TRANSPOWER

Opportunities and challenges to the future security and resilience of the New Zealand power system

Draft report for discussion

Version: 1.0

Date: November 2021

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Foreword

Aotearoa's electricity sector is on the cusp of a once in a generation transformation. This report, commissioned by the Electricity Authority, is the first phase in a project to plot a course through the transformation to come which will see our electricity system become more renewable, variable, digitised and distributed with a higher proportion of inverter based supply.

Our transformation is being driven by technology, economics and a wider external context focused on the move towards a 100% renewable electricity system which will be the primary platform for creating a net-zero emissions economy by 2050.

This transformation presents many opportunities and challenges. The challenges include the need to identify those issues that could stand in the way of a smooth transition, be they technical or related to regulatory settings. Dry year risk and core market design are outside the project's scope.

The opportunity is to harness the cost and flexibility advantages of our future system to enhance system security and resilience both as the new system is put in place, then over the long term.

Three technologies stand out as being pivotal to the transformation of the supply side of the electricity system over the next ten years. These are wind, solar photovoltaics (PV), both rooftop and network connected, and batteries. Recent deployments, in-flight projects and a steady stream of new announcements demonstrate that these three technologies are setting the stage for a shift away from more traditional, predominately synchronous, forms of generation. Notwithstanding further investment in synchronous geothermal supply, we anticipate a system that will be more variable, less synchronous and that has more inverter-based supply. All these factors bring their own challenges in maintaining system security.

The ability of the system to integrate the wide-spread uptake of these technologies is a function of system strength. In rising to the challenge, we have the benefit of much overseas experience in dealing with low system load during periods of high self-consumption of variable renewables and the voltage stability challenges that can bring. It is a similar story in terms of frequency management with the shift from synchronous to inverter-based supply.

On the demand side, there is the potential for a digitisation revolution driven by the mass deployment of distributed energy resources (DER). The potential for millions of connected, smart, devices to be harnessed to provide demand response, load shedding or load shifting has massive potential to help manage demand, especially around the peaks, and to maximise the utilisation of variable supply.

Sector coupling is another emerging issue, especially between electricity and transport. The sort of rapid uptake of electric vehicles consistent with meeting emissions goals is another example of both a challenge and opportunity. The challenge is around their system integration, but, get this right, and the opportunity is to harness the mass deployment of potentially millions of battery storage systems on wheels to manage peaks, shift demand, provide load and, to some extent, injection.

All of these factors raise the stakes around the imperative to maintaining, and enhancing, system security and resilience through the transformation to come.

The objective of this report is to set the scene for what is to come. In it we provide an overview of today's system, define what we mean by security and resilience and set out in some detail what the future might look like. From this base, we have been able to identify likely opportunities and challenges we will face.

Inevitably, this report is scenario based. Nobody can say with certainty what our system will look like in 2030, but the direction of travel is clear. It is anticipated that the system will become more decentralised with assets distributed further down the line into local networks and towards the point of use than at present. The deployment of more wind and solar PV will make the system more variable. The retirement and displacement of synchronous plant will change the system's operational characteristics as it becomes more inverter based. Digitisation and DER means the system will likely become much more multi-directional in its operation.

A such, this report sets the scene. It is the foundation for a collaborative work programme between the Authority, assisted by Transpower, and the wider sector. Its content is to be discussed, refined and improved though a programme of sector collaboration to ensure that all views and perspectives are heard. This phase, Phase 1, should be completed by the end of December 2021.

The completion of Phase 1 sets the scene for Phase 2: the creation of a roadmap for action so that, together, we can establish the necessary programme of work to address the many challenges and opportunities identified through Phase 1. This should be complete by the end of March 2022. Phase 3 concerns the ongoing delivery of the Phase 2 roadmap.

We are in good hands. The sector is already engaged in how best to deal with many of the challenges ahead. There is a real appetite for new investment in new renewable generation, policies are in place to drive the electrification of our vehicle fleet and the process heat sector and to build new sectors such as data centres and potentially green hydrogen production utilising highly renewable electricity.

We are also very well placed to be a fast follower and learn from oversees. Our Australian friends are proving to be most instructive in this regard. Luckily, the scale and pace of our own transformation is likely to be much less than that they are experiencing which is akin to changing the engine in the car whilst driving down the road.

I look forward to the collaboration to come as we go through our own transformation together.

Dr Stephen Jay

General Manager Operations, Transpower New Zealand Limited

Contents

1.0 Context

New Zealand's power system is on the cusp of significant transformation as New Zealand pursues its climate change ambitions. This transformation is driven by four key factors:

- decarbonisation of the electricity industry – reducing greenhouse gas emissions by increasing renewable generation, such as wind and solar photovoltaic (PV), while reducing reliance on gas and coal fuelled generation
- decarbonisation of the wider economy – reducing the use of fossil fuels by increasing electrification throughout the economy including process heat and transportation
- distribution – increasing adoption of distributed energy resources (DER) such as solar PV, electric vehicles (EV), batteries and smart appliances throughout the power system
- digitisation – increasing volume of data and the digital tools necessary to manage increasing energy resources and complexity.

Figure 1 below shows the impact of these four factors on the current power system and the changes expected by 2030.

Key trends	Current	2030
Decarbonised: Transition to 100% renewables	• 85% renewable electricity • Mostly synchronous generation • Security of supply managed by market • Thermals to meet peaks and dry years • Small amount of DER	• 100% renewable electricity • More asynchronous and inverter-based generation • Will energy-only market manage security of supply? • New solutions needed for peaks and dry year • Increased reliance on DER
Decarbonised: More electrified economy	• High reliance on electricity in the economy • Electricity not relied on heavily for transport • Few, traditional demand growth sources – new industry, new housing	• Very high reliance on electricity in the economy • Electricity relied on heavily for transport and in industry • Many different demand growth sources – hydrogen, data centres, EVs, process heat
Distributed: More distributed electricity system	• Small amount of DER • Limited performance requirements in the Code but small penetration means this is not yet an issue • Limited use of demand-side and battery technology to manage peaks	• Millions of DER able to manage peaks in real-time (EVs, batteries, smart appliances) • Multi-directional power flows • More consumer participation and more market players • Potential issues caused by inverter-based DER
Digitised: Increasing digitisation and use of digital tech	• Increasing data and data management requirements • Gradual use of automation for control and switching • Increased use of data-driven decision making	• Increased complexity and volume of data • Expectation from operators and customers that controls, and communications will be automated and data-driven • Opportunities to improve consistency and efficiency

Figure 1 - Key trends in energy transformation and anticipated outcomes in 2030

The transformation of the power system will result in:

- a move from a largely centralised power system, where large-scale generation of electricity occurs at central power plants connected to the grid, to a more decentralised power system, where more energy sources are located outside the grid, which will challenge the existing industry operating boundaries
- an increase in variable and intermittent energy sources, being wind and solar, to meet increasing demand from transport and process heat electrification
- the displacement and retirement of synchronous generation, e.g. coal and gas fired generation, together with an increase in inverter-based resource (IBR) generation, being wind and solar PV
- a switch from passive consumers to active consumers, who can feed excess generation from DER back into the distribution network and manage their electricity usage.

Despite the power system undergoing such a huge transformation, the underlying physics that determine how electrical energy flows remain the same. At the highest level, stability and the ability to quickly recover from supply disruptions are fundamental requirements for managing a power system. Voltage management, frequency management and the ability to flex supply to meet demand are essential for preventing supply disruptions but also preventing transmission and distribution assets from being subjected to undue stress. As New Zealand transitions to 100 per cent renewables it is critical that these requirements can still be met with a changing generation mix and an increase in demand.

Clearly, these changes will impact generation, transmission, distribution and consumption of energy in New Zealand. In the face of such widespread change it is useful to remember that electrons do not recognise operational or ownership boundaries and all power system components will need to securely integrate to deliver electricity to consumers. The future security and resilience programme will assist in delivering a prioritized and coordinated approach which will be essential in achieving New Zealand's energy ambitions.

2.0 Executive Summary

This report, commissioned by the Electricity Authority, outlines potential opportunities and challenges to the future security and resilience of the New Zealand power system considering New Zealand's changing energy context driven by decarbonisation, distribution and digitisation.

The intent of producing this report is to enable a shared understanding of different opportunities and challenges to the future security and resilience of the power system considering New Zealand's context and provides a starting point for engaging with industry to develop a long-term roadmap to address these in an efficient and timely manner.

Security is considered the ability of the system to withstand disturbances, ensuring a steady and stable grid that delivers generation to where it's needed. Whereas resilience in our context is taken as our ability to identify and mitigate high impact low frequency (HILF) threats quickly and efficiently to ensure the least possible damage to infrastructure and support services, while enabling quick recovery and restoration to a stable operating state. This is becoming increasingly important as HILF events such as extreme weather events increase due to climate change.

While no one knows exactly what the future will look like, the following points and trends all have implications for security and resilience of the power system and are likely to occur under most future scenarios as we electrify the economy and push for higher levels of renewable generation:

- the physics of electricity remain the same and electrons don't recognise operational or ownership boundaries
- a move from a largely centralised power system to a more decentralised power system
- an increase in variable and intermittent energy sources, being wind and solar
- the displacement and retirement of synchronous generation, together with an increase in inverter-based resource (IBR) generation, being wind and solar PV
- a switch from passive consumers to active consumers.

While core market design and energy adequacy during dry winters both have implications for power system security and resilience, given work presently being undertaken in these areas by others we have excluded any associated opportunities and challenges from this report.

We also acknowledge that Transpower, as System Operator, is not an expert in distribution network design and operation and therefore have only included opportunities and challenges where we see distribution level trends impacting on grid operation. Other specific opportunities and challenges relating to distribution networks not covered in this report will also need to be addressed in the future to ensure the ongoing security and resilience of the New Zealand power system.

Considering the above we reviewed our previous work and other international jurisdictions experiences in incorporating high levels of renewable generation to identify the following opportunities and challenges to the future security and resilience of the New Zealand power system:

The rise of Distributed Energy Resource (DER) – opportunities and challenges

- Leveraging DER to build and operate the future grid: Increasing DER (e.g. solar PV, electric vehicles (EVs), battery storage) provides an opportunity to avoid transmission, distribution and generation costs by using these resources to shape the daily load curve such as reducing daily peaks.
- Leveraging new technology to enhance ancillary services: The introduction of new technologies such as batteries provides an opportunity to enhance existing ancillary services relied on by the System Operator to maintain frequency, voltage and for restoration of the power system after a blackout. These technologies could also provide new services, such as synthetic inertia or very fast instantaneous reserves if required.
- Visibility and observability of DER: The performance and impact of increasing DER on the power system needs to be monitored and managed as the power system becomes more decentralised.

The challenges of the changing generation portfolio

- Balancing renewable generation: An increase in variable and intermittent renewable energy sources, i.e. wind and solar PV, will make balancing demand and generation more challenging and is likely to result in more frequency fluctuations.
- Managing reducing system inertia: Low system inertia is a key characteristic of New Zealand's power system today with frequency management being essential to the secure operation of that system. Increasing IBR generation and displacement of synchronous generation will fundamentally change the way system frequency responds to imbalances in power.
- Operating with low system strength: Low system strength is another key characteristic of New Zealand's power system today with voltage management being essential under these conditions for secure operation. Higher proportions of IBR generation will alter the way low system strength needs to be managed to avoid operational issues arising including reduction in power quality. There is a limit to the amount of IBR generation that a low system strength power system can take considering current technology.
- Accommodating future changes within technical requirements: As DER and IBR increase, and the power system becomes more decentralised, a challenge arises to update and reflect those changes in the current technical requirements set out in the Electricity Industry Participation Code, technical standards, grid and distribution operation processes and procedures. Revised requirements need to ensure any new technology can be easily integrated, that all technology can operate to its optimal capacity and that all parties meet the obligations specific to the technology they're connecting.

Other opportunities and challenges

- Loss of control due to cyber security breach: As technology continues to transform the power system, the grid will become smarter, more observable with an ever-increasing reliance on data management, automatically controllable and more accessible to users. As a result, it will be more vulnerable to cyberattack.
- Coordination of increased connections: Moving away from a centralised power system, with predominately large generating units, to a decentralised system, with vast amounts of DER, will challenge how new connections are studied and managed to avoid operational issues.
- Growing skills and capabilities of the workforce: As technology changes the current workforces' skills and capabilities need to evolve to ensure we continue to provide quality services and overcome any challenges that arise in the future.

Based on our experience and knowledge as System Operator, we have included our view of the likely timeframe for the opportunity or challenge to present, along with a proposed priority for addressing each considering their implication on future security and resilience as summarised in Table 1 below.

Table 1 FSR dashboard

Opportunities & challenges	Timeframe	Priority
Leveraging DER to build and operate the future grid	3-7 years	Medium
Leveraging new technology to enhance ancillary services	Enduring	Low
Visibility and observability of DER	3-7 years	Medium
Balancing renewable generation	3-7 years	Low
Managing reducing system inertia	7-10 years +	Low
Operating with low system strength	3-7 years	Medium
Accommodating future changes within technical requirements	0-3 years	High
Coordination of increased connections	0-3 years	High
Loss of control due to cyber security	Enduring	Medium
Growing skills & capabilities of the workforce	Enduring	High

3.0 Purpose of the Future Security and Resilience Programme

As New Zealand's power system is transformed it's important to understand the implications of the changes on the security and resilience of the system to ensure that as an electricity supply industry we can continue to coordinate and operate the power system, as well as continuing to meet consumer expectations.

The Electricity Authority has engaged Transpower, as System Operator, to develop a shared understanding of the future opportunities and challenges for the ongoing security and resilience of New Zealand's power system, and to outline how they can be addressed in an orderly and timely way. That work will be undertaken within what is being called the future security and resilience programme of work.

The programme is being undertaken in three phases (as shown in Figure 2 below):

- Phase 1: This report which identifies the potential security and resilience opportunities and challenges for the New Zealand power system arising from expected future changes in technologies and use of the system. Due to be completed by the end of December 2021.
- Phase 2: A roadmap that outlines a pathway to understand and address these opportunities and challenges in a timely manner and an approach for monitoring the manifestation of risks. Due to be completed by the end of March 2022.
- Phase 3: Delivery of the programme of work outlined in the roadmap. Ongoing from the end of March 2022.

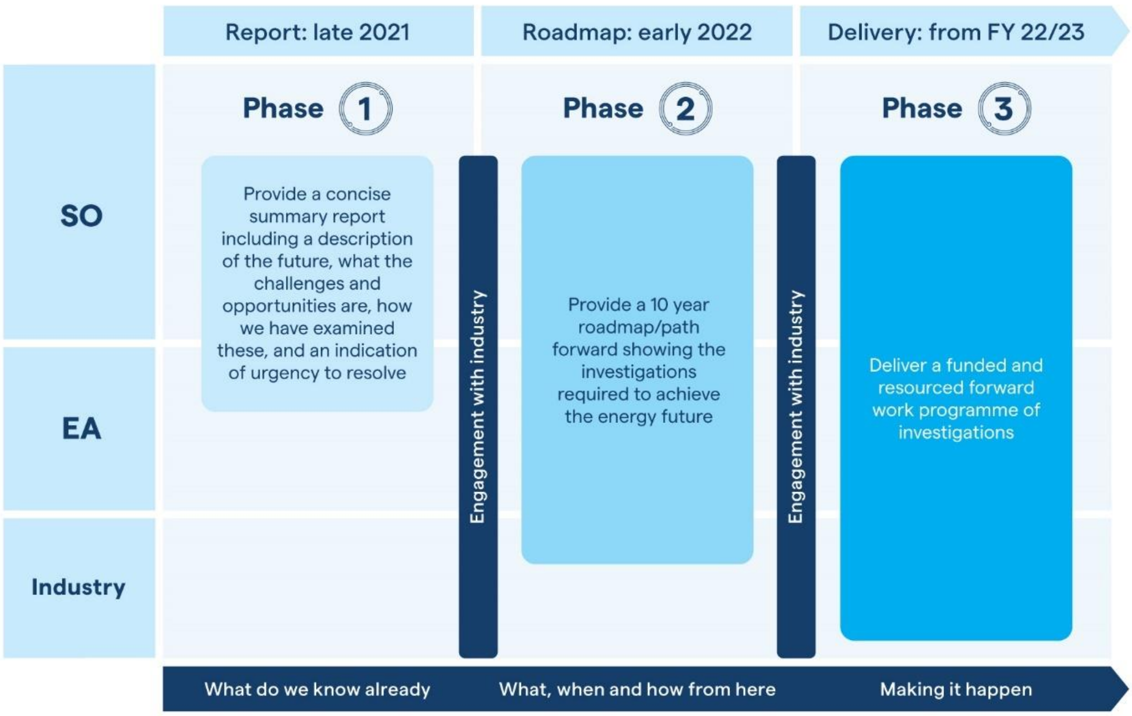


Figure 2 - Phases of the future security and resilience programme

It is important to note that Phase 1 (this report), is essentially delivering opportunity and problem definitions for the future. It is not intended to scope the activity required or propose solutions for each opportunity or challenge. This activity will form part of Phases 2 and 3.

