Australian Energy Market Commission

Approaches for the flexible expression of electricity transmission reliability standards

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PARSONS BRINCKERHOFF

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Author, Reviewer and Approver details			
Prepared by:	Peter Walshe, John Thompson, Andrew Cunningham	Date: 06/09/2013	
Reviewed by:	Paul Williams	Date: 06/09/2013	
Approved by:	Peter Walshe	Date: 18/09/2013	Signature:

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Parsons Brinckerhoff Australia Pty Limited *ABN 80 078 004 798* Level 15 28 Freshwater Place Southbank VIC 3006 Tel: +61 3 9861 1111 Fax: +61 3 9861 1144 Email: melbourne@pb.com.au www.pbworld.com *Certified to ISO 9001, ISO 14001, AS/NZS 4801* *A GRI Rating: Sustainability Report 2011*

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Glossary

AEMC	Australian Energy Market Commission
AEMO	Australian Energy Market Operator
AER	Australian Energy Regulator
CAIDI	Customer average interruption duration index
DNSP	Distribution network service provider
EENS	Expected energy not supplied
NEM	National Electricity Market
NER	National Electricity Rules
NSP	Network service provider
RIT-T	Regulatory investment test for transmission
SAIDI	System average interruption duration index
SAIFI	System average interruption frequency index
SARI	System average restoration index
TNSP	Transmission network service provider
VCR	Value of customer reliability

Executive summary

As requested by the Australian Energy Market Commission, this report identifies and describes potential parameters that could be used to support the flexible expression of electricity transmission reliability standards. The Commission's proposed expression of transmission reliability standards is in support of economically derived N-x and restoration time measures, and is seeking to include additional measures to provide greater flexibility in the expression of transmission reliability standards.

A key component of the Commission's recommended framework will be the development of a national reference standard template. The template will identify the range of input and output measures that standard setters could choose to express transmission reliability standards and provide consistent definitions of those measures. This report by Parsons Brinckerhoff can inform the body who is responsible for preparing the template

The key objectives of the proposed standard is to provide transparency for the reliability standard; drive economic efficiency; be fit for purpose; foster accountability; and not present an overly administrative burden.

Parsons Brinckerhoff's approach to this assignment included:

- researching, and extracting from previous studies, information relevant for this project for analysis
- providing discussion and analytical thoughts on the current state, potential solutions and potential impacts
- completing a multi criteria analysis to derive the most appropriate reliability measures that meet the study objectives
- based on Parsons Brinkerhoff specialist knowledge and experience, provide guidance for the use of the reliability measures in a National reference standard template.

In the report Parsons Brinckerhoff also responds to questions asked by the Commission. A large component of this study is addressed through these questions. A summary of these questions is included in the following table.

In particular, the Commission asks whether a combination of input measures and output parameters can be applied in the expression of transmission reliability. Defining input measures as being network focussed measures of reliability and output parameters as being the reliability that can be directly observed by customers, Parsons Brinckerhoff found that a combination of input measures and output parameters can be used and should be used so as to properly express transmission reliability across connection points with different characteristics, including:

- those that have frequent outage events allowing direct measurement of output parameters
- those that have infrequent events and require measure of input measures or simulation.

Research provided more than 70 potential measures of transmission network reliability. From this list, 21 measures in addition to the N-x expression and Restoration times were identified as being suitable for inclusion in a National reference standard template.

<table>
<tr><th>Commission's questions</th><th>Response</th></tr>
<tr><td>Define an approach to undertaking an analysis in relation to:
▪ Developing a view on long term reliability (security) of supply vs. medium term and how input measures and output measures relate to each.
▪ What is the feasibility of using simulation methods versus actual data to enable TNSPs to comply with reliability standards that are expressed as a combination of input standards and output parameters?</td><td>The expression of long term reliability requires the inclusion of events that occur infrequently. This makes direct measurement difficult as insufficient events occur to provide a meaningful measurement.

The N-x planning standard provides an expression of reliability aimed at establishing the long term level of reliability. Complementary is the use of simulation, which includes either the full modelling of network performance or the use of probability of failure information to establish the contribution over the longer term of infrequent events. Simulation is, however, an approximation to actual performance and inherently uncertain.</td></tr>
<tr><td>Can a combination of input measures and output parameters be applied, and if so how?

What are the implications for the Value of Customer Reliability (VCR) having a mixture of input measures and output based parameters of transmission reliability?

What are the implications for high impact, low probability events?

What are the interactions between the output parameters?</td><td>A combination of input measures and output parameters can be used and are currently used in expressing transmission reliability in the Bowen Basin coal mining area of Queensland and in Tasmania.

For a complete expression, the various attributes of reliability – frequency, duration, exposure and market value – should be considered, but may not be needed. Reducing the number of attributes to suit the appropriate expression for a specific connection point may reduce the associated administrative burden.

From a list of more than 70, Parsons Brinckerhoff has identified 21 measures/parameters that are suitable for inclusion in a National reference standard template in addition to the N-x expression and Restoration time measures.

All measures/parameters can be assigned an economic value through applying either a Value of Consumer Reliability value established through surveying customers, or by their impact on the market price for electricity.

Where multiple measures/parameters are used, they may overlap in the attributes of reliability that they cover. A table identifying overlaps is included in the report. Where material, the application of VCR to a measure/parameter may be apportioned to avoid over- emphasising the overlapping attribute.</td></tr>
<tr><td>Determine an optimal design of potential reliability standards that:
▪ combines various input measures and output parameters that can be presented as a 'menu' of transmission reliability standards
▪ considers interactions between each of the output parameters
▪ enables the body that sets the transmission reliability standards (the standard setter) to have flexibility to select from a 'menu' of transmission reliability input measures and output parameters
▪ enables TNSPs to make planning and investment decisions in light of standards expressed as a combination of input measures and output parameters.</td><td>To establish an optimal design, principles were established including transparency; economic efficiency; accountability; targets can be established; and can be applied to shared networks. Any measure/parameter not meeting these principles was rejected.

Of the 21 measures/parameters that met the principles, 5 are input measures and 18 are output parameters, providing a balance to suit the expression of transmission reliability across the full range of connection point types, including:
▪ directly measurable output parameters to suit transmission networks with low levels of redundancy where outage events occur often enough to allow direct measurement
▪ a range of simulated output parameters to allow the impact of high impact low probability events to be included
▪ input measures that can be used in conjunction with the N-x expression to define reliability where the transmission network has high levels of reliability and the frequency of outage events does not allow for direct measurement of output parameters.

The proposed measures/parameters are shown in the following table.

The interaction between each measure/parameter was established and categorised as either compatible, compatible but with an overlap in some aspects of reliability covered, or conflicting. A table providing guidance about the interactions is included in this report.

The ability of TNSPs to make planning and investment decisions based on each measure/parameter was assessed. A table providing guidance about the clarity in planning and investment decisions is</td></tr>
</table>

Commission's questions	Response
	included in this report.
Provide guidance in relation to what additional principles and factors need to be considered in the development of the template in light of the Commission's intention that transmission reliability standards be expressed as a combination of input standards and output parameters.	A further two principles were identified that require consideration by the standard setter; fit for purpose; and financial burden. Tables providing guidance about the application of these principles for each measure/parameter are included in this report. To demonstrate the potential application of the measures/parameters, an assessment framework is set out, including: ▪ consider the characteristics of the connection point ▪ consider the desired outcome in expressing transmission network reliability ▪ select the appropriate input parameter/s and output measure/s giving consideration to what is covered by the metric/s ▪ assess the measure/parameter against the criteria - fit for purpose and financial burden ▪ determine the appropriate combination of input and/or output measures ▪ understand the cost to consumers by applying a VCR or the impact of the market price. Two worked examples following the assessment framework are provided.

To assist the development of the template, Parsons Brinckerhoff has provided guidance on:

- the attributes of reliability covered by each measure/parameter – frequency, duration, exposure, market impact
- the interaction or overlap between each measure/parameter
- any fit for purpose issues; both in terms of their ability to support the expression of reliability standards in general, but also with reference to their use in relation to particular network connection points
- the likely administrative burden
- the ease of use of each measure/parameter by a TNSPs to make planning and investment decisions.

Parsons Brinckerhoff also notes that:

- Input measures might be aimed at ensuring an appropriate level of long term reliability by setting an appropriate planning standard (N-x), while short term impacts are addressed through specifying the duration of their application (e.g. N-1 for 99.9% of the demand). Other input/output measures such as Energy Not Supplied could have exclusions to remove low probability/high impact events and be used to test the success of the reliability management system.
- The use of output parameters that directly measure reliability are preferable in combination with input measures as they are generally more understandable and relevant to consumers and provide an enhanced understanding of the economic value of network improvements.
- The design of measures needs to be logically consistent - a paired input measure and output parameter needs to be consistently applied and determined.
- Input measures and output parameters need to be relevant to the characteristics of the network connection point and the customers supplied through the connection point.
- Neither simulation modelling nor the application of VCR may fully capture the impacts of low probability/ high impact events, requiring the standard setter to exercise judgement.

The proposed measures/parameters are shown in the following table, together with definitions for N-x and Restoration time.

Service Standard Measure	Definition
N-x	A planning standard where x defines the number of network elements that can fail without resulting in a loss of customer supply. Usually limited to credible outages.
Restoration time	The time to restore supply following an unplanned outage. Set as a threshold value, and expressed as a percentage achieved. Excludes momentary outages
System Average Interruption Duration Index (SAIDI)	The sum of the duration of each sustained customer interruption (in minutes) divided by the total number of customers. Maybe planned, unplanned or both. Excludes momentary interruptions.
System Average Interruption Frequency Index (SAIFI)	The total number of sustained customer interruptions divided by the total number of customers. Maybe planned, unplanned or both. Excludes momentary interruptions.
Customer Average Interruption Duration Index (CAIDI)	The average time taken to restore supply following a supply interruption, and is generally expressed in minutes. Maybe planned, unplanned or both. Excludes momentary interruptions.
System Average Restoration Index (SARI)	Average duration of sustained interruptions of supply to a connection point
SAIDIs	The aggregation of the observed Connection point SAIDI and a probability weighted SAIDI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events) - a simulated measure
SAIFIs	The aggregation of the observed connection point SAIFI and a probability weighted SAIFI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events) - a simulated measure
CAIDIs	The aggregation of the observed CAIDI and a probability weighted CAIDI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events) - a simulated measure
Interruption - energy not supplied	Energy not supplied to consumers in MWh. Maybe planned, unplanned or both.
Expected energy not served	The mean energy that will not be supplied to customers over a defined period, allowing for the effects of events that could occur over that period - a simulated measure
Transmission circuit availability	The actual circuit hours available for defined (critical/non-critical) transmission circuits divided by the total possible defined circuit hours available. Maybe planned, unplanned or both.
Annual total of unplanned outages causing loss of supply to a consumer	Simple count
Energy not supplied during unplanned outage	Energy in MWh not supplied to consumers during an unplanned outage. May also be applied to a particular network element
Maximum load lost during unplanned outage	Load in MW not supplied to consumers during an unplanned outage.
Annual total of energy not supplied during unplanned outage	Annual total of Energy in MWh not supplied to consumers during an unplanned outage.
Duration of planned interruptions	Sum of outage durations in minutes per year
Frequency of planned interruptions	Sum of the number of outages per year
Annual total of network constraint events > $x/MWh	Number of dispatch intervals where an outage on a TNSP's network results in a network outage constraint with a marginal value greater than $10/MWh
Interconnector and critical circuit availability	Excludes planned outages
Total number of loss of supply events > x or y	Number of events greater than X or Y minutes pa, where X and Y are to be defined for each TNSP, such that: - an X system minute event has a return period of 1 year - a Y system minute event has a return period of 2 years
MAIFI Momentary Forced Interruptions	The total number of customer interruptions of one minute or less, divided by the total number of customers.
Unplanned outage per 100 kms	The number of outages of transmission lines divided by the total transmission line length



1. Introduction

Parsons Brinckerhoff was engaged by the Australian Energy Market Commission (the Commission) to assist in the design of flexible alternative approaches to expressing reliability standards for electricity transmission networks. The Commission seeks to understand how reliability standards could be supported by additional parameters to provide greater flexibility both in how standards are set, and in how transmission networks invest to meet these standards.

Presently reliability standards are expressed on a deterministic ‘N-x’ basis, an input based measure, across most National Energy Market (NEM) jurisdictions.[1] The Commission seeks to retain the ‘N-x’ basis for the expression of standards, while establishing an economic basis for its application, supported by a Restoration Time parameter and including additional parameters to provide greater flexibility in the expression of transmission reliability standards.

This report identifies and describes potential parameters that could be used to support the flexible expression of transmission reliability standards that could be included in a National reference standard template. The template will identify the range of input and output measures that standard setters could choose to express transmission reliability standards and provide consistent definitions of those measures. This report by Parsons Brinckerhoff can inform the body who is responsible for preparing the template by setting out parameters that could be practically and technically feasibly applied by standard setters in the process of setting standards and by transmission network businesses in planning and managing their networks.

