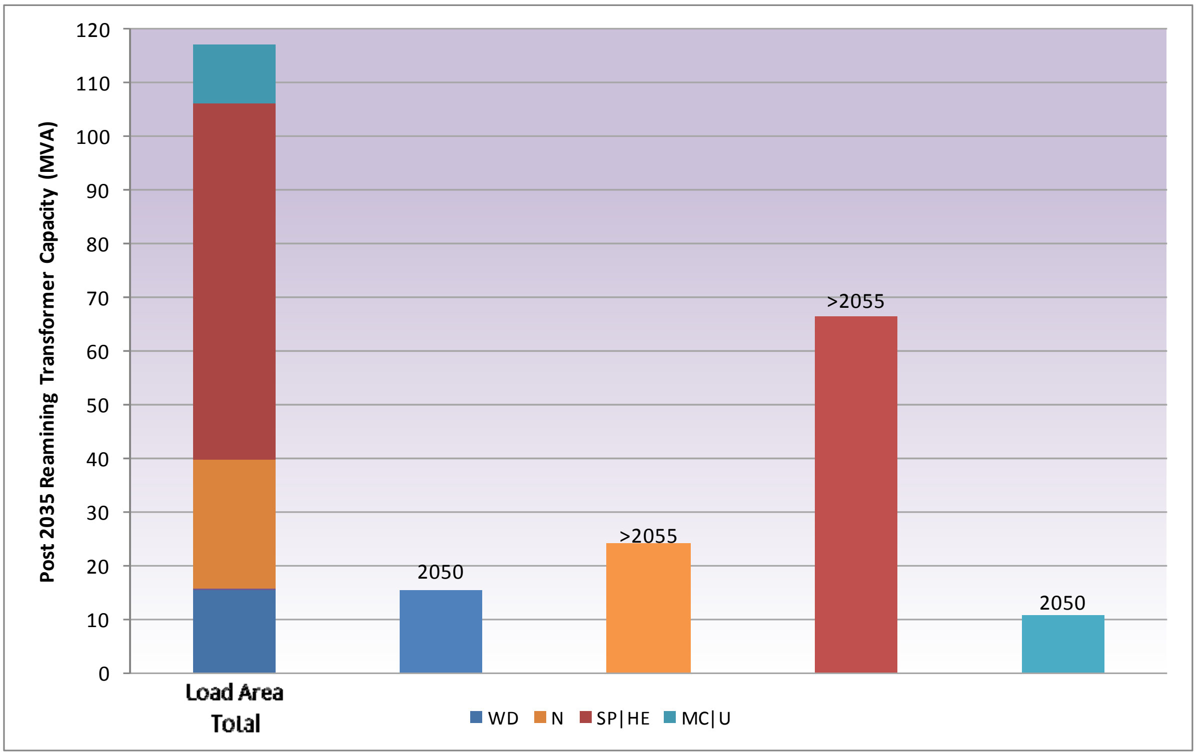
The capital cost of this strategy design is calculated as $156.8M with an NPV cost based on the staging described in Appendix D.4 of $119.4M. Further detail on these costs is provided in Appendix D.4.

This development strategy results in a much more radial transmission network than the existing ring design providing greater capacity availability under N-1 conditions. There are seen to be no requirements for additional circuits or uprating of 132 kV lines for the foreseeable future following the design illustrated in Appendix C – Figure 42.

Figure 19 illustrates the remaining transformer capacity forecast to be available at each substation in 2035. As all substations are supplied at 132 kV from Western Terminal and not restricted by the 132/66 kV transformers there are now no restrictions on achieving the maximum remaining capacity at individual substations. Consequently, the remaining total substation capacity within the load area in 2035 is 117MVA, the greatest of all the development strategies. It can also be seen that the requirement for additional capacity at the substations has been pushed back to beyond 2050 with the added advantage of fewer substations and assets to manage.

As with Strategy 3, the 132 kV overhead lines installed under this strategy are not expected to result in any restrictions in available substation capacity with all lines having sufficient capacity until post 2050.

■ Figure 19 Development Strategy 4 – remaining transformer capacity



In terms of cost-benefit, this development strategy will result in 117 MVA of substation capacity remaining available at 2035, which given the capital investment cost of $156.8M result in a remaining capacity/capital cost ratio of $1.34M/MVA, the lowest of the strategies considered.

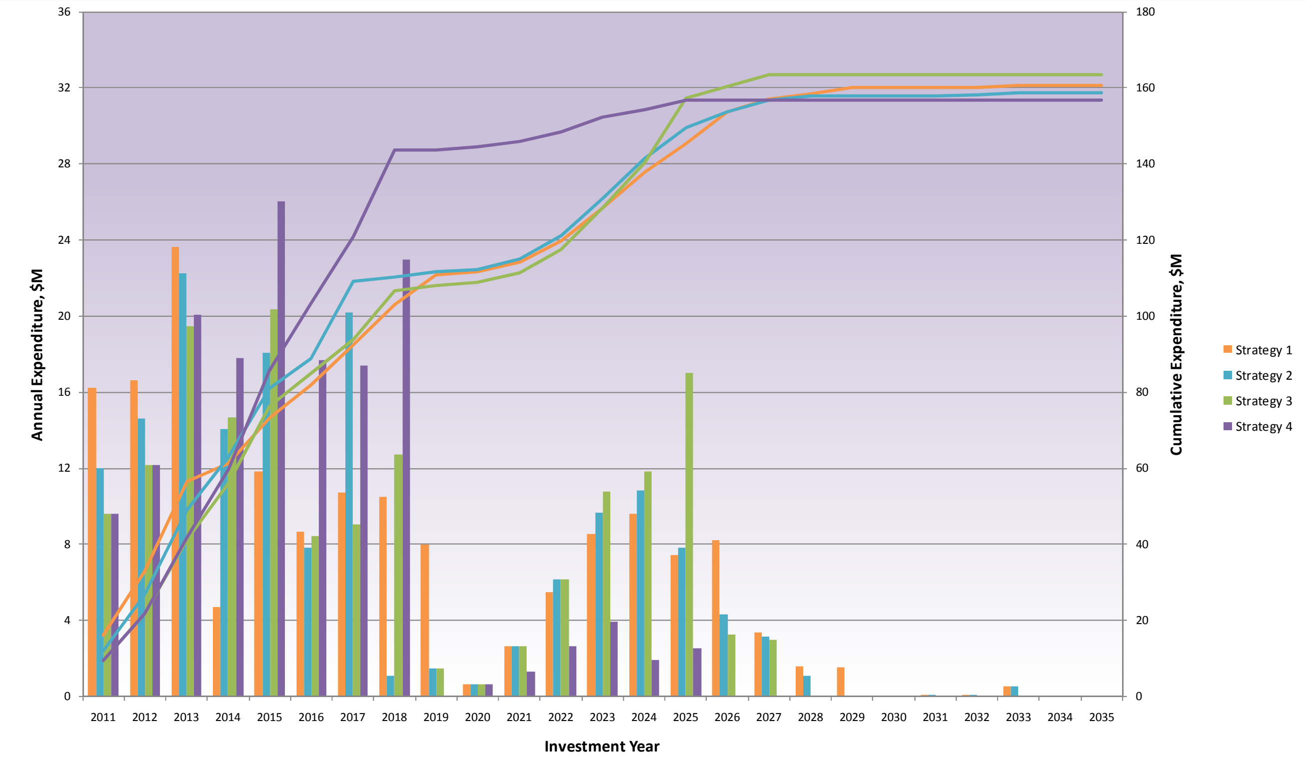
8.7. Comparison of development strategies

8.7.1. Financial and cost benefit appraisal

The previous sub-sections have presented the details of the individual development strategies considered for the Western Terminal load area, as well as key financial and technical parameters associated with each. This section now brings the strategies together to contrast and compare the costs and benefits of each in order to identify the optimal strategy for the Western Terminal load area over the next 25 years.

The cumulative capital cost requirement for each development strategy and the individual yearly expenditure (based on the investment staging for each strategy presented in Appendix D) is shown in Figure 20, with key financial metrics summarised in Table 5.

■ Figure 20 Annual and cumulative capital investment expenditure for strategies



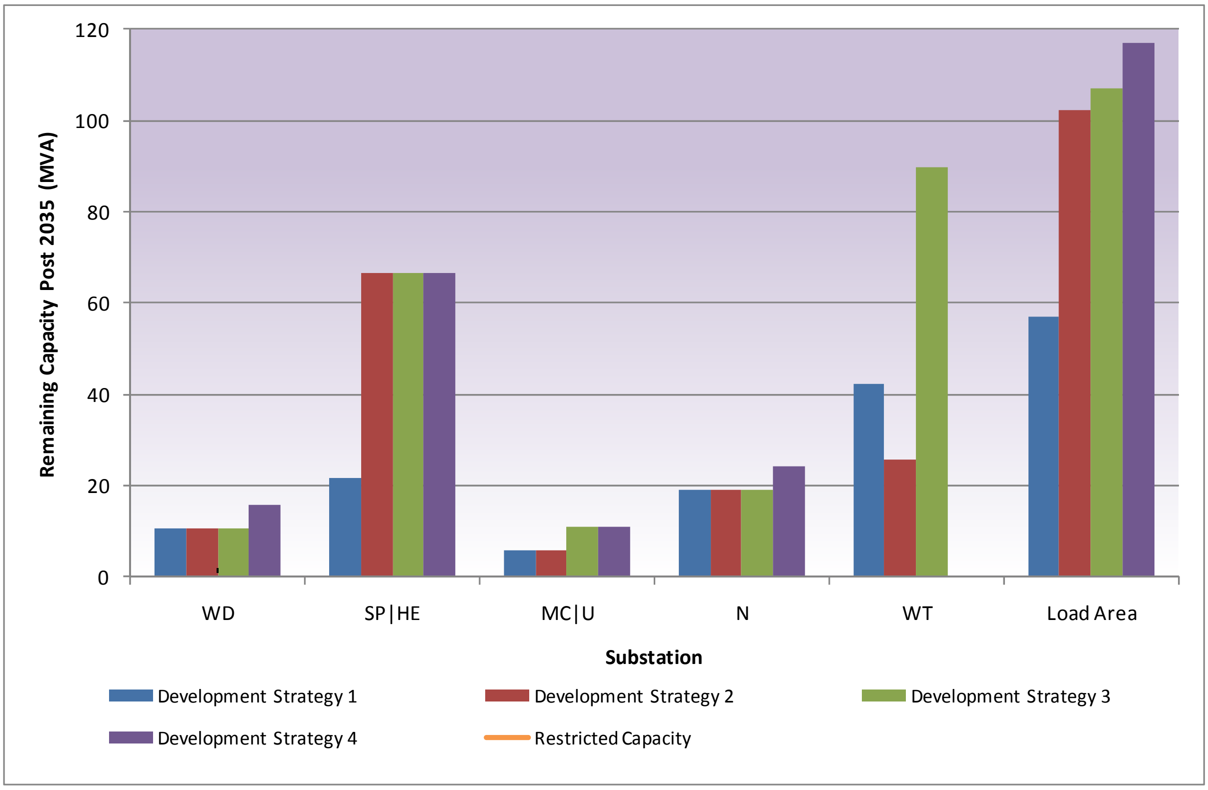
■ Table 5 Financial characteristics of strategies

Name	Description	Capital Cost, $M	NPV, $M	Remaining TX MVA at 2035	$M (Capital Cost) / 2035 MVA
Strategy 1	Retain 66 kV	160.7	117.7	42	3.68
Strategy 2	SP and H at 132 kV	158.6	114.8	92	1.72
Strategy 3	SP and H plus MC and U at 132 kV	163.5	112.1	107	1.53
Strategy 4	All 132 kV	156.8	119.4	117	1.34

It is evident from review of Figure 20 and Table 5 that the strategy with the lowest capital cost by a narrow margin is Development Strategy 4 – all 132 kV, with Development Strategy 3 indicating the lowest Net Present Value. Critically though, the difference in capital cost between the lowest cost option (Strategy 4) and the highest cost option (Strategy 3) is $6.7M with all of the strategies having very similar investment profiles, other than Strategy 4. Given that the building block costs used in this assessment (obtained from Western Power) are considered as average costs for delivering the outlined equipment and works required for each strategy and not fully detailed cost estimates they are therefore subject to a degree of tolerance (see Section 8.9), it cannot be stated categorically that Strategy 4 will deliver the lowest cost design for the Western Terminal area over the coming decades. The reality is that any one of the strategies could yield the lowest overall capital cost depending on the extent of the final site works required for each substation and outturn equipment costs. Similarly, any one of the strategies could potentially yield the lowest NPV over the strategy period, although this is less likely with Strategy 4 given the earlier phasing of key elements of the work (ie, Wembley Downs asset replacement). Therefore, in order to support the selection of a recommended strategy consideration needs to be given to another metric by which to assess the desirability of each strategy.

As mentioned previously the requirement for capital investment and demand growth across the Western Terminal load area will not simply stop once the year 2035 occurs, therefore it is important to give consideration to the residual substation capacity left across the Western Terminal area as well as the capital cost of each strategy. This assessment has therefore considered the cost-benefit provided by each strategy in the form of a ratio of the remaining Western Terminal substation capacity that can be obtained post-2035 without further investment to the total cumulative capital cost of each strategy. Figure 21 outlines the remaining capacity at each substation at 2035 under each strategy.

▪ Figure 21 Development strategy comparison - 2035 remaining transformer capacity



From review of Figure 21 and Table 5 it is immediately apparent that Development Strategy 1 (retain 66 kV) provides significantly lower remaining substation capacity expected at 2035 than any other the other options. Consequently, when this is considered along with the capital cost of this option the ratio of remaining unrestricted capacity available across Western Terminal to capital cost is more than twice that of the best option, full migration to 132 kV. Put simply, the cost for creating each MVA of residual substation capacity across the Western Terminal load area at 2035 is more than twice as high as the strategy with full migration to 132 kV. In terms of economic efficiency, it is clear then that the 'retain 66 kV' strategy, despite having notionally the lower capital cost of the strategies considered (which is subject to a degree of uncertainty), would appear to be the least efficient investment option for the Western Terminal area over the long term.

8.7.2. 2050 strategy view

Although not explicitly required as part of the scope of this study, in order to provide a comparable basis to assess the longer term, post-2035, suitability of each strategy the analysis performed to identify network investment drivers up to 2035 has been extended out to 2050. This has identified the following additional network reinforcements required for Strategy 1 and 2. Note that there are no further works required for Strategy 3 and 4.

Strategy 1:

- The 2050 Western Terminal area demand is expected to be around 60 MVA higher than the 2035 figure. If all of the remaining firm (N-1) substation capacity could be used up post-2035 (with idealised transfers) then there would be around 57 MVA of available capacity. Recognising that not all substations can transfer/pick-up demand from the other substations then a new 2 x 35 MVA substation would be required.

  Given that Medical Centre has little remaining capacity post 2035 it has been assumed that the new substation would be needed in 2036 and would be situated at the Western Terminal site, given the lack of other options. Distribution cabling works of a similar order to the Herdsman to Shenton Park transfer would be required also. This adds approximately $16.2M for the new substation and $9.4M for the 11 kV cabling works to the cost of Strategy 1.

- In around 2040 the Western Terminal – Medical Centre 66 kV circuit and Western Terminal – Nedlands 66 kV circuit would be overloaded for an outage of the other, requiring the Western Terminal to Cottesloe to Nedlands 66 kV overhead line to be retained and rebuilt[7]. This is expected to cost around $6M, including the necessary switchgear replacements.
- A fifth 132/66 kV 100 MVA transformer would also be required at Western Terminal in 2046 to provide continued N-1 compliance. Including 132 kV and 66 kV switchgear this is estimated to cost around $7.4M.

Strategy 2:

- The 2050 Western Terminal area demand is expected to be around 60 MVA higher than the 2035 figure. With Strategy 2 there is over 100 MVA of spare substation transformer capacity which is theoretically sufficient to support the additional area demand, if idealised transfers are considered. In reality some demand will be able to be transferred from some substations and some not, however it is assumed that the cost for distribution transfers is again similar to the Herdsman to Shenton Park transfer cost at $9.4M.
- In around 2040 the Western Terminal – Medical Centre 66 kV circuit and Western Terminal – Nedlands 66 kV circuit would be overloaded for an outage of the other (as outlined in Section 8.7), again requiring the Western Terminal to Cottesloe to Nedlands 66 kV overhead line to be retained and rebuilt at an expected cost of $6M (~$2M for the line rebuild plus $4M for switchgear at Western Terminal and Nedlands).
- An additional (fourth) 100 MVA 132/66 kV transformer is also required at Western Terminal in 2046. Including 132 kV and 66 kV switchgear this is again estimated to cost around $7.4M.

The impact of these additional capital investment projects on the capital cost and Net Present Value of each strategy as shown in Table 6.

- Table 6 2050 financial characteristics

2050	Strategy 1	Strategy 2	Strategy 3	Strategy 4
Capital Cost, $M	199.8	183.1	163.5	**156.8**
NPV, $M	119.5	116.8	**112.1**	119.4

It is evident from comparison of Table 5 and Table 6 that although Strategy 3 has the highest capital cost at 2035, when the expected network reinforcements up to 2050 are included, the total cost of Strategy 1 and 2 is expected to be significantly higher. Additionally, the NPV of Strategy 1 and 2 when accounting for the expected 2050 reinforcements is now materially higher than that of Strategy 3, with the NPV of Strategy 1 higher even than Strategy 4.

It should also be pointed out that the recalculated 2050 NPV values for Strategy 1 and 2 are based on the additional works outlined above. These are preliminary estimates and it is possible that additional costs will be required for Strategy 1 and 2, most likely in relation to additional substation refurbishments, and this may increase the cost of these strategies further. This would increase both the capital cost and NPV of these strategies.

This additional analysis demonstrates that whilst Strategy 1 and 2 may potentially yield financial savings when viewed at a 2035 horizon year (in comparison with Strategy 3 capital cost and Strategy 4 NPV), the additional capital investment

[7] Further uprating of the WT – N and WT – MC 66 kV overhead lines to 100 deg C operation may be possible however it is not clear if statutory line clearances can be achieved. As a result it is likely to be necessary to reinforce either one of the line sections with a new circuit. This will not be possible using an overhead line following the existing routes and unless an underground cable is installed (cost in excess of $10M for the cable) the only viable option is to retain the WT – C – N 66 kV overhead lines.

required post-2035 is likely to negate any such savings. As a result, Strategy 3 and 4, which have notionally higher capital cost and NPV in comparison with Strategy 1 and 2, are actually more attractive from a financial perspective when viewed over a longer planning horizon.

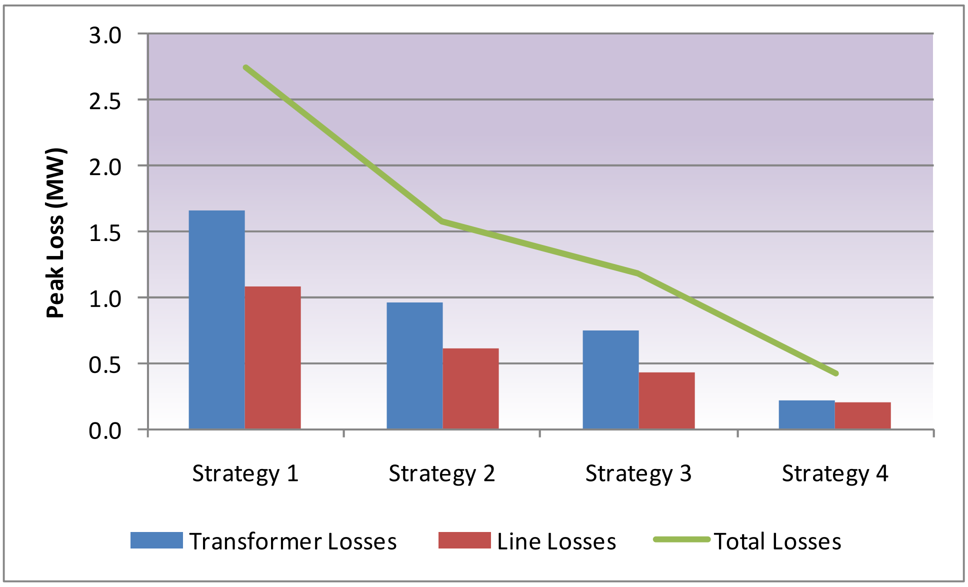
Other relevant factors

Losses

The opportunity to migrate to a higher transmission system voltage across the Western Terminal area, whether in whole or part, brings with it the potential to reduce electrical (MWh) losses. Figure 22 illustrates the comparison of losses throughout the Western Terminal load area for each development strategy in the year 2035. Losses include real power losses in both transformers and transmission lines within the load area.