It is also notable that there are multiple other future-focused initiatives being undertaken concurrently by the Authority and the likes of the Market Development Advisory Group (MDAG), Innovation and Participation Advisory Group (IPAG) and the Ministry of Business, Innovation & Employment (MBIE)..

Power system security is focused on real-time, 'now', activities e.g. frequency management. Power system resilience is focused on activities which follow an unplanned event. Consequently, this report focusses on opportunities and challenges which either present in, or which enable successful delivery of security and resilience in, real-time.

Accordingly, despite the anticipated future outlined in this report having broader ramifications than power system security and resilience, the scope of this report excludes consideration of:

- energy supply security (adequacy) including the dry year risk. Management of dry year risk in future is being considered by MBIE in its New Zealand Battery Project, and efficient pricing during extended periods of scarcity by MDAG in its 100% renewables project
- distribution network design and operation, except when distribution level impacts are also observed on the transmission network
- recommending change to core electricity market design.

As can be seen in Figure 3 there are many interdependencies between the various initiatives currently underway. Consideration of those interdependencies and the potential for 'win-win' outcomes will occur in Phase 3 (solution design) of the FSR programme. Phase 3 will have pan-industry engagement to enable the requirements of different parties in the industry to be heard and the optimal solution designed.

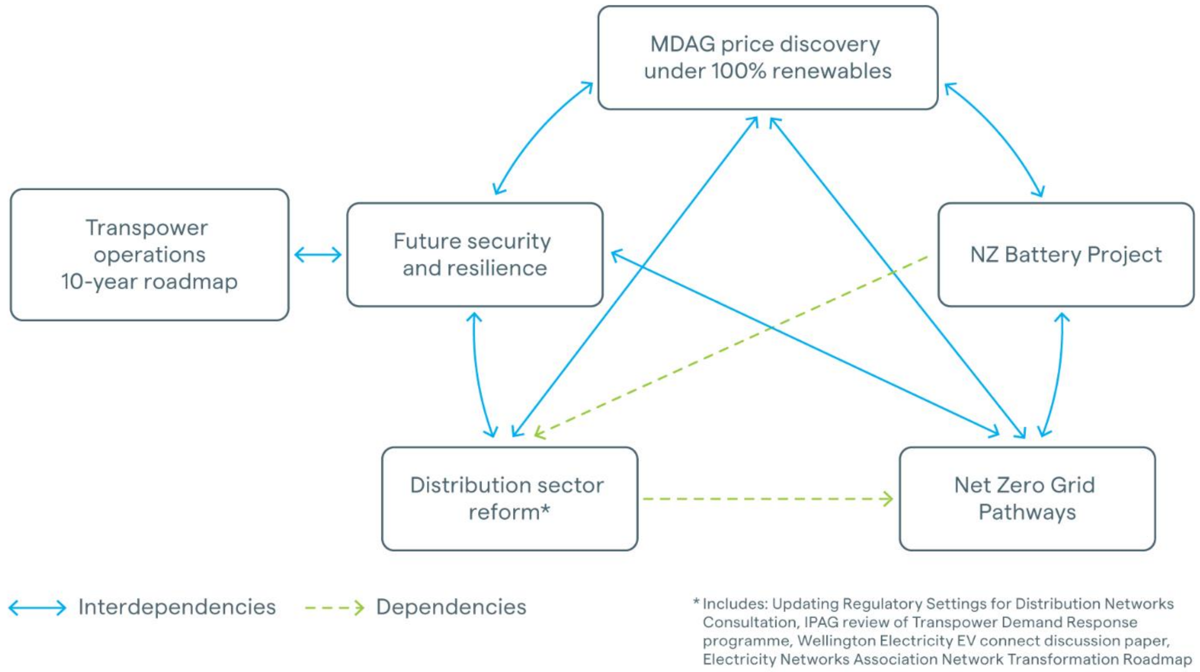


Figure 3 - Known future security and resilience interdependencies and dependencies

All these initiatives may inform future changes to market design. For example, Phase 3 of the FSR programme may identify a need for new ancillary service. It will also enable trade-offs between market and non-market solutions to be considered as well as determinations around cost allocation. The Authority's support [1] for the recommendations made by MDAG means MDAG's paper "Enabling participation of new generating technologies in the wholesale electricity market" [2] will be a key input to Phase 3 of the FSR programme.

To compile this report several assumptions have been necessary to make. Chief amongst these is that the System Operator role will endure and be the party responsible for the provision of security and resilience for the New Zealand power system. Whilst significant change is expected to occur in the future, the grid, grid connected generation, provision of ancillary services over the grid, and some form of central coordinator are assumed to remain in the future.

While there will undoubtedly be changes in exactly how it works in the future a second key assumption is the wholesale electricity market will endure, as its core roles will continue. Generators will offer their capacity to market and purchasers will source power from this market. Consequently, the need to dispatch wholesale market participants is also assumed to remain in the future.

It is acknowledged this report is a 'top-down' view - this is the current role of the System Operator. When the FSR programme moves into Phase 3 and solutions begin to be designed, a key priority for the Electricity Authority and the System Operator will be to ensure the voices of consumers, distributors, and others within the industry are heard.

4.0 Overview of the New Zealand Power System

The New Zealand power system is relatively small and isolated, with no inter-connection to other power systems. The grid comprises of a transmission network made up of a core backbone of 220 kV and 110 kV transmission lines, along with a HVDC link connecting the North and South Islands [3]. Energy is fed out of the transmission network directly to large industrial loads and lower voltage local networks which distribute this energy on to smaller consumers.

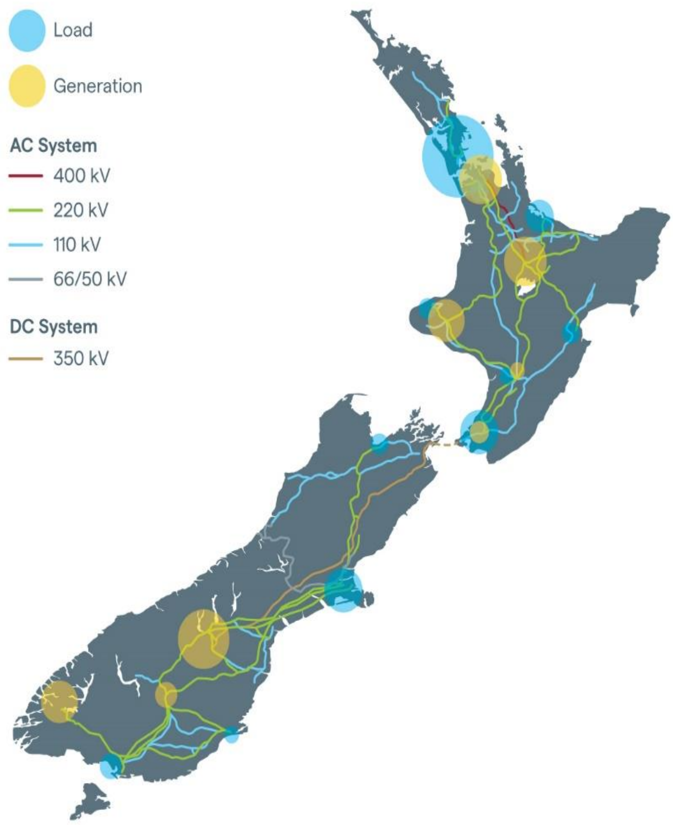


Figure 4 - New Zealand power system overview

Major generation sources are remote from most major loads. As a result, the amount of electrical power that can be delivered through the grid to supply these loads is constrained in some major centres (in particular, Auckland).

Most of the time, excess electricity from South Island hydro generation is exported through the HVDC link to supply load in the North Island.

The system has a mixture of generation types, including fast-ramping hydro, slower-ramping thermal, constant geothermal and variable wind and solar PV.

As shown in Figure 5, today our system has a high proportion of dispatchable renewable generation resources (hydro and geothermal) and a low proportion of non-dispatchable renewables (wind and solar PV[1]). Non-renewable generation includes thermal (diesel, coal and gas) and cogeneration (industrial processing and electricity generation).

[1] Solar PV is not included in Figure 5 along with other distributed generation (not offered into the market or visible to the System Operator). Today there is approximately 170 MW of installed distributed solar PV generation capacity. Source: Electricity Authority - EMI (market statistics and tools) (ea.govt.nz)

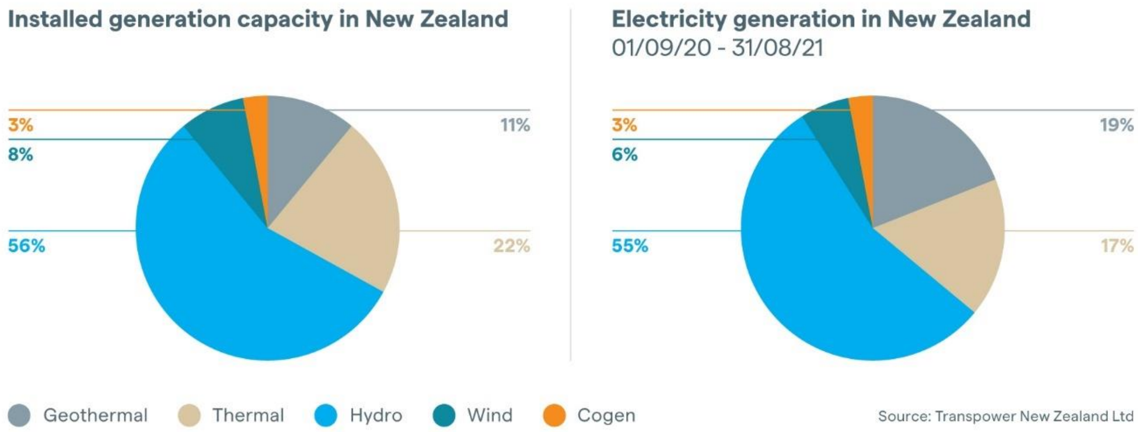


Figure 5 - New Zealand wholesale electricity generation (Source: Transpower New Zealand Ltd)

For contextual purposes, the North Island power system serves an island maximum load of 4,847 MW, and the South Island a maximum load of 2,319 MW. As shown in Figure 6 below, peak system load in New Zealand occurs during the early evening in winter when consumer demand is greatest for heating and cooking. A second, smaller peak is observed every morning as consumers wake and prepare for their day.

During the late evening and early morning, low system demand is experienced as New Zealand sleeps, with the lowest system loads occurring in summer. During these low demand periods managing high voltages in areas such as the Upper North Island (UNI) and Upper South Island (USI) can be tricky due to the lightly loaded state of the grid and there being less generation available online near to the affected regions to provide voltage support.

New Zealand's power system has inherently low system strength and low inertia compared to many jurisdictions, particularly those which are interconnected to other jurisdictions.

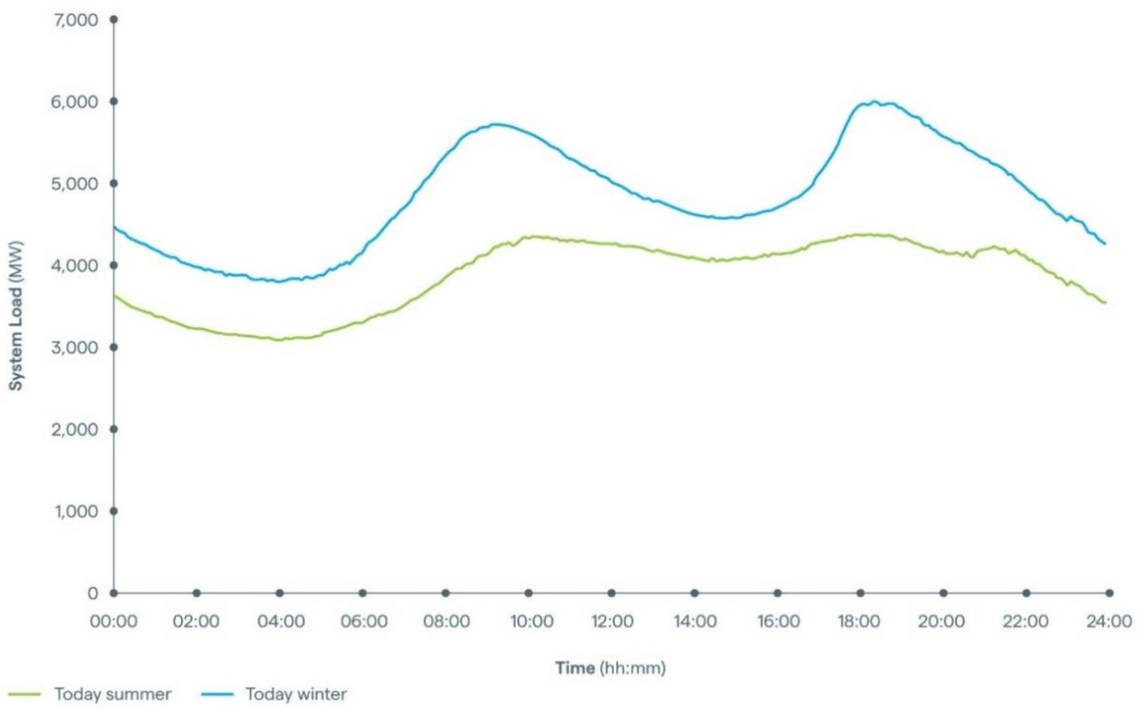


Figure 6 - Typical summer and winter daily load profiles (Source: Transpower New Zealand Ltd)

5.0 What is Security and Resilience and How Is It Achieved Today?

What is security?

Reliability of a power system generally refers to the ability to deliver electricity to consumers with an acceptable standard of quality and availability. There are two components to reliability; (1) security and (2) adequacy as illustrated in Figure 7.

Security, which is the focus of this report, is defined by the System Operator as "*the ability of the system to withstand disturbances, ensuring a steady and stable grid that delivers generation to where it's needed*". In New Zealand there is a focus on managing security for credible events, e.g. the disconnection of a large generator, loss of transmission circuits, or even the loss of the HVDC link, by defining safe and secure operational limits to protect the integrity of the power system. Security defines the operational limits related to voltage magnitude, power flows, transfer capability, inter-island exchange, generation reserves, stability limits etc. and the available margins with respect to these limits.

Adequacy is defined by the System Operator as "*the ability of the system to meet the aggregated demand requirements by having enough generation and available transmission capacity to deliver the generation.* Adequacy is outside the scope of this report.

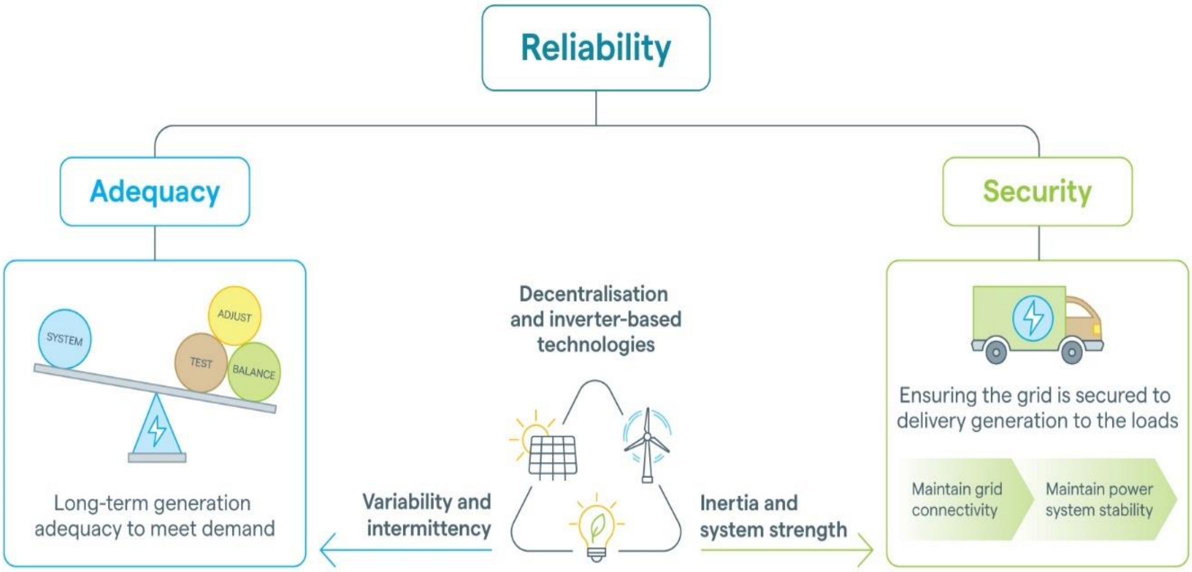


Figure 7 - Components of reliability

There are many factors that can affect reliability such as:

- the amount of generation capacity to meet changing demand over seconds, hours, days and weeks
- sufficient transmission transfer capacity to service loads under normal conditions and after credible events which have caused a reduction in capacity
- operational procedures and risk management strategies
- reliable monitoring, control systems and communication to ensure effective and efficient system operation
- well maintained grid equipment.

What is resilience?

Resilience is a relatively new power system concept from a system operation perspective, designed to consider a system's ability to recover from high-impact low frequency (HILF) events like extreme weather events, natural disasters, pandemics, cyber-attacks and major failures of generation and transmission assets.

Extreme weather events are occurring more frequently than ever before and there has been a recent increase in cyber-attacks on various government agencies and private institutions arising from the introduction of new generation technologies and digitalisation of operating tools.