This report does not cover connection services for generators.

1.1 Our approach

Parsons Brinckerhoff’s approach includes several steps designed to answer key questions posed by the Commission. After an initial meeting with the Commission to confirm the intended approach and to clarify the deliverables, Parsons Brinckerhoff undertook the work as outlined below.

1.1.1 Research of possible parameters

A desktop review of international and national practices was undertaken to develop the range of possible parameters. Parsons Brinckerhoff’s own experience and that of Nuttall Consulting through its report for AEMO[2] was also considered. The full list of reviewed material is referenced at the end of this report.

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[1] The N-x standard is either based on a set threshold value that must be achieved or probabilistic where the standard can be relaxed if the risk of a significant impact is low.

[2] Nuttall Consulting, 2013, Electricity Transmission Reliability Measures

Parsons Brinckerhoff is aware of the considerable volume of information available about N-x reliability, the impact this standard has on Transmission Network Service Provider (TNSP) behaviours, and the relationship to other possible measurement parameters and planning standards.

Through our work in developing performance reporting for the AER, we explored the potential for using a broad range of parameters to measure performance, the interactions between parameters and the behavioural impact of changes in performance reporting.

Parsons Brinckerhoff's research focused on identifying and describing the potential parameters that could be used to support the N-x expression of transmission network reliability standards to provide greater flexibility in how standards are expressed. This included how each parameter could be practically and technically feasibly applied and the relative advantages and disadvantages of each parameter. The parameters considered included:

- Quantity of customer load lost or quantity of expected unserved energy (in MW or MWh per year respectively)
- Frequency of supply interruptions (planned and unplanned)
- Duration of supply interruptions (planned and unplanned)
- Restoration times to rectify supply interruptions
- Percentage of capacity that must be restored within a set restoration time period.

1.1.2 Testing of parameters against criteria

Upon completion and validation of the research, Parsons Brinckerhoff tested the identified measures and parameters for appropriateness. The identified input and output reliability measures were assessed against the Commission's key criteria of:

- Transparency – both the process for setting transmission reliability standards and the standards themselves should be transparent to stakeholders
- Economic Efficiency – transmission reliability standards should promote economically efficient investment decisions by transmission networks, and should not be biased towards network solutions where non-network solutions can provide a comparable level of reliability
- Fit for purpose – standards should be able to be clearly specified for each transmission connection point. Standards should also be able to differ across networks according to the value placed on reliability by customers and the costs of investing to meet set reliability levels at each connection point.
- Accountability – standards should be expressed in a manner which allows transmission networks to be held accountable for the level of reliability they are required to provide at each connection point.
- Administrative Burden – the administrative burden for standard setters and transmission networks of respectively setting and applying these standards should not be disproportionate to the expected benefits of applying the standards in a more flexible manner.

An additional two criteria were also considered relevant by the Parsons Brinckerhoff project team, and applied in the assessment:

- Targets can be established – ensuring that meaningful targets are able to be set via modelling or via a defined methodology that is transparent and repeatable.
- Applies to the shared network – the measure is relevant to the shared network, i.e. the network excluding connection assets, as well as at customers' connection points to the network.

A group session was held to assess the measures identified against each of the potential criteria. Consideration was given to the ability of each parameter to provide the standard setter with greater flexibility in how standards are set to ensure standards meet the value placed on reliability for the customers at each transmission connection point. Potential parameters were also analysed in terms of their potential implications on a transmission network's planning and investment decisions.

1.1.3 Answering the Commission's questions

The aim of this assignment is to develop a menu of potential parameters to choose from rather than a prescriptive set of parameters. At the same time, the range of parameters proposed must be able to be applied within the existing regulatory framework. Provided below are the questions that are answered within this report, as outlined by the Commission in the Request for Proposal of Services.

1. Define an approach to undertaking an analysis in relation to:
   a) Developing a view on long term reliability (security) of supply vs. medium term and how input measures and output measures relate to each.
   b) What is the feasibility of using simulation methods versus actual data to enable TNSPs to comply with reliability standards that are expressed as a combination of input standards and output parameters?
2. Can a combination of input measures and output parameters be applied, and if so how?
   a) What are the implications for the Value of Customer Reliability (VCR) having a mixture of input measures and output based parameters of transmission reliability?
   b) What are the implications for high impact, low probability events?
   c) What are the interactions between the output parameters?
3. Determine an optimal design of potential reliability standards that:
   a) combines various input measures and output parameters that can be presented as a 'menu' of transmission reliability standards
   b) considers interactions between each of the output parameters
   c) enables the body that sets the transmission reliability standards (the standard setter) to have flexibility to select from a 'menu' of transmission reliability input measures and output parameters
   d) enables TNSPs to make planning and investment decisions in light of standards expressed as a combination of input measures and output parameters.
4. Develop a worked example of how the measures and parameters could be designed to achieve a greater level of flexibility for standard setters.
5. Provide guidance in relation to what additional principles and factors need to be considered in the development of the template in light of the Commission's intention that transmission reliability standards be expressed as a combination of input standards and output parameters.



2. What is reliability?

Nuttall Consulting's report to AEMO defined transmission network reliability and discussed the potential measurement options. In this section Parson Brinckerhoff extends this work by considering additional measures not covered by the Nuttall report to ensure all potential measures for the national standard reference template are identified. For the purpose of this report we have adopted the definitions proposed by Nuttall, particularly the key descriptors of interruption and outage:

- Interruption is the total loss of supply of electricity to a customer
- Outage is the loss of ability or availability of a power system component. Of note here, an outage may not always result in an interruption.[3]

This report predominantly discusses reliability in the context of transmission networks. Customers of TNSPs are a small number of directly connected consumers and Distribution Network Service Providers (DNSPs), with most consumers connected to DNSPs distribution networks. In this report, the term customer is used in the broader sense to include all consumers of electricity.

2.1 Attributes of reliability

Reliability performance of transmission networks is typically monitored by consideration of performance indices obtained through the systematic reporting of faults on the network that result in outages of network elements and interruptions to a customer's supply of electricity. Transmission reliability can be thought of as having two slightly different perspectives – the customer perception of reliability and the network system effects of reliability. The latter is useful as it may include effects not regularly perceived by customers, such as the risk of a high consequence event that occurs infrequently such as the total blackout of a CBD area.

The customer perception of reliability can be broken down further into those factors that significantly affect customers. These are set out below.

The frequency of a supply interruption – customers become increasingly impatient when supply interruptions are repetitious, even if the interruptions are short. Such irritation can be caused by having to re-set electronic clocks, or for industrial customers, restart manufacturing processes.

The duration of a network outage – knowledge of the duration of a network outage determines the customer's likely response in terms of making alternative plans or arrangements. Typically, DNSPs are obligated to advise customers of the expected length of a supply interruption. TNSPs advise DNSPs and directly connected customers of likely outage times. If the network outage causing the supply interruption is likely to be short in length, a domestic customer may 'wait it out'. If the network outage is of moderate length, say up to 4 hours, the customer may decide to 'eat out' or make other plans to visit unaffected areas. If the network outage is of considerable length, then the customer can take steps to minimise spoilage of refrigerated food or unacceptable discomfort due to loss of hot water, air-conditioning, or heating, etc. Small business and

[3] Ibid, pg. 9

industrial customers may take steps to minimise costs by arranging for temporary power supplies, or re-scheduling production to accommodate the electricity supply interruption.

The consequence of a supply interruption – a network outage may affect a small or large volume of energy delivery. Where large areas of supply are affected, domestic consumers may lose the ability to visit unaffected areas, and small business and industrial customers may not be able to hire temporary power supplies due to demand for such equipment. Events with very high consequences may require a State or National disaster response. An assessment of the energy not supplied and the associated economic impact is a common method of measuring the consequence of a supply interruption.

The network system effects of reliability might include:

- **The unavailability of network elements** – in a transmission network with multiple levels of redundancy, unavailability is a measure of the risk that further events might result in a loss of supply to customers.
- **Market impacts of an outage** – the market price of electricity may be impacted by network constraints caused by outages.

Other dimensions for consideration include the following.

Planned versus unplanned outages – customers are usually more accepting if they receive notice in advance of planned outages, as this provides an opportunity to make other arrangements.

Sustained versus momentary interruptions – prior to the 1980's, momentary interruptions did not attract significant levels of customer complaint, but over the last three decades, the widespread use of electronic devices has increased the sensitivity of customers to momentary interruptions that cause electronic devices to reset.

As noted in the Nuttall report, sets of reliability measures are often related, and therefore, grouped and reported together. This grouping occurs because the measures rely on similar techniques and data, and provide different views of the characteristics of reliability.

Reliability can also be measured at the system–wide level; for individual network elements or groups of network elements; or for individual customers. Given the importance of supply reliability for most customers, improving system reliability has been a higher priority for regulators than improving other aspects of customer service, such as call centre performance. Hence, the monitoring of reliability tends to be better developed than other service performance indicators.

As highlighted, reliability can affect household, business and industrial customers differently. Also their view of, and approach to, supply interruptions, whether planned or through an outage, may be different. The way we express reliability is not always discrete, hence requiring reliability challenges to be addressed with skill and care.



3. The N-x expression of reliability

The Commission desires to retain the N-x expression of reliability, while establishing an economic basis for its application. Parsons Brinckerhoff's understanding of the N-x expression is set out in this section, which forms the basis for the development of a list of additional measures that might support this expression.

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 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 approaches. Non-network approaches include:

- use of standby generation
- demand reduction schemes
- voltage reduction schemes.

The N-x expression can be applied in a deterministic fashion, or as the AEMC proposes, in an economically derived fashion. The potential expressions are:

- **Deterministic N-x** - The network is planned to provide x levels of redundancy for credible events. The x value is set at 0, 1, 2 etc. to specify the 'target' level of reliability. Credible events are defined to include those events that could be expected to occur within the planning horizon.

  A degree of granularity can be included in the expression by allowing N-x to be not met when a measure does not exceed a threshold value, i.e. when Energy not served is less than 30 MWh or all load is resupplied within 30 minutes. The latter would enable use of standby generation or demand reduction to be considered rather than redundant network.

- **Economically derived N-x approach** - Economic analysis of reliability scenarios is undertaken, based on probability of interruptions, and assigned a value. The outcome is used to specify the x in the N-x expression and, if included, the threshold values for other measures, i.e. for maximum restoration time.

The economically derived N-x is a **probabilistic approach** as it is based on the probability of an interruption/outage occurring. The key difference between deterministic and probabilistic approaches is that the probabilistic approach allows a value to be assigned to the expression of reliability, hence establishing an economic basis for the reliability level selected.

The choice of whether to apply a deterministic N-x expression or to adopt a probabilistic approach is currently influenced by the regulatory framework that applies to a TNSP. In jurisdictions that allow some load to be placed at risk, a probabilistic rather than an N-x approach is able to be adopted.[4]

Where a probabilistic approach is adopted, the increased risk of supply outages is balanced against the cost. Where the probabilistic approach is focussed on one aspect of reliability such as consequence, it is logical for the expression to be supported by a range of measures/parameters to ensure a complete expression of reliability, depending of course on the characteristic of the connection point.

[4] For example, section 50F(2) of the National Electricity Law, which currently only applies to the shared network in Victoria, requires a probabilistic approach to be used unless certain conditions are met.



4. Measuring reliability

In this section, the options for measuring reliability performance are discussed.

4.1 Input measures and output parameters

Measures of reliability can be either a direct measurement of an attribute of reliability such as frequency, duration, or consequence as observed by customers, or a direct or indirect measurement of an indicator of reliability such as the level of redundancy in the network as expressed by N-x (an indirect measure) or the availability of a network element (a direct measure). In this report, the term input measure is used to represent the latter and output parameter is used to represent measures that customers can observe. For consistency, we have adopted the definitions used by Nuttall, except that Nuttall uses the term measure in lieu of parameter:

- ***output reliability measure [parameter]*** is a measure of the reliability of the supply of electricity that a customer receives from the transmission network. This is the reliability of supply that a customer could directly observe and measure.
- ***input reliability measure*** is a measure of the reliability of the transmission network, but not explicitly the reliability of supply provided by the network. This is a measure of the reliability of the network components that a TNSP can observe and measure.

In effect, output parameters are a direct measure of transmission reliability, whereas input measures are not. While they may be directly measured, input measures are measures of things other than the reliability of supply that customer's experience and hence may not be transparent to consumers.

Output parameters and input measures may be used individually or in combination to express transmission reliability. The desirability of using individual or multiple measures is discussed in section 6, but firstly the options for measurement are presented.

4.2 Options for measurement

Most transmission networks in Australia offer high standards of reliability. Failure events of network elements do occur, and usually often enough to allow the reliability of network elements to be directly measured using a range of input reliability measures such as Energy Not Supplied by a network element or the Availability of a network element or the Average Duration of Outages.

Interruptions of supply to consumers occur much less frequently. As loss of supply is an infrequent event on most transmission networks, measurement of these events becomes difficult, particularly over shorter timeframes such as a year. Few events may mean that none have occurred in a reporting period. In such circumstances, the expression of transmission reliability may be better focussed on the potential for a low probability but high consequence event to occur.

