Nuttall Consulting

Regulation and business strategy

Victoria over-capacity review

Is over-capacity the reason for low augmentation levels in Victoria?

A report to the AEMO

27 July 2012

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Executive summary

Introduction

Since the formation of the National Electricity Market (NEM), there has been significantly less augmentation of the Victorian transmission network than the networks in other states, particularly NSW and Queensland. Recently, this has meant that the Victorian regulated asset base has remained relatively constant, whereas the asset bases in NSW and Queensland have increased considerably. This in turn has resulted in more significant price increases in these states.

Victoria has different planning arrangements than other states in the NEM. Therefore, there is a question as to whether the difference between states in the level of augmentation is primarily due to these differences or simply a result of differences in the historical level of spare capacity (called *over-capacity* in this report).

AEMO has commissioned Nuttall Consulting to consider whether greater levels of over-capacity in the Victorian electricity transmission network could be the main reason for the low amount of network augmentation in Victoria compared to NSW and Queensland.

It is important to stress that the aim of this assignment has not been to answer definitively whether or not over-capacity was the reason for the lower level of network augmentation in Victoria[1]. Rather, it has been to consider whether there is high-level evidence that this may or may not have been the case. With this in mind, a high-level review has been conducted involving the following.

- **Background review**. A background review of relevant material has been conducted, including previous regulatory proposals, annual planning reports and AEMO documents. Meetings with AEMO operational and planning staff have also been held. This background review has considered:
    - the external drivers of augmentation (e.g. growth in peak demand) in each region
    - the historical development of the networks in each region and the extent of recent augmentations
    - the changing profile of operational challenges in each region.
- **Analysis of asset utilisation**. To gauge the level of over-capacity, the average utilisation of the lines and transformers in each region, at the time of the peak demand in that region, has been calculated over the period 2000 to 2011[2]. To improve the robustness of this measure for making relative comparisons, adjustments have been made to correct for weather and differences in how the ratings are defined in each region.

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[1] Such positive assurance would require far more extensive analysis of the specific network limitations and augmentations that have occurred over this period.

[2] Utilisation here is defined as the loading on the asset divided by its rating, where both the loading and rating are those applicable at the time of the regional peak demand.

Background review

The background review suggests that there was over-capacity in Victoria and NSW in the late 90s. This resulted from the development, in both regions, of 500 kV networks in the 70s and 80s, based upon anticipated load that did not eventuate. This view is also supported by the valuations of both networks that were conducted in the 90s that led to portions of the value of these networks being removed from the asset base.

Circumstances were different for Queensland however. This region appears to have been under far more challenging conditions than Victoria or NSW. Prior to NEM entry in 1998, AEMO operators noted that the Queensland network was close to its natural limits, and so, network support from generation was often used to optimise network capability further. At times, the system was also permitted to operate in an insecure state, if the risks were considered acceptable. However, following entry to the NEM, due to the NEM rules, a more risk-averse approach to operating and developing the network appears to have been taken.

Since that time, Queensland has also faced significantly greater external drivers on augmentation than Victoria or NSW. In Queensland, peak demand has doubled since around 1994/95, with almost a 50% increase over the study period here, 2000 to 2011. This growth rate is around double that which occurred in Victoria and about three-times that which occurred in NSW over the same periods. Importantly, in all three regions, the annual growth rate has reduced significantly during the same period. Furthermore, in Queensland and NSW, actual peak demand has been lower than forecast.

Queensland has also had by far the greatest increase in new generation, with around a 50% increase since 2000/01, which is over three-times the increase in Victoria and NSW.

To counter these external pressures, a very large augmentation program has been undertaken in Queensland. It has been estimated that this resulted in transformer capacity more than doubling over the period from 2000 to 2011, and line capacity increasing by over 50% over the same period. NSW has also undergone a large augmentation program over this period, with line capacity increasing by nearly 50% and transformer capacity by 30%. In both Queensland and NSW, the majority of the line developments have occurred since 2006 – noting that this is during the period when growth rates have been at their lowest and actual peak demand has been lower than forecast.

Victoria, on the other hand, has seen relatively modest augmentation levels, making use of load shedding control schemes, line uprating opportunities, and additional capacity released through the real-time rating system adopted in Victoria. Transformer capacity over 2000 to 2011 increased by around 25%, with line capacity only increasing by approximately 3%.

AEMO operational staff no longer consider that Queensland has significant operational challenges, and now consider that Victoria has the most pressing issues. This view also can be seen through changes to regional congestion (where there now appears to be far less congestion in Queensland) and AEMO's contingency planning documents (which show that Victoria has a greater number of high-impact contingencies that may need to be managed).

That said, many of the current challenges in Victoria cannot be directly linked to a lack of spare capacity. Some are due to historical design decisions, and others are due to accepted fault-level mitigation practices. Moreover, some of the most significant operational risks in Victoria for the preceding summer (2011/12) were more a consequence of delays in planned augmentations, rather than decisions to defer projects.

Overall, these findings suggest that over-capacity in Victoria could have been the reason for differences between Victoria and Queensland, at least in the late 90s and some years following. However, over-capacity may not be the main reason for the difference in augmentation levels between Victoria and NSW.

Analysis of utilisation

This view is supported in part by the analysis of the utilisation of the transmission networks in the three regions. The two charts below show the results of this analysis for transformers and lines. The results include the corrections for weather and line ratings. The dashed lines signify the unknown utilisation for the years between the calculated figures for 2000 and 2006.

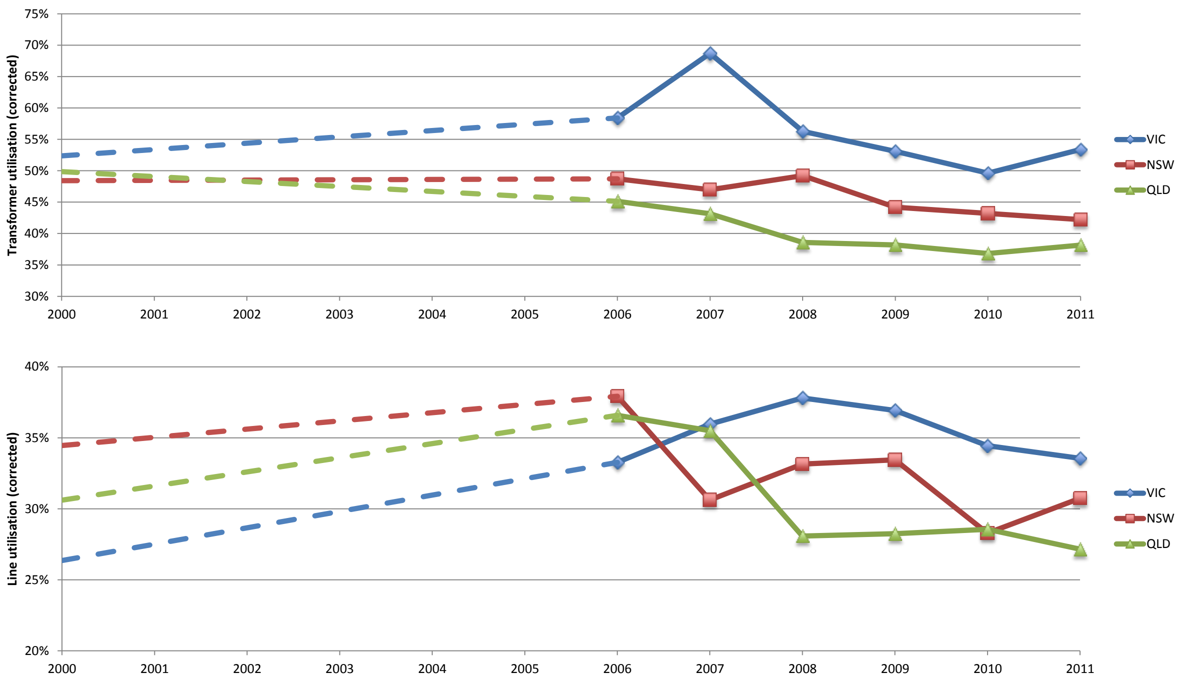

Figure i – transformer and line average utilisation

For transformers, this analysis suggests that Victoria has been operating with significantly higher utilised transformers than both NSW and Queensland since around 2000. In the late 90s, the utilisation of Victorian transformers was probably similar to NSW and Queensland transformers. However, since that time, transformer utilisation has diverged between Victoria and NSW/Queensland. Up to around 2006, transformer capacity additions in NSW and Queensland largely tracked the growth in peak demand, with utilisation being maintained in NSW and reduced modestly in Queensland. In Victoria, however, up to around 2007, there was little transformer capacity added to the network, and so, utilisation increased. Since that time, utilisation has reduced in all three regions, but with the relative difference between regions being maintained.

For lines, the analysis suggests that both the Queensland and NSW lines were utilised significantly more than Victoria in 2000. This is in line with the findings of the background review for Queensland, but also suggests that NSW was also in a more challenging situation than Victoria with regard to the utilisation of its lines. This *does* suggest that around 2000, for both Queensland and NSW, over-capacity in Victoria could have been a reason for the lower levels of line augmentation in that region.

From around 2006 however, the Victorian lines began to be utilised at higher levels than NSW and Queensland. In particular, Queensland line utilisation has reduced significantly since that time. This reduction in utilisation is as expected, given the high levels of augmentation and lower levels of demand growth over this period, noted from the background review. The higher utilisation of the Victorian lines compared to NSW and Queensland could suggest that over-capacity is not the reason for the lower line augmentation levels, since around 2006.

Importantly, in Victoria, the utilisation of the 500 kV lines has a large impact on the average utilisation. The Victorian 500 kV lines, on average, have a lower utilisation than the other lines in Victoria. For example, the average 500 kV line utilisation from 2006 to 2011 is 28%, whereas it is 37% for the 220 kV lines and 51% for the 330 kV lines. The low average utilisation for the 500 kV lines is significantly affected by the two long circuits from Heywood to Moorabool, which have a very low utilisation at the time of peak demand. From this analysis, it seems clear that there was, and still is, significant over-capacity in these lines.

However, an important point for this review is not whether over-capacity exists, but whether it is resulting in lower levels of augmentation. From this point of view, AEMO planners consider that this spare capacity – which is significant in scale – has not affected the augmentation needs in Victoria in a significant way. Furthermore, the review of operational challenges found that the current arrangements, particularly associated with the 500 kV network, might affect the usable capacity. As such, the Victorian line utilisation metric may understate the augmentation pressures in comparison to the utilisation of other regions.

Other factors

Other differences between regions have also been considered with regard to affecting the relationship between this utilisation measure and augmentation pressures. These factors concern:

- **demand diversity** - where the peak loading of many assets may not be at the time of the regional peak – this is most relevant in Queensland due to the distances between its main load centres in the south, central and north/far north area
- **demand peakiness** - where the higher peakiness in the Victorian demand may reduce the risks compared to the less peaky demand in Queensland and NSW, such that a higher utilisation can be achieved for a similar risk profile
- **demand density** (e.g. MW delivered per km of line) – where voltage and stability limits in lower density areas may mean that the thermal ratings cannot be economically achieved.

Based upon area-specific loading data for Queensland, provided by AEMO, and the demand duration curves provided in the AEMO's statement of opportunities, the implication of diversity and peakiness have been estimated. This analysis found that the Queensland and NSW utilisations could be boosted by around 16% and 6% respectively to put them on a like-for-like basis with Victoria[3].

[3] These are in relative terms i.e. 16% boost to a 40% utilisation would be an increase of 6.4%.

For transformers, this would close the gap between Victoria and NSW/Queensland. However, the utilisation of Victorian transformer would remain significantly higher than both Queensland and NSW.

For lines, this would still leave Victoria with higher utilised lines from around 2008, but the difference would be small (i.e. 1% to 3%), with Queensland at similar levels. That said, there is some uncertainty in the basis of the line ratings used in Queensland. AEMO data showing the increase in ratings that have been achieved when real-time ratings have been adopted in Queensland suggest that the ratings may be more conservative than assumed in the results presented above. This may mean that Queensland line utilisation should be reduced by 10% to 20%. If this were the case then this would offset the diversity and peakiness adjustments noted above. As such, Victoria would remain with utilisation differences around the level suggested by Figure *i* above.

The lower load densities – and therefore longer transmission distances – in NSW, and particularly Queensland, could still mean that the lower utilisations in NSW and Queensland are comparable to Victoria in defining augmentation needs. To gauge this effect, the relationship of the line utilisation metrics against the load density has been examined. However, the results of this analysis are less definitive as it is difficult to determine a trend from the limited number of data points.

On balance, its seems reasonable to assume Queensland and possibly NSW were above a comparable utilisation with Victoria around 2006, but had both fallen below this level by 2011. As such, there is probably a transitional period between 2006 and 2011, when over-capacity in Victoria ceased to be a cause for lower levels of augmentation. This position seems reasonable, given:

- the actual growth in peak demand over this recent period in NSW and Queensland, which has been lower than forecast, while augmentation levels have been at their highest
- the significant reduction in the operational challenges in Queensland, since 2000
- the points made above on the 500 kV network and Heywood to Moorabool 500 kV lines in Victoria.

Overall view and concluding comments

Based upon the overall review, it seems reasonable to conclude that over-capacity in Victoria compared to NSW and Queensland is unlikely to have resulted in the lower levels of augmentation in Victoria, at least over the recent past i.e. from around 2006/07.

