Review of potential security, reliability, and resilience concerns arising from future scenarios for the electricity industry

Report for the Electricity Authority

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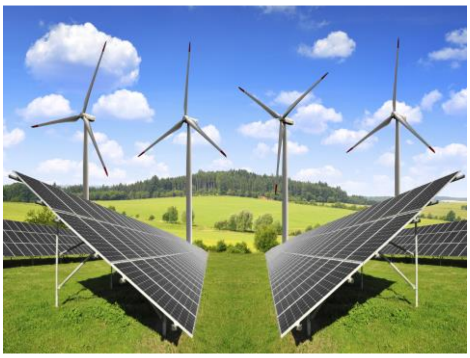

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Glossary

Abbreviation	Stands for
ACOPF	AC optimal power flow
AUFLS	Automatic under-frequency loading shedding
BEC	BusinessNZ Energy Council
BOP	Bay of Plenty
CCC	Climate Change Commission
CNI	Central North Island
DCOPF	DC optimal power flow
DER	Distributed energy resources
DG	Distributed generation
EDGS	Electricity demand and generation scenarios
EPR	Electricity Price Review
ESRs	Electricity Safety Regulations
EV	Electric vehicle
FIR	Fast Instantaneous Reserve
GIP	Grid injection point
GT	Gas turbines
GXP	Grid exit point
HLY	Huntly Power Station
HVDC	High-voltage direct current
ICCC	Interim Climate Change Committee
ICP	Installation control point
IR	Instantaneous Reserve
LSI	Lower South Island
OFA	Over Frequency Arming
PV	Photovoltaic
TPR2020	Transpower Planning Report 2020
UNI	Upper North Island
USI	Upper South Island
WCM	Winter Capacity Margin
WEM	Winter Energy Margin

Executive summary

In recent years a number of organisations have modelled scenarios of the New Zealand energy sector. Each exercise has had different purposes in mind, but they share the desire to understand the implications of policies targeting our emissions profiles and the consequence of major decisions in the sector, such as moving to 100 per cent renewable electricity, or the closure of industrial plants, such as Rio Tinto's aluminium smelter in Southland or Methanex's methanol production plant in Taranaki.

The Electricity Authority is now undertaking a review of the potential impacts of technological advances and future changes on the long-term reliability, security, and resilience of New Zealand's electricity system. One of the initial steps in this review is to assess whether existing recent modelling asks and answers questions specific to this review or whether additional modelling is required. The assessment would include specifying modelling still required to address the issues in the review.

In the context of the above, the Authority is seeking a report that summarises the scenarios and analysis of the future electricity industry from the perspective of security, reliability, and resilience. The report should derive what it can from existing work and highlight areas where more modelling might be required.

The key question the Authority is asking in relation to future scenarios, at the system level, is:

> Given the ongoing changes to the external environment, are fundamental changes to the mechanics of the wholesale market required to maintain reliability, security and resilience?

We used a staged approach where we first reviewed current documents relating to security, reliability, and resilience. Issues, and the conditions that lead to those issues, were categorised and tabulated.

In the second stage we reviewed a number of forecast documents, such as Whakamana i Te Mauri Hiko, BusinessNZ Energy Council (BEC) pathways, electricity demand and generation scenarios (EDGS) and the ICCC work to discern discrete scenarios for which we could assess the conditions that lead to issues. The Climate Change Commission (CCC) draft advice also became available for assessment as well. The scenarios, conditions and issues were further categorised by geographic region and the results tabulated in two heatmaps.

In the third stage the heatmaps were used to rank the issues and key insights were summarised. In addition, detailed assessments of each issue were completed.

The fourth stage was originally unanticipated but arose because none of the scenarios explored were particularly informative about distribution. To augment the distribution assessment, we reviewed two further papers on the penetration limits of solar Photo Voltaic cells (PV), and the effect of Electric Vehicles (EV) charging on harmonics, in the low-voltage network.

We conclude there are a significant number of issues that could arise as New Zealand pursues the decarbonisation of the economy underpinned by renewable electricity generation. However, when it comes to understanding the implications for security, reliability, and resilience in the New Zealand

Electric Power System, increasingly detail will matter. Where, when, and what loads and generation are deployed controls a large number of permutations for reliability concerns and the associated solutions.

The industry is increasingly dynamic. Over the relatively short period the scenarios we have considered were developed much has already changed. Tiwai exit has gone from an uncertainty to an announced date, for example, and Government policy has changed to 100 per cent renewable electricity by 2030.[1] Very little scenario work has been done to understand the stresses and strains on the system under a 100 per cent renewable electricity system on top of the anticipated electrification of transport and industrial heat in particular. Government has also initiated its NZ Battery project and has conducted scenario work on the merits of an additional intervention to add to the mix.[2] None of the scenarios consider the combination above as an explicit, consistent scenario.

As a matter of modelling convenience none of the scenarios seemed to consider Demand Response (DR) as a dynamic resource for managing resource adequacy. Where DR was modelled it was presented in a change in demand forecasts and the relative growth of peak demand to average.

The Authority may want to consider curating a dynamic scenario, or set of scenarios, against which it can baseline its work. As described above, such a scenario(s) would need to encompass some detail about where, when, and what to be able to inform security, reliability, and resilience.

Techniques have been advanced by which reliable approximations can be made about the distribution network. Currently the distribution network, and particularly the low-voltage network, is substantially opaque. Using new techniques, the Authority may be able to extend some detail around its scenarios to a representation of the distribution network.

A baseline scenario(s) would be helpful for the Authority to identify and define the most pressing reliability concerns but also would be helpful for the broader industry as well. It may also help to focus the industry on the key concerns, and possibly on the key opportunities. Early planning and incentives for new technology, such as Distributed Energy Resources (DER), may be valuable even where high levels of penetration are only likely in the medium term.

Generally, the key concerns for security and reliability occur because of the potential speed of demand growth and whether generation, transmission, and distribution can respond appropriately, quickly enough. Uncertainty does not help this, and any certainty the Authority can bring to the global supply and demand balance in the future would help the industry adapt. It may be worth keeping a close measure on demand to try to pick any underlying changes in the rates of growth of EVs, DER more generally, underlying demand, and the electrification of transport and process heat.

[1] The Tiwai Point smelter exit was announced for the end of 2021. Since then, arrangements with the industry have led New Zealand Aluminium Smelters (NZAS) to change its exit date to December 2024. Even this date, however, is not completely certain.

[2] NZ Battery is considering whether intervention is required to ensure security of supply under the 100% renewable policy. MBIE is running the project and commissioned two independent pieces of analysis: The scale of intervention required and how an intervention would interact with the current market arrangement. We carried out the work on the second question in a consortium with Energy Link and Chapman Tripp.

The Authority needs to be alert to resilience. The power system's ability to withstand shocks from outages or events could be eroded well before capacity limits and congestion become obvious. The removal of large thermal plant with the associated inertia, voltage support, and reserve capacity can create a significant change in the resilience of the North Island power system, as can the concentration and location of new technology and investment.

1. Introduction

In recent years a number of organisations have modelled scenarios of the New Zealand energy sector. Each exercise has had different purposes in mind, but they share the desire to understand the implications of policies targeting our emissions profiles and the consequence of major decisions in the sector, such as moving to 100 per cent renewable electricity, or the closure of industrial plants, such as Rio Tinto's aluminium smelter in Southland or Methanex's methanol production plant in Taranaki.

The Electricity Authority is now undertaking a review of the potential impacts of technological advances and future changes on the long-term reliability, security, and resilience of New Zealand's electricity system. One of the initial steps in this review is to assess whether existing recent modelling asks and answers questions specific to this review or whether additional modelling is required. The assessment would include specifying modelling still required to address the issues in the review.

1.1 Electricity Price Review

The Electricity Price Review recommendation G2 is behind the Authority's brief for this work. The G2 recommendation was to examine the security and resilience of the electricity supply. The verbatim recommendation is:

> **The Electricity Authority should commission the Security and Reliability Council to examine the potential impact of technological advances and other changes on the long-term security and resilience of the country's electricity supply.**
>
> **The Council should interpret resilience and reliability broadly, taking into account developments throughout the electricity supply chain. It should draw on relevant reports written here and overseas to avoid duplication of effort, and should take special note of policy settings relevant to the sector that arise from the Government's response to the Interim Climate Change Committee report.**
>
> **The Council should complete its work within 12 months, having been given sufficient resources, including access to specialist advice and analysis, to carry out the task. The Authority should report back to the Minister on actions it is taking in response to the review and any recommendations for the Government and other agencies.**
>
> **The review's considerations should include:**
>
> - **the Council's own charter, terms of reference and work programme**
> - **the potential impact of large increases in intermittent generation, particularly wind and solar panels, large increases in electric vehicle charging**

and industrial heat, and possible proliferation of battery installations throughout distribution networks

- **the risk monitoring policies and procedures of Transpower (as system operator responsible for managing the power system and operating the wholesale electricity market)**
- **the Electricity Authority's market development work programme and market performance monitoring functions**
- **other relevant matters, including matters overseen by agencies such as the Ministry of Business, Innovation and Employment, the Commerce Commission and the Gas Industry Company.**

We consider a review necessary because it is highly likely developments such as "digital disruption", increasing electrification of transport and process heat, and the emergence of alternative fuel sources will eventually have a profound impact on the security and resilience of the electricity supply. Less certain is how these developments will make themselves felt. Knowing this will enable the Government to take steps to ensure the continued security, reliability and resilience of the electricity system. The Council's members have the necessary experience and expertise to undertake such a review.

A range of submitters supported such a review. Some emphasised the importance of ensuring the Council had enough resources to carry out the review. Others urged an evaluation of the review's terms of reference to ensure its role was clear. The Electricity Authority said the review should not duplicate the work of other reviews in recent years. Contact said it should not overlap with the monitoring function the Council, the Electricity Authority and Transpower are required to perform in this area. Several submitters highlighted the relevance of work by the Interim Climate Change Committee and the possible impact of future Government policy decisions on climate targets.