A key issue then is how to express transmission reliability in a manner that is useful to the interested parties. Four possibilities are:

- direct measurement of an input measure or an output parameter
- direct measurement of an indicator that approximates the longer term reliability outcome
- probability modelling based on assigning a probability of failure using actual outage data
- simulation methods.

Measurement of output parameters has the advantage of transparency in that these are based on attributes of reliability of supply that a customer can directly observe. Variability around the average performance can be impacted by low probability events that have high consequence resulting in a lack of comparability in outcomes from year to year. Hence, output measures often exclude extreme events, so as to show the trend in underlying reliability. A limitation is that events being measured may not occur often enough to provide for meaningful measurement.

Measurement of input measures solves the issue of infrequent events as these measures typically focus on the more frequent outages of elements of the network. A disadvantage is that some input measures may be difficult for stakeholders to interpret. For example, a commonly used measure is ‘unavailability’. In a typical transmission network with multiple levels of asset redundancy, the unavailability of a network element does not in itself result in a loss of supply, but places the network at risk for a second element failure. Hence, measurement of ‘unavailability’ can indicate the potential for, or heightened risk of supply interruptions to consumers. But without an understanding of the probabilities of failure of the second element, the measure lacks certainty. Nevertheless, the measurement of unavailability is commonly undertaken because of the relatively high number of events that can be measured.

Simulation methods are useful when historic reliability data is either unavailable or is not likely to be a satisfactory base from which to predict future levels of reliability performance. In particular for complex networks, simulation using load flow modelling techniques may be the only satisfactory way of establishing the potential long term reliability outcomes.

Simulation - probability modelling offers a more realistic approach to expressing transmission reliability incorporating low probability, high consequence events. Based on actual outage data, the probability of consumers experiencing an interruption to supply over the longer term can be assessed. This approach, however, is not often adopted in reliability reporting due to the higher cost and lower lack of transparency than for direct measurement. It is more commonly adopted when planning changes of the transmission network to assess the likely impact of those changes on future reliability outcomes.

The strengths and limitations of each approach are set out in Table 4.1.

In the following section we consider in more detail the relative ‘pros’ and ‘cons’ of the feasibility of using simulation methods versus actual reliability performance data to enable TNSPs to ascertain compliance with the required reliability performance standards.

Table 4.1 Strengths and limitations for options to measure reliability

Type	Strength/weaknesses	Other considerations
Output parameters	***Strengths*** ▪ observable by customers ▪ generally low cost ***Limitations*** ▪ events may not occur often enough to be measured	Output parameters are inherently backwards looking, unless simulation is used to include the contribution of low frequency events on a risk based probability basis.
Input measures	***Strengths*** ▪ shows underlying performance of network elements ▪ focussed on events that occur frequently enough to be directly measured ▪ generally low cost ***Limitations*** ▪ impacted by low frequency events, unless excluded ▪ not observable by customers	Measuring the inputs means more than one measure is required to have a complete expression of transmission reliability, typically a combination of availability, average outage restoration, and frequency of events.
Simulation	***Strengths*** ▪ provides a way to assess the potential reliability of networks ***Limitations*** ▪ higher cost than input/output measures and probability modelling ▪ not transparent to stakeholders due to technical nature of the simulation ▪ not observable by customers ▪ outcomes may not be able to be benchmarked, unless the simulated measure can be applied consistently	In simulation, the choice of inputs is critical. Operational inputs such as the expected response time to restore supply is difficult to include unless historic values are used, leading to the need to measure a range of input values.
Simulation - Probability modelling	***Strengths*** ▪ provides a way to annualise low frequency events ***Limitations*** ▪ higher cost than input/output measures ▪ not observable by customers	Considered a subset of simulation, probability modelling uses actual outage events and the contribution of low frequency events on a risk based probability basis.

4.3 Using simulation methods versus actual reliability performance data

Simulation of electricity networks has been used as a tool for assessing network reliability performance for many years both in Australia and internationally. Such methods may be used in planning network investments in order to forecast the impact on network reliability of the various operational or investment options. Where events that impact on reliability are relatively infrequent, but have potentially large economic consequences, simulation methods can also provide a valuable tool for assessing current network reliability performance or compliance as well as future reliability performance under a range of scenarios. Moreover, network reliability simulation methods can be used to model all reliability metrics identified in this paper.

While such methods can be used, the practical feasibility of using simulation methods requires consideration of a number of issues:

- For what purpose will the results of the simulation or the actual performance data be used, e.g. is the ability to benchmark important?
- Can meaningful simulation model parameters and a suitable simulation model be established for the transmission network being assessed?
- Are meaningful actual reliability performance data available (or likely to be available) for each of the chosen reliability metrics relevant to the assessing compliance of the transmission network or connection point?
- What is the relative ‘cost’[5] of using a simulation method as opposed to using actual performance data for each of the chosen reliability metrics?

In considering these factors it must be recognised that simulation methods generally provide information that defines the theoretical reliability performance inherent in a transmission network – usually observed in the long term average performance – and that these results reflect the veracity[6] of both the simulation model used and the characterisation of the model parameters. That is, simulation methods provide only an approximation to the actual network reliability performance that might be observed in a defined reporting period. Depending on the specific simulation modelling used, the results of a simulation model are most likely an estimate of the average[7] and the associated error in the average, or an estimate of the range of possible values that could be actually observed for the reliability metrics being studied (e.g. the output of a Monte Carlo model). Hence in general, simulation methods are concerned with characterising the set or range of possible reliability outcomes for each of the reliability metrics studied as a reflection of the inherent reliability performance capability of the network.

Simulation models may be forward looking to assess the potential reliability of a network or backward looking to understand why events affecting reliability levels have occurred. In contrast, the use of actual reliability performance data is inherently backwards looking in that it reflects the observed outcomes of real network performance over the period of observation. Using backward looking approaches to predict future performance may not be appropriate, such as when a TNSP undertakes significant reliability improvement works. Consequently, in choosing whether to adopt forward or backward looking simulation methods or direct

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5 We use the term cost in the broadest possible sense to include all factors that reduce the value of the approach selected (i.e. simulation model or actual data). Hence cost includes aspects such as the administrative and TNSP burden, IT and information resource requirements, the time required to obtain the information required at the required quality, the uncertainty in the results obtained from each approach, etc.

6 We note that the veracity of a simulation model and its parameters is often a matter of expert opinion rather than objective fact.

7 The term average has been used here as a general reference to a measure of the centre of a possible range of values and is not intended to exclude other central measures (e.g. mean, mode, etc.).

measurement methods, it is important to consider the purpose the results of the simulation or the actual performance data will be used for.

An example

An example of the difference between a simulation method and direct measurement is provided to demonstrate the way each approach can be used to focus on different expressions of transmission reliability.

> Consider that the reliability performance of a network supplying a connection point might be assessed using a metric of transmission circuit availability. By gathering actual reliability performance data over a period of time the relevant transmission circuit availability metric could be evaluated for the connection point. This is a backward looking assessment of the actual reliability performance observed for the connection point over the period of the observations.
>
> A simulation approach on the other hand would consider details of the network supplying the connection point, along with estimates of the performance of this network’s elements such as mean time between failures, mean time to repair, etc., in order to create a model of the inherent reliability capability of the network over any period of time. As failure events for particular network elements are ‘random’ in nature, as are other factors considered in such a model (e.g. repair time, weather, etc.) a simulation approach would consider the range of possible values these ‘random’ variables could take on in order to estimate the range of possible values that could be observed for transmission circuit availability at the connection point. In addition to the ‘random’ variables considered by the simulation method, other variables such as system configuration or operational practices could also be studied to assess their impact on the range of possible values that could be observed for transmission circuit availability at the connection point. Hence while the simulation method has not provided actual performance information, it has provided a method to study and characterised the range of reliability performance outcomes possible given the inherent reliability capability of the network.

Advantages

As simulation methods generally characterise the range of possible reliability outcomes to provide an approximation to real network reliability performance for each reliability metric studied, they are best suited to purposes where we need to consider a range of scenarios, study infrequent events, rank a set of options, ration capital, assess the impact of uncertainty on decision making outcomes, or seek to understand the probability of crossing a reliability performance limit.

In contrast, actual performance data reflects the real reliability outcomes of a network over the period observed and hence is best suited to purposes where high levels of certainty are required such as where high levels of transparency and auditability are required. Processes associated with the use of actual reliability performance data are relatively easily established and maintained; do not suffer from the complexities of model parameter establishment and maintenance; and their relative ease of auditability supports a high level of transparency.

It must be stressed that we are not suggesting that simulation cannot be used in circumstances where high levels of certainty, transparency and auditability are required, rather that simulation methods introduce added complexities (see below) when used in such contexts.

Limitations

A key limitation in the use of simulation methods is the establishment and maintenance of the simulation model itself, as well as the parameters of the model. While there are a broad range of network reliability simulation methodologies available, the resulting models can be quite complex to implement, require ongoing maintenance, and are inherently less transparent and auditable than processes associated with the use of actual reliability performance data.

Moreover, the values of typical parameters used in simulation models (e.g. failure rates, repair rates, restoration rates) can be difficult to evaluate and tend to change slowly[8] over time with consequent implications for the veracity of the simulation results. It should be noted that while the model parameters may change slowly over time, model variables such as network configuration, network loads, capacity, etc. are generally well handled in the implementation of such models and hence while such variables are important they are generally of less concern in considering the ongoing maintenance of the model's veracity.

With regard to auditability, simulation models can be audited against criteria such as appropriate design, appropriate consideration of variables and assumptions, sensitivity to key inputs, knowledge of operators and interpretation of outcomes. Such an audit is technical in nature and network specific, however, and may be difficult for customers and other stakeholders to have confidence in.

4.3.1 Simulation methods

In considering the use of simulation methods to express reliability performance, it is also important to recognise that, in the practical application of such methods to modelling TNSP reliability performance, each TNSP could implement a different reliability simulation methodology and model. This would introduce considerable additional complexity into the overall management of using simulation methods to enable TNSPs to comply with reliability standards. Possible options to address this concern may include:

1. **Use one centralised simulation model that is applied to all TNSPs.** While this approach may simplify overall management it will introduce complexities in managing the associated modelling data and raises questions in regards to whether a 'one size fits all' approach is reasonable or will achieve the outcomes required.
2. **Mandate the methodology and model to be used by TNSPs.** Such an approach would provide TNSPs with some flexibility with regards to the model parameters but is sufficiently prescriptive to achieve efficiencies in the overall implementation and management of a simulation approach to reliability performance modelling within the industry.
3. **Allow each TNSP to use its own simulation methods subject to periodic independent review.** This option provides considerable flexibility to the TNSPs to find the best solution for their individual circumstances and addresses the shortcomings of option 1, but has inherent additional costs and complexities (as noted above). We note that the independent review process could be simplified by the use of a standardised test network which would involve a standard network definition, model parameters and a known set of results that the TNSPs model would need to achieve.

Similar to the use of actual reliability performance data, the use of simulation methods may be impacted by TNSPs using different process to capture and assess the input data. In particular different data definitions, definitions of extreme events, and different practices in capturing, storing and managing network information data can have a significant impact on the accuracy and comparability of the reported reliability performance from the model. Notwithstanding these complexities, meaningful simulation model parameters and suitable simulation models can be established to demonstrate and manage compliance with reliability standards within the TNSP environment.

Regardless of which method is adopted, an issue is whether a common approach should be adopted for determining the probability of an outage so as to drive a degree of consistency into the chosen methodology. A standard approach could specify:

- the probability of failure of 'standard' network assets such as lines and transformers, modified to suit condition or environmental conditions
- the credible events that are to be included in the modelling
- the way that the outputs of the modelling should be expressed.

[8] We note that some parameters may also change rapidly with changes to business operational practices (e.g. restoration rates).

Parsons Brinckerhoff sees value in adopting a common approach. In particular, specifying the probability of failure of 'standard' network assets such as lines and transformers, modified to suit condition or environmental conditions, would provide transparency and limit the ability for manipulation or data errors.

So far in this discussion we have focused on the range of issues that arise in using simulation methods for assessing TNSP network reliability performance, and specifically with regards to consideration of the purpose for which the results will be used and whether meaningful simulation models and their parameters can be established. However we also need to acknowledge that simulation methods have a range of distinct benefits over the use of actual reliability performance data when considering transmission network reliability performance. In particular, simulation methods have the unique ability to characterise the reliability performance of a network over a broad range of analysis timeframes, for a wide range of possible scenarios (e.g. network state, configuration, environment, operations practices) for all reliability metrics, and these methods inherently reflect the reliability performance capability of the network. This ability to provide a rich view of network reliability performance capability over a broad range of time periods makes simulation methods valuable for assessing current and future reliability performance, understanding the probability of crossing a reliability performance limit or achieving a target, assessing infrequent events, and studying solutions to manage reliability performance. Moreover, the rich view of network reliability performance provided by simulation models can support economic analysis of the costs and benefits of applying differing reliability standards as well as solutions to meeting those standards. Hence, simulation can provide a valuable tool in managing and planning network reliability performance and compliance.

