IPART
New South Wales

Independent Pricing and Regulatory Tribunal

Electricity transmission reliability standards

Unserved energy allowances for Inner Sydney and Broken Hill, Molong, Mudgee, Munyang and Wellington Town

Energy — Supplementary Draft Report
September 2016

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Invitation for submissions

IPART invites written comment on this document and encourages all interested parties to provide submissions addressing the matters discussed.

Submissions are due by 28 October 2016.

We would prefer to receive them electronically via our online submission form <www.ipart.nsw.gov.au/Home/Consumer_Information/Lodge_a_submission>.

You can also send comments by mail to:

Review of electricity transmission reliability standards
Independent Pricing and Regulatory Tribunal
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1 Executive summary

The Independent Pricing and Regulatory Tribunal (IPART) has been asked to recommend reliability standards for electricity transmission in NSW, to apply from the next regulatory period which starts on 1 July 2018.[1]

Historically the level of reliability provided by the NSW electricity transmission network has been high. This has, at least in part, been driven by reliability standards that were set without reference to the value customers place on reliability.

As required by our terms of reference for the review, we have developed reliability standards by applying an economic assessment that aims to identify the level of reliability that would provide the most value to customers. This assessment takes into account both the cost of providing reliability, which is paid for by customers through their electricity prices, and the costs to customers of experiencing outages.

We made final recommendations to the Minister on 31 August 2016 setting out recommended standards, which include a level of redundancy and an annual unserved energy allowance at each bulk supply point across TransGrid's network. The Minister is considering these recommendations before making a decision on the reliability standards that will apply.

However, there are a number of supply points where we consider that further analysis and consultation is required before finalising the value of the expected unserved energy allowance. Those supply points are Inner Sydney, Broken Hill, Molong, Mudgee, Munyang and Wellington Town.

The wording of the standards and the proposed level of redundancy for these areas was included in our recommendations made to the Minister in August. For Inner Sydney, we have recommended that the required level of redundancy remains unchanged at modified N-2. For the other bulk supply points we have recommended that the required level of redundancy remains unchanged at N. More information is available in our Final Report for the review.[2]

1 The terms of reference are in Appendix A.

2 IPART, *Electricity transmission reliability standards, an economic assessment – Final Report,* August 2016.

1.1 Overview of our methodology

This supplementary draft report specifically considers the unserved energy allowance for Inner Sydney, Broken Hill, Molong, Mudgee, Munyang and Wellington Town. We applied the same methodology to determine the expected unserved energy allowance at these bulk supply points that we used for our final recommendations to the Minister for the other supply points.[3]

We decided to issue a further draft decision and consult on the unserved energy allowances for these bulk supply points because:

- For Inner Sydney we proposed a separate consultation process in our draft report released in May 2016 as:
  - At that time TransGrid and Ausgrid (the distribution network service provider for the Inner Sydney area) were exploring options for the relief of emerging supply constraints.
  - The complexity of the network in the Inner Sydney area, particularly the meshing of the transmission and distribution networks, makes the modelling for this area more complex.
  - It is likely that substantial investment will need to be made over the next regulatory period and this investment will be costly and will affect a substantial number of people over a long period.
- For Munyang and Wellington Town – the inclusion of supply point specific information in our modelling following release of our draft report led to increases in the optimal unserved energy. Information provided by TransGrid suggests that the updated model result for Munyang is likely to be above the current expected value, allowing TransGrid to reduce the level of reliability at this bulk supply point.
- For Broken Hill, Molong and Mudgee – our optimisation model suggests that the optimal value of unserved energy is likely to be less than the current expected value, implying that an increase in reliability would be warranted at these bulk supply points.

This supplementary draft report outlines our proposed approach and resulting estimates of expected unserved energy for these bulk supply points. We are seeking feedback on the draft recommendations in this report by 28 October 2016.

1.2 Overview of draft recommendations

We propose that the annual unserved energy allowance to be included in the reliability standards to apply from 1 July 2018 for each of the bulk supply points considered is set equal to the value determined by our optimisation model.

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3 IPART, *Electricity transmission reliability standards, an economic assessment – Final Report*, August 2016.

For the Inner Sydney area, our draft recommendation is that the value should be 0.6 minutes per year, at average demand. This value would apply across the five Inner Sydney bulk supply points (Beaconsfield West, Haymarket, Rookwood Rd, Sydney North and Sydney South) as a single group. We consider that our recommendations will allow a small increase in the expected value of unserved energy in the Inner Sydney area but given the size of the unserved energy allowance at around half a minute, we consider that our recommendations would not result in a significant change to the level of reliability experienced by customers.

A significant proportion of the 0.6 minutes of annual unserved energy in our draft recommendation for Inner Sydney reflects an allowance for non-catastrophic transformer failures. Because back-up capacity is available, a non-catastrophic failure would lead to an outage lasting only as long as it takes to switch to the back-up capacity. We used TransGrid's historical rates of non-catastrophic failure and repair times in estimating this allowance. Although TransGrid has not calculated the level of expected unserved energy in its network that is associated with non-catastrophic events, we consider that our allowance is likely to be consistent with the current level of expected unserved energy associated with these types of failures.

For Munyang, our draft recommendation is that the unserved energy allowance should be 191 minutes at average demand. Information provided by TransGrid suggests that this unserved energy allowance could result in worsening reliability for end-customers supplied via this bulk supply point as the network is currently very reliable. The high unserved energy allowance estimated by our model is driven by the load factor for Munyang, which is substantially below other NSW bulk supply points due to seasonal load variation.[4]

For Wellington Town our draft recommendations are that the unserved energy allowance should be 21 minutes at average demand. For Broken Hill 22kV our draft recommendation is that the expected unserved energy values should be 14 minutes at average demand. We do not expect our draft recommendations to result in a significant change to the level of reliability at either of these bulk supply points.

For Broken Hill 220kV our draft recommendation is that the expected unserved energy values should be 5 minutes; for Molong our draft recommendation is 46 minutes and for Mudgee it is 14 minutes, all at average demand. Information provided by TransGrid suggests that these unserved energy allowances may require TransGrid to make changes to its network to improve its reliability in these areas.

4 Munyang has a very pronounced winter peak and little demand during the summer reflecting the seasonality associated with the ski fields that Munyang serves.

Differences in the expected unserved energy allowance reflect in the main the value different customers place on reliability, the cost of providing it and customers' willingness to pay for it. They also reflect the specific characteristics of the bulk supply point, such as the load profile and maximum demand. The recommended standards do not prescribe how TransGrid must meet them but instead, explicitly provide for TransGrid to determine the combination of network and non-network solutions required to provide reliability.

1.3 List of draft recommendations

Our draft recommendations are:

1.4 Structure of this report

This supplementary draft report is structured as follows:

- Chapter 2 outlines IPART's approach to developing its recommendations on the NSW transmission reliability standards
- Chapter 3 discusses the unserved energy allowance for Inner Sydney
- Chapter 4 sets out the unserved energy allowances for Munyang and Wellington Town
- Chapter 5 sets out the unserved energy allowances for Broken Hill, Molong and Mudgee
- Appendix A provides the terms of reference for the review
- Appendix B includes a map of the Inner Sydney area
- Appendix C provides information on our modelling approach including the inputs and assumptions we have adopted.

2 Overview of IPART's approach to the review

We have recommended to the Minister that the NSW transmission reliability standards should move away from being heavily based on network capability and should better focus on what customers value. The standards should also introduce the concepts of probabilistic analysis and positive expected unserved energy into TransGrid's decision making processes as well as making explicit provision for the standards to be met using non-network solutions.

Our recommendation is that the standards should be implemented as planning standards, which means that TransGrid must plan its network in order to meet the requirements set out in the standards.

This approach provides greater flexibility around how TransGrid meets the reliability standards. It also ensures that the reliability standards are more responsive to changes in technology. From the customers' point of view this approach is designed to deliver outcomes that are more closely aligned with their expectations around reliability and their willingness to pay for it.

2.1 Our objectives

We outlined the following objectives for the review:

- Move away from standards that are heavily based on network capability and towards standards that better focuses on what customers value – we noted the high level of reliability being delivered by TransGrid and the fact that the existing standards were not developed with any reference to the value that customers place on the level of reliability.
- Introduce the concept of positive expected unserved energy into TransGrid's decision making processes – currently the standards that apply are deterministic. They focus on what happens in the event of different contingencies and require TransGrid to ensure it invests to reduce the expected unserved energy associated with these contingency events to zero. Requiring TransGrid to consider the likely probability and impact, in terms of expected unserved energy, of different assets failing provides a step away from a completely deterministic approach to setting reliability standards.

- Make explicit provision for the standards to be met using non-network solutions. The current standards are heavily focused on network capability. This effectively limits the scope for pursuing non-network solutions, even where these may be more economically desirable.
- Not result in a significant change from the current level of reliability experienced by customers – as this will be the first time an economic approach to setting reliability standards has been applied. There is significant uncertainty involved in some of the inputs, for example VCRs. We have undertaken sensitivity analysis but have also noted that there is further work that should be done to develop these concepts for future use.

We had regard to these objectives in developing our approach.

2.2 Overview of our recommended standards

We have recommended reliability standards to the Minister for each bulk supply point[5] across the transmission network to apply for the 2018 regulatory period. The standard requires the TransGrid – to plan and develop the network's supply capability to meet the forecast demand at that bulk supply point so that it provides:

- the required level of redundancy (that is, it specifies the number of back-up arrangements that must be in place to support continued supply of electricity in the event that part of the transmission network fails), and
- an allowance for TransGrid to plan for some expected unserved energy at each bulk supply point.

The recommended standards provide for TransGrid to meet the requirements for redundancy and expected unserved energy using any combination of transmission network assets, non-network solutions (like back-up power generation) or agreements with distribution network service providers (DNSPs) to use part of an attached distribution network.

2.2.1 Redundancy requirement

Our terms of reference require us to include a level of network capability informed by an economic assessment process to be expressed in terms of a network redundancy/N-x standard in our recommendations. Redundancy refers to the back-up arrangements that are in place to allow supply to continue to be provided in the event that part of the transmission network fails.

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5 We define a bulk supply point as a location where supply is provided to DNSPs or directly connected customers. Generally, the locations are the busbar(s) at TransGrid substations but sometimes the locations are where connections are made to TransGrid's transmission lines or cables (including "tee" connections). A more detailed definition is in the Glossary of this Draft Report.

The inclusion of a redundancy requirement is consistent with the current NSW transmission standards and with how transmission reliability standards are specified in other states of Australia. It is also consistent with the recommendations of the Australian Energy Market Commission (AEMC) following its review of the transmission reliability standards.

Moving away from a redundancy requirement would be a substantial departure from the standards that are currently in place and we consider that there is not evidence to support such a move. Therefore, we have recommended standards that continue to specify the level of 'redundancy' at each bulk supply point.

However, we have recommended complementary measures within the standards that provide greater flexibility around how the specified redundancy requirements can be met. For example, the standards we recommended explicitly provide that the specified level of redundancy can be met:

- even where the full load is not able to be supplied under all covered contingency circumstances, subject to the allowance for expected unserved energy being met
- by an arrangement that involves the use of non-network solutions and/or the distribution network (see discussion below), or
- by means of an alternative arrangement that does not provide the specified level of redundancy provided TransGrid can demonstrate that this would provide a better outcome for customers.

We intend the redundancy requirements to apply 'post-switching'. In other words, TransGrid may lose supply at a particular bulk supply point following the outage of a system element provided it has the capacity to put in place back-up arrangements that are able to supply a non-zero amount of load. The time that TransGrid will have available to switch to back-up arrangements will be limited by the expected unserved energy allowance. This approach ensures that the definition does not prevent non-network solutions from being implemented.

2.2.2 Allowance for expected unserved energy

We decided to include an allowance for expected unserved energy in the standard to give TransGrid some flexibility in terms of how it meets the specified level of redundancy. Including an allowance for a positive amount of expected unserved energy provides an additional constraint on TransGrid that avoids the need to be too prescriptive about the redundancy requirements (eg, we do not need to specify the capacity required for each level of redundancy, the time within which it needs to be activated or what type of assets need to be used).