For lines, it *does* appear that over-capacity in Victoria, compared to NSW and Queensland, could have been a significant factor in the lower augmentation levels prior to 2006/07. This certainly seems to be the case in the late 90s and the early part of the last decade, when Victoria appears to have had a significantly lower line utilisation than Queensland and NSW. For transformers, however, it appears that this has not been the case since around 2004, and possibly much earlier.

Noting the caveat in the introduction above on the nature of this review, it is important to stress that these findings are not considered conclusive proof on this matter (i.e. a proof positive that over-capacity did not or does not exist). Nonetheless, it is believed that sufficient confidence could be taken from these findings that reasonably compelling evidence to the contrary would be required to justify an opposing position.

1 Introduction

1.1 Summary findings

In this paper it is shown that the reason for the recent low levels of augmentation expenditure in Victoria compared to NSW and Queensland is unlikely to be due to historical levels of excessive spare capacity (over-capacity) in the Victorian electricity transmission network.

The analysis presented here does support a view that over-capacity in Victoria, particularly in lines, could have been a cause for the low levels of augmentation compared to the other states in the late 90s to around 2006. However, the analysis indicates that, for around the last six years, it is less likely that this was the cause of expenditure differences.

It is important to stress that the review has been conducted at a high-level; detailed technical/economic analysis of past network limitations and their solutions has not been examined. As such, these findings should *not* be considered to provide conclusive proof on these points. Nonetheless, we consider that sufficient confidence could be taken from the findings that reasonably compelling evidence to the contrary would be required to justify an opposing position.

1.2 Background and appreciation

Since 2000, capital expenditure associated with increasing the capability – also known as augmentation - of the National Electricity Market (NEM) transmission networks has increased. This has resulted in significant increases in the value of some of the Transmission Network Service Provider's (TNSP) regulatory asset bases (RABs), most notably in NSW and Queensland.

In Victoria however over the same period the level of augmentation has been much lower. Consequently, the Victorian RAB has not changed so significantly over this period.

Victoria has different structural arrangements associated with transmission network planning than the other NEM states. In this regard, the party responsible for planning the augmentation of the network is different from the party responsible for owning and maintaining the network. The Australian Energy Market Operator (AEMO) has the responsibility for the augmentation of the network (e.g. planning and procuring the additional network capacity)[4]; SP AusNet is the owner and maintainer of the majority of the transmission assets.

Victoria also operates an economic risk-based network planning approach – often referred to as probabilistic planning. This approach assesses the economic risks associated with specific network limitations (e.g. the likelihood and consequence of interrupting supplies

[4] This is in addition to AEMO's role as the independent system operator and national planner across the NEM.

to customers or constraining the economic dispatch of generation) and uses cost-benefit assessments to determine whether a specific augmentation is required and what the optimal solution should be.

This approach differs from NSW and Queensland, where state-based standards define redundancy levels in the network for particular circumstances – often referred to as deterministic planning.

AEMO's view is that the Victorian arrangements and its planning approach, taken together, are a primary factor in its recent lower levels of augmentation expenditure compared to other states. This view has been put forward by AEMO in recent reviews of the transmission arrangements being conducted by the AEMC and the Productivity Commission.

It is understood that a counter-argument being put forward is that the primary reason for the reduced level of augmentation in Victoria is over-capacity (or "gold-plating") that existed in its network in the 90s, compared to NSW or Queensland. In this regard, the view is that AEMO's ability to draw upon this existing over-capacity is the main reason for augmentation expenditure in Victoria being low, rather than the differing arrangements and/or planning approach deferring needs.

AEMO has engaged Nuttall Consulting to undertake a review to determine whether this could be the case. This report details the findings of this review.

1.3 Terms of reference

The review was to build upon previous analysis of asset utilisation that had been undertaken by Nuttall Consulting on behalf of AEMO, and was to focus on the transmission networks in the three regions Victoria, NSW and Queensland.

The aim of the review was to consider the extent of over-capacity in the Victorian network, and determine whether this was the reason for the lower augmentation levels in Victoria compared to NSW and Queensland. In assessing this issue, the review was to have regard to historical, current and future outlook between the three regions of the following:

- network development
- network expenditure
- maximum demand
- network utilisation
- network operating practices applied
- operational issues
- other planning or operational matters which will contribute to the analysis.

1.4 Structure of report

This report is structured as follows:

- Section 2 provides a brief overview of the review methodology.
- An important aspect of this review is the analysis of asset utilisation. The rationale for this analysis is provided in Section 3.
- The findings of a background review on network demand, developments and operations are contained in Section 4.
- Sections 5 and 6 discuss the utilisation analysis and present the results of the analysis. These sections discuss various approaches that have been applied to allow like-for-like comparisons of utilisation between regions.
- The overall findings are summarised and conclusions drawn in Section 7.

2 Methodology

The review has included the following tasks:

- the analysis of asset utilisation
- a background review of relevant published information
- a series of meetings with AEMO operating and planning staff.

A brief outline of the methodology associated with these tasks is discussed in turn below.

2.1 Analysis of asset utilisation

To gauge whether the level of network capacity could be causing a difference in augmentation needs, the assessment process has focused on the analysis of the average utilisation of the transmission network assets at regional peak demand periods. To limit the review, we have focused on the period from 2000 to 2011. The rationale for this analysis is provided in Section 3.

This analysis has involved the following:

- extraction of actual utilisation data from AEMO's data systems for the years between 2006 and 2011 (inclusive)
- the calculation of average utilisation metrics between 2006 and 2011 from this data, covering transformers and lines in each region.
- the correction of these metrics to enable like-for-like comparisons between regions
- the estimation of the equivalent metric in 2000, based upon the growth in peak demand and network developments in each region.

Further details of the analysis methodology are contained in Sections 5 and 6.

2.2 Background review

To support the utilisation analysis, available documents have been reviewed. The aim of this review has been to determine for each region:

- drivers of recent augmentation, including
  - the actual and forecast growth in peak demand
  - generation and interconnector developments
- network developments and implications on network capacity
- operational approaches and past issues.

The main documents reviewed have included TNSP annual planning reports, TNSP regulatory proposals and AER/ACCC regulatory determinations, and AEMO's statement of opportunities.

It is important to stress that it has not been possible in the time available to undertake extensive reviews of all these documents. In particular, this review has not attempted to review each network development and its associated network limitations and constraints.

2.3 AEMO meetings

The review has also included three formal meetings with AEMO staff, covering:

- Victoria/NSW operations (in AEMO NSW operations centre)
- Queensland operations (in AEMOs Queensland operations centre)
- Victoria planning (in AEMOs Melbourne offices)

The aim of these meetings was to obtain views from AEMO staff on various matters associated with this review, including:

- similarities and differences between regions in the data extracted from AEMOs systems, which has been used to prepare the utilisation metrics – particularly differences in asset ratings
- views on the historical development of the networks in each region
- views on different operating practices between regions
- views on the challenges faced by AEMO staff responsible for operating the networks in each state, and how these challenges have changed since the late 90s.

These meetings have been supported by various following-up clarifications.

3 Definition and rationale for the utilisation metric

The calculation and assessment of historical asset utilisation has been an important factor in this review. The utilisation of assets is considered a useful quantitative metric for this review as it is fairly simple and transparent to calculate, and it provides a useful gauge to the comparative level of spare capacity between regions. In turn, this suggests the different augmentation pressures – setting aside the differences in planning arrangements and approaches between regions.

It is important to stress, Nuttall Consulting is not claiming a perfect correlation between asset utilisation and augmentation pressures. Even allowing for the correction factors noted in this report, there will be specific network circumstances that can result in comparatively different augmentation needs for a similar utilisation level. Nonetheless, conceptually at least, it seems reasonable to assume that as the utilisation of a network increases then the likelihood that it will need to be augmented should increase also. Moreover, a business that can achieve a higher utilisation of its assets compared to others – while still providing a comparatively equivalent output service – could be considered more efficient/productive in some sense (although, gauging efficiency/productivity is not the focus of this review).

In this section, the utilisation metrics used in this review are defined and the rationale for the metric is discussed. Following this, the main factors that need to be considered when calculating such a metric and using it for the purposes here are discussed.

The utilisation metric is defined to reflect the average utilisation across a population of assets in each region. The **utilisation** (as defined in this document) of any individual asset is taken to be its **loading at the time of regional peak demand** as a percentage of its **continuous thermal rating** at that time.

Two metrics are used to reflect the two main network planning components: transformers and lines[5]. A weighted average across the population of components is used to account for the scale of the individual components in each category i.e. the utilisation of a 1000 MVA transformer should have a greater contribution to the average than say a 100 MVA transformer. For each transformer, its rating is used as the weighting. For each line, its rating multiplied by its length is used.

Obviously, both the asset loading and its rating can vary with time, and as such, the utilisation will vary. Furthermore, the time when any individual asset (or group of assets) will be at its (or their) peak utilisation will depend on load patterns and the generation dispatch. For example, the highest utilisation of some assets associated with the interconnection to another region could reflect minimum regional demand conditions.

[5] Individual circuits rather than lines are actually used. However, to aid the readability of this report, the more general term of lines is used.

Moreover, specific transmission augmentation needs usually will be related to the utilisation of assets under outage conditions. For meshed transmission networks, typical in the NEM, the utilisation of any specific network element may change considerably under such an outage condition.

Nonetheless, we believe that asset utilisation at the regional peak demand time (and resulting dispatch pattern) should reflect the most onerous condition *across* the regional network asset base. Therefore, a metric based upon an average utilisation at that time represents a useful gauge to undertake comparative analysis across regions.

Setting aside issues under the control of policy makers, owners and planners (i.e. state-base planning standards, planning approaches, and risk aversion) there are still factors that could lead to differences between regions when making comparisons using such a metric. These factors can be considered in terms of:

- those affecting the calculation of the utilisation metric on a like-for-like basis
- those affecting the use of the metric for inferring comparable augmentation needs.

With regard to the calculation of the metric, the most critical factors to address to achieve like-for-like comparisons cover correcting for:

- differences in how thermal ratings are defined and applied in each region (as noted in Section 4, this differs in each state)
- the effect that weather (e.g. temperature) may have on the asset loading or asset ratings at the time of the regional peak.

In the analysis presented here, corrections to the actual measures, to account for both these factors, have been estimated. These matters are discussed in more detail in Section 5.

With regard to inferring augmentation needs from the metric, factors to consider include:

- the diversity in the timing of the load or location of generation – which may impact the extent that assets are at their peak utilisation at the time of the regional peak
- the "peakiness" of the demand – which would impact risks associated with the metric
- the impact transmission distances may have on network limits – which may affect whether or not thermal limits can be achieved or another underlying limitation will constrain the network first.

These matters are discussed in more detail in Section 6.

4 Background on networks

This section provides some background on the power systems in Victoria, NSW and Queensland. This information is considered relevant to the analysis of asset utilisation and the review in general.

This section provides:

- a summary of key parameters of the transmission networks in each region, indicating their relative scale
- an overview of the power systems in each state
- the different approach to define the thermal rating in each region
- the main external drivers of network augmentation faced by each TNSP, in terms of the growth in peak demand and connection of new generation
- the historical development of the network in each region, and the extent of recent major network augmentations
- the changing profile of operational challenges.

This section draws upon information obtained from the literature survey, views and information provided by AEMO staff, and the author's experience.

4.1 TNSP key parameters

Table 1 TNSP key parameters

	Victoria	NSW	Queensland
Peak demand (MW)	9,858	14,051	8,891
Energy (GWhr)	50,925	72,814	49,593
Line length (km)	6,553	12,656	13,569
RAB ($ billions)	2.7	4.6	4.9

The table above provides an overview of some of the key parameters of the transmission networks in Victoria, NSW and Queensland[6]. These parameters indicate the following:

- **Load size** - NSW is the largest system in terms of load delivered, including energy and peak demand. Victoria and Queensland are similar in scale in terms of energy delivered, at approximately 70% the size of NSW. However, Victoria has a

[6] This data is taken from the latest AER TNSP performance report (2009/10).

materially higher peak demand than Queensland, reflecting the "peakier" summer load in Victoria.

- **Network size** – Queensland has the largest network in terms of length of line, with Victoria the smallest. The Queensland network is over twice as long as Victoria, and approximately 5% longer than NSW. This difference results in a fairly significant difference in customer and load densities between Victoria and Queensland. For example, based upon the figure presented above, Victoria has a load density of 1.5 MW per km of transmission line, whereas the load density of Queensland is less than half that value at 0.7 MW per km.
- **Network value** – Reflecting the length of the network to some degree, the Queensland network also has the highest regulated asset base (RAB) and Victoria has the lowest. The Queensland RAB is almost double the Victorian RAB and approximately 7% greater than NSW[7].

4.2 Overview of transmission network and load characteristics

The following provides a brief overview of the transmission networks and load characteristics in each region.

4.2.1 NSW

The NSW demand can be considered in terms of three broad load centres. The main load centre spans the Wollongong, Sydney, and Newcastle area – accounting for the majority of demand. The remaining demand is largely located in the north east and south of the state and to the west of Sydney. NSW is currently a summer peaking state; however, it has only recently changed from a winter peaking state. This change occurred around 2008/09.