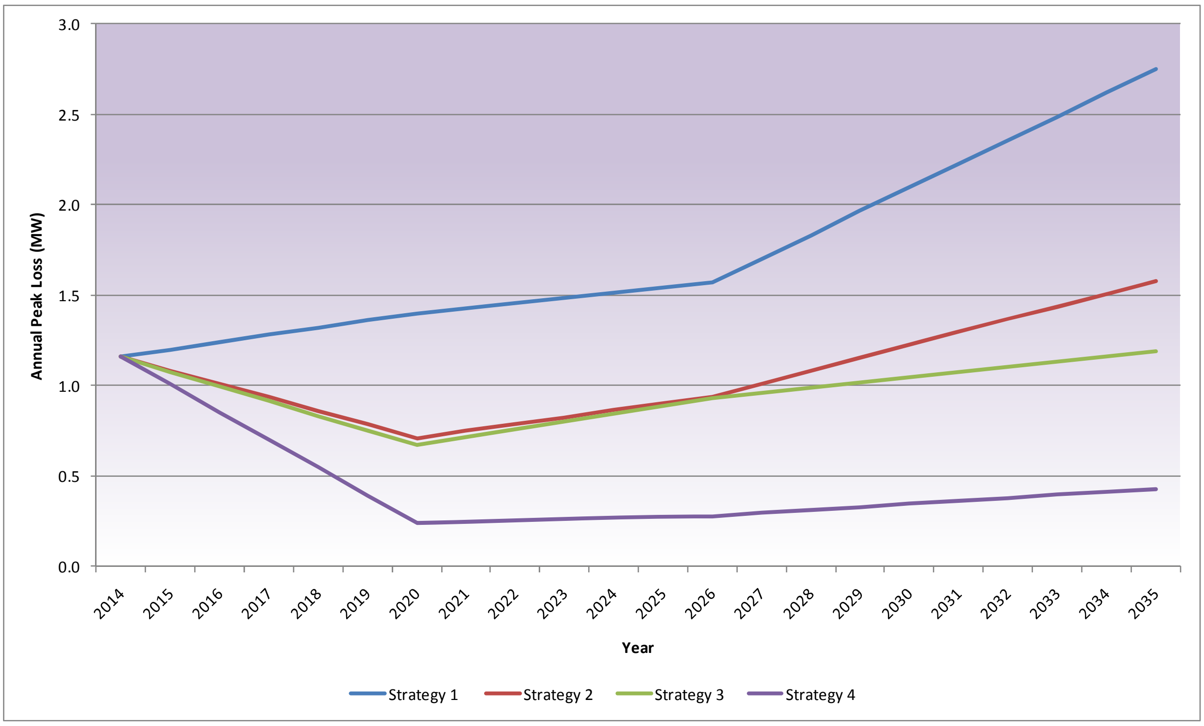
It can be seen that by increasing the transmission voltage in the area to 132 kV there is a significant reduction in losses, by approximately 70%, when moving from Strategy 1 (retain 66 kV) to Strategy 4 (full 132 kV migration). The reduction in losses from Strategy 3 to Strategy 4 is still significant (40%) due to the complete removal of the 132/66 kV transformation stage at Western Terminal and full 132 kV operation in all transmission lines. The reduction in MW losses at peak demand in 2035 between Strategy 1 and 4 is seen to be approximately 2.3 MW.

- Figure 22 Breakdown of development strategy power losses for the year 2035



The impact of the strategies on losses over the study period is illustrated in Figure 23. Losses values for the years 2014, 2020, 2026 and 2035 have been calculated and a linear interpolation applied. It can be seen that by retaining the 66 kV network (Strategy 1) that the losses will continue to rise and demand grows. By introducing greater numbers of 132 kV assets in the load area the losses can be seen to reduce as deloading of the Western Terminal transformers and lower line losses occurs, as is seen in Strategies 2 to 4, with the greatest impact occurring as a result of the higher number of 132 kV assets installed under Strategy 4. Following proposed strategy developments, losses begin to increase with forecasted load increases in the area.

- Figure 23 Comparison of development strategy power losses 2014-2035



In order to provide a capitalisation of these losses the loss load factor and cost of losses is required. Based on an average load factor for the Western Terminal area of 42.6%[8] the loss load factor[9] can be derived as follows:

LLF = 0.1LF + 0.9LF2

Therefore, LLF = 0.206.

In addition, the cost of energy as provided by Western Power, is assumed to be $56/MWh and when combined with the loss load factor calculated above can be utilised to provide an indicative financial cost to losses.

An NPV analysis of the capitalised cost of losses over the study period has been provided in Table 7.

- Table 7 Indicative capitalisation of losses NPV analysis for 2014-2035

Strategy	Total losses (MW)	NPV capitalised losses, $M
1	38.0	1.60
2	23.3	1.03
3	21.0	0.96
4	9.8	0.53

The NPV analysis outlined above indicates that through the reduction of losses a financial saving over the considered 25 year strategy period of over $1 million could be achieved with the implementation of Strategy 4 over Strategy 1. Strategies 2 and 3 also provide reduced losses in comparison with Strategy 1, although diminished financial savings in comparison with Strategy 4.

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[8] Western Power Summer Loads and Trends Report 2012-2030 quotes annual load factors (average load/Peak load) for each of the Western Terminal substations as: SP (43%), MC (47%), N (39%), WD (37%) and U (47%).

[9] Loss load factor (LLF) equation obtained from “Electricity Distribution Network Design”, Lakervi, E, Holmes, E.J. IEE Power Engineering Series 21, 1995.

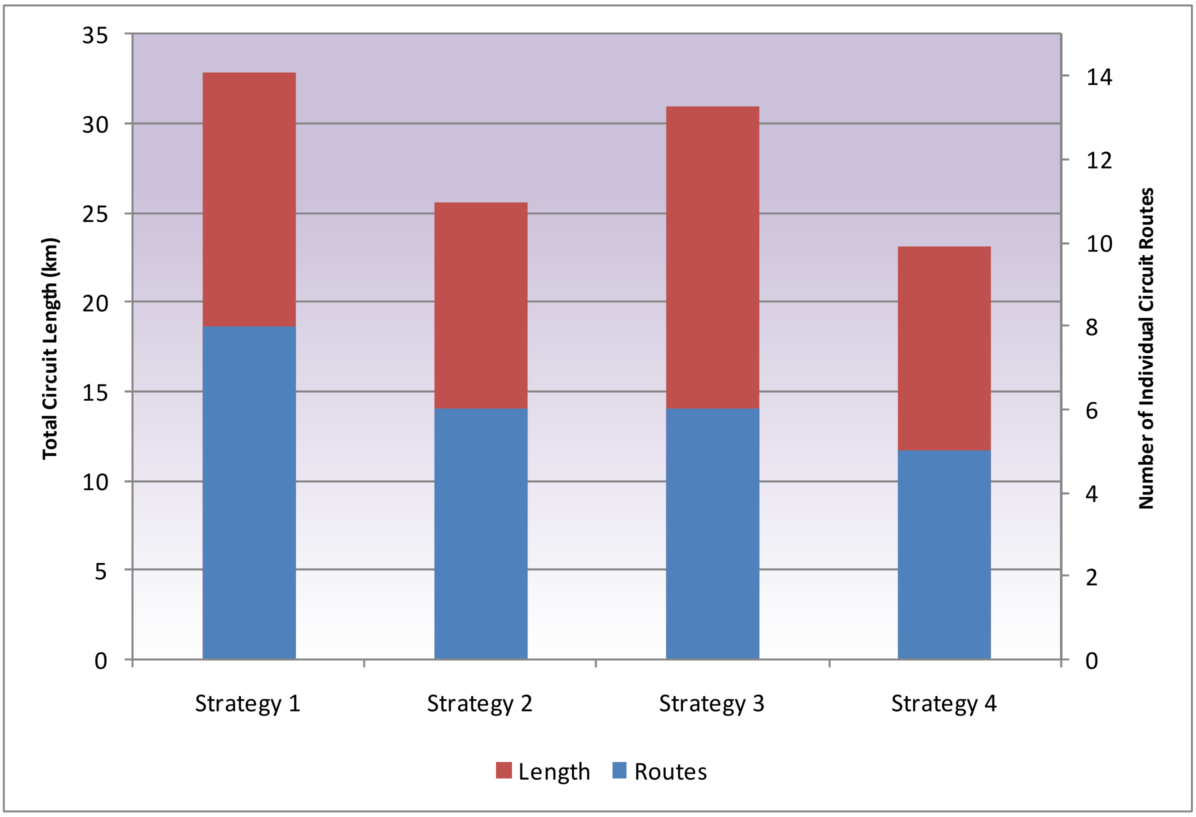
Total circuit length

It is recognised that reductions in overhead line circuit lengths through network investment brings with it intrinsic, if sometimes difficult to quantify, benefits associated with lower perceived environmental impacts, operation and maintenance costs and potentially higher circuit availability. Figure 24 illustrates the total circuit length for overhead lines in the Western Terminal area for each strategy as well as the number of individual circuit routes utilised.

It is evident from Figure 24 that Strategy 4 has the shortest total line length and lowest number of individual circuit routes. This will reduce the total line length required to be maintained, can potentially improve supplying substation reliability (ie, through less frequent overhead line flash-overs, transient line outages, etc.) and will reduce costs associated with environmental consenting and permitting. There will also be a community benefit associated with the lower visual impact of the reduced total area installed line length.

Over the five periods 2006/07 to 2010/11 Western Power's maintenance expenditure on the existing eight 66 kV overhead lines in the Western Terminal area was $591,626 with an average expenditure per km per year of $3,607. The reduction in overhead circuit length between Strategy 1 and 4 is 9.7 km and could lead to an indicative reduction in maintenance costs of circa $35,000 per annum. The impact of this has not been included in Table 5 and Table 6.

▪ Figure 24 Comparison of installed circuit length and individual routes



Ability to up-rate overhead lines

A further risk associated with Development Strategy 1, in particular, is that as stated earlier, all existing 66 kV overhead lines are assumed to be replaced or re-conductored with Venus AAC conductor to 132 kV specification. There is a possibility that statutory line clearances will not be achievable with Venus conductor at the desired operating temperature (85°C) across the entire 66 kV Western Terminal network, or that wholesale pole replacement may result in difficulties in construction as well as associated community acceptance issues due to taller poles and larger cross section conductors[10]. This may necessitate the need for additional cable circuits at significant additional cost. Strategy 2 is also similarly affected, although to a lesser degree, with Strategy 3 and 4 unlikely to be affected at all as all circuits have a summer rating far in excess of that required at 2035, even if lower rated line designs are adopted. Further analysis on this risk and sensitivity is given in Section 8.9.4.

Substation sites

Strategies 2, 3, and 4 involve the decommissioning of the existing 66 kV substations at University and Herdsman Parade. The substation site at University is leased to Western Power by the University of Western Australia who own the freehold. The substation site at Herdsman is owned freehold by Western Power and could be sold on completion of the works. The Corporate Real Estate branch of Western Power has estimated the value of the land, based on recent sales, in the range of $5.2M to $5.7M. The Herdsman site would require remediation prior to sale and this is estimated at $0.5M to $1.6M, depending on whether ground water remediation is required, it is likely to take one and a half to three years to complete the remediation process. The net impact of this is that Strategies 2, 3 and 4 could recover costs in the range of $3.6M - $5.2M. The impact of this has not been included in Table 5 and Table 6.

N-1-1 strategy

Western Power has long recognised the emerging need to support Western Terminal under N-1-1 conditions by establishing a fourth 132 kV infeed into Western Terminal. Previous analysis has indicated that an additional 132 kV circuit could be bought into Western Terminal from South Fremantle via Amherst 132 kV substation, utilising the existing South Fremantle to Edmund Road 66 kV circuit (constructed at 132 kV) and a new 132 kV circuit from Amherst to Western Terminal. Development Strategies 1, 2, and 4 propose to relinquish an existing Cottesloe to Western Terminal 66 kV line corridor which could be reused to facilitate the new 132 kV circuit from Amherst to Western Terminal

Through the Development Strategies 2, 3 and 4 proposed, it has been realised that an additional 132 kV infeed to Western Terminal could be implemented from Cook Street utilising the future redundant 66 kV line routes. This would provide a low cost solution and minimise objections from the community by utilising an existing easement.

It should be noted that either of these solutions are only possible with some upgrade to 132 kV to allow the 66 kV line route to become available. Should such a strategy not be employed then the additional circuit to Western Terminal will potentially be required to be provided by a 132 kV cable route from Cook Street or a second circuit from South Fremantle or Northern Terminal, all of which would be expected to have far greater cost and consent difficulty than utilising the redundant 66 kV line. For example, reusing the existing 66 kV line section and upgrading the line to 132 kV Venus wood pole specification would be expected to have a capital cost less than $3M, given the circa 5.5 km distance. In comparison, the cost of a new underground cable circuit circa 5.2 km in length this would be around $15M, around $12M more than the wooden pole option.

Figure 25 illustrates how the second circuit from Cook Street could be implemented by utilising the redundant 66 kV line route made available in Development Strategy 2, 3 and 4.

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[10] The highest rated line conductor current employed within the Western Terminal 66 kV network is Centipede AAC, which has an overall diameter of 26.5 mm versus 33.8 mm for Venus – circa 28% larger.

■ Figure 25 Second circuit from Cook Street to allow future N-1-1 compliance

8.8. Development Strategy 3 and 4 comparison

8.8.1. Benefits of each strategy

The previous analysis and comparison presented in Section 8.7 has demonstrated that Development Strategies 3 and 4 can provide significant long term benefits over and above Strategies 1 and 2. However, Strategy 3 and 4 are very similar in design and financial performance hence there is little visibility between which is ultimately the preferred strategy. A summary of the key benefits of the two strategies is shown in Table 8.

■ Table 8 Comparison of Strategy 3 and 4

Strategy	Advantages	Disadvantages
Strategy 3	NPV lower by $7.3M Extracts maximum 66 kV asset lifetime	Higher MWH losses Greater number of overhead line routes and total length 66 kV infrastructure remains at Western Terminal for long term
Strategy 4	Capital cost lower by $6.7M Remaining 2035 TX capacity 10 MVA higher Lower capital cost/remaining TX MVA capacity ratio Reduced 2035 total circuit route numbers and length MWH losses 53% lower	Requires GIS switchgear at Nedlands Early replacement of WD assets

It is evident from Table 8, that Strategy 4 provides the greatest available substation MVA post 2035 to allow future demand growth with minimal additional capital cost over Strategy 3. This results in Strategy 4 having the lowest cost per remaining substation MVA capacity. On the other hand, Strategy 3 counters with a usefully lower NPV over the considered 25 year strategy period, which translates to a very similar cost per remaining transformer MVA on a net present cost basis as Strategy 4. Strategy 4 does however lead to the replacement of Wembley Downs assets (transformers, switchgear, overhead lines) around seven or eight years ahead of the anticipated end of asset life and will further require the Nedlands site to be rebuilt with GIS switchgear posing potential design, construction, commissioning and maintenance issues that will require further detailed consideration.

Other relevant factors that have been considered show that Strategy 4 could potentially reduce losses by a further 11.2 MW ($430,000 NPV) over Strategy 3 and reduce the installed circuit length by some 7.76 km. Both strategies allow the implementation of an additional 132 kV connection from Cook Street to Western Terminal to provide N-1-1 compliance whilst utilising existing line routes.

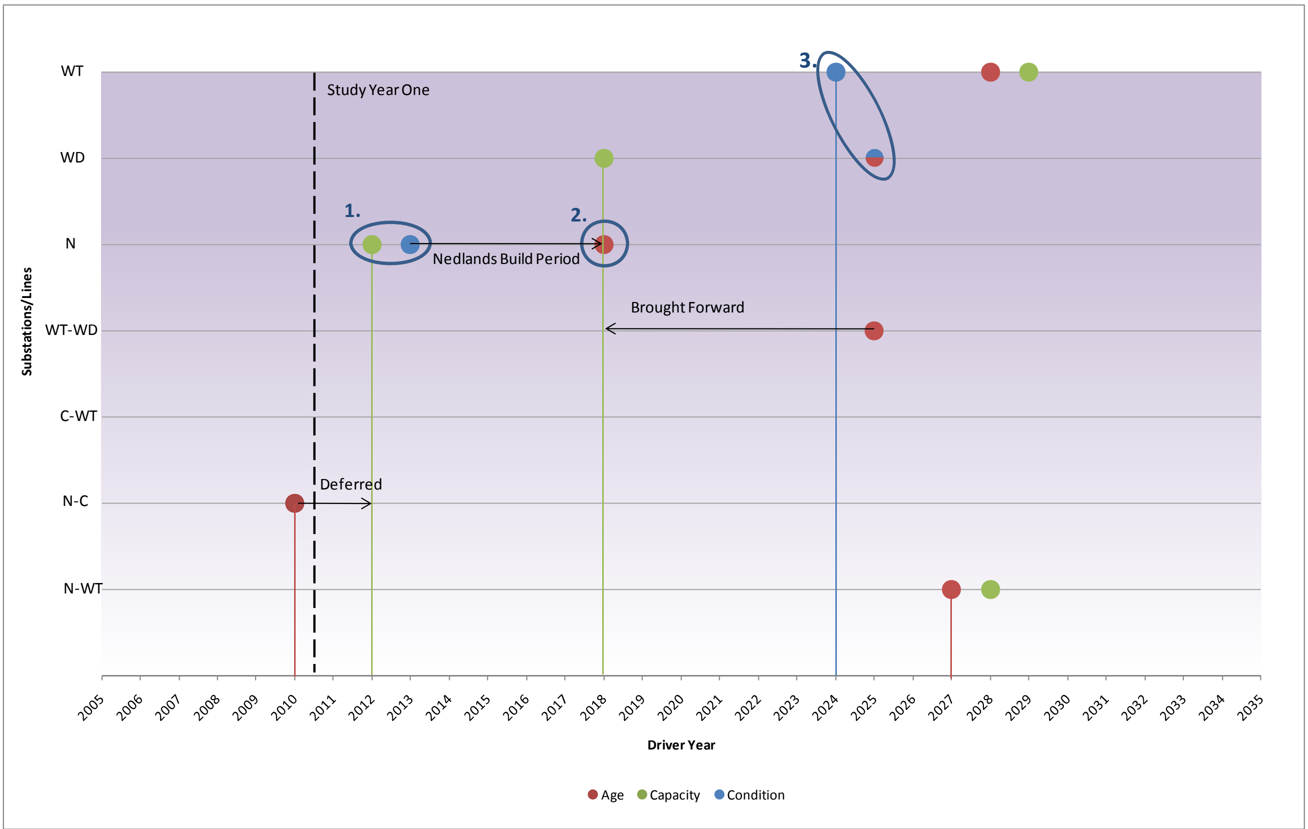
In summary, Development Strategy 3 and 4 are conceptually very similar and would lead to much of the same electrical transmission system equipment being installed and assets replaced over the considered strategy period. That said; there are some aspects of each strategy that are considered to be attractive over the other, most notable the lower NPV of Strategy 3. In the end, the decision to select and recommend one strategy over the other is difficult. However in this case, and on balance based on the work carried out and reported on in this study, the recommendation is that Development Strategy 3 should be considered for implementation.