Some flexibility in the redundancy requirements that are in place in other states of Australia exists. However, rather than considering expected unserved energy these standards tend to focus on the amount of demand (in MW) that may be put at risk. In Queensland and Tasmania this flexibility is in the form of provision for loss of load. In South Australia, an availability standard of 95% applies to network support arrangements.[6]

We consider that expected unserved energy is a superior indicator of the level of reliability of the network and should be the focus of the standard. It is broader than a load at risk measure as it takes into account both the probability of outages occurring and the expected impact, including the duration of outages, whereas load at risk does not. In order to demonstrate compliance with this expected unserved energy allowance TransGrid will need to consider both the probability and impact, in terms of unserved energy, of different asset failures occurring. The impact will be affected by the back-up and switching arrangements that are in place as well the time it would take to restore supply.

We consider that requiring TransGrid to have regard to the probability and impact of asset failures occurring will, over time, change TransGrid's planning philosophy. It should provide greater flexibility to TransGrid to find the optimum mix of firm network capacity, network back-up (post-switching capacity), switching arrangements and network support in order to meet the expected unserved energy limit at the least cost. It also better reflects customers' willingness to pay for reliability.

We recommended an allowance for expected unserved energy at each bulk supply point as a maximum value that should be allowed to be planned for in any year, in minutes at average demand.

2.2.3 Greater flexibility for non-network solutions

The way in which reliability standards are drafted can have a significant impact on the potential for non-network solutions to be a viable alternative to network investment.

6 Essential Services Commission of South Australia (ESCOSA), *Electricity Transmission Code TC/08*, 29 October 2015, clause 2.12. ESCOSA notes that the current wording of the availability standard is ambiguous as it does not define the term 'availability'. ESCOSA is proposing changes that will clarify that the network support arrangement must have at least 95% availability on the occasions it is called upon. (ESCOSA, *Electricity Transmission Code Review - Draft Decision*, March 2016, p 11).

The current standards, which specify reliability in terms of required redundancy (N-x), do not prescribe how that level of reliability will be met. For example, reliable electricity supply could be provided by a combination of cables, transformers, generators, demand-side management or battery storage. However, the form of the reliability standards may inadvertently limit the potential for some types of non-network alternatives, even if they are the most efficient option.

It is not possible to know in advance all of the potential solutions that will be available over the 2018 regulatory period. Some of the potential options for providing reliability, particularly non-network solutions, are not able to be considered in advance of when an investment decision is needed. Others depend on the forecast maximum demand and load profile at each bulk supply point, which changes over time. In addition, technological advances may also enable new options and/or reduce the cost of others. As a result, part of our aim in making recommendations on the standards is to ensure that they provide enough flexibility so as not to prohibit the uptake of new technologies.

To facilitate the adoption of non-network solutions where they are the most efficient option, we recommended reliability standard which incorporate the following:

- Terminology that focuses on the supply of electricity (the service output), rather than the specific technology used to meet this supply (the inputs). This provides scope for non-network options to be pursued and reduces the bias towards transmission network assets such as cables and transformers.
- Standards that specify the 'supply capability' required at each bulk supply point but not how this supply capability is provided.
- Standards that clarify the potential role of non-network solutions by noting that supply capability may be met by means of the transmission network, distribution network, network support arrangements, back-up supply capability, or any combination of these.
- Standards that allow for an exception to the required level of redundancy in certain circumstances.

We have recommended reliability standards that are framed to promote the most efficient network or non-network solution by using technology-neutral language, rather than promoting a specific type of network or non-network solution.

2.2.4 Implemented as planning standards

We have recommended standards that are specified as 'planning' standards rather than 'performance' standards.[7]

Performance standards have some advantages over planning standards: they are simpler to understand, the compliance process is likely to be less involved, and hence less costly, and they provide greater certainty to customers around what level of reliability they can expect to receive. However, for a performance standard to be appropriate there must be a sufficiently close relationship between planned outcomes and actual outcomes. Unlike distribution networks, transmission networks tend to have a low number of outages, which means that focusing on output measures may provide a false view of their reliability. There may be no outward signs that there is a major vulnerability in a transmission network until reliability is badly affected.

We expect that TransGrid would undertake simulation modelling as part of the planning process, which IPART would review when assessing compliance with the standard.

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7 The difference between these two types of standards is at what point compliance with the standard is assessed. Planning standards require TransGrid to plan its network according to specified criteria. Compliance with the standard is assessed at the planning stage. On the other hand, performance standards would require TransGrid to deliver specified reliability outcomes. Compliance with the standard would be assessed by reviewing actual network performance.

3 Unserved energy allowance for Inner Sydney

TransGrid is proposing to undertake substantial additional investment in Inner Sydney in the 2018 regulatory period. The upcoming expenditure for the Inner Sydney is costly, long lasting and impacts a substantial number of customers. We have considered several ways of deriving an appropriate value for the expected unserved energy parameter in the reliability standard for Inner Sydney.

In our Draft Report released in May 2016, we proposed a separate process for determining the expected unserved energy allowance for Inner Sydney.[8] Broadly, the process we set out involved TransGrid and Ausgrid using their joint planning process to identify various reliability options in terms of the range of expected unserved energy values that could be delivered for this area and then providing a proposed unserved energy allowance for us to consider.

TransGrid has subsequently advised us that it is not in a position to propose an unserved energy allowance for Inner Sydney within the timeframe required. As a result, we have decided to adopt the results of our own modelling as the basis for our draft recommendations on the unserved energy allowance for Inner Sydney.

3.1 Recommended unserved energy allowance for Inner Sydney

We propose that the unserved energy allowance to be included in the reliability standard for the Inner Sydney supply area is the value determined by our optimisation model. Our draft recommendation is that the value should be 0.6 minutes per year, at average demand. This value would apply across the five Inner Sydney bulk supply points (Beaconsfield West, Haymarket, Rookwood Rd, Sydney North and Sydney South) as a single group.

Draft recommendation

1 The allowance for expected unserved energy for Inner Sydney that should be included in the NSW transmission reliability standard is 0.6 minutes (maximum value per year in minutes at average demand).

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8 IPART, *Electricity Transmission Reliability Standards - Draft Report*, May 2016, p 25.

Box 3.1 Electricity transmission in the Inner Sydney area

How is Inner Sydney defined?

The Inner Sydney transmission system supplies most of the eastern Sydney metropolitan area, extending from the Pacific Ocean, west to Auburn, north to the Hawkesbury River and south to the Royal National Park. The network supplies electricity to over 500,000 customers including homes, businesses, hospitals and public transport as well as Australia's financial hub, Sydney Airport and Port Botany. The network is technically defined as TransGrid's 330kV cables 41 and 42, 330/132kV substations Beaconsfield, Haymarket, Rookwood Road, Sydney North and Sydney South and Ausgrid's 132kV transmission network that links to those TransGrid substations. A map of the Inner Sydney area is included in Appendix B.

What investment is TransGrid considering in this area?

The Inner Sydney transmission network represents an integrated supply arrangement between TransGrid and Ausgrid. A number of the underground cables supplying the Inner Sydney area were built more than 50 years ago. Due to deteriorating cable conditions, increasing environmental risks and growing maintenance concerns, some parts of the network are scheduled for retirement in the coming years.

TransGrid and Ausgrid are working together with the aim of achieving a coordinated and cost effective solution. This joint project is known as the 'Powering Sydney's Future' project. Powering Sydney's Future was initially being considered for the 2014-15 to 2017-18 regulatory period as a result of the combined impact of the proposed retirement of a number of Ausgrid's aged oil-filled cables and forecast demand growth in the area. The project did not proceed over this period as condition assessments determined that the cable retirements could be deferred and the load forecast was revised down.

The project has now recommenced and forecast investment is likely to be included in TransGrid's regulatory proposal to the Australian Energy Regulator for the 2018-19 to 2022-23 regulatory period.

Source: TransGrid, *Fact Sheet – Powering Sydney's Future*, May 2014, p 2, and additional information provided to IPART by TransGrid.

3.2 Overview of IPART's modelling for Inner Sydney

We have undertaken our own modelling of the optimal unserved energy for the Inner Sydney area, consistent with our approach for the rest of the NSW transmission network. We applied an optimisation model that identifies an optimal amount of expected unserved energy at each individual bulk supply point, estimated on a life-cycle basis. Our modelling suggests an expected unserved energy allowance for Inner Sydney of 0.6 minutes, at average demand.

The optimisation model we developed covers all bulk supply points (substations) for the TransGrid network. The optimisation model allows us to optimise the annual amount of expected unserved energy at each bulk supply point. The model takes into account certain features that vary between substations. These include the number and capacity of transformers, the number and capacity of lines served by the substation, the maximum demand, load profile, and the VCR for end-users served by that substation. However, at this stage the model does not take account of details of the switchgear design or of the network surrounding the substation.

Given certain settings that affect reliability and the value of customer reliability (VCR) and load characteristics at the bulk supply point, the model calculates both:

- the average cost of owning and operating the assets comprising the substation and associated lines, and
- the dollar value of the expected unserved energy.

The sum of the asset cost and the expected unserved energy value is the total social cost[9] for the chosen reliability settings. Different combinations of the reliability settings are examined, and the one that leads to the least social cost is selected and the corresponding level of expected unserved energy is chosen as the optimal value. We have estimated annual demand at each bulk supply point using forecast maximum demand (in MWh) and an estimated load factor.

The corresponding level of expected unserved energy in MWh is then used to calculate the allowance for expected unserved energy in minutes per annum. The allowance for expected unserved energy per annum is calculated by dividing the optimal expected unserved energy (in MWh) produced by the optimisation model, by the estimated average annual demand at that bulk supply point (in MW) and converting it to minutes (by multiplying it by 60).

The reliability settings that are used as the control variables in this optimisation are:

1. level of network redundancy (ie, N, N-1 or N-2)
2. load at risk (% of maximum demand) at each level of redundancy
3. time taken to restore service at each level of redundancy following an asset failure, and
4. time taken to repair or replace the failed asset.

Separate settings can be chosen for transformers and lines.

9 Within the electricity market, consistent with the cost-benefit framework adopted in the NER for the RIT-T.

The optimisation model calculates expected unserved energy for each possible combination of reliability settings by considering the:

- failure rate for each asset type at the bulk supply point (transformers, overhead cables and underground cables)
- load at risk – the load supplied from a bulk supply point, which is at risk of being interrupted if an asset fails, after allowing for available backup capability, but before repair of the asset that has failed
- restoration time – the time to restore the network to the relevant redundancy level, using back-up capability (which depends on switching arrangements), and
- repair time – the time to restore or repair failed assets.

An overview of each of the main inputs to the optimisation model is set out below. More detail regarding the inputs and assumptions included in the model are set out in Appendix C.

In addition to using the unserved energy value obtained from the optimisation model, we have included an allowance in the unserved energy to account for non-catastrophic transformer failures. In our optimisation model, only catastrophic failures (that is, where the transformer needs to be replaced following failure) are included.[10] However, the rate of non-catastrophic transformer failure (failures that can be repaired) is significant and this adds to the expected unserved energy for the network. So as not to exclude the impact of non-catastrophic transformer failure, we have separately estimated an allowance for the unserved energy associated with these failures at each bulk supply point.

To estimate the allowance for non-catastrophic transformer failures we used information on the rate of these failures (provided by TransGrid) as well as information on the average repair time (also from TransGrid) and the speed of switching available at the bulk supply point (based on our modelled optimum). Where back-up capacity is available, we assumed that a non-catastrophic failure would lead to an outage lasting only as long as it takes to switch to backup capacity. These allowances are added to the optimal unserved energy allowances estimated by the model.

3.2.1 The cost of providing reliability

In the optimisation model, reliability is provided by having standby assets available. The cost of reliability depends on the extent of standby capacity, which is partly determined by the amount of load at risk that can be tolerated. The load at risk drives both the direct cost of providing reliability and the expected cost of unserved energy.

10 Because this rate and the cost of minor repairs are largely independent of the planning criteria adopted, the presence of non-catastrophic transformer failures would not affect the optimisation calculation.

Standby capacity can be accessed by switching—to an alternate transformer at a possibly different location, or to an alternate line that follows a different route. The model does not identify these alternate locations or routes specifically, and it assumes that standby capacity is divisible, perhaps by having several bulk supply points share the same standby transformer or line. These simplifying assumptions make the model tractable.

The supply arrangement costs cover the capital and operating costs for the following elements:

- transformer and line capacity
- backup capacity and restoration obligations, and
- repair obligations.

Transformer and line capacity costs provide the cost of system capacity in its normal state, ie, no asset failures. The cost of backup capacity, restoration obligations and repair obligations drive the cost of system capacity to deal with a single or double asset failure.

The model only includes costs that vary when the reliability settings change. This means, for example, that it excludes the cost of substation land, fencing and other site costs as they are the same across all the possible planning criteria. The cost benchmarks in the model were informed by cost information provided by TransGrid as well as expert advice we received from Brian Nuttall Consulting. The costs focus on network costs but do not relate to any specific investments proposed by TransGrid.

