5.10

GHD Review of cost benefit methodology

Ausgrid

Ausgrid

Review of Cost Benefit Methodology

Final Report

September 2017

Executive summary

Background

In July 2014, Ausgrid's licence conditions were amended with the deterministic standards removed. Ausgrid now relies on a cost benefit analysis approach for investment planning. A key part of cost benefit analysis relies on using probabilistic planning methods to form a view of the expected level of unserved energy (USE) and the value of that USE under different network investment options.

Ausgrid has developed a suite of probabilistic planning tools to implement a cost benefit methodology for investments addressing the following drivers:

- Expanding the capacity at substations to meet demand requirements (substation capacity model).
- Cable replacements to address deterioration of aged oil-filled underground cables (feeder model).
- 11 kV switchgear and switchboard replacements to address aged and poor condition switchgear and switchboards (11 kV SB model).

GHD Pty Ltd (GHD) was engaged to perform an independent review of the tools and processes developed by Ausgrid to implement its cost benefit methodology. Specifically the review assessed whether the adopted approach is sufficient to meet Ausgrid and regulatory requirements and aligned with good industry practice.

Assessment

The scope of the review was developed in consultation with Ausgrid to:

- Assess the appropriateness of Ausgrid's cost benefit methodology in relation to input parameters, end of life failure models, treatment of load transfers, process and economic decisions.
- Assess the appropriateness of Ausgrid's planning tools (11kV SB model, substation capacity model and feeder model).
- Review methods and approaches used by other Network Service Providers (NSPs) to benchmark Ausgrid's selected approach.

The review was performed from 7 June to 31 August 2017.

Key principal observations and opportunities for improvement

Overall, GHD's review found:

- The existing models are considered an adequate first implementation of tools for applying the Cost Benefit Methodology and are consistent with good industry practice.
- Comparison of Ausgrid's approach with national and international industry practice, based on informal benchmarking with a sample of NSPs, has indicated that processes and tools developed appear to be appropriate and reflect a level of functionality that is likely to be at or above that used by other NSPs.
- Ausgrid has annually reassessed the reliability benefits delivered by proposed investments to identify whether any revision to the timing of the projects in the capital investment program is warranted. The reliability assessment performed annually replicates the process used by Ausgrid to assess a project's reliability benefit as part of regulatory test assessment or investment justification process.

The level of detailed analysis incorporated into Ausgrid's annual process exceeds that adopted by other NSPs. Others tend to undertake detailed probabilistic analysis to support the investment decision and adopt simplified annual processes that is focussed on identifying emerging reliability risks. Where the annual process identifies a new reliability risk or a significant change to an existing risk an investigation using detailed probabilistic analysis is scheduled to occur outside of the annual review process.

Ausgrid should consider whether sufficient value is gained from the annual calculation process to justify the effort expended.

A strength of Ausgrid's annual process is that it captures any material changes to the economics of the proposed investment arising from changes to key inputs including demand forecasts, project costs and asset condition. It is consistent with good industry practice to re-evaluate investment decisions in light of material changes to key inputs.

- The probabilistic analysis undertaken by Ausgrid identifies the preferred investment timing as the year when the annualised investment cost matches the annual expected reliability, safety and environmental benefit achieved by undertaking the investment. The result from the base case analysis is used to set the preferred investment date. A limited number of sensitivity studies are then undertaken to identify how the preferred investment date changes with key modelling assumptions[1]. GHD has suggested a number of additional sensitivities be considered. The increased set of sensitivity studies would identify a band of years in which the optimal investment timing is likely to reside. It is recommended that Ausgrid consider leveraging the sensitivity analysis to a greater extent in setting the optimal investment timing. Using the mid-point of the band instead of the timing determined from the base case analysis may provide a more appropriate view of the optimal investment year balancing the risks posed by uncertainty in key inputs.
- There is an opportunity to leverage results of the cost benefit assessment to identify projects that could provide scope for optimising the delivery of the total Ausgrid capital works program. The change in relationship between costs and benefits with investment timing defines the sensitivity of the captured net economic benefit. A high sensitivity suggests a greater importance in achieving the optimal investment timing. A low sensitivity suggests scope to vary the investment timing without a significant economic impact. Rescheduling those projects could be used to support optimal delivery of the Ausgrid works program while minimising any economic loss. The existing models should allow extraction of this additional information with minimal change to reporting.
- The tools and processes developed by Ausgrid appear to be adequate and appropriate for assessing the impact on reliability of supply of different investment options and identifying the option that maximises the net benefit, when compared with power industry practice for probabilistic planning.
- Ausgrid's current probabilistic planning tools assume a linear relationship between the severity of an event and the population impacted by it. For instance, the reliability calculation assumes a constant Value of Customer Reliability (VCR) value irrespective of the duration and size of the supply interruption. Approaches adopted by other industries (i.e. oil and gas) recognise that the severity of safety and environmental impacts generally follow a logarithmic relationship with the size of the impacted population (10 fatalities are viewed as 100 times worse than 1 fatality). FN analysis is

[1] Sensitivities examine the impact of varying the discount rate, value of customer reliability, project cost and demand forecast.

used in these industries to capture this effect. Ausgrid may wish to consider applying FN analysis techniques in cases where the asset failure could lead to increased safety and environmental impacts in terms of the geographic spread or the number of people effected.

- The suite of documentation prepared by Ausgrid to provide guidance around the cost benefit methodology and tools requires review and refinement to ensure consistency and clarity regarding the functionality of the tools. These documents should more clearly define any key assumptions and known limitations of the models. A detailed list of suggested refinements is contained in Appendix A.

Further principal observations and opportunities for improvement have been identified and are detailed in section 3 and 4 of this report.

This report is subject to, and must be read in conjunction with, the limitations set out in section 1.4 and the assumptions and qualifications contained throughout the Report.

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1. Introduction

1.1 Background

The aim of probabilistic planning is to consider potential failure events and, by analysing the likelihood of each failure event and its consequence, form an expected view of the monetised impact of equipment failures on customers. The timing of replacements or augmentations is selected by comparing the expected benefit delivered to customers by investing to avoid the impact of equipment failures against the cost of the network investment. This is different from the traditional deterministic approach to investment planning, which seeks to plan investments using deterministic redundancy based standards.