The principal reason for the recommendation of Strategy 3 is that that it will lead to the extraction of the maximum asset life for the existing 66 kV transmission infrastructure, and in turn lead to a lower net present cost for the total capital investment over the strategy period than Strategy 4. Given that the projected difference in net present cost is more than $7M, this cannot be easily overlooked. While it is accepted that the calculated costs are subject to a degree of uncertainty, this is true of both strategies, hence Strategy 3 is likely to always yield the lower capital cost and NPV.

8.8.2. Key decision and action points

Whilst the recommendation of this study, on the basis of the analysis and empirical evidence compiled, is that Development Strategy 3 should be pursued for implementation, it is worth noting that a final decision on which strategy to implement can be deferred for a short time without affecting the technical and financial viability of Strategy 3. This is because Strategy 4 follows Strategy 3 closely only differing in that Nedlands and Wembley Downs substations are upgraded to 132 kV operation rather than remaining at 66 kV. All other aspects of Strategy 3 (ie, Shenton Park, Herdsman Parade, Medical Centre and University substation) remain the same in Strategy 4. Figure 26 illustrates the key points in the strategy timeline at which decision/actions are required to continue to pursue Strategy 3 or migrate to Strategy 4.

- Figure 26 Strategy 3 and 4 decision triggers



Referring to Figure 26 the key points of interest are:

1) In 2012/13 Nedlands has insufficient substation capacity to meet NCR requirements (load transfers may be effective in the short term to extend compliance) and the existing substation transformers will have reached the end of their useful life. The Nedlands – Cottesloe 66 kV overhead line already requires replacement to due age related deterioration, however the decision to rebuild the line will be pushed back to 2012/13.

The decision must be taken at this point as to whether Nedlands and Wembley Downs remain as 66 kV connected substations or will be migrated to 132 kV[11].

2) Regardless of whether Nedlands is rebuilt as a 66 kV or 132 kV substation, the work is not expected to be completed until 2018, given a notional start date of 2014. If the decision is taken to migrate Nedlands to 132 kV, then the Western Terminal – Wembley Downs 66 kV single circuit wooden pole line must be upgraded to a 132 kV double circuit line to enable Wembley Downs to continue to be supplied and meet N-1 requirements. This work must be completed ahead of the final Nedlands migration to 132 kV which would otherwise leave Wembley Downs supplied at 66 kV from its direct Western Terminal circuit only, the 66 kV circuit via Herdsman Parade having been disconnected.

3) Around 2024/25 the existing Western Terminal 132/66 kV transformers, the existing Wembley Downs 66/11 kV transformers plus the existing Western Terminal – Wembley Downs 66 kV overhead line will need to be replaced due a combination of age and condition related deterioration. This provides the backstop such that regardless of whether Wembley Downs continues to be supplied at 66 kV or migrates to 132 kV, the existing substation equipment and supplying overhead line from Western Terminal is required to be upgraded/replaced by this date.

The above points highlight that a final decision as to whether Strategy 3 or 4 should be implemented can be delayed by a number of years, however the Nedlands substation rebuild/upgrade will be the trigger for the potential migration to 132 kV given that it requires capital investment significantly ahead of Wembley Downs substation.

However, the requirement to upgrade Nedlands substation to 132 kV will depend on the ability of the existing 66 kV substation assets to be upgraded in situ, which may be problematic given the larger transformers that will be required and the limited space available. This in turn may necessitate GIS switchgear, which would essentially have the same cost as the 132 kV conversion (GIS being the only option at 132 kV given the limited space on site) as specifically rated 66/72.5 kV GIS switchgear is not likely to be widely available. The resultant cost increase would make Strategy 3 even more expensive that Strategy 4, by around an additional $6M, although the NPV would likely still be more attractive than Strategy 4.

It is therefore recommended that in the intervening period, the logistical and practical issues associated with the Nedlands substation rebuild are examined in detailed to confirm the ability of the existing substation site to be rebuilt at 66 kV whilst accommodating new larger power transformers. If this proves difficult to manage and deliver and GIS switchgear is required, then it is suggested that the substation is upgraded to 132 kV with GIS switchgear, assuming that detailed cost estimates from equipment suppliers plus required environmental, construction and operational factors can be satisfactorily accounted for whilst yielding a lower project capital cost than retaining 66 kV transmission for Nedlands and Wembley Downs.

8.9. Sensitivity analysis

In conducting this study a number of assumptions have been made with regards to demand forecast, equipment sizes, unit cost building blocks, environmental restrictions, etc. These, plus other aspects have influenced to varying degrees the timing, capacity and cost of the required network reinforcements and capital investments and as such explicit consideration needs to be given as to the impact of these aspects on results and recommendations of the study. This subsection therefore considers the impact of the following aspects:

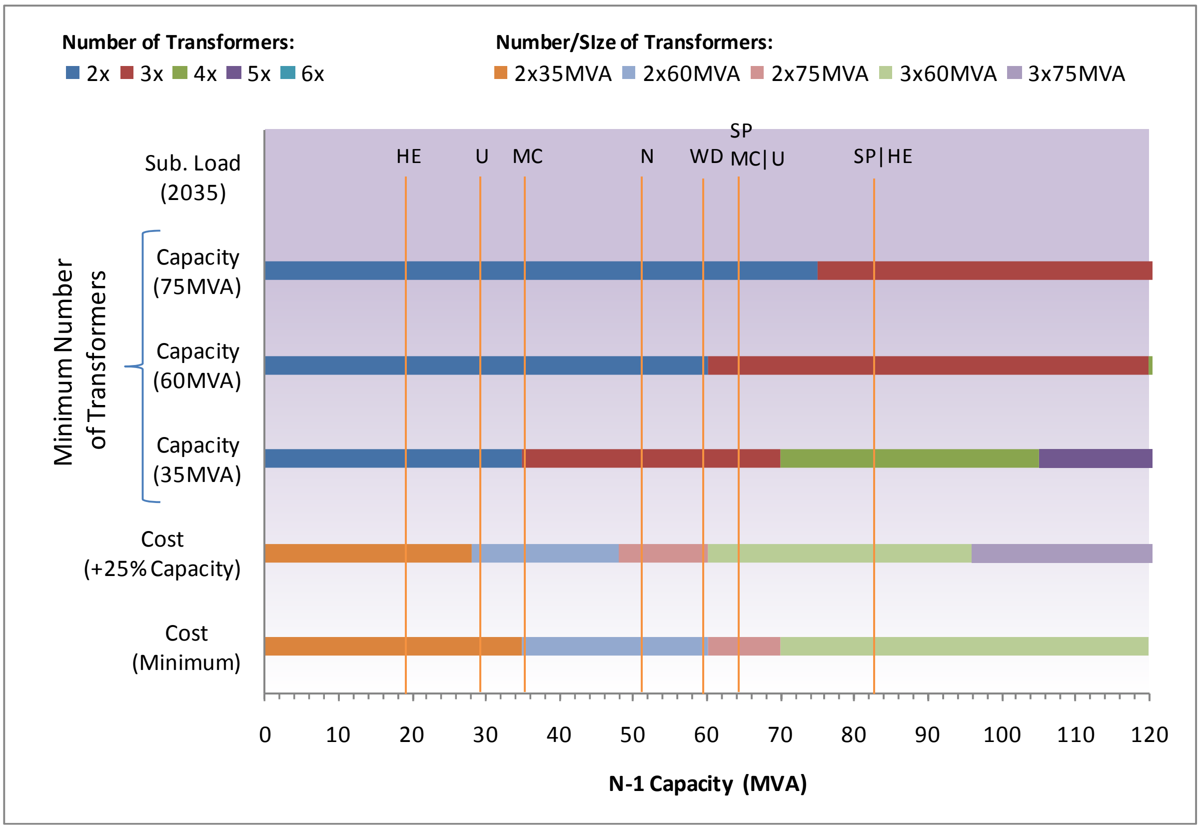
1) Alternative transformer ratings
2) Variations in building block costs
3) Variations in demand growth
4) Impact of lower rated line conductor

[11] Retaining one substation, either Nedlands or Wembley Downs at 66 kV only has been discounted as inefficient given the ongoing requirement for 132/66 kV transformers and 66 kV infrastructure at Western Terminal.

8.9.1. Transformer ratings

Although this assessment has been based on the assumed 66/11 kV and 132/11 kV substation transformer ratings (35 MVA and 75 MVA duel LV winding respectively), alternative substation designs and transformer ratings could also be adopted. The following figure (Figure 27) outlines the minimum number of transformers required to deliver a firm N-1 substation capacity. Also shown in Figure 27 is the 2035 peak demand on each substation, with a reference line indicating the minimum number and rating of transformers for each substation.

▪ Figure 27 Sensitivity analysis of transformer number and sizing



From Figure 27 it is evident that 2 x 35 MVA transformers (regardless of voltage) would be sufficient to supply the expected 2035 peak demand at Herdsman Parade and University and also at Medical Centre, although in the case of the latter substation there would be no remaining substation capacity post-2035. Both Nedlands and Wembley Downs substations would require 3 x 35 MVA transformers or alternatively 2 x 60 MVA or 75 MVA (duel LV winding) transformers. In the case of Wembley Downs there would be little remaining substation capacity post 2035 if 60 MVA duel LV winding units are installed.

For the larger substations (either Shenton Park or the combined Medical Centre and University) 3 x 35 MVA transformers or 2 x 75 MVA transformers would provide sufficient capacity. For the largest substation, the combined Shenton Park and Herdsman substation, either 3 x 75MVA or 4 x 35 MVA transformers would be required to provide sufficient capacity.

Taking the outlined points into consideration the following statements can be made as regards alternative substation design and transformer rating configurations:

1) For lower demand substations (University or Herdsman Parade) 2 x 35 MVA transformers will provide sufficient substation capacity, even post-2035.

2) Given the limited space available at Medical Centre it is recommended that two duel LV winding transformers are installed, either 60 MVA units if University will remain as an individual substation or 75 MVA units if University is combined with Medical Centre.

3) Nedlands or Wembley Downs substation could adopt either 3 x 35 MVA or 2 x 75 MVA transformers, with both options providing similar firm capacities.

The combined Shenton Park and Herdsman Parade substation could conceptually adopt 4 x 35 MVA transformers instead of 3 x 75 MVA units. The costs are again expected to be similar between the two designs however 3 x 75 MVA design will provide a longer term solution.

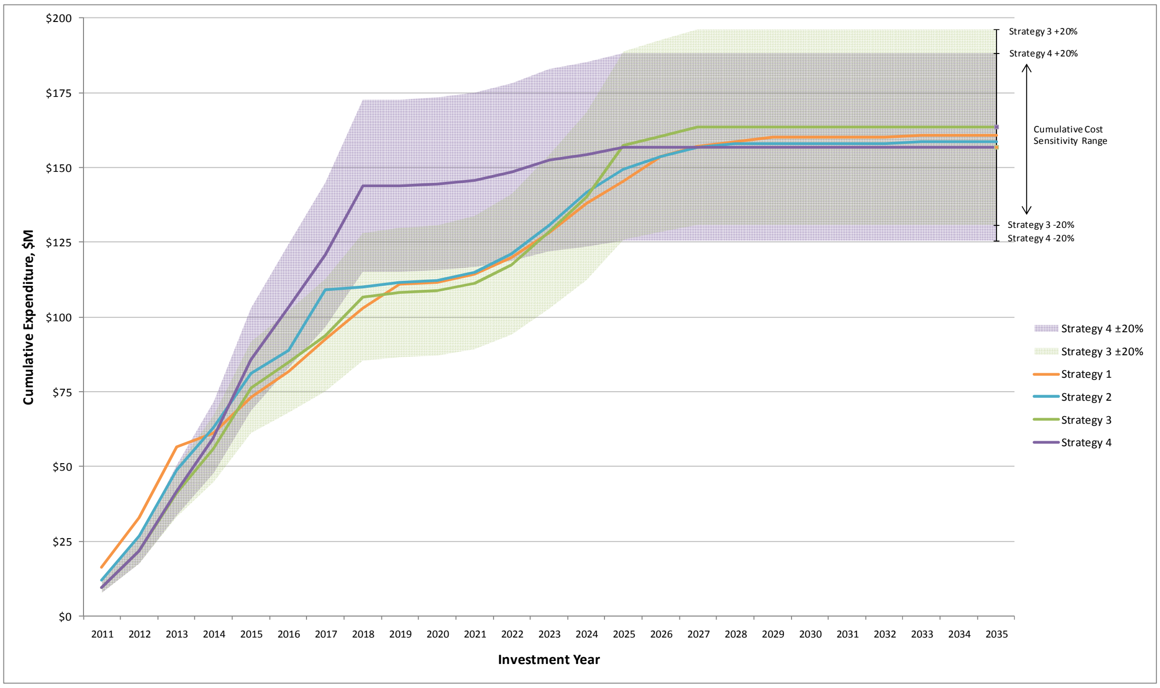
Figure 27 also indicates the lowest cost substation design (number and rating of transformers) for providing different firm demand capacities as well as the lowest cost design which would still have at least 25% available capacity headroom. These results have been calculated based on the provided building block costs for the alternative transformer ratings and typical substation AIS 132 kV switchgear configurations. The results indicate that as expected smaller substations should adopt standard sized 2 x 35 MVA transformers with increasingly larger substations adopting larger duel LV winding units. It is also worth noting that based on the adopted cost building blocks, 3 x 35 MVA transformers are not shown to be economic, either when considering the absolute minimum capital cost or providing at least 25% firm capacity headroom.

8.9.2. Cost building blocks

As outlined in Section 5.3, the total capital cost calculated for each development strategy has been calculated based on the required number of asset units (determined from the investment drivers – see Section 7.1 and 7.2) as well as the asset building block costs (obtained from Western Power). The building block costs are however average costs for the delivering the outlined equipment and works required and are not fully detailed costs estimates taking account of site specific requirements. They will therefore be subject to a degree of variation and revision at a later stage, once more accurate details of site, planning, environmental and network constraints are known in detail.

At this time it can however be stated that whilst the costs are considered appropriate for this assessment a tolerance margin of ±20% does need to be considered. Figure 28 illustrates the cumulative capital investment expenditure shown previously in Figure 20 but with a ±20% cost tolerance band applied to Strategy 4 (in light purple) and Strategy 3 (light green).

■ Figure 28 Sensitivity analysis of development strategy investment cost



It is evident from review of Figure 28 that when the ±20% investment cost tolerance is added to the cost of Strategy 4, the upper estimated cost of Strategy 4 could reach $188.2M. This would be higher than the base estimated cost of Strategy 3.

Conversely, when the same tolerance is added to Strategy 3, the lower estimated could reduce to $130.8M which is lower than the base estimated cost for Strategy 4.

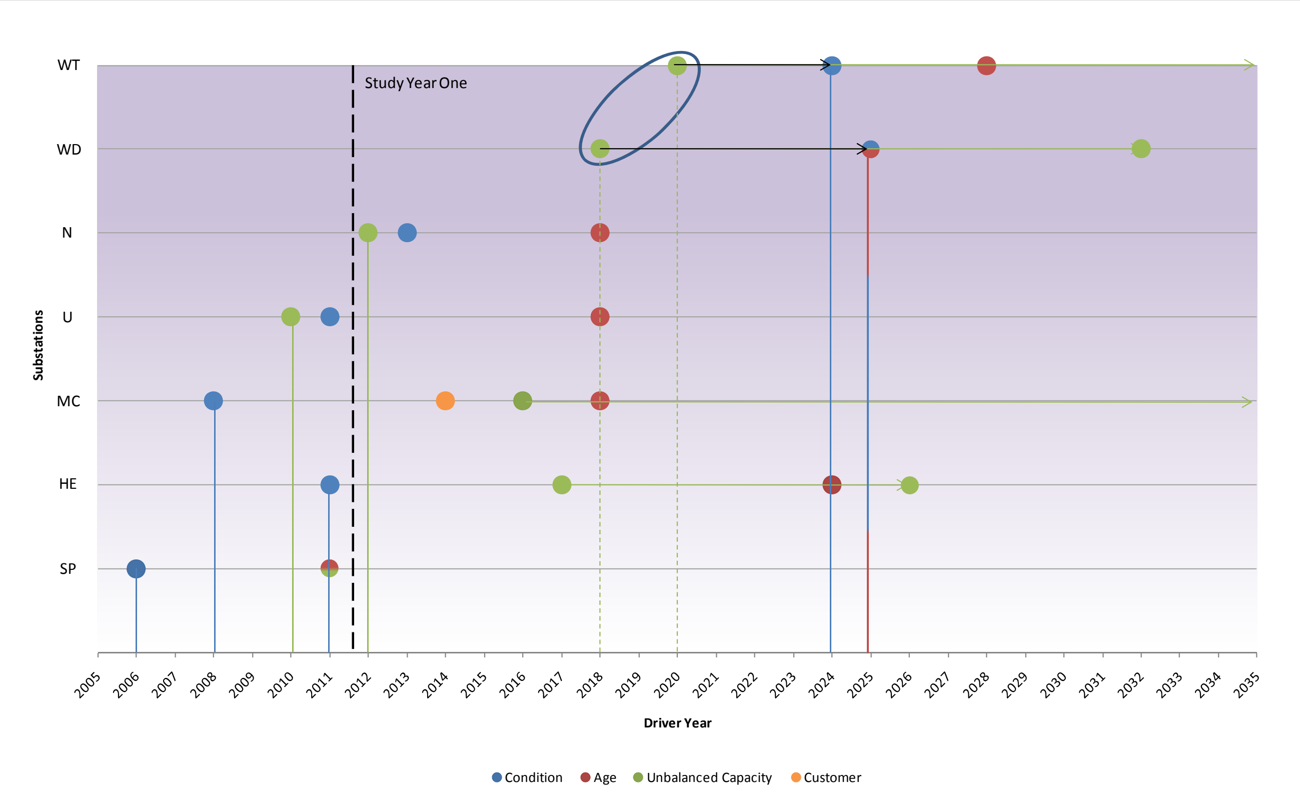
The overlap between the considered cost tolerance for Strategy 4 and 3 is shown in Figure 28 as the darker shaded area (labelled cumulative cost sensitivity range). The key consideration here is that the overlap between the two cost tolerance ranges (some $57.4M) encompasses the base estimated capital cost for all four considered strategies easily. This supports the statement made in Section 8.7 that any one of the considered strategies could potentially yield the lowest overall capital cost (and NPV) depending on the extent of the final site works required for each substation and outturn equipment costs. Hence, consideration is required to be given to other metrics to enable the desirability of each development strategy to be more thoroughly assessed and identify a recommended strategy for implementation.

8.9.3. Demand growth

The driver underpinning much of the required reinforcement of the Western Terminal transmission system over the considered strategy period is the present lack of network capacity and the impact of prospective future demand growth. The assessment has been based on the May 2011 Western Power demand forecast which provides a projection of the prospective future demand at each substation in the Western Terminal area to 2035. This forecast has been central to this assessment, and the outlined demand figures have been incorporated within the associated Dig SILENT power system studies to identified network capacity limitations going forwards. The output of these studies, the identification of specific network capacity restrictions, has been combined with the other identified asset investment drivers (age and condition related replacement) to generate the timeline of substation and network investment requirements outlined previously in Figure 11.

However, whilst the considered Western Power demand forecast indicates the most likely demand growth path across the Western Terminal area over the considered strategy period it is important to understand the sensitivity of the resulting study outcomes to potential variations in actual demand growth. To this end the Western Power demand forecast growth rate for Western Terminal substations up to 2035 has been halved and the timeline of substation and network investment requirements redrawn to illustrate the potential impact on this assessment, as shown in Figure 29.