While we have focused on network costs, there may be non-network solutions to provide reliability to customers, and these solutions could be cheaper than the network options considered. If reliability can be increased (ie, expected unserved energy reduced) more cheaply than the cost estimates provided by TransGrid, this will affect the optimised levels of expected unserved energy specified in the standard. In essence, if a cheaper non-network (or network) option is available then we would expect the optimised allowance for expected unserved energy to be lower.

The discount rate used in the model for our report is 5.6% (real pre-tax). This is IPART's estimate of TransGrid's Weighted Average Cost of Capital (WACC). In calculating the WACC IPART assumed an equity beta of 0.7 and 60% gearing level. These assumptions are specific to the electricity transmission industry. Other market parameters (market risk premium, risk free rate, inflation forecast and debt margin) are based on IPART's standard WACC methodology.[11]

11 IPART completed a major review of the WACC in 2013 (IPART, *Review of WACC Methodology – Final Report,* December 2013). More recently we updated the method of estimating the debt margin and the inflation adjustment (IPART, *WACC – IPART's New Approach to Estimating the Cost of Debt – Fact Sheet,* April 2014; IPART, *New approach to forecasting the WACC inflation adjustment – Fact Sheet, March 2015*).

3.2.2 Failure rates

The actual failure rate of each asset depends on the type of asset and its age. However, the model considers the lifecycle average failure rate of a typical asset of that type. In reality the condition of a specific asset may be better or worse than average, and that will affect the likelihood of failure, but this is not taken into account in the model.

Our model looks at single asset failures as well as the simultaneous failure of two transformers or two lines. For Inner Sydney, we considered whether we should expand the number of simultaneous asset failures, for example, to consider the simultaneous failure of three or more assets. However, at the life-cycle failure rates included in our optimisation model, we expect that doing this would make very little, if any, difference to the optimal unserved energy estimated by the model.

Non-catastrophic transformer failures

We have also included an allowance for non-catastrophic transformer failures (failures that can be repaired). To estimate the allowance for non-catastrophic transformer failures we used information on the rate of these failures (provided by TransGrid) as well as information on the average repair time (also from TransGrid) and the speed of switching available at the bulk supply point (based on our modelled optimum). Where back-up capacity is available, we assumed that a non-catastrophic failure would lead to an outage lasting only as long as it takes to switch to backup capacity. For the Inner Sydney area the allowance for these failures makes up a significant portion of the expected unserved energy allowance.

Low probability, high impact events

Certain combinations of asset failures are explicitly captured by the recommended standard including some with quite a low probability of occurrence but a high impact on customers should they occur such as double transformer and double line failures. However, we have not considered other very low probability events such as some of those raised in a submission we received.[12]

To alter the analysis to give a different weighting to these events would be inconsistent with the probabilistic approach to standard setting that underpins our analysis (this approach relies on both the probability of asset failures and the impact of failure, should it occur). However, we have taken a conservative approach in that we are not recommending any changes to the level of

12 Anonymous submission to IPART Draft Report, 28 June 2016, p 1. The submission mentioned system black, space weather, cyber-attack, SCADA failure, market operator control room failure, malicious attacks and rare coinciding (Black Swan) events.

redundancy provided at any bulk supply point – our recommendations include complementary measures aimed at providing more flexibility around how these redundancy requirements are met.

3.2.3 Value of customer reliability (VCR)

Our terms of reference require us to have regard to the latest estimates of VCR published by AEMO. These values are set out in Table 3.1.

Table 3.1 AEMO VCR results ($2014-15)

	VCR ($/kWh)
Residential	26.53
Commercial	44.72
Industrial	44.06
Agricultural	47.67
Direct connect	6.05
Aggregate NSW, including direct connects	34.15

Note: Residential VCR results are for NSW (including the ACT); Commercial, Industrial, Agricultural and Direct connect results are across the National Electricity Market.

Source: AEMO, *Value of Customer Reliability Review - Final Report*, September 2014, pp 2, 18, 31.

We used these values to estimate a VCR for each bulk supply point across the network based on the different types of customers using electricity at each point and their consumption. However, we considered that further work is needed to better understand the true value that different customers place on reliability and have made a recommendation that more work be undertaken in relation to VCRs.

For the analysis that TransGrid and Ausgrid are undertaking for the Powering Sydney's Future project, TransGrid engaged consultant HoustonKemp to provide an estimate of VCRs for the Inner Sydney and Sydney CBD areas. TransGrid has provided us with a copy of this report, which is available on our website, and has recommended that we use these VCRs in determining the unserved energy allowance for the Inner Sydney area.

The HoustonKemp report argues that the VCRs for Inner Sydney are significantly higher than those developed by AEMO (see Table 3.2).

Table 3.2 Value of customer reliability ($/kWh)

Customer	HoustonKemp ($2016)	AEMO NSW aggregate, inc direct connect ($2014)
Inner metropolitan	$90	$34.15
CBD	$150-$192 ($170)	$34.15

Source: HoustonKemp, *CBD and inner metro VCR estimates – A final report for TransGrid on research, methodology and results*, 28 July 2016. AEMO, *Value of customer reliability review – Final report*, September 2014.

As part of our review of transmission reliability standards stakeholders' submissions noted that the AEMO estimates are calculated from a very small sample size,[13] are overly dependent on the methodology used,[14] do not include important customers such as the Australian Stock Exchange, NSW Parliament, large financial institutions,[15] and do not adequately capture low probability but high impact supply interruptions.[16]

While we have adopted the AEMO values for the rest of our analysis, we consider that there are likely to be special circumstances in relation to the nature of customers in the Inner Sydney area, and the CBD in particular, that mean the AEMO values for the rest of the state are not as relevant. For example, the Sydney metropolitan train network, international airport and stock exchange are likely to have higher VCRs than typical commercial and industrial customers as a result of their quite unique business needs. The higher HoustonKemp estimates reflect the higher VCRs of these customers.

It is likely that many high-VCR customers, such as these, would invest in their own back-up supply arrangements (eg, batteries or local generators) in order to ensure that their need for very high reliability is met. However, once these customers have back-up arrangements in place they may actually be more tolerant of supply outages than other customers (and so would then have lower VCRs). This raises the question of whether our modelling should use VCRs based on the value of reliability to such customers without back-up arrangements in place (higher, pre-investment VCR) or with back-up arrangements in place (lower, post-investment VCR).

We consider that our optimisation model should use the pre-investment VCR values for all customers. The optimisation model seeks to determine the reliability standard that will minimise the total social cost of electricity supply, which includes investment costs incurred to provide reliability and the costs of unserved energy incurred by customers. If we were to use the post-investment VCR values, then we would also need to include any investment costs incurred by end-customers to provide their own back-up systems, as that cost forms part of the total social cost of providing reliability. The pre-investment VCR would

13 Essential Energy submission to IPART Issues Paper, 28 January 2016, p 5.
14 ETSE Consulting submission to Issues Paper, 27 January 2016, p 7.
15 Ausgrid submission to IPART Issues Paper, 22 January 2016, pp 7-8.
16 Ausgrid submission to IPART Issues Paper, 22 January 2016, p 9.

provide a reasonable estimate where customers make rational decisions about installing back-up capacity.[17]

For these reasons, we have chosen to adopt a VCR value of $90/kWh in our optimisation model, consistent with the Inner metropolitan value estimated by HoustonKemp rather than use the AEMO values in our analysis.

3.2.4 Demand

We have used estimates of maximum demand at each bulk supply point published by TransGrid[18], which use information provided by DNSPs. The estimates are based on the 50% POE maximum demand forecast reflecting the most recent estimates for 2018-19.

Currently the model does not capture unserved energy that results from growth in peak demand.[19] AEMO's current statement of opportunities forecasts that maximum demand will be relatively stable over the period to 2024-25.[20] For this reason, we consider that the use of the 2018-19 value of maximum demand is reasonable.

3.2.5 Grouping supply points in the Inner Sydney area

We recognise that there are some bulk supply points that are so closely linked within the network that they are difficult to differentiate in terms of reliability. We consider that the five Inner Sydney bulk supply points should be considered as a single group for the purpose of setting an unserved energy allowance.

Although we would have liked to jointly model these grouped supply points, this would introduce a significant additional level of complexity into the modelling. As a result, we have continued to model each of the five Inner Sydney bulk supply points separately and to use these to derive a group unserved energy allowance in the same way as we did for other grouped bulk supply points across the network. To derive the unserved energy allowance for the group we:

- added the unserved energy allowances in MWh for the individual bulk supply points within the group, then
- converted this value to minutes by dividing it by annual average demand at the combined individual bulk supply points.

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17 A rational end-customer would only invest in back-up supply if doing so would reduce its total expected costs. Therefore, the pre-investment VCR will be greater than or equal to the post-investment VCR plus the cost to customers of putting back up arrangements in place.

18 TransGrid, *Reliability Scenarios, NSW Electricity Transmission System*, November 2015, pp 6-12. For some bulk supply points we sought further clarification from TransGrid on the maximum demand forecasts in this publication.

19 We intend on incorporating growth in peak demand in the optimisation model at our next review.

20 AEMO, 2015 *Electricity Statement of Opportunities*, p 16.

3.2.6 Sensitivity analysis

At each bulk supply point, the model selects the unserved energy that is associated with the optimal combination of reliability settings it identifies based on the various inputs. An input change may result in a different value of unserved energy because it leads to a change in the optimal combination of reliability settings or it may result in the same unserved energy because it does not lead to a change in the optimal combination of reliability settings.

We tested the following input sensitivities in coming to our decision on the unserved energy allowances in the recommended standard:

- VCR – the use of the AEMO value rather than $90/kWh.
- Maximum demand - up and down 30%.
- Cost co-efficient/exponent – up and down 30%.
- Asset lives – up and down 30%.
- Discount rate – 4.7% and 6.4% (compared to a base of 5.6%).
- Failure rate – up and down 10%.
- Line length – up and down 30%.

For the Inner Sydney area, the sensitivity analysis suggests that:

- Using the AEMO VCRs increases the optimal value of unserved energy to 1.7 minutes – almost 3 times our draft recommendation.
- The results are somewhat sensitive to changes in maximum demand – with a 30% lower maximum demand increasing the unserved energy to 1.3 minutes and a 30% higher maximum demand reducing it slightly to 0.5 minutes.
- Changes to the discount rate within the range we tested made only a very small difference (the low value did not result in any change, the high value raised the unserved energy from 0.6 minutes to 0.8 minutes).

3.3 Expected impact of our draft recommendations

The changes we have recommended are designed to introduce the concept of customer value into the standards and to make this more of a focus in TransGrid's decision making processes. They are also designed to provide greater flexibility for using non-network solutions.

Overall, we expect that the unserved energy allowance in our draft recommendations would reflect a slight loosening of the reliability standard compared with the current standard. This should allow TransGrid to consider a broader range of investment options for the Inner Sydney area and result in investment decisions that better reflect the value that customers place on reliability.

Through the regulatory revenue determination process with the AER, TransGrid will be required to demonstrate that any investments it proposes are efficient, and where relevant, necessary to meet the reliability standards that are in place. In our view, the recommendations we propose will provide additional flexibility to TransGrid in terms of expanding the number of investment options available to it, including delivering a greater ability to adopt new technologies.

3.3.1 Current value of expected unserved energy in Inner Sydney

The current standard[21] requires TransGrid to plan its network so that the Inner Sydney metropolitan system (provided jointly by TransGrid and Ausgrid) is capable of meeting the peak load under the following contingencies:

- the simultaneous outage of a single 330kV cable and any 132kV feeder or 330/132kV transformer, or
- an outage of any section of 132kV busbar.

This is referred to as a modified n-2 obligation. In addition to this modified n-2 obligation, which applies to the combined TransGrid and Ausgrid system, an n-1 criterion also applies separately to TransGrid's Inner Sydney network. The load forecast to be considered is a 50%POE maximum demand forecast.

As a result of this standard, the current value of expected unserved energy associated with the Inner Sydney transmission network, taking into account the maximum demand and combination of outages listed above is zero.

TransGrid has advised us that under current forecast demand and planned cable withdrawals by Ausgrid, it would continue to expect an annual unserved energy of zero for several years, even taking into account the current age and condition of the assets in service.[22] Beyond this time, increases in maximum demand and the retirement of some of Ausgrid's older cables would lead to a positive value of expected unserved energy unless additional investment in the network is made.