Increased reliance on innovative technologies and electrification has led to an increase in interdependencies between the power system and other infrastructure sectors, e.g. communication and transportation. That increase in interdependencies has also widened the impact threats may have on consumers.

With the increasing probability of HILF threats and greater potential impacts on power system reliability, utility providers are being prompted to consider how they incorporate resiliency into their operational practices in order to help minimise disruption to consumers.

There is no universally accepted definition of resilience for power systems. The definition used in this report is adapted from international reports, considering the possible future power system in New Zealand.

The way the New Zealand power system recovers from any HILF threats is the key factor in defining what resilience is. The System Operator definition of resilience is "*the ability to identify and mitigate HILF threats quickly and efficiently to ensure the least possible damage to infrastructure and support services, while enabling a quick recovery and restoration to a stable operating state*". The stable operating state may differ from the initial state but will provide the ability to fully and quickly restore the power system.

Figure 8 demonstrates the different states the power system transitions through during a HILF event and the operational strategies employed to restore the power system back to a secure and safe operating state.

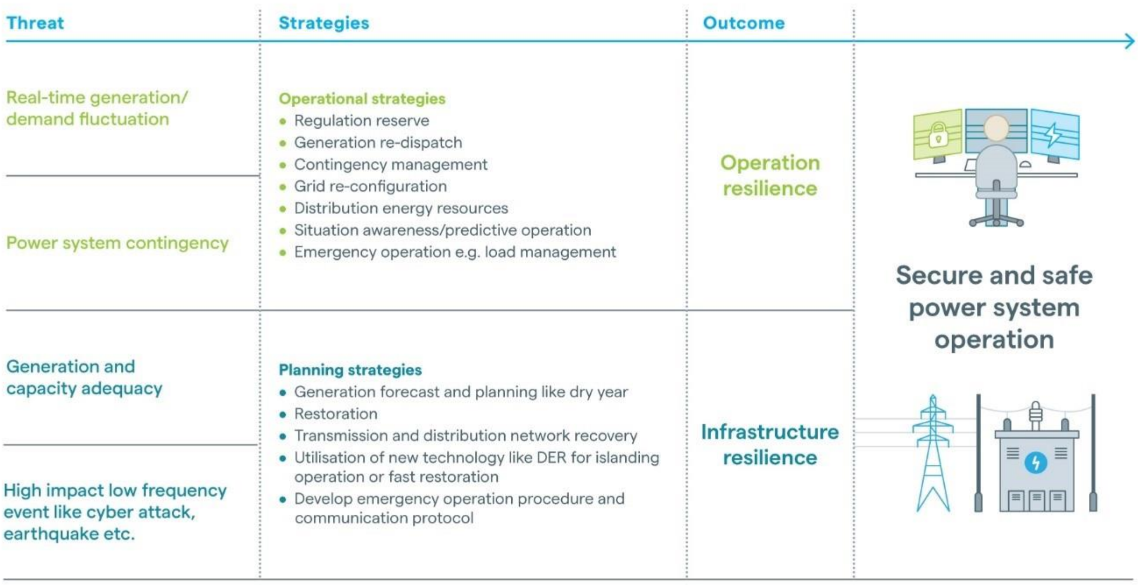


Figure 8 - Impact of a HILF threat

How is the power system currently operated to maintain security?

A power system which is secure can answer 'yes' to the following questions:

- is demand being met by supply?
- is frequency within the allowed limits?
- is voltage within the allowed limits?

The components which make up a power system, i.e. generation, transmission and distribution assets, are fallible. Credible events will happen on the power system, e.g. the tripping of a generator or a transmission circuit. When these events occur the System Operator needs to ask:

- will cascade failure be avoided?
- will frequency remain within the allowed limits?
- will frequency recover within the acceptable timeframe?
- will voltage remain within the allowed limits?

The Electricity Industry Participation Code 2010 (the Code) places obligations on the System Operator to be able to affirm each of these questions. In New Zealand rather than detailed obligations stating how the System Operator must manage security the Code details frequency and voltage limits within which the System Operator must manage the power system in a range of scenarios. These are known as the Principal Performance Obligations (the PPOs) and are contained in clauses 7.2A to 7.2D. of the Code.[2]

The System Operator's Policy Statement sets out how it meets Code obligations, including the PPOs. Within the Policy Statement the Security Policy section states the System Operator's frequency and voltage management policies. Implementing those policies and undertaking various assessment activities across different timeframes will, as best as possible, ensure the power system remains secure and resilient for all credible events.

As New Zealand's economy electrifies and reliance on electricity increases the PPOs will need to be checked to ensure alignment with consumer expectations and the changing capabilities of the power system. For instance, consumers may in future be less tolerant of disruptions to service and some future resilience needs may be met by DER. Consideration of any future changes to the PPOs may occur as appropriate during Phase 3 of the FSR programme.

Credible events

The System Operator must seek to manage outcomes of credible events (asset failures) that may cause cascade failure. Identified credible events are classified using a probabilistic approach into one of three categories:

- Contingent events: a credible event for which the System Operator has deemed it necessary to take action prior to the event occurring using the scheduling and dispatch processes to manage the potential impacts of the event if it was to occur. Management options include procurement of Fast and Sustained Instantaneous Reserves (FIR and SIR).
- Extended contingent events: a credible event where it is not justified to take action prior to the event occurring to totally avoid demand shedding or maintain the same quality limits defined for contingent events. Management options include the use of FIR/SIR, Over Frequency Reserve (OFR) and automatic under-frequency load shedding (AUFLS).
- Other events: an event that is considered so uncommon or the impact, probability and cost do not justify using an option to manage or mitigate the impact of the event prior or post the event occurring

[2] Electricity Industry Participation Code: https://www.ea.govt.nz/code-and-compliance/the-code/

Planning and forecasting

To meet the PPOs the System Operator needs to perform significant forward planning. Threats to the delivery of a secure and resilient power system are best identified, and mitigation plans created, ahead of real-time.

The focus of planning and forecasting activities is to assess the ability of the power system to have enough resources, i.e. via generation, transmission capacity and ancillary services, available to meet the expected needs of a secure power system.

Long term

The System Operator produces a System Security Forecast (SSF) at least every two years. The SSF considers the System Operator's ability to meet the PPOs over the next 3 years considering all available and committed generation and transmission assets. It considers a range of scenarios and identifies potential difficulties managing avoidance of cascade failure, voltage management, and thermal overload in both a steady operating state with planned outages, and in post-event operating conditions.

The System Operator also performs an annual assessment of expected future generation adequacy, compared to margins defined in the Code, over the next 10 years. New Zealand's reliance on hydro generation combined with comparatively little hydro storage means there is a need to monitor the likelihood of energy shortages arising from a lack of hydro generation capacity. The performance of this function is outside the scope of this report.

Medium term

The New Zealand Generation Balance produced by the System Operator helps predict, isolate and prevent situations where available generation is insufficient to meet projected New Zealand load within the next 200 days. The assessment includes planned generation outages and the impacts of transmission outages on generation availability.

Individual impact assessments are also undertaken for planned outages of key transmission and generation assets. These can be performed up to a year ahead and identify the impacts to the power system, not just the impact on generation availability.

Short term

Outage planning incorporates the assessment of the impacts of all planned generation, transmission and significant distribution outages.

Market scheduling activities start a week ahead of real-time activity and become more frequent in the approach to real-time. All market schedules contain the identification of credible event risks and scheduling of instantaneous reserves (IR) to cover those risks. Any energy or IR deficits are communicated to market participants.

The System Operator issues notices to market participants:

- drawing their attention to situations which have the potential to threaten achieving delivery of the PPOs,
- requesting they take actions to mitigate the situation, and
- advising of the potential outcomes and management measures the System Operator will take to maintain security.

Dispatch

In real-time the System Operator coordinates resources made available by issuing dispatch instructions. On average this occurs every 5 minutes. The dispatch instructions are calculated by a market schedule which includes real-time assessment of the magnitude of credible event risks. This process is known as 'Security Constrained Economic Dispatch' – the least cost solution is dispatched from an optimisation which includes all the known requirements of a secure power system e.g. generation is scheduled to meet system load and losses, all assets are dispatched within their capability, IR is scheduled to cover the largest risk etc.

Shortages in the availability of offered resources, when compared to the needs of the system, result in deficits of energy and/or IR which may ultimately result in load being shed to ensure security is maintained.

Frequency management

The PPOs place obligations on the System Operator to manage frequency of the power system in three states:

- Steady state (within the normal band between 49.8 Hz and 50.2 Hz)
- During the recovery of a contingent event (at or above 48 Hz for both islands)
- During the recovery of an extended contingent event (at or above 47 Hz in the North Island and 45 Hz in the South Island)

The range within which system frequency can deviate reflects the changing operating conditions these states represent. Simplistically, the bigger the event the larger the frequency may deviate from 50 Hz.

The following ancillary services are used to manage frequency (refer Figure 9):

- Frequency keeping: This product responds to small changes in frequency and is provided from selected generators to manage fluctuations in frequency second by second in between each five-minute dispatch
- Over Frequency Reserve: This product is generation that turns off instantly if frequency gets too high
- Instantaneous (Under Frequency) Reserve:
    - fast instantaneous reserve (FIR: reserve that must act within 6 seconds of an under-frequency event and then maintain its post-event output for 60 seconds)
    - sustained instantaneous reserve (SIR: reserve that must act within 60 seconds of an under-frequency event and then maintain its post-event output for 15 minutes)
    - interruptible load (IL: reserve provided through the disconnection of load following an under-frequency event. Can be provided as either FIR or SIR)
- Automatic Under Frequency Load Shedding (AUFLS). This is up to 32 per cent of either island's demand that cuts off automatically if frequency drops too low. It is effectively the last layer of defence to avoid cascade failure.

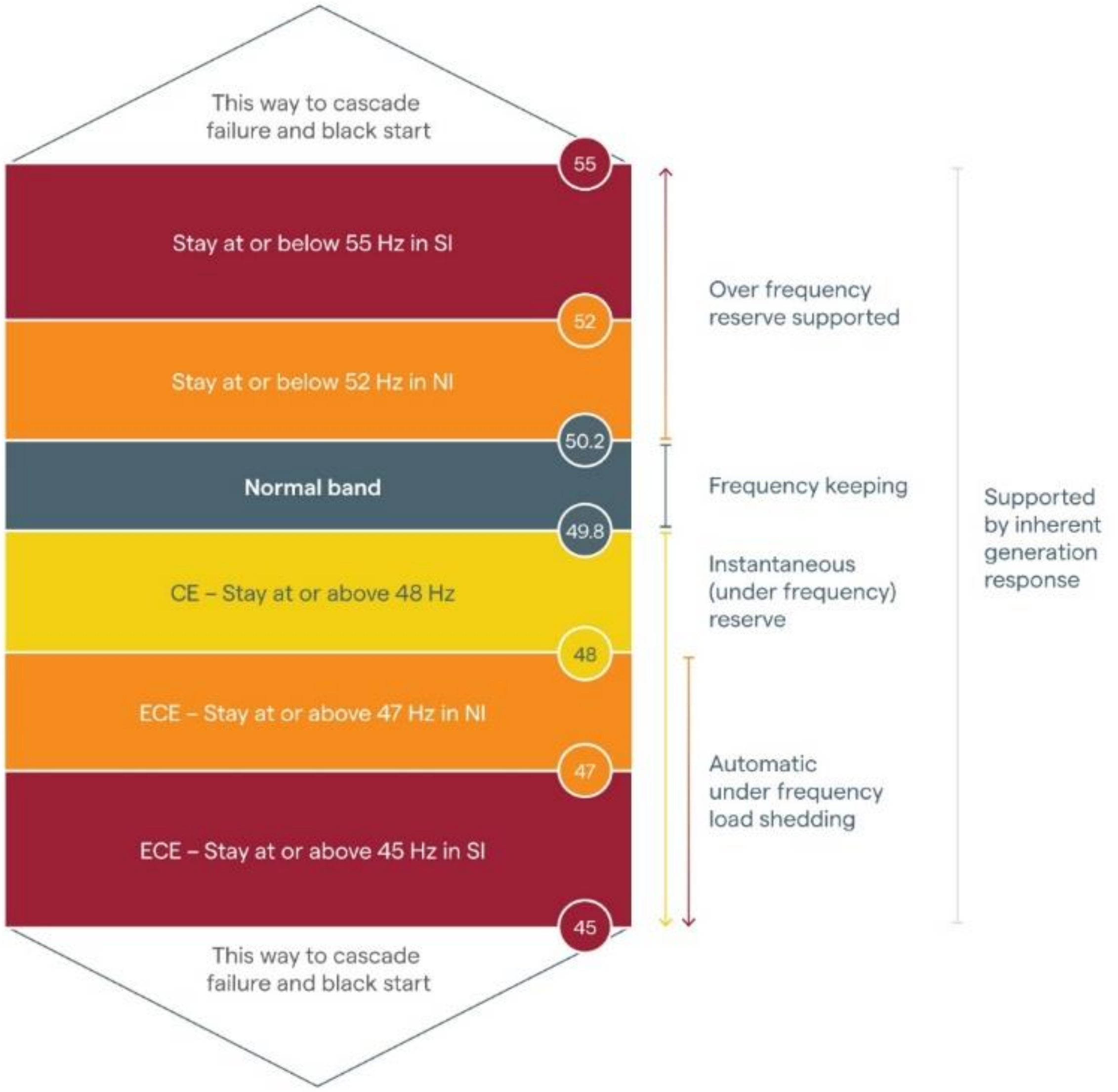


Figure 9 - Frequency barometer

Voltage management

To manage voltage within the allowable Code limits the System Operator dispatches generating units or static equipment which can produce or absorb reactive power. The System Operator may enter into voltage support contracts, if necessary.

Black start restoration

Black start is the first step in the process of system restoration in the unlikely event of an island-wide black-out. Black start can only be carried out by a generating station that can self-start without requiring power from the grid. This service needs to be available in both islands so the System Operator can re-energise the power system, and allow other generation to connect, following such an event.

6.0 How Were the Future Opportunities & Challenges for Security and Resilience Identified?

What was the approach for identifying opportunities and challenges?

The System Operator was enlisted to prepare this report given its extensive knowledge of the New Zealand power system, research it has already conducted into New Zealand's energy future and its oversight of what has been occurring in other jurisdictions as they transition to higher proportions of renewables. Opportunities and challenges were identified based on a systematic review of all elements of the power system under a specific future scenario. This was then assessed against select overseas experience to both validate anticipated issues and ensure any additional issues were not overlooked.

It is acknowledged this report is System Operator centric. Operating a secure and resilient power system in New Zealand is, currently, the responsibility of the System Operator. The pan-industry engagement planned for Phase 3 of the FSR programme will ensure other voices will be heard in the design of any changes made to address the challenges and opportunities the future holds.

The starting point for the System Operator to assess future security and resilience was to ensure that as the generation mix and demand profile changes, it could still meet its PPO's as currently outlined in the Code. If the PPOs could be met within a future scenario, then the assumption is that the future power system will be sufficiently secure and resilient.

Which future scenario was chosen?

The second step in identifying future opportunities and challenges was to articulate what the future could look like. There are varying scenarios as outlined in the Sapere review of security reliability and resilience with electricity industry transformation [4], yet all predict there will be greater demand for electricity, less thermal generation (being the burning of fossil fuels to generate heat to power turbines), more renewable generation and more DER.

The 'Mobilise to Decarbonise' scenario outlined in Whakamana i Te Mauri Hiko [5] was chosen as the base scenario for this report because out of all Transpower's scenarios it has the highest electricity demand and is the most ambitious scenario in terms of electrification of the economy. The expectation was this scenario would flush out the best opportunities and the hardest challenges. The thinking was if New Zealand can address opportunities and challenges to security and resilience under this scenario, it should be well placed to cover other scenarios should they unfold. Availability of data for future work was also a consideration of choosing this Transpower scenario.

The key characteristics of this future power system are outlined in Section 7.

Which future scenarios have already been studied?

The System Operator has been considering the future for several years and impacts it could have on power system operations. Studies have been prepared on wind, solar PV, battery energy storage systems (BESS), EVs, DER, inertia and system strength. A list of those studies, and the opportunities and challenges they relate to, are outlined in Section 8.

Based on previous studies, and what the future is expected to look like, the System Operator has found ten opportunities and challenges to be within the scope of the future security and resilience programme. The opportunities and challenges fall under three categories:

The rise of DER – opportunities and challenges

- Leveraging DER to build and operate the future grid
- Leveraging new technology to enhance ancillary services
- Visibility and observability of DER

The challenges of the changing generation portfolio

- Balancing renewable generation
- Managing reducing system inertia
- Operating with low system strength
- Accommodating future changes within technical requirements

Other opportunities and challenges

- Loss of control due to cyber security breach
- Coordination of increased connections
- Growing skills and capabilities of the workforce

Which jurisdictions were selected?

Information from previous New Zealand studies was supplemented with a review of the expected and unexpected opportunities and challenges that other jurisdictions have encountered in implementing renewables and retiring conventional thermal generation. The review also considered the challenges which those jurisdictions expected to arise but did not eventuate, assessed events and trends and provided commentary (which can be found in Appendix 2), on their applicability to New Zealand.