Nova and Orion said Treasury or the Ministry of Business, Innovation and Employment were better choices to conduct the review, which should encompass other infrastructure, such as the gas supply. We think the Council can consider these wider questions through its engagement with other agencies.

1.2 Our brief

In the context of the above, the Authority is seeking a report that summarises the scenarios and analysis of the future electricity industry from the perspective of security, reliability, and resilience. The report should derive what it can from existing work and highlight areas where more modelling might be required.

The Authority's brief was:

1. A reliable, secure and resilient electricity supply is critical to the lives and prosperity of New Zealanders and New Zealand businesses. It is important to ensure that New Zealand has the right settings in place to ensure a reliable electricity supply to meet consumer needs.
2. Given the importance of electricity to New Zealand, the Electricity Authority is undertaking a review of the potential impacts of technological advances and future changes on the long-term reliability, security and resilience of New Zealand's electricity system.
3. This review will also identify the options for how New Zealand can best maximise the opportunities and minimise the risk of these future changes.
4. The kind of future changes to reliability, security and resilience that this review will likely cover include digital disruption, the increasing electrification of transport and process heat, and the emergence of alternative fuel sources.
5. This review is in part a response to a recommendation of the Electricity Price Review (EPR) completed in 2019 and builds also on the Authority's long history of supporting a reliable electricity supply.
6. For the purposes of this review, the term electricity system refers to the process through which electricity is created, moved, and used across New Zealand.
7. Reliability is an umbrella term which describes this system consistently working to generate and transmit electricity to meet consumer needs.
8. Security and resilience both have specific meanings within the concept of reliability.
9. Security refers to the ability of physical assets, market settings and the regulatory environment to produce and deliver enough electricity to meet the country's needs, including during periods of high demand and during and after an adverse event (e.g. an electricity outage).
10. Resilience refers to the ability of the electricity system to adapt to changing risks, and to recover from an external shock (e.g. a natural disaster or a cyber-attack).
11. The Authority wishes to draw on existing research and analysis in order to inform its own analysis.
12. It is particularly keen to draw on the range of future scenario modelling and analysis that has been undertaken or commissioned in recent years to support energy and climate change policy analysis.
13. This kind of analysis includes MBIE's electricity demand and generation scenarios (EDGS), Transpower's Whakamana i Te Mauri Hiko scenarios, the Business Energy Council's Kayak and Waka scenario, modelling undertaken in support of the Productivity Commission's inquiry into a low-emissions economy, and the Interim Climate Change Committee's report into accelerated electrification. We note that the Climate Change Commission is also in the process of undertaking similar analysis.[3]

[3] The CCC's draft advice was released in February and has been considered in this report. The final advice has also be released but not in time to be considered in our analysis.

The key question the Authority is asking in relation to future scenarios, at the system level, is:

> Given the ongoing changes to the external environment, are fundamental changes to the mechanics of the electricity market required to maintain reliability, security and resilience?

2. Approach

2.1 Stage 1

Stage 1 of the process begins with reviewing current security documents to establish the conditions that could create security issues.

For this we reviewed:

- Transmission Planning Report (Transpower, 2020a)
- System Security Forecast (Transpower, 2020b)
- Security of Supply Assessment (Security and Reliability Council, 2020)
- Distributed Battery Energy Storage Systems in New Zealand (Transpower, 2019)
- Distributed Energy Resources: Understanding the potential – main paper (Reeve, Comendant, & Stevenson, 2020).

2.2 Stage 2

The next stage of the process was to read through the identified forecast documents looking out for statements about reliability, security, and resilience, while also looking out for the conditions identified in the stage 1 process.

The forecast documents reviewed were:

- Te Mauri Hiko (Transpower, 2018)
- Whakamana i Te Mauri Hiko (Transpower, 2020c)
- Electricity Demand and Generation Scenarios (EDGS) (MBIE, 2019)
- New Zealand Energy Scenarios: Navigating energy futures to 2050 (BEC, 2015)
- New Zealand Energy Scenarios: Navigating our flight path to 2060 (BEC, 2019)
- Low emissions economy: Final Report (ProdCom, 2018)
- Transitioning to zero net emissions by 2050: Moving to a very low-emissions electricity system in New Zealand (Stevenson et al, 2018)
- Distributed Energy Resources: Understanding the potential – main report (Reeve, Comendant, & Stevenson, 2020)
- Accelerated Electrification: Evidence, Analysis and Recommendations (ICC, 2019) (including Consultant reports)
- Draft advice for consultation to the New Zealand Government on its first three emissions budgets (CCC, 2021).

For each of the stage 2 documents, the conditions which can be inferred from the document were categorised as **Yes**, **Possibly**, **Maybe**, or **No** as per the descriptions below.

Yes – applies where the document states that an issue will occur, or where a condition is clearly met in the forecast and in every scenario.

Possibly – applies where the document states that an issue is possible, or where a condition is met in at least one forecast scenario.

Maybe – applies where the document states that an issue is plausible, or where a condition could be met in at least one forecast scenario.

No – applies where the document states that an issue cannot occur, or where no forecast scenario could lead to a condition being met.

It was envisaged that there would be a lot of **maybe**s, and **maybe**s were applied anywhere conditions or issues are uncertain. Identifying where there is a lack of certainty around future reliability, security, and reliability issues is the objective of the project.

An assessment was also made of the potential year that an issue might manifest for each scenario. Two heatmaps were then generated that identify the possible issues and the urgency with which the issue might need to be addressed in that scenario, and another heatmap was generated for the probable issues and their urgency.

2.3 Stage 3

For the third stage, the heatmap results were ranked for the level of probability by scenario and the level of urgency in terms of likelihood to occur earlier rather than later. The issues have then been discussed in detail in this ranking order. The main themes coming through from the issues have been used to develop summaries and insights of the issues and uncertainties.

It also became apparent that the variety of approaches to the scenario developed under each of the projects documented above also created uncertainties to be considered. Much of this uncertainty became evident in trying to reconcile the different scenarios.

2.4 Stage 4

Stage 4 was not originally anticipated. However, once the detailed issues were summarised, it became obvious that distribution was only lightly considered, and yet distribution is where many of the challenges for the future may arise.

To add to the discussion of security, reliability, and resilience in distribution. two University of Canterbury papers were reviewed and the distribution section expanded.

These papers were:

- Impact of solar photovoltaics on the low-voltage distribution network in New Zealand (Watson et al, 2016)
- Impact of electric vehicle chargers on harmonic levels in New Zealand (Watson & Watson, 2017).

3. Results

3.1 Stage 1 and 2 tabulation

From the stage 1 and 2 reviews, 42 conditions were identified that could give rise to future reliability, security, or resilience issues. These conditions give rise to 36 separate power system issues (there is sometimes a many-to-many relationship between issues and conditions) giving 44 issue and condition combinations. Some duplication resulted from this approach, but all issues were separately considered to ensure a comprehensive assessment.

The issues were broadly categorised under reliability, security, or resilience; they have then been further sub-categorised as described below. The sub-categories grouped the specific conditions together to enable efficient and consistent general evaluation

For this exercise, the general locations where the specific conditions applied were also grouped to assist a logical order and improve efficiency in assessing the conditions.

The full matrix of condition and location groupings and specific conditions is given in Appendix A.

3.2 Condition groupings

3.2.1 Fast or high load growth

Eighteen specific conditions were generally grouped under this macro condition. These are issues that arise predominantly because the load growth in a scenario is accelerated or reached extremely high levels.

3.2.2 Increase in grid generation to meet fast demand growth

Five specific conditions were grouped under this macro condition. These specific conditions did not arise directly because of fast demand growth but where the required fast generation investment response might occur before the lines investment can respond, or occurs in unexpected locations.

3.2.3 Generation outages or restrictions

The two specific conditions under this macro grouping are currently potential issues where the severity or the occurrence of the issue depends on the location and/or rate of demand growth.

3.2.4 Increase in distributed generation or DER to meet demand growth

The 12 specific conditions grouped under this macro condition potentially cause issues where a significant amount of demand growth is met through distributed resources. These issues can arise due to the resources being concentrated in distribution networks, or due to the nature of the resource, e.g. asynchronous and electronic.

3.2.5 Displacement of NI thermal from dry year reserve

These five issues arise to the extent that existing thermal dry year reserve plant is displaced. These issues can arise due to the nature of the plant being displaced, i.e. large plant with high inertia, or due to the location of the plant.

3.2.6 Other issues

Two issues remained that were generally related to security, one around the potential for insufficient IR investment, and one related to the potential for harmonic distortion.

3.2.7 Insights from issues analysis

Even before the stage 3 assessment, some insights came through.

1. The issues are based on the power system, energy market, ancillary services, and operating practices as they are today. Modifications to any of the above could change many issues; for example, admitting Distributed Generation (DG) to ancillary services would alleviate some issues but potentially cause others, such as how to coordinate such a system.

2. Transmission constraints tend to limit energy transfer between regions more than they limit peak capacity, mainly because most regions have reasonable amounts of local generation (notably Upper North Island (UNI) and Upper South Island (USI) are the most exposed to peak capacity problems).

3. We know that voltage and capacity are strongly linked in distribution networks, but the linkage is also strong in transmission in some areas (again notably UNI and USI). This raises the related question of whether we need to look at market models that incentivise efficient solutions for the combination of both, e.g. Alternating Current Optimal Power Flow (ACOPF) models rather than Direct Current Optimal Power Flow (DCOPF) for pricing in some regions.

4. Resilience will generally be eroded before transmission constraints bind. The consequence of fast electrification could mean difficulty, and even risk in, having transmission and/or generation outages before capacity problems become obvious.

3.3 Stage 3 assessment

The review of the stage 2 documents yielded 23 complete scenarios and seven partial scenarios. The partial scenarios come about because of the approach taken in Te Mauri Hiko where one complete scenario was presented and three variants of demand side scenarios and four variants of supply side scenarios.

The scenarios assessed are given in Table 1.