Table 3.3 Inner Sydney BSPs – annual USE in minutes at average demand

	IPART modelling	TransGrid estimate of current network
Inner Sydney	0.6	≈ 0[a]

[a] Estimate based on the impact of both a single asset failure (n-1 contingency) and a simultaneous outage of a single 330kV cable and any 132kV feeder based on expected actual probabilities of outages and historical outage durations.

Source: IPART Draft Report, IPART calculations and TransGrid indicative compliance assessment.

21 NSW Department of Industry and Investment, *Transmission network design and reliability standard for NSW*, December 2010, p 10.

22 Note that TransGrid has advised that it has not included the simultaneous outage of a single 330kV cable and any 330/132 kV transformer in this estimation and that to do so would require further assessment.

TransGrid's estimate of unserved energy is based on the impact of single asset failures (n-1 contingency) and a simultaneous outage of a single 330kV cable and any 132kV feeder using expected actual failure probabilities and historical outage durations. As a result, this estimate is not directly comparable with the 0.6 minutes per year estimated by our modelling (see above for a discussion of our modelling assumptions). Our modelling takes into account the probability and impact of the following situations, based on life-cycle average failure rates:

- system normal
- single transformer failure
- single line failure
- double transformer failure, and
- double line failure.

In addition, a significant proportion of the 0.6 minutes of annual unserved energy in our draft recommendation for Inner Sydney reflects an allowance for non-catastrophic transformer failures. Because back-up capacity is available, a non-catastrophic failure would lead to an outage lasting only as long as it takes to switch to the back-up capacity. We used TransGrid's historical rates of non-catastrophic failure and repair times in estimating this allowance. Although TransGrid has not calculated the level of expected unserved energy in its network that is associated with non-catastrophic events, we consider that our allowance is likely to be consistent with the current level of expected unserved energy associated with these types of failures.

While TransGrid has not yet estimated the equivalent value for the Inner Sydney area, it would be required to do so in the future in order to assess compliance with the standards. It is important that the set of risks that TransGrid is asked to consider as part of the planning standards reflect the set of risks that were used to determine the allowance for expected unserved energy (the optimisation model).[23]

Considering an expanded combination of asset failures, consistent with our modelling, may further raise the expected unserved energy associated with the current network above the zero value currently estimated by TransGrid.

23 If the definition in the standards is broader than was included in the optimisation model TransGrid may find it difficult to meet the standards without significant additional investment in reliability. This is not efficient and not driven by the value that customers place on reliability. On the other hand if the definition in the standards is narrower than what was included in the optimisation model TransGrid may find it too easy to meet the standards and not invest when there would be value in doing so.

3.3.2 Impact on customers

We consider that our recommendations would allow a small increase in the expected value of unserved energy in the Inner Sydney area but given the size of the unserved energy allowance at around half a minute, we consider that our recommendations would not result in a significant change to the level of reliability experienced by customers.

Our recommended standards are planning standards not performance standards. We chose this approach because, unlike distribution networks, transmission networks tend to have a low number of outages, which means that focusing on output measures may provide a false view of their reliability.

The recommended standards would require TransGrid to plan its network to keep the expected value of unserved energy associated with a specified combination of asset failures below the allowance. There may be times when the actual value of unserved energy for the network exceeds the value in the standard for that year. This is the same as under the current standard, which is also a planning standard. Even though TransGrid estimates an expected unserved energy of zero for the current network, supply outages still do occur from time to time.

The recommended standards would also require TransGrid to consider life-cycle average failure rates in estimating the expected value of unserved energy. This means that the expected unserved energy value in the standard will understate the actual probability of expected outages in years where assets are older than average, and hence more likely to fail, and overstate the actual probability of expected outages in years when assets are younger than average, and hence less likely to fail. See Box 3.2 for more information.

As provided for under the current standard, TransGrid would continue to decide at what point the age or condition related probability of asset failure is such that it warrants the replacement of assets. We are aware that for the Inner Sydney area, many of the assets that are currently in place are older than the life-cycle average. As a result, their actual probabilities of failure are likely to be higher than assumed in our modelling. This means that at this point in the life-cycle of the Inner Sydney network, the actual expected unserved energy may be higher than 0.6 minutes per year.

Box 3.2 Life cycle failure rates vs actual expected failure rates

The unserved energy allowances our recommended standards are based on life-cycle average failure rates. In reality, TransGrid's assets will have different expected failure rates over the planning horizon because their network contains assets with ages and/or condition that do not reflect the life-cycle averages.

To be consistent with the way the standards are expressed, life-cycle average failure rates should be used in the compliance assessment and not expected rates over the planning horizon. Using condition based failure rates would have unintended consequences – for example, requiring TransGrid to bring forward asset replacement when that would not be efficient or easily allowing TransGrid to meet the standards where assets are relatively young.

However, focusing compliance on life-cycle averages creates a risk that TransGrid could run down its assets by delaying replacement, accepting a higher probability of asset failure and worsening reliability, without affecting its ability to meet the reliability standard.

To address this issue the unserved energy allowances in the standards could be recalculated based on the actual condition of TransGrid's assets – this condition could also be used for the compliance assessment. However, this means aligning the standards more closely to TransGrid's transmission network assets which is inconsistent with moving towards technology neutral standards. It also means that the standards would require constant updating in response to changes in TransGrid's network and the resulting allowances for unserved energy would fluctuate significantly over time.

We are already proposing significant changes to the way TransGrid is required to consider reliability (eg, building restoration times, switching arrangements and failure probabilities into the reliability assessment). Capturing condition-based failure rates in the standards would be a further significant change.

For these reasons, we do not recommend trying to capture actual condition based failure rates. However, we recommend that as part of the compliance process TransGrid provides information on its asset replacement strategy. This should provide additional information on the appropriateness of TransGrid's life-cycle failure rates. It should also provide information on changes to asset condition that may impact reliability.

4 Unserved energy allowance for Munyang and Wellington Town

Between our draft and final reports we made a number of changes to our optimisation modelling in order to ensure that it better took into account supply point specific information, such as load factors and the actual number of lines and transformers. For Munyang and Wellington Town bulk supply points, these changes led to increases in the unserved energy allowances compared with what was in our draft report (see Table 4.1).

TransGrid has provided us with an estimate of the expected unserved energy at each of these bulk supply points. For Munyang, this information indicates that setting an unserved energy allowance based on our final modelling could lead to a significant reduction in the level of reliability for customers. The results of our modelling at Munyang suggest that a relatively high allowance for unserved energy is appropriate but the network is currently very reliable at this point.

Table 4.1 BSPs in this category – annual USE in minutes at average demand

	IPART draft report	IPART final modelling	TransGrid estimate of current network
Munyang	10	191	Less than 1
Wellington Town	10	21	Around 15

Source: IPART draft report, IPART calculations and TransGrid indicative compliance assessment (provided to IPART on a confidential basis).

At Munyang, the high unserved energy allowance estimated by our model is driven by the low load factor at this bulk supply point (see Appendix C). The Munyang load factor (0.18) is well below the range of load factors for the other NSW bulk supply points and the average load factor that we used in our draft report modelling (0.51). The low load factor at Munyang results from the combination of a very pronounced winter peak and low summer demand. This seasonal variation is a result of the load served by the Munyang bulk supply point – the nearby ski fields. As our modelling uses an annual average load factor to estimate the optimal unserved energy, it does not reflect this seasonality.

There may also be a seasonal aspect to the VCR at Munyang, and potentially other bulk supply points, which is also not reflected in our modelling. We continue to support an updated and comprehensive study of VCRs across NSW. Such a study could investigate whether it would be useful to try to capture such seasonal variation.

TransGrid has indicated that Munyang has a low level of expected unserved energy currently because it has fast switching in place, whereas our model found manual switching to be optimal. We understand that in some cases automatic switching can be a relatively cost-effective option (due to the geography and proximity to other infrastructure at the bulk supply point). Munyang is relatively close to other infrastructure, including electricity generation in the Snowy area. If this means that the cost relativities in our model are not correct for Munyang, the optimal unserved energy identified by our model may be higher than it should be.

One of our objectives for the review was that the recommended standard would not result in a significant change in the reliability experienced by customers. This was in recognition that this is the first time an economic approach has been applied to reliability standards and there is significant uncertainty in some of the inputs, in particular the VCR. While overall this is true of our approach, adopting the unserved energy allowance we have estimated for Munyang could potentially result in a large deterioration in reliability for electricity users in this area.

However, one of the reasons for applying the economic assessment was to move towards a reliability standard that better reflects what customers value. TransGrid currently has a prescriptive reliability standard and a very high level of reliability that our analysis suggests may not be justified in these areas. Our draft decision is to adopt the allowances that reflect our updated modelling estimates in Table 4.1.

Draft recommendation

2 The allowance for expected unserved energy for Munyang that should be included in the NSW transmission reliability standard is 191 minutes (maximum value per year in minutes at average demand).

3 The allowance for expected unserved energy for Wellington Town that should be included in the NSW transmission reliability standard is 21 minutes (maximum value per year in minutes at average demand).

5 Unserved energy allowance for Broken Hill, Molong and Mudgee

At Broken Hill, Molong and Mudgee preliminary information provided by TransGrid suggests that the unserved energy allowances we have calculated are likely to be below the expected value of unserved energy currently associated with the transmission network. This suggests that TransGrid would need to improve the reliability of its network at these points.

A comparison of our draft report, final modelling and TransGrid's estimate of the expected unserved energy of the current network are set out in Table 5.1.

Table 5.1 BSPs in this category – annual USE in minutes at average demand

	IPART draft report	IPART final modelling	TransGrid estimate of current network
Broken Hill 22kV	5	14	Around 5
Broken Hill 220kV	n/a[a]	5	Around 10
Molong	16	46	Around 100
Mudgee	3	14	Around 30

[a] Following release of the draft report we identified that our model did not correctly calculate the level of unserved energy in instances where a bulk supply point had no transformers. This resulted in a very high value of unserved energy at the Broken Hill 220kV bulk supply point. We have now corrected this.

Source: IPART draft report, IPART calculations and TransGrid indicative compliance assessment (provided to IPART on a confidential basis).

For Broken Hill, our final modelling for the 22kV bulk supply point is above TransGrid's estimate of the current expected unserved energy; however, it is below TransGrid's estimate at the 220kV bulk supply point. These two bulk supply points are related in terms of the available back-up arrangements and as a result, we have decided to consider them both together as part of this supplementary draft report.

TransGrid has access to back-up generation at Broken Hill. Currently, the back-up generation takes around half an hour to restore supply to the 22kV bulk supply point (the township) and around an hour to restore supply to the 220kV bulk supply point (industrial load). We understand that TransGrid restores the 22kV bulk supply point first because it is closer to the gas turbines. TransGrid advises that these restoration times drive its unserved energy estimates associated with the current network at these two supply points.

Our modelling suggests that the optimal value of unserved energy is higher (that is, reliability should be lower) at the more residential 22kV bulk supply point and lower at the more industrial 220kV bulk supply point (that is, reliability should be higher). This modelling was based on very similar VCR values at both Broken Hill bulk supply points of around $34/kWh. This reflects our decision to use the aggregate NSW value for sub-transmission load at bulk supply points in the Essential Energy areas.[24] This was in response to feedback from Essential Energy that these customers were typically not agricultural customers, as assumed by PB, but that a more detailed breakdown by customer type was unavailable.[25]

However, all of the load at the Broken Hill 220kV bulk supply point is mining related. AEMO's industrial VCR values, which include both mining and manufacturing, are higher than the aggregate value we have used for this bulk supply point. However, AEMO's VCR study also looked at mining customers specifically as part of the direct connect category and found that VCR for these customers is much lower than the aggregate value we used. A summary of the AEMO VCRs is set out in Table 5.2.

Table 5.2 AEMO VCR results ($2014-15)

	VCR ($/kWh)
Residential	26.53
Commercial	44.72
Industrial	44.06
Agricultural	47.67
Aggregate NSW, including direct connect customers	34.15
Direct connect	6.05
Direct connect (mining)	14.96

Note: Residential VCR results are for NSW (including the ACT); Commercial, Industrial, Agricultural and Direct connect results are across the National Electricity Market.

Source: AEMO, *Value of Customer Reliability Review - Final Report*, September 2014, pp 2, 18 and 28.