In July 2014, Ausgrid's licence conditions were amended with the deterministic standards removed. Ausgrid now relies on a cost benefit analysis approach for investment planning. A key part of cost benefit analysis relies on using probabilistic planning methods to form a view of the expected level of unserved energy (USE) and the value of that USE under different network investment options.

Ausgrid has developed a suite of probabilistic planning tools to implement a cost benefit methodology for investments addressing the following drivers:

- Expanding the capacity at substations to meet demand requirements (substation capacity model).
- Cable replacements to address deterioration of aged oil-filed underground cables (Feeder model).
- 11 kV switchgear and switchboard replacements to address aged and poor condition switchgear and switchboards (11 kV SB model).

The models comprise a combination of database, PSSE applications and spreadsheet tools that have been prepared to develop estimates of the expected unserved energy likely to emerge under different investment scenarios including the status-quo scenario in which no new investment occurs.

GHD Pty Ltd (GHD) has been engaged to provide independent review of Ausgrid's developed methodology and associated tools and processes. We have also completed a benchmarking exercise to compare the practices developed by Ausgrid with those currently used by other national and international NSPs.

1.2 Objective

This review has been undertaken to provide independent limited assurance that the cost benefit methodology developed and to be formally adopted by Ausgrid is in accordance with Ausgrid's business and regulatory requirements and is adequate to meet good industry practice for probabilistic planning.

1.3 Approach

The review was undertaken in three stages; a detailed assessment of the processes and tools developed to apply Ausgrid's cost benefit methodology, informal benchmarking against national and international NSPs who have adopted probabilistic planning approaches and an investigation of appropriate improvement opportunities for the developed tools and processes. Figure 1 below illustrates the review process adopted by GHD:

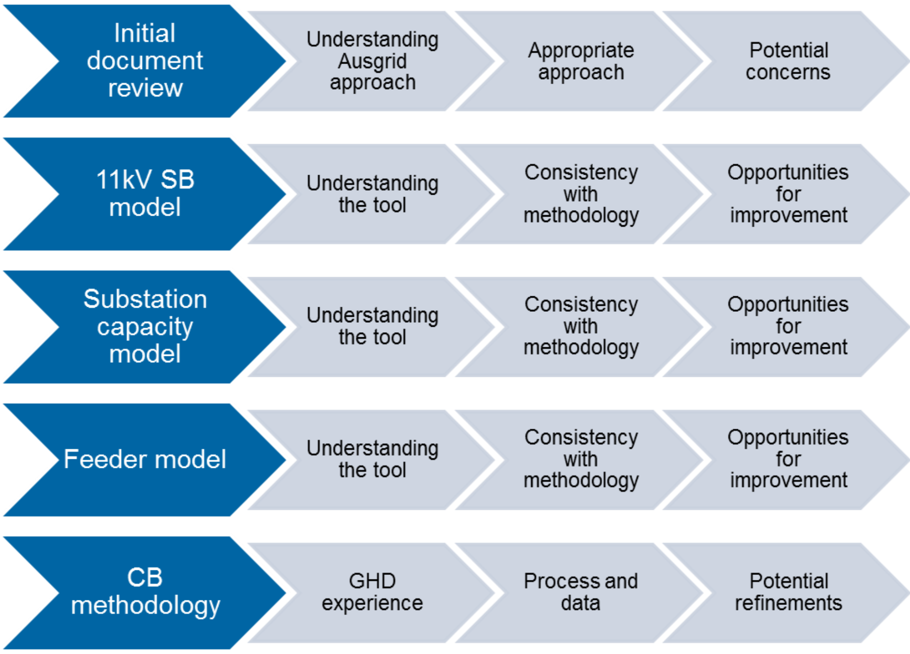


Figure 1 GHD review process for investigation of Ausgrid approach

GHD's review approach relied on review of documents and demonstration of the various models developed by Ausgrd, as well as the review of inputs to the models and outputs produced by the models. In all cases, the reviewer used professional judgement in the collection of sufficient appropriate evidence with that evidence being persuasive rather than conclusive in nature.

1.3.1 Examination and assessment of Ausgrid approach

The first stage of GHD's review examined the adequacy and appropriateness of the:

- Cost benefit methodology in relation to input parameters, end of life failure models, treatment of load transfers and process and economic decisions.
- Developed probabilistic planning tools (11kV SB model, Feeder model and substation capacity model).

The three tools were assessed individually against corresponding documentation explaining the intent and application of each tool. While the tools themselves are standalone, a holistic assessment of the methodology and tools was also performed, from the perspective of understanding the commonalities across underlying assumptions and to identify whether there were any material gaps or inconsistencies in the individual tools.

1.3.2 Comparison of industry practice

GHD consulted with key subject matter experts from the following NSPs for the purpose of conducting informal benchmarking to understand and compare national and international approaches to probabilistic planning:

- Western Power.
- Australian Energy Market Operator (AEMO).
- ElectraNet.
- AusNet.
- Northern PowerGrid (UK).
- Scottish Hydro-Electric Transmission.

Criteria for these consultations included:

- Review of methods and approaches used by other NSPs to establish reliable parameters for use in probabilistic planning.
- The availability of benchmark parameters that can be used for probabilistic planning when reliable data is not available (e.g. estimated repair times for major items of equipment).
- Review approaches adopted by other Network Service Providers (NSPs) using probabilistic planning to evaluate the replacement of equipment at end of life.

Where areas of significant variance from Ausgrid's adopted methodology were detected, the question framework was explained to extract further detail of the key differences in approach.

1.3.3 Investigation of opportunities for improvement

The final stage of the review concentrated on developing improvement recommendations focused on addressing issues identified in the previous stages.

1.4 Scope and limitations

This report has been prepared by GHD for Ausgrid and may only be used and relied on by Ausgrid and the Australian Energy Regulator (AER) for the purpose agreed between GHD and the Ausgrid as set out in section 1.1 of this report.

GHD otherwise disclaims responsibility to any person other than Ausgrid arising in connection with this report. GHD also excludes implied warranties and conditions, to the extent legally permissible.