Table 1: Scenarios assessed

Source	Scenarios
Te Mauri Hiko	NZ Inc • Vibrant haven, Mobilise, Struggling along • Clean NZ, Peakers permitted, Big south, Max solar
Whakamana i Te Mauri Hiko	BAU, Measured action, Tiwai exit, Accelerated electrification, Mobilise
EDGS (MBIE)	Reference, Growth, Global, Environmental, Disruptive
BEC2050	Kayak, Waka
BEC2060	Kea, Tui
ICCC	BAU, 100% renewable, Accelerated electrification
CCC (draft advice)[4]	Current policy, Headwinds, Further behaviour change, Further technology change, Tailwinds

The tabulation of conditions, regions affected, issues and the scenarios were tabulated in heatmaps, shown in 4.Appendix B. Some specific conditions were also noted in three stage 1 documents, which were also included in the heatmapping.

3.3.1 Scenario comparison

The different reports varied greatly in terms of demand and/or generation detail, time granularity, and approach.

For example, EDGS 2019 had little detail about the make-up of demand, and its scenarios were quite similar. The CCC's scenarios were also substantially homogenous but had good detail for every year to 2050. The BEC scenarios were the most varied and had detail for every five years up to 2050 and 2060. The ICCC had reasonable detail but just for one time point (2035). Every scenario in EDGS 2019 had slow take-up of solar PV, and every Transpower scenario had fast solar take-up.

These differences do create some problems with comparisons, but the comparisons are still useful given the context of each scenario.

3.3.2 Scenario insights and issue summaries

Key insights and summaries of key issues are discussed below. However, all specific conditions are explicitly discussed in Appendix C.

[4] The final advice has since been released but our assessment was based on the draft advice.

3.3.2.1 Winter Energy Margin/Winter Capacity Margin

The most urgent probable problems, that occur across several reports, are with the Winter Energy Margin (WEM) and Winter Capacity Margin (WCM). Both issues arise where demand growth is potentially faster than generation can come to market, or where thermal generation is retired faster than the market generally expects. These occur under scenarios with expedited and significant load growth, i.e. from expedited electrification of transport and process heat; or where policy decisions might directly influence the viability of thermal generation.

These issues are strongly influenced by the exit of Tiwai. For many reports, no announcements had been made relating to Tiwai and most approaches were to consider Tiwai a sensitivity rather than include it in a scenario. For scenarios where Tiwai does exit, e.g. all the CCC scenarios, then the issues are delayed.

The issue analysis is mostly a static analysis. The probable coding is given where a scenario does meet the criteria. In practice this is probably more a short-term issue, as supply responses should be more dynamic in the future. Nevertheless, where scenarios start with gentler initial load growth, e.g. CCC scenarios, they can have later periods of significant demand ramping that could prove a problem at that time.

3.3.2.2 Overloaded GXPs and regions[5]

The next most common probable problem is overloaded Grid eXit Points (GXP). This is causally related to the electrification of process heat, where significant extra demand can be concentrated at GXPs. Transpower has identified many GXPs where this could happen based on the embedded connection of dairy factories. For these GXPs identified, Transpower has proposed solutions.

However, other large potential loads may affect more GXPs. The question might be, if enough large loads electrify quickly, could Transpower manage the GXP upgrades? The same question could be asked of the affected distributors.

The same concentration of potential demand growth can also affect regions. For example, the electrification of the Edendale dairy factory has implications for lower South Island (absent Tiwai exit), and Darfield has implications for Canterbury capacity. Again, yet-unknown electrification projects could cause significant concentration of demand growth in regions of the power system with the associated security, reliability, and resilience impacts.

A key uncertainty is whether biomass or electricity is best for reducing major process heat emissions and, particularly for security, whether this is different in different areas.

[5] Transpower and the SI EDBs are working with Deta Consulting to assess the implications on the grid and distribution networks of full electrification of process heat. The output from that work will contribute to our understanding in this area.

3.3.2.3 Uptake of solar and DER

Prima facie the forecasts around solar uptake are highly variable, with many scenarios clearly meeting the issue criteria and some not meeting it. This is not so clear cut, however, as the main reports that don't have solar meeting the uptake criteria (2GW) are EDGS 2019 and the ICCC scenarios. Both reports only forecast up to 2035, although the EDGS forecasts are the lowest for solar uptake even up to 2035. Many other scenarios meet the solar criteria after 2035.

Transpower's solar forecasts are the most aggressive. Our heatmap makes it seem that Transpower muted its solar forecasts in Whakamana i Te Mauri Hiko, but this is more to do with not presenting the explicit data for alternative scenarios in Whakamana. Without the explicit data, solar uptake conditions were assessed as possible rather than probable.

In some ways the slower probable solar uptake might be the bigger issue as it would be advisable to consider solar/DER in conjunction with the Auckland/Northland and USI capacity issues (see below). An unfortunate outcome could be that sufficient solar/DER becomes installed that, if coordinated, could have avoided the need for transmission upgrades to solve capacity and quality issues. The question would be: could eventual solar/DER deployment be coordinated to avoid the need for transmission upgrades, and would it be economic to try to bring the deployment forward? Obviously, this has consequences for distribution as well.

There are a range of subsequent issues that arise from high DER uptake, ranging from offsetting grid regulating capacity, affecting net Automatic Under Frequency Load Shedding (AUFLS) response, harmonics, and inertia. These are all issues that may or may not actually manifest but could be significant if they do.

3.3.2.4 Auckland/Northland and USI capacity and quality

These two sets of issues are grouped together because, despite the differences in scale, they are the same continual problem: how to supply significant load from remote generation where increased transmission increases voltage management problems. Transpower has options to manage these problems in the short run but the longer run may be more problematic.

As this problem essentially arises from load centres not having any local generation to speak of, then it is somewhat ironic that both load centres are likely to eventually have relatively large amounts of local solar/DER (see above).

It is possible, given enough load growth and transmission capacity, that the voltage issues become unmanageable without local generation. A more strategic approach to capacity and voltage management is probably required.

The capacity requirements for these regions, and other regions as well, is complicated by two key decarbonisation questions, both of which are uncertain:

- How much does transport electrification lift urban demand, and how does the profile change?
- How much does DER deployment reduce this demand and/or alter the profile?

To be useful for assessing security of supply, these assessments need to be transmission zone specific, and ideally GXP specific for major GXPs, e.g. Penrose.

3.3.2.5 Mix of generation

Different mixes of generation have significant potential impacts on the power system. Scenarios with a focus on geothermal development potentially create issues with Bay of Plenty (BOP) export capacity. Wind focused developments may cause issues with import to Waikato and the UNI, as well as affect export limits in certain regions, e.g. Canterbury.

It is even complicated for the scenarios which have made use of Gas Turbines (GT) for peak security, e.g. BEC and CCC. A concentration of GT capacity in Taranaki relative to Huntly and/or Auckland has different import/export problems than if the capacity is concentrated at Huntly or in Auckland, or somewhere else. Further, it is a different set of issues for supporting UNI peak capacity from supporting peak southward flow on the HVDC.

Transpower has made a start in assessing locational impacts in Whakamana i Te Mauri Hiko, but there is more to understand yet.

In the case of wind, it is also going to be critical to understand how wind output will vary between regions and how they are correlated. The results could show a much higher set of power flow combinations than the power system currently deals with.

3.3.2.6 Major market uncertainties

The impacts on security for major market uncertainties vary too significantly to come to firm conclusions about urgent needs. The existing key uncertainties are Tiwai and Huntly Rankine exits.

Huntly was probably more certain, with most scenarios plausibly picking Huntly Rankine exit by 2030. Any variation from this assumption would be disruptive, however, and there is still the issue of what replaces the role the Rankines play. Many scenarios still anticipated thermal peaking being required, presumably mostly from Open-Cycle Gas Turbines (OCGT). This raises other uncertainties around the availability of gas for purely peaking or, to meet 100 per cent renewable, the potential use of biofuels or hydrogen.[6]

Tiwai is a greater uncertainty in the analysis even though an exit date has now been announced, albeit perhaps still subject to change. None of the scenarios included Tiwai exit explicitly in the short term. Some analysis considered Tiwai exit as a sensitivity, although none could really give certainty on the issue anyway. Any change in the timing of Tiwai exit is an uncertainty that creates binary security outcomes, especially in the LSI.

[6] Generally, as the scenario authors assumed the continued availability of gas in limited volumes, biomass was used in other parts of the economy such as direct industrial heat, chemical process feedstock, or liquid biofuels for transport.

3.3.2.7 100 per cent renewable by 2030

None of the scenarios anticipated the full removal of thermal power stations by 2030, which is now Government policy. Most scenarios that explicitly ensured security of supply relied on thermal peakers in their assessments. Under the Government's 100 per cent renewable by 2030 policy, many of the scenarios' conclusions that affect security, reliability, and resilience no longer hold. It would be advisable to recalibrate at least one of the secure scenarios that rely on gas thermal peaking for 100 per cent renewable by 2030 and reassess security concerns.[7]

3.3.2.8 Transmission and distribution investment

In Whakamana i Te Mauri Hiko, Transpower has begun to assess high-level transmission needs. However, the devil is in the detail. Most scenarios assume that transmission will be built as necessary, but more capacity does not necessarily mean fewer problems. The issue of more transmission capacity in combination with solar PV output leading to lighter net off-peak loads raises the issue of high voltage and voltage instability all over the grid. The detail of transmission build needs to be better understood.

The same issue could be even more difficult in distribution where the combination of more lines with lighter net loads leading to greater voltage swings could make distribution capacity unmanageable at high levels of penetration, especially in urban areas (see below).

3.3.2.9 Invisible erosion of resilience

A theme that occurs regularly is that the ability to manage transmission outages and the outages of some key generating assets can be eroded before any security constraints become obvious. With so many new potential pinch points on the grid, and change potentially occurring so quickly, it is possible that some areas are forced to endure pre-event load shedding to manage outages before the capacity issues can be planned for.

3.4 Stage 4

After the main analysis above there was little insight distilled about potential distribution issues. Therefore, this section has been separately expanded based on Watson et al (2016) and Watson & Watson (2017).