4.3.2 Simulation versus actual data

While the use of simulation methods has a range of complexities and benefits, so too does the use of actual reliability performance data. The most significant complexities of using actual reliability performance data are associated with the availability of meaningful data[9] that is relevant to the chosen reliability metrics. Availability of suitable data may be limited by problematic data capture and ongoing data management practices, disparities in data across the transmission network industry, and due to the timescales required to observe reliability incidents on a transmission network. As reliability incidents can be relatively infrequent, obtaining consistently meaningful data relevant to some reliability metrics may take many years; and even more so if such data is needed for each supply point. These timescales may also be such that fundamental network changes may occur between reliability incidents further eroding the quality of actual reliability performance data. However it should be stressed that this is not suggesting that the use of actual reliability performance data is flawed to the extent that it is becomes meaningless, rather that it should be recognised that the use of actual reliability performance data is also impacted by complexities that must be managed in the practical use of actual reliability performance data.

As would be expected, using actual reliability performance data also has a range of benefits. Most notably using actual performance data is a relatively simple, well understood, and highly auditable practice. Hence using actual data supports a more transparent process and can provide more certainty regarding the overall veracity of the results over the period of observation. Nonetheless, actual reliability performance data should be recognised as only a sample of the inherent reliability performance capability of a network, and it should be used accordingly. That is, despite the relative benefits of using actual reliability data, the data itself represents only the reliability performance of the network in the particular circumstances that prevailed over the time the data was observed. Hence such results do not measure the capability of the network, but rather the expression of the networks inherent capability under the prevailing circumstances. This is a key point of contrast with simulation methods that intrinsically reflect the networks inherent capability.

9 It should be acknowledged that simulation also suffers from similar data availability issues that may impact on the development of robust model parameters.

4.3.3 Conclusion

In considering the application of simulation methods versus actual reliability performance data it should be recognised that this is not a mutually exclusive decision, and both approaches can (and arguably should) be used together to enable the inherent reliability performance capability of the network to be managed while understanding the performance that has actually occurred. Moreover, given the relative ‘pros’ and ‘cons’ of using simulation methods versus actual reliability data the use of a mixed approach using both simulation methods and actual reliability data is likely to support an outcome that will enable TNSPs to comply with reliability standards and in supporting regulators in monitoring compliance to those standards.

This discussion on the relative ‘pros’ and ‘cons’ of using simulation methods versus actual data has focused on highlighting and contrasting simulation methods with the use of actual reliability data in the context of the purpose for which the results will be used, whether meaningful models can be established, and whether meaningful data is available (or likely to be available). In discussing these aspects we have noted the complexities as well as the benefits of the practical use of simulation methods or actual performance data and hence outlined key considerations in understanding the relative ‘cost’[10] of each approach. This discussion suggest that overall the use of actual reliability performance data is likely to have a significantly lower implementation ‘cost’ and lower ongoing ‘cost’ than simulation methods. However, despite the higher ‘costs’, simulation methods have a distinct range of benefits and provide a more tractable approach than actual data observations when assessing reliability metrics that measure relatively infrequent events. In contrast, the use of actual reliability performance data is likely to have a lower overall ‘cost’ and is well suited to reliability metrics that measure more frequent events.

Given these observations, we conclude that simulation methods have a place in the expression of transmission reliability.

10 Again it should be emphasised that we use the term cost in the broadest possible sense to include all factors that reduce the value of the approach selected (i.e. simulation model or actual data). Hence cost includes aspects such as the administrative and TNSP burden, IT and information resource requirements, the time required to obtain the information required at the required quality, the uncertainty in the results obtained from each approach, etc.



5. Economic value of reliability

Parsons Brinckerhoff recognises that the Commission desires that parameters/measures should be able to be given a value so they can be included in an economic analysis.

Keeping in mind that an economic value may be assigned to output parameters only or to a mixture of input measures and output parameters, a key issue is how to derive a suitable value. The attributes of reliability discussed in section 2.1 indicate that values might be found separately or in combination for frequency, duration, exposure, and market impact. Some of the issues to be considered are set out below:

- To be of use in an economic analysis, the value should preferably be expressed from the customer's viewpoint, i.e. the value that consumers place on reliability.
- When applied to multiple measures or parameters, any overlap or double counting of value should be minimised so as not to overemphasise that attribute of reliability and to maintain comparability across the options being subject to analysis.

Parsons Brinckerhoff's research found three approaches to assigning an economic value to transmission reliability:

- direct cost assessment
- value that consumer's place on reliability
- impact on the market price for electricity.

While direct cost assessment is commonly used in economic analysis where a specific investment can be analysed, it is more difficult to determine the specific costs to a customer. Customers value reliability differently and a value approach is therefore preferred. The value approach and market impact approach are discussed in the following sections.

5.1 Value of Customer Reliability

One of the economic analysis measures commonly used to assess network reliability investment decisions is the Value of Customer Reliability (VCR). Analysis of VCR has been conducted for a number of countries; and the values adopted have largely been utilised as an input to the economic assessment of transmission investment.

Typically, VCR is assessed as the value to customers of an incremental change in reliability. Although non-survey approaches are available, the majority of research is focussed on survey-based approaches.[11] It is noted that:

[11] AEMO- Value Of Customer Reliability Background Paper (p6,7)

- separate VCRs can be found for interruption duration and interruption frequency and can be applied to exposure measures such as energy not supplied through combining these
- separate VCRs can be found for different types of customers – domestic, commercial and industrial.

VCR is typically applied at a broad level, as the studies are subjective in nature. The VCR is used in transmission planning to value changes in unserved energy[12] that are modelled for a proposed transmission project. It is also used in the AER's Service Target Performance Incentive Scheme for DNSPs, where it is applied to reliability parameters SAIDI, SAIFI and MAIFI.

The surveys used to collect data about the impact of supply interruptions may not adequately capture the impact on communities of widespread interruptions to supply and hence judgement may be required when applying a VCR value to measures/parameters that include the impact of such events.

AEMO notes that VCR is currently only available for the Victorian region and is used by it for Victorian transmission planning, with no consistent VCR for other regions.[13] It intends to publish VCRs for all NEM regions by March 2014.

5.2 Market price impact

Some input measures cannot be directly related to transmission reliability that can be observed by customers, but can be related to a market price impact. As customers' price paid for electricity is usually impacted by the market price[14], a market price impact assessment can be a suitable way of assigning an economic value to transmission reliability.

The market price is impacted when certain network elements are unavailable. The constraints created by this unavailability may result in a different pattern of generator dispatch within a region or may affect power flows through regional interconnectors, both of which may raise the market price within a region.

Market price impacts are currently used in the NEM as part of the AER's Service Target Performance Incentive Scheme for TNSPs and these are related to specific input measures, which are included in the selection of reliability measures in section 7.

[12] We note that unserved energy is a proxy measure of interruption duration impact and may or may not reflect the customer cost of interruption – an incident and frequency related metric.

[13] AEMO, 2013, Value Of Customer Reliability Issues Paper, p.7

[14] In some jurisdictions, the price paid by consumers is regulated and is not directly impacted by the market price.



6. Design principles for setting reliability standards

This section identifies and describes potential parameters that could be used to support the N-x expression of transmission standards that could be included in a National reference standard template. Initially, it responds to questions raised by the Commission and then brings this together to establish a framework for design principles.

Parsons Brinckerhoff has set out parameters that could be practically and technically feasibly applied by standard setters in the process of setting standards and by transmission network businesses in planning and managing their networks.

6.1 Questions posed by the Commission

Parsons Brinckerhoff's approach to developing broad design principles for a network reliability measurement framework is structured around the following questions posed by the Commission.

a. Can you apply a combination of input measures and output parameters and if so, how?

Historically in Australia, network reliability input measures and output parameters have typically been used independently in assessing network performance and informing network planning and investment decisions. However there is no irrefutable evidence to suggest that input and output reliability measures cannot be used together to provide a greater level of flexibility to setters of reliability standards.

Canada is an example of a jurisdiction that utilises both input measures and output parameters to gauge performance of transmission networks. Canada uses model driven theoretical performance to determine investment levels. Utility companies such as the British Columbia Transmission Corporation (BCTC) have determined that using a combination of input measures and output parameters can provide a sound framework for analysing network investment. This also provides greater understanding of the level of network risk, therefore assisting customers to better understand the potential impacts to their business should network outages occur.

Other reasons for using a combination of input measures and output parameters in a framework that expresses transmission reliability are:

- not all transmission networks (or connection points to the transmission network) are the same and require an individual expression of reliability that suits the characteristics of, and customer preferences at the network connection point
- emphasising one aspect of reliability over others may place undue focus on that aspect and influence a TNSP to act contrary to good practice.

For example, not all transmission systems have N-1 or better redundancy, with some having N-0 redundancy (no redundancy). In such cases the frequency of loss of supply events is great enough to allow direct measurement and hence use of output parameters are appropriate. In contrast, networks with N-1 redundancy have less frequent events and input measures are often specified. In both cases, the expression of reliability requires an N-x expression combined with an input or output measure to adequately express the characteristics of reliability.

A further consideration is those jurisdictions that allow some load to be placed at risk, where a greater level of graduation can be applied. An example of the application of this type of variation is the Bowen Basin coal mining area of Queensland, where the N-1 parameter is applied with a time limitation, maximum load to be interrupted and unserved energy limitation. This requires the measurement of output parameters 'Energy not supplied during unplanned outage' and 'Maximum load lost during unplanned outage'. The combination of N-x with these measures allows for an optimal risk position to be achieved at a lower cost than if N-x had been applied by itself. A further example is Tasmania, where up to 25 MW load may be lost or 300 MWh of energy may not be supplied following a credible contingency event. Again, this requires the measurement of output parameters 'Energy not supplied during unplanned outage' and 'Maximum load lost during unplanned outage'.

Once the decision has been made to combine input measures and output parameters there are other considerations that need to be assessed to ensure that the combination is logical and appropriately measures network reliability in a way that informs network investment decisions. Some of these considerations include:

- The use of output parameters that directly measure reliability are preferable in combination with input measures as they are generally more understandable and relevant to consumers and provide an enhanced understanding of the economic value of network improvements.
- Input measures and output parameters need to be relevant to the characteristics of the network connection point and the customers supplied through the connection point.
- Consideration should be made as to whether the measure combination needs to include the impact of low probability high impact events, versus year on year network reliability performance.
- For those highly reliable transmission systems, a suitable output parameter may be constructed by using the probability of failure, i.e. a simulation model can be developed to produce a probability weighted SAIDI, SAIFI, or EENS output measure that reflects a combination of actual performance and annualised value of low probability interruptions.
- Input measures might be aimed at ensuring an appropriate level of long term reliability by setting an appropriate planning standard (N-x), design standard (quality of materials/construction) or other measure while short term impacts are addressed through specifying the duration of their application (e.g. N-1 for 99.9% of the demand).
- Input/output measures could be focussed on year on year performance by specifying exclusions to remove low probability/high impact events and hence be used to test the success of the reliability management system.
- The design of measures needs to be logically consistent - a paired input measure and output parameter needs to be consistently applied and determined. That is, if an input measure of N-2 is selected then an output parameter such as SAIDI is not appropriate, given that interruptions of supply would be unlikely to occur often enough to be able to calculate the SAIDI metric.

b. What are the implications for the Value of Customer Reliability (VCR) having a mixture of input measures and output based parameters of transmission reliability?

The key consideration for utilising VCR is to have a consistent application when assessing the need for network investments. Consistency can be achieved by applying a common VCR to connection points with similar connection characteristics and avoiding double counting if overlapping measures/parameters are used. Care will need to be taken in choosing appropriate input measures and output parameters that are exclusive (as far as reasonably practical) to ensure that VCR calculations are undertaken in a manner that provides a logical determination.

An example of overlapping measures/parameters is the use of Energy not supplied, which is a combination measure affected by frequency, duration and exposure, and Unavailability, which is a measure of frequency and duration. The overlap is on frequency and duration. To minimise the impact of the overlap, a simple approach would be to apportion the VCR value across each of these measures in a ratio of 50:50.

In particular, the input measure N-x can be assigned an economic value based on VCR through consideration of the changes in reliability expected through establishing different levels of redundancy in the network, i.e. different reliability scenarios, and expressing these in terms of interruption frequency and interruption duration. When combined with other measures/parameters, the economic value so assigned will overlap with measures/parameters that also include interruption frequency and interruption duration, i.e. most other measures/parameters. Apportioning the VCR across N-x and other measures/parameters is problematic as N-x sets the long term expectation for reliability rather than reliability as measured within a reporting period. Hence, it may be appropriate to apportion the VCR value across N-x and other measures/parameters in a ratio of 0:100.

c. What are the implications for high impact, low probability events?

Critical to gaining an informed and accurate level of understanding in relation to transmission network reliability is a consideration of the influence on overall network risk of high impact events that have a low level of probability. Any full combination of input measures and output parameters should consider the loss of redundancy in a network component and its potential to result in a high impact low probability event and hence on the level of risk borne by customers.