The services undertaken by GHD in connection with preparing this report were limited to those specifically detailed in the report and are subject to the scope limitations set out in the report.

The opinions, conclusions and any recommendations in this report are based on conditions encountered and information reviewed at the date of preparation of the report. GHD has no responsibility or obligation to update this report to account for events or changes occurring subsequent to the date that the report was prepared.

The opinions, conclusions and any recommendations in this report are based on assumptions made by GHD described in this report (refer section 1.4 of this report). GHD disclaims liability arising from any of the assumptions being incorrect.

GHD has prepared this report on the basis of information provided by Ausgrid and others who provided information to GHD (including Government authorities), which GHD has not independently verified or checked beyond the agreed scope of work. GHD does not accept liability in connection with such unverified information, including errors and omissions in the report which were caused by errors or omissions in that information.

1.5 Assumptions

GHD has made the following assumptions in relation to the review:

- While GHD has reviewed some sample calculations and the results have appeared reasonably acceptable, GHD has not assessed all underlying calculations performed by the tools for accuracy. This would require the ability to audit the internal workings of the models and perform offline calculations using the stated formulae to verify the output calculations. It is recommended that this exercise is performed, either as an internal exercise or by engaging external support, in order to provide demonstration that the outputs generated are accurate and representative. Developing a test case and data set for each tool would also be useful in validating implementing an enhancements to the tools do not inadvertently introduce calculation errors.

- Review of the PSS/E Application was limited to a demonstration of the operation of the Application by Ausgrid and the main data forms and inputs / outputs. No review of model's python script was performed.
- Review of the MS Access model (11 kV SB model) and Excel model (substation capacity model) was limited to the main data forms and inputs / outputs. No review of underlying macros or calculation codes was performed.
- Assessment of the accuracy and correctness of the input data was not included in the scope of our assessment. All input data was assumed to be correct.

2. Comparison of industry practice

2.1 Approach

Planning criteria are a set of standards applied by NSPs to maintain network security and reliability and are used as a planning and design tool to protect the interests of network users in terms of reliability and quality of supply. The standards are generally targeted at achieving objectives related to:

- Ensuring sufficient capacity is available to meet current and future anticipated network demand.
- Maintaining adequate network reliability.
- Maintaining quality of supply to customers as per the NER.

Different jurisdictions are governed by planning approaches that are set within codes administered by state or regional authorities. For example, in South Australia it is the South Australian Electricity Transmission Code which is managed by the Essential Services Commission of South Australia, while Western Australia is governed by the WA Access Code which is the overarching regulation that gives rise to the Technical Rules (administered by Economic Regulation Authority) under which Western Power is required to plan the network. Similarly, in the UK, NSPs plan their networks in accordance with Engineering Recommendation (ER) P2/6 published by the Electricity Networks Association.

The UK and some Australian jurisdictions remain governed by approaches that support the use of deterministic redundancy based methods, despite popularity among NSPs to develop independent probabilistic risk based methods for informing investment decisions. The transition towards probabilistic techniques has been fuelled by attempts to avoid capital investments that may either be uneconomic or less efficient, as is a key risk with a deterministic approach. In most cases, there are mechanisms available to NSPs to allow exemption from the stipulated requirements on the basis that departure to an alternative practice can be appropriately supported.

Traditionally there are two types of scenarios commonly considered by NSPs to assess reliability and quality of supply; capacity planning and condition driven replacement planning. In consultation with NSPs, it was apparent that where the responsibility lay with the NSP to make decisions on both capacity extension and asset replacement investments, consistent planning criteria were applied and, particularly for Australian NSPs, those techniques incorporate probabilistic analysis to determine reliability benefits.

The general consensus from Australian NSPs is that generally, for capacity expansion and asset conditions decisions, the reliability assessment determines the optimal timing, selection of options, and characterisation of risk associated with project deferral (i.e. defining baseline and residual risk) for proposed investments. An example of the various factors considered to select the preferred date for the capacity expansion augmentation included:

- Earliest date is the year the deterministic planning standard is first violated.
- Maximum deferral is the year where the USE benefit first exceed the annualised cost of the augmentation.
- Deferral period may be shortened if the firm (n) capacity of the substation is forecast to be exceeded prior to reaching the breakeven point where the reliability benefit equals the annualised cost of the augmentation.

- Deferral period may be shortened if the risk mitigation measures needed to be deployed to manage the transformer failure are considered to be particularly difficult (site access issues make deployment of the Rapid Response Spare Transformer (RRST) problematic, the number of zone substation exceeding the deterministic level would risk having insufficient RRST available and the cost of an additional transformer is not considered to be economic compared to the deferral benefit.

For UK based NSPs, while the external facing network planning activities undertaken generally follow deterministic principals, the majority do consider the risks associated with asset failure, over-firm capacity operation and reliability and performance considerations within their business capital investment documentation. This will generally include a detailed risk analysis evaluation that considers aspects such as potential safety, quality of supply (customer interruptions, customer minutes lost) and environmental impacts and will be supported by a detailed probabilistic based risk assessment, and will include calculating the probability of an incident occurring as well as assessing the potential consequential range of impacts. For safety related incidents this could range from near miss or minor injury to staff up to death of a staff member or members of the public. For environmental impacts this could include potential oil leakage of transformers or oil-filled cables into water courses or release of SF6 gas from switchgear equipment.

2.2 Frequency of assessment

In order to identify whether any revision to the timing of the proposed network investment program is warranted, it is necessary to reassess the reliability benefits for proposed investments using current information regarding future network utilisation and asset performance. Responses from all Australian NSPs surveyed indicate that some level of annual assessment of emerging reliability risks is undertaken with the results summaries in their annual planning reports. As a minimum this analysis seeks to review updated information on network demand to identify any new reliability risks or changes to previously identified reliability risks for which solutions are yet to be committed.

GHD has reviewed a number of the annual planning reports and it appears that the analysis supporting the annual reviews of reliability risk is a simplified version of the probabilistic analysis that might be undertaken in support of an actual investment business case or regulatory investment test (RIT-D). Some of the simplifying assumptions include:

- Using deterministic planning criteria as an initial identifier of emerging network reliability issues, and
- Limiting probability analysis to calculation of energy at risk for N-1 contingencies assuming all outage durations align with a standard equipment repair time.[2]

The approach adopted by AusGrid to repeat the detailed probabilistic analysis annually requires a level of detail in the annual assessment which appears to exceed that implemented by other NSPs.