3.4.1 Distribution

In the main assessment we simply assumed Transpower's grid assessment of 2GW of solar in Transpower (2019) was likely an appropriate trigger for distribution issues. Transpower (2019) did not suggest that 2GW was a limit for solar PV but is the point where its integration needs to be managed. In Watson et al (2016) the question is explicitly considered for solar PV in the low-voltage network, and harmonics is considered for EVs in Watson & Watson (2017).

[7] The NZ Battery work will inform this discussion when it is made public.

The two Watson papers demonstrate a technique by which a realistic and New Zealand-specific range of low voltage networks can be derived from SCADA and GIS data. This offers an approach whereby the – otherwise unknown – low-voltage network of New Zealand can be reliably modelled.

Watson et al (2016) used a clustering technique to group nodes of similar electrical characteristics. Upon investigating the resulting clustering Watson et al (2016) categorised the clusters as Industrial, City, Urban, and Rural. We use the Watson et al (2016) categorisations in the rest of the paper but we interpreted them, based on the characteristics and descriptions, as follows:

Industrial – large industrial loads most often with dedicated transformers

City – inner city/high-density urban with residential and commercial connections

Urban – low density urban/suburban with residential and commercial connections

Rural – rural or very low density areas with residential and commercial connections.

3.4.1.1 Voltage

Watson et al (2016) assessed low-voltage network performance against the Electricity Safety Regulations (2010) (ESR) which prescribes that the voltage delivered to low-voltage customers must be 230 volts plus or minus 6 per cent. In practice it can be difficult to economically supply all customers within this specification.

One of the key findings from Watson et al (2016) was that urban networks were the least able to host large penetrations of solar PV due to voltage management issues.

Industrial low-voltage networks had larger loads and network capacity within which the assessed solar installations could be integrated, although this analysis might not hold if much larger solar PV installations were deployed on these networks (Watson et al (2016) used a standard PV installation of 3.7kW output through a 5kW inverter).

High-density city networks had relatively short circuit lengths, giving lower circuit impedance, and generally had larger transformers. This makes city networks generally less susceptible to voltage fluctuation and, therefore, makes it easier to integrate solar PV.

For rural networks, the low number of connections per transformer and the low-voltage circuit lengths made each solar PV installation less likely to affect neighbours. Rural networks also had a greater incidence of voltages lower than the prescribed limits generally, which made solar PV quite beneficial; however, there could also be high-voltage problems during periods of light loading. The voltage fluctuations on rural networks can be high.

It should be noted that all voltage issues are context-specific and there are still a significant number of city, industrial, and rural connections where it might prove difficult, or costly, to integrate solar PV within the prescribed voltage limits.

In urban networks, with relatively small connections closer together and a relatively higher number of solar PV circuits for circuit capacities, voltage management became significantly more difficult. Unfortunately, it would be expected that the majority of residential solar PV would be urban.

Using a criterion of limiting the remedial maintenance of the low voltage network to 1 per cent of the network to enable solar PV, Watson et al (2016) gives 10 per cent as the limit of solar PV penetration in urban low-voltage networks. Above this limit then remedial work would be required on more than 1% of the current low-voltage network.

To put this in the context of the 2GW Transpower assessed as being the point the grid might need to be coordinated, using rough calculations based on there being 1.88 million residential Installation Control Points (ICP)s in New Zealand and 80 per cent of those being separate houses limited to 10 per cent solar PV penetration. Then, assuming even solar PV growth across industrial, city, urban, and rural, then the national low-voltage limit would be reached 800MW earlier than Transpower's grid assessment at 1.2GW. This is a rough estimate. Many separate houses will be rural but then many units and attached flats will also be urban. The number is indicative only.

Watson et al (2016) propose four ways of improving the hosting capacity of urban networks.

1. Remedial maintenance of more of the low-voltage network.
2. Setting all urban solar inverters to reactive power control down to 0.8 power factor.
3. Reducing the secondary voltage settings of urban distribution transformers.
4. Increasing the prescribed ESR limit on low-voltage variation from within 6 per cent to within 10 per cent of 230 volts.

Of these the most effective mitigation by far (an improvement from 10 per cent solar PV penetration to 30 per cent) is increasing the statutory limit to 10 per cent, although this has other implications for power system and connected equipment performance. Having said that, Watson et al (2016) find that 11 per cent of all ICPs suffer low voltages under the statutory limit now. The Electricity Safety Regulations (ESRs) should be questioned in this regard. The low-voltage range is the only one in the ESRs that is non-negotiable. In a future where more technology will be available to manage power quality locally, it is likely to be efficient to allow consumers to accept an increased voltage range if their contribution to voltage management costs is then duly recognised.

The second most effective mitigation (increasing solar PV penetration from 10 per cent to 17 per cent) was reducing distribution transformer secondary voltages, although this also leads to more incidence of low voltages. This suggests to us that another mitigation may be even more effective.

The mitigations suggested by Watson et al (2016) are static solutions. They are engineering solutions that are set once and then only periodically reviewed. The assessment that a static adjustment to secondary voltages can be relatively effective suggests to us that managing the voltage profile in the low-voltage network through the dynamic coordination of DER in real-time may be the most effective mitigation.

3.4.1.2 Thermal overload

Watson et al (2016) find that increasing levels of penetration of solar PV initially reduces the incidence of circuit overloading in the low-voltage network. The paper also notes that this effect would be stronger if peak solar were aligned with peak residential consumption. This supports the proposition that coordinated PV and battery systems could significantly increase the effective capacity of distribution networks, potentially offsetting the need for new investment for future load growth.

At the point where a significant number of transformers start incurring reverse power flow is the point where the incidence of overloaded circuits increases again. Watson et al (2016) assess that penetration levels of almost 50 per cent are achievable before the number of overloaded circuits exceeds current levels. This proportion could be higher with the use of batteries and coordination.

At this level of penetration around 15-20 per cent of transformers would have periods of reverse power flow. This may have implications for the protection settings of the low-voltage network, sub-transmission, and maybe even some GXPs.

3.4.1.3 Harmonics

Harmonics are a form of noise on the electric power system that can be harmful to equipment in high enough concentrations.

Watson & Watson (2017) analyse the potential for harmonic distortion for high levels of penetration of EV charging. At levels of 50 per cent penetration, harmonics are not an issue, even when combined with 40 per cent penetration levels of PV. At these levels of penetration, the coordination of EV charging needs to occur to manage circuit loadings; this also has the effect of distributing through time the harmonic distortion.

An issue identified in Reeve, Comendant, and Stevenson (2020) is where back-feeding of PV occurs in the low-voltage network, there could be a concentration of harmonic distortion where the back-feeds push as far as they can back into the network and net power flows are low. It is not clear whether Watson & Watson (2017) explicitly considered this in their scenario with PV and EVs, but overall harmonics do not look to be a big issue.

However, the greater the number of non-linear, capacitive, and inductive components in the distribution network, then it is likely that resonance issues could become more acute.[8] These are difficult to predict, although they are likely to result in only a small number of power system faults. Nevertheless, the increasing complexity of the distribution network may require significant upskilling in diagnostic capacity.

3.4.1.4 Urgency

Based on the DER deployment in the scenarios, high levels of DER penetration are not expected within the next five years. However, DER will be progressively installed, and without early incentives for higher specification equipment, or some other form of guidance, the equipment installed may not be able to be coordinated or managed in the future. In some cases, while not widespread, remedial network investment might occur that could be avoided.

[8] Resonance is something that can occur in electric circuits where capacitance and inductance 'bounce' off each other. Resonance can amplify voltage and current spikes and also amplify harmonics.

It is also possible that enabling coordination and recognising genuine value contributions from DER might significantly accelerate DER investment.

4. Conclusions

There are a significant number of issues that could arise as New Zealand pursues the decarbonisation of the economy underpinned by renewable electricity generation. However, when it comes to understanding the implications for security, reliability, and resilience in the New Zealand Electric Power System, detail will increasingly matter. Where, when, and what loads and generation are deployed controls a large number of permutations for reliability concerns and the associated solutions.

The industry is increasingly dynamic. Over the relatively short period in which the scenarios we have considered were developed, much has already changed. Tiwai exit has gone from an uncertainty to an announced date, for example, and Government policy has changed to 100 per cent renewable electricity by 2030.[9] Very little scenario work has been done to understand the stresses and strains on the system under a 100 per cent renewable electricity system on top of the anticipated electrification of transport and industrial heat in particular. Government has also initiated its NZ Battery project and has conducted scenario work on the merits of an additional intervention to add to the mix.[10] None of the scenarios consider the combination above as an explicit, consistent scenario.

As a matter of modelling convenience none of the scenarios seemed to consider Demand Response (DR) as a dynamic resource for managing resource adequacy. Where DR was modelled it was presented in a change in demand forecasts and the relative growth of peak demand to average.

The Authority may want to consider curating a dynamic scenario, or set of scenarios, against which it can baseline its work. As described above, such a scenario(s) would need to encompass some detail about where, when, and what to be able to inform security, reliability, and resilience.

Techniques have been advanced by which reliable approximations can be made about the distribution network. Currently the distribution network, and particularly the low-voltage network, is substantially opaque. Using new techniques, the Authority may be able to extend some detail around its scenarios to a representation of the distribution network.

A baseline scenario(s) would be helpful for the Authority to identify and define the most pressing reliability concerns but also would be helpful for the broader industry as well. It may also help to focus the industry on the key concerns, and possibly on the key opportunities. Early planning and incentives for new technology, such as DER, may be valuable even where high levels of penetration are only likely in the medium term.

Generally, the key concerns for security and reliability occur because of the potential speed of demand growth and whether generation, transmission, and distribution can respond appropriately and quickly

[9] The Tiwai Point smelter exit was announced for the end of 2021. Since then, arrangements with the industry have led New Zealand Aluminium Smelters (NZAS) to change its exit date to December 2024. Even this date, however, is not completely certain.