While there are many jurisdictions that we could consider, in order to contain the scope of this initial work the following five jurisdictions were selected for review: Australia, Great Britain, Ireland, Hawaii and Singapore. These jurisdictions represent power systems that have similarities with New Zealand in terms of geography, and/or they are further down the path of distributed renewable electricity deployment and have experience that could prove valuable.

It's important to remember that no two power systems are the same. Each has a different geography, including physical size, population density, generation mix, climate, and interconnection with neighbouring grids. Local regulations and market design also influence how systems are implemented in different locations.

7.0 What Will the Future Look Like?

As New Zealand decarbonises, it is expected that electricity demand will grow significantly as fossil fuel powered infrastructure, e.g. vehicles and process heat, are converted to electricity. Extra electricity needed will be generated using renewable resources like wind and solar, both at grid scale and distributed within local networks and on residential and commercial buildings. Battery storage will become more commonplace as technology improves and costs reduce, enabling excess electricity generated during the day to be used later when demand is high.

The Mobilise to Decarbonise scenario, outlined in Whakamana i Te Mauri Hiko [5], assumes that at some point the world will get serious and move into rapid action. When this occurs, response to climate change will be much stronger and urgent. There will be significant efforts to reduce activity that changes the climate.

The infographic below shows some of the key changes that are forecast in this scenario.

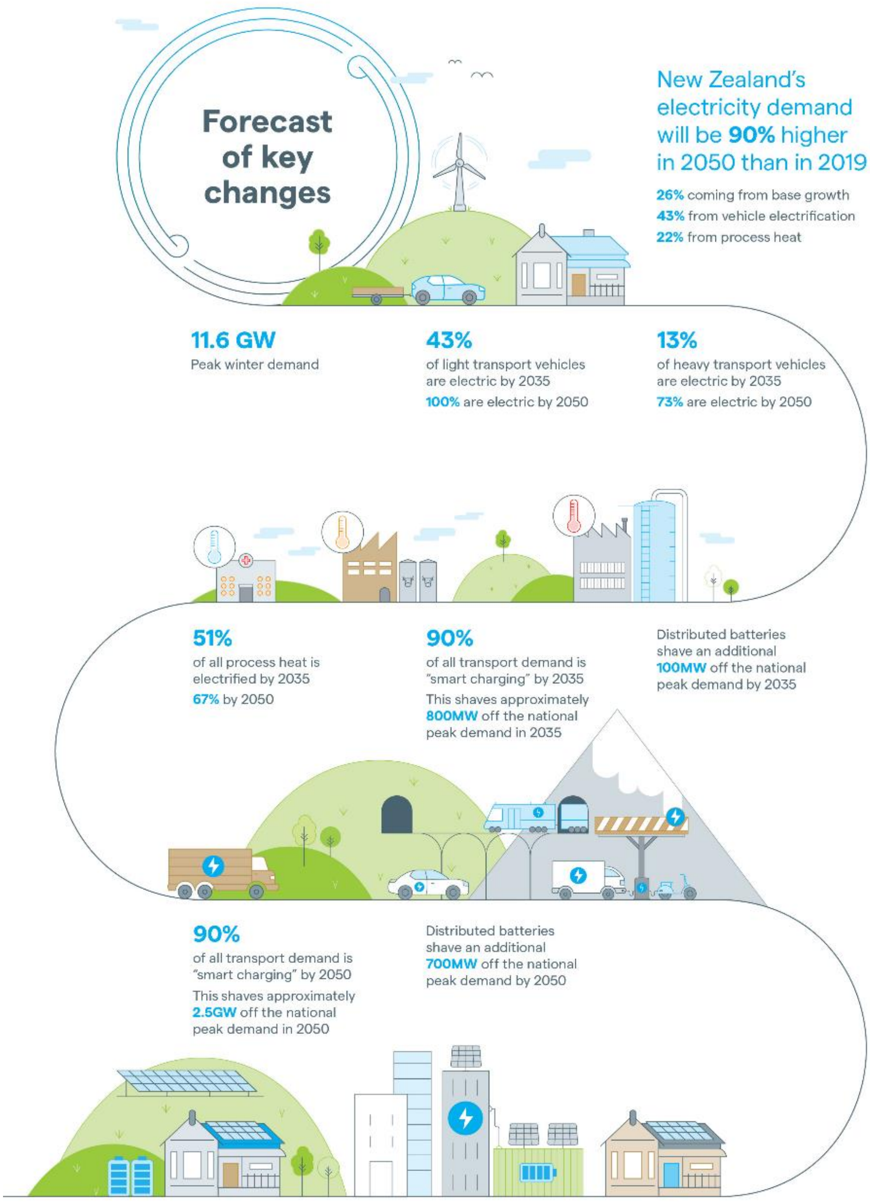


Figure 10 - Infographic: Forecast of key changes

Figure 11 and Figure 12 show the current and forecast split in delivered electricity by fuel types and generation technology types to meet the demand growth in our chosen scenario.

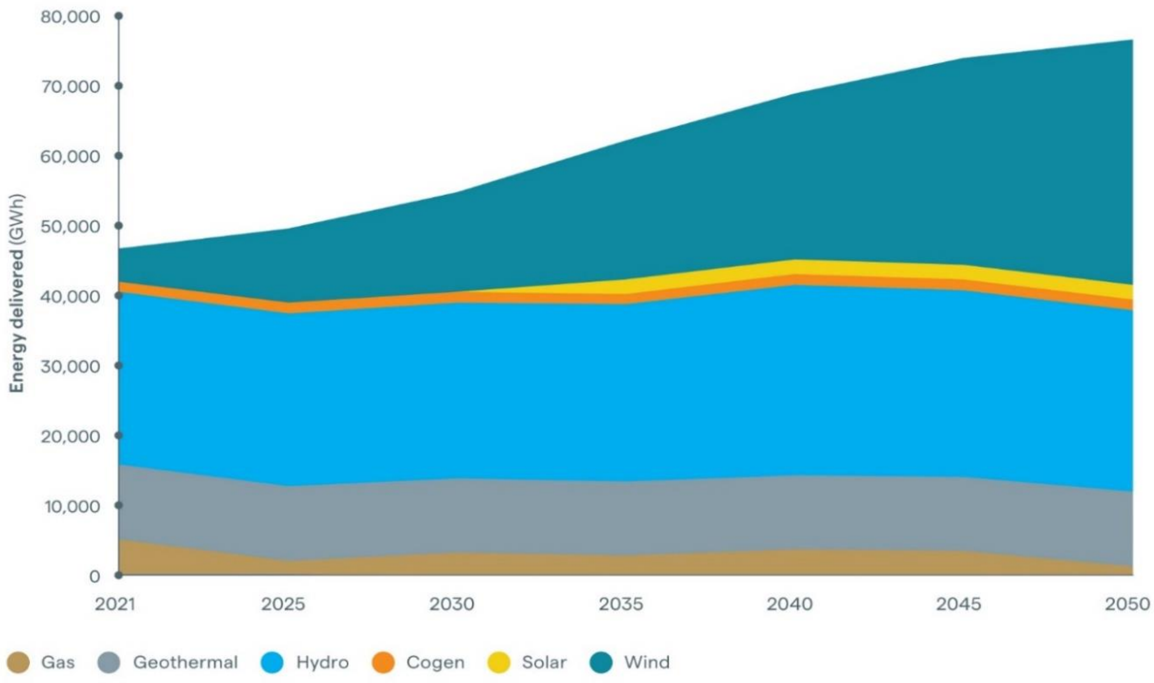


Figure 11 - Energy delivered by fuel type

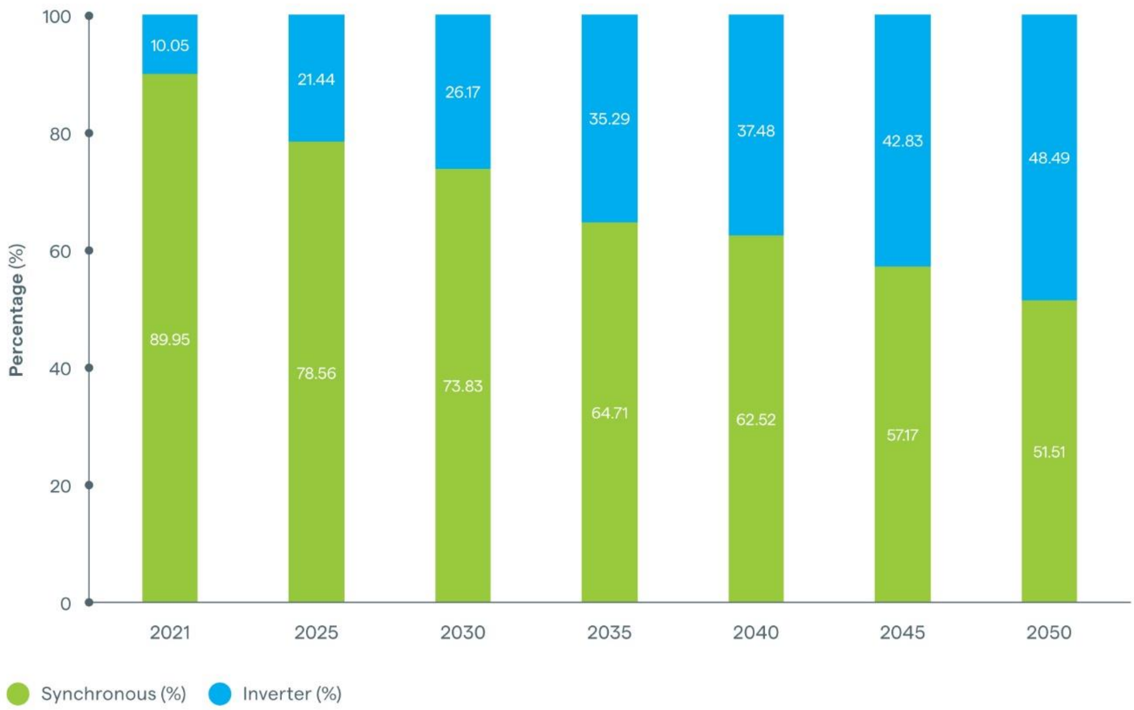


Figure 12 – Energy delivered by generation type

8.0 What Has Already Been Studied and Found?

Table 2 presents the power systems studies previously undertaken by the System Operator, and relevant parties, that were used to inform key opportunities and challenges summarised in Section 10 and in consideration of the future outlined in Section 7

Table 2 - Previous studies undertaken and applicable opportunities and challenges

Study	Reference	The rise of DER			The challenges of the changing generation portfolio				Other opportunities and challenges		
		Leveraging DER to build and operate the future grid	Leverage new technology to enhance ancillary services	Visibility and observability of DER	Balancing renewable generation	Managing reducing system inertia	Operating with low system strength	Accommodating future changes within technical	Loss of control due to cyber security	Coordination of increased connections	Growing skills and capabilities of the workforce
Battery Storage in New Zealand	[6]	✓	✓								
Distributed Battery Energy Storage Systems in New Zealand	[7]	✓	✓		✓	✓	✓				
Solar PV in New Zealand	[8] [9] [10] [11] [12]				✓	✓	✓				
Wind Generation Investigation Project	[13] [14] [15] [16] [17] [18] [19] [20] [21] [22]				✓	✓	✓				
Net Zero Grid Pathways	[23]	✓	✓		✓					✓	

Study	Reference	The rise of DER			The challenges of the changing generation portfolio				Other opportunities and challenges		
		Leveraging DER to build and operate the future grid	Leverage new technology to enhance ancillary services	Visibility and observability of DER	Balancing renewable generation	Managing reducing system inertia	Operating with low system strength	Accommodating future changes within technical	Loss of control due to cyber security	Coordination of increased connections	Growing skills and capabilities of the workforce
The Sun Rises on a Solar Energy Future	[24]	✓	✓		✓			✓		✓	
Te Mauri Hiko	[25]	✓			✓			✓		✓	✓
Taking the climate heat out of process heat	[26]				✓					✓	✓
Transmission Tomorrow – Our Strategy	[27]	✓	✓		✓			✓		✓	✓
Whakamana i Te Mauri Hiko	[5]	✓	✓		✓			✓		✓	✓
A Roadmap for Electrification	[28]				✓						
Does Size Matter?	[29]			✓							
TAS096 – Performance Requirements for Inverter Connected Parties	[30]					✓	✓	✓			
Review of potential security, reliability, and resilience concerns arising from future scenarios for the electricity industry by David Reeve, Toby Stevenson (Sapere Research Group)	[31]	✓				✓	✓			✓	

Study	Reference	The rise of DER			The challenges of the changing generation portfolio				Other opportunities and challenges		
		Leveraging DER to build and operate the future grid	Leverage new technology to enhance ancillary services	Visibility and observability of DER	Balancing renewable generation	Managing reducing system inertia	Operating with low system strength	Accommodating future changes within technical	Loss of control due to cyber security	Coordination of increased connections	Growing skills and capabilities of the workforce
International Power System Event Review: Lessons for New Zealand – Queensland and South Australia system	[32]							✓			
International Power System Event Review: Lessons for New Zealand – National Grid Low Frequency Demand Disconnection Event in the United Kingdom	[33]							✓			

9.0 What Can Be Learned from Other Jurisdictions?

Five international jurisdictions were reviewed to assess events and trends in implementation of renewable electricity generation and its effect on security and resilience. Key characteristics of each jurisdiction selected and why they were chosen are outlined in Table 3.

Table 3 - Key characteristics of selected jurisdictions

Jurisdictions	Key characteristics of the power system	Reasons for selection
Australia	- Islanded power system(s). - Extremely high penetration of solar PV DER. - Approaching 'zero grid demand' operating conditions. - Significant increases in grid scale wind and solar PV. - Retirement of thermal generation.	- World-leading in residential PV deployment. Already produces 12.5% of its electricity from solar PV, 84% of which is via DER. - Has experienced issues in growth of DER that New Zealand can learn from. - Has experienced challenges with the scale and pace of new generation connections. - Geo-politically relevant.
Great Britain (England, Wales and Scotland)	- High volume of DER. - Significant increases in wind and solar PV generation. - Advanced integration of DER into power system operations. - Retirement of thermal generation.	- Well advanced in implementation of renewable electricity production, particularly wind. 20% of net installed capacity is wind and 12% is solar PV. - Similar weather patterns as to New Zealand with a temperate climate and unreliable sunshine hours and wind strength.
Ireland (Republic of Ireland and Northern Ireland)	- Extremely high penetration of wind generation. - Retirement of thermal generation.	- Comparable population and electricity demand to New Zealand. - Similar climate to New Zealand. - Already has a third of net installed capacity from grid-scale wind. - Has expanded ancillary service products to accommodate the change to a higher renewable electricity generation mix.

Jurisdictions	Key characteristics of the power system	Reasons for selection
Hawaii	- 100% renewable electricity goal. - Islanded power system. - Increasing solar PV penetration. - Retirement of thermal generation.	- Island nation with no grid interconnection to other geographies. - Aggressive renewable electricity target – 30% of total electricity sales from renewables by the end of 2020, 100% by 2045. - Has faced grid-related issues due to increasing penetration with variable renewable energy that could provide valuable insights for New Zealand.
Singapore	- Aiming for 2GW of solar PV by 2030. - Islanded power system.	- Island nation. - Advanced thinking in how to increase DER solar PV generation. - Excellent consideration of skills and capabilities required for future power mix.

High-level metrics about the chosen jurisdictions are detailed in Table 4 in order to provide a comparison to the New Zealand system.

Table 4 - Comparison of jurisdiction metrics

Metric	New Zealand	Australia	Great Britain	Ireland	Hawaii	Singapore
Population [millions]	5.1 [34]	25.5 [34]	65.2 [35]	6.8 [36]	1.4 [37]	5.9 [34]
Electricity – total net installed capacity of electric power plants, main activity & auto-producer 2018 [MW]	9,353 [38]	69,274 [38]	108,280* [38]	10,981^ [38]	1,820 [39]	13,614 [38]
Wind (net installed capacity of electric power plants) [%]	7.4 [38]	8.2 [38]	20.1* [38]	33.5^ [38]	4.9 [39]	0 [38]
➢ Proportion that is 'self-producer' [%]	0 [38]	0 [38]	17.0* [38]	0.6^ [38]	0 [39]	0 [38]
Solar PV (net installed capacity of electric power plants) [%]	1.0 [38]	12.5 [38]	12.1* [38]	0.2^ [38]	11.2 [39]	0.8 [38]
➢ Proportion that is 'self-producer' [%]	100 [38]	84.0 [38]	70.9* [38]	100^ [38]	83.0 [39]	0 [38]
Expected greatest source of future renewable electricity	Grid-scale wind and solar PV, DER solar PV	Grid-scale wind and solar PV, DER solar PV	Grid-scale wind, DER solar PV	Grid-scale wind	Grid-scale and DER solar PV	DER solar PV

* Data is for the UK rather than Great Britain because of data availability

^ Data is for the Republic rather than the island of Ireland because of data availability

Table 5 highlights where the System Operator identified jurisdictions experiencing or forecasting similar opportunities and challenges that are likely to unfold in New Zealand. The table includes citations of the documents for each jurisdiction that support our observations. Commentary on specific opportunities and challenges faced by each jurisdiction can be found in Appendix 2.