2.3 Tools and systems

A variety of tools and systems are used by NSPs, which attests to the uniqueness and variable complexity of probabilistic planning approaches adopted, and the need for tools tailored to suit individual requirements of each NSP.

[2] Section 5.2 of the Ausnet DAPR for 2017 – 2021 provide information on the energy at risk calculation employed (https://www.ausnetservices.com.au/en/Misc-Pages/Links/About-Us/Publications)

Referenced commercial tools used to perform probabilistic analysis include Power Plan, Prophet, Plexos and PSS/E. The use of internally and externally developed Excel spreadsheets was also reported; either to perform the complete analysis or to be used as a supplementary tool, to perform a component of the analysis only. Two examples were given for the use of spreadsheets:

- To perform an assessment of the economic viability of capacity upgrades, using the outcomes of probabilistic analysis to determine the economic case for a proposed investment.
- Implements state enumeration techniques to calculate the unserved energy resulting from substation transformer failures.

2.4 Application

2.4.1 Failure modelling

In the probabilistic assessment of reliability benefits, failure modelling performed on the relevant asset classes. Consultation with NSPs found that the more explicitly asset classes considered are transformers (power and instrument), overhead lines and underground cables, and to a lesser extent switchgear, generating units and reactive plant.

Where the failure model is required to account for changes in performance expected through asset replacement works, NSPs reported either using:

- The probability of asset failure which captures the expected change in asset performance (i.e. the probability of failure decreases once an asset is refurbished and/or replaced); or
- Modelling the change in failure rate (i.e. high failure rates for assets that are in poor condition versus low failure rates for new assets) following replacement of an asset that is in poor condition.

For capacity expansion decisions, one NSP reported using standard (average) failure rates for transformers and lines, unless specific asset condition information or recent performance indicates that the use of alternative failure rates is likely to have a material impact.

Upon consideration of the measures used to assess failure likelihood, there was some divergence between Australian NSP approaches, with one approach relying on asset condition only via the use of a set of failure curves (representing best to worst condition) for each major asset type to estimate future failure rates. A contrasting approach was explained to use age only as a trigger to conduct condition assessment, which is then fed into to an asset life cycle assessment, which takes into account a wide range of factors to determine where the asset sits on the life cycle curve.

In the case of UK, a more hybrid approach is taken which considers both age and condition. Whereby, as data is usually representative of the average age / condition of the plant in question, if the assets or plant subject to the risk analysis are in unusually poor condition or much older than average, a multiplier may be applied on the base failure rate data to model this aspect. This can be a matter of applying engineering judgement however as the frequency of a risk event occurring (asset failure) is generally considered in logarithmic steps i.e. a factor of ten increase between steps, then the impact of choosing an asset age / condition multiplier of say 3 rather than 4 is usually limited.

2.4.2 Uncertainty

Broadly the use of sensitivity analysis was advised as the leading mechanism for addressing the impact of uncertainty in reliability assessments, with a wide range of uncertainties highlighted, including asset failure rate, demand growth, Value of Customer Reliability (VCR), discount rate and project cost estimates of the investment decision, government policies on CO2 emissions, new generation connections, weather conditions, outage rates, dynamic ratings of transmission lines, fuel costs, new technologies and availability of resources (wind, hydro, solar, gas).

2.4.3 Value of Customer Reliability

The VCR In dollar terms represents a customer's willingness to pay for the reliable supply of electricity. In network planning, the VCR may be used to assess the economic merits of carrying out additional investment in the electricity network. Following the rollout of a NEM wide survey of residential and business customers of various sizes and industries by AEMO, survey results were processed to determine VCR rates and subsequently published by AEMO. The latest VCR rates were published in 2014 and it is anticipated that AEMO will conduct another market survey to revise the rates in 2018. From the responses received from Australian NSPs regarding their approach toward determining VCR, it was evident that all NSPs, use the rates published by AEMO.

2.4.4 Other benefit streams

While there was limited experience reported by Australian NSPs in the way of applying probabilistic approaches to alternative benefit streams, such as safety and environment, the UK NSP responses provided insight into the methods of considering the less well-considered benefit streams.

Following the occurrence of an asset fault or failure event and determination of how much peak consequential exposure exists (i.e. maximum lost demand, customers interrupted), UK NSP approach is to give consideration to the overall fault restoration strategy. This could include consideration of worst case asset repair or replacement times, including whether suitable spares, parts and resources exist and at the correct location in order to effect the repair. Depending on the type of failure or fault incident occurring, e.g. a potential catastrophic failure or fire, then aspects such as availability of staff access may also be an issue that requires consideration, including whether buildings and sites could be safe to enter.

As with the failure rate multipliers used to represent excessive aged or deteriorated assets, consideration of many of the aspects detailed above could be fairly subjective, particularly if none of the incidents or outcomes being considered have happened previously or for some time. However, the consequential rating applied to the risk analysis calculation will also follow logarithmic principals, hence the overall impact of minor differences in assumed multipliers is generally low.

3. Assessment overview and principal observations

The following section provides an overview of GHD's review process and the principal observations made during our review of the components of Ausgrid's cost benefit methodology.

To the extent of GHD's review, which is subject to the assumptions contained throughout this report and specifically in section 1.5; most notably that the calculations and internal workings of the tools have not been verified by GHD, our overall finding has been that the Cost Benefit Methodology and associated tools and accompanying documentation developed by Ausgrid appear to have been well developed in comparison with industry peers.

The principal observations and comments outlined below reflect deficiencies detected in Ausgrid's developed processes and tools. We have suggested opportunities to improve the three models and associated documents to address the identified deficiencies. The majority of improvements require changes to documentation or additional calculations with the existing models to assess sensitivities. The existing models are considered an adequate first implementation of tools for implementing the Cost Benefit Methodology and are consistent with good industry practice.

Further opportunities for improvement are provided in section 4 of this report. Those improvement opportunities have a lower priority and those identified in section 3.