An example of a high impact low probability event is the simultaneous loss of multiple transmission network elements that might occur during an extreme weather event, resulting in widespread interruptions to supply. A combination of measures/parameters that accounts for both regular and low probability events may be required to be able to express transmission reliability, depending on customers' expectations or the economic impacts.

Events with a very high consequence may require a State of National disaster response. An example is the collapse of the national grid that occurred in the US in 2003[15]. Given that such events are usually subject to specific studies and reviews, the standard setter may decide not to include such events in reliability reporting. A mechanism of exclusions is often used to remove such events from the measurement of reliability performance.

Direct measurement of transmission reliability including high impact low probability events is problematic due to the low frequency of occurrence. A simulated measure could be used. In a network with redundancy, when a network element fails it does not result in a supply interruption, however, the loss of a second or third elements will. The probability of failure of the second or third network element can be used to produce a probability weighted SAIDI, SAIFI, or EENS output measure that reflects the reduced value inherent in higher risk of interruption in a redundant network; a metric that in essence provides an annualised value of a low probability interruption. A combination of actual and probability weighted data could also be utilised so that a single measure would represent actual interruptions and the annualised value of low probability interruptions.

[15] The US Northeast blackout of 2003 was a widespread power outage that occurred throughout parts of the Northeastern and Midwestern United States and the Canadian province of Ontario affecting an estimated 55 million people. The blackout's primary cause was a software bug in the alarm system at a control room of the FirstEnergy Corporation in Ohio. Operators were unaware of the need to re-distribute power after overloaded transmission lines hit unpruned foliage. What would have been a manageable local blackout cascaded into widespread distress on the electric grid.

While this approach provides a potential solution for measuring network reliability for these types of event, a level of customisation would be required by standard setters to ensure that such measures are fairly applied across the network. It is important to make a differentiation for poor performing networks in the target setting process due to their increased level of exposure to these types of events. For example, networks exposed to an increased level of risk from environmental factors, such as storms, bushfires and extreme heat, should be assessed differently from networks with poor design characteristics, such as a lack of protection from lightning strikes. Hence it is important the extreme events are appropriately and uniformly accounted for so that it is the underlying network performance that is measured and assessed.

Despite that simulated measures typically carry a higher administrative burden than direct measurement, they provide the standard setter with a useful way of capturing high impact low probability events in the expression of transmission reliability and in a form to which VCR can be conveniently applied. On this basis, several have been considered when selecting reliability measures later in this report.

As noted in section 5.1, the surveys used to collect data about the impact of supply interruptions may not adequately capture the impact on communities of widespread interruptions to supply and hence judgement may be required when applying a VCR value to measures/parameters that include the impact of such events.

d. What are the interactions between the output parameters?

Output parameters may interact in terms of:

- the attributes of reliability that they cover – frequency, duration, exposure or market impact – and hence measured performance could be expected to move in unison
- some output parameters may be a subset of another, e.g. circuit availability of ‘critical’ circuits is a subset of total circuit availability
- the value customers place on an attribute of reliability may change if another aspect changes, i.e. customers may place less value on reducing the frequency of interruptions if their duration was shortened
- the data collection and measurement process may be the same for some parameters.

Of these interactions, the most important is the potential for some input measures and/or output parameters to overlap in the attributes of reliability they cover. This may lead to overemphasising specific aspects of transmission reliability unless the overlap is understood and taken into account. For instance, the measures ‘transmission circuit availability’ and ‘energy not supplied’ overlap as they both are affected by the duration of an outage.

Additionally, there is potential for some input measures or output parameters to conflict. By their inherent characteristics, some input measures and output parameters work together to enhance the expression of transmission reliability. However, some measures counter each other or do not logically work together. Any selection of measures to form part of the network reliability standard should be evaluated in terms of their compatibility.

The overlap between output parameters is further discussed in section 8.

6.2 Identified design principles

In this section we set out the principles that could be applied by standard setters when setting transmission network reliability standards that consist of input measures and output parameters. These principles are not intended to be prescriptive rules; rather they seek to inform the standard setter when determining network reliability standards.

Our analysis is based around two groupings of the principles. As outlined below, some are considered critical and are either met or not met. These have been classified as Deal Breakers since measures that do not meet these are excluded. The second group of principles are applied to determine the optimal design, and have been classified as Differentiators.

Deal breakers- Input and output parameters have been analysed against the assessment principles of:

- Transparency – the process for setting standards should be transparent to stakeholders, or be able to be interrogated by an independent expert dependent on the level of complexity.
- Economic Efficiency - promote economic efficient decisions, with no bias towards network solutions.
- Accountability – the TNSP is able to be held accountable for performance at each connection point. Preferably to be benchmarked on a NEM wide basis.
- Targets can be established – performance targets against the standard can be set via modelling, observation or other defined methodology.
- Applies to the shared network – the measure is relevant to the shared network, i.e. the network excluding connection assets, as well as at customer's connection points to the network.

Differentiators- the remaining measures are assessed against their:

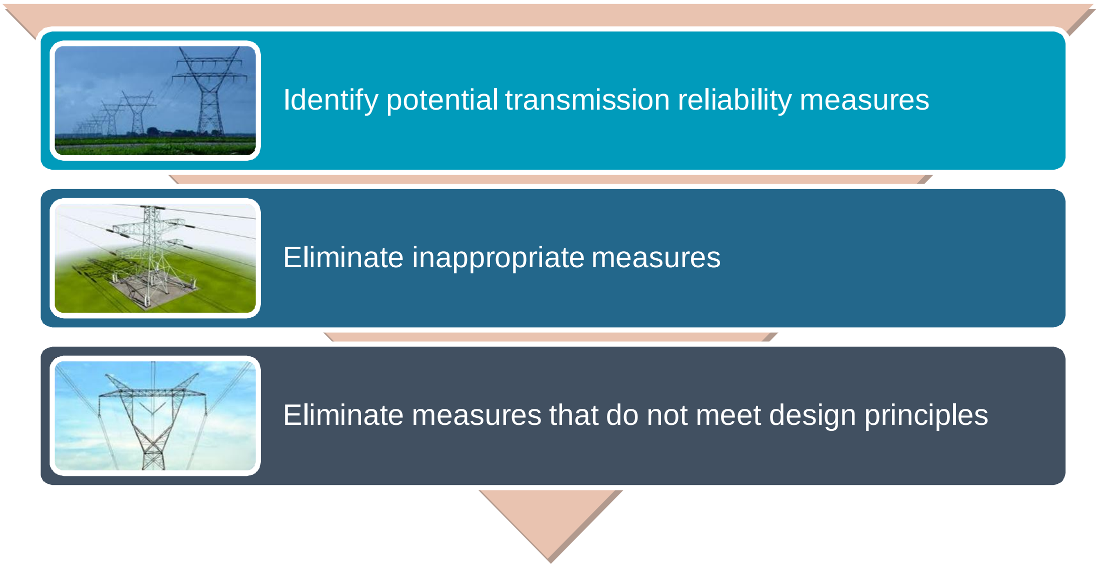
- Fit for purpose - clearly specified by each connection point and is meaningful to customers.
- Administrative Burden - burden for standard setters and TNSPs does not exceed the benefits.

These deal breaker criteria form the basis of the multi criteria analysis outlined in section 7, while the differentiators are applied when determining the optimal design of the parameters in section 8. Fit for purpose could also be considered a deal breaker. In this report, however, it is applied as a differentiator to assist the developer of the template to consider the information needed by a standard setter about how well a measure/parameter meets customers' expectations for the expression of transmission reliability at a given connection point.

7. Selecting reliability measures

Parsons Brinckerhoff applied a multi criteria analysis (MCA) approach to determine which of the identified transmission network reliability measures were best suited to the Commission's criteria. The assessment framework adopted in applying the MCA methodology is outlined in Figure 5.1.

Figure 7.1 Multi criteria analysis framework



7.1 Identifying potential reliability measures

To ensure appropriate consideration is given to the full list of potential transmission network reliability measures, a desktop study of previous studies and reports has been conducted to derive a suite of network reliability measures from which to select a set of measures that meets the Commission's requirements. This review is not exhaustive as it focussed on those jurisdictions where significant work has been undertaken on the expression of transmission reliability – United States of America, Canada and the United Kingdom – as well as Australia and New Zealand.

Some of the sources analysed during the desktop analysis included:

- Nuttall Consulting (2013) Electricity Transmission Reliability Measures: Review of options and concept design; prepared for Australian Energy Market Operator.
- Parsons Brinckerhoff (2007) Distribution Service Standards and Incentives Framework; prepared for the Australian Energy Regulator.
- SKM (2003) Transmission Network Service Provider (TNSP) Service Standards for the Australian Competition and Consumer Commission.

The previous work by Parsons Brinckerhoff in 2007 on DNSPs service standards provided potential measures for transmission networks that do not have redundancy, as this aspect was not well covered in the literature research conducted for transmission networks.

In all, over 70 potential measures for consideration have been identified by this process. The measures identified have been assessed in terms of their applicability to network or customer impact measurement and whether they are input measures or output parameters. The manner in which Parsons Brinckerhoff refined this list is described briefly below.

The full suite of measures and their definitions are listed in Appendix A.

Note that simulation has been applied to several output parameters so as to allow these parameters to capture the impacts of low probability events. These are:

- SAIDIs - Defined as the aggregation of the observed connection point SAIDI and a probability weighted SAIDI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events).
- SAIFIs - Defined as the aggregation of the observed connection point SAIFI and a probability weighted SAIFI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events).
- CAIDIs - Defined as the aggregation of the observed CAIDI and a probability weighted CAIDI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events).
- EENS - Defined as the expected energy that will not be supplied to customers, over a defined period, allowing for the effects of events that could occur over that period.

In their normal form, SAIDI, SAIFI and CAIDI are only useful where events occur frequently enough to allow measurement within the reporting period, i.e. in transmission networks without redundancy (N-0). In their simulated form, SAIDIs, SAIDIs and CAIDIs also include the probability weighted impact of low probability events, i.e. when a network element fails the parameter assesses the probability that a second or third network element might fail resulting in interruptions to customers' supplies. This allows the parameters to be applied to networks with higher levels of reliability (N-1, N-2 etc). The simulation requires modelling of the network and hence carries a higher administrative burden.

EENS does not include a backward looking component. It is the modelled energy not supplied based on the probability of failure of network elements, expected restoration times and expected customer demand levels.

In this report, Parsons Brinckerhoff has not considered 'qualifiers' that might be applied to individual measures/parameters, i.e. N-1 for x% of the time period. Qualifiers can be applied to most of the measures/parameters discussed. It is important to note that qualifiers generally just change the 'target' values associated with the measures/parameters and are more appropriately considered in target setting than in the definition of a measure/parameter. We would encourage the body responsible for the National reference standard template to consider appropriate qualifiers that might provide flexibility in the setting of targets should a measure be included in the template.

7.2 Eliminating inappropriate measures

The list of potential measures includes those that more appropriately describe quality of supply or customer service levels rather than reliability of supply. Identifying inappropriate measures resulted in the rejection of four measures:

- In some jurisdictions, the issues of quality of supply and reliability of supply are considered together. Defining reliability as a loss of supply and quality as a drop in voltage levels, or other attributes of supply that do not result in a loss of supply, resulted in the rejection of three measures in our analysis.
- Measures of levels of service associated with reliability were also common. Such measures include the notice provided to consumers of planned interruptions and as such are not actual measures of reliability of supply as defined in this report. This resulted in the rejection of one measure in our analysis.

7.3 Eliminating measures that do not meet design principles

The next stage of the MCA process involves assessing each of the identified measures against the first set of design principles, the '"Deal Breakers" outlined in section 6.2. These include:

- Transparency
- Economic efficiency
- Accountability
- Targets can be established
- Applies to shared networks.

Failure to meet any of these "Deal breaker" principles means that the measure is excluded from further analysis. Of the initial measures, 21 are deemed appropriate to include in the resulting list of potential reliability measures. Assessment of the measures that passed the 'deal breaker' principles is set out in Table 7.3.

In assessing each measure/parameter against the principle of economic efficiency, consideration was given to whether the measure/parameter would promote economically efficient decisions and not provide a bias against the adoption of a non-network solution. The non-network solutions considered were the use of generation, demand reduction schemes and voltage reduction schemes.

As noted in section 1, many of the input measures and output parameters can be assessed though a simulation method that allows the measures/parameters to include the impact of low probability events. The list also identifies these measures.

Table 7.2 shows the application of the "Deal breaker" principles to the input measure 'mean duration of forced outages – transformers'. It shows that measures that focus on the performance of individual assets such as transformers do not meet the principles.