Table 5 - Summary of opportunities and challenges experienced by the chosen jurisdictions

Jurisdiction	The rise of DER			The challenges of the changing generation portfolio				Other opportunities and challenges		
	Leveraging DER to build and operate the future grid	Leverage new technology to enhance ancillary services	Visibility and observability of DER	Balancing renewable generation	Managing reducing system inertia	Operating with low system strength	Accommodating future changes within technical requirements	Loss of control due to cyber security	Coordination of increased connections	Growing skills and capabilities of workforce
Australia		✓ [40]	✓ [41]	✓ [41], [42]	✓ [42]	✓ [42]	✓ [43], [44]	✓ [45]	✓ [42]	
Great Britain	✓ [46]	✓ [47]	✓ [48], [49]	✓ [48]	✓ [46], [47]	✓ [47]	✓ [49], [50], [51], [52]	✓ [53]	✓ [47], [48]	✓ [54], [46]
Ireland		✓ [55]		✓ [56], [42]	✓ [56]					✓ [56]
Hawaii				✓ [57], [58]		✓ [59]	✓ [60]		✓ [61]	✓ [62]
Singapore		✓ [63]		✓ [64]	✓ [64]	✓ [64]		✓ [65]	✓ [64]	✓ [66]

10.0 What Future Opportunities and Challenges Have Been Identified?

The rise of DER – opportunities and challenges

This section details two opportunities and one challenge which are expected to occur as a result of increase in DER in the future. The opportunities arise from leveraging the capability of DER to flatten the daily load curve (avoiding expenditure to meet peak loads) and technical capabilities of DER to enhance ancillary services.

When the FSR programme moves into solution design in Phase 3 the common driver of an increase in DER means these opportunities and challenge should be considered collectively. It is likely that taking this approach will result in the best solution rather than considering the opportunities and challenges in isolation.

As noted earlier, this report has a System Operator centric view. When FSR moves to solution design in Phase 3 it will be critical to have pan-industry engagement on these opportunities and challenges. During Phase 3 it will be important to focus first on the 'what' (the physical requirements) before designing the 'how' (the solution) and finally deciding the 'who' (roles and responsibilities).

10.1 Leveraging DER to build and operate the future grid

Electricity demand varies throughout the day and is represented by the daily load curve. There is an opportunity to use DER to manage demand and change the shape of the curve.

What is DER and why is it important?

DER can be considered as energy systems that are connected within the distribution network, including systems located within businesses or households that are controllable and dispatchable. Some common examples of DER are rooftop solar PV, battery storage, EVs and their chargers, and home energy management systems which when aggregated can be considered as virtual power plant (VPP). Small scale power generation and battery storage connected within a distribution network can also be considered as DER.

There is a well-documented opportunity to avoid significant transmission, distribution, and generation costs (see Distributed-energy-resources-der-report and Cost-benefit-analysis-of-distributed-energy-resources-in-New-Zealand) through leveraging DER. The Whakamana I Te Mauri Hiko report shows moving EV charging from the evening peak can reduce the peak by nearly 20%.

How will New Zealand be impacted in the future?

As DER penetration increases, there is a substantial opportunity for it to offset some of the challenges that renewable energy (specifically solar PV) introduce. As solar PV penetration increases, the daily load curve starts to look quite different. Midday generation will potentially exceed demand, but evening demand peaks will be retained, creating a much steeper ramp for the System Operator to balance.

The duck curve in Figure 13 models power production over the course of a day, highlighting the timing imbalance between peak demand and renewable solar PV energy production.

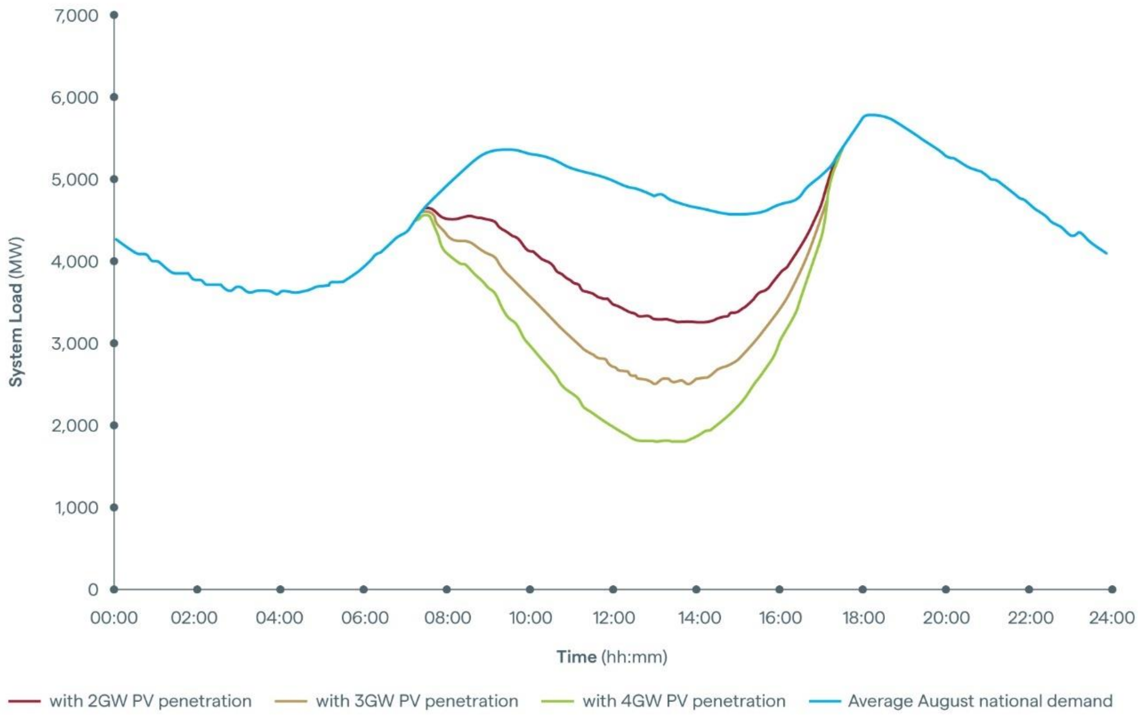


Figure 13 – Solar PV penetration changes the daily load curve

DER can shape the daily curve by reducing the daily peaks or increasing the daily trough if incentivised or otherwise controlled in a coordinated manner. The bulk of this will be achieved by shifting most EV charging to off-peak times. Additional effects will be seen from controllable load management, distributed generation, and battery storage. These could be affected through any combination of retail tariffs, bilateral contracts, time-of-use (TOU) or other cost-reflective network pricing tariffs, response to real-time wholesale spot prices, and direct management of the resources by a third party.

The opportunities are not limited to daily load curve management. The increasing adoption of DER and the advancement of communication technologies to coordinate and manage DER provides an opportunity to:

- provide consumers with an option to manage their own energy usage to lower their costs and increase their energy efficiency and independence
- reduce energy transportation losses by reducing the physical distances between generation and load
- reduce transmission and/or distribution bottlenecks and reduce or defer transmission and distribution investment by managing demand
- provide ancillary services to regulate frequency and voltage which will enhance security and resilience
- provide balancing services to help the power system maintain the right generation and demand balance
- provide back-up power during an outage.

For New Zealand to take full advantage of this opportunity there needs to be:

- clear expectations between the System Operator, electricity distribution businesses (EDB) and flexibility traders on services delivered by DER
- visibility of DER at both transmission and distribution levels
- up to date technical requirements considering how DER operates, in order to support security and resilience, e.g. should installed inverters be grid forming rather than following (see Section 10.6 for more information on this challenge)
- Incentives for consumers to use smart EV chargers that can be programmed to charge at a specific time and avoid increasing peak loads.

This opportunity impacts New Zealand's entire power system. When New Zealand can take advantage of this opportunity will depend on how quickly the adoption of DER increases and required changes to the regulatory framework are made.

Timing and priority

It is inevitable that DER uptake will continue to increase in the next 10 years. The distribution network will benefit with low DER penetration, for example, 10 MW DER will have negligible effect on grid operation but will be very useful to help manage distribution network congestion. The grid will only benefit with significant uptake of DER and the right framework to coordinate its operation is in place. The priority of this task is considered medium (3-7 years) requiring market framework, technical standards and communication model to be established before the grid can benefit from services provided by DER.

10.2 Leveraging new technology to enhance ancillary services

Ancillary services are relied on by the System Operator to maintain frequency, voltage and for restoration of the system after a blackout. There is an opportunity to use the introduction of new technologies to enhance our existing services.

What are ancillary services and why are they important?

Ancillary services are functions that help the System Operator maintain a secure and reliable power system, and ensure electricity is delivered to consumers to an acceptable standard. These services maintain the flow of electricity, address imbalances between supply and demand and help the power system recover after a credible event.

These services include a wide variety of electrical efficiency and safety nets, all focused on ensuring the power system delivers enough electrical power to meet demand, while remaining stable. They can be broadly classified into three categories:

- Regulation - to correct active and reactive power imbalances arising from constant fluctuations of demand and generation
- Contingency reserve - to respond to an unexpected change in demand and generation caused by failure or outage of system components, e.g. generating unit, demand, capacitor bank or other power system equipment
- Black start service - to re-energise the grid after a partial or total blackout using generation that can restart without relying on any external electrical supply.

Consumers expect a highly reliable power supply without significant interruption. Regulation and contingency reserve services provide an automatic re-balancing of active and reactive power in the power system to ensure system frequency and voltage are maintained within statutory limits. This is shown in Figure 14 below.

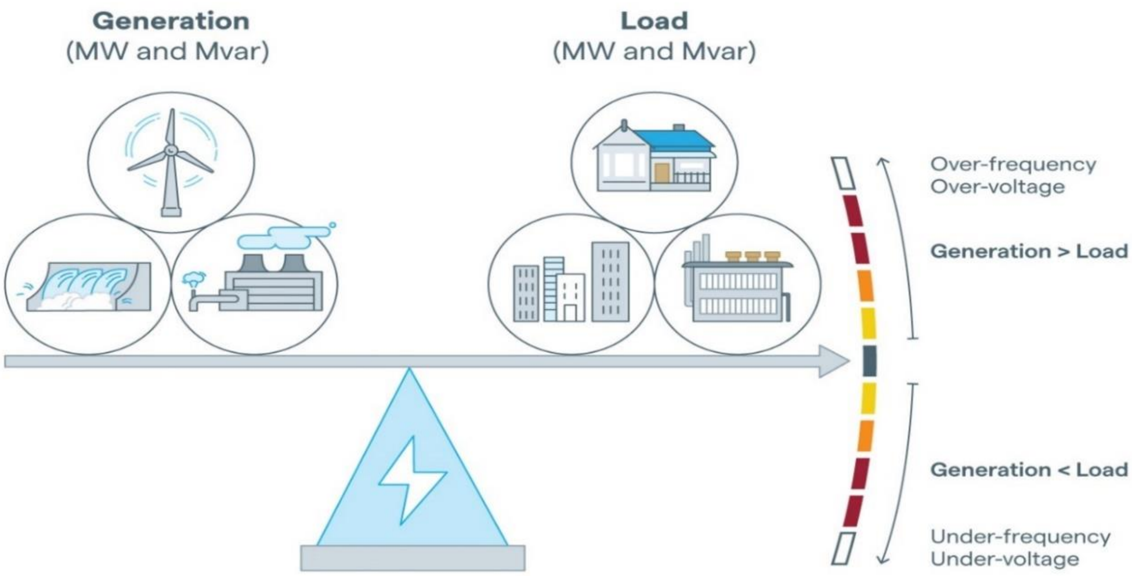


Figure 14 – Balancing of generation and demand

How will New Zealand be impacted in the future?

New Zealand operates a small power system with low inertia and system strength. This implies that the system is more susceptible to active and reactive power imbalances that will cause bigger changes in frequency and voltage, respectively. In addition, the grid is extensive and reaches most parts of New Zealand, with many system components being exposed to external hazards, e.g. local environment and weather conditions

The System Operator relies on ancillary services to maintain frequency and voltage and deliver electrical power safely and stably to consumers. It has developed unique methods of managing frequency, e.g. a real-time frequency management tool to estimate IR requirements and co-optimise that requirement with generating unit commitment to find the most economic generation schedule.

With higher levels of intermittent renewable generation such as wind and solar PV along with widespread DER, the System Operator may need to procure more ancillary services in order to maintain the balance between supply and demand. However, an opportunity exists for renewable energy generation and DER to support the operation of the grid if enabled to provide the ancillary services needed. In some cases, these resources could be utilised to provide new ancillary services such as synthetic inertia or very fast instantaneous reserves should a sufficient use case present itself.

Table 6 shows which products and services could be provided by different energy technologies today if enabled.

Table 6 - Products and services provided by energy technology

	Frequency management					**Voltage management**
Energy technology	Inertia	Very fast IR	Fast IR	Sustained IR	FK	Voltage
Synchronous Generation						
Wind Generation (inverter-based)						
Solar PV Generation						
Batteries						
Electric Vehicles*						

	Can offer this product or service
	Can be programmed to provide this service
	Cannot offer this product or service

* Require EV2G hardware to provide the ancillary services

This opportunity has potential to provide more options to participate in the energy market (depending on the design and selection of future ancillary services) and to 'value stack' revenue opportunities for DER from existing and any new ancillary services. To take advantage of this opportunity the regulatory framework, procurement mechanisms, tools and operational procedures would need to be updated to enable new technologies to participate in the energy market and ancillary services markets.

With the expected uptake in DER the System Operator does not foresee an immediate need to revise the current ancillary service products required for operation of the power system. The System

Operator does recommend existing technology specific barriers to entry for new technologies should be addressed as a priority to enable participation in existing energy and ancillary services markets.

Further, the System Operator observes there may be benefits to DER uptake rates, and consequently the services and benefits they can provide, if additional stackable revenue opportunities are available through new ancillary services which, while beneficial to power system operations, are implemented ahead of need. Instigating such a plan is a policy decision and can only be made by the Electricity Authority.

Timing and priority

Ancillary services are evolving with the changes in the power system behaviour and the types of ancillary service the IBR can offer. This is an ongoing activity with the system operator currently working on enabling BESS to offer instantaneous reserve into the market and will continue to work on new ancillary services to ensure the secure and cost-effective power system operation.

10.3 Visibility and observability of DER

The impact of the continued uptake of DER needs to be monitored and managed as the power system becomes more decentralised leading to a reduction in visibility and controllability.

How is performance of the power system currently monitored?

The grid is an extensive network covering the entire country with many types of equipment and loads, connected to it. Close monitoring of critical power system parameters, e.g. voltage, frequency and electrical power flow, is important to ensure well-coordinated system operation that delivers a reliable and secure power supply to consumers.

Today the System Operator monitors the power system through:

- Supervisory Control and Data Acquisition (SCADA), a well-recognised and important strategic asset in any power system operation. It is a system of different hardware and software elements that come together to enable a plant or facility operator to supervise and control processes
- receiving asset capability and market related information from other communication channels.

Monitoring the power system is essential to the day-to-day operation of the system. In the past, operational network conditions were determined from limited remote monitoring and onsite interrogation. The existing level of network monitoring and control has progressed significantly.

How will New Zealand be impacted in the future?

The power system is set to become more distributed with larger numbers of DER embedded into the distribution network and behind-the-meter, e.g. residential solar PV, EVs and batteries. In addition, there are more smart technologies, e.g. home energy management systems, which will make demand more flexible and potentially less predictable.

The System Operator models the transmission network, and the equipment connected to it, in detail allowing us to predict behaviour of the system via contingency analysis and other dynamic stability analysis thus determining operational limits for the system in real-time. As we only have limited visibility of assets connected within distribution networks, these assets are generally represented as lumped loads or aggregated simplified generation sources.

While the influence of DER is minimal for now and overall behaviour can be predicted with adequate accuracy to enable the System Operator to operate the power system, the current visibility of the distribution network is at a bare minimum and will need to increase with increasing levels of DER. Aggregation at high voltage level will likely not be enough in the future to predict and monitor load behaviour making load forecasting more challenging.

Due to the nature of DER being highly distributed, more intermittent and flexible, additional data points and higher frequency data/sampling rates will likely be required to increase visibility and enhance the operability of these resources. Examples of future power system behaviour that require more monitoring and high frequency data for system operation are:

- Bi-directional power flow – only monitoring current flow may not be adequate to determine power flow in circuits that potentially can have reverse power flowing due to the presence of DER. Additional data points may be required to monitor reactive power flow and power factor

- Asset capability information – extensive uptake of DER will influence the System Operator's decision making in balancing supply and demand, procuring ancillary services, managing asset overloading, voltage control and restoration. Asset capability information allows an accurate representation of the network and assets within the power system model. That model is a critical tool that allows the System Operator to perform steady state and dynamic analysis to ensure the power system is operating within secure limits.

As generation becomes more intermittent and demand becomes more flexible, data collected will need to be more granular and at a higher frequency to record the fast-changing behaviour of a more dynamic power system. Data requirements will apply for long term network planning and for real-time operation by Transpower and distributors alike. This complexity will result in a need for the System Operator and distributors to exchange real-time information to ensure operational co-ordination and ongoing system security. How this is achieved in New Zealand will need to be determined, however other jurisdictions are developing Distributed System Operators (DSOs) who interface with the System Operator.