3.1 11kV SB Model

3.1.1 Overview of process

GHD's review the 11 kV SB model and associated documents included a review of a MS Access database tool (Substation VER 86), the accompanying 11 kV Switchgear Cost Replacement Document (11 kV SG Overview – Ver 01) and the overall Cost Benefit Methodology Document (D17 308976 Revision 5 Cost Benefit Methodology). Our approach for the review of the 11kV Database Tool was to:

- Understand how the MS Access model functions, and compare this with the methodology and descriptions included in the 11 kV switchgear overview document as well as the Cost Benefit Methodology document[3].
- Cross compare assumptions stated in the Methodology Document with the model,
- Review the calculations being performed, as far as possible given the visibility within the model, to understand how this compares with industry practice.
- Identify any potential improvements, either within the actual model or accompanying documentation, to help improve accuracy, auditability and usefulness of the results / outcomes.

As highlighted above, GHD has not been able to verify the detailed calculations or workings of the model.

[3] Ausgrid document titled Network Investment Planning Cost-Benefit Analysis for Planning – March 2017

3.1.2 Principal observations & comments

1. **The VCR costs in the MS Access model do not align with the stated VCR costs presented in Table 3.5 (reproduced below as Table 1) of the Cost Benefit Methodology document.**

Table 1 VCR Values Stated in Cost Methodology Document

Type	NEM ($/kWh)	New South Wales ($/kWh)
Residential	25.95	26.53
VCR excluding direct connects	39.00	38.35
VCR including direct connects	33.46	34.15

Within the MS Access model two VCR values are quoted, one based on Ausgrid values which vary based on each substation and a second based on an AEMO VCR value ($40.04 / kWh). This has been calculated based on the stated NEM $39.00 / kWh value shown in Table 1 (excluding direct connects) after applying CPI inflation.

Note that the application of the CPI inflation factor to the VCR value is inconsistent with the approach adopted in relation to project costs, which are stated as being in “constant dollars” with “no time variation in value”. It is recommended that a consistent basis is used for all costs and benefit within the calculations.

GHD is aware that VCR numbers used for network investment planning in NSW have sometimes exceeded those published by AEMO. We note that the Project Assessment Draft Report recently published by TransGrid for the powering Sydney’s Future project refers in Table E.2 to VCR values of between $90 / kWh to $170 / kWh and the 11 kV Switchgear Overview document also identifies a set of Ausgrid VCR values and values described as preferred by the AER. It is recommended that references to VCR value be made consistent across all documents with the Cost Benefit Methodology document amended to reflect Ausgrid standard VCR numbers and note any reasons for differences with the AEMO numbers and the AER preferred numbers.

2. **It is unclear what Confidence Interval (CI) applies to historical failure data and Weibull values, how data is normalised and whether is it representative for majority of Ausgrid plant.**

A confidence interval is stated in the underground cable model in Section 3.4.2 of the Cost Benefit Methodology document as being 95%. Although no similar value is stated in relation to the 11 kV switchgear model Ausgrid have since confirmed that the same confidence interval applies to the switchgear model.

Additionally, with any dataset it is often necessary to perform some filtering and remove data elements that may not be representative or are particularly unusual in order to produce a revised dataset that yields the clearest representation possible of the overall asset population being modelled. No commentary is made as to whether this has or has not been performed which would be useful to state for the avoidance of doubt.

It is recommended that information is included in the Cost Benefit Methodology or the 11 kV Switchgear Overview to explain how the Weibull parameters for the three different categories of asset condition have been derived. This explanation would help the reader understand the appropriate confidence interval for the failure model. Understanding the confidence interval for failure rates and repair times would help understand the importance of sensitivity studies to test the impact of varying failure rates and repair times on the calculated USE and the optimal investment timing.

3. **Sensitivity analysis does not consider variations on failure rates or repair times, both considered likely major impacts.**

   Plant failure rates and repair times are some of the principal data parameters that underpin the calculations. It would be expected to see some consideration of variabilities in these rates and how this may affect the model results. It is possible that some considered variations / sensitivities will be effectively second order impacts – if this is the case then it may be useful to indicate in Section 6.1 of the Cost Benefit Methodology document which factors have been considered or given standalone assessment and excluded as not having the highest impact.

4. **Cited Dielectric Dissipation Factor, Partial Discharge & Insulation Resistance tests in Section 3.4.1 of the Cost Benefit Methodology document for plant condition are not necessarily conclusive for all circuit breaker types. It is unclear how is data normalised and what confidence intervals apply.**

   As per point 2 above, not all underlying data can be used or is fully applicable to all plant models and types. Again, it would be expected to see some commentary in relation to this although this may be included in the Strategic Asset Prioritisation document (version 2.1 April 2013) which is currently referenced in the Cost Benefit Methodology document.

5. **It is unclear how “condition” rating affects overall circuit breaker and busbar failure rate – not detailed in Cost Benefit Methodology document.**

   The above comment was included in an earlier set of observations provided to Ausgrid and relates to the Methodology Document. However, the 11 kV Switchgear Overview document does provide an outline of condition ratings and resulting failure rates (for minor failures) and Weibull shape parameters for major failures for different categories of asset condition. Ausgrid have subsequently confirmed that the inclusion of this information in the Methodology Document was considered, but the decision was taken not include this level of detail in the overview document.

6. **Model outputs need comparison with previous approach to calibrate outputs and understand increased / decreased replacement volumes.**

   A fundamental consideration when adopting any new model or tool, particularly where the model / tool lacks fully transparency, is to understand how the modelling output results compare with previous techniques or assessments. In the case of 11 kV switchgear it would seem reasonable to understand if a comparison of the modelling tool outputs, in terms of potential number of unit failures and lost energy matches with historic experience as a closed loop check to confirm suitability.

3.2 Substation Capacity Model

3.2.1 Overview of process

The approach adopted for the substation capacity model review was largely the same as the 11 kV SB model, that is both the MS Excel model (Substation Capacity Constraint Assessment v 4.5) and accompanying support document (Capacity constraint Ver 01) were reviewed.

Note that for the substation capacity review the previously discussed Cost Benefit Methodology document was not considered as it does not cover substation capacity at the time of GHD’s review.