Table 7.2 Assessment of measure 'mean duration of forced outages – transformers' against design principles

Principle	Description	Comment
Transparency	Process for setting standards should be transparent to stakeholders	Not met – technical, not related to actual network reliability
Economic efficiency	Promote economic efficient decisions, with no bias to network solutions.	Partially met – assigning an economic value is possible, but measure focuses on one asset in the supply chain so non-network options are difficult to incorporate
Accountability	TNSP able to be held accountable for performance at each connection point. Preferably to be benchmarked on NEM wide basis.	Partially met - measure focuses on one asset in the supply chain so contribution to connection point performance may require modelling depending on levels of redundancy, making benchmarking difficult
Targets can be established	Standards able to be set via modelling, etc.	Met
Applies to the shared network	The measure is relevant to the shared network, i.e. excluding connection assets	Not met – transformers are usually connection assets
Administrative burden	Burden for standard setters and TNSPs not to exceed the benefits.	Not met – focussing on individual assets increases the burden
Any fit for purpose issues?	Clearly specified by each connection Point. Meaningful for customers	Not met – performance of an individual asset class is not meaningful to customers

Table 7.3 Measures that passed the Deal Breaker principles

No	Service Standard Measure	Network/ Customer Focus	Input/ output Measure	Can measure be simulated ?	Transparency	Economic Efficiency	Accountability	Targets can be established	Applies to Shared Network	Comment
1	System Average Interruption Duration Index (SAIDI)	Customer	Output	Y	Y	Y	Y	Y	Y	
2	System Average Interruption Frequency Index (SAIFI)	Customer	Output	Y	Y	Y	Y	Y	Y	
3	Customer Average Interruption Duration Index (CAIDI)	Customer	Output	Y	Y	Y	Y	Y	Y	
6	System Average Restoration Index (SARI)	Customer	Output	Y	Y	Y	Y	Y	Y	
7	SAIDIs	Customer	Output	Y	Partial	Y	Partial	Y	Y	This measure would require simulation and hence is less transparent than directly measured metrics.
8	SAIFIs	Customer	Output	Y	Partial	Y	Partial	Y	Y	This measure would require simulation and hence is less transparent than directly measured metrics.
9	CAIDIs	Customer	Output	Y	Partial	Y	Partial	Y	Y	This measure would require simulation and hence is less transparent than directly measured metrics.
10	Interruption - energy not supplied (Customers)	Customer	Output	Y	Y	Y	Y	Y	Y	
11	Expected energy not served	Customer	Output	Y	Y	Y	Y	Y	Y	
12	Transmission circuit availability	Network	Input	N	Y	Y	Y	Y	Y	
16	Annual total of unplanned outages	Network	Input	N	Y	Y	Partial	Y	Y	Benchmarking difficult as measure not normalised.
17	Energy not supplied during outage (Element)	Customer	Output	Y	Y	Y	Partial	Y	Y	Economic value is dependent on impact of losing network element, requiring modelling.
18	Maximum load lost during unplanned outage	Customer	Output	Y	Y	Y	Y	Y	Y	
23	Annual total of energy not supplied during unplanned outage	Customer	Output	Y	Y	Y	Partial	Y	Y	Economic value is dependent on impact of losing network element, requiring modelling.
24	Duration of planned interruptions	Customer	Output	N	Y	Y	Y	Y	Y	
25	Frequency of planned interruptions	Customer	Output	N	Y	Y	Y	Y	Y	
32	Annual total of network constraint events > $x/MWh	Customer	Input	Y	N	Y	Y	Y	Y	
35	Interconnector and critical circuit availability	Network	Input	N	Y	Y	Y	Y	Y	Economic value of interconnector availability requires a market price simulation
53	Total number of loss of supply events > x or y	Customer	Output	Y	Y	Y	Y	Y	Y	
58	MAIFI Momentary Forced Interruptions	Network	Output	Y	Y	Y	Y	Y	Y	
73	Unplanned outage per 100 kms	Network	Output	N	Y	Y	Y	Y	Y	



8. Design of optimal reliability standards

Given that our approach is to express transmission reliability standards as a combination of input measures and output parameters, this section considers the optimal design of such standards. This design reflects the principles we have already considered, including economic efficiency, plus the two new principles of transparency and being fit for purpose. This section aims to identify the optimal design for transmission network reliability standards that:

- combines, where appropriate, various input measures and output parameters that can be presented as a 'menu' of transmission reliability standards
- enables the body that sets the transmission reliability standards (the standard setter) to have flexibility to select from a 'menu' of transmission reliability input measures and output parameters, and
- enables TNSPs to make planning and investment decisions in light of standards expressed as a combination of input measures and output parameters.

To achieve these objectives requires an understanding of:

- how the expression of transmission reliability meets the two remaining principles:
  - fit for the purpose of describing reliability at the connection point, i.e. should it cover one or more of the key dimensions of reliability – being Duration, Frequency, Exposure and Market Impact (see section 8.1.1)
  - consideration of the administrative burden
- when each of the input measures and output parameters work together and when they don't
- practical considerations such as how the interactions between each of the output parameters affects the assessment of an economic value etc.

Each of these points forms a key criterion for selection.

8.1 Key criteria

8.1.1 Fit for purpose

The choice of an appropriate expression of transmission reliability for the point on the network being measured is the most important key criteria. The selected measures need to be understood in terms of their ability to measure one of the key dimensions of transmission network reliability, namely:

a) Frequency – count of instances of interruptions or outages over a period of time

b) Duration – time period over which a supply interruption or outage of a network element occurs

c) Exposure – the consequence of a supply interruption or the level of network risk assumed through the outage of a network element

d) Market impact – change in market price as a result of an outage.

Standard setters should also consider if there is value in measuring only one or more of these dimensions. Choosing all dimensions may result in a more thorough expression of transmission reliability but will have a higher administrative burden. Conversely, choosing a single input measure or output parameter may place undue emphasis on that aspect of transmission reliability which may not be consistent with the desires of customers connected at that point in the network. This situation may also arise if an inappropriate selection of several input measures or output parameters is made.

Some input measures and output parameters cover more than one attribute, for instance energy not supplied is a combination of frequency, duration and exposure. While these are useful in reducing the administrative burden, a potential disadvantage is that when improvement is required the choice of which attribute should be improved is less clear for the TNSP.

Our design is structured to provide a sufficiently broad range of input measures and output parameters to allow the standard setter to make an appropriate and practical choice to meet their objectives in expressing transmission reliability.

8.1.2 Consideration of the administrative burden

An important consideration for standard setters is the effort required to actively measure or simulate the selected measures to determine network reliability. As demonstrated in section 3, uses of direct or simulated measures have their advantages and disadvantages. It is also important for standard setters to give due consideration to the types of data and information that TNSP's will be required to collate or simulate in order to meet the required standards. The administrative burden will be higher when multiple input measures or output parameters are chosen and when simulation is chosen over measured reliability data. In addition some input measures and output parameters will also have greater administrative burdens than others.

The administrative burden associated with specific multiple input measures or output parameters should be transparent to the standard setter. The standard setter may then weigh the burden on the TNSP against the benefit to consumers in making their selection of network reliability measures.

8.1.3 Interaction between input measures and output parameters

Some input measures and output parameters overlap in the attributes of reliability they cover. This may lead to overemphasising specific aspects of transmission reliability unless the overlap is understood and taken into account.

Additionally, there is potential for some input measures or output parameters to conflict. By their inherent characteristics, some input measures and output parameters work together to enhance the expression of transmission reliability. However, some measures counter each other or do not logically work together. Any selection of measures to form part of the network reliability standard should be evaluated in terms of their compatibility.

Information about the appropriate groupings of input measures and output parameters should be made transparent to the standard setter, particularly those that should not be used together.

8.1.4 Practical considerations

Measures that overlap may lead to an overestimation of the economic impact because of the potential to monetise the value of that overlap in the economic analysis. The materiality of this potential overlap needs to be assessed and considered by standard setters in selecting measures and an appropriate allowance made in determining their economic value.

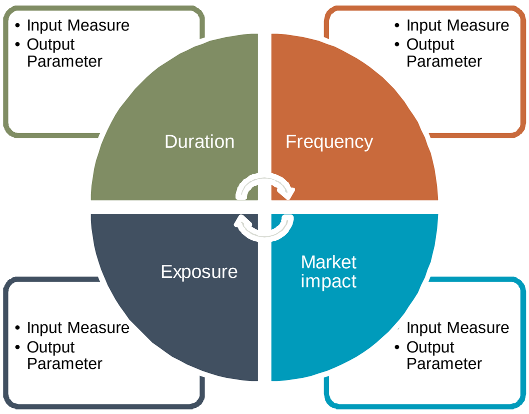
For example, the standard setter may choose two measures that have a significant overlap because they suit the requirements for expressing transmission reliability at a particular connection point. However, it is important in doing so that the standard setter recognises the overlap when assessing the economic value.

Information about the interaction, in terms of the economic value, between input measures and output parameters should be made transparent to the standard setter.

8.2 Applying the criteria

Once the standard setter establishes the context in relation to the element or network connection point for which the transmission network reliability standard is to be set, the criteria should be applied to provide a methodical approach for selection of the input measures and/or output parameters. The standard setter should give due consideration to each of the criterion to ensure that the resultant reliability performance standard provides an appropriate and economically efficient approach to determine network reliability. Table 7.1 provides an example of an overall process flow for standard setters in selecting transmission network reliability measures.

Figure 8.1 Process for applying the criteria

Step	Rationale
Determine the needs for measuring reliability based on the characteristics of the connection point	The section of appropriate input measures and output parameters should be based on the required expression of transmission reliability
Selecting the appropriate input parameter and output measure needs to give consideration to what is covered by the metric.	In selecting the reliability measures consideration should be given to understanding which key dimension of reliability is addressed by the measures being considered. 
Input measures and output parameters are assessed against required criteria.	In selecting the reliability measures consideration should be given to assessing the measure against the assessment criteria of: ▪ Fit for purpose - clearly specified by each connection Point. Meaningful for customers ▪ Administrative Burden - burden for standard setters and the TNSP not to exceed the benefits.

Step	Rationale
Determine the appropriate combination of input and/or output measures	An analysis of the potential measures/parameters should be made to determine an appropriate combination. Combinations of measures that overlap should be minimised or avoided. **Compatable Measures** – • Green measures were assessed as having an appropriate level of synergy to complement each other. **Compatable but measures overlap** – • Amber measures were assessed as compatable but having an overlap in the aspects of reliability covered by each measure that may need to be considerd when assigning an economic value to the measures. Some additional analysis should be undertaken to ensure that the combinations are appropriate in the context and against the connection point for which they have been selected. **Measures in conflict** – • Red combinations have been deemed as conflicting for the purposes of asigning an economic value in a logical and consistent manner.
Understand the cost to consumers	Standard setters may need to give consideration to the: ▪ ease of measurement ▪ cost of measurement ▪ ability to assign an economic value. Standard setters may need to undertake an analysis of the cost impacts to consumers with reference to the relevant connection point. Consideration may need to be given to the type of consumers who are connected to the supply point, the likely impacts of non-supply on them and the value they place of supply reliability. In undertaking an economic assessment, standard setters may need to conduct a cost benefit analysis to determine appropriate reliability standard requirements weighted against the likely costs involved in achieving the standard for each connection point.

8.3 Measure limitations and compatibility

This section assists with the selection of appropriate input measures and output parameters by defining limitations and compatibility between measures or parameters.

8.3.1 Data on fit for purpose and administrative burden

The data required to make an assessment of whether a combination of input measures and output parameters is appropriate to express transmission reliability is set out in Table 8.2. The table shows data on:

- Administrative Burden – an indication of whether the administrative burden is likely to be low, medium or high; based on the effort needed to obtain data, and to analyse and assemble the data into the required form.
- Fit for purpose – a description of any limitations or other information that might assist the standard setter in determining whether an input measure and output parameter is appropriate to use.