[10] NZ Battery is considering whether intervention is required to ensure security of supply under the 100% renewable policy. MBIE is running the project and commissioned two independent pieces of analysis: the scale of intervention required and how an intervention would interact with the current market arrangement. We carried out the work on the second question in a consortium with Energy Link and Chapman Tripp.

enough. Uncertainty does not help this, and any certainty the Authority can bring to the global supply and demand balance in the future would help the industry adapt. It may be worth keeping a close measure on demand to try to pick any underlying changes in the rates of growth of EVs, DER more generally, underlying demand, and the electrification of transport and process heat.

The Authority needs to be alert to resilience. The power system's ability to withstand shocks from outages or events could be eroded well before capacity limits and congestion become obvious. The removal of large thermal plant with the associated inertia, voltage support, and reserve capacity can create a significant change in the resilience of the North Island power system, as can the concentration and location of new technology and technology.

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Appendix A – Tabulation of conditions, regions, and issues

Macro condition	Region	Specific condition	Issues
Fast or high load growth	New Zealand	Fast electrification	Don't meet Winter Capacity Margin
			Don't meet Winter Energy Margin
		Large single site industrial electrification	Overloaded GXPs
	Waikato-Auckland-Northland	Significant increase in net load	Voltage instability
			Insufficient peaking capacity
			No standby reserve above n-1
			Can't manage transmission outages
			Can't manage Huntly U5 outage
		Significant increase in net load with transmission outages	High voltage during off-peak loadings
	Wellington-Lower North Island	Transmission built for significant increase in net load (including South transfer)	High voltage during off-peak loadings
			HVDC limits due to filter shutdowns for high voltage

Macro condition	Region	Specific condition	Issues
Fast or high load growth	Upper South Island	Significant increase in net load	Voltage instability
			Insufficient peaking capacity
		Transmission built for significant increase in net load and/or distribution undergrounding	High voltages during off-peak loading
		Increased summer peak loadings	Can't manage voltage during transmission outages
	Otago-Southland-Lower South Island	Significant increase in net load with transmission outages	Limited on import to Otago-Southland-Lower South Island
		Increased transmission capacity and reduced off-peak load	Can't manage high voltages
	Canterbury	Increased peak loading	Insufficient peak capacity

Macro condition	Region	Specific condition	Issues
Increase in grid generation to meet demand electrification	Eastern North Island	Significant increase in net generation	Limit on import to Waikato, Auckland, and Northland
	Taranaki		
	Bay of Plenty		Limit on export from BOP, especially if displacing Huntly
		Moderate increase in BOP generation with tx outages	
	Wellington-Lower North Island-Central North Island	Significant increase in net generation	Limit on import to Waikato, Auckland, and Northland
		Moderate increase in net generation with transmission outages	
	Canterbury	Significant quantities of wind generation from inland Canterbury	Limit on export from Canterbury
	Southland-Otago-Lower South Island	Significant increase in net generation	Limit on export from Lower South Island
Generation outages or restrictions		Manapouri station outage	Voltage instability Lower South Island
		Manapouri restrictions and tx outages	Insufficient peak capacity

Macro condition	Region	Specific condition	Issues
Increase in distributed generation or DER to meet demand electrification	New Zealand	Over 2GW of distributed solar	DER tripped with load results in low AUFLS response
			Variable DER contribution results in variable AUFLS response
			Reducing solar output before evening peak results in ramp rates too fast for grid plant
			Potential for harmonic distortion in feeders with DER export
		Over 2GW of distributed solar during off-peak periods with reduced grid plant output (high solar)	Reduced inertia leads to severe frequency events
			Insufficient frequency regulating capacity
			Insufficient voltage regulating capacity
		Over 2GW of distributed solar in conjunction with transmission investment	High voltages during off-peak loading
		High DER deployment dispatched ahead of grid plant with Over-Frequency Arming contracts	Insufficient over-frequency response
		High DER deployment without coordination	Reduced distribution network capacity
	Upper North Island		High voltage
	Auckland	High solar deployment	High fault currents

Macro condition	Region	Specific condition	Issues
Displacement of NI thermal from dry year reserve	New Zealand	Early decommissioning before new reserve established	Don’t meet Winter Capacity Margin
			Don’t meet Winter Energy Margin
		Dry year reserve comes from asynchronous plant	Reduced inertia leads to severe frequency events
	North Island	Significant load growth and Huntly retirement	Insufficient instantaneous reserve
		Moderate load growth, Huntly retirement and tx outages	
	South Island-Lower North Island	Dry year reserve concentrated in Waikato-Taranaki-Upper North Island	Insufficient import capacity
		More dry year reserve in Taranaki	
		More dry year reserve from UNI with tx outages	
	South Island	Dry year reserve concentrated in NI wind overbuild with tx outages	
		HVDC limited for voltage stability with concentration of dry year reserve in NI with tx outages	
Reliability	North Island	Smaller generating unit sizes result in near zero IR prices most of the time	Insufficient IR capacity available for high HVDC loadings
	New Zealand	Inadvertent mixes of high DER deployment with power factor and/or voltage correction capacitors during lightly loaded periods	Potential for harmonic distortion and/or resonance, especially in dx network but possibly in tx as well

Appendix B – Heatmaps

Possible issue heatmap

Issues	Forecast source	Transmission Planning Report 2020	System Security Forecast 2020	Assessment of Security of Supply 2020	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	EDGS 2019	EDGS 2019	EDGS 2019	EDGS 2019	EDGS 2019	BEC2050	BEC2050	BEC 2060	BEC 2060	ICCC	ICCC	ICCC	CCC	CCC	CCC	CCC	CCC
	Scenario				NZ Inc	Vibrant Haven	Mobilise	Struggling Alone	Clean NZ	Peakers Permitted	Big South	Mass Solar	BAU	Measured Action	Tiwai Exit	Accelerated Electrification	Mobilise	Reference	Growth	Global	Environmental	Disruptive	Kayak	Waka	Kea	Tui	BAU	100% renewable	Accelerated electrification	Current Policy	Headwinds	Further Behaviour Change	Further Technology Change	Tailwinds
Don't meet Winter Capacity Margin																																		
Don't meet Winter Energy Margin																																		
Overloaded GXPs																																		
Voltage instability																																		
Insufficient peaking capacity																																		
No standby reserve above n-1																																		
Can't manage transmission outages																																		
Can't manage Huntly U5 outage																																		
High voltage during off-peak loadings																																		
High voltage during off-peak loadings																																		
HVDC limits due to filter shutdowns for high voltage																																		
Voltage instability																																		
Insufficient peaking capacity																																		
High voltages during off-peak loading																																		
Can't manage voltage during transmission outages																																		
Limited on import to Otago-Southland-Lower South Island																																		
Can't manage high voltages																																		
Insufficient peak capacity																																		
Limit on import to Waikato, Auckland, and Northland																																		
Limit on export from BOP, especially if displacing Huntly																																		
Limit on import to Waikato, Auckland, and Northland																																		
Limit on export from Canterbury																																		
Limit on export from Lower South Island																																		
Voltage instability Lower South Island																																		
Insufficient peak capacity																																		
DER tripped with load results in low AUFLS response																																		
Variable DER contribution results in variable AUFLS response																																		
Reducing solar output before evening peak results in ramp rates too fast for grid plant																																		
Potential for harmonic distortion in feeders with DER export																																		
Reduced inertia leads to severe frequency events																																		
Insufficient frequency regulating capacity																																		
Insufficient voltage regulating capacity																																		
High voltages during off-peak loading																																		
Insufficient over-frequency response																																		
Reduced distribution network capacity																																		
High voltage																																		
High fault currents																																		
Don't meet Winter Capacity Margin																																		
Don't meet Winter Energy Margin																																		
Reduced inertia leads to severe frequency events																																		
Insufficient instantaneous reserve																																		
Insufficient import capacity																																		
Insufficient IR capacity available for high HVDC loadings																																		
Potential for harmonic distortion and/or resonance, especially in dx network but possibly in tx as well																																		

Probable heatmap

Issues	Forecast source	Transmission Planning Report 2020	System Security Forecast 2020	Assessment of Security of Supply 2020	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	Whakamana i Te Mauri Hiko	EDGS 2019	EDGS 2019	EDGS 2019	EDGS 2019	EDGS 2019	BEC2050	BEC2050	BEC 2060	BEC 2060	ICCC	ICCC	ICCC	CCC	CCC	CCC	CCC	CCC
	Scenario				NZ Inc	Vibrant Haven	Mobilise	Struggling Alone	Clean NZ	Peakers Permitted	Big South	Mass Solar	BAU	Measured Action	Tiwai Exit	Accelerated Electrification	Mobilise	Reference	Growth	Global	Environmental	Disruptive	Kayak	Waka	Kea	Tui	BAU	100% renewable	Accelerated electrification	Current Policy	Headwinds	Further Behaviour Change	Further Technology Change	Tailwinds
Don't meet Winter Capacity Margin																																		
Don't meet Winter Energy Margin																																		
Overloaded GXPs																																		
Voltage instability																																		
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No standby reserve above n-1																																		
Can't manage transmission outages																																		
Can't manage Huntly U5 outage																																		
High voltage during off-peak loadings																																		
High voltage during off-peak loadings																																		
HVDC limits due to filter shutdowns for high voltage																																		
Voltage instability																																		
Insufficient peaking capacity																																		
High voltages during off-peak loading																																		
Can't manage voltage during transmission outages																																		
Limited on import to Otago-Southland-Lower South Island																																		
Can't manage high voltages																																		
Insufficient peak capacity																																		
Limit on import to Waikato, Auckland, and Northland																																		
Limit on export from BOP, especially if displacing Huntly																																		
Limit on import to Waikato, Auckland, and Northland																																		
Limit on export from Canterbury																																		
Limit on export from Lower South Island																																		
Voltage instability Lower South Island																																		
Insufficient peak capacity																																		
DER tripped with load results in low AUFLS response																																		
Variable DER contribution results in variable AUFLS response																																		
Reducing solar output before evening peak results in ramp rates too fast for grid plant																																		
Potential for harmonic distortion in feeders with DER export																																		
Reduced inertia leads to severe frequency events																																		
Insufficient frequency regulating capacity																																		
Insufficient voltage regulating capacity																																		
High voltages during off-peak loading																																		
Insufficient over-frequency response																																		
Reduced distribution network capacity																																		
High voltage																																		
High fault currents																																		
Don't meet Winter Capacity Margin																																		
Don't meet Winter Energy Margin																																		
Reduced inertia leads to severe frequency events																																		
Insufficient instantaneous reserve																																		
Insufficient import capacity																																		
Insufficient IR capacity available for high HVDC loadings																																		
Potential for harmonic distortion and/or resonance, especially in dx network but possibly in tx as well																																		

Appendix C – Detailed issues assessments

Possible issues

Discussion of detailed possible issues in priority of their likely urgency.