AEMO also found that the value for direct connect mining customers varied significantly with outage duration. For direct connect mining customers the VCR for an initial short (10 minute) outage was around $38/kWh but was significantly lower for longer outages, around $4/kWh for a 12 hour outage (see Table 5.3).[26] AEMO noted that the reason for this is that a short outage is likely to halt production for longer than the duration of the outage, whereas for longer outages the halt in production time better matched the lost outage time.[27]

24 Other inputs were quite different at the two Broken Hill bulk supply points, including maximum demand, load factor/load duration curves and network infrastructure.

25 IPART, *Electricity transmission reliability standards, an economic assessment – Final Report*, August 2016, p 38.

26 AEMO, *Value of Customer Reliability Review - Final Report*, September 2014, p 30.

27 AEMO, *Value of Customer Reliability Review - Final Report*, September 2014, p 30.

Table 5.3 AEMO VCR results ($2014-15) – direct connect mining sector

	VCR ($/kWh)
10 minute outage	37.99
1 hour outage	19.50
6 hour outage	4.79
12 hour outage	4.21

Note: Results for direct connect mining customers across the National Electricity Market.

Source: AEMO, *Value of Customer Reliability Review - Final Report*, September 2014, p 30.

Our modelling does not include VCRs by outage duration so it is not possible for us to model this with more precision. However, using a lower VCR that is more in line with the direct connect mining customer value identified by AEMO ($14.96/kWh) does not change the optimal unserved energy value found by our optimisation model.[28]

For Molong, TransGrid does not have available back-up supply and therefore, should an outage occur, the estimated time to restore supply depends on how quickly the fault can be repaired (as opposed to how quickly the back-up arrangements can be put in place). For Mudgee, TransGrid has informal arrangements in place with Essential Energy's distribution network to provide back-up for the transmission system but it takes around one hour to switch between the two.

Having reviewed our modelling for these four bulk supply points and discussed each of them with TransGrid we consider that our modelling is appropriate. As a result, our draft recommendation for each of these bulk supply points is to adopt the allowances that reflect our updated modelling estimates in Table 5.1.

The implications of this draft decision for TransGrid are that it may need to undertake additional capital investment to improve the level of reliability at the Broken Hill 220kv, Molong and Mudgee bulk supply points.

Draft recommendations

4 The allowance for expected unserved energy for Broken Hill 22 kV that should be included in the NSW transmission reliability standard is 14 minutes (maximum value per year in minutes at average demand).

5 The allowance for expected unserved energy for Broken Hill 220 kV that should be included in the NSW transmission reliability standard is 5 minutes (maximum value per year in minutes at average demand).

28 The model selects the unserved energy that is associated with the optimal combination of reliability settings it identifies based on the various inputs. An input change may result in a different value of unserved energy because it leads to a change in the optimal combination of reliability settings or, as in this case, it may result in the same unserved energy because it does not lead to a change in the optimal combination of reliability settings.

6 The allowance for expected unserved energy for Molong that should be included in the NSW transmission reliability standard is 46 minutes (maximum value per year in minutes at average demand).

7 The allowance for expected unserved energy for Mudgee that should be included in the NSW transmission reliability standard is 14 minutes (maximum value per year in minutes at average demand).

Appendices

A Terms of reference for the review

Premier of New South Wales

IPART

Doc No ....

File No ....

RECEIVED

INDEPENDENT PRICING & REGULATORY TRIBUNAL

Reference: A1330398

28 SEP 2015

Dr Peter Boxall
Chairman
Independent Pricing and Regulatory Tribunal
PO Box K35
HAYMARKET POST SHOP NSW 1240

Dear Dr Boxall Peter

Pursuant to section 12A of the *Independent Pricing and Regulatory Tribunal Act 1992*, I am referring the following matter to the Tribunal for investigation and report: Transmission Reliability Standards. The Terms of Reference are enclosed.

This investigation should result in the development of a set of transmission reliability standards in advance of the next regulatory control period for the NSW Transmission Operator (currently known as TransGrid), commencing on 1 July 2018.

If your officers wish to discuss this matter they should contact Laura Christie, Director, Resources and Land Use Branch, Economic Policy Group, Department of Premier and Cabinet on 9228 4213.

Yours sincerely

MIKE BAIRD MP
Premier

GPO Box 5341, Sydney NSW 2001 ▪ P: (02) 9228 5239 ▪ F: (02) 9228 3935 ▪ www.premier.nsw.gov.au

A1330398

Terms of Reference

I Michael Bruce Baird, Premier of New South Wales, pursuant to section 12A of the *Independent Pricing and Regulatory Tribunal Act 1992*, refer the following matter to the Independent Pricing and Regulatory Tribunal "IPART" for investigation and report:

The recommendation of Electricity Transmission Reliability Standards

In November 2013 the Australian Energy Market Commission "AEMC" recommended a new framework for setting and regulating transmission reliability standards in its report *Review of the national framework for transmission reliability*, 1 November 2013 "the AEMC November 2013 Report".

In December 2014, the COAG Energy Council published its *Response to the Australian Energy Market Commission's Review of the National Framework for Distribution Reliability and Review of the National Framework for Transmission Reliability* "the COAG Energy Council Response".

The NSW Government has decided to broadly adopt the approach to standard setting recommended by the AEMC in the AEMC November 2013 Report and the National Electricity Network Reliability Principles and the Minimum Requirements for setting reliability targets set out in the COAG Energy Council Response.

IPART's investigation will result in a set of transmission reliability standards being recommended to the NSW Minister for Industry, Resources and Energy (the "Minister") in time for the standards to be set in advance of the next regulatory control period for the NSW Transmission Operator (currently known as TransGrid) commencing on 1 July 2018.

Consistent with this, IPART, under this reference, is to provide advice to the Minister and carry out the role of economic advisor as set out in the AEMC November 2013 Report:

- **Standard setter**. As standard setter, the Minister will set the transmission reliability standards for NSW.

  IPART is to assist the Minister in this role by:
  a. selecting the reliability scenarios to be economically assessed from scenarios initially provided by the NSW Transmission Operator; and
  b. recommending the transmission reliability standards to the Minister.

  When recommending the transmission reliability standards to the Minister, IPART should consider the transmission reliability standards recommended by the AEMC (if any) and any other matter considered relevant including:
  i. a required level of network capability informed by an economic assessment process to be expressed in terms of a network redundancy/N-x standard; and
  ii. a requirement relating to when supply would need to be restored following planned and unplanned interruptions at a connection point.

- **Economic advisor.** IPART should undertake an economic assessment of the efficient costs and reliability impact for each selected reliability scenario, based on information obtained from the NSW Transmission Operator and any other information considered relevant by IPART and provide a report to the Minister on its assessment.

As part of undertaking its investigation:

IPART is to develop an economic assessment methodology having regard to, amongst other considerations, the most recent values of customer reliability published by AEMO. That methodology is to be used during the standard setting process in formulating IPART's recommendations

After development of the methodology, IPART is to:

a. select a range of feasible reliability scenarios from reliability scenarios developed by the NSW Transmission Operator following a customer consultation process;
b. undertake an economic assessment using probabilistic analysis, or other appropriate analytical techniques, to evaluate how efficient network capital and operating costs vary with different levels of reliability, and then compare the level of expected capital and operating expenditure against the value that customers place on reliability for each selected scenario; and
c. recommend the transmission reliability standards for the NSW Transmission Operator to the Minister to apply to the regulatory control period commencing 1 July 2018.

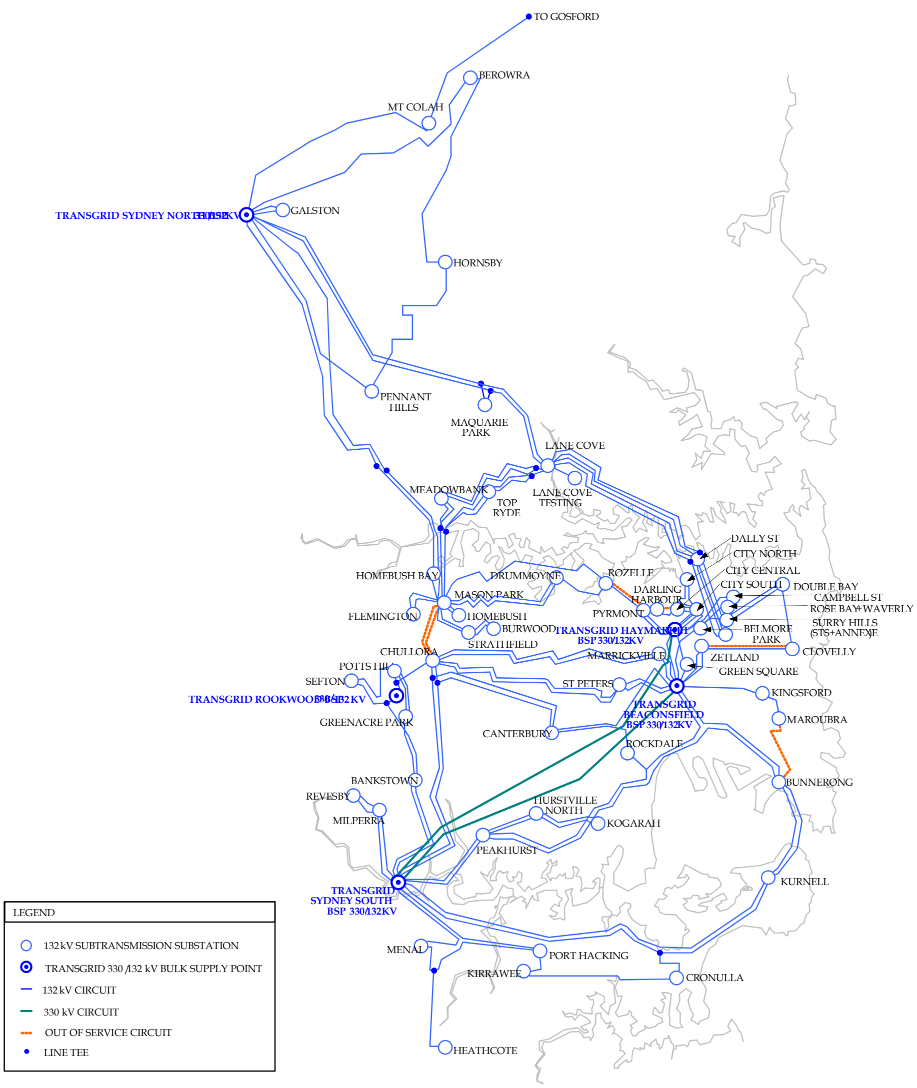
Consultation
IPART should, when undertaking its investigation, conduct a public consultation process at appropriate stages of the review to ensure that the standard setting process is open and transparent and involves all relevant stakeholders.

Timeline
IPART is to conduct the review and publish a draft report on its economic assessment on selected scenarios within 6 months of receiving TransGrid's scenarios and will provide a final report to the Minister and recommendations on reliability standards within a further 3 months from publishing its draft report.

The target date for the final report recommending reliability standards to the Minister is end May 2016, however it is recognised that meeting this date will depend upon the NSW Transmission Operator providing reliability scenarios to the Tribunal by October 2015.

B Map of the Inner Sydney area

Figure B.1 TransGrid and Ausgrid Inner Sydney network



Data source: TransGrid, 26 July 2016.

C IPART modelling inputs and assumptions

This appendix describes the inputs and assumptions used in the optimisation model.

The model finds the 'least total cost' set of planning criteria (see C.1) for each BSP, where *total cost = cost of supply arrangements + cost of expected unserved energy.*

Where two or more sets of planning criteria produce the same total cost, the model selects the set which involves the least load at risk and the quickest restoration time.

In calculating total costs, the model includes the following scenarios:

- system normal
- a single transformer failure
- a single line failure
- a double transformer failure, and
- a double line failure.

C.1 Planning criteria

The model uses **planning criteria** to inform both the cost of expected unserved energy and the cost of supply arrangements.

The planning criteria include the required level of redundancy at each BSP. The model is able to find the optimal level of redundancy at each BSP. However, we have recommended that the level of redundancy at each BSP remains the same as that which is required by the current electricity transmission reliability standard.

The values for other planning criteria are determined through the optimisation process. For each of these criteria, the model defines a range of discrete options. The criteria cover:

- **Load at risk** - load supplied from the BSP which is at risk of being interrupted, **after** allowing for any available backup capacity but **before** repair of the asset/s.