Table 8.2 Assessment against the Administrative Burden and Fit for Purpose criteria

No.	Service Standard Measure	Input/ output Measure	Admin-istrative Burden	Any fit for purpose issues?	Comments
1	SAIDI	Output	L	Y	Generally only suitable for radial networks (N-0 redundancy) where outages occur frequently. May be volatile, year on year. Backward looking as based on historic performance, but provides a low administrative burden for connection points that are not subject to changing requirements.
2	SAIFI	Output	L	Y	
3	CAIDI	Output	L	Y	
6	SARI	Output	L	Y	Same as for SAIDI.
7	SAIDIs	Output	M	Y	This measure would require simulation and hence is less transparent than directly measured metrics. The backward looking component of this measure may suffer from data sparsity problems, resulting in volatility year on year.
8	SAIFIs	Output	M	Y	
9	CAIDIs	Output	M	Y	
10	Interruption - energy not supplied (Customers)	Output	M	Y	Generally only suitable for radial networks (N-0 redundancy) where outages occur frequently. May be volatile, year on year. Backward looking as based on historic performance, but provides a medium administrative burden for connection points where customers are sensitive to both interruption frequency and duration.
11	Expected energy not served	Output	H	Y	Requires modelling. May be an overlap if VCR for Energy not served is used to inform the setting of x in the N-x expression. Often used in probabilistic planning of network investments.
12	Transmission circuit availability	Input	L	N	
16	Annual total of unplanned outages	Input	L	Y	Benchmarking difficult as measure not normalised.
17	Energy not supplied during outage (Element)	Output	H	Y	Economic value is dependent on impact of losing network element, requiring modelling. Can be predicted based on load forecast, load profile and average (or maximum allowable) outage duration.
18	Maximum load lost during unplanned outage	Output	L	N	
23	Annual total of energy not supplied during unplanned outage	Output	H	Y	Economic value is dependent on impact of losing network element, requiring modelling.
24	Duration of planned interruptions	Output	L	N	
25	Frequency of planned interruptions	Output	L	N	
32	Annual total of network constraint events > $x/MWh	Input	H	Y	Used in STPIS, based on analysis of market data by AEMO. Not applicable at a connection point.
35	Interconnector and critical circuit availability	Input	M	Y	Economic value of interconnector availability requires a market price simulation
53	Total number of loss of supply events > x or y	Output	M	N	
58	MAIFI Momentary Forced Interruptions	Output	L	Y	Momentary loss of customer supply occurs infrequently. More relevant when 'n-0' planning standards applies.
73	Unplanned outage per 100 kms	Output	L	N	

8.4 Compatibility of measures

As previously stated, some input measures and output parameters overlap in terms of the key dimensions of reliability they cover. Some measures may also be in conflict, or not logically work together to provide an adequate measure of network reliability. Assessing the compatibility of particular measure combinations is critical to ensure the set of standards appropriately represent the reliability performance desired by consumers.

Table 8.3 provides Parson Brinckerhoff's opinion in relation to combinations of measures we consider work together to measure network reliability (green), those that may overlap but are compatible and can be utilised together (yellow), and those that are in conflict and would serve no purpose in being paired to measure transmission network reliability performance (red).

The measures/parameters in conflict are different expressions of SAIDI, SAIFI and CAIDI. Based on the characteristics of the connection point, the following represent conflicting groups of parameters:

- SAIDI, SAIFI, CAIDI: N-0 (no redundancy) or N-1 redundancy measured over an appropriate period, where events occur frequently enough to be measured and the number of customers impacted is important
- SAIDIs, SAIFIs, CAIDIs: N-x redundancy, as low frequency events are included through simulation.

A similar conflict also exists for Energy Not Supplied and Expected Energy Not Supplied.

The measures/parameters that overlap require careful consideration. For example, the table shows that transmission circuit availability (item 5) has an overlap with energy not supplied (item 10). The overlap is the duration attribute. While it might be desirable to include both measures in the expression of reliability at a particular connection point, the overlap flags that the duration aspect of reliability might be over-represented in the expression. The assignment of a VCR value may also need to be apportioned, depending on the manner in which an economic value is assigned.

More detailed examples are provided in the section 9.

A further consideration is when three or more measures/parameters are selected. Minimisation of the potential for overlap will generally provide a more workable expression of transmission reliability. Alternatively, careful thought as to how each measure/parameter might be weighted may provide the optimal outcome.

Table 8.3 Compatibility of the assessed measures

No	Service Standard Measure	Metric Type	SAIDI	SAIFI	CAIDI	SARI	SAIDIs	SAIFIs	CAIDIs	Interruption - energy not supplied (Customers)	EENS	Transmission circuit availability	Annual total of unplanned outages	Energy not supplied during unplanned outage (Element)	Maximum load lost during unplanned outage	Annual total of energy not supplied during unplanned outage	Duration of planned interruptions	Frequency of planned interruptions	Annual total of network constraint events > $x/MWh	Interconnector and critical circuit availability	Total number of loss of supply events > x or y	MAIFI Momentary Forced Interruptions	Unplanned outage per 100 kms	Restoration time	N-x
1	SAIDI	Frequency & duration		Freq.	Duration	Duration	Freq & Duration	Freq	Duration	Freq & Duration	Freq & Duration	Freq & Duration	Freq	Freq & Duration		Duration	Duration	Freq		Freq & Duration	Freq		Freq	Duration	Freq & Duration
2	SAIFI	Frequency	Freq.		N	N	Freq	Freq		Freq	Freq	Freq	Freq					Freq		Freq	Freq		Freq		Freq
3	CAIDI	Duration	Duration	N		Duration	Duration		Duration	Duration	Duration	Duration		Duration		Duration				Duration				Duration	Duration
6	SARI	Duration	Duration	N	Duration		Duration		Duration	Duration	Duration	Duration		Duration		Duration				Duration				Duration	Duration
7	SAIDIs	Frequency & duration	Freq & Duration	Freq	Duration	Duration		Freq	Duration	Freq & Duration	Freq & Duration	Freq & Duration	Freq	Freq & Duration		Duration	Duration	Freq		Freq & Duration	Freq		Freq	Duration	Freq & Duration
8	SAIFIs	Frequency	Freq	Freq	N	N	Freq		Duration	Freq	Freq	Freq	Freq					Freq		Freq	Freq		Freq		Freq
9	CAIDIs	Duration	Duration	N	Duration	Duration	Duration	Duration		Duration	Duration	Duration		Duration		Duration				Duration				Duration	Duration
10	Interruption - energy not supplied (Customers)	Duration, exposure & frequency	Freq & Duration	Freq	Duration	Duration	Freq & Duration	Freq	Duration		Freq, Duration & Exposure	Freq	Freq	Subset	Subset	Duration	Duration	Freq		Freq	Freq		Freq	Duration	Freq, Duration & Exposure
11	EENS	Duration, exposure & frequency	Freq & Duration	Freq	Duration	Duration	Freq & Duration	Freq	Duration	Freq, Duration & Exposure		Freq	Freq	Subset	Subset	Duration	Duration	Freq		Freq	Freq		Freq	Duration	Freq, Duration & Exposure
12	Transmission circuit availability	Frequency & duration	Freq & Duration	Freq	Duration	Duration	Freq & Duration	Freq	Duration	Freq	Freq		Freq	Duration		Duration			Freq	Subset			Freq	Duration	Freq & Duration
16	Annual total of unplanned outages	Frequency	Freq	Freq	N	N	Freq	Freq		Freq	Freq	Freq								Freq	Freq	Freq	Freq		Freq
17	Energy not supplied during unplanned outage (Element)	Duration & exposure	Freq & Duration	N	Duration	Duration	Freq & Duration		Duration	Subset	Subset	Duration			Exposure	Duration				Freq				Duration	Duration & Exposure
18	Maximum load lost during unplanned outage	Exposure	N	N	N	N				Subset	Subset			Exposure		Exposure									Exposure
23	Annual total of energy not supplied during unplanned outage	Duration & exposure	Duration	N	Duration	Duration	Duration		Duration	Duration	Duration	Duration		Duration	Exposure					Duration				Duration	Duration & Exposure
24	Duration of planned interruptions	Duration	Duration	N	N	N	Duration			Duration	Duration														Duration
25	Frequency of planned interruptions	Frequency	Freq	Freq	N	N	Freq	Freq		Freq	Freq														Freq
32	Annual total of network constraint events > $x/MWh	Market impact	N	N	N	N						Freq								Freq	Freq		Freq		Markey impact
35	Interconnector and critical circuit availability	Frequency & duration	Freq & Duration	Freq	Duration	Duration	Freq & Duration	Freq	Duration	Freq	Freq	Subset	Freq	Freq		Duration			Freq		Freq		Freq	Duration	Freq & Duration
53	Total number of loss of supply events > x or y	Frequency & exposure	Freq	Freq	N	N	Freq	Freq		Freq	Freq		Freq						Freq	Freq			Freq		Freq & Exposure
58	MAIFI Momentary Forced Interruptions	Frequency	N	N	N	N							Freq												Freq
73	Unplanned outage per 100 kms	Frequency	Freq	Freq	N	N	Freq	Freq		Freq	Freq	Freq	Freq						Freq	Freq	Freq				Freq
74	Restoration time	Duration	Duration	N	Duration	Duration	Duration		Duration	Duration	Duration	Duration		Duration		Duration				Duration					Duration
75	N-x		Freq & Duration	Freq	Duration	Duration	Freq & Duration	Freq	Duration	Freq, Duration & Exposure	Freq, Duration & Exposure	Freq & Duration	Freq	Duration & Exposure	Exposure	Duration & Exposure	Duration	Freq	Markey impact	Freq & Duration	Freq & Exposure	Freq	Freq	Duration	

Conflict | Compatible with overlap | Compatible, no overlap

8.5 Use of measures to make planning and investment decisions

The N-x expression, Restoration time and selected additional input measures/output parameters used to express transmission reliability will guide the TNSP's decisions in planning and investment needs. It is evident that some of the measures/parameters if adopted will provide a clearer incentive than others. For instance, adopting an N-1 input measure is readily incorporated into a TNSP's planning decision process, being easily observed and implemented. In contrast, adopting an Expected energy not served input measure requires the TNSP to make a judgement about the risk of failure, and the potential impact on the reliability measures/parameters. Such judgements are not always without doubt; overinvestments and under-investments are both possible.

All of the measures/parameters provide suitable incentives to TNSPs to make prudent investment decisions. Those output parameters that are based on actual historic performance are more suitable for connection points that are not subject to changing requirements. In effect, these form triggers for remedial actions should reliability decline. Similarly, those input measures that are based on actual performance may require the TNSP to forecast future performance so as to incorporate them into planning and investment decisions. In contrast, those measures/parameters that are predictive can be directly incorporated into planning and investment decisions.

Table 8.4 provides information about the potential for the measures/parameters to be used by a TNSP to make planning and investment decisions. It also includes the administrative burden from Table 8.2. It shows that measures that are more readily included into planning and investment decisions do not necessarily carry a higher administrative burden.

This information would assist the body who is responsible for preparing the National reference standard template. It is left to the standard setter to select appropriate input measures and output parameters that meet customers' expectations of reliability for the transmission network, while considering the ability of the TNSP to include these into its planning and investment decisions and the associated administrative burden.

Table 8.4 Use of measures to make planning and investment decisions

No.	Service Standard Measure	Admin-istrative Burden	Clarity in planning and investment decisions	Comment
1	SAIDI	L	3	
2	SAIFI	L	3	
3	CAIDI	L	2	Linked to operational response
6	SARI	L	2	Linked to operational response
7	SAIDIs	M	3	
8	SAIFIs	M	3	
9	CAIDIs	M	2	Linked to operational response
10	Interruption - energy not supplied (Customers)	M	3	
11	EENS	H	3	
12	Transmission circuit availability	L	2	Well understood by TNSPs
16	Annual total of unplanned outages	L	3	
17	Energy not supplied during unplanned outage (Element)	H	2	Linked to physical network layout, but requires estimation of load lost
18	Maximum load lost during unplanned outage	L	1	Linked to physical network layout
23	Annual total of energy not supplied during unplanned outage	H	3	
24	Duration of planned interruptions	L	1	Linked to operational planning
25	Frequency of planned interruptions	L	2	Linked to size of works program
32	Annual total of network constraint events > $x/MWh	H	3	
35	Interconnector and critical circuit availability	M	2	Well understood by TNSPs
53	Total number of loss of supply events > x or y	M	3	
58	MAIFI Momentary Forced Interruptions	L	3	
73	Unplanned outage per 100 kms	L	3	

Notes: In the clarity column, the use of the measure in making a planning and investment decision is:
1 clear and requires little judgement by the TNSP
2 requires some judgement by the TNSP
3 requires significant judgement by the TNSP.

9. A worked example

The process of selecting optimal input measures and output parameters that provide an expression of transmission reliability can be demonstrated through a worked example. This is not designed to be a prescriptive approach; rather to provide a potential indication to standard setters of how the measures could be used to support the expression of network reliability standards. Table 9.1 provides two worked examples.