Limits on export from BOP with transmission or Huntly outages

This is likely the most urgent uncertain issue, with 11 scenarios signalling that it could be an issue within five years. This issue rises to the top for two reasons:

- Most scenarios anticipate early geothermal development, likely to be in BOP.
- This issue occurs before thermal limits under normal conditions and could cause problems during transmission or Huntly unit outages.

The issue could manifest as an inability to utilise geothermal generation under certain circumstances. The worst scenario could be during a dry period with a long-term forced outage – or removal – of a Huntly unit. This could cause a limit on geothermal export from BOP at the worst possible time.

Uncertainty – this is an identified issue by Transpower and, with Contact suggesting it is going to move ahead with Tauhara II, then it might be a probable issue. However, many scenarios anticipate significant early geothermal development, and the export potential from BOP is complex with the potential for spring washers. The exact location and size of each geothermal station is likely to matter and may require a larger-scale plan. Some of the scenarios may anticipate geothermal development that is faster than is feasible, which might also cause issues if significant wind is developed before geothermal.

Limit on export from BOP, especially during Huntly outages

As many scenarios anticipate significant early geothermal development – 10 scenarios indicate thermal limits could be reached under normal conditions within five years – then this issue comes in second. In this issue any Huntly unit outage could potentially cause a significant limit on geothermal generation export.

Uncertainty – as above, this may not be feasible in the short run as geothermal developments may not be delivered as quickly as some scenarios anticipate. However, this may be an issue that needs to be addressed, at least within the next 10 years. The mix of potential geothermal development may need BOP export to be considered holistically and in the long term.

Limit on Upper North Island import capacity with outages, if fast demand growth met from southern generation sources

This is one of many issues where the urgency of the issue is tied to the assumptions about when significant electrification of the economy occurs – in this case, particularly transport. Forecasts about when significant load growth occurs due to the electrification of transport vary significantly between the scenarios. Nine scenarios suggested this could occur with key transmission outages within five years, although a lot of judgement had to be applied to assess this issue. All the scenarios anticipated that wind and/or geothermal takes up the increase in demand on an energy basis (there are further problems with peaking). Therefore, when significant UNI demand increase occurs (all scenarios anticipate significant electrification of transport with some being very high), transmission into Auckland will become a serious issue.

This issue also ranks highly on the probable list as some scenarios clearly result in increased generation from southern sources to meet UNI demand.

Transpower has already identified this as an issue and has some potential solutions, but the long-term scale of potential problem may warrant longer-term thinking. It also raises the issue of potentially needing the infrastructure and incentives/disincentives for EV smart charging urgently.

Uncertainty – a lot of judgement was necessary to assess this issue, and more detailed analysis would help. Many scenarios anticipated fast demand growth in EVs and industrial process heat as the speed of decarbonisation matters and, practically in a relative sense, these two activities offer the biggest, fastest gains. If the Government were to agree and introduce strong incentives, then the take up of EVs and low-grade heating solutions could be dramatic. Understanding in more detail how this could play out in EVs is an urgent matter. Overall, the electrification of process heat may not affect the Upper North Island more than any other region, but this is not known. There has been only limited work to date on where the impacts of electrification of process heat might manifest, and this is another urgent piece of work.

Limit on Upper North Island import capacity if fast demand growth met from southern generation sources

Seven scenarios have demand growth from electrification with supply met from wind sources sufficient that thermal limits to the UNI are reached within five years. Again this is highly dependent on where the demand growth from electrification occurs, but it is reasonable to expect that a lot of electric transport demand will occur in the UNI.

The issues and uncertainties are the same as the issue above.

Voltage instability in the UNI

Five scenarios suggest this could be an issue within five years, while a further nine suggest within ten years. This issue also ranks high in the probable list due to some scenarios explicitly identifying high industrial process heat electrification. However, a lot of judgement was needed to assess this. This issue became likely to be urgent for three reasons:

- The electrification of transport, and possibly process heat, leads to significant demand growth in the UNI.
- The energy for the UNI is primarily supplied from wind power south of Whakamaru.
- There is significant take up of solar PV in the UNI, which without coordination could further destabilise voltage.

Predominantly this is another issue tied to the speed, size, and location of demand growth from the electrification of transport and possibly process heat. The issues and the uncertainties are the same as discussed above.

The added complexity here is in solar PV, especially distributed rooftop installations. Little has yet been assessed of what the impacts might be of high Auckland demand with higher solar PV concentration. It could be that the solar PV, especially if coordinated possibly with batteries and EV smart charging, could reduce both peak and average import to the UNI. It is also possible that the solar PV contribution could lead to lightly loaded transmission lines at times with more significant peaks at other times, with varying active voltage sources acting on voltage as well. This could cause the UNI to operate in two regimes from high voltages to low voltages with, potentially, a quick transition between the two.

Uncertainty – a lot of judgement was again necessary here, and more analysis would help. More needs to be understood about how the import profile into the UNI would change (both level and profile) with varying levels of electrification and solar PV uptake. It would also be useful to understand better whether coordination and incentives/disincentives for solar PV coordination, in combination with EV smart charging, could make UNI demand and voltage more manageable. It would then be useful to understand how quickly such coordination could be done, although incentives are probably also required to ensure remotely controllable technology is installed, and possibly to also incentivise batteries.

The process didn't explicit draw distribution issues out here, but it is likely that more extreme ranges in voltage will also cause significant problems for capacity management in distribution networks. There is little public information available on the distribution effects currently.

High voltage in USI during lightly loaded periods after transmission investment for demand growth

This is similar to the voltage stability problem above but affects the Upper South Island and is more directly related to the high voltage problem. Again, it is related to the speed of demand growth from electrification and the impact of uncoordinated solar PV. While far less demand growth from electrification would be expected in the USI compared to the UNI, the transmission connections are weaker and high voltage is a looming problem. Any transmission investment where light loads don't also increase commensurately with peak loading would lead to high voltages.

This issue also ranks highly in the probable list as some scenarios explicitly forecast high industrial process heat electrification.

Transpower has some proposed solutions in mind for the issue, but the question could be: does the problem become more difficult with solar PV, especially if uncoordinated? It's also possible that the problem becomes more one of voltage stability as the same rapid regime shifts of high voltage to low voltage could occur as in the UNI.

Uncertainty – similar to the UNI problem, Similar to the UNI problem, we need greater understanding of how various levels of electrification and solar PV uptake affect the level and profile of USI import.

The specific location of Grid Injection Points (GIP)s with significant profile changes might also be important for the USI. Again, the issues related to coordinating solar PV and EVs are relevant.

Limit on import to UNI exacerbated by generation from eastern NI

Due to the complex nature of the potential spring washers around the Wairakei loop and loops potentially created by Tokaanu-Whakamaru, extra generation from the eastern NI could further limit imports to the UNI. This becomes an issue under the highest demand scenarios that are predominantly met from wind power. As more wind power tries to get north from more locations, transmission loops in the Central North Island could become more problematic. This complexity is further increased as more diverse locations should also increase the diversity of wind combinations. This should improve the intermittency issues associated with wind but could lead to many transmission flow combinations around the Central North Island (CNI) loops.

Uncertainty – further study into the locations and diversity of future windfarms would allow an assessment of the range of potential transmission flow combinations. This would clarify whether the solutions currently considered by Transpower would be sufficient or whether a larger coordinated plan is required. If security of supply were to be provided by wind generation overbuild, then this assessment would also suggest the farms most likely to be constrained off under normal conditions.

Limit on import to LSI with demand growth and transmission outages

This issue features as somewhat urgent due to five scenarios forecasting fast load growth due to the electrification of industrial process heat. The LSI features one large dairy factory and potentially other candidates for heat electrification. Most scenarios didn't include the exit of Tiwai and so the potential for issues, or at least the urgency of issues, is highly dependent on that key variable.

Uncertainty – this issue is highly binary, being driven by the outcomes of a couple of large decision points. However, the difference could drive inefficient decisions in decarbonisation. The key decision points are:

- When does Tiwai exit?
- Is electricity or biomass the best fuel for the electrification of significant industrial process heat in the LSI?

The second decision point could rest on the first. With Tiwai, significant industrial process heat conversion could attract significant transmission costs and/or lower than baseload reliability. Without Tiwai, electricity could be the most economic choice for industrial process heat in the LSI. If biomass is clearly economic under all scenarios, then there isn't an issue. However, further analysis, in and of itself, probably cannot improve clarity here.

Voltage instability in USI during lightly loaded periods after transmission investment for demand growth

This is effectively the same issue as the high voltage issue described above. This issue ranks slightly lower as Transpower (2020a) identifies the high voltage issue as one that could occur now under light loading scenarios, although this issue also ranks high in the probable list as some scenarios explicitly identify high industrial process heat electrification. Otherwise, the issues and uncertainties are the same as above.

Limit on peak capacity to LSI with Manapouri restrictions and/or transmission outages

This issue arises again from the electrification of process heat. Again, the four scenarios that indicated this issue forecast significant process heat conversion and did not have Tiwai exiting. None of the scenarios explicitly forecast industrial process heat growth in LSI, and some judgement was required. This is similar to the limit on LSI import described above but includes Manapouri in the potential mix for causing problems. The issues and uncertainties are the same as above.