- **Restoration strategy** - the strategy to bring any available backup capacity into service following an asset failure or failures. An integer parameter from 0 to 5 is defined to select different forms and timescales of switching to the backup supply capacity, from no switching allowed (ie, no backup capacity), to automatic switching, remote switching and manual switching. This criterion imposes design requirements on switching arrangements.
- **Repair strategy** - the strategy to repair the failed asset(s) to their normal service levels (or to replace failed asset(s)). An integer parameter from 1 to 4 is defined to reflect the length of repair time, with longer repair times requiring less costly actions to achieve. This criterion imposes requirements on the management of spares, asset procurement and repair and replacement protocols.

The model assumes an upper bound for repair of transformers of 15,351 hours, repair of overhead lines of 120 hours, and repair of underground cables of 2,016 hours. These values were based on consultant advice to IPART, and correspond to the least-cost repair options.

Table C.1 Planning criteria (0 level of redundancy required, ie, N standard)

Planning criteria	Range of possible values		
	System normal (no failures)	Single failure	Double failure[a]
Load at risk for transformers	0%, 10%, 20%, …, 80% 90%	n/a	n/a
Load at risk for lines	0%, 10%, 20%, …, 80% 90%	n/a	n/a
Restoration strategy (same for transformers, lines and cables)	n/a	n/a	n/a
Repair strategy for transformers[b]	n/a	1 = 24 hrs 2 = 720 hrs 3 = 6,579 hrs 4 = 8,772 hrs	Equal to repair strategy for single failure
Repair strategy for overhead lines	n/a	1 = 8 hrs 2 = 24 hrs 3 = 48 hrs 4 = 120 hrs	Equal to repair strategy for single failure
Repair strategy for underground cables	n/a	1 = 168 hrs 2 = 672 hrs 3 = 1,344 hrs 4 = 2,016 hrs	Equal to repair strategy for single failure

[a] Many BSPs with 0 level of required redundancy (N standard) may only have one transformer or line. For these BSPs the planning criteria for a double failure are not relevant. However, some BSPs with 0 level of required redundancy (N standard) may have multiple transformers or lines. For example, three transformers might supply a load and a failure of any one of the three transformers would mean that the required supply cannot be met. In this situation, the repair strategy for transformers becomes relevant.
[b] The repair times for transformers have been updated since IPART's Draft Report, based on advice from TransGrid.
Data source: IPART based on consultant advice and advice by TransGrid.

Table C.2 Planning criteria (1 level of redundancy required, ie, N-1 standard)

Planning criteria	Range of possible values		
	System normal (no failures)	**Single failure**	**Double failure**
Load at risk for transformers	0%	0%, 10%, 20%, …, 80% 90%	n/a
Load at risk for lines	0%	0%, 10%, 20%, …, 80% 90%	n/a
Restoration strategy (same for transformers, lines and cables)[a]	n/a	0 = 0 1 = 0-5 mins 2 = 5 to 30 mins 3 = 0.5 to 1 hr 4 = 1 to 4 hrs 5 > 4 hrs	n/a
Repair strategy for transformers[b]	n/a	1 = 24 hrs 2 = 720 hrs 3 = 6,579 hrs 4 = 8,772 hrs	Equal to repair strategy for single failure
Repair strategy for overhead lines	n/a	1 = 8 hrs 2 = 24 hrs 3 = 48 hrs 4 = 120 hrs	Equal to repair strategy for single failure
Repair strategy for underground cables	n/a	1 = 168 hrs 2 = 672 hrs 3 = 1,344 hrs 4 = 2,016 hrs	Equal to repair strategy for single failure

a A restoration time of 0 means that no backup is available. The model assumes a restoration time of 8 hours for strategy option 5.

b The repair times for transformers have been updated since IPART's Draft Report, based on advice from TransGrid.

Data source: IPART based on consultant advice, and advice from TransGrid.

Table C.3 Planning criteria (2 levels of redundancy required, ie, N-2 standard)

Planning criteria	Range of possible values		
	System normal (no failures)	**Single failure**	**Double failure**
Load at risk for transformers	0%	0%	0%, 10%, 20%, …, 80% 90%
Load at risk for lines	0%	0%	0%, 10%, 20%, …, 80% 90%
Restoration strategy (same for transformers, lines and cables)[a]	n/a	0 = 0 1 = 0-5 mins 2 = 5 to 30 mins 3 = 0.5 to 1 hr 4 = 1 to 4 hrs 5 > 4 hrs	0 = 0 1 = 0-5 mins 2 = 5 to 30 mins 3 = 0.5 to 1 hr 4 = 1 to 4 hrs 5 > 4 hrs But such that it is longer than or the restoration time for a single failure.
Repair strategy for transformers[b]	n/a	1 = 24 hrs 2 = 720 hrs 3 = 6,579 hrs 4 = 8,772 hrs	1 = 24 hrs 2 = 168 hrs 3 = 2,190 hrs 4 = 4,380 hrs But such that it is longer than or equal to the repair time for a single failure.
Repair strategy for overhead lines	n/a	1 = 8 hrs 2 = 24 hrs 3 = 48 hrs 4 = 120 hrs	1 = 8 hrs 2 = 24 hrs 3 = 48 hrs 4 = 120 hrs But such that it is longer than or equal to the repair time for a single failure.
Repair strategy for underground cables	n/a	1 = 168 hrs 2 = 672 hrs 3 = 1,344 hrs 4 = 2,016 hrs	1 = 168 hrs 2 = 672 hrs 3 = 1,344 hrs 4 = 2,016 hrs But such that it is longer than or equal to the repair time for a single failure.

[a] A restoration time of 0 means that no backup is available. The model assumes a restoration time of 8 hours for strategy option 5.

[b] The repair times for transformers have been updated since IPART's Draft Report, based on advice from TransGrid.

Data source: IPART based on consultant advice, and advice from TransGrid.

C.2 Existing network inputs and assumptions

The model also uses input data and assumptions about the existing network and demand for electricity to inform both the cost of expected unserved energy and the cost of supply arrangements.

It uses the following input data, supplied by TransGrid, which is specific to each BSP:

- estimated maximum demand for 2018-19 (50% Probability of Exceedance (POE) forecast)[29]
- actual number of transformers, and
- actual number of lines.

For simplicity it assumes that:

- each transformer at each BSP is of equivalent capacity
- each line at each BSP is of equivalent capacity, and
- lines at each BSP are all either overhead or underground.

Where necessary to meet required level of redundancy, the model will increase the number of transformers or lines at a BSP. For example, if an N-2 BSP has only two transformers and no ability to switch to backup capacity, the model will add one transformer to allow the N-2 requirement to be met.

While the number of transformers and lines is based on the actual configuration at the BSP (subject to the caveat in the prior paragraph), the sizing of these assets is done dynamically by the model. Normally the assets are sized so that the maximum demand can just be met. For example, at a BSP with four transformers and a maximum load of 100 MW, each transformer would be sized to 25 MW capacity. However, if the transformer load at risk criterion is set to 40%, then the model will "shrink" the transformers so that each would be sized to 15 MW capacity.

IPART estimated line lengths based upon the location type for each BSP (ie, whether it is CBD, suburban, regional, or remote).

29 Probability of Exceedance (POE) refers to the likelihood that a maximum demand forecast will be met or exceeded. A 50% POE maximum demand projection is expected to be exceeded, on average, five years in 10.

Table C.4 Estimated line lengths

Location type	Estimated line length (km)
CBD	15
Suburban	30
Regional	150
Remote	300

Data source: IPART estimates.

C.3 Cost of supply arrangements

The supply arrangement costs cover the capital and operating costs for the following elements:

- transformer and line capacity
- backup capacity and restoration obligations, and
- repair obligations.

Transformer and line capacity costs provide the cost of system capacity in its normal state, ie, no asset failures. The cost of backup capacity, restoration obligations and repair obligations drive the cost of system capacity to deal with a single or double asset failure.

The model only includes costs that vary when the planning criteria change. This means, for example, that it excludes the cost of substation land, fencing and other site costs as they are the same across all the possible planning criteria.

C.3.1 Capital cost of transformer and line capacity

Life time capital costs

The model uses a power law to calculate the capacity cost of transformers and lines of a given MW rating.[30] It then multiplies the cost per transformer/ line circuit for each BSP by the number of transformers/ lines at each BSP.

Transformer unit costs are calculated using the following equation:

Cost = c.MW^b

where:

c = 0.094214

b = 0.640401

30 It assumes that transformers (and circuits) of any capacity can be purchased at a price given by the power law function. In practice, organisations like TransGrid tend to buy transformers of standard types and sizes to minimise purchase prices and inventory costs.

IPART derived the values for 'c' and 'b' by fitting a power law function to transformer purchase price data provided by TransGrid.

For **lines**, the capacity cost is multiplied by the line length to give a per circuit cost. An underground scaling factor is applied if the circuit is defined as an underground (UG) cable. Line circuit costs are calculated using the following equation:

Cost =(UG scaling factor if UG cable).km.c.MW^b

where:

c = 0.024784

b = 0.640401

UG scaling factor = 15

IPART assumed the value for 'b' in the line equation is the same that is used in the transformer equation. The value for 'c' and the underground scaling factor were based on consultant advice to IPART. The assumed line lengths are shown in Table C.4.

Cost multipliers are applied to the unit costs for transformers and circuit costs for lines to allow for installation. The multipliers vary by location type and the values used are shown in Table C.5.

Table C.5 Transformer and line cost multipliers

Location type	Transformer cost multipliers	Overhead line cost multipliers	Underground cable cost multipliers
CBD	2	2	1
Suburban	1.5	1.5	1
Regional	1	1	1
Remote	1.5	1.5	1

Data source: IPART based on consultant advice.

Annualising capital costs

Transformer and line capacity capital costs are transformed to an average annual basis using the following formula:

$$\text{Annualised capital cost} = d \cdot \text{capital cost} / [(1-(1+d)^{-L}) \cdot (1+d)];$$

where d = discount rate

L = life of asset

Discount rate

The model assumes a discount rate of 5.6% (real pre-tax).[31]

Life of asset

The model assumes the following asset lives, based on TransGrid's Regulatory Information Notice submitted to the AER:

- Transformer average life = 40 years.
- Overhead line average life = 50 years.
- Underground cable average life = 45 years.[32]

C.3.2 Backup capacity and restoration obligation costs

The total cost per MW of transformer and line capacity at each BSP is used as a proxy to cost backup capacity.[33] There are two further assumptions that scale these costs down:

- it is assumed backup capacity is shared between two BSPs, and therefore, only 50% of the cost is assigned to the BSP being assessed, and
- an additional efficiency factor of 50% is included to allow for backup capacity primarily being installed to service other requirements (for example, backup capacity may be provided by the distribution network, but it is likely that this distribution capability will also be being used for its own supply purposes. Therefore, only part of the distribution network costs are assigned to backup for the transmission system).

The costs of equipment or labour associated with having and using backup capacity include:

- the capital costs associated with any facilities or services necessary to achieve the required restoration times (eg, automatic control schemes), and
- the operating costs associated with using these facilities or services, when an asset failure occurs.

31 Using IPART's WACC methodology sampled to 22 July 2016 for inflation and interest rates, and to the end of June 2016 for market risk premium and debt margin.

32 The asset lives have been updated since the Draft Report.

33 Note: backup capacity could be provided by various forms that are not explicitly modelled.

Table C.6 Backup capacity and restoration strategy costs

Restoration time	Form of switching	Fixed capital cost ($m)	per MW capital costs ($m)	Fixed operating cost (per use) ($m)	per MW operating cost (per use) ($m)
0	firm - no requirement for switching	-	-	-	-
0 to 5 mins	fast-automatic	1.000	0.002	-	-
5 to 30 mins	slow-automatic	0.500	0.001	-	-
0.5 to 1 hr	fast-remote	0.100	0.0002	-	-
1 to 4 hrs	slow-remote / manual	-	-	0.050	0.0002
> 4 hrs	manual	-	-	0.100	0.0004

Data source: IPART based on consultant advice.

C.3.3 Repair obligation costs

The costs of equipment or labour associated with repairing (or replacing) assets include:

- the capital costs associated with any facilities or services necessary to achieve the required repair times (eg, spares, network arrangements, etc), and
- the operating costs associated with implementing the repair (or replacement), when an asset failure occurs.

Table C.7 Transformer repair strategy costs

Repair time[a]	Comment	Fixed capital cost ($m)	per MW capital costs ($m)	Fixed operating cost (per repair) ($m)	per MW operating cost (per repair) ($m)
24 hours	Requires on-site bay spare and fast change over	-	0.0144	0.050	0.001
720 hours	Requires spares and fast installation	-	0.0036	0.100	0.003
6,579hours	Fast procurement, delivery and normal installation	-	-	-	0.0018
8,772 hours	Normal procurement, delivery and installation	-	-	-	-

a The repair times for transformers have been updated since IPART's Draft Report, based on advice from TransGrid.