The negative effects of a lack of visibility on system operation are:

- inaccurate forecasting of demand and intermittent generation leading to more conservative constraints in dispatch, which in turn can lead to market inefficiencies
- less predictability of power system behaviour in response to unexpected events leading to more conservative technical operating limits and greater requirements on regulation services (frequency and voltage)
- inability to monitor power system parameters reduces the System Operator's management of the power system's steady state and dynamic stability
- insufficient asset capability and test data reduces the accuracy of the System Operator's power system model that is critical for long-term and real-time analysis
- uncertainty over the effectiveness of emergency control mechanisms, such as AUFLS, reduces the System Operator's ability to accurately determine the power system's state after an event.

In addition to the potential operability issues listed above the System Operator has identified a likely need to consider how DER interacts with the wholesale market. The current market design stops at the edge of the grid, participants who are connected to a distribution network offer their generation as though they are at the GXP. The increase in DER will test whether the current arrangements are optimal. Sub-optimal integration of DER into the wholesale market could pose a risk to delivery of a secure and resilient power system.

Timing and priority

As DER penetration increases, visibility will become a fundamental challenge for overall management of the power system. This challenge is expected to become an operational issue when there are significant amounts of DER incorporated in the New Zealand power system changing the direction of power flow and introducing uncertainty in system operation. This challenge will present as an operational issue in the mid-term with an expected priority of medium.

The challenges of the changing generation portfolio

This section details five challenges identified which arise from expected changes to the future generation mix. An increase in intermittent generation (including DER sources) and an increase in asynchronous inverter-based generation are the drivers for these challenges.

While each challenge laid out here is quite distinct there may be commonalities which can be leveraged when the FSR programme commences Phase 3 and considers solutions.

10.4 Balancing renewable generation

An increase in variable and intermittent renewable energy sources will make balancing demand and generation more challenging and is likely to result in more frequency fluctuations.

What is system balancing and why is it important?

Operating a power system involves balancing generation against demand instantaneously in real-time. System balancing describes the process undertaken by the System Operator to supply enough electricity to the grid to meet the demand of consumers.

Keeping the power system balanced is important because any imbalance will cause the power system's frequency to diverge from 50 Hz. Section 10.5 outlines the issues faced with frequency deviations.

Large imbalances, e.g. one that could bring the system frequency below 48 Hz, may impact the System Operator's ability to meet its PPOs.

How will New Zealand be impacted in the future?

New Zealand operates a small power system with low inertia and a small generation base. A small imbalance can cause deviations of frequency outside of operational limits. It is of the utmost importance that the System Operator has the right information and tools to help it to achieve the critical function of balancing.

With the increase in proportion of variable and intermittent generation in the power system, i.e. wind and solar PV, actively balancing the power system will become more challenging and likely result in more frequency fluctuations.

Wind generation is highly intermittent which can lead to generation output varying quickly due to wind gusts and potentially shut down due to low or high wind speed.

Solar PV is affected by weather in a similar way to wind [9] but may have a weaker correlation which will reduce the overall variable and intermittent effect. Cloud movement can cause solar PV generation to vary, and in some instances a fast fluctuation in active power output can occur.

Variability caused by clouds and wind can make it more difficult for the System Operator to predict the amount of additional generation that will be required from one hour to the next. This in turn makes it difficult to calculate exactly what the output of each generator should be to match demand each trading period.

The short-term balance (second-to-second) between demand and generation is also affected by fast changes in wind speed or cloud movement, presenting a real challenge for the System Operator to maintain frequency within the normal band of 49.8 Hz to 50.2 Hz.

Active power load forecasting, planning, scheduling and regulation will become even more important for reliable and secure operation of the power system.

The System Operator currently relies on load forecasts and generation offers to plan and schedule enough generation to meet demand. Load forecasting is straight forward when the loads are static and have less flexibility to vary. Load variations are generally seasonal and affected by extreme weather or big events, e.g. the Rugby World Cup. These variations can be predicted with reasonable accuracy. However, the power system is evolving with continued uptake of smarter and more distributed generation technologies which makes forecasting demand, and planning and scheduling generation, more challenging.

Giving consumers the option to produce electricity on their own makes loads more flexible, creating more variability and uncertainty which in turn makes load forecasting more complex and less accurate.

The geographic dispersion and mix of different generation types will help to reduce variability and smooth electrical power production, but that geographic spread can introduce other localised challenges, e.g. voltage management. The System Operator is expecting load and generation behaviour to continue to change with continued uptake of different generation technologies and a smarter utilisation of electricity by consumers.

Timing and priority

More variable and intermittent generation (wind and solar PV) has been installed in recent years and it is expected more will be installed in the future. It is anticipated that the present operational practices will carry enough reserve to mitigate low penetration level of wind and solar PV, however this will be monitored closely. This challenge will occur in the mid-term as the penetration level of wind and solar PV generation increases. The priority is considered low as there are other opportunities that can be leveraged to reduce the impact of this challenge.

10.5 Managing reducing system inertia

The continued uptake of inverter generation will fundamentally change the way the system responds to imbalances in power and the way frequency is managed by the System Operator.

What is system inertia and why is it important?

System inertia refers to the energy stored in the rotating shaft of generators, motors and other industrial plant as they rotate at a speed that is synchronised to a power system's frequency. Only synchronous generation stores energy in this way whereas inverter-based generation does not inherently provide inertia.

New Zealand's power system operates at a frequency of 50 Hz. It's important to maintain the system near to this frequency so that all assets connected to the power system can function safely and efficiently.

When two islanded power systems are connected and operating at a stable frequency all generators are in synchronism, swinging together at any instant, which makes frequency more or less identical at every point of the system. Any large deviation of frequency, if not mitigated, can cause cascading failure of the power system as:

- generating units are automatically disconnected by protection devices to avoid permanent damage
- electrical loads, e.g. the appliances in your home, are automatically disconnected by protection devices to protect equipment against erroneous operation and permanent damage
- equipment like the HVDC, transformer or transmission circuits disconnected by protection devices to avoid permanent damage.

This kind of uncontrolled disconnection has a negative impact on the System Operator's ability to mitigate frequency deviations.

Inertia is an integral part of power system operation as it slows frequency deviation allowing recovery activities to restore balance after an electricity supply and demand imbalance caused by a disturbance. It also helps the System Operator manage frequency, which in turns maintains supply security and quality.

During the first moments after a disturbance, inertia determines the behaviour of frequency. Its main function is to slow the rate of change of frequency to allow mitigation actions to arrest frequency fall. The slower the rate of change, the more time there is to act and restore frequency. The lower the system inertia, the faster frequency will fall and the larger the frequency deviation will be.

Figure 15 demonstrates the impact of inertia on rate of change of frequency for the same size contingent event. You can see that as inertia decreases the rate of change of frequency increases, dropping the frequency to much lower levels before ancillary services can kick in to recover frequency.

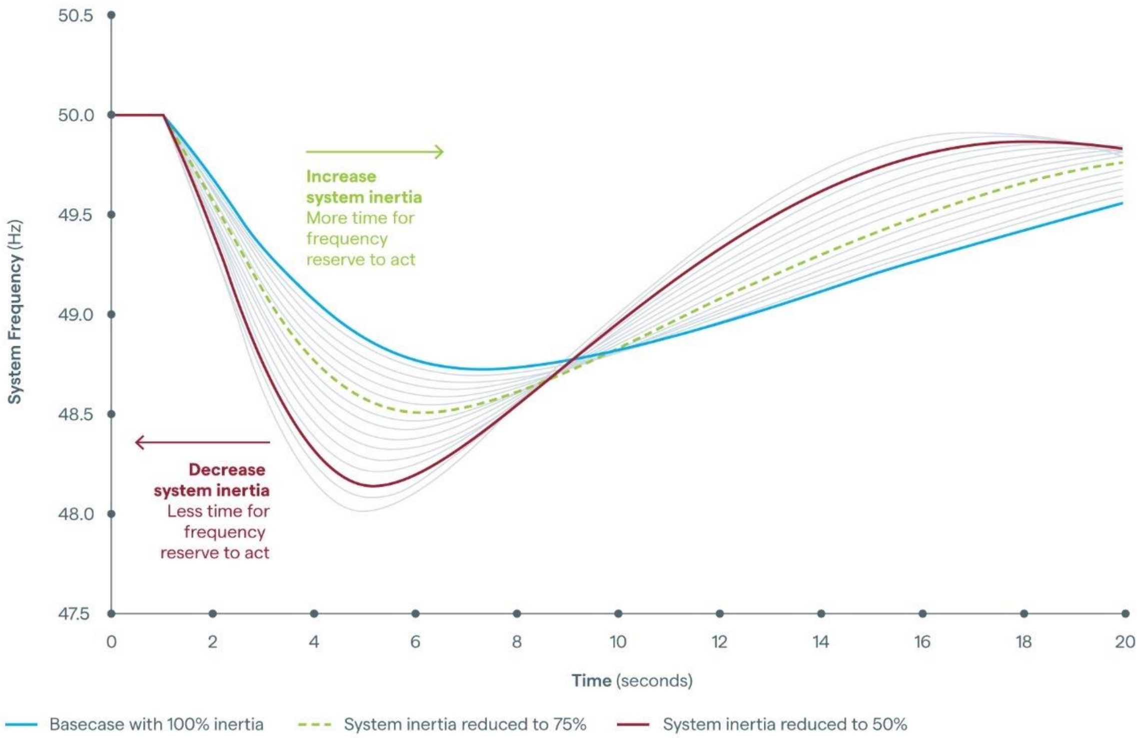


Figure 15 – System frequency responses from the reduction in inertia

The amount of inertia contributed by different synchronous generation technologies varies. Generally, thermal generators provide more inertia than other generation types due to their size.

There are two main types of wind generation technology used in New Zealand. Doubly fed induction generators which do provide inertia as they have a direct coupling of the induction generator to the power system. Their response is slightly different from synchronous generation, resulting in a slow and lower inertial response. Whereas modern full back-to-back generators are completely decoupled from the grid, so no inertia is provided to the system. However, if enabled, this technology can provide synthetic inertia to mimic the inertia provided by synchronous generation.

Solar PV has a similar arrangement to full back-to-back technology except that the energy conversion source is solar irradiance instead of wind. Solar PV generation does not provide inertia.

How will New Zealand be impacted in the future?

New Zealand operates a small power system, which naturally has low inertia. That means system frequency tends to fluctuate more than other jurisdictions, which requires extra effort by the System Operator to manage frequency within operational limits. The amount of inertia the power system has is adequate for our existing ancillary services (as referred to in Section 4 and 5) to work effectively to maintain system frequency with the current mix of generation types.

Figure 16 shows the inertia contributed (represented as an inertia constant[3]) by different generation types in New Zealand.

[3] Inertia contributed by synchronous generators is usually presented as inertia constant; defined as the ratio of stored kinetic energy of a rotating machine to the rating of a machine in Mega Volt Ampere (MVA).

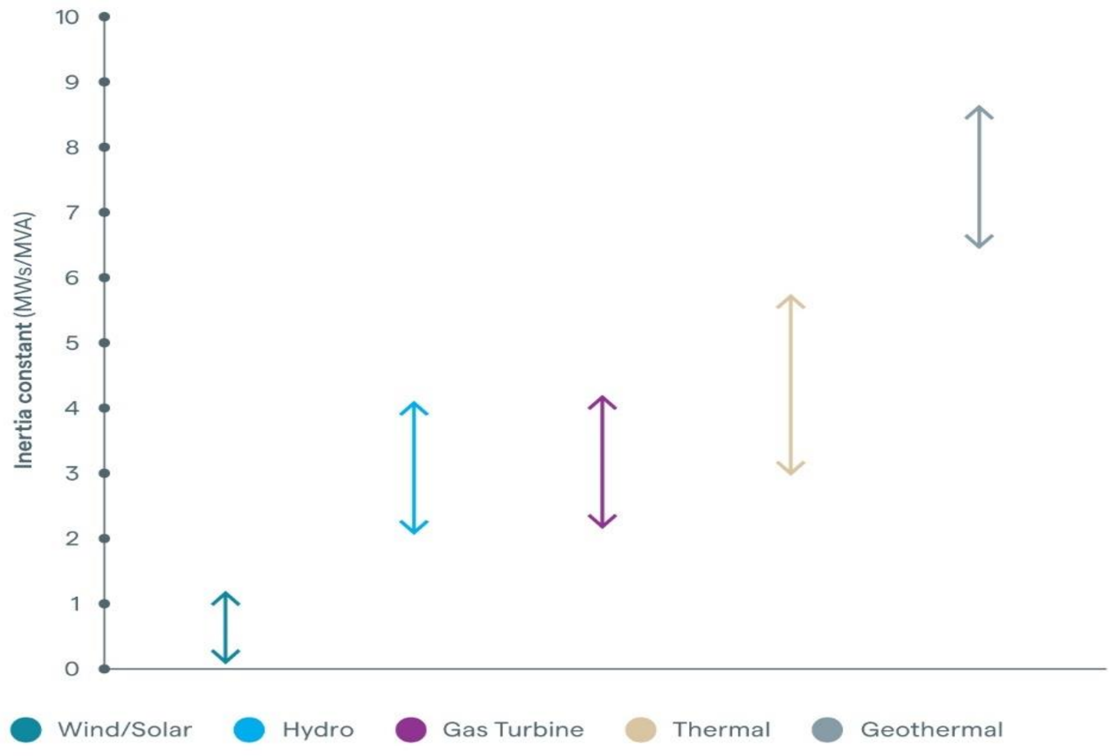


Figure 16 – Summary of inertia constant

When inverter generation displaces synchronous generation, it also displaces system inertia. The System Operator expects that with future high penetration levels of inverter generation system inertia will reduce, resulting in higher rates of change of frequency for system disturbances, potentially leading to larger frequency deviations than we see today for the same sized contingency. The continued uptake of inverter generation will change the way system frequency is managed. The System Operator will need to do more to mitigate large deviations.

The challenge of reducing inertia will be offset by:

- overall demand for electricity is forecast to increase. That increase should help to maintain more synchronous generation online throughout the day as there won't be enough inverter generation to meet the increase in demand alone. However, under some extreme operating conditions, e.g. during mid-day in summer when demand is traditionally low and sunshine is high, and a reasonably high wind situation, inverter generation may drive more synchronous generation offline which will reduce system inertia at the time
- Thermal generation is likely to have been retired or only retained for security of supply. These large generators typically set the contingent event risk, so if not dispatched the contingent event risk will likely be less meaning the risk of large disturbance is reduced.

Timing and priority

Going forward, the Mobilise to Decarbonise scenario (outlined in Section 7) forecasts that synchronous generation may reduce to about 50 per cent, with inverter generation making up the other 50 per cent, by 2050. When synchronous generation is at, or above 50 per cent, system inertia will be sufficient to allow existing ancillary services to mitigate credible events. This challenge will need to be monitored carefully but is expected to be a long-term challenge with low priority.

10.6 Operating with low system strength

Low system strength is a key characteristic of New Zealand's power system today, and voltage management is essential to secure operation of that system. The changing generation mix (moving from synchronous generation to higher proportions of inverter-based generation) will alter the way the power system needs to be managed. There is a limit to the amount of inverter generation a low system strength power system can take considering current inverter technology.

What is system strength and why is it important?

System strength is a measure of the power system's ability to maintain voltage waveform and recover stably following a fault or disturbance. It is important for:

- maintaining normal power system operation
- dynamic response during a fault or disturbance
- recovery, or return, of the power system to an acceptable and stable operating condition after a fault or disturbance.

Low system strength can affect the power system's operation and cause system wide disturbance. If a fault or disturbance occurs, a power system with low system strength will be more susceptible to a large voltage deviation and instability. This will affect power quality and equipment operation, especially for inverters which rely on a clean voltage waveform to function correctly.

Other operational challenges that may occur for inverters operating under low system strength conditions include instability ranging from voltage to control instability, inability for equipment to ride through low voltage disturbances, protection relay mal-operation, reduced voltage recovery following a voltage disturbance and power quality issues ranging from increased harmonic distortion to worsening voltage sag.

In the past, synchronous generation technology was the main positive contributor to system strength whereas inverter generation technology was considered a negative contributor. Advancement of inverter generation technology has led to development of grid-forming inverters and advanced site-specific grid-following inverters which can operate in low system strength and provide a positive contribution to system strength. This advancement could be an opportunity that is worth exploring further for New Zealand.

System strength can be influenced by many factors, e.g. density of inverter generation in close proximity, the number of online synchronous generators contributing to short circuit current and the electrical remoteness of the point of connection (POC).

The amount of available short circuit current at the POC of inverter generation is directly related to system strength. A low short circuit current equals low system strength. Figure 17 shows the relationship between short circuit level (also known as system strength level) and generation plant size and its impact on power system operation.