Limit on peak capacity to Canterbury with increased peak loading

This is another issue linked to the electrification of industrial process heat. This is a region that has a dairy factory and potentially other industrial demand. If baseload industrial lifted existing peak demand, then import limits would be reached.

Uncertainty – again the uncertainty for this issue revolves around exactly where and how much industrial process heat could be electrified, and whether electrification would be a superior option to other options such as biomass.

Can't manage high voltages in the LSI when lightly loaded

A lot of judgement was required for this issue. This one arises because of the potential for extra transmission investment to the LSI, with the potential for periods of light loading. This could occur with Tiwai exit and a desire to export more generation from the LSI. In the absence of some base load taking up the Tiwai demand, situations could arise when generation and local demand are both low and voltages in the LSI could go very high.

Uncertainty – This issue depends on several factors:

- Tiwai exit
- transmission investment
- new demand
- correlation of low local demand with low local generation.

It could prove to be a significant problem if Tiwai exits and maximum contribution is sought from LSI renewable generation. It could be exacerbated if new renewable generation were to be constructed in the region.

Insufficient peaking capacity in the Upper South Island

This is one of the issues associated with the potential for demand growth from the electrification of transport, which may or may not be helped by solar PV installation. However, voltage is expected to become an issue before thermal limits. The issues and uncertainties are as described above.

High voltage in the UNI during light loading

This issue is a function of supplying high UNI demand with supply from south of Whakamaru. In this case, somewhat ironically, transmission outages during lightly loaded periods can restrict voltage support from power stations in the region, leading to high voltages in parts of the UNI. This is a known issue now that Transpower has solutions for. However, the situation could get worse if electrification leads to peak demand growth in the UNI and supply is predominantly from the south, leading to transmission capacity increases through the Waikato region.

Uncertainty – understanding this issue depends on understanding how the level and profile of UNI is expected to change with electrification, where the grid supply comes from, and the degree to which local DER could assist in managing the issue.

Can’t manage voltage in the USI during transmission outages in the Summer

This issue is similar to the other issues around demand growth in the USI. However, this one arises particularly if electrification of transport and/or industrial process heat leads to proportionally higher summer peak loadings. Under summer line ratings, voltage would become unmanageable with transmission outages.

Uncertainty – again this issue would benefit from understanding how electrification would affect the level and profile of USI demand, but specifically in the summer. It could also be that in summer solar PV contribution eliminates this issue as a problem, particularly if coordinated with EV charging.

Insufficient peaking capacity in the UNI; insufficient standby reserve in the UNI; can’t manage transmission outages to the UNI; can’t manage supply to the UNI with an outage on Unit 5 at HLY

These are all issues related to accelerated demand growth in the UNI. They have the same issues and uncertainties as previously discussed. However, these ones are greatly exacerbated by the exit of the Huntly Rankine units. Most scenarios have the Rankine units exiting by 2030, but there is no clear agreement on what replaces the capability provided by the Rankine units to the UNI.

Of the scenarios that have explicitly considered security of supply and peak security, the universal conclusion has been some form of thermal peaking is required. However, the location of such peaking capacity is also critical. If this peaking capacity was installed in or near Auckland, then it would improve all the issues. If it was installed at Huntly or a similar electrical location in the Waikato, then the issues would at least be no worse. If it was installed in Taranaki or other southern location, then the issues will be worse.

Uncertainty – the exit of the Rankine units by 2030 is a realistic forecast; the units cannot last forever. The form and location of the capability that replaces the Rankine units is critically important. It may be that such peaking capacity can no longer be sited in Auckland; between land values, land availability, and gas pipeline capacity, this may be infeasible. If similar barriers exist to locating peak capacity in the Waikato, then issues will be significant.

As the only currently economic technology identified for the 2030 Rankine replacement in the scenarios is thermal peaking generation, then the Government's policy of 100 per cent renewable by 2030 requires urgent industry response. This policy will not only not allow the replacement peak capacity to be thermal but would also require the removal of Huntly unit 5. Drastic action would be needed to manage Auckland peak capacity in this case. Even if the policy intends, as the previous policy did, to allow some transitional thermal generation for security purposes only, then uncertainty on this point is still likely to mean that no firm generation capacity is being planned for the region. This point needs clarification, and response to that clarity, urgently.

Reiterating from previous uncertainties, understanding how DER might actually affect the level and profile of UNI demand and whether it can usefully be deployed to help these issues would be valuable.

Don't meet Winter Energy Margin

All the scenarios have the current WEM being not met at some point. Some are well into the future, but some expect fast electrification and, in one, the WEM is exceeded within five years. Eight more indicate the WEM could be eroded within 10 years, including probable scenarios. The macro issue, regardless of timing, is how could policies for electrification lead to fast demand growth and would generation investors have the information and time to respond.

This issue also ranks highly on the probable list as some scenarios anticipate fast demand growth for electrification.

Uncertainty – the key uncertainty is what will be the policy levers to influence electrification, when would these levers apply, and what could the speed of response be.

Don't meet Winter Capacity Margin

The dynamics here are the same as for WEM. Because the ranking is based on the frequency of near-term occurrence for possible scenarios, then this issue ranks just behind the WEM. However, for most scenarios, the WCM is eroded before WEM. The issues and uncertainties are much the same, but assessments of the profile of demand growth under fast electrification could change the order in which the WEM or WCM are considered the more serious.

This issue also ranks highly on the probable list as some scenarios anticipate fast demand growth for electrification.

Overloaded GXPs

This is the highest ranked issue under the probable scenarios. This is because Transpower has already identified several GXPs supplying dairy factories where the electrification of the process heat would overload the GXP. For the GXPs identified, Transpower has possible solutions. Exactly how many, and which, GXPs will be overloaded would depend on how much process heat is electrified, how fast, and where.

Uncertainty – apart from some initial work on dairy factories by Transpower, we don't know where and how much process heat conversion might be electrified. In aggregate, many scenarios have predicted how much process heat would be converted. However, 'how much' and 'where' are the critical criteria for assessing security, reliability, and resilience concerns. A key question is, could electrification policies lead to a rate of overloading of GXPs that is faster than Transpower can manage? In addition, for every GXP affected, at least, the distributor will also have issues.

Voltage instability in LSI with Manapouri outages

This is the first issue where it isn't expected to be an issue within the next five years, but 11 scenarios have it as an issue within ten years. Although, a lot of judgement was required to assess this one. This is another issue that could depend on the exit of Tiwai. It could also be triggered with the electrification of industrial process heat, which may make it more urgent. This was predominantly assessed based on how much underlying load growth might be encouraged by 2030.

Uncertainty – this issue could become more urgent than currently assessed. It could also be that anything that might affect high or low voltage levels in the LSI will rely heavily on Manapouri. This might include Tiwai exit, industrial process heat electrification, transmission upgrades, and underlying load growth.

Limit on wind generation export from Canterbury

This issue is related to the degree of wind generation that might be developed and how much is in the Canterbury region. Our assessment is based on North Island wind sites being developed before large-scale South Island wind resources. If SI resources were to be developed at the same time or before large-scale NI projects, then this issue would become more urgent.

Uncertainty – the location and timing of wind development to meet the most aggressive electrification plans is the key uncertainty for this issue.

Insufficient over-frequency arming response with dispatch of DER

This is the first occurrence of a DER related ranking in the possible list. Most high DER related issues occur in the probable list. This is because Transpower has assessed the grid's hosting capacity of solar PV and determined that the grid could host 4GW with issues starting at 2GW. As most scenarios have specific solar PV forecasts, most DER issues are either probable or don't occur.

This issue features in the possible list because it could occur with hundreds of MWs rather than thousands. It is the issue where DER is dispatched, or simply deployed, ahead of OFA plant and so there is insufficient OFA capacity available.

Uncertainty – there are wide differences between the scenarios. For example, Transpower's Te Mauri Hiko forecasts have the fastest investment in DER in most of their scenarios, while none of the EDGS scenarios reach 2GW, although their forecast period ends at 2035.

If DER investment is likely to be fast, then all DER related issues will become more urgent.

Reduced inertia with light loads during bright days leading to more severe frequency events

This issue doesn't rank in the probable list as Transpower's assessment of hosting capacity didn't come to any conclusions about inertia. If inertia does become a problem, influencing the severity of frequency events, this is the issue where it might first manifest.

Uncertainty – the degree to which inertia could be affected by future asynchronous technology is an uncertainty. It would also be affected by other choices, such as whether thermal generation was used for peaking capacity. The inertial problem might still occur but then running OCGTs as synchronous motors could be one solution, or batteries could also provide a solution. This issue needs a lot more study. It also needs to consider whether there could be significant change to inertia on the demand side.

Insufficient frequency regulating capacity with dispatch of DER

This issue is very similar to the lack of OFA above and could occur when DER is dispatched, or deployed, ahead of plant that provides frequency regulation. However, DER could also be a solution to the problem.

Uncertainty – the uncertainties are the same as above, but the issue of whether DER could provide alternate frequency regulating services would also be worth exploring. Perhaps DER could also provide OFA.

HVDC limited due to shutting down filter capacitors due to high LSI voltage

This issue is a consequence of another issue but creates new problems. In the event of more transmission being built to move power in and out of the LNI, including HVDC transfer, high voltages could occur during lightly loaded periods. These periods might then require the shutting down of filter capacitors to mitigate the voltage, thereby limiting the HVDC.

Uncertainty – this issue might only occur if high voltages need to be managed in the LNI. Even then, this issue may not be a practical problem as lightly loaded lines may mean low HVDC transfer anyway. It would be worth understanding if this issue could occur, perhaps in the condition where it is intended to supply Wellington (with higher demand) from the South Island, but the AC lines north are lightly loaded.

Limit on effective southward HVDC capacity in dry years with a different mix of NI dry year reserve and transmission outages

When high southward HVDC transfers are required several AC transfer constraints can occur. This can make the mix of Huntly to Stratford thermal generation difficult sometimes. If dry year reserves come from different locations in the North Island then the constraint problems could get worse, especially with transmission outages.