NSW has approximately 16 GW of installed generation capacity. The majority of this generation is located to the north of Sydney in the Hunter Valley region and west of Sydney. There is also a significant portion of generation in the Newcastle region.

The transmission network operates predominantly at 330 kV and 132 kV, but has a 500 kV ring that links the main generation sources to the north, north west and west of Sydney to the main Wollongong/Sydney/Newcastle load centre. The 500 kV ring has only recently been converted from 330 kV operation.

The 330 kV network transmits energy to the north and south load centres, with the 132 kV lines supplying surrounding areas in looped and meshed arrangements. There is also a small portion of 220 kV network that supplies load to the south west of the state (Balranald to Buronga to Broken Hill).

In NSW, the DNSPs also own and operate some of the 132 kV network and some substations that would be considered transmission terminal stations in Victoria. Of most

[7] The most recent AER regulatory determination for Queensland shows that the RAB has increased since the 2009/10 figure quoted here. The opening RAB for July 2012 is $6.4 billion (nominal).

note here is Ausgrid and Endeavour, who own, operate and plan the majority of the 132 kV network that services the Wollongong/Sydney/Newcastle load centre.

The main interconnections with other states are a 330 kV line to Queensland (QNI), and a predominantly 330 kV interconnection with Victoria. There is also a relatively weak 220 kV interconnection with Victoria, via the 220 kV circuit at Buronga; however, this interconnection serves more to support the load in that area.

4.2.2 Victoria

The Victorian demand can be considered in terms of two load centres. The main load centre covers Melbourne and Geelong – accounting for the majority of demand. The remaining demand is largely located in the regional areas north and west of the state. Victoria is a summer peaking state, with a relatively peaky demand due to the extremeness of summer peak temperatures.

Victoria has approximately 11 GW of installed generation capacity. The majority of this generation is located in the Latrobe Valley region to the east of Melbourne. Victoria is interconnected to NSW in the North, SA to the West, and Tasmania to the South (via Basslink and the Latrobe Valley).

The transmission network operates predominantly at 500 kV and 220 kV. The 500 kV network serves the bulk transfer of energy between the Latrobe Valley generators (and Basslink) to Melbourne and on to the interconnection with SA in the far west of the state. The 220 kV network provides support to the 500 kV network, but mainly provides an interconnected supply to the main Melbourne/Geelong load centre and the regional areas. Victoria also has some 330 kV lines linking the 330 kV interconnection with NSW to the 500 kV and 220 kV networks, north of Melbourne.

4.2.3 Queensland

The Queensland demand can be considered in terms of three main load centres that are relatively isolated from each other. The main load centre covers the south east of the state, including Brisbane and the Gold Coast. The remaining demand is largely located in the central area, including Rockhampton, and the north, including Cairns. Queensland is a summer peaking state; although, its peak is less pronounced than Victoria as it does not have such extreme changes in temperature.

Queensland has approximately 12 GW of installed generation capacity. The majority of this generation is located in the south and central areas. The load in the north is however supported by some generation also. Queensland is interconnected to NSW via a 330 kV link, known as QNI.

The transmission network operates predominantly at 275 kV, 132 kV and 110 kV. The 275 kV network provides the main backbone, linking the south to the north and the major generators to the three main load centres. The 275 kV is underpinned by the 132 KV or 110 kV network.

4.3 Approaches to rating lines

The analysis presented in this report relies upon the continuous thermal rating of transformers and lines. Therefore, it is important to appreciate differences in how the TNSPs define these ratings.

The asset owner – not the planner or system operator – is responsible for defining the thermal ratings that AEMO must operate the transmission network within. As we understand it, there is little difference in how owners approach defining the rating of transformers. For lines however there are major differences between TNSPs. Box 4.1 below provides an overview of the approach to determine line ratings.

Box 4.1 – Overview of line rating approaches

The actual thermal rating of lines is related to the temperature of the conductor. This temperature defines how much the conductor will deform – i.e. sag between adjacent towers. For safety reasons, a line has clearance limits that define the maximum permissible amount of sag. Additionally, a conductor has a maximum temperature beyond which its elastic properties will be lost, and so, its temperature should not exceed this point. The conductor temperature is related to a number of factors, most notably the loading on the conductor, but also the environmental parameters such as the ambient temperature and amount of wind.

Static line ratings

The historical method of defining a thermal rating was to define the set of environmental parameters that were not likely to be exceeded, such that there was a reasonable likelihood that a maximum loading could be defined that would be reasonably unlikely to exceed the conductor temperature or sag criteria. This approach is often referred to as a static rating, as the rating is fixed (or static) across a time period. To reduce conservatism in this approach, different static ratings can be defined for different time periods that have different environmental parameters. For example, winter and summer ratings, or even day and night ratings.

Real time line ratings

A more contemporary approach that has gained popularity recently is based upon making measurements of some of the environmental parameters or even the sag in the line, and then using a computer model of the thermal dynamics of the line to calculate the rating of the line associated with those measurements. This approach can calculate the rating of the line on a real-time basis, and so such ratings are often referred to real-time ratings (or alternatively dynamic ratings due to the use of the line model). A real-time rating system can normally achieve additional capacity for operational purposes over the conventional static rating approach.

NSW and Queensland both use a static rating to define most line ratings. It is noted that the TransGrid APR suggests that it applies some form of probabilistic approach to define the rating[8]; however, it is understood that this is used to define the appropriate parameters to calculate the relevant static rating.

In Victoria, the majority of the 220 kV lines use such a real-time rating system. All of these lines use a temperature measurement to calculate their rating. Additionally, some of the more heavily loaded lines use other measurements, such as wind speed, to optimise the rating further. These real-time ratings are calculated by SP AusNet's systems, but fed directly to AEMO's operational systems. AEMO also uses historical outcomes from these systems to define the ratings it uses for planning purposes.

4.4 Recent external drivers

Figure 1 Growth in peak demand

The growth in peak demand is generally the strongest driver of augmentation needs. The figure above shows the growth in peak demand that occurred over the three periods, covering the late 90s, the first half of the last decade and the second half of that decade up to 2010/11.

This chart shows that Queensland has faced significantly more challenging conditions than Victoria, and particularly NSW. The Queensland peak demand has more than doubled since the mid-90s, whereas the Victorian peak demand has only increased by just over 50% and the NSW demand has increased by less than 40%.

Interestingly, the growth in peak demand has been reducing appreciably in all three states over this whole period. This may be partly due to economic factors, such as the GFC, that affected the 2005/06 to 2010/11 period. But it could also be suggestive of a general trend in the growth in peak demand.

[8] A1.6, TransGrid Annual Planning Report 2011

Table 2 Accuracy of MD forecasts

	Previous review period			Current review period		
	Actual MD (MW)	Forecast MD (MW)	Difference	Actual MD (MW)	Forecast MD (MW)	Difference
VIC[a]	9700	9914	2.2%	10000	10057	0.6%
QLD[b]	7950	7198	-9.5%	8700	9624	10.6%
NSW[c]	14000	14370	2.6%	14100	14970	6.2%

a – Weather corrected actual demand, based upon 2011 APR. Previous review period forecast from 2002 SOO; current period forecast from 2006 APR.
b - Weather corrected actual demand, based upon 2011 APR. Previous review period forecast from 2000 SOO; current period forecast from 2006 APR.
c - Weather corrected actual demand, based upon 2011 APR. Previous review period forecast from 2003 APR; current period forecast from 2007 APR.

To appreciate the timing of the augmentation developments, discussed in the next sub-section, it is also useful to gauge the accuracy of the peak demand forecasts that underpinned these plans at the time of the TNSP's regulatory proposals. The table above indicates this accuracy. For the previous regulatory period, it shows the difference between the forecast maximum demand and actual maximum demand at the end of that period. For the current regulatory period, it shows the difference at 2010/11 – the end point for our analysis[9].

This table indicates that in the previous regulatory period the peak demand grew at a significantly greater rate than anticipated by Powerlink, possibly placing greater challenges on Powerlink during that period. However, in both Victoria and NSW, peak demand did not grow at the rate anticipated.

In the current period, the Victorian peak demand has grown largely at the rate anticipated. However, in NSW and particularly Queensland, the growth in actual peak demand is significantly lower than anticipated. For NSW the actual peak demand is still significantly lower than what was anticipated for the end of the previous regulatory period, possibly suggesting that any plans made for the previous regulatory period could have been spread over the previous and current regulatory periods. If augmentations have occurred as planned in Queensland and NSW then unnecessary capacity could have been added to the network.

The growth in new generation can also drive some augmentations; although, whether costs associated with these augmentation would enter the asset base is more likely to relate to their market impact[10]. The table below shows the increase in scheduled generation capacity that has occurred in each region from 2000/01 to 2005/06 and from 2005/06 to 2010/11.

[9] It is worth noting that as the regulatory periods in each region begin and end in different years. The number of years that the forecast to 2010/11 spans also differs.
[10] Noting that state-based customer reliability standards can define market assumptions.

Table 3 – Growth in generation capacity

	Growth in generation capacity	
	2000/01 to 2005/06	2000/01 to 2010/11
VIC	7%	15%
QLD	23%	54%
NSW	11%	14%

This table indicates generation capacity in Queensland has grown at approximately three times the pace of NSW and Victoria. These Queensland generation developments are predominantly to the South of the state, including Millimerran, Swanbank E, Tarong North, Braemar, Darling Downs, and Kogan Creek.

In addition to these generation developments, they have also been some major interconnector developments, including:

- the interconnector between NSW and Queensland, QNI, around 1999
- the interconnector between Victoria and Tasmania, Basslink, which is a direct current link that came into service in 2006.

From discussions with AEMO staff, it is understood that the effect of the increased level of generation in the south of Queensland plus the development of QNI has been to reduce the power flows that tend to move from the central to the south of the state. At times, the direction of flow can reverse, such that power can sometimes flow from the south to the central areas.

In Victoria, significant generation developments have occurred in the Melbourne metropolitan area and in the south west of Victoria. AEMO has advised that both these developments deferred planned transmission augmentations.

4.5 The development of the networks

In Victoria, the first 500 kV line was constructed in 1969, linking the Latrobe Valley generation to the Melbourne load centre (at South Morang). The 500 kV lines in NSW and other 500 kV lines in Victoria were developed in the 70s to early 90s. In NSW, many of the lines, although constructed to 500 kV, were only operated at 330 kV.

In Victoria, the 500 kV lines to the east of Melbourne were constructed to cater for the high load growth in Melbourne, increasing the transfer capacity from the main generation centre in the Latrobe Valley. It is understood that the basis for the anticipated need for the network capacity in NSW and to the west of Melbourne, achievable by these extra-high voltage lines, was state-based plans for the aluminium industry – and its power requirements. The industry however did not develop to the extent assumed at that time, and hence, much of the capacity available from this voltage was not required[11].

In Victoria and NSW, this appears to have resulted in the value of some of these assets being "optimised" out of the regulated asset base of the asset owners in the 90s. In NSW, it also resulted in the majority of the 500 kV lines continuing to be operated at 330 kV up until very recently (i.e. around 2010).

Queensland on the other hand did not develop with such a major transmission voltage. It appears that the transmission networks largely developed to supply the three main load centres and then the 275 kV network developed from the 70s in line with major generation developments, forming the backbone linking these load centres and generation sources. It appears that Queensland did not have any significant optimisations associated with the setting of its regulated asset base, possibly suggesting a lack of over-capacity at that time.

Since around 2000, there have been a large number of major augmentations in NSW and Queensland.

In NSW, there have been a large number of substation and transformer augmentations, covering Warahtah West, Coffs Harbour, Molong, Nambucca, Balranald, Gadara, Canberra, Koolkhan, Munmorah, Regentville, Tamworth, Vineyard, Glen Innes, Armidale, Vales Point, Port Macquarie, South Sydney, Sydney West, Sydney North, Tuggerah, Kempsey, Parkes, Tomago, Wollar, Macarthur. A number line augmentations have also been undertaken, covering the 330 kV cable to Haymarket, Western 500 kV line conversion, Wollar – Wellington 330 kV line, Coffs Harbour - Kempsey 132 kV line and 2nd circuit, uprating of Tamworth – Armidale line, uprating Armidale - Kempsey 132 kV line, uprating Armidale-Koolkhan 132 kV.

In Queensland, there has been a large number of 275 kV line developments, including the Belmont line, a line associated with the Gold Coast reinforcement project, a line associated with the Cairns reinforcement project, Belmont - Murarrie, Stanwell - Broadsound, the Lilyvale reinforcement, Maudsland – Molendinar, Greenbank-Maudsland, Broadsound-Nebo-Strathmore-Ross, Middle Ridge – Greenbank, Ross - Yabulu South, South Pine – Sandgate. In addition to these 275 kV lines, there have also been a number of line developments at other voltages, including the Millmerran –Middle Ridge 330 kV line, Ross-Townsville South 132 kV, Nebo – Pioneer Valley 132 kV, Lilyvale – Blackwater 132 kV, Rownsville South – Townsville East 132 kV, Bouldercombe - Pandoin 132 kV line, Bowen North – Strathmore 132 kV. There have also been a number of substation and transformer augmentations, including Algest, Goodna, Sumner, Loganlea, Molendinar, Murrarie, QR Mindi, Alan Sherriff, Strathmore, Edmonton, Nebo, Rocklea, Woolooga, Palmwoods, Swanbank, Greenbank, Middle Ridge, Woree, Teebar Creek, Townsville East, Abermain, Murarrie, Yabulu South, Pandoin, Larcom Creek, and South Pine.