Table 9.1 Worked example for consideration by standard setters

Consideration	Example A	Example B
Characteristics of connection point.	Mining load fed by a single overhead transmission line. Connection point has no significant NEM operational impacts.	Urban/CBD load fed by multiple supply options. Connection point is a significant element in the NEM.
Desired outcome in expressing transmission network reliability	Mining clients sensitive to long duration outages which have the potential to shut down operations. Frequency of interruptions is also of concern.	Consumers sensitive to both frequency and duration of outages and other stakeholders (regulators, local councils, etc.) are also sensitive to the volume of load lost.
Determine the x value and restoration time	Following a suitable economic analysis the x value has been set at N-0, and the restoration time threshold determined.	Following a suitable economic analysis the x value has been set at N-1, and the restoration time threshold determined.
Selecting the appropriate input parameter and output measure needs to give consideration to what is covered by the metric.	A frequency and duration measure/s is required.	A full expression of transmission reliability is required (Frequency, duration, exposure and market impact should be considered).
Input parameter Output measures have also been assessed against the criteria.	**Fit for purpose** - The following measures are fit for the expression; ▪ SAIDI ▪ CAIDI ▪ Interruption - energy not supplied (Customers) ▪ Energy not supplied during unplanned outage (Element) ▪ Average unplanned outage duration or Average restoration time ▪ Annual total of energy not supplied during unplanned outage ▪ Duration of planned interruptions. **Administrative burden**- All of the fit for purpose measures are also of low	**Fit for purpose** - The following measures are fit for the expression; ▪ SAIDI ▪ SAIFI ▪ CAIDI ▪ Interruption - energy not supplied (Customers) ▪ Transmission circuit availability ▪ Annual total of unplanned outages ▪ Annual total of unplanned outages causing loss ▪ Energy not supplied during unplanned outage (Element) ▪ Maximum load lost during outage ▪ Average unplanned outage duration or

Consideration	Example A	Example B
	administrative burden. .	Average restoration time ▪ Annual total of energy not supplied during unplanned outage ▪ Maximum load lost during unplanned outage ▪ Duration of planned interruptions ▪ Frequency of planned interruptions ▪ Annual total of network constraint events > $x/MWh ▪ Interconnector and critical circuit availability ▪ Total number of loss of supply events > x or y ▪ MAIFI Momentary Forced Interruptions ▪ Unplanned outage per 100 kms **Administrative burden-** since a broad range of measures are available the combination with the minimal burden is preferable.
Determine the appropriate combination of input and/or output measures	Following a suitable analysis, the preferred measures are selected (say): ▪ SAIDI	Following a suitable analysis the preferred measures are selected (say): ▪ SAIDIs ▪ Energy not supplied during unplanned outage (Element) ▪ Annual total of network constraint events > $x/MWh
Understand the cost to consumers	VCR applied to SAIDI.	Reference to Table 8.3 shows an overlap in the duration attribute of SAIDIs and Energy not supplied during unplanned outage (Element). VCR to be allocated across both measures.



10. References

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Appendix A

Reliability measures

A1. Reliability measures list

No.	Service Standard Measure	Network/ Customer Focus	PB to consider	Nuttall Report	Input/ output Measure	Definition
1	System Average Interruption Duration Index (SAIDI)	Customer	Yes	Yes	Output	The sum of the duration of each sustained customer interruption (in minutes) divided by the total number of customers. Maybe planned, unplanned or both. Excludes momentary interruptions.
2	System Average Interruption Frequency Index (SAIFI)	Customer	Yes	Yes	Output	The total number of sustained customer interruptions divided by the total number of customers. Maybe planned, unplanned or both. Excludes momentary interruptions.
3	Customer Average Interruption Duration Index (CAIDI)	Customer	Yes	Yes	Output	The average time taken to restore supply following a supply interruption, and is generally expressed in minutes. Maybe planned, unplanned or both. Excludes momentary interruptions.
4	Total of unplanned outages (T-SAIDI)	Customer	No, not normalised so is not comparable between connection points.	Yes	Output	Sum of the outage durations over a defined period at a connection point in minutes
5	Total of unplanned outages (T-SAIFI)	Customer	No, not normalised so is not comparable between connection points.	Yes	Output	Number of sustained interruptions of supply to a connection point over a defined period
6	System Average Restoration Index (SARI)	Customer	Yes	Yes	Output	Average duration of sustained interruptions of supply to a connection point
7	SAIDIs	Customer	Yes	No	Output	The aggregation of the observed Connection point SAIDI and a probability weighted SAIDI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events) - a simulated measure
8	SAIFIs	Customer	Yes	No	Output	The aggregation of the observed connection point SAIFI and a probability weighted SAIFI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events) - a simulated measure

No.	Service Standard Measure	Network/ Customer Focus	PB to consider	Nuttall Report	Input/ output Measure	Definition
9	CAIDIs	Customer	Yes	No	Output	The aggregation of the observed CAIDI and a probability weighted CAIDI impact from simulation of network performance over the long term (that is the impact of rare events and under contingency events) - a simulated measure
10	Interruption - energy not supplied	Customer	Yes	No	Output	Energy not supplied to consumers in MWh. Maybe planned, unplanned or both.
11	Expected energy not served	Customer	Yes	Yes	Output	The mean energy that will not be supplied to customers over a defined period, allowing for the effects of events that could occur over that period - a simulated measure
12	Transmission circuit availability	Network	Yes	Yes	Input	The actual circuit hours available for defined (critical/non-critical) transmission circuits divided by the total possible defined circuit hours available. Maybe planned, unplanned or both. May apply to lines, transformers or circuit (line plus transformers)
13	Annual total of sustained under / over voltage	Network	No, a quality of supply measure	No	Quality	
14	Annual total of excessive transient voltage	Network	No, a quality of supply measure	No	Quality	
15	Annual total of unplanned outages	Network	No, not normalised so is not comparable between connection points.	No	Input/	Same as 5
16	Annual total of unplanned outages causing loss of supply to a consumer	Customer	Yes	No	Output	Simple count
17	Energy not supplied during unplanned outage	Customer	Yes	No	Output	Energy in MWh not supplied to consumers during an unplanned outage. Similar to 10. May also be applied to a particular network element
18	Maximum load lost during unplanned outage	Customer	Yes	No	Output	Load in MW not supplied to consumers during an unplanned outage.

No.	Service Standard Measure	Network/ Customer Focus	PB to consider	Nuttall Report	Input/ output Measure	Definition
19	Average unplanned outage duration or Average restoration time	Customer	No, similar to 6	No	Output	The cumulative summation of the outage duration time for the period, divided by the number of outage events during the period. Excludes planned outages. Similar to 6
20	Customer maximum interruption duration	Customer	No, similar to 74	No	Output	The duration in minutes of the longest interruption of a customer's supply
21	Customer minimum interruption duration	Customer	No, not applicable to shared network, lacks an economic basis	No	Output	The duration in minutes of the shortest interruption of a customer's supply
22	Customer average interruption frequency	Customer	No, similar to 2	No	Output	Number of interruptions divided by the total number of customers (all customers not just each DNSP)
23	Annual total of energy not supplied during unplanned outage	Customer	Yes	No	Output	Same as 17, except annual
24	Duration of planned interruptions	Customer	Yes	Yes	Output	Sum of outage durations in minutes per year
25	Frequency of planned interruptions	Customer	Yes	Yes	Output	Sum of the number of outages per year
26	Period of notice for planned interruptions	Customer	No, a service level measure	No	Service level	The number of business days between when notice was provided and the start of a planned interruption
27	Cost of transmission outages	Customer	No, lacks an economic basis	No	Output	Dollars per year
28	Potential / actual cost benefits from rescheduling planned outage / improved restoration performance	Customer	No, not a measure of reliability	No	Input	Dollars per year
29	Comparison of potential savings and actual costs of outage from rescheduling planned outage / improved restoration performance	Customer	No, no link to economic efficiency	No	Input	Dollars

No.	Service Standard Measure	Network/ Customer Focus	PB to consider	Nuttall Report	Input/ output Measure	Definition
30	Retrospective assessment of actual costs and benefits of augmentation	Network	No, targets cannot be established	No	Input	Dollars
31	Outcomes from availability incentive scheme	Network	No, TNSP not accountable, targets cannot be established	No	Input	Dollars
32	Annual total of network constraint events > $x/MWh	Customer	Yes	No	Input	Number of dispatch intervals where an outage on a TNSP's network results in a network outage constraint with a marginal value greater than $10/MWh
33	Amount of additional generation to overcome network constraints	Network	No, lacks transparency, target setting difficult	No	Input	where an outage on a TNSP's network results in a network outage
34	Cost of additional energy to overcome network constraints	Network	No, lacks transparency, no link to economic efficiency	No	Input	constraint with a marginal value greater than $10/MWh
35	Interconnector and critical circuit availability	Network	Yes	Yes	Input	Excludes planned outages
36	SAIIR System Minutes	Customer	No, similar to 17	No	Output	Amount of unsupplied energy across the transmission system divided by peak demand,
37	SAIIR No. of Supply Interruptions	Customer	No, not normalised so is not comparable between connection points.	No	Output	Number per year
38	Interconnector Forced Outage Rate	Network	No, similar to 12	No	Input	The actual hours available divided by the total possible hours.
39	Line Forced Outage Rate for equipment failure	Network	No, not normalised so is not comparable between connection points.	No	Input	Number of forced outages of lines due to equipment failure per year
40	Line Forced Outage Rate for Lightning and Storms	Network	No, not normalised so is not comparable between connection points.	No	Input	Number of forced outages of lines due to lightning and storms per year

No.	Service Standard Measure	Network/ Customer Focus	PB to consider	Nuttall Report	Input/ output Measure	Definition
41	Mean Duration of Forced Outages (Circuits)	Network	No, similar to 74	No	Input	Sum of outage durations of circuits divided by total number of outages of circuits
42	Successful Auto Reclose of Circuits	Network	No, lacks a link to economic efficiency	No	Input	Expressed as a percentage of all reclose operations
43	Forced Outage Rate (transformers)	Network	No, not normalised so is not comparable between connection points.	No	Input	Number of forced outages of transformers per year
44	Mean Duration of Forced Outage (transformers)	Network	No, similar to 74, lacks transparency as not related to actual network reliability	No	Input	Sum of outage durations of transformers divided by total number of outages of transformers
45	Availability of Transformers	Network	No, as above, similar to 12	No	Input	The actual hours available divided by the total possible hours.
46	Availability of Static VAR Compensators	Network	No, lacks a link to economic efficiency	No	Input	The actual hours available divided by the total possible hours.
47	Availability of Synchronous Condensers	Network	No, as above	No	Input	The actual hours available divided by the total possible hours.
48	Availability of Capacitor Banks	Network	No, as above	No	Input	The actual hours available divided by the total possible hours.
49	Availability of Protection Systems	Network	No, as above	No	Input	The actual hours available divided by the total possible hours.
50	Incorrect Protection Operations	Network	No, as above	No	Input	Expressed as a percentage of total protection operations
51	Contractual (Rebates) - Generation constrained	Network	No, as above	No	Input	Contractual incentive scheme where service provider gives back (rebates) dollar amounts when constraint targets are not achieved
52	Contractual (Rebates) - Shared Network	Network	No, as above	No	Input	Contractual incentive scheme where service provider gives back (rebates) dollar amounts when availability targets are not achieved

No.	Service Standard Measure	Network/ Customer Focus	PB to consider	Nuttall Report	Input/ output Measure	Definition
53	Total number of loss of supply events > x or y	Customer	Yes	Yes	Output	Number of events greater than X or Y minutes pa, where X and Y are to be defined for each TNSP, such that: - an X system minute event has a return period of 1 year - a Y system minute event has a return period of 2 years
54	Percentage unplanned connection point interruptions not restored within 3 hours	Customer	No, similar to 74	No	Output	Number not restored in the time specified divided by the total number
55	Total balancing costs	Customer	No, lacks transparency, lacks a link to economic efficiency	No	Input	Cost of balancing supply and demand (including constraints & network losses) in dollars
56	No. of frequency excursions larger than + / - 1%	Network	No, a quality of supply measure	No	Quality	
57	Transmission Availability Composite (TAC)	Network	No, lacks transparency, lacks a link to economic efficiency	No	Input	A composite measure of availability of different asset types expressed as a score
58	MAIFI Momentary Forced Interruptions	Network	Yes	No	Output	The total number of customer interruptions of one minute or less, divided by the total number of customers.
59	500 kV Annual Forced Outage Frequency	Network	No, lacks a link to economic efficiency	No	Input	Forced outage
60	500 kV Annual Forced Outage Duration	Network	No, as above	No	Input	Forced outage
61	500 kV Proportion of Lines without Forced	Network	No, as above	No	Input	Forced outage
62	220 kV Annual Forced Outage Frequency	Network	No, as above	No	Input	Forced outage
63	220 kV Annual Forced Outage Duration	Network	No, as above	No	Input	Forced outage
64	220 kV Proportion of Lines without Forced	Network	No, as above	No	Input	Forced outage

No.	Service Standard Measure	Network/ Customer Focus	PB to consider	Nuttall Report	Input/ output Measure	Definition
65	115 kV Annual Forced Outage Frequency	Network	No, as above	No	Input	Forced outage
66	115 kV Annual Forced Outage Duration	Network	No, as above	No	Input	Forced outage
67	115 kV Proportion of Lines without Forced	Network	No, as above	No	Input	Forced outage
68	66 kV Annual Forced Outage Frequency	Network	No, as above	No	Input	Forced outage
69	66 kV Annual Forced Outage Duration	Network	No, as above	No	Input	Forced outage
70	66 kV Proportion of Lines without Forced	Network	No, as above	No	Input	Forced outage
71	French Interconnector availability	Network	No, similar to 35	No	Input	The actual hours available divided by the total possible hours.
72	Scottish Interconnector availability	Network	No, similar to 35	No	Input	The actual hours available divided by the total possible hours.
73	Unplanned outage per 100 kms	Network	Yes	No	Input	The number of outages of transmission lines divided by the total transmission line length
74	Restoration time	Customer	Yes	No	Output	The time to restore supply following an unplanned outage. Set as a threshold value, and expressed as a percentage achieved. Excludes momentary outages
75	N-x	Network	Yes	Yes	Input	A planning standard where x defines the number of network elements that can fail without resulting in a loss of customer supply. Usually limited to creditable outages.