■ Figure 29 Sensitivity analysis of trigger points with reduced demand growth



It is evident from review of Figure 29 that many of the identified investment/reinforcement triggers within the Western Terminal area had already occurred prior to 2011 (shown to the left of the dotted line) and consequently are unaffected by any changes in the future area demand growth rate.

Of those investment triggers that were expected to occur from 2011 onwards the only change as a result of the revised demand growth rate has been to Wembley Downs and Western Terminal substations. At Wembley Downs the reduced demand growth has pushed the capacity investment trigger out to 2032. However, the age/condition of the Wembley Downs 66/11 kV transformers is such that this will now be the trigger for investment in 2025. Similarly for Western Terminal, the reduced demand across the 66 kV network has pushed the capacity investment trigger previously identified for 2020 out to potentially beyond 2035. However, the condition of two of the Western Terminal 132/66 kV transformers is such that they will now be the trigger for investment around 2024 to 2028.

In summary, the requirement for capital investment across the Western Terminal area is not expected to change significantly, even if the expected future demand growth rate is half the expected rate. The only two substations that would potentially see some revision to the investment requirements are Western Terminal and Wembley Downs substation. That said; asset age/condition investment drivers will become the backstop at both substations meaning that the benefit gained through potentially lower demand growth, in terms of deferred capital investment, is not likely to be significant. Additionally, with respect to the outcomes of this study, as the bulk of the capital investment triggers will remain as previously identified, potential variations in future Western Terminal area demand grow will not have any material impact on the recommended development strategy.

8.9.4. Line ratings

Although this assessment has been based on the assumption that new overhead lines will be constructed of Venus AAC conductor type at a maximum operating temperature of 85°C, alternative conductor types and operating temperatures could be adopted. Appendix G illustrates the line loading in 2035 for each of the development strategies with a range of conductors and maximum operating temperatures.

It can be seen in Appendix G that for Development Strategy 1 and 2, the choice of conductor and operating temperature will have a significant impact on the loading of the lines post-2035. Figure 47 shows that for Strategy 1, the first line out of Western Terminal for both ends of the Southern ring will require consideration for uprated conductors as any conductor size smaller than Venus will provide insufficient or close to insufficient capacity by 2035. Figure 48 illustrates the same analysis for Strategy 2. Figure 49 and Figure 50 show that there is little sensitivity on which conductor size is selected for Strategies 3 and 4 respectively.

In summary, this sensitivity analysis has shown that Strategies 1 and 2 will depend, to some extent, on being able to install high capacity overhead line conductors strung to operate at high temperature along existing line routes, primarily driven by the restriction in capacity when energised at 66 kV. This introduces a risk to these strategies based on the requirement to install this level of overhead line design. In comparison Strategies 3 and 4 are non-reliant on high capacity, high temperature conductors requiring to be installed due to the more widespread energisation at 132 kV and hence reduce the risk involved with constructing specific high capacity overhead lines.

9. Summary and recommendations

9.1. Summary

This report has considered potential development strategies for the Western Power electrical transmission system assets in the Western Terminal area over the next 25 years. Four development strategies have been considered:

1) Development Strategy 1 – Retain 66 kV
2) Development Strategy 2 – Shenton Park and Herdsman Parade upgraded to 132 kV
3) Development Strategy 3 – Shenton Park, Herdsman Parade, Medical Centre and University upgraded to 132 kV
4) Development Strategy 4 – Full 132 kV migration

These strategies have been developed taking account of the following network investment drivers:

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

Each development strategy has been assessed on the basis of a number of financial and technical metrics:

- Total 25 year strategy capital investment cost
- NPV of total strategy investment
- Post-2035 remaining substation transformer capacity
- Cost-benefit ratio – capital cost/remaining substation capacity
- Electrical losses in 2035
- Total number of overhead line circuits and route length
- Practical issues related to individual overhead line and substation developments

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

- All substations in the Western Terminal area will require capital investment for asset replacement/capacity enhancement within 15 years, including Western Terminal.
- All existing 66 kV overhead lines in the Western Terminal area (except Cottesloe – Western Terminal) will require asset replacement and capacity upgrading within the considered strategy period.
- Space restrictions at Medical Centre and Nedlands will limit the former site to two new transformers and require the latter to adopt GIS switchgear if migration to 132 kV is considered.
- Strategy 4 has the lowest overall capital cost and Strategy 3 the lowest NPV at a 2035 horizon year.
- The difference in total capital cost between the considered strategies is relatively small, around $7M or circa 4% of the total cost of the lowest cost Strategy 4.
- Strategy 1 has the lowest remaining substation capacity post-2035, with all other options providing significant greater remaining capacity.

- Strategy 4 has the most attractive cost-benefit ratio (capital cost/remaining 2035 substation capacity), with Strategy 1 by the far the worst ratio, even if an additional Western Terminal 132/66 kV transformer is considered.
- Strategy 1 and 2 will require further investment post-2035 that will result in the total capital cost of these strategies increasing significantly above that of Strategy 3 or 4, although the 2050 NPV of Strategy 1 is expected to be similar to Strategy 4.
- Strategy 4 provides the greatest improvement in electrical losses and will result in the lowest number of total number of overhead line routes and installed circuit length.
- Any one of the strategies could yield the lowest capital (and NPV) cost when the preliminary nature of the cost building blocks is considered which could vary the calculated cost of the strategies by around 20% from the values quoted.
- All strategies, except Strategy 1, will enable an additional 132 kV infeed to Western Terminal to be provided from Cook Street.
- Variations in expected future demand growth will not impact on the level of area capital investment required, but may have a minor impact on the timing of certain investments.
- Potential restrictions on the ability to uprate existing 66 kV wooden pole overhead lines to 132 kV Venus AAC conductor specification at a high line operating temperature (85°C) may impact on the technical viability of Strategy 1 and 2. Strategy 3 and 4 are not reliant on high temperature and capacity overhead line ratings.
- Substation configurations and transformer ratings other than those explicitly considered in this assessment could be adopted by Western Power for the Western Terminal area. This would not be expected to impact on the outcomes of this study, although there would be a minor impact on the cost and timing of certain substation capital investments.
- The lack of existing substation capacity combined with deteriorated assets at Nedlands will be the trigger/decision point for deciding if Nedlands and Wembley Downs substation should be migrated to 132 kV. This decision will require to be made within the next three years.

9.2. Recommendations

Having studied the capital investment requirements of the Western Terminal transmission system over a period of 25 years, by way of the evaluation of four potential development strategies, the following recommendations to Western Power are made:

1) Retaining 66 kV (Strategy 1) as the principal sub-transmission system voltage across the Western Terminal area is not recommended as it is the least economically efficient strategy and also performs poorly when assessed against a range of other technical metrics.
2) Connecting Shenton Park (only) to 132 kV (Strategy 2), whilst providing a potentially attractive capital cost and reasonably good cost-benefit ratio within the considered study period, will require further capital investment post-2035 that Strategy 3 and 4 will not require. It also does not provide the associated benefits of Strategy 3, and Strategy 4, in particular.
3) Strategy 3 and 4 are very similar across all technical and financial metrics considered, although Strategy 4 has a more attractive cost-benefit ratio, remaining substation capacity post-2035 as well as lower electrical losses and total number of overhead lines and installed circuit length. Strategy 3 does however have a significantly lower NPV, reflecting the more desirable investment phasing of this strategy.

We therefore consider that it is a finely balanced decision over whether to recommend Strategy 3 or 4 and a sound argument could be made for either strategy. However, on the basis of the analysis and assessment detailed in this document, on balance, we recommend that Strategy 3, migration of Shenton Park, Herdsman Parade, Medical Centre and University substations to 132 kV is adopted. The principal reason for the recommendation of Strategy 3 is the significantly

lower NPV (in comparison with Strategy 4), as a result of extracting the maximum lifetime from the existing 66 kV transmission assets in the Western Terminal area.

Although Development Strategy 3 has been recommended on the basis of the analysis conducted as part of this study, there are a number of key areas that require further analysis and assessment before a definitive statement can be made of the overall superiority of this option. As a result it is recommended that:

4) The practicalities of uprating the existing 66 kV wooden pole overhead lines within the Western Terminal area identified under this study are investigated to confirm that the desired line operating temperature and ratings considered can be achieved in practice.

5) Detailed conceptual designs are developed for each substation to confirm that the number and rating of transformers considered under this study can be achieved in practice, with specific consideration given to operational and construction issues. Particular attention is required at Medical Centre and Nedlands given the restricted site plots available.

6) The technical and financial viability of the existing 66 kV switchgear at Nedlands to be rebuilt, either in situ or on a vacant part of the existing site, should be determined as well as the practicalities of installing GIS 132 kV switchgear.

7) The capital cost building blocks used in this assessment are reviewed in conjunction with the network design proposed under each development strategy and cost input from equipment suppliers, to confirm the calculated strategy capital investment costs.

Finally, the analysis conducted as part of this assessment has shown that whilst Development Strategy 3 and 4 are very similar, between them they perform well in virtually all of the technical and financial metrics considered. Given that both strategies contain a number of same key capital investments it is recommended that the following projects are subjected to detailed engineering design studies as a means by which to confirm the concept design, specification, procurement, construction and commissioning requirements to ensure deliverability in the desired timescales:

8) Shenton Park substation migrated to 132 kV, with Herdsman Parade substation load transferred to Shenton Park.

9) Medical Centre substation migrated to 132 kV with a design adopted to maximise available substation capacity, with University substation load transferred to Medical Centre.

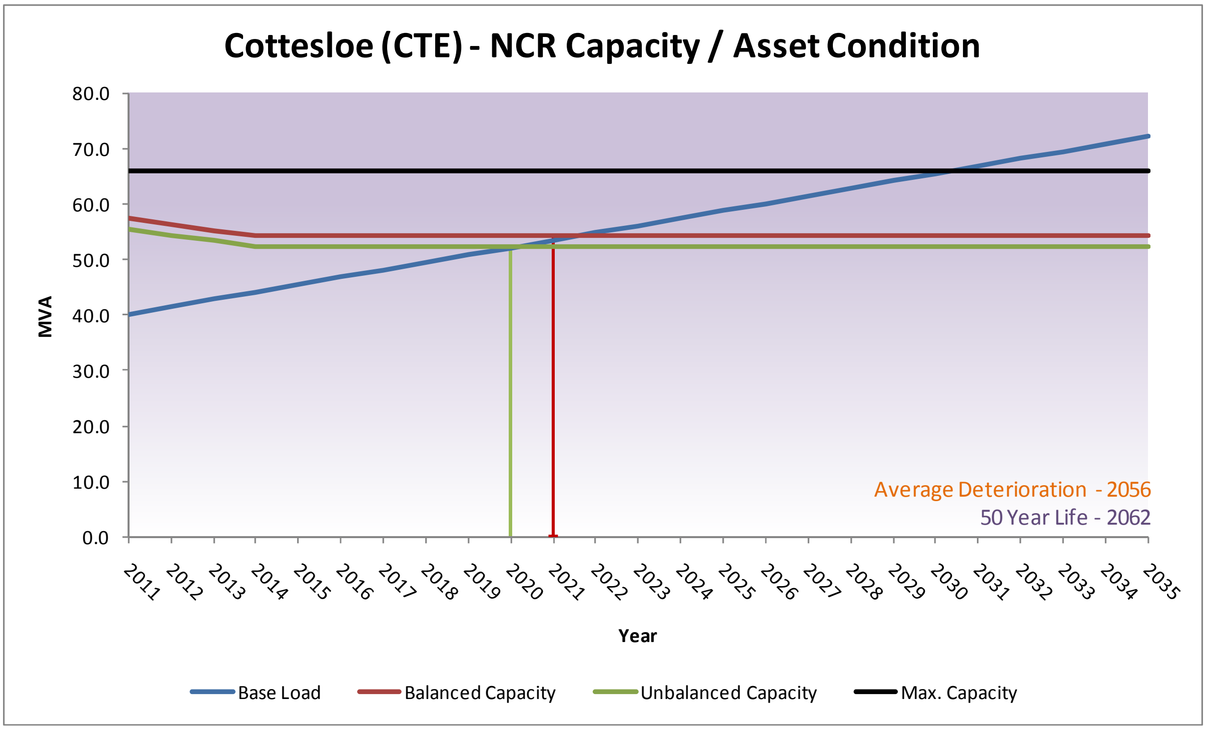
Both projects will require overhead line construction and reconfiguration works that will also necessitate detailed engineering assessments to confirm financial and technical viability.

Appendix A Western Terminal load area

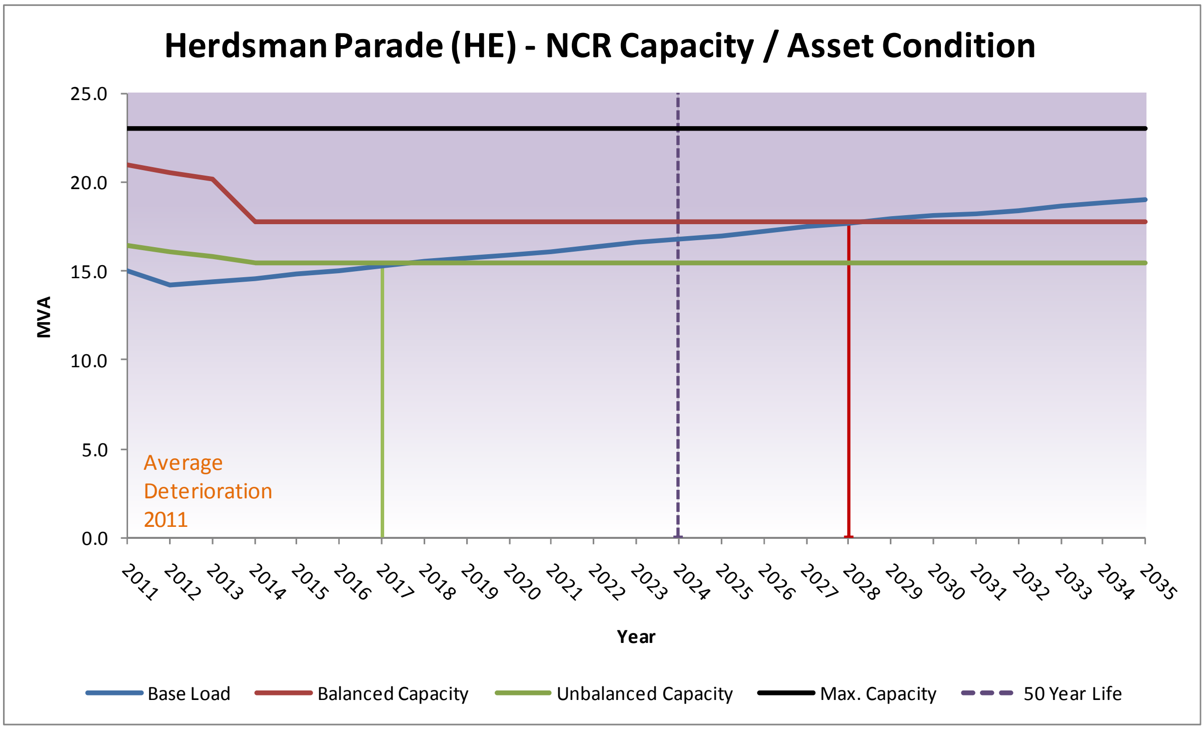
- Figure 30 Western Terminal load area – geographic