[11] In NSW, this also resulted in the mothballing of a generating unit at Mt Piper for a number of years following its construction.

In contrast, there have been relative few major developments in Victoria. Three new 1000 MVA 500/220 kV transformers have been added (Cranbourne, Rowville and Moorabool) and two new terminal stations have been developed (South Morang and Wemen).

There have been no major line developments in this period. A significant amount of additional line capacity (2000 MW) was released by the conversion of an existing 220 kV line to 500 kV operation. But this was achieved at a relatively modest cost. The other major project, resulting in increased line capacity of 400 MW, was the upgrade to the NSW-VIC interconnector. But once again, this extra capacity was gained through fairly minor works, involving the addition of reactive plant, line upgrades and changing switching arrangements.

The bulk of additional line capacity since 2000 has been achieved by uprating existing lines and implementing wind monitoring schemes to allow line ratings to be increased, via the real time rating system used in Victoria which is discussed further below. Other risks due to the rising peak demand have been reduced via control schemes that can automatically shed load following critical network outages.

4.6 The changing profile of operational challenges

When the network is loaded close to its limits then operating it can be more challenging. For example, outages are more likely to lead to overloaded assets, and the need to re-arrange the network, re-dispatch generation, or in extreme situations, shed load. This can require risks to be assessed beforehand by operating staff and appropriate contingency plans prepared in anticipation of these circumstances. Therefore, views on the challenges associated with operating the network can be an indicator of the level of spare capacity in the network.

During the course of this review, AEMO operating staff have provided views on the challenges they face operating the networks in each region, and how these challenges have changed over recent times. The main views expressed were that significant challenges existed at various times in Queensland and Victoria, with NSW being *relatively* unchallenging. As such, this sub-section summarises these views in terms of Victoria and Queensland, and then provides a discussion on their relevance to the main issue under consideration in this review, namely over-capacity in Victoria.

4.6.1 Victorian challenges

The overall view from AEMO's Victorian operators is that operating the Victorian system has had some challenges since the 90s. Some challenges have eased; however, over the last decade, many challenges have increased significantly as network loading has increased.

The challenges relate to six main issues as follows.

- **Acceptance of risk associated with transformer loading**. Around the 80s, Victoria installed load shedding control systems in most terminal stations. This allowed the risks associated with transformer outages to be reduced, via the ability to perform reliable post-contingent load shedding. This in turn led to a planning and operating philosophy that accepted some risk of the interruption of customer supplies for transformer outages.

This acceptance was different to other states, particularly NSW, where sufficient spare transformer capacity was normally provided to ensure customer supplies would not be interrupted for a transformer outage. The loading of Victorian transformers has increased significantly since this time, and so there are a far greater number of transformers where these risks are material and need to be managed.

- **The use of split bus arrangement to manage fault levels**[12]. The growth in generation and the introduction of the 500 kV network in Victoria increased fault levels on the 220 kV network. This resulted in the fault level exceeding the rating of circuit breakers in a number of locations. In many cases, rather than upgrade the circuit breakers (e.g. replace them with higher rated units) or install fault-level-limiting reactors, a decision was made to reduce fault levels by operating many substation buses with an open point between bus sections (also known as a split-bus arrangement).

  Although this solution saves costs associated with the network upgrades, it increases the complexity associated with operating the network. For example, securing the system under planned and unplanned outages can require long and detailed switching sequences. The more complex the switching sequence, the more prone to error it is, either increasing the risks to load and generation or requiring further work to manage these risks.

  Presently, five substations in Victoria (Hazelwood, Rowville, Thomastown, South Morang and Keilor) operate with a split-bus arrangement. This number has reduced from historical levels, due both to network upgrades procured by AEMO, and SP AusNet's recent substation refurbishment program, which has also replaced some circuit breakers with higher rated units. Similar to Victoria, Queensland has often used a split-bus arrangement to manage fault levels. In contrast, however, NSW does not have any split bus arrangements.

- **Limited use of circuit breakers**. Recently, the Victorian network has been designed with a minimum number of circuit breakers. This results in reduced flexibility when operating the network, particularly when circuit breaker outages occur.

  Other states are also adopting these practices; however, this is more prevalent in Victoria.

- **Easement and meshing limitations**. In Victoria, the transfers of bulk power to the main load centre in Melbourne is mainly achieved via double circuit lines, often with

[12] AEMO's Victorian planning responsibilities extend to the management of fault levels. For example, AEMO is responsible for directing the upgrade of existing assets or the installation of new fault level mitigation assets, if the fault level rating of existing assets will be exceeded.

multiple lines sharing the same easement. NSW on the other hand has more single circuits and separate easements supplying its main load centre, Sydney. The reduced number of easements results in a more challenging operating environment at times of major events (e.g. major storms or bushfires). These types of major events can affect the whole easement, taking out multiple lines. This possibility requires more complex contingency plans to be developed by AEMO, and acted upon should the events occur.

For example, in the Victorian bushfires of 2009, a single fire front resulted in the loss of all lines forming the northern interconnection with NSW and a second fire front at the same time nearly resulted in the loss of the lines connecting to the main Victorian generation centre in the Latrobe Valley. However, during similar extreme bushfire conditions in NSW in 2004, the different fire fronts tended to effect the various easements at different times, such that the supply to Sydney was not at such extreme risk.

- **Capability differences between the 500 kV and 220 kV networks**. The 500 kV lines in Victoria can transfer significantly greater levels of power than the 220 kV network. For example, a typical 500 kV line ratings are around 2500 to 3000 MVA, whereas typical 220 kV line ratings may be around 500 to 800 MVA. The effect of this is that the 220 KV network risks being overloaded following the outage of a 500 kV circuit. Consequently, generation may be constrained or load may need to be shed to ensure the system can be returned to a secure state, in line with the NER obligations on AEMO.

  In contrast, the difference between the load carrying capability of the 500 kV and 330 kV lines in NSW, or the 275 kV and 132 kV lines in Queensland is not so significant. As such, the outage of the higher voltage line does not tend to result in such extreme transfers, and so, managing these occurrences is less challenging.

- **220 kV capability limitations in the state outer grid**. The 220 kV state outer grid, servicing the north west of Victoria, has limited capability under certain outage conditions. This can require careful control of the system to return the system to a secure state following other unplanned outages. This can lead to competing requirements for the dispatch of Murraylink, which in turn could require load shedding in some circumstances.

4.6.2 Queensland challenges

The overall view from AEMO's QLD operators is that operating the QLD network around the time of entry into the NEM was significantly more challenging than other states. However, this is no longer the case.

Prior to NEM entry, in the late 90s, parts of the QLD network operated close to its limits. At times of high demand or significant outages, this meant that the system may have only been in a satisfactory state, rather than a secure state i.e. following a contingency, customer load may have been required to be shed to keep the network assets with their ratings[13].

Related to the above issue, the vertical integration of generation and transmission meant that the use of operating solutions (i.e. support from generators) to increase the capability of the transmission network was more common around that time. In Queensland in particular, such solutions are often appropriate due to the longer transfer distances, and so, the greater extent of voltage and stability limitations that may lower the actual transfer capability well below the maximum level that could be set by the thermal rating of the transmission assets.

These operating solutions were particularly helpful in optimising the transfer capability during times of planned network outages. However, this required a greater integration and optimisation of network and generation outages

Examples of such uses, as explained by AEMO operators, include:

- The siting of the Townsville and Mt Stuart gas turbines in the North of Queensland, which were specifically located to increase the transfer capability.
- The use of the pumped-storage ability of Wivenhoe power station, which was often used to manage the loading of the transmission lines linking the South and Central Queensland.
- The use of Barron Gorge and Kareeya power stations to allow network outage to be taken in order to allow the construction of the second 275 kV circuit between Ross and Chalumbin.

Determining the suitability of such operating solutions involved a risk-assessment process, requiring technical and economic considerations. This in turn resulted in a more challenging environment for operating staff, due to the greater roles and responsibilities associated with these assessments.

Structural change in Queensland resulted in the removal of the vertical integration between transmission and generations. Furthermore, on entry to the NEM, around 1998, the rules associated with operating the system changed. This required transitional arrangement to relax the NEM system security obligations for the Queensland system, which could not always be operated in a secure state at that time. Most notably, generation developments, availability and dispatch became market driven, meaning network support contracts were required with a generator, if the market could not be relied upon to deliver the outcomes previously used to manage network capability.

These changes appear to have had two main effects relevant to this review.

The first was that Powerlink took a more risk-averse approach to network development, particularly where it concerned reliability of supply to customers. Powerlink has statutory obligations to provide sufficient transfer capacity to ensure the peak demand is met for

[13] Prior to NEM entry, the Queensland operators did not have the tools to perform contingency analysis in real-time, and as such, it was not always possible to be certain that the system was in a secure state.

credible single outages. The changes to the industry structure and rules appears to have had two main consequences on planning to comply with these obligations:

- The greater uncertainty in the availability of critical generation, required at times of peak demand, resulted in more conservative assumptions (i.e. planning criteria) that are used to determine the timing of actions (i.e. network development or network support) to achieve future compliance[14].
- The need to negotiate network support agreements appears to have resulted in network developments being the predominant options used to raise transfer limits for these purposes[15]. It also appears that, although these developments were aimed at ensuring the statutory obligations associated with the reliability of supply to customer where met, they also improved the transfer limits that could effect market outcomes. As such, other forms of market-related network support, determined by AEMO through its (former) obligations associated network load control and reactive ancillary services, reduced also (see the discussion below).

The second effect of the changes, particularly with regard to the rules around AEMO's roles and responsibilities, concerned outage planning. The system operational role under the NEM is concerned with the coordination of outages (as determined by transmission and generation owners), rather than the Queensland operators' previous assessment tasks, which involved assisting in planning the optimum timing of outages.

The consequence of these two effects was that, since entry to the NEM, operating the Queensland network has become significantly less challenging. Some of this reduction could be associated with the more limited roles and responsibilities of the operators around outage planning. However, the view was that much of the reduced challenge is due to the scale of the network development program, which has removed many of the limitations that caused the previous operational challenges. That is, even if Queensland moved back to its old rules and structure, it now would be a significantly less challenging system to operate.

It is worth noting that the significant change in operational challenges seen in Queensland, following NEM entry, did not occur in NSW or Victoria following entry to the NEM for these states. AEMO operators consider that, prior to NEM entry, the Victorian and NSW networks did not require generation to be optimised to the same degree to manage network capability. Consequently, even though the roles and responsibilities around outage planning may have reduced following NEM entry, this did not affect the operational challenges in such a significant way.

4.6.3 Relevance to this review

The views from AEMO staff clearly support a position that Queensland was possibly the most challenging operational environment in the late 90s. However, this is no longer the

[14] It is important to stress that that this review is not aimed at deciding whether these criteria are appropriate, and the comments here should not be interpreted as the acceptance of this point or otherwise.

[15] As above, this statement should not be interpreted as the acceptance or otherwise of the appropriateness of this consequence.

case, where currently Queensland may be the least challenging from on operational perspective.

The Victorian system has also had challenges since the late 80s. Although, it is difficult to gauge how less challenging Victoria was than Queensland in the late 90s. NSW appears to have been less challenging than either Victoria or Queensland in the late 90s. It remains less challenging than Victoria, but may have now surpassed Queensland.

It is difficult in this review to confirm the validity and extent of all the claims made by AEMO operating staff. Nonetheless, there does not appears to be any obvious evidence to dispute these clams either. Furthermore, AEMO's views largely reflect the author's past experience from previous reviews he has conducted of capital plans of the TNSP's in each region[16]. As such, it seems reasonable to accept these views on face value.

There is also other information that could point to the relative challenging nature of operating each network:

- **AEMO NEM summer readiness report**. AEMO prepared an internal board paper that summarises the key issues that AEMO system operations could face in the subsequent summer.

  The summer 2011/12 paper notes the following for the three regions in this review:

  - **Victoria** – The paper defines two specific network issues. Both appear to relate to delays in planned augmentations. One concerns a connection transformer, for which the delay may require some radialising of the 66 kV network during the peak demand period. The other concerns a delay in the establishment of a new terminal station, which may result in load shedding on extreme demand or outage conditions. The paper also notes that under peak demand conditions it may be difficult to support exports to South Australia via Murraylink – presumably due to limitations in the Victorian transmission network in the north west of the state.
  - **NSW** – The paper defines two specific network issues. One concerns outages of the Bayswater-Regentville or Bayswater-Sydney West 330 kV double circuit lines, which may require loaded shedding under extreme peak demand conditions. The other concerns security in the far north coast during peak demand times, which may require support via Directlink or automatic load shedding.
  - **Queensland** – The paper does not list any specific network issues, noting that recent completed augmentations have increased the resilience of the transmission network to cyclone events.

  This suggests that currently Victoria and NSW have the potential for more challenges compared to Queensland, associated with operating the network during the peak demand period.

[16] That is reviews the author has conducted on behalf of the ACCC/AER, during revenue resets, pass-through and contingent project applications.

- **AER transmission congestion analysis.** Around 2006, as part of its investigations into a congestion management scheme, the AER analysed network-related congestion[17]. This analysis assessed actual binding constraints between 2003/04 and 2006/07. The analysis found significantly more intra-regional constraint causing congestion in Queensland than in NSW or Victoria. This suggests that at least up to 2006/07, Queensland may have been a more challenging operational environment.