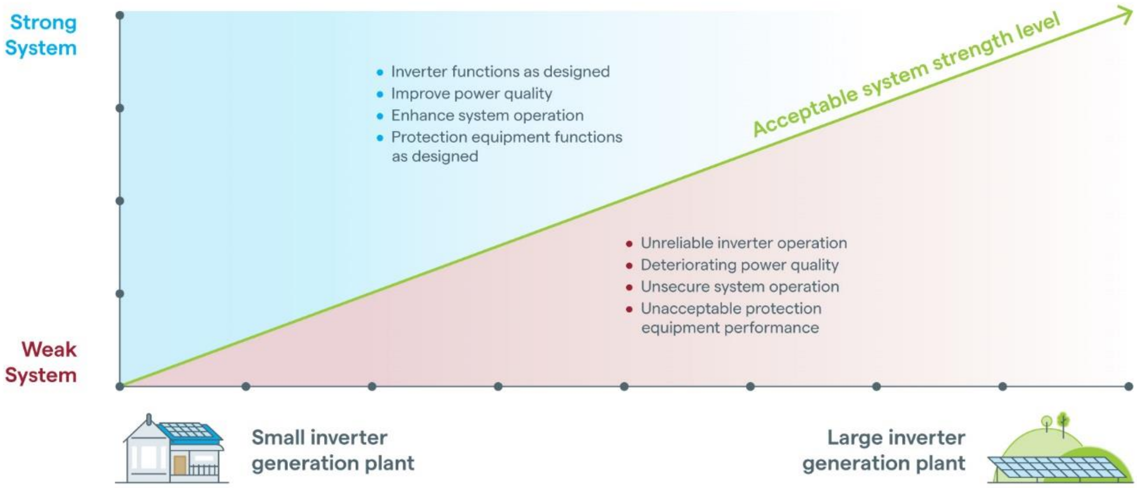


Figure 17 - Relationship between short circuit level, plant size and impact on security

How will New Zealand be impacted in the future?

NZ has traditionally experienced a low short-circuit level, which has been managed effectively by the System Operator. Most locations in NZ are at a level of system strength that it is just acceptable [12]. This is not currently a concern however as the penetration of inverter generation technology is still low and synchronous generation is considered to be a positive contributor to short-circuit levels.

As the number of IBRs (wind and Solar PV) connected to the power system increases in the future, there is a higher chance of operational issues, e.g. tripping of IBR generation or more interactions/oscillations of IBR. It may not be possible to accommodate a high penetration or concentration of inverter generation at a single location, which could negatively impact on New Zealand meeting its climate change targets. At present it is unclear in New Zealand at what level of IBR penetration operational issues will occur, i.e. how many large wind farms can be added to a system that already has low system strength?

Timing and priority

The Mobilise to Decarbonise scenario (outlined in Section 7) forecasts that by 2030 synchronous generation will form about 50 per cent of the generation mix and the other 50 per cent will be inverter generation technology. In addition, nearly 40 per cent of inverter generation will comprise smaller distributed generators.

With this generation mix, the power system will likely experience lower system strength in the transmission network and higher system strength in the distribution network, as distributed inverter generation displaces grid connected synchronous generation.

This challenge will occur in the mid-term as penetration of IBR increases. It is expected to present as a localised issue with greater potential for problems where multiple IBR are connected in proximity.

10.7 Accommodating future changes within technical requirements

Changes in technology are fundamentally changing the way the power system operates. Technical requirements for the power system will need to reflect those changes.

What are technical requirements and why are they important?

Technical requirements of the New Zealand power system are contained in the Code[4], technical standards, grid and distribution operation processes and procedures.

The Code was developed in 1996 after the de-regulation of the electricity industry in New Zealand. At that time the predominant type of generation was synchronous. Demand was mainly made up of industry, commercial and residential, representing more traditional passive load behaviour. The Code sets out the duties and responsibilities that apply to industry participants, including the System Operator. It includes the technical requirements for connecting to, and using, New Zealand's power system; establishing the basic rules, requirements, procedures and standards that govern the operation of the system.

Technical requirements and performance standards are important as they:

- address design requirements and considerations covering associated components, systems and technologies that have an impact on the reliability functions of equipment
- ensure equipment is designed to meet the requirements of the grid, i.e. voltage and frequency control, low voltage ride through capability and other power quality requirements
- ensure a level playing field throughout the entire power system, with grid and distribution connected assets sharing the same access rights and the same obligations to support the operation of the power system.

Lack of up to date technical requirements or performance standards can cause a misalignment of performance, e.g. asking an inverter generator to behave like a synchronous generator, and a lack of fairness in assigning obligations, e.g. voltage and frequency support requirements. Fit-for-purpose technical requirements would allow each technology to perform to its optimal capability, providing critical power system support that enables reliable and secure electricity supply.

How will New Zealand be impacted in the future?

Expected increase of IBRs and DER, together with the move to a decentralised power system, means that New Zealand's technical requirements for the power system need to be updated in order to accommodate these changes and different operating characteristics in a way that ensures the power system remains secure, is safely operated and the technology operates in an optimal capacity. The status quo in terms of how the power system is managed and operated cannot be maintained.

The Code must be updated to address new and emerging technology (wind, solar PV, battery energy storage systems, pumped hydro, etc.) to ensure the power system can be operated in a secure and economic manner.

There are three parts to this challenge. Technical requirements need to ensure that:

- new technology can be easily integrated so that everyone can connect to the power system
- all technology can work to its optimal capacity
- everyone is playing their part by meeting their obligations, depending on the technology they are connecting.

[4] Including documents incorporated into the Code by reference e.g. Ancillary Services Procurement Plan, Policy Statement, Emergency Management Policy, Benchmark agreement, etc

Anticipated changes with the continued uptake of new technologies are:

- future generation installations are likely to be powered by renewable energy sources
- inverter generation technologies are decoupled from the power system by the inverter. It is expected that this type of generation will behave differently from synchronous generation
- generating stations tend to be smaller and may have many units connected by a collector system to form a single interface to the power system
- the protection and control systems of inverter generation plants are complex, and the technology is still evolving.

To enable the efficient and secure integration of any new technologies, while ensuring the System Operator can continue to comply with its PPOs, the characteristics and behaviour of these technologies needs to be identified. This is also key to ensuring that all technology is working to its optimal capacity and enabling ancillary services.

Technical requirements need to ensure there is a level playing field throughout the entire power system, with transmission and distribution connected assets sharing the same access rights to use the system and the same obligations to support the functions of power system operation (depending on the technology).

There is an immediate and ongoing need to update technical requirements to:

- make them technology neutral
- ensure Asset Owner Performance Obligations (AOPO's) are appropriately shared and enforceable
- ensure obligations to support the power system are fairly allocated across all generation types capable of doing so
- enable new technology to offer ancillary services, as synchronous generation does now
- align with performance requirements stated in AS/NZS 4777.2:2020 for smaller inverter-based generation embedded in the distribution network.

Timing and priority

It is of utmost importance to amend the Code, technical standards, processes and guidelines to enable a smooth integration of the new generation technologies, ensure the technologies are performing to optimal capability, and to support secure power system operation. Given the downstream impacts if not addressed, this challenge is considered high priority today to ensure a strong foundation for the future.

Other opportunities and challenges

Three additional challenges are outlined in this section. The common thread between these topics is that while the bulk of their respective activities take place well ahead of real-time their impacts can be felt acutely in real-time. The potential real-time impacts of a cyber security breach may be more obvious than issues arising from dealing with the connection of new assets or workforce capability. Nevertheless, the final two challenges can present issues in real-time; for example, poorly executed connection studies could result in unstable power system operations (e.g. voltage oscillations in areas of low system strength) and a lack of a skilled workforce to serve the whole industry in real-time. When considering the challenge of cyber security in Phase 3 of the FSR programme it will be important to leverage and complement the work undertaken in this space to date by the Electricity Authority's Security and Reliability Council (SRC).

Because of the potential impact of an absence of a skilled workforce to assess asset connection studies it may be prudent to consider both challenges together in Phase 3 of the FSR programme.

10.8 Loss of control due to cyber security

Increased digitisation and advancement of information and communication technology (ICT) have transformed and will continue to transform the power system to become even more connected, smarter and controllable. The system will become more distributed with many DER and behind-the meter resources participating in meeting demand, and more dynamic due to an increase in variable and intermittent generation.

All these changes require more sensors, information and connectivity to enable control, monitoring and facilitation of energy transactions. The power system will be smarter, more observable with an ever-increasing reliance on data management, automatically controllable and more accessible to users. Consequently, it will be more vulnerable to cyber-attack.

Figure 18 shows possible connectivity of the future power system needed to deliver electric power and to communicate with the various devices and equipment within the system.

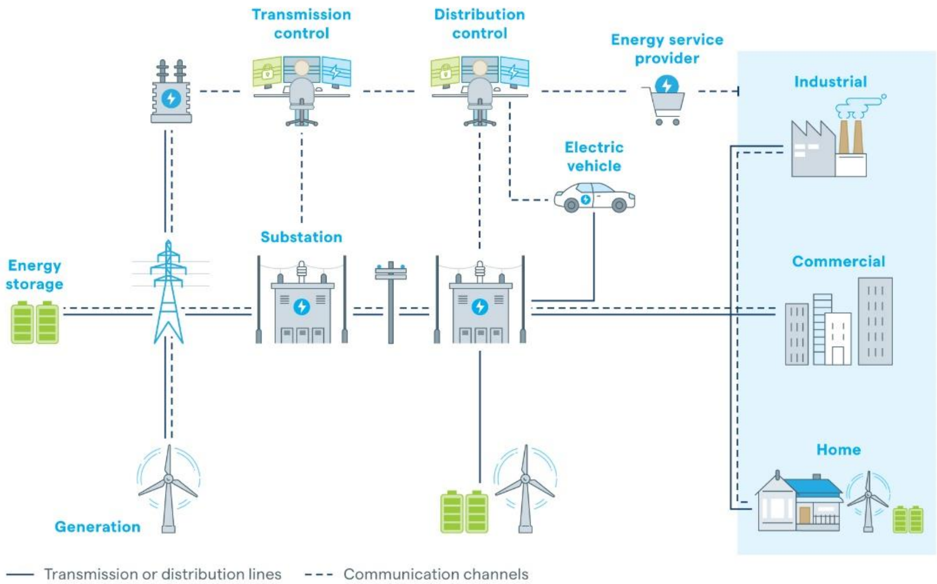


Figure 18 - Connectivity of the future power system

While New Zealand has not experienced significant cyber incidents that disrupt the operation of the grid, there have been attacks on various government agencies and private institutions [67] [68]. Also, cybersecurity events targeting the energy sector internationally are already occurring. A Dragos report has found that the number of cyber intrusions and attacks targeting the electric sector is increasing. Additionally, supply chain risks and ransomware attacks continue to enable intrusions and disruptive impacts on electric utility operations [69].

According to data tracked by Dragos and IBM Security X-Force between 2018 and 2020, ten per cent of ransomware attacks that occurred on industrial and related entities targeted electric utilities [70]. They were the second most targeted industry after manufacturing.

Cyberattack is a credible threat now, and will remain so in the future, due to the extensive use of ICT. While ICT continues to play an important role in efficient operation of the power system, the highly integrated systems essential for the successful operation of a more distributed system make cyber security more complex with increasing vulnerabilities due to the increased number of access routes. The future power system will be more vulnerable to both loss of capability due to malware and hostile takeover of operations.

Timing and priority

Cyber security is a challenge that industry faces today, and it will require a continuous effort to prevent an attack that may cause widespread disruption to power system operation. Cyber incidents are likely to increase over the next decade making this an enduring challenge to manage.

Cyber security is a key focus of the SRC. SRC workstreams may be the best place to continue to address this key aspect of future operation of a secure and resilient power system.

10.9 Coordination of increased connections

New Zealand's power system is a typical centralised power system, with grid connected generating stations producing the bulk of supply to meet demand. Generation is built near to fuel sources, and electrical power is delivered to load centres through long high-voltage transmission circuits.

In the future it is expected that the number of generating stations will increase and that units will be smaller and highly distributed. Transitioning away from a centralised power system with predominately large generating units to a decentralised system with vast amounts of DER embedded in distribution networks will challenge how new connections to the power system are managed in the future as well as how the larger, more distributed volumes of connected generation are managed overall.

Figure 19 shows the upward trend in the number of connections enquires that Transpower has already started to receive.

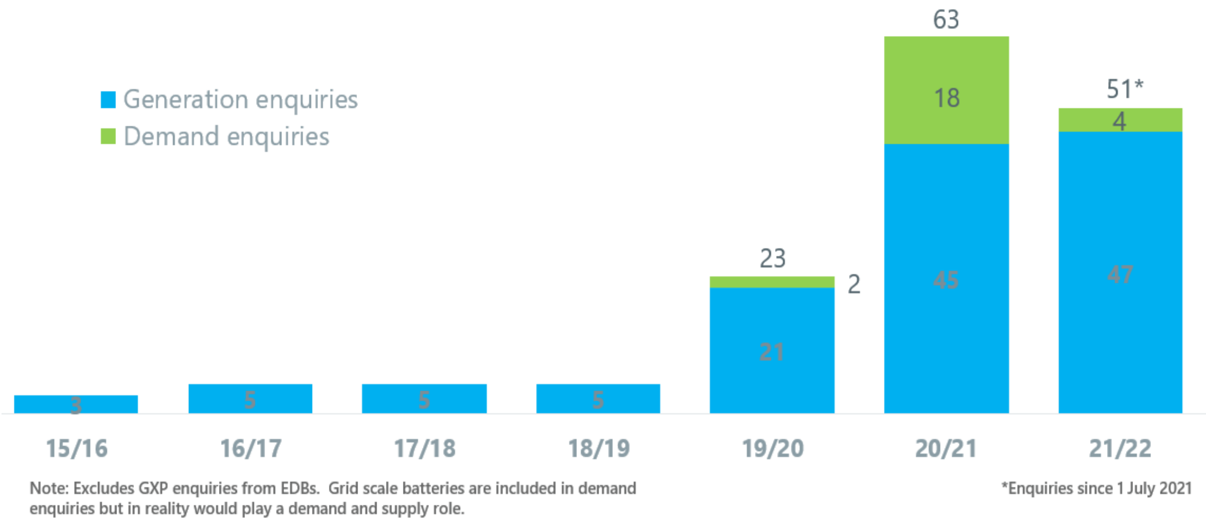


Figure 19 - Number of connection enquiries made to Transpower

How will New Zealand's connections be impacted in the future?

Generating stations intending to connect to the grid are required to meet connection requirements and asset owner performance obligations as stipulated in the Code. The processes to connect large synchronous generating stations to the grid are well-established and have been used for years.

However connecting large numbers of distributed inverter-based DER changes the paradigm requiring the current connection processes to adapt to the characteristics of DER, being more distributed, faster to build, able to be connected in more locations within the power system and not having the same behaviour as traditional synchronous generating stations. Planning and coordinating connections of different generation types will add an additional layer of complexity compared to what is dealt with today and if not executed well, may lead to delays in new generation being connected.

There will be an increase in uncertainty when it comes to connection, e.g. there could be an increased number of projects moving at speed – having a large number of solar farms in one location will have a bigger impact than if located in multiple locations - that will all need to be managed, both in terms of being connected and the impact of those connections on the power system. Consideration needs to be given to how this change can be managed in an efficient way when a large number want to connect at different times.

The future challenges that New Zealand is likely to face in relation to connections include:

- increasing number of assets wanting to connect to the power system concurrently will require additional resources to achieve
- re-skilling our workforce to understand the behaviour of inverter-based generation technology ensuring the assets are adequately tested to meet the performance and technical requirements
- addressing inconsistencies in requirements for assets connecting to the transmission network and distribution networks to better align performance standards
- assessing impacts of new connections will need to be carried out in a more holistic manner to consider impacts of all connections, instead of the individual connection
- asset performance obligations need to be shared fairly across the range of assets connecting to ensure they support system operation
- developing new standards and guidelines for commissioning and testing new generation and energy technologies like battery energy storage system
- commissioning and testing multiple generation stations simultaneously increases the risk of cascade tripping of un-proven assets.

Timing and priority

The increased number of generating stations requesting to connect is an imminent challenge. The generating stations are likely to be smaller, more distributed and using inverter-based technology. This challenge has a high priority due to the need to change connection evaluation processes and re-skill the workforce to facilitate a high volume of generating station connection requests and avoid any delays.

10.10 Growing skills & capabilities of the workforce

Expanding the skills and capabilities of the current workforce to reflect changes in technology is critical in order to retain experienced workers, provide a smooth transition for the next generation and ensure we can enable New Zealand's energy future.

The need for a skilled workforce

To deliver the fundamental purpose of the power system of generating and delivering electrical power, a highly skilled workforce is required to:

- derive universal technical standards and guides to reduce cost and improve the design, operation and maintenance of the power system
- design and build the power system, ensuring successful integration of system components
- operate the power system to ensure secure power supply
- maintain system components to ensure reliable operation
- understand and operate control and management software and tools
- design, develop and deploy information technology systems required to operate the power system
- aid in developing rules and policies associated with new participation and new power system operational practices.

The changing nature of technology

The history of power generation is long, marked by many milestones, both conceptual and technical, from hundreds of contributors. Technologies such as synchronous generators, transformers, transmission lines and cables are mature with many standards and guides available to regulate the design, construction and implementation of these technologies into the power system.

The Code and regulatory framework were developed to operate a power system built with these technologies. Equally, the curriculum of universities was designed to educate engineers based on these technologies. However, the need to decarbonise and meet climate change targets has resulted in the development of new generation technologies harvesting renewable resources. Other technologies, e.g. BESS and EV, have been developed and commercialised to provide the flexibility needed to operate a highly intermittent power system and to speed up decarbonisation of the economy.