Appendix B Substation transformer capacity/condition triggers

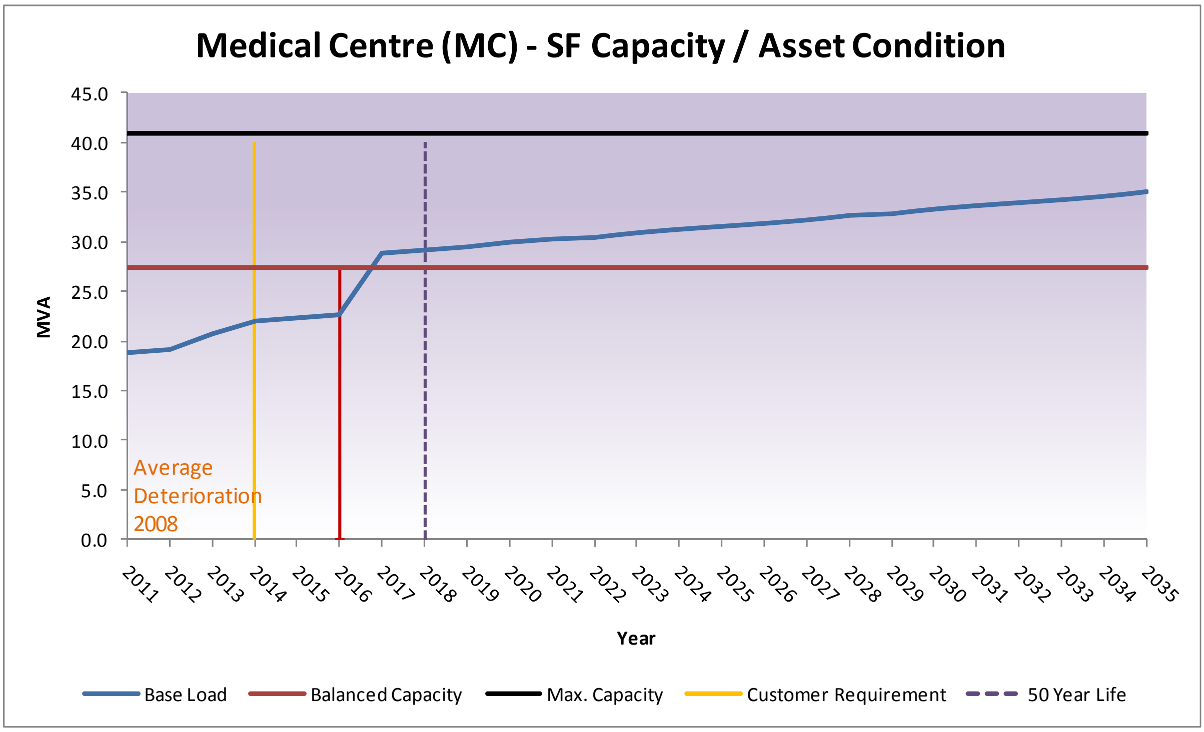
■ Figure 31 Cottesloe - 132/11 kV



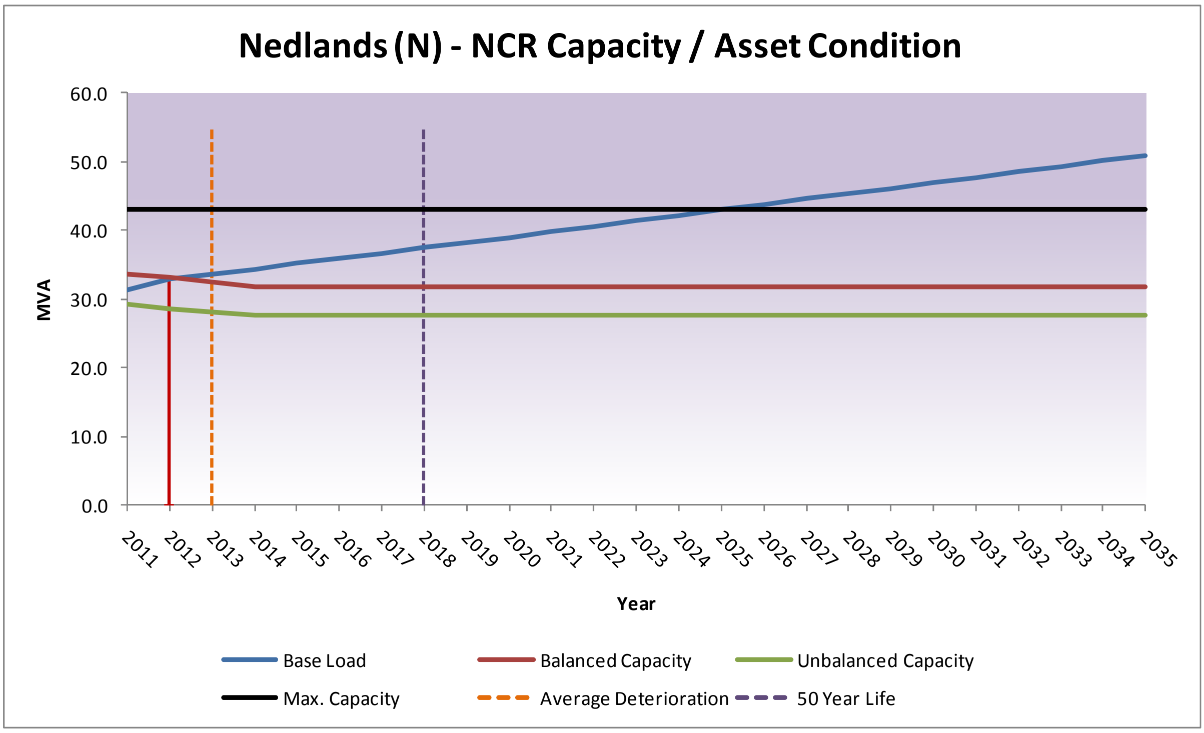
■ Figure 32 Herdsman Parade – 66/6.6 kV



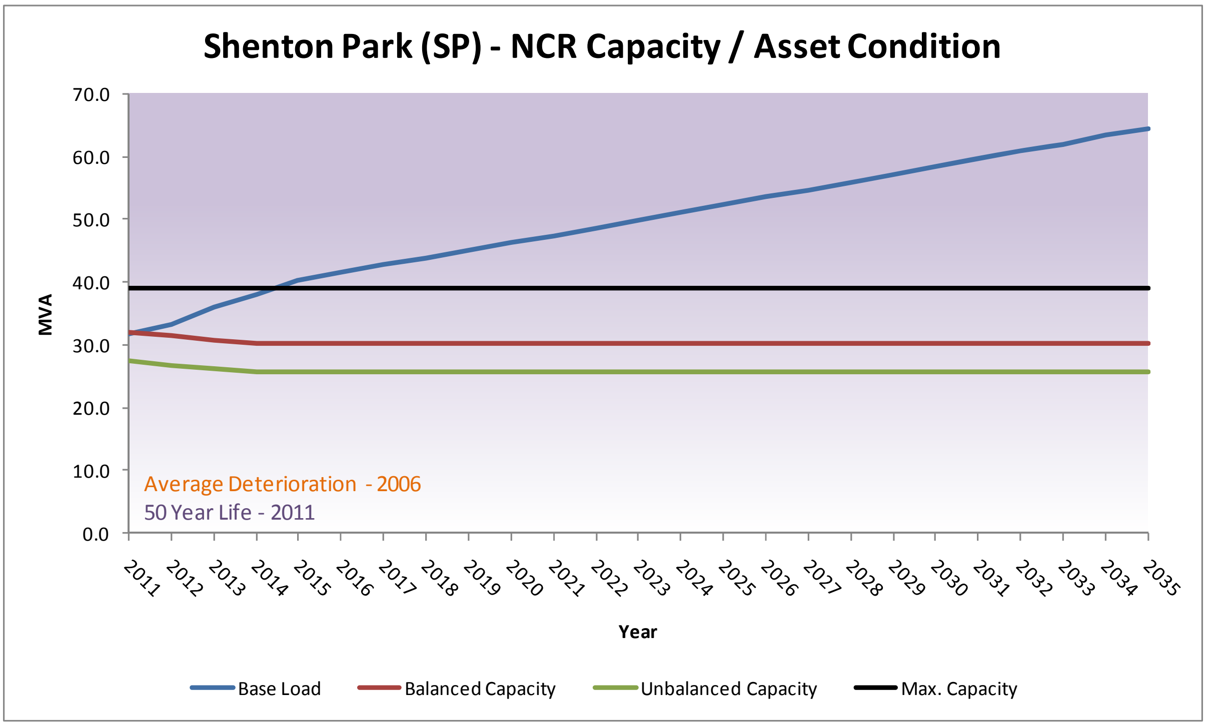
■ Figure 33 Medical Centre – 66/6.6 kV



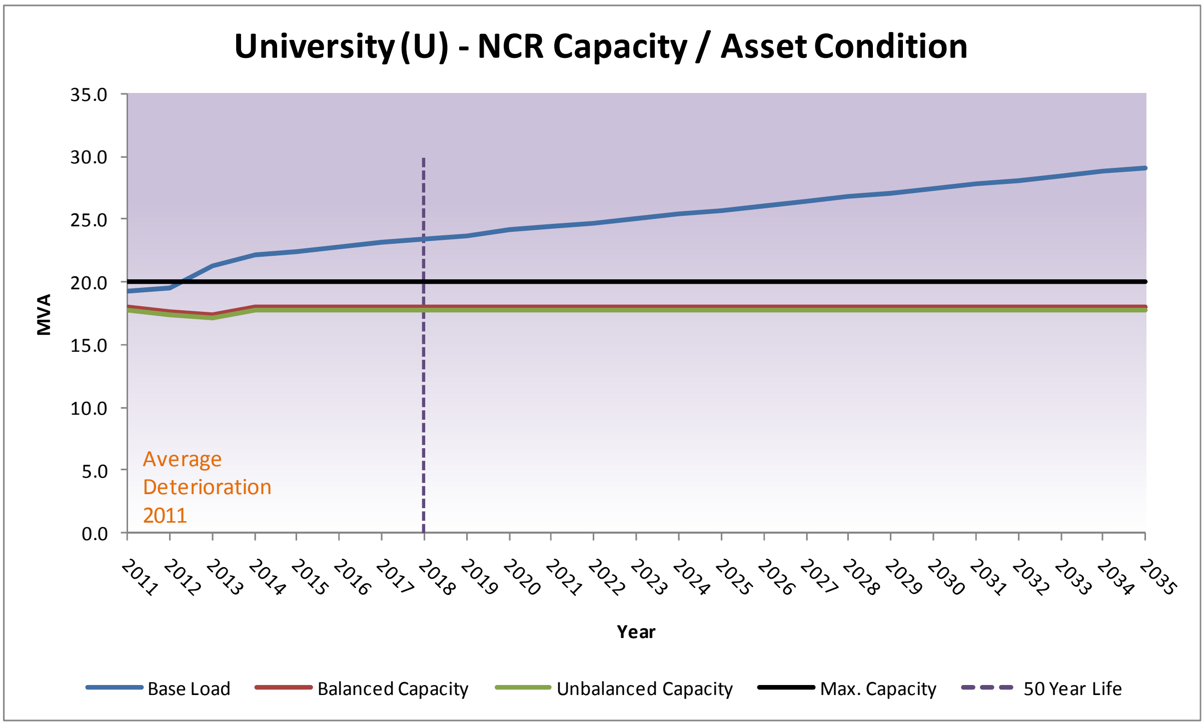
■ Figure 34 Nedlands – 66/6.6 kV



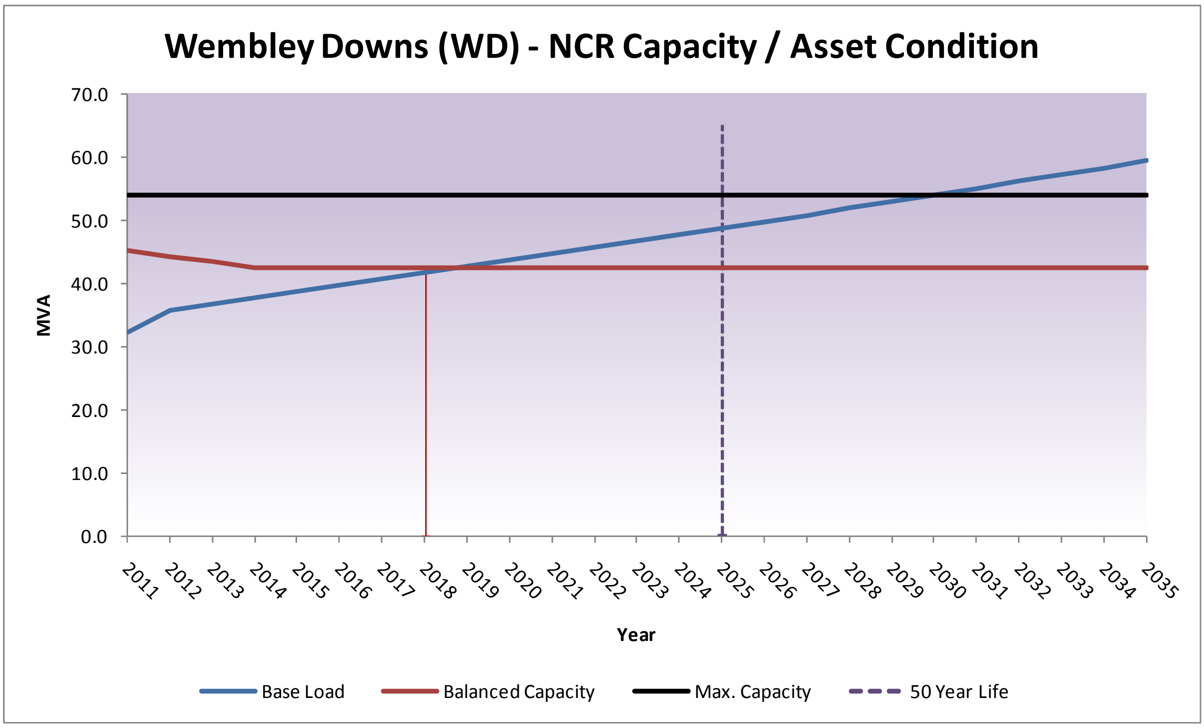
■ Figure 35 Shenton Park – 66/6.6 kV



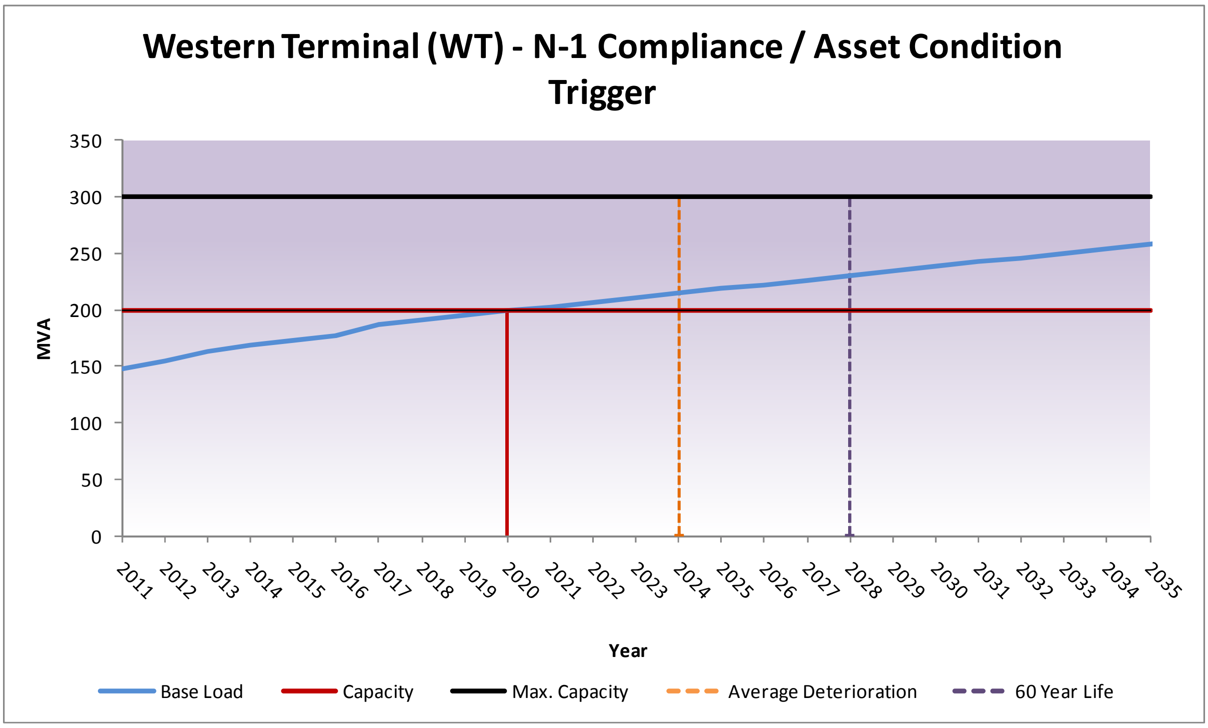
■ Figure 36 University – 66/6.6 kV



- Figure 37 Wembley Downs – 66/11 kV

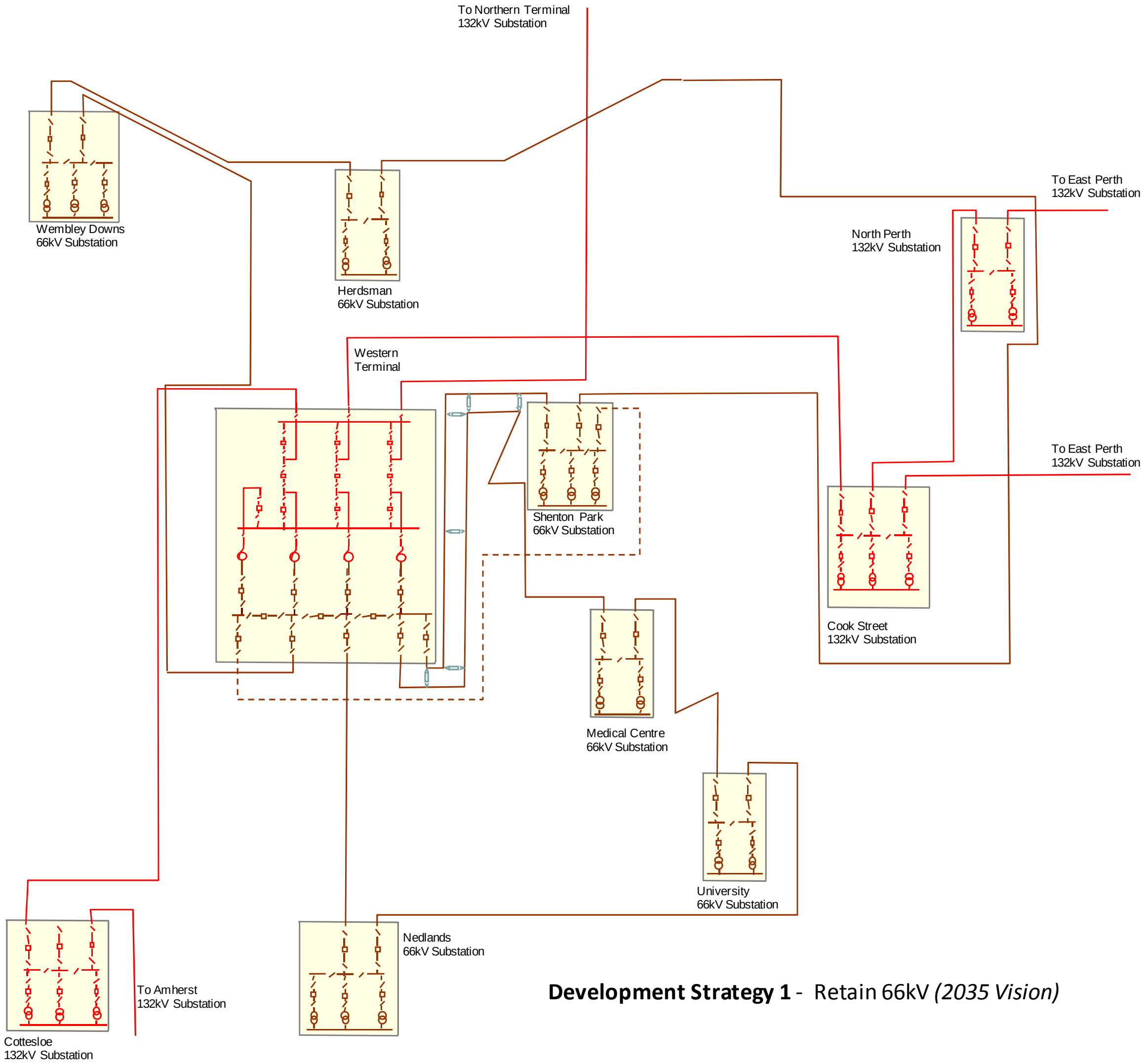


- Figure 38 Western Terminal – 132/66 kV

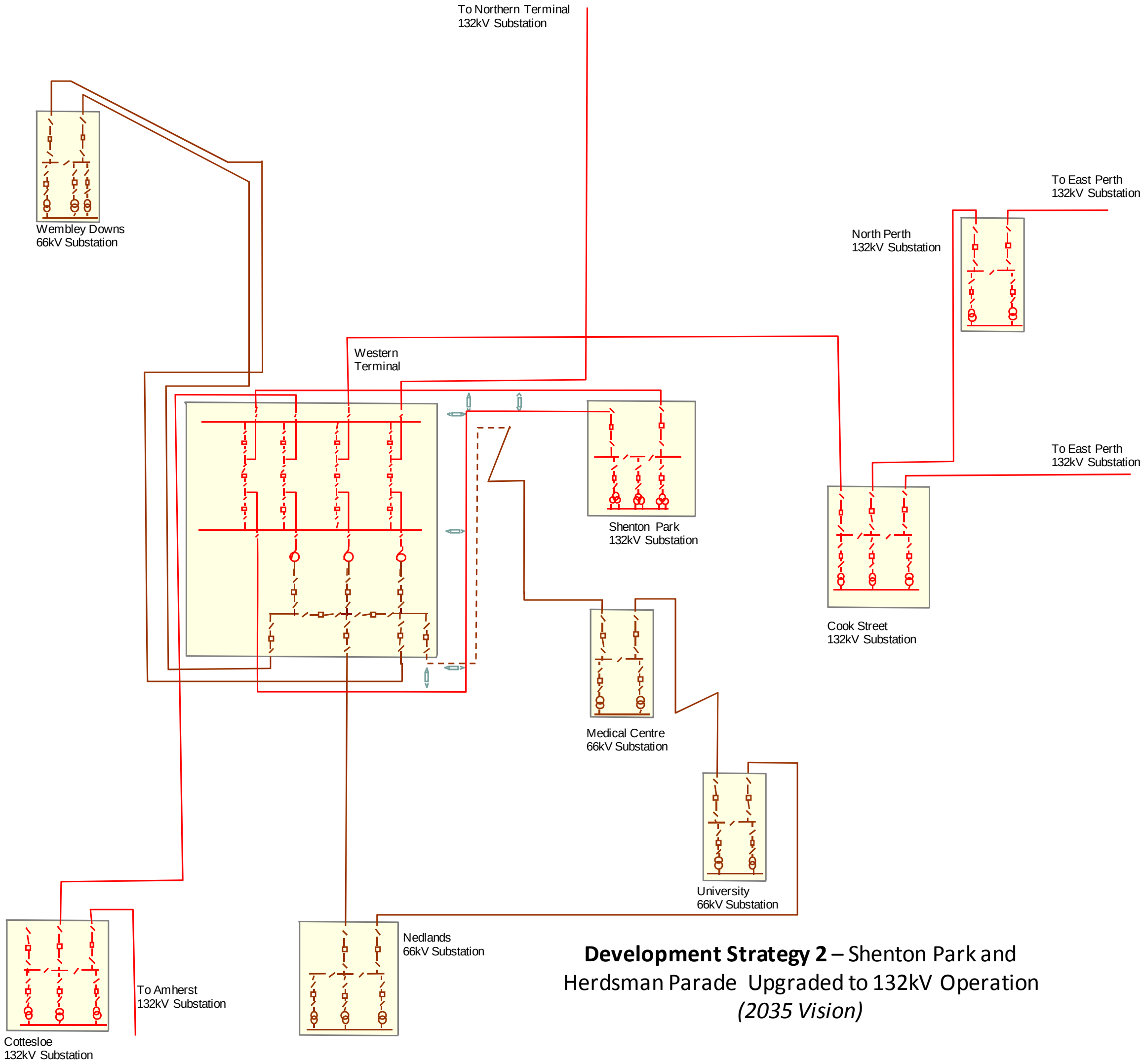


Appendix C 2035 Single line diagrams

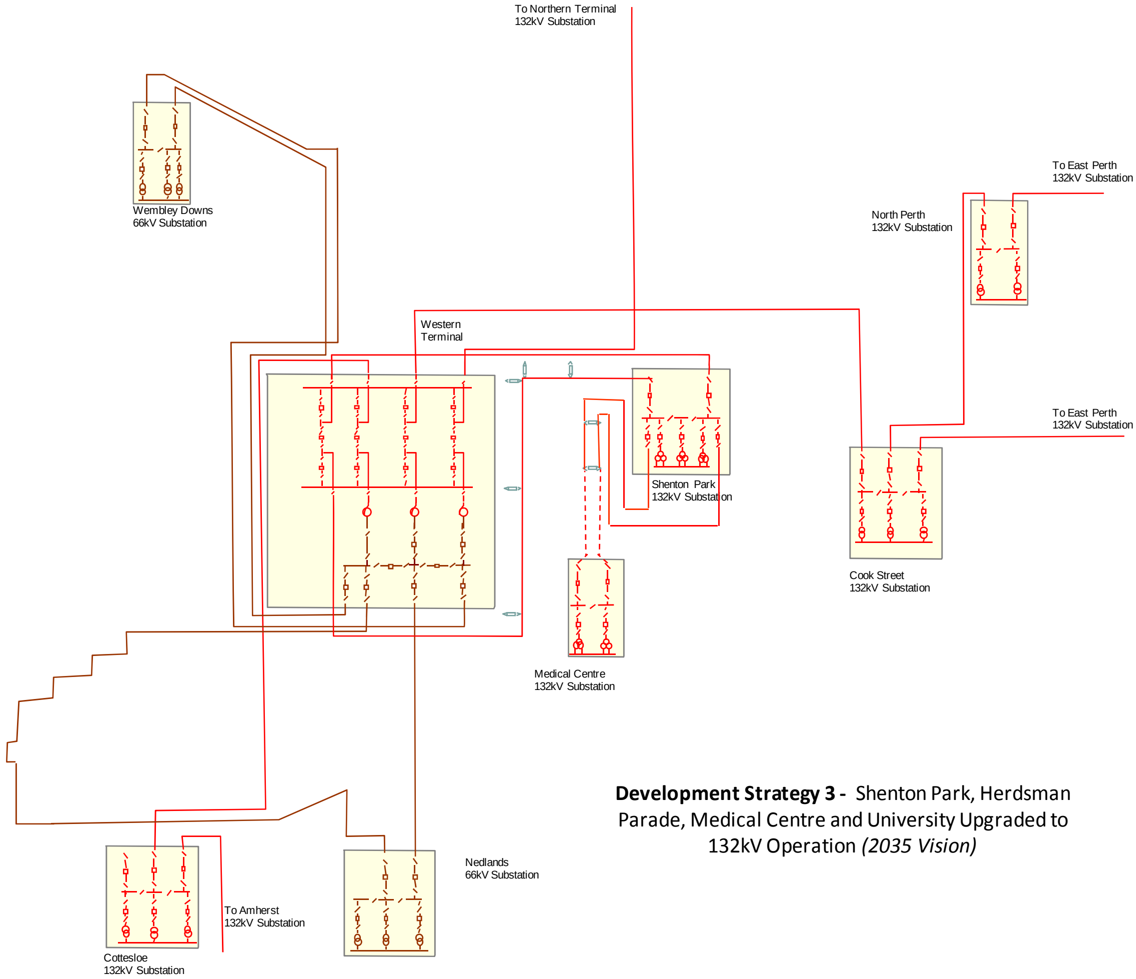
- Figure 39 Development Strategy 1 – 2035 system design



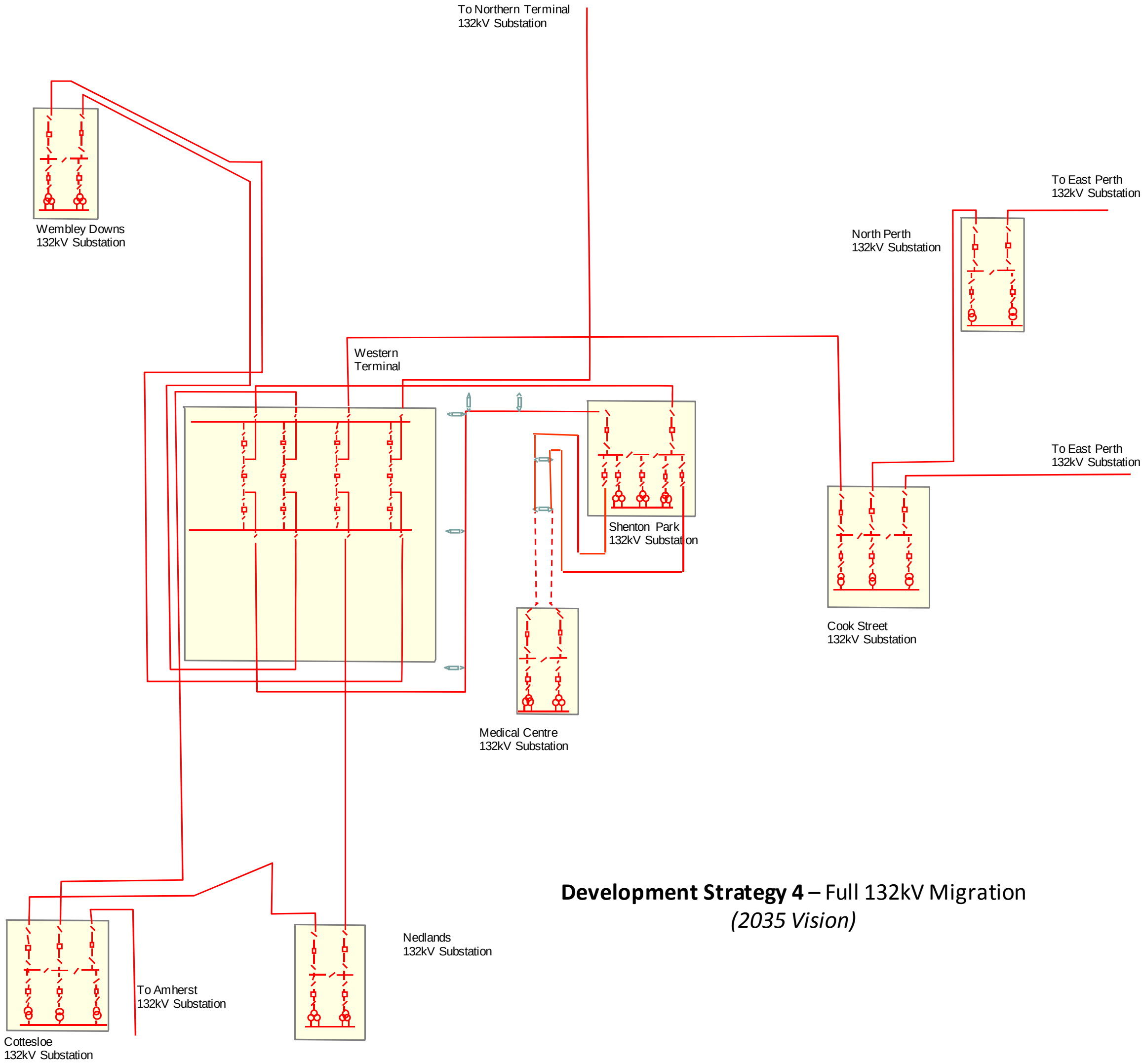
■ Figure 40 Development Strategy 2 – 2035 system design



■ Figure 41 Development Strategy 3 – 2035 system design



- Figure 42 Development Strategy 4 – 2035 system design



Development Strategy 4 – Full 132kV Migration
(2035 Vision)

Appendix D Cost breakdown

D.1 Development Strategy 1

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Medical Centre	66/6.6 kV	Existing transformers are >51 years old in 2011.	Replace transformers with 2 x 35 MVA in 2014	2.18	2	4.36	2014
Medical Centre	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	1	1.01	2014
Medical Centre	66 kV	Replacement line switchgear	New 66 kV line circuit, single bus	1.21	2	2.41	2014
Medical Centre	11 kV	2 x replacement LV switchboard	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2014
Medical Centre	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2014
Shenton Park	66/6.6 kV	Existing transformers exceed N ratings in 2013	Replace transformers with 3 x 35 MVA in 2014	2.18	3	6.54	2014
Shenton Park	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	3	3.03	2014
Shenton Park	66 kV	Replacement switchgear to accompany replacement 66 kV circuits	New 66 kV line circuit, single bus	1.21	1	1.21	2014
Shenton Park	66 kV	New 66 kV CB required for new WT - SP cable circuit	Add 66 kV line circuit, single bus	1.21	1	1.21	2014
Shenton Park	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	1	1.54	2014
Shenton Park	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2014
University	66/6.6 kV	Existing transformers exceed N rating in 2013	Replace transformers with 2 x 35 MVA in 2014	2.18	2	4.36	2014
University	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2014
University	66 kV	Replacement line switchgear	New 66 kV line circuit, single bus	1.21	2	2.41	2014
University	11 kV	2 x replacement LV switchboard	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2014
University	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2014
Herdsman	11 kV	Additional distribution cabling for 11 kV conversion	9.5km 11 kV 3 x 1C 400Al XLPE cable	0.41	9.5	3.94	2015
Western Terminal	66 kV	New switchgear for fourth 132/66 kV transformer	Add 66 kV transformer circuit, single bus	1.01	1	1.01	2014
Western Terminal	66 kV	New switchgear for fourth 132/66 kV transformer	Add 66 kV bus coupler - required to provide fourth bus-section	1.00	1	1.00	2014
Western Terminal	132 kV	New switchgear for fourth 132/66 kV transformer	Add 132 kV breaker and half 1 ocb for new TX, 2 gantry, 1 cct	1.61	1	1.61	2014
Western Terminal	132/66 kV	Existing transformers exceed N-1 rating in 2015	Add 100 MVA 132/66 kV transformer in 2015	3.74	1	3.74	2015
Wembley Downs	66/6.6 kV	Existing TXs exceed NCR rating in 2018	Add third TX (35 MVA) in 2017	2.18	1	2.18	2017
Wembley Downs	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	1	1.54	2017

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
University	11 kV	Additional distribution cabling for 11 kV conversion	13.6km 11 kV 3 x 1C 400Al XLPE cable	0.41	13.6	5.64	2015
Nedlands	66/6.6 kV	Existing transformers exceed N rating in 2018	Replace transformers with 2 x 35 MVA in 2018	2.18	2	4.36	2018
Nedlands	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	3	3.03	2018
Nedlands	66 kV	Replacement switchgear to accompany replacement 66 kV circuits	New 66 kV line circuit, single bus	1.21	2	2.41	2018
Nedlands	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2018
Western Terminal	66 kV	New 66 kV CB required for new WT - SP cable circuit	Add 66 kV line circuit, single bus	1.21	1	1.21	2018
WT - SP	66 kV	New circuit required for N-1 outage of WT - SP or WT - WD in 2018	Add 132 kV UGC cable (3 x 1C 2000mm^2 CU XLPE)	3.75	1.5	5.63	2018
Herdsman	66/6.6 kV	Existing transformers exceed NCR rating ~2030. 50 Years old in 2011.	Replace transformers with 2 x 35 MVA in 2014	2.18	2	4.36	2020
Herdsman	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2020
Herdsman	66 kV	Replacement line switchgear	New 66 kV line circuit, single bus	1.21	2	2.41	2020
Herdsman	11 kV	2 x replacement LV switchboard	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2020
Herdsman	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2020
Nedlands	66/6.6 kV	Replacement 35 MVA units exceed N-1 rating by 2020	3rd 35 MVA Tx at Nedlands	2.18	1	2.18	2020
Nedlands	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	1	1.54	2020
Cottesloe	132/11 kV	Loading exceeds NCR rating by 2020	Replace 33 MVA TXs with duel LV winding 75 MVA units	3.31	2	6.63	2020
Wembley Downs	66/6.6 kV	Existing 27 MVA TXs time expired by 2025	Replace 27 MVA units with 2 x 35 MVA in 2025	2.18	2	4.36	2025
Wembley Downs	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2025
Wembley Downs	66 kV	Replacement line switchgear	New 66 kV line circuit, single bus	1.21	2	2.41	2025
Wembley Downs	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2025
WT - WD	66 kV	Existing OHL will be 60 years old by 2025	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	5.31	2.11	2025
N - U	66 kV	Existing OHL 60 years old by 2026, not N-1 compliant by 2030	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	3.05	1.21	2026
SP - HE	66 kV	Existing OHL 60 years old by 2025, not N-1 compliant by 2026	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	12.02	4.78	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement 66 kV circuits	New 66 kV line circuit, single bus	1.21	4	4.82	2026

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Western Terminal	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV bus coupler	1.00	2	1.99	2026