  AEMO congestion reports, published since that time, are in a different form so direct comparisons cannot readily be made. However, these reports shows that the number of constraint equations and binding hours seem to be reducing in Queensland. Furthermore, congestion in NSW seems to be related to planned outages associated with its network augmentation program.

- **Network support and control ancillary services**. Reactive power and load control ancillary services are procured from market participant to allow AEMO to meet its security obligations and achieve market benefits, if economic. These services affectively raise the network capability, where it may be limited by voltage issues or post-contingent loading violations.

  Historical trends in the levels of these ancillary services[18] indicate that, since around 2007, the requirement for these services has reduced significantly in Queensland, such that currently none of these ancillary services are anticipated to be required. Requirements seem to have reduced in NSW and Victoria, but not to the same degree.

All that said, the extent of challenges does not necessarily relate to whether over- or under-capacity exists or existed on the network. This concerns the nature of the issues that underlie the challenges.

With regard to Queensland, the issues raised by AEMO operators *do* appear to largely relate to network capacity issues. That is, the historical challenges associated with the need for optimising generation availability appears to be directly related to the level of capacity in the network. As such, it seems reasonable to conclude that over-capacity was not affecting Queensland around 2000. In fact, if anything, Queensland could have been in a state of under-capacity – allowing for the more stringent NEM security obligations.

Furthermore, the removal of these challenges since that time suggests that Queensland is no longer in this situation. The current AEMO readiness report, which does not note any specific network issues, and the lack of the need for network support and control ancillary services in that region support such a conclusion, particularly given the extent of the augmentation program untaken in Queensland.

For Victoria however the relevance to under- or over-capacity is less clear. Certainly the transformer loading issue *does* appear to be a clear network capacity issue. Therefore,

[17] Published in a series of report on “Indicators of the market impact of transmission congestion” available on the AER website

[18] Based upon amounts published in the AEMO statement of opportunities and now published in its National Transmission Development Plan

these views *do not* support a position that lower levels of augmentation expenditure on transformers in Victoria could be considered to be due to over-capacity. Also, the 220 kV capability limitations in the state outer-grid appear to be a network capacity issue, suggesting there is *not* over-capacity at least in this portion of the 220 kV network.

However, for the other four issues raised by operating staff, whether they are directly relevant to proof that the system did not have over-capacity is not as obvious.

With regard to the extent of easements and the difference in capability between the 500 kV and 220 kV lines, neither of these challenges is directly driven by limitations in the available capacity. Both largely reflect past design decisions that now affect risks and how to best manage these. Nonetheless, managing these risks could impose limits on the appropriate utilisation of these assets. As such, although over-capacity may appear to be present in some lines, particularly in the 500 kV network, it may not be usable.

This could suggest inefficiencies in past design and development decisions. However, given the easements and lines were largely planned in the 70s and 80s, its unlikely that these issues could be associated with planning decisions over the horizon of this review (i.e. since around 2000).

In the context of the utilisation analysis presented in this report, this is an example of circumstances when direct comparability between metrics, in terms of defining augmentation needs, may be affected. In this regard, Victoria could be subject to a comparably lower utilisation level due to these design considerations.

In the case of the use of split buses to manage fault levels and the adoption of lower numbers of circuit breakers, the reliance on both of these methods in Victoria *do* support the broad efficiency claims associated with the Victorian arrangements. However, the heightened operating challenges associated with these issues can not directly be claimed to show that over-capacity does not exist in the Victoria network, compared to the others. That is, there could still be excessive capacity in Victoria and these specific operating challenges could still exist.

Finally, with regard to the AEMO readiness report, this also suggests a more challenging situation than Queensland, and possibly similar challenges to NSW. These challenges also appear to be due to the lack of spare capacity in locations in Victoria. However, this lack of spare capacity in Victoria appears to be largely related to delays in anticipated developments, not through intended planning actions. As such, this may support the view that Victoria currently has less spare capacity than Queensland, but it is questionable whether this is because of the Victorian arrangements.

Based upon the above reasoning, it appears that the changing nature of operating challenges could suggest that over-capacity is *not* the reason for lower levels of transformer augmentation in Victoria.

For lines, however, there is less evidence that over-capacity did not, or still does not, exist in Victoria.

The operating challenges in Queensland following NEM entry support a position that Queensland had less *usable* capacity than Victoria or NSW. Furthermore, the AER network congestion analysis suggests that this could have persisted, at least, up to 2006/07.

However, although Victoria is now the most challenging region to operate, the challenges largely reflect past design decisions from the 70s and 80s, accepted fault mitigation practices and recent unintended delays in planned augmentations. Consequently, the existence of these challenges do not represent confirming evidence of a lack of *usable* spare capacity in Victoria compared to Queensland or NSW.

5 Analysis of asset utilisation

Section 3 defined the utilisation metrics and the rationale for their use in this study. This section provides an overview of the calculation process and presents the results of the analysis.

As noted in the methodology section, this process has involved a number of stages, covering:

- 2006-2001 "raw" metrics - the preparation of utilisation measures reflecting the actual loading and rating of assets between 2006 and 2011 (inclusive)
- 2006-2011 "corrected" metrics - the adjustment of the raw measures to correct for weather and rating effects
- the estimation of equivalent utilisation metrics for 2000.

The process associated with each stage and the results are discussed in turn below.

5.1 Actual utilisation for 2006 to 2011

5.1.1 Overview of methodology and assumptions

The basis for calculating the utilisation metrics is actual loading and rating information of all the transformers and lines in a region at the time of the regional peak demand.

An AEMO database (called the Operations Planning Data Management system – or OPDMS) has been used to extract historical data sets that reflect these loadings and ratings. OPDMS is explained further in Box 5.1 below.

Due to the effort required to extract data from this system and the time-frames for this review, it has only been possible to obtain data sets for each regional peak, covering the years 2006 to 2011 (inclusive)[19].

The following summarises the main modifications we have applied to the OPDMS data sets to calculate the weighted average utilisation.

- Line lengths – Line lengths are required to calculate the weighted average utilisation. The OPDMS data sets do not include line lengths. Therefore, line lengths have been obtained from two sources: an AEMO data file containing many line lengths in Victoria and Queensland; and the TransGrid 2011-2016 Network

[19] 18 data files have been extracted from OPDMS, covering the peak demand time in each of the three regions for each year between 2006 and 2011.

Management Plan[20]. Where actual line lengths were not available, the line lengths have been estimated[21].

- Snowy region – Network assets in the former Snowy region transferred to the Victorian and NSW regions in 2008. To ensure this change does not affect the results, the Snowy region assets have been ascribed to their respective Victorian or NSW region for the years prior to the change.
- Defining transmission assets – The OPDMS data files contain the power system network elements relevant to the power system and market operations. This contains significantly more assets than just those under the responsibility of the TNSPs. The OPDMS files do not provide a simple identification to map transformers or lines to their owners. Therefore, voltage rules have been applied to define the transmission assets that should be covered by this study. These are as follows:
  - transmission lines are those with an operating voltage above 60 kV
  - tie transformers (i.e. a transformation between two transmission voltages) are those transformers with a lower voltage greater than 100 kV
  - transmission terminal station (or sub-transmission connection) transformers are those transformers with a lower voltage between 60 kV and 110 kV in Victoria and NSW, and between 30 kV and 110 kV in Queensland.
- Exclusions
  - Lines that begin and end in different regions (i.e. form part of an interconnector) have been excluded from the regional metric
  - Transformers and lines with a zero rating are excluded – it is understood that these generally relate to assets that are not owned by the TNSPs (e.g. DNSP or generator assets)
  - Transformers or lines with an apparent anomalous rating are excluded[22].

Based upon the above, various weighted averages have been calculated covering:

- Transformers
  - All transmission transformers (i.e. tie and terminal station)
  - Tie transformers
  - Terminal station transformers
- Lines
  - All lines

[20] Available on the TransGrid website

[21] This estimate is based upon a function we have derived that maps the known line lengths to the resistance of the line. Separate functions have been derived for each voltage level, using regression analysis and the AEMO line length data file.

[22] Typically, an erroneous rating of 9999 MVA can be used in the OPDMS data files. A rule that excludes any assets with a rating higher than 5000 MVA is applied to exclude such assets.

- Lines within the various transmission voltage levels (500 kV, 330 kV, 275 kV, 220 kV, 132 kV, 110 kV and 66 kV).

Box 5.1 Overview of OPDMS

A role of the power system's SCADA (Supervisory Control and Data Acquisition) is to take measurements of the power system in real-time. These measurements may include various currents, voltages, power flows, and the status of assets (e.g. whether a circuit breaker is open or closed) at various locations.

This information is passed to the EMS (Energy Management System), which has various functions. One of these functions is a state-estimator. The state-estimator takes SCADA measurements (which can be noisy or erroneous) and then, using power system parameters (e.g. line impedances), it estimates the voltages and power flows across the whole network.

OPDMS is database tool that links with the EMS. A major function of OPDMS is to take the state estimates and network data at a point in time, and then construct data files in a format suitable for use in power system analysis software. OPDMS imports the data from EMS at half-hourly intervals.

Each data file (or "snapshot") extracted from OPDMS contains the power flows estimated for every network asset (i.e. transformers, lines, etc.) at that point in time. For each network asset, they also provide other relevant modelling data, including impedances, continuous and short terms ratings, and nominal voltages.

5.1.2 Transformer results

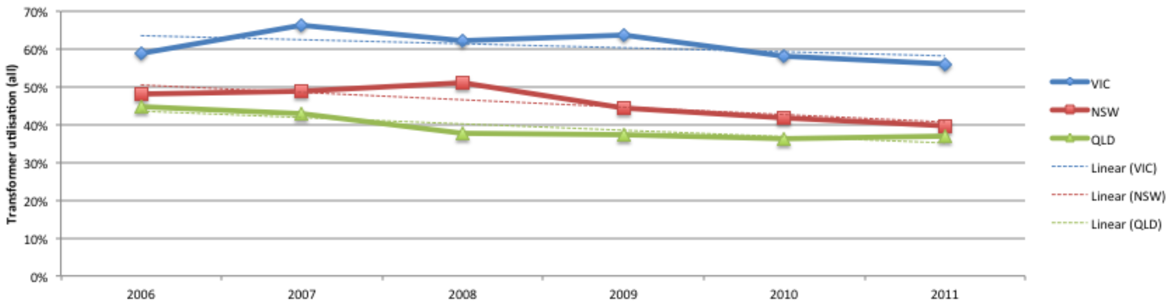

Figure 2 – weighted average actual utilisation of all transformers

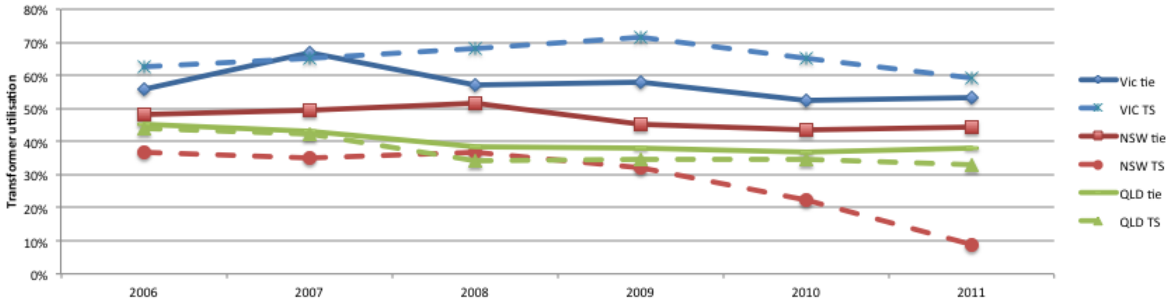

Figure 3 – tie and terminal station (TS) transformer weighted average actual utilisation

The two charts above show the utilisation metric, based on actual data, for transformers. The first chart provides the average utilisation across all transformers. This chart also includes a linear trend showing the overall pattern of the change in utilisation over the 2006 to 2011 period. The second chart shows the utilisation metric separately for tie transformers and terminal station (TS) transformers.

These charts show the following:

- Victoria has the highest utilised transformers, both in terms of tie and terminal station transformers. Over the 2006 to 2011 period, the average utilisation of all Victorian transformers was 61% compared to 46% in NSW and 39% in Queensland – or the Victorian transformers were loaded approximately 33% higher than in NSW and 56% higher than in Queensland.
- All regions are showing a general downward trend, but the difference is not changing significantly i.e. Victoria does not appear to be catching-up to the NSW and Queensland utilisation levels.
- The pattern of higher transformer utilisation in Victoria is similar for both tie and terminal station transformers. However, terminal station transformers show an even more marked difference.
- Terminal station transformers in NSW shows a significant reduction in average utilisation, from 37% in 2006 to only 9% by 2011. This appears to be due to a substantial increase in installed capacity over this period. That said, care is required in comparing terminal station transformer utilisation between regions as there are far fewer terminal station transformers owned by the TNSPs in NSW and Queensland. In this regard, the terminal stations in Victoria represent approximately 45% of the total transformer capacity, where in Queensland it is just over 20% and in NSW around only 5%.