As with 11 kV switchgear our approach for the substation capacity review has been to:

- Understand how the MS Excel model functions, and compare this with the methodology and descriptions included in the accompanying support document.
- Review the calculations being performed, as far as possible given the visibility within the model, to understand how this compares with industry practice.
- Identify any potential improvements, either within the actual model or accompanying documentation, to help improve auditability and usefulness of the results / outcomes.

As highlighted above, GHD has not been able to verify the detailed calculations or workings of the model.

3.2.2 Principal observations & comments

1. **It is unclear how factors such as transformer age or condition data e.g. Dissolved Gas Analysis, partial discharge, acoustic measurements, etc are used to augment base failure rates.**

   Whilst none of the above aspects are explicitly detailed in the substation capacity model, these factors are typically considered within transformer asset management / maintenance / condition assessment activities across the industry. Ausgrid have confirmed that these aspects have been considered in deriving the Weibull shape parameters.

2. **Maintenance costs are detailed in the supporting model document (Section 7) and also included in the Excel model, however it is unclear how they are used.**

   Based on the above it is suggested that a comment or footnote in the accompanying support document is added to clarify how maintenance costs are used.

3. **It is currently unclear where transformer repair costs are entered into the model or whether a standard value is used.**

   Ausgrid have confirmed that transformer repair costs have been excluded from the model on the basis that they run transformers to failure and are looking at solution options involving additional capacity and load transfers.

   Based on the above it is suggested that commentary is included in the accompanying support document to explain the above calculation process further. A worked example may also be useful to include.

4. **There is little explanation contained within the Capacity Constraint documentation about the process of determining how the actual load transfer values were calculated.**

   Through consultation with Ausgrid, it is understood that the model assumes a consistent load transfer and is re-assessed (annually for summer) based on actual topology. The annual process involves feedback from Ausgrid network operations specialists to validate that there is a high degree of confidence that the proposed transfer levels can be achieved in practice. The load transfer is assumed to stay constant across time and does not vary with demand growth. This assumption is considered acceptable for the vast majority of substations given the difficulty in accurately forecasting future load transfer capabilities. However, for substations where investment is already committed (or near certain) to facilitate a capacity upgrade that will impact on transfer capabilities it is recommended that transfers are determined on the basis that the project will proceed.

Additionally, it is recommended that the treatment of load transfers in the Cost Benefit Methodology document be enhanced to explain the annual process used to determine the available level of load shedding.

3.3 Feeder Model

3.3.1 Overview of process

PSS/E software is used by many other utilities in Australia and around the world for power system analysis and has a number of modules to perform different types of analysis. One of the PSS/E modules is contingency analysis which can be coupled with outage statistics for network elements to calculate unserved energy (USE) for a given system condition. Many utilities, including Ausgrid, use this feature of PSS/E calculate USE.

Ausgrid has developed a comprehensive python script to automate the calculation process using the PSS/E feature of contingency analysis to automate calculation of Unserved Energy (USE). The calculation considers all feeder contingencies in a contingency list, both N-1 and N-2 for each system condition setup for the planning period. To support the use of the PSS/E Application, Ausgrid has also prepared a User Manual (PSS/E Model Operation Ver 02) on how to prepare data and run studies.

GHD's approach for the review of the PSS/E Application has been to:

- Understand how the PSS/E Application functions and compare with the user manual.
- Assess a sample of the outputs for reasonability.
- Identify any potential improvements, either within the actual application or accompanying documentation, to help improve auditability and usefulness of the results / outcomes.

Note that review of the PSS/E Application itself was limited to a demonstration performed by Ausgrid. While this has allowed us to gain an understanding of the inputs, outputs and operation of the Application, we have not completed a detailed review of the model script or calculations, or interrogated the model to any further level of detail beyond the demonstration and a high level review of a sample of outputs.

3.3.2 Principal observations & comments

1. **Our review did not identify any issues with the application that are likely to result in material errors in the calculated reliability outcomes**

   Through the demonstration and a high level review of a sample of the model outputs we did not identify any deficiencies in the model that would result in a material error in the reliability outcomes calculated by the model.

2. **There is no guidance provided in the User Manual on how to interpret the results in the output spreadsheet.**

   Without guidance on how to analyse results, there is a greater reliance on the experience and capability of the user to know how to interpret the results.

   It is recommended that a process map be included as an appendix to the User Manual, which shows inputs, outputs, process steps and dependencies.

3. **There is no flow chart or process map that identifies the steps and relationships between processes.**

   The absence of an illustration of the work flow steps applied in the overall calculation can create confusion or conceal deficiencies and dependencies in the process.

4. **The confidence interval for key inputs should be declared and sensitivity studies used to assess the impact of varying inputs.**

   The confidence interval for key inputs such as failure rate and repair time should be declared and sensitivity studies used to assess the impact of varying inputs such as repair time consistent with the confidence interval.

5. **There is a lack of definition for key terms in the User Manual, such as "Connectivity Scenario".**

   All key terms in the user manual should be defined. For example, there is no definition for "Connectivity Scenario" which can cause confusion around the intent of the reference.

6. **Additional guidance is recommended regarding when to model load diversity.**

   It is understood that the model script assumes entered load curves are coincident for different substations unless the user configures the tool by adjusting the script to model diversity. In the majority of applications the feeder model will be considering feeders supplying substations in adjacent geographic areas of the Ausgrid network. Assuming no diversity between the loads is likely to be a reasonable assumption in the majority of applications of the feeder model on the Ausgrid network.

   While there is functionality within the script to model diversity by increasing number of load levels (and therefore cases solved), the value of activating this additional level of complexity needs to be weighed against the additional time required to prepare inputs and perform the computation, particularly in cases where there is little diversity. It is recommended that the User Manual include advice regarding how to implement the modelling of load diversity and the scenarios when it would be necessary to activate that level of detail.

3.4 Cost Benefit Methodology

3.4.1 Overview of process

GHD has reviewed the Cost Benefit Methodology Document. Our approach for the review has been to:

- Review and understand the formulae used, and compare the Cost Benefit Methodology with the methodology and approaches typically used by network companies and in other industries.
- Understand the nature of uncertainty in the data used for the Ausgrid cost benefit analysis.
- Identify any potential improvements, either within the actual formulae or accompanying documentation, to help improve the usefulness of the results / outcomes. Includes thinking around the use of confidence levels, and societal risk aversion.