WT - N	66 kV	Existing OHL 60 years old by 2026, not N-1 compliant by 2029	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	3.13	1.24	2026
Western Terminal	132/66 kV	TX1 and TX2 60 years old by 2028, TX1 in poor condition from 2024	TX1 and TX2 60 years old by 2028. Replace with new 2 x 100 MVA.	3.74	2	7.48	2028
WT - MC	66 kV	Existing OHL 60 years old by 2034, not N-1 compliant by 2028	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	2.73	1.09	2028
WT - MC	66 kV	Existing steel tower line section rated at 105MVA.	Re-string 1.39km steel tower line with Venus conductor	0.50	1.39	0.70	2028
WD - HE	66 kV	Existing OHL will be 60 years old by 2029	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	4.8	1.91	2029
U - MC	66 kV	Existing OHL 60 years old by 2033	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	1.64	0.65	2033

D.2 Development Strategy 2

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Medical Centre	66/6.6 kV	Existing transformers are >51 years old in 2011.	Replace transformers with 2 x 35 MVA in 2014	2.18	2	4.36	2014
Medical Centre	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	1	1.01	2014
Medical Centre	66 kV	Replacement line switchgear	New 66 kV line circuit, single bus	1.21	2	2.41	2014
Medical Centre	11 kV	2 x replacement LV switchboard	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2014
Medical Centre	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2014
University	66/6.6 kV	Existing transformers exceed N rating in 2013	Replace transformers with 2 x 35 MVA in 2014	2.18	2	4.36	2014
University	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2014
University	66 kV	Replacement line switchgear	New 66 kV line circuit, single bus	1.21	2	2.41	2014
University	11 kV	2 x replacement LV switchboard	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2014
University	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2014
Herdsman	11 kV	Distribution cabling works associated with transfer of Herdsman	6 x 3.8km 11 kV feeders with 3 x 1C 400Al XLPE	0.41	22.8	9.44	2015
Shenton Park	132/11 kV	New TXs for 132 kV upgrade to achieve N-1 compliance	132/11 kV (duel winding 75 MVA) TXs installed	3.31	2	6.63	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV line circuit, single bus	1.37	2	2.74	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV transformer circuit, single bus	1.29	3	3.86	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV bus coupler	1.11	2	2.22	2015
Shenton Park	11 kV	Additional LV switchboards for duel wind transformers	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2015
Shenton Park	132 kV	New substation building and site works	Site Works - standard zone substation Metro	1.91	1	1.91	2015
Shenton Park	132 kV	New substation building and site works	Zone sub relay room (brick wall)	1.46	1	1.46	2015
Shenton Park	132 kV	New substation building and site works	Other substation costs - estimate	1.00	1	1.00	2015
University	11 kV	Additional distribution cabling for 11 kV conversion	13.6km 11 kV 3 x 1C 400Al XLPE cable	0.41	13.6	5.64	2015
Western Terminal	132 kV	New 132 kV switchgear for SP/MC double circuit line	132 kV breaker and half 3 ocb, 3 gantry 2 cct	3.00	1	3.00	2015
WT - NT	132 kV	SP upgraded to 132 kV to deload northern 66 kV ring	132 kV Venus wood pole line (for temporary loop in and out at SP)	0.40	0.5	0.20	2015
WT - SP	132 kV	SP upgraded to 132 kV to deload northern 66 kV ring	132 kV Venus wood pole line (permanent loop in and out at SP)	0.40	0.5	0.20	2015
Wembley Downs	66/6.6 kV	Existing TXs exceed NCR rating in 2018	Add third TX (35 MVA) in 2017	2.18	1	2.18	2017

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Wembley Downs	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	1	1.54	2017
WT - SP	66 kV	New circuit required for N-1 outage of WT - SP or WT - WD in 2018	Add 132 kV UGC cable (3 x 1C 2000mm^2 CU XLPE)	3.75	1.5	5.63	2017
WT - WD	66 kV	Existing OHL will be 60 years old by 2025	132 kV double circuit steel pole - Venus	2.19	5.31	11.62	2017
Nedlands	66/6.6 kV	Existing transformers exceed N rating in 2018	Replace transformers with 2 x 35 MVA in 2018	2.18	2	4.36	2018
Nedlands	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	3	3.03	2018
Nedlands	66 kV	Replacement switchgear to accompany replacement 66 kV circuits	New 66 kV line circuit, single bus	1.21	2	2.41	2018
Nedlands	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2018
Nedlands	66/6.6 kV	Replacement 35 MVA units exceed N-1 rating by 2020	3rd 35 MVA Tx at Nedlands	2.18	1	2.18	2020
Nedlands	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	1	1.54	2020
Cottesloe	132/11 kV	Loading exceeds NCR rating by 2020	Replace 33 MVA TXs with duel LV winding 75 MVA units	3.31	2	6.63	2020
Wembley Downs	66/6.6 kV	Existing 27 MVA TXs time expired by 2025	Replace 27 MVA units with 2 x 35 MVA in 2025	2.18	2	4.36	2025
Wembley Downs	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2025
Wembley Downs	66 kV	Replacement line switchgear	New 66 kV line circuit, single bus	1.21	2	2.41	2025
Wembley Downs	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2025
N - U	66 kV	Existing OHL 60 years old by 2026, not N-1 compliant by 2030	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	3.05	1.21	2026
Shenton Park	132/11 kV	3rd transformer required to maintain N-1 compliance post 2026	132/11 kV (duel winding 75 MVA) TXs installed	3.31	1	3.31	2026
Shenton Park	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement 66 kV circuits	New 66 kV line circuit, single bus	1.21	4	4.82	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV bus coupler	1.00	2	1.99	2026
WT - N	66 kV	Existing OHL 60 years old by 2026, not N-1 compliant by 2029	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	3.13	1.24	2026
Western Terminal	132/66 kV	T1 and T2 60 years old by 2028, TX1 in poor condition from 2024	T1 and T2 60 years old by 2028. Replace with new 2 x 100 MVA.	3.74	2	7.48	2028

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
WT - MC	66 kV	Existing OHL 60 years old by 2034, not N-1 compliant by 2028	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	2.73	1.09	2028
WT - MC	66 kV	Existing steel tower line section rated at 105MVA.	Re-string 1.39km steel tower line with Venus conductor	0.18	1.39	0.25	2028
U - MC	66 kV	Existing OHL 60 years old by 2033	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	1.64	0.65	2033