Data source: IPART based on consultant advice and advice from TransGrid.

Table C.8 Overhead line repair strategy costs

Repair time	Comment	Fixed capital cost ($m)	per MW capital costs ($m)	Fixed operating cost (per repair) ($m)	per MW operating cost (per repair) ($m)
8 hours	Requires special equipment and fast response	0.100	0.001	0.050	0.002
24 hours	Requires fast response	-	-	0.050	0.002
48 hours	Enhanced response	-	-	0.050	0.0015
120 hours	Normal response	-	-	0.050	0.0005

Data source: IPART based on consultant advice.

Table C.9 Underground cable repair strategy costs

Repair time	Comment	Fixed capital cost ($m)	per MW capital costs ($m)	Fixed operating cost (per repair) ($m)	per MW operating cost (per repair) ($m)
168	requires special equipment, spares and fast response	0.2000	0.0020	0.1000	0.0070
672	requires spares and fast response	-	0.0020	0.1000	0.0070
1,344	enhanced response and repair	-	-	0.0500	0.0025
2,016	normal response and repair	-	-	0.0500	0.0010

Data source: IPART based on consultant advice.

C.3.4 Operating costs

The long-term average annual operating costs associated with capital costs (eg, to cover maintenance activities)[34] are assumed to be linearly proportional to the calculated capital cost, with a single constant input in the model to define this relationship. The constant used in the model is 2%. That is, the annual operating cost of equipment is 2% of the annual capital cost of the equipment.

The average annual operating costs are separate to the operating costs associated with particular repair or restoration strategies which are only incurred when there is an asset failure.

C.4 Cost of expected unserved energy

C.4.1 Expected amount of unserved energy

The expected unserved energy at each BSP is the sum of the expected amount of unserved energy for each scenario[35] at that BSP.

The expected amount of unserved energy for each scenario=

expected number of asset failures (forced outages) per year *

duration of supply outage associated with the asset failure(s) *

proportion of annual energy required that cannot be supplied while the asset is in a failed state *

annual energy required (MWh)

Where backup capacity is available, the model calculates:

1) the expected unserved energy before switching has occurred, and

2) the expected unserved energy after switching has occurred but before repair of the asset.[36]

34 These are in addition to operating costs associated with the use of specific restoration or repair strategies as described in sections C.3.2 and C.3.3.

35 The scenarios are: system normal, a single transformer failure, a single line failure, a double transformer failure and a double line failure.

36 For double contingency events (double transformer failures of double line failures) the model performs an equivalent four-stage process as it steps through the two restorations and two repair stages.

Expected number of asset failures (forced outages)

The expected number of asset failures (forced outages) is the probability of asset failure multiplied by the number of assets, for each asset type at each BSP.

The probabilities of asset failure used in the model are summarised in Table C.10. They are reflective of the average life-cycle failure rates for each asset type. For transformers and overhead lines, IPART derived these values using TransGrid's historic failure data, weighted by asset subcategory. For underground cables, IPART derived the values from Ausgrid failure data for Inner Sydney, provided by TransGrid. TransGrid provided separate rates for catastrophic transformer failure (requiring replacement) and non-catastrophic transformer failure (not-requiring replacement).

Table C.10 Asset failure frequency

Asset type	Failure frequency
Transformers (catastrophic failures per year per transformer)	0. 557%
Transformers (non-catastrophic failures per year per transformer)	17.0%
Overhead lines (failures per year per 100km)	29.01%
Underground cables (failures per year per 100km)	5.95 %

Data source: IPART based on TransGrid historic performance data and Ausgrid underground failure rates provided by TransGrid.

The model assumes the primary and secondary buses of the transformers are effectively solid and fully switched (ie, a fault on any transformer or line will not automatically result in the outage of other transformers or lines).[37]

Duration of supply outage

The duration of supply outages associated with a particular scenario is determined by the restoration and repair strategies (see section C.1).

Proportion of annual energy required that cannot be supplied

The model uses a normalised integral of a load duration curve to determine the proportion of annual energy required that cannot be supplied while an asset remains in a failed state. The curve relates the proportion of annual energy required that cannot be served to the proportion of maximum demand that can still be served following a failure event.

The proportion of maximum demand that can be served following a failure event is equal to (1- %load at risk) for the relevant scenario (see section C.1).

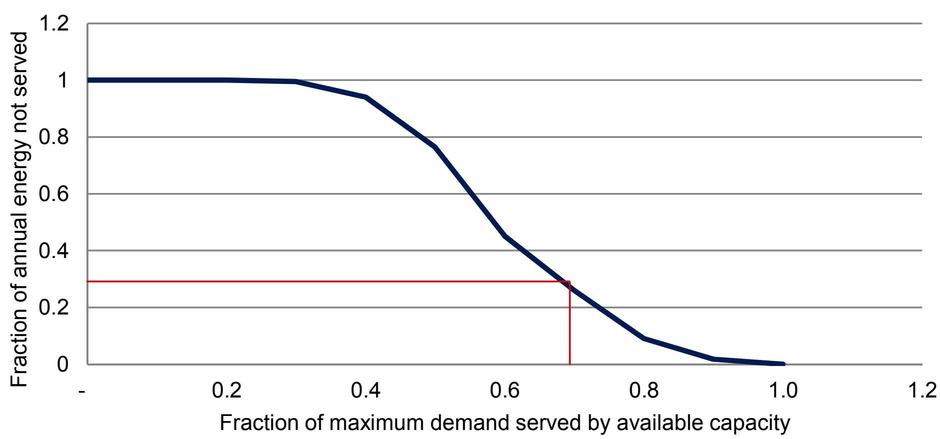
37 An underlying assumption is that for actual circumstances where this is not the case, operating arrangements would be such that any "good" assets would be rapidly switched back into service following the fault, such that the resulting actual reliability is approximately equal to these assumed arrangements.

A hypothetical example is provided in Box C.1.

The model uses curves which are specific to each BSP.[38] IPART derived the curves using TransGrid data (load at 15 minute intervals for the 2011 calendar year).

Box C.1 Proportion of annual energy required that cannot be supplied if a single transformer fails

Normalised integral of the load duration curve for a hypothetical BSP



In this example, the load at risk if a transformer fails is 30% of maximum demand at the BSP (as set by the planning criteria). Therefore 70% of maximum demand can be served following a transformer failure (ie, capacity is reduced to 70% of maximum demand).

If the transformer failure occurs during a period of low demand then it is likely that the required supply at that point in time could be met. However, if the failure occurs during a period of high demand, then it is possible that none of the required supply could be met.

Because we do not know when a transformer failure will occur, we consider what proportion of energy would be lost if the failure lasts for an entire year (which includes periods of low and high demand). The curve tells us that, on average across all possible moments of failure, around 30% of energy required at this BSP would not be served if capacity of the BSP was reduced to 70% of maximum demand.

Note: If there are load shedding protocols in place, some supply may still be met even if the failure occurs during a period of high demand.

38 The model used for IPART's Draft Report used TransGrid's state-wide load duration curve.

Annual energy required

The **annual energy required** (MWAh) at each BSP is the maximum demand (MW) multiplied by the load factor (%) multiplied by the number of hours in a year.

IPART estimated a load factor for each BSP using TransGrid data (load at 15 minute intervals for the 2011 calendar year).[39] Maximum demand assumptions are discussed in section C.2.

C.4.2 Cost of expected unserved energy

The cost of unserved energy (ie, annual reliability cost) is the total amount of expected unserved energy for each BSP multiplied by the value of customer reliability (VCR) for that BSP.

The model uses the most recent VCRs published by AEMO[40], weighted by customer type at each bulk supply point.

IPART engaged WSP Parsons Brinckerhoff (PB) to recommend VCRs for each bulk supply point, based on the values published by AEMO, weighted by customer type. For bulk supply points that were based on Ausgrid data, PB developed a non-weighted VCR using the straight average of the customer type splits. This is because there was no consumption data provided to undertake a weighted average. Additionally, no weighting was required for direct connect customers as there is only one customer type at each bulk supply point.

Since publishing our Draft Report we have updated the VCRs for some BSPs based on advice from TransGrid, Ausgrid and Essential Energy.

C.5 Unserved energy allowance

The unserved energy allowance for each BSP that IPART has adopted for our recommended reliability standards takes the expected unserved energy associated with the 'least total cost' set of the following planning criteria, given the required level of redundancy:

- load at risk
- restoration strategy
- repair strategy.

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39 The model used for IPART's Draft Report had an average load factor of 51% for all BSPs, based on TransGrid's state-wide load duration curve.

40 AEMO, *Value of Customer Reliability Review - Final Report*, September 2014, pp 2, 18.

To this value we add an allowance for non-catastrophic transformer failure. While the optimisation model only takes into account catastrophic failures (that is, where the transformer needs to be replaced following failure),[41] the rate of non-catastrophic transformer failure (failures that can be repaired) is significant and this adds to the expected unserved energy for the network.

To estimate the allowance for non-catastrophic transformer failures we used information on the rate of these failures (provided by TransGrid) as well as information on the average repair time (also from TransGrid) and the speed of switching available at the BSP (based on our modelled optimum). Where back-up capacity is available, we assumed that a non-catastrophic failure would lead to an outage lasting only as long as it takes to switch to backup capacity. Where no backup capacity is available, then we assumed that the non-catastrophic outage would last for the repair time (TransGrid's average is approximately 35 hours).

While the model identifies the optimal level of redundancy, we have recommended that the level of redundancy at each BSP remains the same as that which is required by the current electricity transmission reliability standard.

The expected unserved energy in MWh is then used to calculate the allowance for expected unserved energy in minutes per annum by dividing it by estimated average annual demand at that BSP (in MW) and converting it to minutes (by multiplying it by 60).

We have estimated annual demand at each bulk supply point using forecast maximum demand (in MW) and the estimated load factor.

41 Because this rate and the cost of minor repairs are largely independent of the planning criteria adopted, the presence of non-catastrophic transformer failures would not affect the optimisation calculation.

C.6 Bulk Supply Point (BSP) data

Table C.11 BSP data

Bulk Supply Point/s	Level of redundancy (category)[a]	Maximum demand (MW)	Number of transformers	Number of lines/ cables	Location type	Line/ cable length (km)	Overhead line or underground cable	Load factor	VCR ($/MWh)
Albury 132 kV	2	112	0	3	Regional	150	o'head line-s	0.49	36,119
ANM 132 kV	2	100	0	3	Regional	150	o'head line-s	0.73	6,050
Armidale 66 kV	2	26	2	4	Regional	150	o'head line-s	0.57	34,827
Balranald 22 kV	1	4	1	1	Remote	300	o'head line-s	0.45	33,793
Beryl 66 kV	2	67	2	2	Regional	150	o'head line-s	0.55	34,024
Boambee South 132 kV	2	22	0	2	Regional	150	o'head line-s	0.54	33,835
Broken Hill 22 kV	1	38	2	1	Remote	300	o'head line-s	0.48	34,676
Broken Hill 220 kV	1	22	0	1	Remote	300	o'head line-s	0.75	34,150
Canberra 132 kV and Williamsdale 132 kV	2	Canberra 132 kV =435 Williamsdale 132 kV =180	Canberra 132 kV = 4 Williamsdale 132 kV = 2	Canberra 132 kV = 5 Williamsdale 132 kV = 4	Regional	150	o'head line-s	0.55	37,279
Coffs Harbour 66 kV	2	48	3	6	Regional	150	o'head line-s	0.54	36,373
Coleambally 132 kV	2	11	0	2	Regional	150	o'head line-s	0.38	38,166
Cooma 66 kV	2	17	3	3	Regional	150	o'head line-s	0.24	34,357
Cooma 132 kV	2	40	0	2	Regional	150	o'head line-s	0.52	34,357
Cowra 66 kV	2	30	2	3	Regional	150	o'head line-s	0.43	33,831
Dapto 132 kV	2	571	4	3	Regional	150	o'head line-s	0.65	39,575
Darlington Point 132 kV	2	18	2	1	Regional	150	o'head line-s	0.9	37,691
Deniliquin 66 kV	2	45	2	2	Regional	150	o'head line-s	0.53	35,547
Dorrigo 132 kV	1	2	0	1	Regional	150	o'head line-s	0.62	34,513