GHD has reviewed the Methodology against, and made principal observations pertaining to, the areas of reliability, safety, financial and environment, and sensitivity.

3.4.2 Principal observations & comments

Reliability

1. **The methodology has limited explanation of the confidence intervals for the calculated outcomes.**

Mean Time To Repair (MTTR) is expressed as an average number, however this may lose the information inherent in the underlying repair data. If the confidence intervals for the MTTR were provided it would be helpful in suggesting a range for sensitivity analysis to understand influence of uncertainty in repair times on the calculated level of USE.

Safety

1. Adopt an approach for value of safety risk that is more aligned with those used in high hazard industries

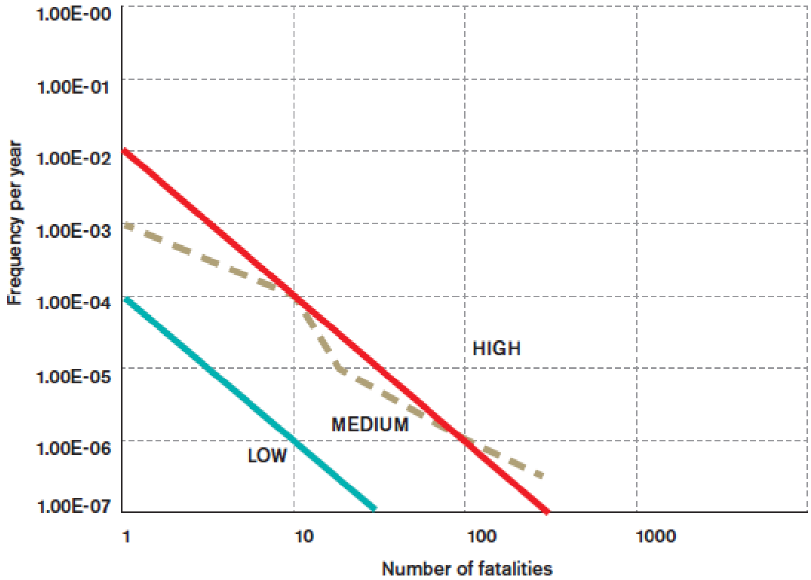
Section 4.3.1 of the Cost Benefit Methodology document relates to the value of safety risk.

FN (societal risk calculation as per The NSW Government's Hazardous Industry Planning Advisory Paper No 4 (HIPAP 4)[4], or Victorian Interim Risk criteria) type calculations consider relationship between frequency and cumulative severity of safety events. The FN principle is logarithmic, i.e. killing 10 people is 100 times worse than killing one person, and is used in the calculations criteria for the tolerability of risks for hazards that give rise to societal concerns in NSW and in Victoria. The FN approach involves developing curves which plot the Frequency at which events might kill N or more people against N. The technique provides a means of comparing the impact of profiles of man-made accidents with the profiles for natural disasters with which society has to live.

With the design of most electrical network assets and the use of barriers to limit public proximity tends to limit the opportunity for a failure to risk a significant number of fatalities, this may not always be the case. Consider a substation situated adjacent to a major pedestrian thorough fare which relied primarily on a wire mesh boundary fence. The fence may not be sufficient to prevent injuries and fatalities if there was an explosive equipment failure. A failure in an indoor substation in the basement of a building could risk fatalities if it triggered a fire that escaped the substation. With the anticipated encroachment of urban density in future years, it is expected that buffer zones around electrical assets will be likely challenged, and exposure of public to electrical assets may therefore likely increase.

While the approach to valuing safety risk is likely to be acceptable in the majority of situations for Ausgrid, this may not always be the case. In situations where there is a risk of multiple fatalities the linear approach to valuing the safety risk described in the cost benefit methodology may not reflect societal expectations. The following graph for measuring societal risk demonstrates the logarithmic approach for modelling.

[4] http://www.planning.nsw.gov.au/Policy-and-Legislation/~/media/0D39F08E7889409BBA1FA88D5FB859FD.ashx



LOW: Risk acceptable and tolerable. Must be managed.
MEDIUM: Risk tolerable, not necessarily acceptable. Must be reduced SFARP.
HIGH: Risk unacceptable and intolerable. Must be reduced immediately.

Figure 2 Interim risk criteria[5]

In recognition of the use of logarithmic FN curve thinking adopted by industry representatives for safety[6] and within industries outside Power, Ausgrid's approach may be considered deficient in situations where there is a risk of multiple fatalities. In those situations Ausgrid may wish to consider using and FN approach.

The Cost Benefit Methodology document indicates that at present there is no uncertainty modelling (confidence intervals) of fatality values for forward projection in Ausgrid's methodology. In hazardous industries lower/likely and upper values would typically be used for risk and population values to generate overall profile.

Financial & environmental

1. **It is unclear from the Cost Benefit Methodology (Section 4.3.2) how confidence intervals are considered.**

   There may be scope to improve the methodology by better articulating the confidence intervals for the calculated outcomes. This may need better articulation of the confidence interval for key input data (failure parameters and repair parameters).

2. **The costs in Section 4.3.3 do not include probabilities.**

   Where a hazard has the potential for a wide spread and severe environmental impact the non-linear relationship between the scale of the impact and societal acceptability should be considered. The design of the assets in the Ausgrid network may be such that hazards seldom have the potential for wide spread and sever impacts. Ausgrid may wish to enhance the environmental risk valuation approach in situations where there is the potential for severe and wide spread environmental impacts. In this situation probabilities should be estimated for lower/upper and most likely values for EC and β

[5] WorkSafe Victoria: https://www.worksafe.vic.gov.au/__data/assets/pdf_file/0019/211267/ISBN-Requirements-for-demonstration-major-hazard-facilities-2011-04.pdf
[6] Adopted by WorkSafe Victoria, Worksafe NSW, Department of Planning NSW, Department of Planning Victoria.

and should have non-linear relationship (as exists for safety, see above). Model should therefore have logarithmic/exponential equation.