5.1.3 Line results

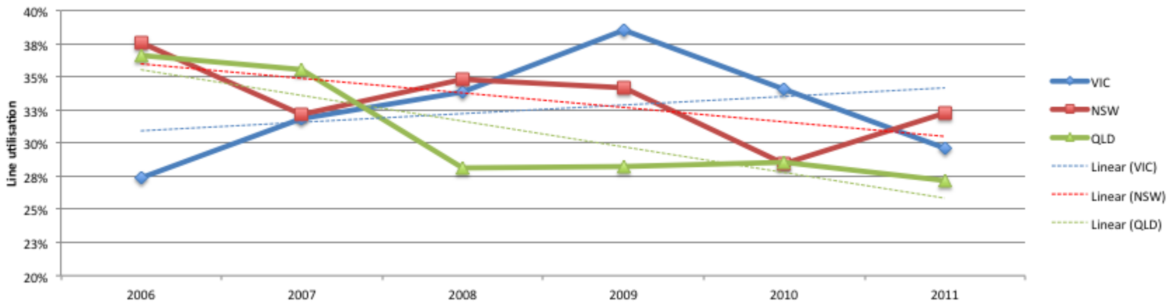

Figure 4 – weighted average actual utilisation of all lines

The chart above shows the utilisation metric for lines, based on actual data. Similar to transformers above, the chart also includes a linear trend showing the overall pattern of the change in utilisation over the 2006 to 2011 period.

This chart shows the following:

- The difference in Victorian utilisation compared to NSW and Queensland is less noticeable than it was for transformers. Across the period, Victoria had a similar average utilisation to NSW, at 33 %, and a marginally higher utilisation than Queensland at 31%.
- The actual profile suggests Victorian lines were much lower utilised in 2006 than NSW and Queensland lines. But NSW and Queensland utilisation has been reducing generally over the period. The Victorian utilisation on the other hand increased significantly by 2009, such that Victorian utilisation was much higher than NSW and particularly Queensland in 2009, but then reduced again to 2011 to be below NSW but above Queensland.
- The differences in the trends in utilisation are more pronounced however. In this regard, the utilisation of lines in NSW and Queensland at the beginning of the period (around 2006) was still significantly higher than in Victoria. However, although over the period utilisation in NSW and particularly Queensland has trended down significantly, in Victoria it has trended up significantly. By the end of the period, the trend suggests that Victorian line utilisation is above NSW and Queensland.

Table 4 – Line utilisation by voltage

Line voltage	VIC		NSW		QLD	
	utilisation	proportion	utilisation	proportion	utilisation	proportion
500 kV	28%	65%	18%	18%		
330 kV	51%	12%	39%	71%	27%	8%
275 kV					31%	80%
220 kV	37%	22%	30%	2%		
132 kV			30%	9%	28%	10%
110 kV					32%	2%

The table above indicates the average utilisation at the various voltage levels used in each region. This table also indicates the contribution the voltage level represents to the overall weighted average (i.e. the sum of the line ratings multiplied by their lengths). The following are important points about these results:

- For Victoria, the 500 kV lines represent the greatest contribution (65%) to the overall utilisation metric of lines. But the 500 kV lines are the lowest utilised at 28% on average through 2006 to 2011. The detailed results suggest a few very lightly loaded lines have a significant impact on the average, namely the two Heywood to Moorabool circuits. For example, in 2011, these two lines are utilised at around 7%, but contribute approximately 30% to the 500 kV average. These reasonably high capacity lines are the longest 500 kV lines in Victoria at 241 km each.
- The other two main transmission voltages in Victoria, 330 kV and 220 kV, are much more heavily utilised at 51% and 37% respectively.
- The Victorian 500 kV lines are still utilised much higher than the NSW 500 kV lines, which have an average utilisation of only 18%. However, in NSW, the 500 kV lines are relatively insignificant, contributing only 18% to the overall utilisation metric – although, this does increase to around 30% by 2011. The 330 kV lines in NSW are far more significant, contributing 71% to the overall utilisation, with an average utilisation of 39%. Interestingly, the utilisation of the NSW 500 kV lines appear to reduce significantly, from over 20% around 2006 to around only 9% by 2011. This movement however is offset by an increase in the utilisation of the 330 kV lines, which increase from 40% in 2006 to 46 % in 2011. It is assumed that these apposing movements are due to the 330 kV to 500 kV line conversion projects that TransGrid had been undertaking around that time.
- In Queensland, the 275 kV network is by far the most significant, contributing 80% to the overall utilisation. The average utilisation of these lines is 31%, which is slightly above the Victorian 500 kV lines, but well below the other Victorian voltages and the 330 kV lines of NSW. As suggested by the chart above, the utilisation of the Queensland 275 kV lines is reducing fairly significantly, from 39% in 2006 to 26% in

2011. The detailed results indicate that this reduction is mainly due to the large number of new lines that were commissioned during this time.

5.2 Corrected utilisation metrics for 2006 to 2011

5.2.1 Overview of methodology and assumptions

As discussed in Section 3, the actual average utilisation measures discussed above have been adjusted to correct the loading and rating, to ensure they are on a like-for-like basis across regions. These corrections have been applied at the aggregate level (i.e. to the weighted average utilisations discussed above), and not to the individual asset loading and ratings taken from the OPDMS data files.

5.2.1.1 Corrections to account for asset loading

The peak demand on the network is related to the extremeness of the temperature around the time of the peak. For example, the 2009 peak in Victoria was associated with extreme temperatures, well above what may typically occur. In turn, the loading, and so utilisation, in that year may appear higher than what would be expected on-average.

To correct for this effect, we have assessed the actual peak demand in each region between 2006 and 2011, against the 50% probability of exceedance (PoE) weather corrected value for the corresponding year. The relative change from the actual to the weather corrected value has then been applied to the actual average utilisation (as discussed above). In effect, it is assumed that this overall change in the peak demand, from actual to the weather correct value, corresponds to similar individual changes to the loading of each asset, assuming the 50% PoE peak demand had occurred. In reality, the loading on any asset may not have this relationship; nonetheless, across the total population it seems reasonable to assume that this is a reasonable approximation.

To determine the relative change in each year, we have taken the actual peak demand and weather corrected demands from published data in either the TNSP's annual planning report or the AEMO Statement of Opportunities (SOO). The table below shows the corrections in each region and each year, based upon this analysis.

Table 5 Annual loading weather corrections

	2006	2007	2008	2009	2010	2011
VIC	105%	103%	98%	92%	95%	100%
NSW	101%	95%	95%	98%	100%	95%
QLD	104%	101%	108%	105%	104%	107%

This analysis indicates that the peak in the Victorian average utilisation, shown in the charts above, is at least partly due to the extreme conditions at that time. Conversely, the lower Victorian utilisation in 2006 appears to be at least partly due to fairly mild conditions that year.

NSW had fairly extreme conditions in 2007, 2008 and 2011[23], suggesting the average utilisation shown in the charts above is higher than expected in those years.

Unfortunately, the Queensland results look anomalous. From this data it appears that Queensland has had very mild conditions over the whole six-year period, and as such, utilisation would be higher for typical conditions. However, given the correction is intended to achieve the average conditions, it would be expected that for some years in the six-year period, the actual demand would be at or above average conditions. It is accepted that other extreme weather events, such the floods and cyclones, may have affected actual peak demand. Nonetheless, we do not have sufficient confidence in these results to use them to correct the loadings. Therefore, in the corrected charts shown below, we have maintained the actual loadings for Queensland.

5.2.1.2 Corrections to account for different asset ratings

As defined in Section 3, the utilisation of any assets is calculated from its continuous rating at the time of the peak demand. Ideally, for comparative purposes, the continuous rating in each region should be equivalent e.g. reflect equivalent risks to the TSNP.

The continuous rating used in the analysis here is taken directly from the OPDMS data file. This information reflects rating information provided by the responsible TNSP. However, as noted in Section 4, different TNSPs use different approaches to define the applicable ratings at any point in time. For example, Victoria uses a real-time rating system to define the applicable rating of many of its lines at any point in time, whereas NSW and Queensland largely rely upon static ratings.

We have discussed the basis of the OPDMS continuous rating with AEMO staff to determine their comparability between regions. Based upon these discussions, we have not found any significant reason to consider that the basis of the continuous transformer ratings within OPDMS differs appreciably. Therefore, we have not applied any adjustments to the transformer metrics to correct for rating differences.

For lines, however, we do consider that there are differences that may be material enough to warrant correction. For Victorian lines, the ratings provided by OPDMS reflect the real-time ratings that were calculated at that time.

For the majority of lines in NSW and Queensland, the static rating that was applicable at the time of the peak demand is used. In Queensland, a small number of lines have real-time ratings. For these few lines, the real-time continuous rating that was calculated at the time is provided in the OPDMS file.

Ideally, it would be useful to correct all ratings to the appropriate real-time rating. In this way, the utilisation would be defined by the theoretical loading limit. However, this would require relevant temperature measurements, which are not readily available for the NSW

[23] 2007 and 2008 relate to winter peaks (i.e. cold temperatures), whereas 2011 was a summer peaking year (i.e. high temperatures).

and Queensland data sets. Therefore, the Victorian metrics have been adjusted to reflect an equivalent static rating.

This has been performed by defining an equivalent design ambient temperature for the static rating and then calculating the average adjustment that would need to be made to the OPMDS continuous ratings to reflect this design temperature, given the actual ambient temperature at the time of the peak[24]. An average adjustment is calculated across all Victorian lines at the time of the peak demand. The adjustment determined for each year is then used to correct the Victorian average utilisation metrics.

This approach requires a design ambient temperature to be defined that is equivalent (from a risk perspective) to the NSW and Queensland static ratings. Unfortunately, there is some uncertainty on the basis of the Queensland and NSW ratings. This review has not been able to determine actual design parameters to determine an equivalent Victorian temperature.

Nonetheless, there is some evidence that suggests that the NSW and Queensland static ratings may be fairly conservative, as follows:

- In NSW there appears to be a rating increase of approximately 10% from the normal continuous rating of lines to the long-term emergency rating[25].
- In Queensland, data provided by AEMO suggests that the use of a real-time rating on some lines has resulted in an increase of up to 40% over the static rating at the time of the peak demand.

Based on the above, a fairly conservative ambient temperature of 45°C has been assumed. This temperature reflects around a 1 in 50 year event for Victoria. The table below indicates the corrections to Victorian utilisation metrics, based upon this assumption.

Table 6 – Victorian line rating corrections

2006	2007	2008	2009	2010	2011
116%	110%	114%	104%	107%	113%

This analysis indicates that the average reduction in rating to move to this static rating is approximately 10%. For a year, such as 2009, that had a temperature of 42°C at the time of the peak demand, the reduction is only 4%. But in 2006, which had a temperature at the peak demand time of only 34°C, the reduction in rating is 16%.

It is important to note that, given the 40% increase seen in the Queensland data for some lines that moved to a real-time rating, the Queensland static ratings may be even more conservative than suggested by this 45°C assumption for Victoria. The implications of this possibility will be considered further in Section 6.

[24] For Victorian lines, a continuous rating of each line is defined at two temperatures, 5°C and 35°C. A square law is used to calculate the continuous rating at any other temperature.
[25] Both ratings are provided in the OPDMS data files for lines in the NSW region.

5.2.2 Results

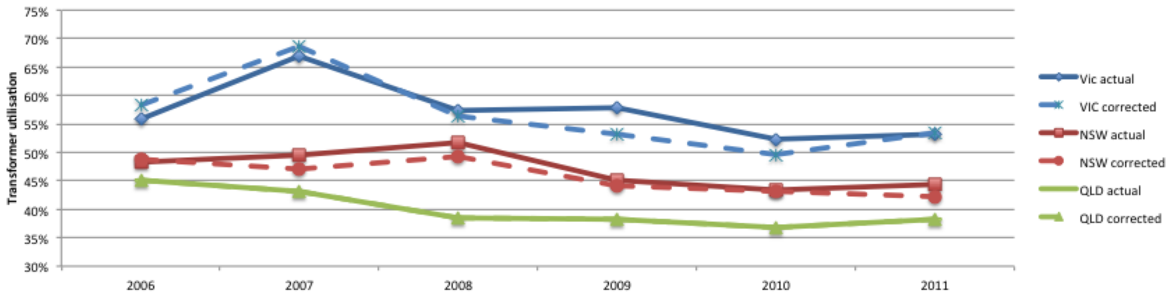

Figure 5 Tie transformer corrected utilisation metric

The chart above shows the corrected metric for tie transformers in each region, compared to the actual measure. This shows that for transformers the corrections have not changed the findings discussed above appreciably.

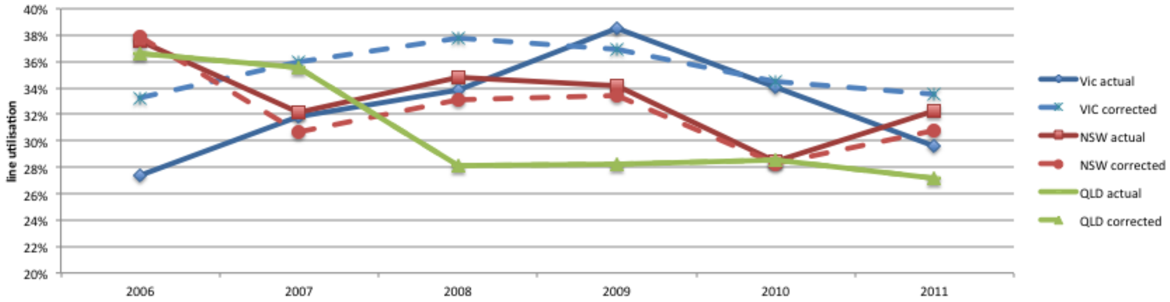

Figure 6 Line corrected utilisation metric

The chart above shows the corrected metric for lines in each region, compared to the actual measure. This shows that the corrections provide an increase in comparable utilisation for Victoria, particularly in the years with relatively mild weather conditions. As such, these corrections have increased the gap between Victoria and NSW/Queensland utilisation over the recent period.