Bulk Supply Point/s	Level of redundancy (category)[a]	Maximum demand (MW)	Number of transformers	Number of lines/ cables	Location type	Line/ cable length (km)	Overhead line or underground cable	Load factor	VCR ($/MWh)
Finley 66 kV	2	18	2	2	Regional	150	o'head line-s	0.49	35,460
Forbes 66 kV	2	31	2	2	Regional	150	o'head line-s	0.54	34,721
Gadara 132 kV and 11 kV	2	60	2	2	Regional	150	o'head line-s	0.61	6,050
Glen Innes 66 kV	2	8	2	3	Regional	150	o'head line-s	0.54	34,432
Griffith 33 kV	2	80	3	2	Regional	150	o'head line-s	0.47	36,683
Gunnedah 66 kV	2	25	2	2	Regional	150	o'head line-s	0.52	36,353
Hawks Nest 132 kV	1	8	0	1	Regional	150	o'head line-s	0.37	32,849
Herons Creek	1	9	0	1	Regional	150	o'head line-s	0.53	38,350
Holroyd 132 kV	2	313	2	4	Suburban	30	u'ground cable-s	0.46	40,650
Ilford 132 kV	1	8	0	1	Regional	150	o'head line-s	0.47	38,350
Ingleburn 66 kV	2	142	2	2	Suburban	30	o'head line-s	0.47	39,149
Inner Sydney	3	Bea = 362 Hay = 446 Roo = 280 SydN = 835 SydS = 1033	Beaconsfield 3 Haymarket 3 Rookwood R 3 Sydney N 5 Sydney S 6	Beaconsf 1 Haymarket 1 Rookwood 2 Sydney N 6 Sydney S 6	CBD	15	u'ground cable-s	Bea = 0.55 Hay = 0.48 Roo = 0.48 SyN = 0.52 SyS = 0.53	90,000
Inverell 66 kV	2	35	2	3	Regional	150	o'head line-s	0.49	34,248
Kempsey 33 kV	2	24	2	5	Regional	150	o'head line-s	0.56	34,693
Koolkhan 66 kV	2	48	3	3	Regional	150	o'head line-s	0.5	35,143
Liddell 330 kV (33 kV supply via Mac Gen)	2	25	0	6	Regional	150	o'head line-s	0.65	40,211
Lismore 132 kV	2	116	2	2	Regional	150	o'head line-s	0.48	36,003
Liverpool 132 kV	2	373	3	2	Suburban	30	o'head line-s	0.42	36,330
Macksville 132 kV	2	8	0	2	Regional	150	o'head line-s	0.57	35,223

Bulk Supply Point/s	Level of redundancy (category)[a]	Maximum demand (MW)	Number of transformers	Number of lines/ cables	Location type	Line/ cable length (km)	Overhead line or underground cable	Load factor	VCR ($/MWh)
Macarthur 132 kV and 66 kV	2	Macarthur 132 kV =162 Macarthur 66 kV =162	Macarthur 132 kV = 1 Macarthur 66 kV = 1	Macarthur 132 kV = 2 Macarthur 66 kV = 1	Suburban	30	o'head line-s	0.47	37,364
Marulan 132 kV	1	104	1	6	Regional	150	o'head line-s	0.61	36,865
Molong 66 kV	1	4	1	3	Regional	150	o'head line-s	0.51	32,176
Moree 66 kV	2	27	2	2	Regional	150	o'head line-s	0.54	37,147
Morven 132 kV	1	7	0	1	Regional	150	o'head line-s	0.49	38,350
Mount Piper 66 kV	2	41	2	3	Regional	150	o'head line-s	0.5	38,401
Mudgee 132 kV	1	21	0	1	Regional	150	o'head line-s	0.48	34,311
Munmorah 33 kV and 132 kV	2	113	1	2	Regional	150	o'head line-s	0.41	35,530
Munyang 33 kV	1	2	2	1	Regional	150	o'head line-s	0.18	39,965
Murrumbateman 132 kV	1	5	0	1	Regional	150	o'head line-s	0.44	29,314
Murrumburrah 66 kV	2	36	2	2	Regional	150	o'head line-s	0.53	34,661
Muswellbrook 132 kV	2	227	2	2	Regional	150	o'head line-s	0.51	40,211
Nambucca 66 kV	2	6	2	2	Regional	150	o'head line-s	0.49	33,775
Narrabri 66 kV	2	44	2	3	Regional	150	o'head line-s	0.56	36,084
Newcastle 132 kV	2	425	3	6	Regional	150	o'head line-s	0.33	39,507
Orange North 132 kV/ Orange 132kV and 66kV	2	Orange North 132 kV/ Orange 132kV =144 Orange 66 kV =49	Orange North 132 kV/ Orange 132kV = 3 Orange 66 kV = 3	Orange North 132 kV/ Orange 132kV = 2 Orange 66 kV =5	Regional	150	o'head line-s	Orange North 132 kV/ Orange 132kV = 0.74 Orange 66 kV = 0.54	34,366

Bulk Supply Point/s	Level of redundancy (category)[a]	Maximum demand (MW)	Number of transformers	Number of lines/ cables	Location type	Line/ cable length (km)	Overhead line or underground cable	Load factor	VCR ($/MWh)
Parkes 132 kV	2	29	0	3	Regional	150	o'head line-s	0.83	6,050
Parkes 66 kV	2	25	2	3	Regional	150	o'head line-s	0.46	34,215
Port Macquarie 33 kV	2	55	3	3	Regional	150	o'head line-s	0.53	35,051
Queanbeyan 66 kV	2	63	2	1	Regional	150	o'head line-s	0.52	32,756
Raleigh 132 kV	2	7	0	2	Regional	150	o'head line-s	0.52	33,951
Regentville 132 kV	2	264	2	2	Regional	150	o'head line-s	0.37	36,346
Snowy Adit 132 kV	1	10	0	1	Regional	150	o'head line-s	0.31	44,549
Stroud 132 kV	2	34	0	3	Regional	150	o'head line-s	0.37	32,960
Sydney East 132 kV	2	533	4	2	Suburban	30	o'head line-s	0.52	36,952
Sydney West 132 kV	2	1,107	5	9	Suburban	30	o'head line-s	0.46	38,534
Taree 66 kV and 33 kV	2	Taree 33 kV =24 Taree 66 kV =47	Taree 33 kV = 2 Taree 66 kV = 2	Taree 33 kV = 3 Taree 66 kV = 3	Regional	150	o'head line-s	Taree 33 kV = 0.47 Taree 66 kV = 0.53	34,906
Tamworth 66 kV	2	101	2	2	Regional	150	o'head line-s	0.52	36,250
Tenterfield 22 kV	2	5	2	2	Regional	150	o'head line-s	0.57	33,891
Tomago 132 kV	2	210	3	4	Regional	150	o'head line-s	0.97	39,507
Tomago 330 kV	2	965	4	4	Regional	150	o'head line-s	0.97	6,050
Tuggerah 132 kV	2	182	2	2	Regional	150	o'head line-s	0.43	35,530
Tumut 66 kV	2	32	2	2	Regional	150	o'head line-s	0.59	33,997
Vales Pt 132 kV	2	99	2	4	Regional	150	o'head line-s	0.37	35,530
Vineyard 132 kV	2	474	3	2	Regional	150	o'head line-s	0.32	35,546
Wagga 66 kV	2	73	3	4	Regional	150	o'head line-s	0.38	34,842
Wagga North 132 kV	2	54	0	2	Regional	150	o'head line-s	0.73	34,842
Wagga North 66 kV	1	20	1	3	Regional	150	o'head line-s	0.38	34,842

Bulk Supply Point/s	Level of redundancy (category)[a]	Maximum demand (MW)	Number of transformers	Number of lines/ cables	Location type	Line/ cable length (km)	Overhead line or underground cable	Load factor	VCR ($/MWh)
Wallerawang 132 kV	2	79	2	4	Regional	150	o'head line-s	0.35	34,085
Wallerawang 66 kV	2	4	2	4	Regional	150	o'head line-s	0.47	34,085
Waratah West 132 kV	2	204	2	2	Regional	150	o'head line-s	0.38	39,507
Wellington 132 kV	2	164	2	2	Regional	150	o'head line-s	0.57	34,747
Wellington Town	1	10	0	1	Regional	150	o'head line-s	0.55	34,747
Williamsdale 132 kV	2	180	2	4	Regional	150	o'head line-s	0.55	37,279
Yanco 33 kV	2	38	2	4	Regional	150	o'head line-s	0.53	35,914
Yass 66 kV	1	12	2	6	Regional	150	o'head line-s	0.51	32,581

a This is the level of redundancy required by the current electricity transmission reliability standard. It is not used an input to the model.

Source: TransGird; IPART based on TransGrid data; IPART assumptions.

Glossary

Australian Energy Regulator (AER)	The AER is responsible for the economic regulation of electricity transmission in the NEM. It determines TransGrid's maximum allowed revenue and approves its pricing methodology and negotiating framework.
Australian Energy Market Commission (AEMC)	The AEMC makes rules which govern the electricity and natural gas markets. It also provides advice to the COAG Energy Council. The AEMC has proposed a national framework to establish better ways to set reliability standards which take account of the value placed on reliability by customers.
Australian Energy Market Operator (AEMO)	AEMO is the system operator for the NEM. The AEMO publishes electricity demand forecasts and VCR values.
Average demand	Total energy supplied during the year (MWh) divided by the number of hours in the year.
Bulk supply point	A location where supply is provided to Distribution Network Service Provider(s) (DNSP) or directly connected customer(s) at a particular voltage. For the avoidance of doubt: ▾ Generally the locations are the busbar(s) at TransGrid substations (where there can be multiple individual connections to the DNSP's or directly connected customer's network). Sometimes the locations are where connections are made to TransGrid's transmission lines (or cables). These can be at "tee" connections or at busbars or substations owned by the DNSP or directly connected customer; ▾ Where there are multiple connections at the same voltage at a particular location, such as the connection of several DNSP lines to the busbar(s) at a TransGrid substation, that constitutes a single bulk supply point; ▾ Where there are supplies provided at different voltages at a particular location, such as from the higher voltage busbar(s) as well as the lower voltage busbar(s) of a TransGrid substation, each voltage level constitutes a separate bulk supply point.

Direct connect customers	Customers that connect directly to the transmission network, excluding DNSPs.
Distribution Network Service Provider (DNSP)	A business in the NEM that operates an electricity distribution network system.
Expected unserved energy	The expected amount of energy that cannot be supplied, taking into account the probability of supply outages attributable to credible contingency events, expected outage duration, and forecast load.
Inner Sydney	Refers to the Inner Metropolitan Transmission System which is constituted by cables 41 and 42, the 330/132kV substations at Rookwood Road, Beaconsfield, Haymarket, Sydney North and Sydney South and future associated 330kV cables and 330/132kV substations, as well as Ausgrid's 132k transmission network that links those supply points.
Megawatt (MW)	A MW is a unit of power referring to the rate of energy conversion. 1 MW is equal to 1,000,000 W.
Megawatt-hour (MWh)	A MWh is a unit of energy measuring the amount of electricity produced or consumed. Using 1 MW of power for 1 hour consumes 1 MWh of energy.
N-x	The N-x expression of transmission reliability is often used by TNSPs when planning augmentations of transmission networks. Starting from the 'Normal' network operating configuration, the N-x expression specifies the number (x) of network elements that can be out-of-service without causing load curtailment, system instability, thermal overloading, or cascading outages. With the value of x commonly set at one, and less often at zero (no redundancy) or two (two levels of redundancy), the N-x expression is easily applied to set the broad expectations of reliability at a connection point. The x value is applied as the required level of redundancy in the network, which can be achieved by either network or non-network solutions.
National Electricity Market (NEM)	The NEM is a wholesale electricity market. It spans Australia's eastern and south-eastern coasts and comprises five interconnected states: Queensland, New South Wales, Victoria, South Australia and Tasmania. TransGrid is one of five state-based transmission networks in the National Electricity Market.
National Electricity Rules	The National Electricity Rules govern the operation of the NEM.

Non-network solutions	Non-network solutions are alternatives to traditional transmission assets, such as lines and transformers, which can be used to address supply constraints. They include demand-side management (eg, load curtailment arrangements) or local generation.
Regulatory Investment Test for Transmission (RIT-T)	As defined in the *National Electricity Rules*. The test is developed and published by the AER. It prescribes how costs and market benefits of transmission investment options should be assessed.
Transmission Network Service Provider (TNSP)	A business in the NEM that operates an electricity transmission network system.
Values of customer reliability (VCR)	These measures, expressed as dollars per kilowatt-hour, indicate the value different types of customers place on having reliable electricity supply.