Uncertainty – some forecasting of potential dry year supply options is needed to test the ability for the dry year reserve energy to be transmitted south when it is needed.

High voltages in LNI with new transmission and during lightly loaded periods

This issue potentially arises if new transmission is needed to move power in and out of the LNI. Then, during lightly loaded periods potentially exacerbated by solar PV contribution, voltages in the LNI could get too high. A consequential issue, as above, is this could require a limit on the HVDC to enable filter capacitors to be switched out.

Uncertainty – this issue needs a specific set of circumstances to occur, However, it is plausible that transmission is built for wind energy to be transmitted north, but there would still be times when power transfer is southward. Then, under lightly loaded conditions, the issue could occur. More certainty about where and how much wind might be built would help and assessment on the volatility of net import to and export from the LNI.

Limit on export from LSI for increase in net generation

Export limits could occur if net generation from LSI increases. This can occur through two mechanisms, Tiwai exit, and/or generation expansion in the LSI. Most scenarios forecast a significant increase in wind generation and some also feature an increase in hydro generation. Depending on how much new generation comes from LSI, through new generation sites or potentially efficiency gains from the Clutha scheme, and maybe more from Manapouri, then export may be limited.

Uncertainty – again some more specific forecasts about where and how much new generation will be built would help assess issues such as this.

Reduced inertia leads to severe frequency events if dry year reserve is replaced with asynchronous plant

This issue is similar to the reduced inertia issue above but could be more prevalent. This issue ranks lower than the other reduced inertia issue as most of the scenarios that have addressed security of supply have retained some thermal peaking capacity. If it is increasingly plausible that asynchronous plant may take the dry year reserve role, or in light of the Government's 100 per cent renewable by 2030 policy, then inertia could be an issue.

Uncertainty – there is still little known about the inertia issue, especially if it is also changing on the demand side and the role of batteries and DER in providing an equivalent service.

Insufficient investment in NI IR capacity with mostly small unit sizes but with HVDC risk

Investors may find it difficult to justify investment in IR if new renewable units are quite small. As the HVDC self-covers most of the time then IR prices would be near zero most of the time. It would only be occasionally that a risk on the HVDC might lift IR prices. This might again be tied to the security of supply solution(s). If thermal peaking is retained, then IR prices may not be too dissimilar to now.

Uncertainty – it would be worth understanding the IR prices under scenarios where most unit sizes are quite small and the HVDC risk, when it binds, is large. An assessment of the forecast price sequence should then assess whether this would be too risky for investors in IR.

Problems with import capacity to SI and sometimes LNI in dry years

Import problems potentially exacerbated where:

- dry year reserve provided by NI wind overbuild
- dry year reserve is concentrated in Waikato and north
- dry year reserve is concentrated in Taranaki
- exacerbated by transmission outages.

Southward transfer in dry years can be affected by several AC constraints. The current system has been adjusted to allow for southward flow in balance from Taranaki and Huntly. If dry year reserve is concentrated in either area, or comes from new areas, then the constraint problems may be worse.

Uncertainty – the potential solutions for dry year reserve, and security of supply generally, can each have a significant impact on southward transfer in dry years. It would be worth understanding the potential solutions and how each impacts on southward transmission.

Potential shortfall in IR supply depending on what replaces the Huntly Rankine units, potentially exacerbated by transmission outages

The steam pressure of the Rankine boilers provides significant six second Fast Instantaneous Reserve (FIR). The eventual removal of the Rankines, depending on the plant that replaces the role performed by the Rankines, may not have the same FIR characteristics, which might mean a requirement for more FIR that isn't available. Depending on where the new reserve providers are concentrated then transmission outages may need to limit reserve provision.

Uncertainty – most scenarios that addressed security of supply assumed some residual thermal peaking. However, these scenarios were still simplifications and OCGTs do not have the same FIR characteristics as Rankines. It would be worth assessing these secure options to see if they have adequate FIR response. The problem could be even worse if security of supply is provided by renewable plant. However, batteries and DER could offer an even faster response that could reduce the overall requirement for FIR.

Limit on import to UNI with increased net generation in Taranaki

Taranaki can be a difficult region to export from. If there is increased net generation in Taranaki, then it might be limited how much can support UNI load. This issue is most likely to occur under scenarios that anticipate security of supply is provided by some thermal peaking if that thermal peaking were to be concentrated in Taranaki. However, if significant wind were to be developed in Taranaki, then this could also trigger the issue.

Uncertainty – again this issue could be better assessed with more detailed locational forecasting of security of supply options and wind development.

Retirement of Huntly Rankines before replacement generation for its firming role is built erodes the Winter Capacity Margin

This issue anticipates that one or more Huntly Rankine units could be retired before replacement generation is built. The Huntly Rankine units are nearing end of life and few scenarios suggest they will still be operating after 2030. This issue could come about either because current policy uncertainty delays dry year reserve and security of supply solutions, and/or a catastrophic failure leads to an early retirement for one of the units.

Uncertainty – most scenarios that considered security of supply retained some thermal peaking capacity. However, with current policy settings thermal generation is more likely to be displaced and new investment is unlikely. The fuel for any such peaking plant is also a concern. But, it is not clear that renewable security of supply options will be available by 2030 either. This issue doesn't rank higher because many scenarios had sufficient thermal capacity by 2030 even with the removal of Huntly Rankines. Some significant factors have changed since these scenarios were developed.

DER tripped with load in an AUFLS event results in insufficient net load reduction, and the net load response is variable

At the point where DER becomes significant then it will affect net load on feeders. This will make it likely that, at some point, AUFLS relays will not trip sufficient net load when activated. This issue ranks low on the possible list because it ranks high on the probable list, although many scenarios have slow growth in solar PV/DER. Nevertheless, most scenarios reach significant levels of DER at some point. As the potential contribution of DER will not be correlated to the load profile the net load response from an AUFLS trip would be highly variable.

Uncertainty – this issue seems difficult to avoid with current AUFLS trip relay approaches. It seems likely that technology could provide a more targeted solution. However, any replacement for AUFLS needs to have protection grade reliability and needs to be fast. The urgency of this issue depends on the speed of growth of solar PV/DER. Under the fastest scenarios this issue is both difficult and urgent.

Over 2GW of solar leads to ramp rates too fast for current plant and potential for harmonic distortion, especially in distribution

With significant solar PV then, when sunset occurs just before an evening peak the resultant ramp rate could be too fast for the current system to deal with.

With significant solar PV output then the reduction in net import reduces the fundamental current whereas harmonic frequencies may not be attenuated. This could lead to unacceptable proportions of harmonic distortion.

Uncertainty – 2GW has been used as the threshold for both cases as it is a significant level of solar PV deployment. However, Transpower's analysis was quite high-level and did not consider the harmonic issue. More analysis is needed to determine how big a resultant ramp rate could be.

The harmonic issue has been identified theoretically but is yet to be assessed for a practical situation. This is likely to mainly affect distribution, but it would be worth understanding if the low fundamental current points could be pushed back into grid assets without attenuation. This might especially affect GXP transformers.

Over 2GW of uncoordinated solar PV leads to high voltages, and reduced distribution network capacity

Significant solar PV take up that is uncoordinated in both its active generation and reactive power response could lift distribution network voltages high. In regions that already have voltage issues, such as the UNI, then maybe the solar PV could also affect transmission. As voltage is critical to managing distribution capacity then this could both affect the solar PV hosting capacity of distribution networks, and the load capacity.

Uncertainty – 2GW has been used as it is a significant contribution of solar PV. However, the Transpower analysis didn't consider distribution effects. How much solar PV – or other uncoordinated DER contribution – might affect voltage is unknown. It also remains to be seen how much coordination might improve the situation and how that would impact on solar PV utilisation.

Insufficient grid voltage regulating capacity with dispatch of DER

This issue is similar to other issues of sufficient grid plant for regulation when displaced with DER. This issue doesn't rank as high as the frequency issues though. As different plants have different frequency regulating responses, the potential for concentration of the problem exists, whereas most grid plant has a relatively uniform voltage and reactive power response. Nevertheless, if non-regulating DER displaces voltage regulating grid plant, then there could be a problem; and, with voltage, location matters.

Uncertainty – this issue is much less of a concern if it can be shown that DER can be coordinated to provide grid level regulation.

Increased high voltage problems with transmission investment during periods where light load is further reduced with DER

This is a general issue where transmission investment is built to enable grid scale renewables but there is also significant DER deployment. During lightly loaded periods there could be significant solar PV contribution reducing loads further. In areas supplied by the extra transmission this could yield high voltages.

Uncertainty – this issue features in scenarios with the largest forecast electrification. Under these scenarios it is feasible that both significant grid scale renewables and DER is built. The degree to which that might require transmission investment and how low residual demand (net of DER) might be is uncertain.

Retirement of Huntly Rankines before replacement generation for its firming role is built erodes the Winter Energy Margin

This is the same issue that affects the WCM above. However, the ASOSA2020 determines that WCM is eroded before the WEM. This is enough to push this issue further down the rankings. The issues and uncertainties are similar to the WCM discussion above.

Significant DER deployment downstream of some Auckland GXPs leads to high fault currents

Some Auckland GXPs could suffer high fault currents if active generation sources are added within the distribution network.

Uncertainty – whether this actually becomes an issue or not would depend on the concentration of DER in certain GXPs and the degree to which downstream injection sources actually affects fault current. Applying suitable injection characteristics to DER may also mitigate the problem, but this would need to be assessed.

Unfortunate combinations of non-linear response, inductance, and capacitance leads to resonant voltages and/or harmonic distortion

With so much more embedded power electronics, with the potential for unexpected non-linear response interacting with inductance and/or capacitance could lead to seemingly random resonance or harmonic distortion events.

Uncertainty – this issue could be very difficult to assess. If issues are likely to occur, Auckland seems like a likely candidate. It is a region already susceptible to voltage instability and with large amounts of installed capacitance and potentially high inductance when transmission lines are highly loaded. It might be worth assessing the potential for resonant frequencies and then testing the effects of non-linear load response to transients.

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