5.3 Estimating the metric in 2000

5.3.1 Overview of methodology and assumptions

As noted in Section 5.1.1, for this review, actual utilisation data has only been able to be extracted from AEMO's data systems back to 2006[26]. Therefore, to gauge the movement in the utilisation prior to this time, an estimate of the metric in 2000 has been made based upon other information.

To estimate the equivalent metric in 2000, the 2006 utilisation metric (as calculated above) has been adjusted to reflect the following:

- the increase in weather corrected peak demand that occurred from 2000 to 2006

[26] Prior to this date, OPDMS data files do not include reliable rating data. Furthermore, it has been difficult in the time frames available to reconcile earlier rating databases (e.g. those from around 2000) to those held from around 2006.

- an estimate of the transformer and line capacity added to the network from 2000 to 2006, based upon the major projects noted in Section 4.

To simplify the assessment, the 2000 metric has only been estimated for the overall lines category (i.e. not by line voltage) and tie transformers[27].

The table below details the projects and the assumed additional capacity achieved by these projects, which have been used to estimate the adjustment from the 2006 metric.

Table 7 – Assumed network augmentation between 2000 and 2006

VIC	NSW	QLD
Transformers (1000 MVA) • Cranbourne 500/220 kV transformer Lines (2000 MVA) • Latrobe Valley to Melbourne 4th line conversion	Transformers (2150 MVA) • Waratah West, Tuggerah, Balranald, Canberra, Regentville, Tamworth, Vinyard Lines (1175 MVA) • 330 kV cable to Haymarket, Coff Harbour – Kempsey 132 kV line, Armidale-Kempsey 132 kV line, Armidale-Koolkhan 132 kV line, Molong-Malindra 132 kV line	Transformers (4667 MVA) • Middle Ridge, Woree, Loganlea, Molendinar, Strathmore, Edmonton, Nebo, Rocklea, Woolooga, Palmwoods, Swanbank Lines (7315 MVA) • Belmont 275 kV, Millmerran – Middle Ridge 275 kV, Chalumbin-Springmount 275 kV, Stanwell-Broadsound 275 kV, Broadsound-Lilyvale 275 kV, Maudsland-Molendinar 275 kV

5.3.2 Transformer results

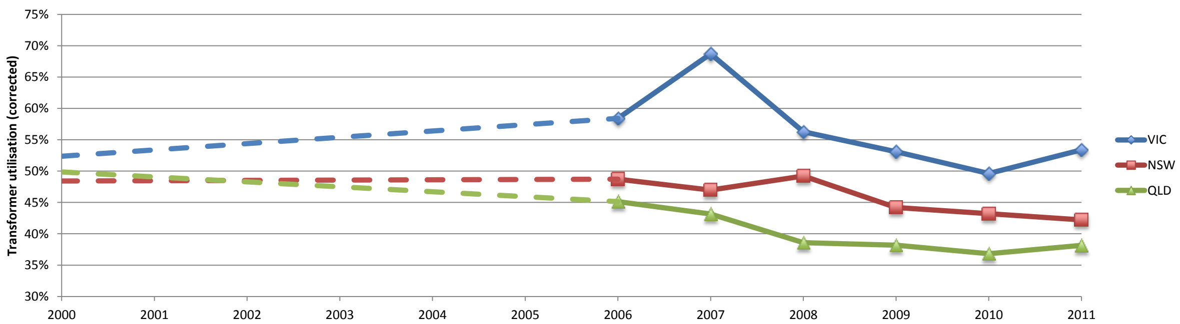

Figure 7 Tie transformer corrected utilisation

The chart above shows the corrected transformer utilisation metric, with the estimated 2000 measure indicated by the dashed line. The chart indicates that the utilisation of

[27] An adjustment for terminal station transformers has not been estimated as there was greater uncertainty over what capacity changes have occurred over this period.

Victorian transformers was probably similar to NSW and Queensland transformers around the late 90s. However, since that time, transformer utilisation has diverged between Victoria and NSW/Queensland. Up to around 2006, transformer capacity additions in NSW and Queensland largely tracked the growth in peak demand, with utilisation being maintained in NSW and reduced modestly in Queensland. In Victoria, however, up to around 2007, there was little transformer capacity added to the network, and so, utilisation increased.

5.3.3 Line results

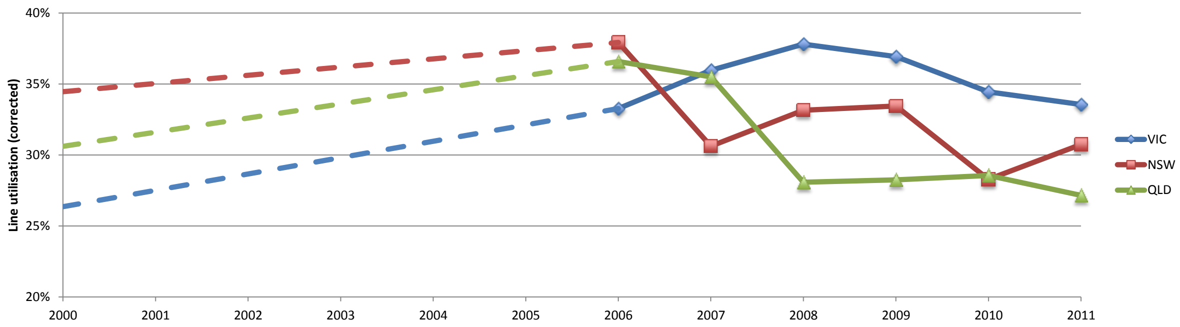

Figure 8 Line corrected utilisation

Similar to the transformer chart, the chart above shows the corrected line utilisation metric, with the estimated 2000 measure indicated by the dashed line. This chart suggests that both NSW and Queensland had significantly higher utilised lines in the late 90s compared to Victoria. Up to around 2006, the utilisation of the lines increased further in all three regions. However, it appears that Victoria and Queensland line utilisation increased more significantly than NSW, such that there was less of a difference by 2006.

6 Assessment of issues affecting like-for-like comparisons

In the previous section, the analysis of utilisation of the networks assets has been provided. This analysis compared the utilisation of transformers and lines between the three regions from 2000 to 2011. This analysis attempted to put these utilisation metrics on a like-for-like basis by correcting for some differences in each region. These corrections covered the extremeness of the weather at the time of the peak and differences in the types of rating in each region.

However, in Section 3, it was noted that there were other factors to consider when using these results to infer equivalent augmentation needs from these metrics. These factors include:

- the relevance of load diversity and generation diversity
- the peakiness of the demand
- the relevance of the customer density – and its relationship to transmission lengths.

In addition to these matters, it was also noted in the previous section that there is still uncertainty in the basis of the static ratings in Queensland and NSW. This appears to be particularly so for Queensland, where there appears to be some empirical and anecdotal evidence that the Queensland line ratings may be more conservative than assumed in our corrected metric provided in the previous section.

The effects of diversity, the peakiness of the demand, and alternative static ratings for Queensland can be considered in terms of further adjustments to the metrics. The density issue needs to be considered via other means. These two matters are discussed further below.

6.1 Further indicative adjustments to the utilisation metric

6.1.1 Load and generation diversity

It was noted in Section 4 that Queensland probably has the greatest level of diversity in the timing of load peaks and the location of its main generators. This is largely a result of the greater distances between major load centres in Queensland. Victoria on the other hand had the least diversity in these factors. Greater diversity could mean that the peak utilisation of many assets is at a time that does not correspond to the regional peak demand. Therefore, the utilisation metric could provide a misleading indication of comparative augmentation needs.

Assessing this issue in detail would require more exhaustive analysis of the profile of the utilisation of assets in each region (e.g. profiles of utilisation at 30-minute intervals). This type of comprehensive analysis was beyond the time frames of this review.

Therefore, to provide an indicative measure, further analysis of the Queensland line utilisation was performed at the time of the south Queensland (SQ), central Queensland (CQ), and north Queensland (NQ) peaks. The analysis only considered the average utilisation of the lines forming the main transmission paths between these sub-regions[28], and was only undertaken for 2009 and 2010[29].

The information provided by AEMO suggested that there was only around 5% diversity in the Queensland peak demand between these three regions[30]. The analysis of the utilisation of the lines forming the three transmission paths indicated that they were utilised approximately 7%[31] higher at the time of the sub-regional peaks compared to the regional peak.

The findings of this analysis are indicative only as the full set of lines and transformers in each region was not provided by AEMO. Furthermore, it would be expected that similar analysis of Victoria and NSW would provide a similar boost to the utilisation, albeit most likely to a lesser degree. Nonetheless, these results are considered sufficient to suggest that an increase in the order of 7% to the Queensland metrics may be reasonable when comparing between Victoria and Queensland.

6.1.2 The “peakiness” of demand

The metrics are based upon the loading at the peak demand time. However – setting aside the implications of state-based reliability standards and planning approaches – the augmentation needs will be related to the risks associated with the profile of the demand around that peak time. For example, if the peak only occurs for a very short period of time then the risks are lower.

This effect relates to the “peakiness” of the demand in each region. In this regard, Victoria is known to have a more peaky demand than Queensland – hence its risk could be considered to be lower. NSW is fairly peaky, but not as great as Victoria.

Demand duration curves[32] offer a useful guide to the implications of this. If it is assumed that the regional demand that is only exceeded for 1% of the year is a fixed risk position for each region, then the difference between the regional maximum demand and this demand value can be used to gauge the equivalent comparable differences in the utilisation metric.

Based upon the demand duration curves provided in the SOO between 2006 and 2011, the average percentage difference in the three regions is as follows:

[28] These paths are often called cut-sets, and generally constitute the set of lines that together provide the bulk transfer of electricity from one location to another.
[29] AEMO provided details of the lines that formed the main SQ, CQ and NQ cut-sets, and provided additional OPDMS data files corresponding to the three different peak times.
[30] The 5% here is based upon the ratio of the regional peak demand to the sum of the three sub-region peak demands.
[31] The 7% quoted here is relative i.e. for a line originally at 30%, the increase would be 7% of 30%, which is only 2.1%.
[32] The demand duration curves indicate the percentage of time in a year that the demand is above a specific value.

- VIC - 17.8%
- NSW – 12.3%
- Queensland - 8.5%

These figures suggest the percentage reduction to each region's utilisation metric that could be applied to place the regions at a comparable risk position. Alternatively, this suggests that the Queensland and NSW utilisation metrics should be approximately 12% and 7% lower than the Victorian metrics to place them at a comparable risk level.

6.1.3 The Queensland static line ratings

The adjustment discussed in Section 5 to correct for the static ratings in Queensland and NSW increased the Victorian utilisation by approximately 10% on average. However, it was noted that the Queensland static ratings could be even more conservative than suggested by this adjustment. Data provided by AEMO of Queensland lines that recently moved to a real-time rating indicated that these lines achieved an increase in rating of over 40% at the time of the peak demand compared to the equivalent static rating. Although for other lines in Queensland, the increase was around 10%.

It is not clear whether the 40% increase would be only achievable on a small set of lines, or this increase is likely to be more systemic across all lines. To some degree however the possibility of a fairly large increase is supported by some anecdotal evidence from AEMO operational staff, who noted that significant up-rating of lines at the direction of Powerlink has often occurred at times when the static rating of the line could result in constraints.

This may suggest that a further adjustment to the Queensland utilisation metric is warranted, possibly reducing the utilisation by 10-20% to correct for the more conservative ratings in Queensland. If this were the case then this would largely offset the additional corrections discussed above.