D.3 Development Strategy 3

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Medical Centre	132/11 kV	New TXs for 132 kV upgrade to achieve N-1 compliance	132/11 kV (duel winding 75 MVA) TXs installed	3.31	2	6.63	2014
Medical Centre	132 kV	New AIS switchgear for substation	132 kV line circuit, single bus	1.37	2	2.74	2014
Medical Centre	132 kV	New AIS switchgear for substation	132 kV transformer circuit, single bus	1.29	2	2.57	2014
Medical Centre	132 kV	New AIS switchgear for substation	132 kV bus coupler	1.11	1	1.11	2014
Medical Centre	11 kV	2 x replacement LV switchboard plus duel winding TXs	11 kV switchboard with tilt panel sw/room Type 1	1.54	4	6.16	2014
Medical Centre	132 kV	New substation building and site works	Site Works - standard zone substation Metro	1.91	1	1.91	2014
Medical Centre	132 kV	New substation building and site works	Zone sub relay room (brick wall)	1.46	1	1.46	2014
Medical Centre	132 kV	New substation building and site works	Other substation costs - estimate	1.00	1	1.00	2014
Herdsman	11 kV	Distribution cabling works associated with transfer of Herdsman	6 x 3.8km 11 kV feeders with 3 x 1C 400Al XLPE	0.41	22.8	9.44	2015
Shenton Park	132/11 kV	New TXs for 132 kV upgrade to achieve N-1 compliance	132/11 kV (duel winding 75 MVA) TXs installed	3.31	2	6.63	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV line circuit, single bus	1.37	4	5.48	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV transformer circuit, single bus	1.29	3	3.86	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV bus coupler	1.11	2	2.22	2015
Shenton Park	11 kV	Additional LV switchboards for duel wind transformers	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2015
Shenton Park	132 kV	New substation building and site works	Site Works - standard zone substation Metro	1.91	1	1.91	2015
Shenton Park	132 kV	New substation building and site works	Zone sub relay room (brick wall)	1.46	1	1.46	2015
Shenton Park	132 kV	New substation building and site works	Other substation costs - estimate	1.00	1	1.00	2015
University	11 kV	Distribution cabling works associated with transfer of University	12 x 2km 11 kV feeders with 3 x 1C 400Al XLPE	0.41	24	9.94	2015
WT - NT	132 kV	SP upgraded to 132 kV to deload northern 66 kV ring	132 kV Venus wood pole line (temporary loop in and out at SP)	0.40	0.5	0.20	2015
WT - SP	132 kV	SP upgraded to 132 kV to deload northern 66 kV ring	132 kV Venus wood pole line (permanent loop in and out at SP)	0.40	0.5	0.20	2015
Wembley Downs	66/6.6 kV	Existing TXs exceed NCR rating in 2018	Add third TX (35 MVA) in 2017	2.18	1	2.18	2017
Wembley Downs	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	1	1.54	2017
Nedlands	66/6.6 kV	Existing transformers exceed N rating in 2018	Replace transformers with 2 x 35 MVA in 2018	2.18	2	4.36	2018

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Nedlands	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	3	3.03	2018
Nedlands	66 kV	Replacement switchgear to accompany replacement 66 kV circuits	New 66 kV line circuit, single bus	1.21	2	2.41	2018
Nedlands	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2018
SP - MC	132 kV	SP and MC upgraded to 132 kV to deload northern 66 kV ring	132 kV double circuit steel pole - Venus	1.15	1	1.15	2018
SP - MC	132 kV	SP and MC upgraded to 132 kV to deload northern 66 kV ring	132 kV 2000mm^2 U/G	3.17	3.6	11.42	2018
SP - MC	132 kV	SP and MC upgraded to 132 kV to deload northern 66 kV ring	132 kV cable transition structure	0.22	1	0.22	2018
Western Terminal	132 kV	New 132 kV switchgear for SP/MC double circuit line	132 kV breaker and half 3 ocb, 3 gantry 2 cct	3.00	1	3.00	2018
Nedlands	66/6.6 kV	Replacement 35 MVA units exceed N-1 rating by 2020	3rd 35 MVA Tx at Nedlands	2.18	1	2.18	2020
Nedlands	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	1	1.54	2020
Cottesloe	132/11 kV	Loading exceeds NCR rating by 2020	Replace 33 MVA TXs with duel LV winding 75 MVA units	3.31	2	6.63	2020
Wembley Downs	66/6.6 kV	Existing 27 MVA TXs time expired by 2025	Replace 27 MVA units with 2 x 35 MVA in 2025	2.18	2	4.36	2025
Wembley Downs	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2025
Wembley Downs	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV line circuit, single bus	1.21	2	2.41	2025
Wembley Downs	66 kV	Substation building and structures refurbishment	Building, civils and substations refurbishment	4.37	1	4.37	2025
WT - WD	66 kV	Existing OHL will be 60 years old by 2025	132 kV double circuit steel pole - Venus	2.19	5.31	11.62	2025
Shenton Park	132/11 kV	3rd transformer required to maintain N-1 compliance post 2026	132/11 kV (duel winding 75 MVA) TXs installed	3.31	1	3.31	2026
Shenton Park	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement 66 kV circuits	New 66 kV line circuit, single bus	1.21	4	4.82	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV transformer circuit, single bus	1.01	2	2.02	2026
Western Terminal	66 kV	Replacement switchgear to accompany replacement transformers	New 66 kV bus coupler	1.00	2	1.99	2026
WT - N	66 kV	Existing OHL 60 years old by 2026, not N-1 compliant by 2029	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	3.13	1.24	2026

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Western Terminal	132/66 kV	T1 and T2 60 years old by 2028, TX1 in poor condition from 2024	T1 and T2 60 years old by 2028. Replace with new 2 x 100 MVA.	3.74	2	7.48	2028

D.4 Development Strategy 4

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
Medical Centre	132/11 kV	New TXs for 132 kV upgrade to achieve N-1 compliance	132/11 kV (duel winding 75 MVA) TXs installed	3.31	2	6.63	2014
Medical Centre	132 kV	New AIS switchgear for substation	132 kV line circuit, single bus	1.37	2	2.74	2014
Medical Centre	132 kV	New AIS switchgear for substation	132 kV transformer circuit, single bus	1.29	2	2.57	2014
Medical Centre	132 kV	New AIS switchgear for substation	132 kV bus coupler	1.11	1	1.11	2014
Medical Centre	11 kV	2 x replacement LV switchboard	11 kV switchboard with tilt panel sw/room Type 1	1.54	4	6.16	2014
Medical Centre	132 kV	New substation building and site works	Site Works - standard zone substation Metro	1.91	1	1.91	2014
Medical Centre	132 kV	New substation building and site works	Zone sub relay room (brick wall)	1.46	1	1.46	2014
Medical Centre	132 kV	New substation building and site works	Other substation costs - estimate	1.00	1	1.00	2014
Herdsman	11 kV	Distribution cabling works associated with transfer of Herdsman	6 x 3.8km 11 kV feeders with 3 x 1C 400Al XLPE	0.41	22.8	9.44	2015
Shenton Park	132/11 kV	New TXs for 132 kV upgrade to achieve N-1 compliance	132/11 kV (duel winding 75 MVA) TXs installed	3.31	2	6.63	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV line circuit, single bus	1.37	4	5.48	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV transformer circuit, single bus	1.29	3	3.86	2015
Shenton Park	132 kV	New AIS switchgear for substation	132 kV bus coupler	1.11	2	2.22	2015
Shenton Park	11 kV	Additional LV switchboards for duel wind transformers	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2015
Shenton Park	132 kV	New substation building and site works	Site Works - standard zone substation Metro	1.91	1	1.91	2015
Shenton Park	132 kV	New substation building and site works	Zone sub relay room (brick wall)	1.46	1	1.46	2015
Shenton Park	132 kV	New substation building and site works	Other substation costs - estimate	1.00	1	1.00	2015
University	11 kV	Distribution cabling works associated with transfer of Herdsman	12 x 2km 11 kV feeders with 3 x 1C 400Al XLPE	0.41	24	9.94	2015
WT - NT	132 kV	SP upgraded to 132 kV to deload northern 66 kV ring	132 kV Venus wood pole line (temporary loop in and out at SP)	0.40	0.5	0.20	2015
WT - SP	132 kV	SP upgraded to 132 kV to deload northern 66 kV ring	132 kV Venus wood pole line (permanent loop in at SP)	0.40	0.5	0.20	2015
Wembley Downs	66/6.6 kV	Existing TXs exceed NCR rating in 2017	Add 3rd 132-66/11 kV 75MVA TX	3.31	1	3.31	2017
Wembley Downs	11 kV	2 x additional LV switchboard for duel wind TXs	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2017

Substation/Circuit	Voltage	Driver	Equipment	Cost $M/Unit	Unit	Cost, $M	Date
C - N	132 kV	Existing 66 kV OHL will be 60 years old by 2018	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	4.4	1.75	2018
Nedlands	132 kV	Reroute line entries to sub to new GIS building, 3 x 100m	132 kV 2000mm^2 U/G	4.33	0.3	1.30	2018
Nedlands	66/6.6 kV	Existing transformers exceed N rating in 2018	Replace existing TXs with duel LV winding units in 2018	3.31	2	6.63	2018
Nedlands	132 kV	New GIS substation for 132 kV uprating	New GIS switchgear for 2 line and 2 transformer circuits	10.00	1	10.00	2018
Nedlands	11 kV	Additional LV switchboards for duel wind transformers	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2018
Nedlands	132 kV	New substation building and site works	Site Works - standard zone substation Metro	1.91	1	1.91	2018
Nedlands	132 kV	New substation building and site works	Other substation costs - estimate	1.00	1	1.00	2018
SP - MC	132 kV	SP and MC upgraded to 132 kV to deload northern 66 kV ring	132 kV double circuit steel pole - Venus	1.15	1	1.15	2018
SP - MC	132 kV	SP and MC upgraded to 132 kV to deload northern 66 kV ring	132 kV 2000mm^2 U/G	3.17	3.6	11.42	2018
SP - MC	132 kV	SP and MC upgraded to 132 kV to deload northern 66 kV ring	132 kV cable transition structure	0.22	1	0.22	2018
Western Terminal	132 kV	New 132 kV switchgear for SP/MC double circuit line	132 kV breaker and half 3 ocb, 3 gantry 2 cct	3.00	1	3.00	2018
WT - N	132 kV	Existing 66 kV OHL 60 years old by 2026, not N-1 compliant by 2029	Rebuild 66 kV line to 132 kV Venus wood pole spec	0.40	3.13	1.24	2018
WT - WD	132 kV	Existing 66 kV OHL will be 60 years old by 2025	132 kV double circuit steel pole - Venus	2.19	5.31	11.62	2018
Cottesloe	132/11 kV	Loading exceeds NCR rating by 2020	Replace 33 MVA TXs with duel LV winding 75 MVA units	3.31	2	6.63	2020
Wembley Downs	66/6.6 kV	Existing 27 MVA TXs time expired by 2025	Replace existing TXs with 132/11 duel LV winding TX in 2017	3.31	1	3.31	2025
Wembley Downs	132 kV	New AIS switchgear for substation	132 kV line circuit, single bus	1.37	2	2.74	2025
Wembley Downs	132 kV	New AIS switchgear for substation	132 kV transformer circuit, single bus	1.29	2	2.57	2025
Wembley Downs	132 kV	New AIS switchgear for substation	132 kV bus coupler	1.11	1	1.11	2025
Wembley Downs	132 kV	New substation building and site works	Site Works - standard zone substation Metro	1.91	1	1.91	2025
Wembley Downs	132 kV	New substation building and site works	Zone sub relay room (brick wall)	1.46	1	1.46	2025
Wembley Downs	132 kV	New substation building and site works	Other substation costs - estimate	1.00	1	1.00	2025
Shenton Park	11 kV	Additional LV switchboard for 3rd TX	11 kV switchboard with tilt panel sw/room Type 1	1.54	2	3.08	2026
Wembley Downs	66/6.6 kV	3rd transformer required to maintain N-1 compliance post 2026	132/11 kV (duel winding 75 MVA) TXs installed	3.31	1	3.31	2026

Appendix E Environmental considerations

E.1 Western Terminal – Nedlands

E.1.1 Transmission line(s)

- Southern end of line route is a very established residential area. Community pushback likely to be very high if an overhead option is chosen.
- Look at utilising existing line route to reduce impact. If double circuit (DC) is required the amount of community pushback is very likely to increase due to greater clearance requirements plus the use of large steel structures.
- If the existing line needs to be kept energised, cabling seems like a very likely option.
- Stirling Highway crossing and busy residential areas likely to have to be cabled.

E.1.2 Substations

- Western Terminal - should be relatively easy to accommodate any substation extension.
- Nedlands – Western Power owns five parcels of land at Nedlands substation including 922 m^2 (vacant), 923 m^2, 461 m^2, 461 m^2 and 922 m^2. This provides a total land area of 3689 m^2 or approximately 80 m x 45 m. Noise mitigation is likely to be required. Costs associated with visual impact to be considered. Located within a residential area and the visual impact of the substation will be a very sensitive issue.

E.2 Western terminal – Wembley Downs

E.2.1 Transmission line(s)

- Look at utilising existing line route to reduce impact. If double circuit is required the amount of community pushback is very likely to increase.
- If a new line route is required large community pushback would be expected along the majority of the line route apart from a small section to the south.

E.2.2 Substations

- Western Terminal – as in E.1.2.
- Wembley Downs – Likely to need to acquire more land around substation which will be very difficult due to limited space. Surrounding land currently owned by local council. Need to also account for noise mitigation, visual impact costs and vegetation clearing.

E.3 Western terminal – Shenton Park

E.3.1 Transmission line(s)

- If a new line route is required it is expected that this will necessitate cabling due to the restriction of current line routes occupying both sides of the road. It may be possible to provide a more creative solution, however considering the constrained roads surrounding the terminal, some sections of these line entries will still require to be cabled.

E.4 Medical Centre – University

E.4.1 Transmission line(s)

- Line route will run through a very established residential area. Utilising the existing 66 kV line route would likely make approvals easier if an overhead option is preferred. If double circuit is required, cabling seems like the only viable option.

E.4.2 Substations

- Medical Centre – It is assumed that the land will be gifted by the customer, therefore there shouldn't be a problem with acquiring the site. Visual impact and noise mitigation to be considered. Line entry is likely to be cabled. Community pushback likely if transition structures are used and an overhead option chosen.
- University – very limited space for an extension.

E.5 Medical Centre - Nedlands

E.5.1 Transmission line(s)

- Utilisation of the existing 66 kV line is the best option. If the same alignment is utilised, community pushback should be reduced. If double circuit is required more issues will arise.
- Stirling Highway crossing plus busy residential areas likely to have to be cabled.
- If a new alignment is used, extensive community engagement will be required.

E.5.2 Substations

- Medical Centre – as in E.4.2
- Nedlands – as in E.1.2

E.6 Shenton Park – Medical Centre

E.6.1 Transmission line(s)

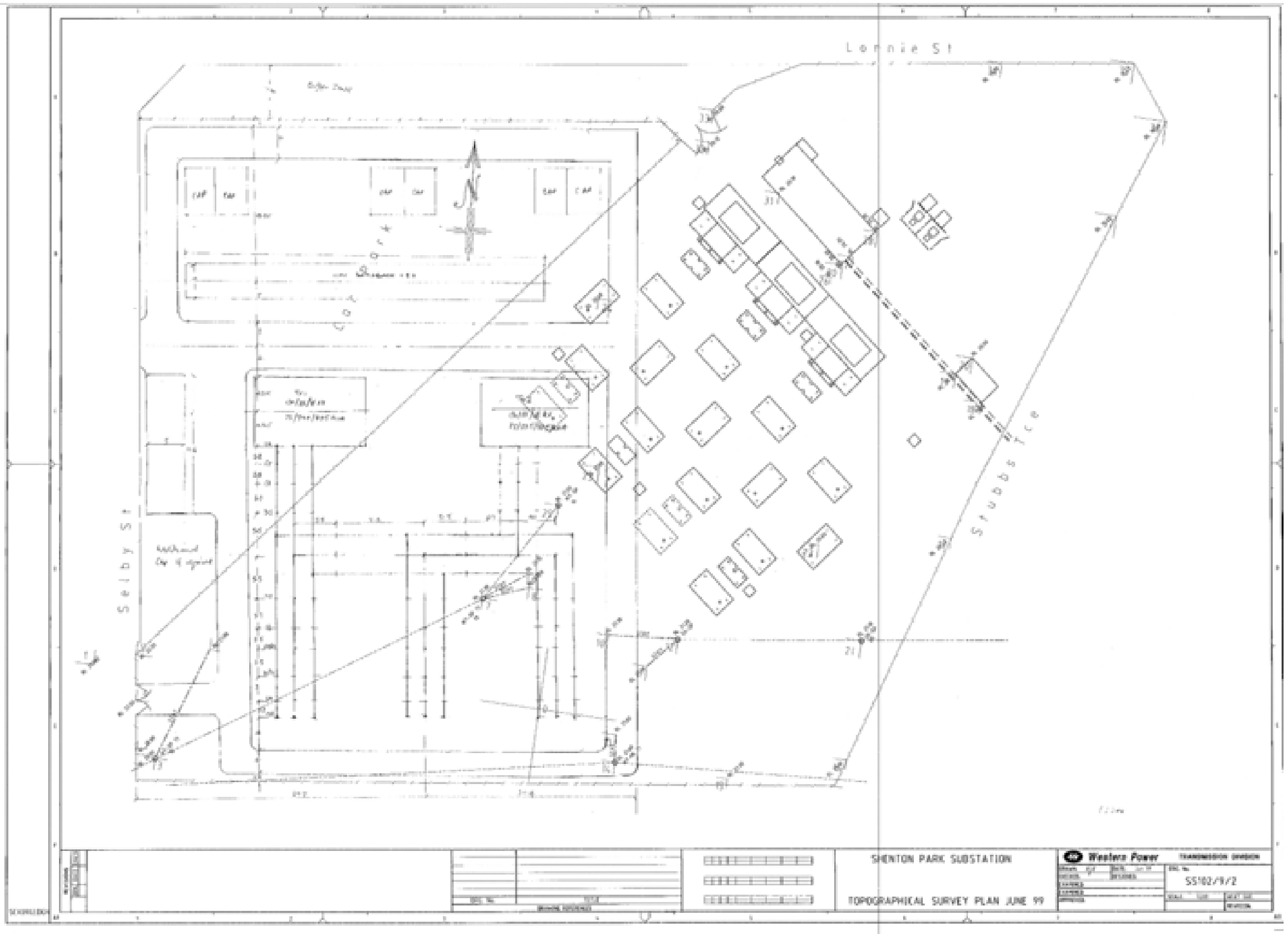
- Utilisation of the existing 66 kV line is the best option. If the same alignment is utilised, community pushback should be reduced. If DC more issues will arise.
- Cabling will likely be necessary from the Medical Centre to Stubbs Terrace then overhead to Shenton Park.