Environmental Cost = F x EC x β

F = failure rate of equipment

EC = environmental criticality (this may have a distribution of uncertainty of location, and of extent, i.e. how wide or how deep, or how concentrated for environmental effect. This may not be linear as most biological curves exhibit non-linear behaviours for effects and therefore criticality).

Sensitivity

1. **Sensitivity analysis (section 6.1 of Methodology) has limited modelling of uncertainties.**

   Overall, the concept for sensitivity analysis as articulated in section 6.1 of the Cost Benefit Methodology lacks certainty and would benefit from the use of a model (i.e. Monte Carlo) to work out confidence levels.

2. **Optimisation (section 6.2 of Methodology) has limited modelling of uncertainties.**

   Similar to sensitivity analysis, certainty of the assessment, this may too have uncertainties that should be modelled with confidence levels to give a complete probabilistic picture.

3. **Cost effective analysis (section 8.1 of Methodology) should be modelled logarithmically.**

   Where hazards are assessed as risking significant fatalities or severe and wide-spread environmental impacts, the cost effective analysis approach, as described under section 8.1 of the Cost Benefit Methodology document, should be modelled logarithmically, similar to the FN concept, to consider the exponential relationship of impact for higher amount of customers (i.e. failure of critical infrastructure). I.e. criticality should have a logarithmic values to it.

4. Opportunities for improvement

4.1 11kV SB Model

1. Include a breakdown of proposed project costs within the model.

The model does not appear to provide a breakdown of proposed project costs, only the total value. This may be visible as a part of other documents produced in the investment planning regime. If that is not the case it may be beneficial to provide that information within the output reports developed by the three probabilistic planning model.

2. Extend sensitivity study by increasing the number of load profiles.

Only four load curves are available for use within the model, although comment is included in the Cost Benefit Methodology document (Section 3.1) that more detailed information is sometimes used, typically for feeder analysis.

The addition of different load profiles could potentially be included as a further sensitivity study.

4.2 Substation Capacity Model

1. Flag in the model where there is an issue of a spare transformer requirement.

The documentation supporting the substation capacity tool highlights that the replacement of transformers is expected to take between 4 to 6 weeks, depending on type. This effectively assumes that a spare transformer unit is available within stores or another location.

This may not be true for all transformer types, hence it would be useful for the model to flag where this issue / risk is known even if no further action is undertaken within the model directly.

2. Relabel “State Generation” limit to better encapsulate intent.

The model includes a “State Generation” limit which is used with reference to N, N-1, N-2. It is suggested that this is relabelled to a more meaningful reference in the context of substation capacity assessments such as “Network Security Standard”.

4.3 Feeder model

No further opportunities for improvement were identified beyond those listed in section 3.

4.4 Cost Benefit Methodology

4.4.1 General

1. Consider further elements within the sensitivity analysis to accompany the four aspects currently included e.g. VCR, discount rate, project cost, load forecast.

The outline of observations and comments in Section 3 has identified a number of potential further sensitivity elements for consideration within the calculation. Consideration should be given to including some of these in the calculation tools particularly where they are considered to have the potential to materially impact the cost benefit assessment. It would be useful to perform and document the range of sensitivities to demonstrate which ones are material and any that are not material and can therefore be ignored. The results could either be recorded in a separate document or included as an appendix in Cost Benefit Methodology document.

2. Clarify time value of costs and benefits across time

The model does not currently include any escalation of stated project costs which are assumed to be in present values. As a minimum the Cost Benefit Methodology should clearly state that all costs and prices used to calculate benefits (ie VCR) are in real dollars and are assumed to remain constant in real dollar terms.

3. Editorial review of documentation.

A number of suggested documentation revisions have been highlighted already in Section 3 those suggestions are consolidated in Appendix A. In addition GHD recommends a complete editorial review of the Cost Benefit Methodology documents that are intended to be review

4. Consider expansion of the model to include 10% POE and 90% POE load forecasts.

The current model uses 50% POE only which, while appropriate for initial implementation, may be worth expanding over time to include data from 10% POE and 90% POE load forecasts with the forecast probability used in developing expected outcomes.

Appendices

Appendix A – Suggested refinements to documentation

Document	Section reference	Suggested opportunity for refinement
Cost Benefit Methodology (D17 308976 (Revision 5) Cost Benefit Methodology)	Section 3.5.1	VCR Table 3.5 should be updated to align with information used in the models and the surrounding text amended to explain the basis for different VCR numbers proposed by Ausgrid, AER and AEMO.
	Section 3.4.1	Reference to statistical data Confidence Interval (CI) should be included in similar manner to underground cables (Section 3.4.2).
	Section 6.1	Further commentary of why selected four variables were included in the sensitivity analysis and why other aspects have been excluded i.e. were other variables assessed for some test substations and found to be second order impacts.
	Section 3.4.1	No detail is included of how plant condition affects Weibull parameter / shape. Suggest including commentary or cross reference to 11 kV Switchgear Overview document
	Section 3.4.1	For switchgear only major (catastrophic) failures are considered. Comment can be included after Table 3.1 that Minor failures, currently classified as negligible, are not explicitly considered in the calculation.
	Section 4.3.2	There may be scope to improve the methodology by better articulating the confidence intervals for the calculated outcomes. This may need better articulation of the confidence interval for key input data (failure parameters and repair parameters).
Substation Capacity Constraint (Capacity constraint- Ver 01)	Input Data, Point 7	Maintenance costs are mentioned however it is unclear how this is being used within the overall calculation.
	Input Data, Point 3	Switching times for load transfers, substations, transformers – it is not clear how all of these inter-relate and a worked example would be useful to include.
	Output	An example and / or commentary to explain and demonstrate how the project deferral calculation is performed would be useful to supplement the current text.
	Input Data, Point 3	Explain how actual load transfer values were calculated.

User Manual (PSSE Model Operation Ver 02)	Propose new section, following Run the Study	Provide guidance on how to interpret the results in the output spreadsheet.
	Run the Study	Define “Connectivity Scenario”.
	Description of GUI, Point 2	Discuss increased computation time for running additional load levels vs. limited value (due to minimal diversity).

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