6.1.4 Indicative results

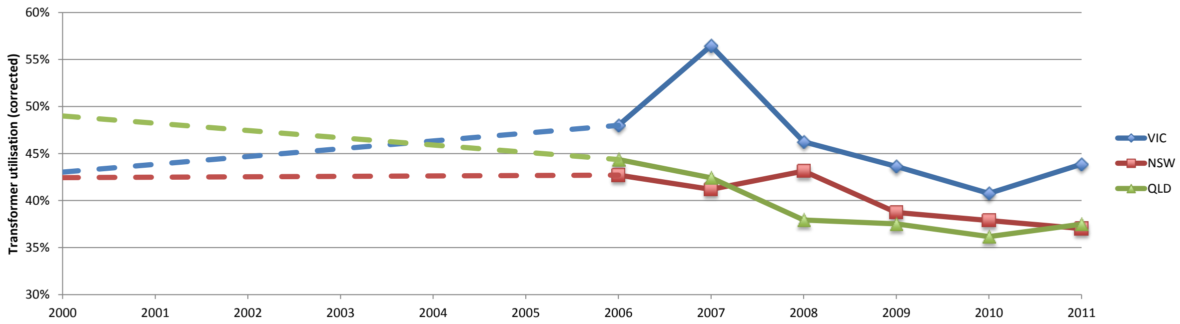

Figure 9 Tie transformer corrected utilisation metrics

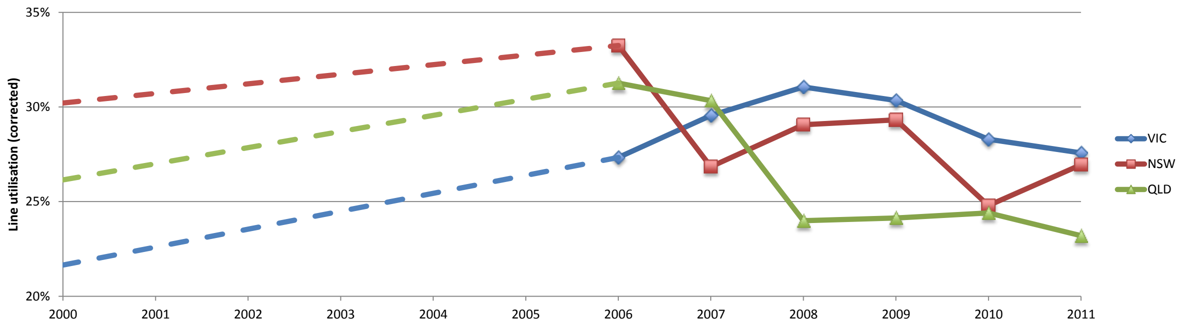

Figure 10 Line corrected utilisation metrics

For indicative purposes, the two charts above show the combined effect of the additional corrections for diversity, the peakiness of the demand, and the Queensland static ratings. The dashed lines signify the unknown utilisation for the years between the calculated figures for 2000 and 2006 (as discussed in Section 5.3).

For transformers, it has increased the utilisation for Queensland relative to NSW and Victoria. This suggests that on a comparable risk basis, Queensland was utilising its transformers to a greater degree than in Victoria or NSW around 2000. However, by 2004, Victorian utilisation overtook Queensland. This higher utilisation in Victoria has continued to 2011. Queensland and NSW have similar utilised transformers.

For lines, NSW and Queensland have remained at a similar comparable level, but the utilisation of Victoria has reduced marginally. Victoria however still remains with a comparable higher utilisation over the 2007 to 2011 period.

6.2 Implication of longer transmission distances – or load density

In Section 3, it was noted that augmentation needs might not be directly correlated to this utilisation metric, which is based upon the thermal rating of assets. As transportation distances increase on an electricity network, other network limitations associated with voltage and stability can mean that exceeding the thermal rating is not the limiting issue. This issue can affect line limits more than transformer limits.

It is important to note however that this issue does not necessarily mean that the line thermal rating cannot be achieved. Instead, it may just mean that additional augmentations (e.g. shunt and series reactive plant, static voltage compensators, and/or phase-regulating transformers) may be necessary to release the full capacity of the line. That said, there could be situations when the optimal solution is to install additional lines (and possibly transformers), rather than try to release the existing thermal capacity.

A typical analysis approach in situations such as these is to compare the metric against some form of customer or load density parameters. This can suggest if a metric for a region is in line with the trend of all regions.

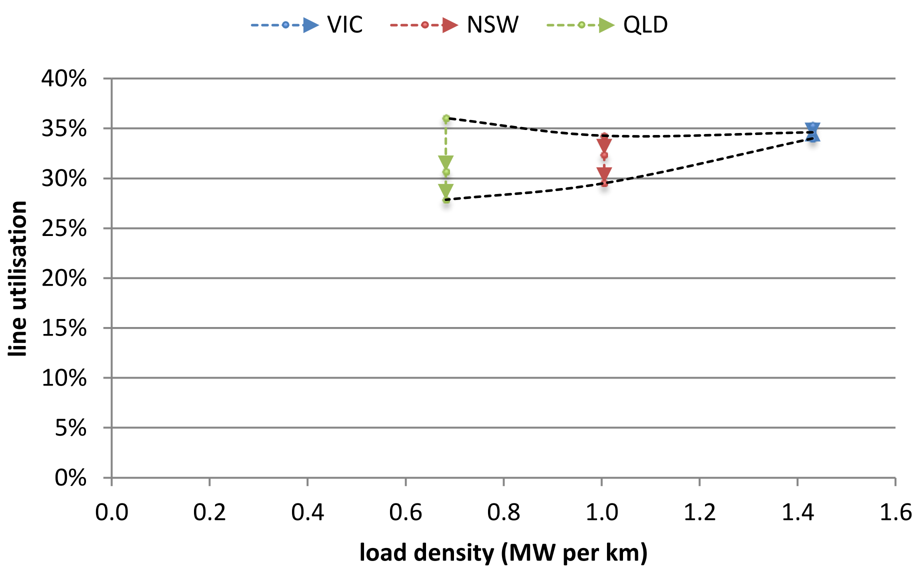

Figure 11 – comparison of utilisation metric against load density

The figure above shows this analysis for the corrected metrics 2006 to 2011 (discussed in Section 5.2). The density parameter is based upon the 5-year average maximum demand per unit length of transmission line. To smooth out some of the variability, the movement in the metric represents the change from the average between 2006 to 2007, compared to the average from 2010 to 2011, with the mid-point represented by the average over the whole period. For example: for Queensland, the metric has moved from a 2006-2007 average of 36%, down to a 2010-2011 average of 28%, with a 2006-2011 average of 31%; for Victoria, the 2006-2007 average of 35% moved down slightly to a 2010-2011 average of 34%, but the 2006-2011 average remained at 35% due to the increase in utilisation that occurred in the middle of that period.

Unfortunately, for this analysis, we are only assessing three regions, and so, the trend is not clear (i.e. the three regions define the trend). This chart could be interpreted to say that around 2006, the NSW and Queensland networks were operating a higher utilisation than Victoria given their load density. This certainly appears to be the case for

Queensland. Alternatively, it could suggest that both NSW and Queensland have moved to a level of utilisations that is below a comparable utilisation to Victoria, given their respective load densities. Or it could suggest a middle ground, in that Queensland and possibly NSW were above a comparable utilisation around 2006, but had fallen below this by 2011.

The significance of these results will be discussed further in the next section when the overall findings of this review are discussed together.

7 General discussion and conclusions

The background review

The background review of the development of the networks, including our discussion with AEMO staff, suggests that there was over-capacity in Victoria and NSW in the late 90s. This resulted from the development, in both regions, of 500 kV networks in the 80s, based upon anticipated load that did not eventuate. This view is also supported by the valuations of both networks that were conducted in the 90s that led to portions of the value of these networks being removed from the asset base.

Since that time, demand has grown at a slightly greater rate in Victoria, but NSW has undertaken significantly more network augmentations. The level of increased augmentation in NSW also has to be seen in the context of the actual peak demand in that region, which has been significantly less than was forecast. In Victoria, the peak demand growth has been addressed by relatively minor augmentations, making use of load shedding control schemes, line uprating opportunities, and additional capacity released through the real-time rating system adopted in Victoria.

Circumstances were different for Queensland however. This region appears to have been under far more challenging conditions than Victoria or NSW, particularly pre-2005. Prior to NEM entry in 1998, AEMO operators noted that the network was close to its natural limits at that time, and so network support from generation was often used to optimise network capability further. At times, the system was also permitted to operate in an insecure state, if the risks were considered acceptable. However, following entry to the NEM, due to the NEM rules, a more risk-averse approach to operating and developing the network appears to have been taken. In addition to these issues, Queensland has had significantly greater growth in peak demand than Victoria or NSW, with peak demand doubling since around 1994/95. It has also had by far the greatest increase in new generation.

To counter this, a very large augmentation program has been undertaken in Queensland, including the development and upgrade of a large number of lines. However, similar to NSW, most recently, the Queensland actual peak demand has been significantly less than forecast.

AEMO operational staff no longer consider that Queensland has significant operational challenges, and now consider that Victoria has the most pressing issues. The current challenges in Victoria cannot all be linked to a lack of spare capacity however. Some are due historical design decisions, and others are due to accepted fault-level mitigation practices. Some of the most significant operational risks in Victoria for the preceding summer (2011/12) were more a consequence of delays in planned augmentations, rather than decisions to defer projects.

Overall, these findings suggest that over-capacity is not the main reason for the difference in augmentation levels between Victoria and NSW. However, over-capacity could have been the reason for differences between Victoria and Queensland, at least in the late 90s and some years following.

Analysis of utilisation metric

This view is supported in part by the analysis we have conducted of the utilisation of transformers and lines over the period from 2000 to 2011.

For transformers, this analysis suggests that Victoria has been operating with significantly higher utilised transformers than both NSW and Queensland since around 2000. Although, allowing for the difference in the peakiness in demand, Queensland was possibly utilising its transformers to a greater degree than Victoria until around 2004.

For lines, the analysis suggests that both the NSW and Queensland lines were significantly higher utilised than Victoria in 2000. This is in line with the findings of the background review for Queensland, but also suggests that NSW was also in a more challenging situation than Victoria with regard to the utilisation of its lines. This does suggest that around 2000, for both Queensland and NSW over-capacity in Victoria could have been a reason for the lower levels of line augmentation.

From around 2006, the Victorian lines began to be utilised at higher levels than NSW and Queensland. In particular, Queensland line utilisation has reduced significantly since that time. This could suggest that over-capacity is not the reason for the lower line augmentation levels, since around 2006.

The analysis of line utilisation suggested that the 500 kV lines in Victoria have a large impact on the overall utilisation metric. The 500 kV lines on average have a lower utilisation than the other lines in Victoria. This low average utilisation is significantly affected by the two long circuits from Heywood to Moorabool, which have a very low utilisation at the time of peak demand. From this analysis, it seems clear that there was and still is significant over-capacity in these lines.

However, an important point for this review, is not whether over-capacity exists, but whether it is resulting in lower levels of augmentation. From this point of view, it does not appear that this spare capacity – which is fairly significant in scale - has had a significant effect on augmentation needs[33]. Furthermore, the review of operational challenges found that the current arrangements, particularly associated with the 500 kV network, may affect the usable capacity. As such, the Victorian line utilisation metric may understate the augmentation pressures in comparison to the metrics of other regions.

Implications of load density and longer distances

The lower load densities – and therefore longer transmission distances – in NSW and particularly Queensland could mean that the lower utilisations in NSW and Queensland are still comparable to Victoria in defining augmentation needs. It is important to stress

[33] In this review it has not been possible to validate this position, which has been noted by AEMO. However, it seems reasonable given the location and role of these lines.

that this review has not been concerned with the structural arrangements, planning approaches, or reliability standards in each region. As such, comparability here means on a purely like-for-like risk basis; it may be that over- or under-capacity is still appropriate given these regional obligations. Noting this caveat, to gauge this effect, the relationship of the line utilisation metrics against the load density has been examined.

The results of this analysis are less definitive, suggesting a range of plausible positions, ranging from:

- Around 2006, the NSW and Queensland networks were operating at a higher comparable utilisation than Victoria, given their load density. As such, over-capacity in Victoria has still been the reason for the lower levels of augmentation in Victoria.
- Or, NSW and Queensland have moved to a level of utilisation that is below a comparable utilisation to Victoria, given their respective load densities. Therefore, over-capacity in Victoria was not the reason for the lower levels of augmentation in Victoria.

On balance, its seems reasonable to assume that a middle ground is most likely i.e. Queensland and possibly NSW were above a comparable utilisation around 2006, but have both fallen below this level by 2011. As such, there is probably a transitional period between 2006 and 2011, when over-capacity in Victoria ceased to be a cause for lower levels of augmentation. This position seems reasonable, given:

- the actual growth in peak demand over this recent period in NSW and Queensland, which has been significantly lower than forecast, while augmentation levels have still been high
- the significant reduction in the operational challenges in Queensland, since 2000
- the points made above on the 500 kV network and Heywood to Moorabool 500 kV lines in Victoria, which do have significant levels of over-capacity and therefore reduce the Victorian line utilisation metric; however, this over-capacity does not appear to have had any significant effect on augmentation needs in Victoria.

Overall view and concluding comments

Based upon the overall review, it seems reasonable to conclude that over-capacity in Victoria compared to NSW and Queensland is unlikely to have resulted in the lower levels of augmentation in Victoria, certainly over the recent past i.e. from around 2006/07.

For transformers, it would appear that this has not been the case since around 2004, and possibly much earlier. However, for lines it does appear that over-capacity in Victoria, compared to NSW and Queensland, could have been a significant factor in the lower augmentation levels prior to 2006/07. This certainly seems to be the case in the late 90s and the early part of the last decade, when Victoria appears to have a significantly lower line utilisation than Queensland and NSW.

In taking these findings forward, it may be useful for AEMO to consider the following points:

- There is still some uncertainty on the basis of the static line ratings used in NSW and Queensland. The assumptions used here could affect the results if they differ considerably. As such, it may be useful to determine the basis for the static ratings in order to more accurately correct the utilisation metrics for these differences.
- AEMO could consider the feasibility of calculating average utilisation metrics across the year, such that energy metrics or confidence limits could be determined (e.g. the utilisation that will not be exceeded for 95% of the year). This would be a more robust way to assess the implications of load and generation diversity and the effects of the peakiness in demand. However, such metrics would require significantly more effort to extract and process data.