E.6.2 Substations

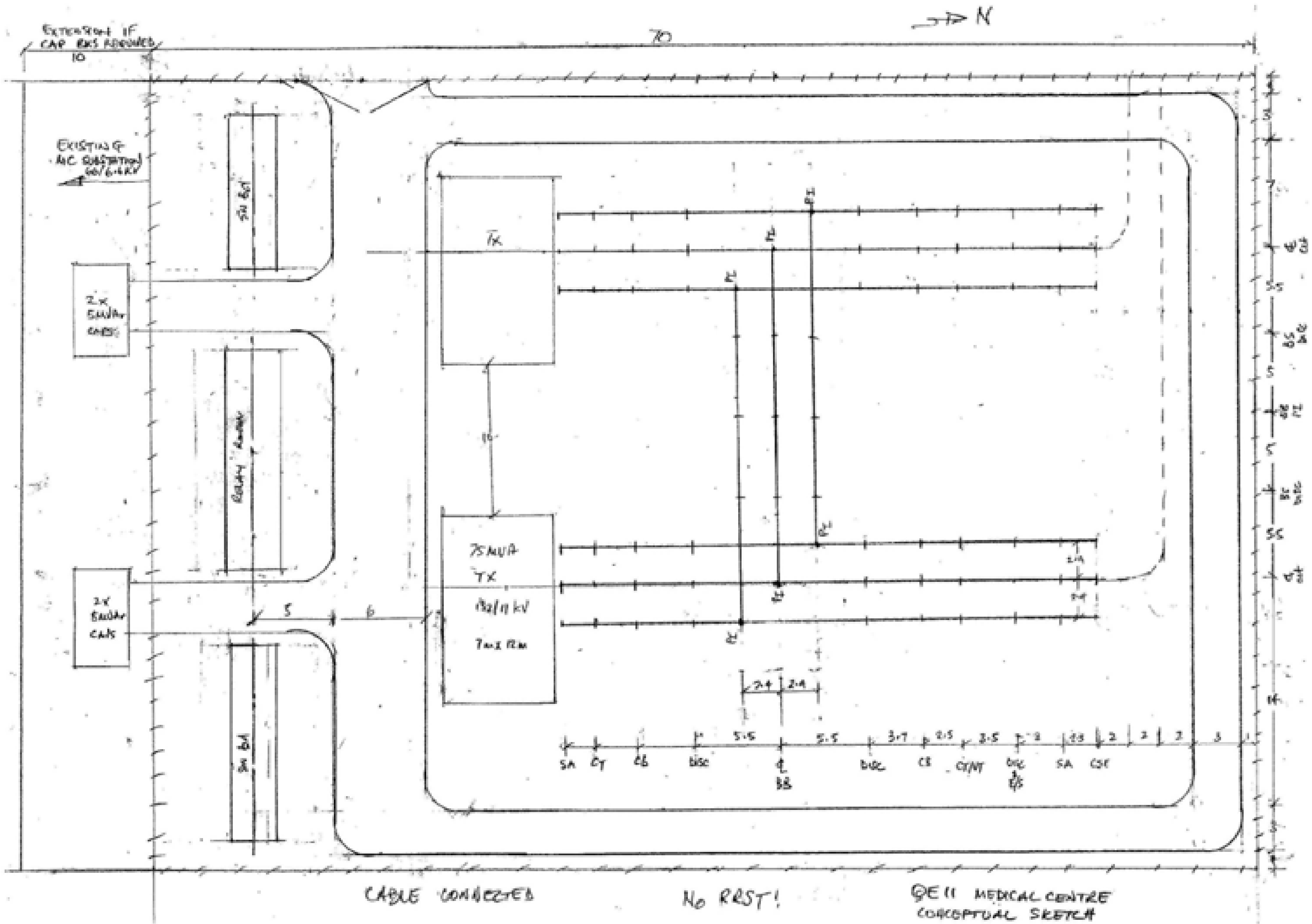
- Shenton Park – Extra land state owned (ie, planning commission) but reserved or 'put aside' for Western Power purposes. Approximately 3000 m^2. Need to also account for noise mitigation, visual impact costs and vegetation clearing.
- Medical Centre – as in E.4.2

Appendix F Substation concepts

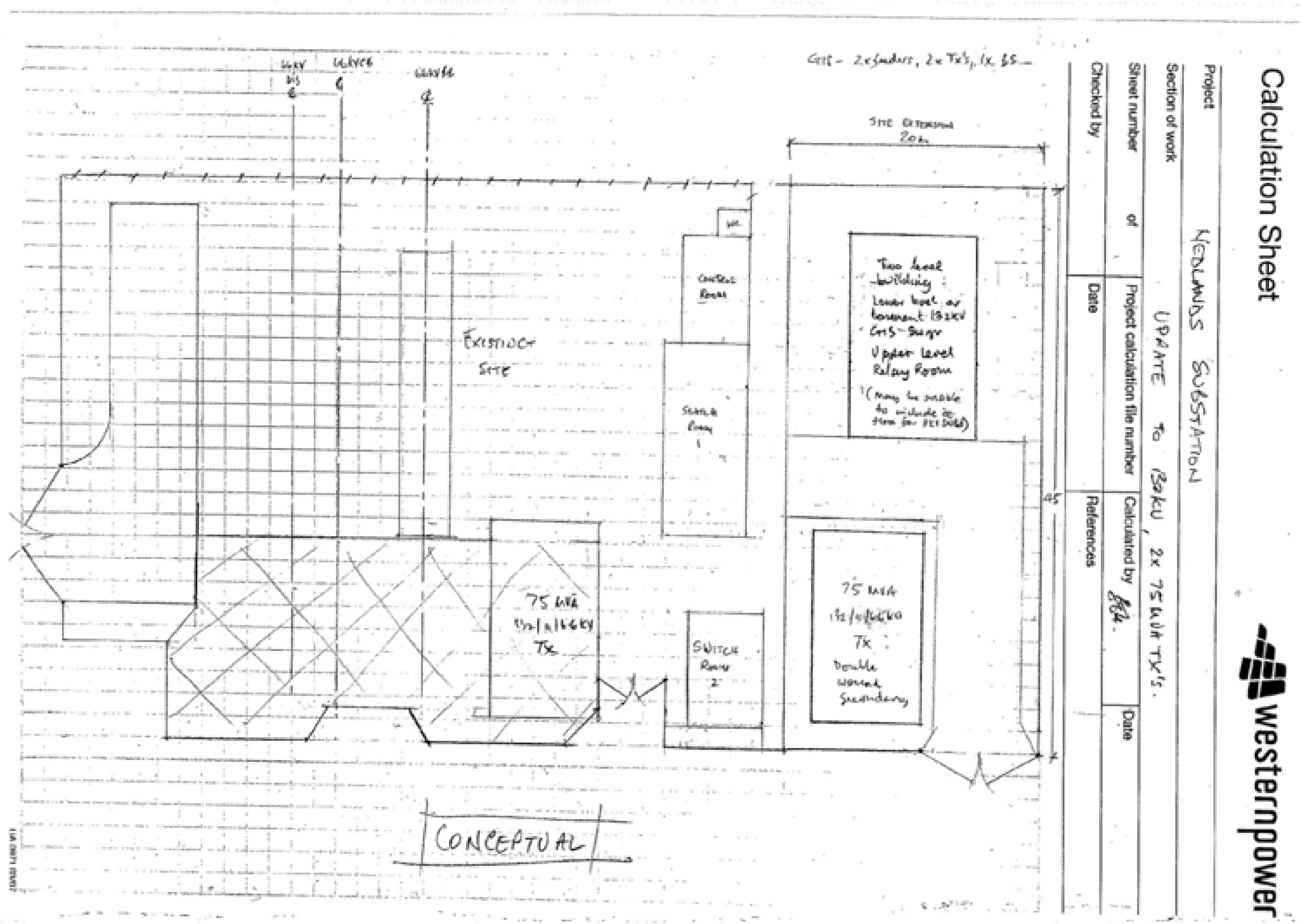
- Figure 43 Shenton Park substation development concept



- Figure 44 Medical Centre substation development concept



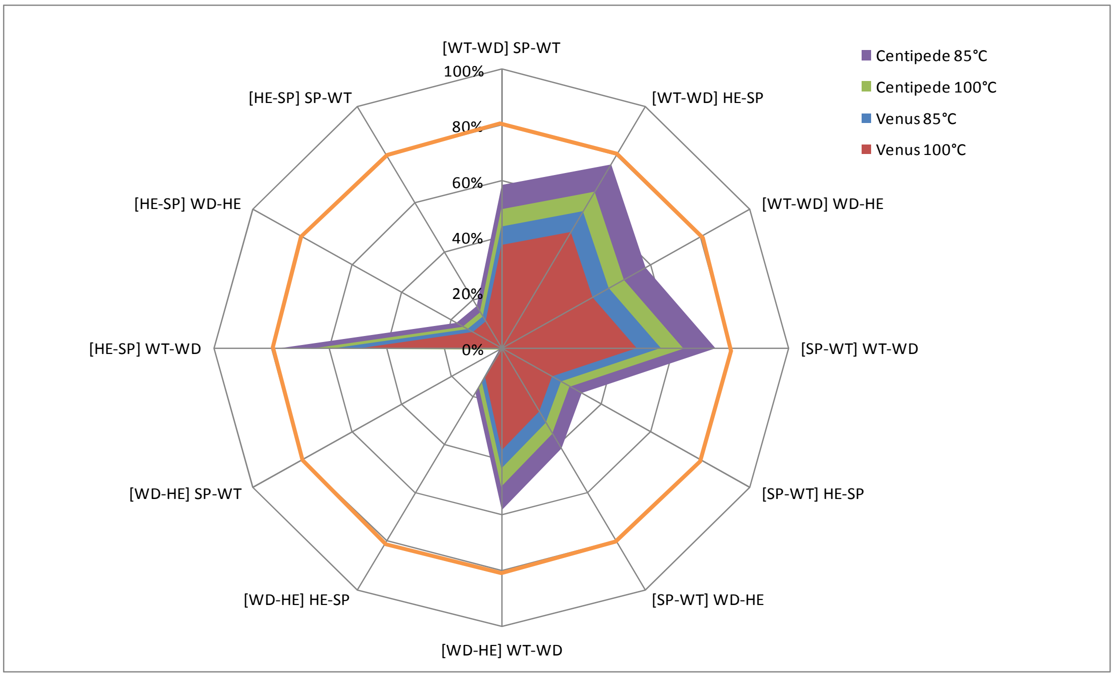
- Figure 45 Nedlands substation development concept



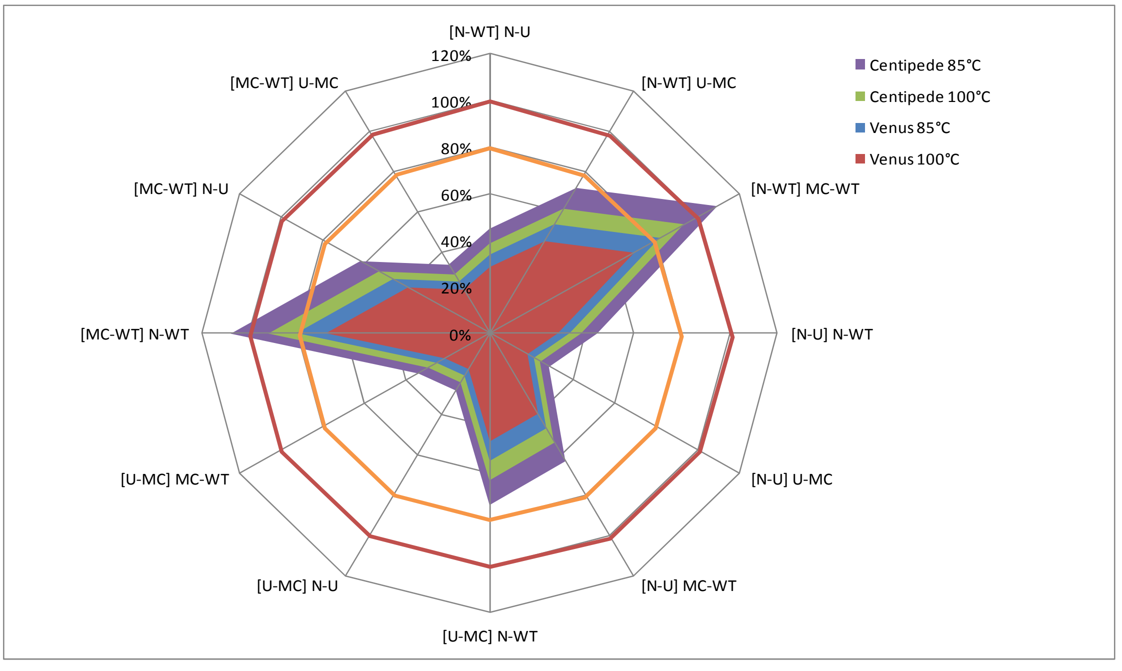
Appendix G Line rating sensitivity

G.1 Development Strategy 1

■ Figure 46 Line rating sensitivity (north ring)

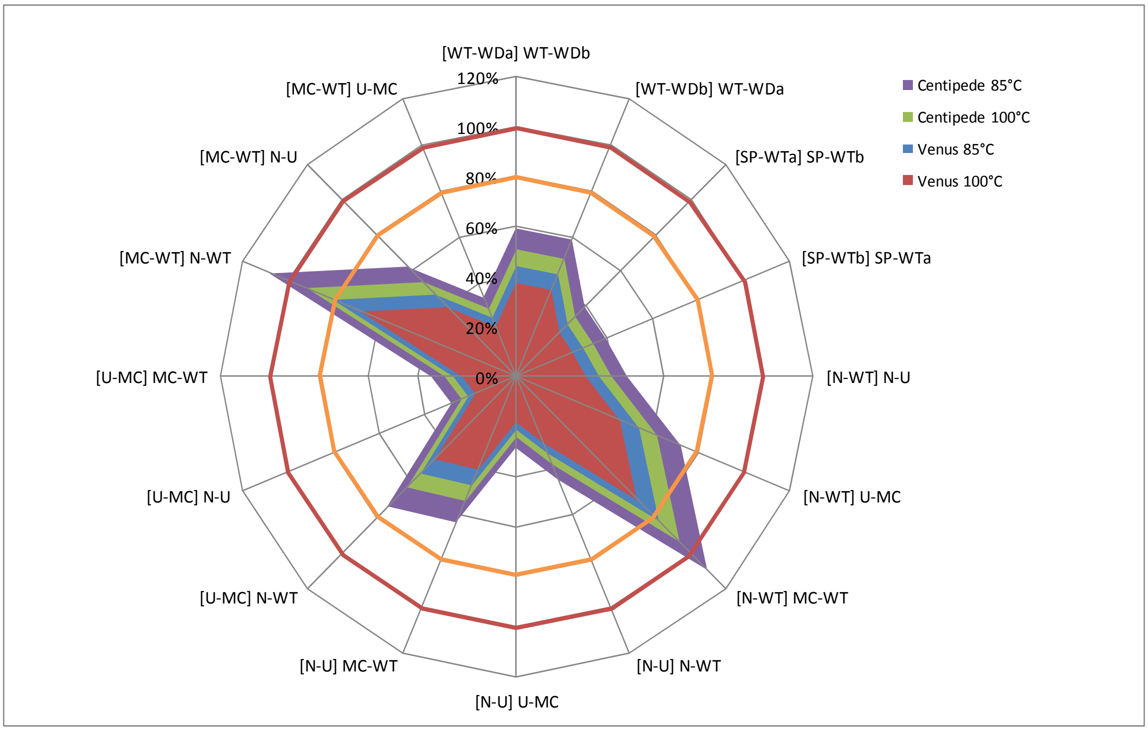


■ Figure 47 Line rating sensitivity (south ring)



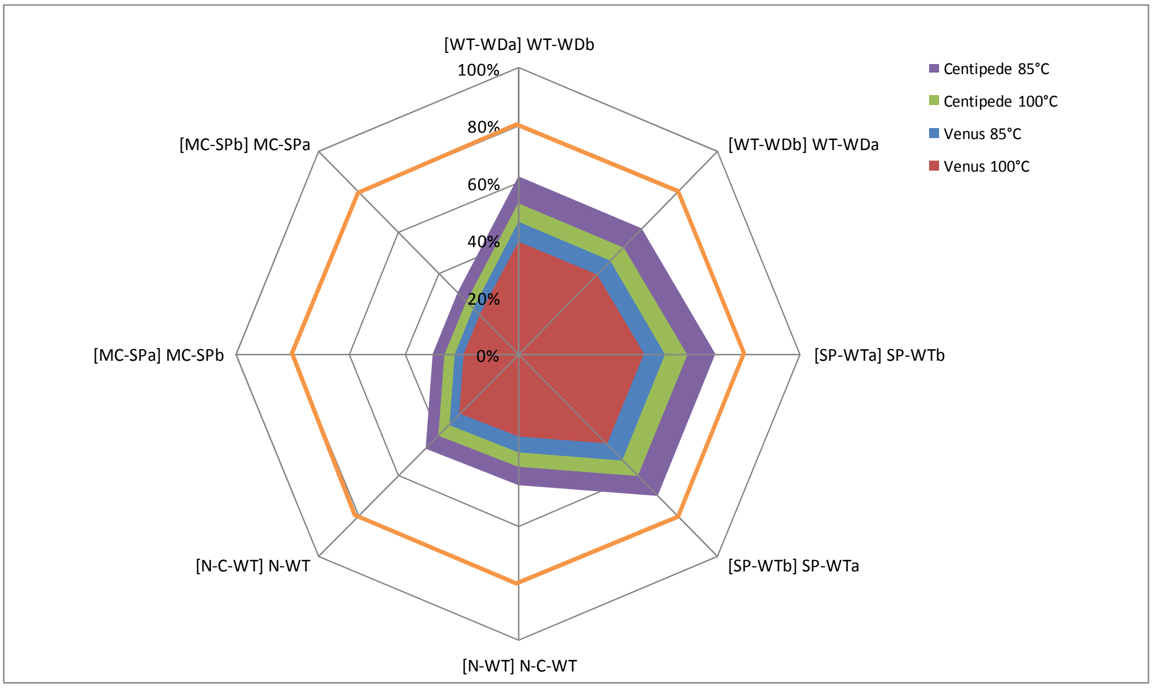
G.2 Development Strategy 2

- Figure 48 Line rating sensitivity



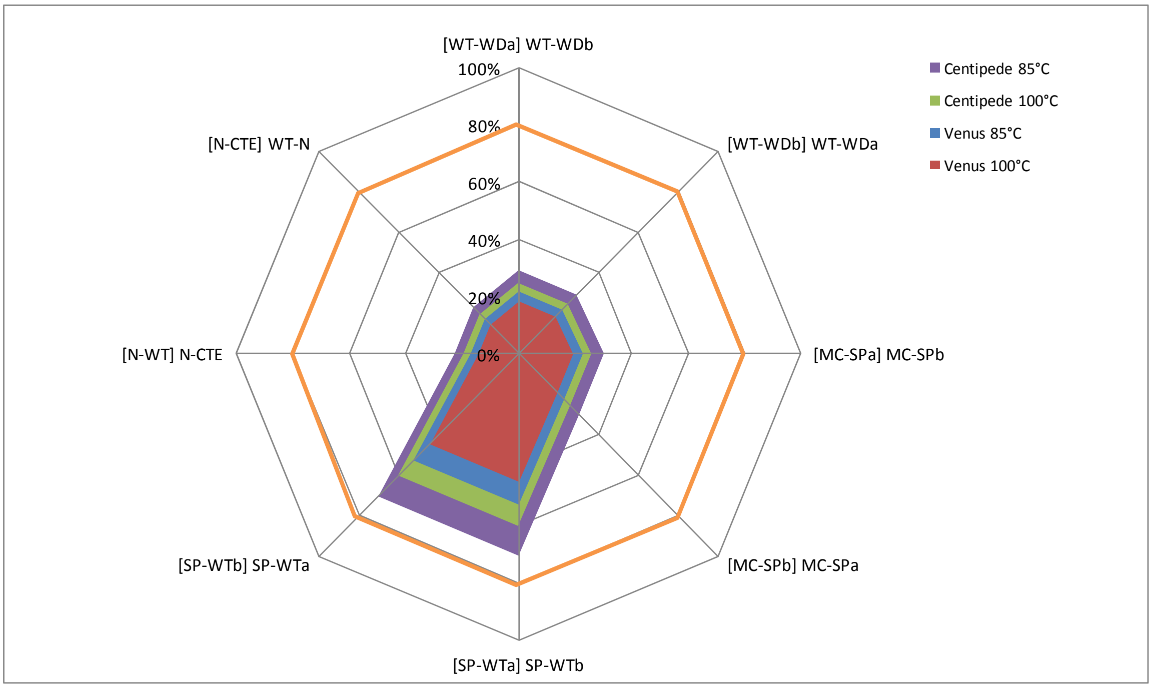
G.3 Development Strategy 3

- Figure 49 Line rating sensitivity



G.4 Development Strategy 4

- Figure 50 Line rating sensitivity



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