These new technologies have changed the behaviour of the power system significantly. There is now a need to review the way the future power system is designed, built, operated and maintained which means changes are needed to the skills and capabilities of our current and future workforce.

How will New Zealand be impacted in the future?

New Zealand's energy landscape is rapidly evolving; driven by consumers' adaptation of innovation to become prosumers, progressive uptake of renewable generation, decarbonisation of the economy and the continued need for a resilient power system. A workforce equipped with relevant skills is important for New Zealand to achieve its climate change target while keeping the lights on.

There are two main challenges: (1) developing the skills and capabilities of the current workforce to ensure a smooth transition to new ways of working and (2) training future graduates with the relevant skills for our evolving energy landscape.

The current workforce is very skilled and experienced in operating a centralised power system based on mature synchronous generation technologies. However, this workforce also needs to become competent with new emerging technologies and be able to overcome any challenges that come with the evolving power system.

In the short-term, there is a need to grow skills and capabilities of the current workforce, so they can operate the future power system. In the medium-term, there needs to be collaboration between the industry and New Zealand's educational institutions to work on the initiatives listed below.

The following will be essential in developing a new generation of engineers, technicians and support personnel to replace the ageing workforce and to resolve the shortage of power system engineers in New Zealand:

- attracting enrolments into the power system engineering stream
- developing relevant curriculum focusing on power electronics, future generation technologies and digital skills, e.g. data modelling, analytical and artificial intelligence
- supporting research and development to work on long-term power system challenges.

This challenge is a national issue affecting New Zealand's power system as skilled workers are needed throughout the country.

Timing and priority

The energy sector is facing an acute resourcing problem with many companies competing for qualified engineers worldwide. Re-skilling the current workforce is an ongoing activity to retain and train the right skillsets to manage the power system with a high penetration of new generation technologies. Training new workforce locally by collaborating with local universities and institutions is a long-term solution. The priority for this challenge is considered high as this solution has a long lead time and requires an immediate start.

11.0 Summary & Next Steps

This report has outlined why power system security and resilience are fundamental cornerstones to delivering a 100% renewable future. The underlying physics on which a power system is built, are universal and the success of New Zealand's transition away from fossil fuelled generation sources relies on being able to manage those physical attributes while accommodating higher proportions of weather-dependent, decentralised resource as well as increased demand.

This report has summarised previous research undertaken in NZ to understand how the future may affect the security and resilience of the power system. Literature reviews were also conducted on five selected jurisdictions to ascertain whether NZ could learn from overseas experience.

The dashboard below summarises the opportunities & challenges identified in this report and prioritises these based on when New Zealand can expect to see these challenges emerge based on the Mobilise to Decarbonise scenario.

Table 7 - FSR dashboard

Opportunities & challenges	Timeframe	Priority
Leveraging DER to build and operate the future grid	3-7 years	Medium
Leveraging new technology to enhance ancillary services	Enduring	Low
Visibility and observability of DER	3-7 years	Medium
Balancing renewable generation	3-7 years	Low
Managing reducing system inertia	7-10 years +	Low
Operating with low system strength	3-7 years	Medium
Accommodating future changes within technical requirements	0-3 years	High
Coordination of increased connections	0-3 years	High
Loss of control due to cyber security	Enduring	Medium
Growing skills & capabilities of the workforce	Enduring	High

These opportunities and challenges affect every component of the power system from generation, to transmission, to distribution, and finally, to consumption which highlights the importance of ensuring a cohesive and innovative industry effort to achieve NZ's renewable ambitions

The next steps for the Future Security and Resilience programme are:

- engage with industry to receive feedback on the content of this report – have we captured all the opportunities and challenges and clearly articulated them?
- incorporate the opportunities and challenges into a roadmap to effectively sequence the work to be undertaken in order to address them in a timely manner
- monitor how these opportunities and challenges manifest over time, tracking any changes in future trajectory and reprioritising as required.

Once confirmed, the Future Security and Resilience programme will integrate with the Electricity Authority's broader future work programme to support New Zealand to meet its energy goals.

Appendix 1 GLOSSARY

Acronym / Term	Description
AC	Alternating current
Ancillary services	The services and functions that support the continuous flow of electricity so that supply will continually meet demand. In New Zealand these are IR, voltage support, black start, OFR and FK
AUFLS	Automatic under-frequency load shedding: a system by which large blocks of load are armed with AUFLS relays ready to be disconnected when the frequency falls below a pre-programmed threshold
BESS	Battery energy storage system
Contingency	The uncertainty of an event occurring, and the planning to cover for it; for example, in relation to transmission, the unplanned tripping of a single item of equipment, or, in relation to a fall in frequency, the loss of the largest single block of generation in service, or loss of one HVDC pole
Contingent event	An event for which the impact, probability of occurrence and estimated cost and benefits of mitigation are considered to justify implementing policies intended to be incorporated into scheduling and dispatch processes pre-event
Cogeneration	Combining of an industrial process and electricity generation e.g. heat is created for an industrial process and then that heat is used to create steam to create generation.
DC	Direct current
DER	Distributed energy resources are controllable energy resource located in the distribution network and not connected directly to the grid. Examples include solar PV, battery energy storage systems and EVs
Dispatch	Scheduling active and reactive power generation to meet demand
EV	Electric vehicle
Distribution network	electricity lines, and associated equipment, owned or operated by a distributor
FIR	Fast instantaneous reserve: reserve that must act within six seconds and then maintain its post-event output for 60 seconds (see also SIR)
FK	Frequency keeping: a service provided by one or more generating units to manage short-term supply and demand imbalances by quickly varying their output to ensure the system frequency is maintained at or near 50 Hz
Frequency	Rate of cyclic change in current and voltage, measured in Hz

Acronym / Term	Description
Generator	A device that converts one form of energy (e.g. rotating mechanical movement, solar irradiance) into electric power. The current generated can be either alternating (AC) or direct (DC)
Grid	System of transmission lines, substations and other works, including the HVDC link used to connect grid injection points and grid exit points to convey electricity throughout the North Island and the South Island of New Zealand
GXP	Grid exit point, any point of connection on the grid at which electricity predominantly flows out of the grid.
Harmonics	Harmonics are sinusoidal voltages or currents having frequencies that are integer multiples of the frequency at which the supply system is designed to operate. Harmonic frequencies are produced by the action of non-linear loads such as rectifiers, discharge lighting, or saturated electric machines.
HILF	High-impact low-frequency
HVDC	High voltage direct current means the converter stations at Benmore in the South Island and Haywards in the North Island and the high voltage transmission lines and undersea cables linking them.
IL	Interruptible load: reserve provided through the disconnection of load following an under-frequency event; can be provided as either FIR or SIR.
Inverter	An apparatus that converts direct current into alternating current.
IR	Instantaneous reserve: an ancillary service comprising of the following three products to restore frequency after a credible event: FIR, SIR and IL
MW	Mega-watts, unit of measure for energy in watts using 000's
OFR	Over-frequency reserve: reserve provided by generating units that can be armed when required and automatically disconnected from the system due to a sudden rise in system frequency
POC	Point of connection; a point at which electricity may flow in or out of the grid, or a local network.
Power system or system	A network of electrical components deployed to supply, transfer and use electric power
PPOs	The system operator's principle performance obligations, as set out in the Code
PV	Photovoltaic: describes generating electric power by using solar cells to convert energy from the sun into a flow of electrons by the photovoltaic effect.
Ramp (Ramp up)	Move a generator or HVDC link to a designated load level at a specified rate

Acronym / Term	Description
SCADA	Supervisory Control and Data Acquisition tool used to provide visibility of the power system in real-time
Short Circuit Ratio	The short circuit ratio (SCR) is the most basic form of system strength measurement, calculating the ratio of available short circuit current at the point of connection to the rating of the inverter generation plant connected to the same point of connection.
SIR	Sustained instantaneous reserve: reserve that must act within 60 seconds and then maintain its post-event output for 15 minutes (see also FIR)
SOC	State of charge (in this context, within a BESS)
System Operator	Referring to Transpower New Zealand Limited as the system operator
the Authority	Electricity Authority
the Code	Electricity Industry Participation Code
UNI	Upper North Island
USI	Upper South Island
Voltage sags	Voltage sags are short duration reductions in voltage magnitude and duration lasting typically from a few cycles to a few seconds. As per IEEE 1159 definition, a voltage sag happens when the rms voltage decreases between 10 and 90 percent of nominal voltage for one-half cycle to one minute.
VPP	Virtual power plant: a system that integrates several types of power sources to give a reliable power supply akin to a grid-connected generator

Appendix 2 Further Information on Opportunities and Challenges from Selected Jurisdictions

This appendix is intended to provide more detailed experience of each jurisdiction studied in relation to each opportunity and challenge (where relevant information was found available).

Leveraging Distributed Energy Resources to Build and Operate the Future Grid

Australia

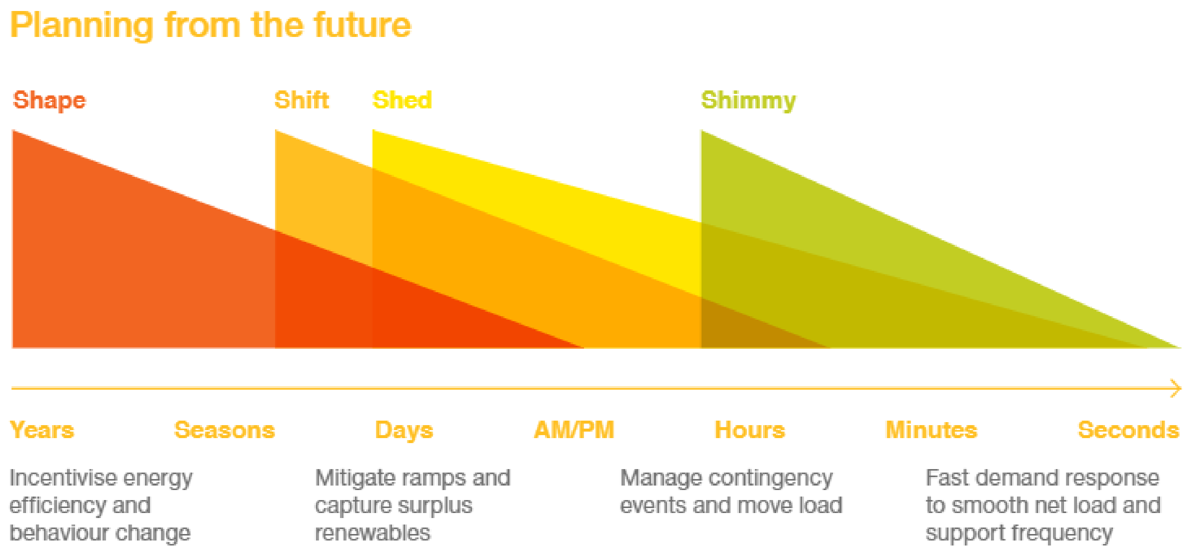
The Energy Security Board (ESB) identified a suite of near-term governance measures intended to maximise value from DER in the National Electricity Market (NEM):

- "expanding the responsibilities of distributors to hosting distributed generation and storage, supporting flexible demand, and introducing technical standards for DER that will smooth the customer experience and assist to ensure the security of the power system"
- putting in place measures across jurisdictions to control DER in the rare event they are needed to ensure power system security
- enhancing market information provided by the Australian Energy Market Operator (AEMO) to reduce the need for security interventions
- developing services which encourage flexible demand to shift away from system peak times
- promoting easy and safe ability for customer switching between DER and non-DER service providers [71].

Similarly, the Energy Transformation Taskforce in Western Australia (South-West Interconnected System) has produced a DER Roadmap. "There's rising variability on the demand side with uptake of rooftop solar PV, batteries and smart appliances. Looking ahead [they] see all sorts of services rewarding people for changing demand patterns or contributing to innovations like community batteries. [They] propose consideration of consumer protections to keep pace with change, and solutions for local congestion/stability issues so more home-made solar PV power can help lower system costs for everyone." [72].

Great Britain

The Electricity System Operator (ESO) has identified an increased need for flexible demand and supply to mitigate 'peaks and troughs'. They are planning to use a model called "Shape, Shift, Shed, and Shimmy" which considers different timeframes (years to real-time) and three levers (data and digitalisation, technology, and markets) to effect the changes needed. These plans have been created by considering what capabilities the energy system needs to have in 2030 and planning now to move in the right direction.



[73]

Ireland

Ireland's electrical transformation is almost exclusively driven by large scale connection of renewable energy in the form of wind farms. Demand side management is identified as a growth opportunity without demand shaping being specifically mentioned as a potential use [74].

Leveraging New Technology to Enhance Ancillary Services

Australia

Australia is in the process of developing a fast frequency response (FFR) frequency control ancillary service (FCAS) product [75]. With lower system inertia brought on by high penetration of IBR, faster frequency control is required to mitigate the risk of blackout from contingencies. The new product is designed to “foster innovation in faster responding technologies and deliver lower costs for consumers.”

Great Britain

The Power Potential project was a world first trial using DER capability to provide dynamic voltage control from DER (as well as energy dispatch to manage constraints and system balancing). Power Potential had participation from solar PV, wind, and BESS [76].

The ESO has contracted five parties to provide inertia from non-generation sources, enabling a more secure power system without the need to retain thermal generation online to provide inertia [77].

Ireland

In 2013, Ireland’s Single Electricity Market (SEM) Committee established new and enhanced system services in order to achieve operability of a system with up to 40 per cent renewable energy penetration. In the System Services Technical Definition Paper the Committee said “…the results of the Transmission System Operator's (TSO) Facilitation of Renewables Studies (2010) and the Report on Ensuring a Secure, Reliable and Efficient Power System (2011) indicate that new and enhanced system services will be required to enable the TSOs to continue to operate the system in a secure and reliable manner as levels of wind generation on the system increase. The Committee accepts that there is a need for new system services, in particular services that will reward flexibility and assist in the delivery of the 40 per cent renewable targets in Ireland and Northern Ireland.” [78]. These services were subsequently developed to achieve up to 70 per cent renewables penetration in 2021.

To achieve higher levels of renewables penetration, EirGrid’s 2021 paper, Shaping Our Electricity Future, commenced an energy market review, looking into how even higher levels of renewable penetration might be achievable, particularly focussing on the ability of the demand-side to provide system services [79].

Hawaii

Equipping wind and solar PV generation with governor controls to reduce power output has been identified as a potential mitigation for over-frequency events. For under frequency events the capabilities of BESS and demand side response may be progressed. It is also noted that applying synthetic inertia control functions on wind farms would assist with frequency management [80, p. 23].

Visibility and Observability of DER

Australia

Regulations have been introduced in the National Electricity Market that mandate collection of static device information of all DER, but Australian distribution network service providers have very limited real-time visibility of PV systems of less than 5 MW [81, p. 3]. AEMO is also planning to update its load models to better represent current load and how it responds during disturbances, particularly with increased penetrations of DER [81, p. 27].

Great Britain

The National Grid ESO has been working with network organisations to develop new business processes, implement new IT systems and co-create new market arrangements to support the delivery of visible and controllable DER [47, p. 74].

Great Britain has modified its Grid Code to make it mandatory for new wind farms to provide the power available signal to the National Grid ESO. This has been integrated with the control room which will allow them to have a second-by-second view of wind operators' potential outputs [48, p. 5].

ESO has comprehensive operability plans considering the effects of the future frequency, stability, voltage, restoration and network limits [47].

Hawaii

Hawaii is implementing a Grid Modernization Strategy to provide grid operators with new tools to manage the grid, the first phase of which addresses visibility through deployment of smart meters and an associated Meter Data Management System communications network. A second phase builds on this by implementing an Advanced Distribution Management System and Field Devices, including Secondary Volt-ampere Reactive (VAR) Controllers, line sensors, remote fault indicators, and remote intelligent switches [82].

Singapore

Because Singapore's PV installations are largely dispersed (e.g. on rooftops), this could give rise to additional challenges, in particular the lack of visibility and control over a large generation fleet that is embedded in the distribution network [83, p. 46].

Balancing Renewable Generation

Australia

Australia has experienced network overload due to the pace at which wind and solar PV is being built and has developed whole-of-system transmission planning in response. Arrangements will be made to manage network congestion between renewable energy zones and customers [41, p. 1].

AEMO is carrying out analysis to understand how ramping challenges are likely to emerge, in particular quantifying how system variability changes as more variable generation is installed, and the level of uncertainty in forecasting the output of these generators [81, p. 2]. There is uncertainty about how quickly conventional generators can ramp up and down with changes in both utility-scale and DER output [81, p. 19].

Great Britain

The ESO predicts that by 2030, instead of matching supply to demand, its control room will be dispatching demand to manage variability from low carbon supply generation, for example from EVs and heat pumps. In order to do this, it has identified three fundamental pillars: data and digitalisation, technology and markets [73, pp. 12, 17].

Ireland

EirGrid has highlighted that by 2030 it is possible that, with an increasingly high installed capacity of variable generation, forecast error may exceed total scheduled system capability. Increasing ramping reserve requirements to cover fewer probable events has been considered but is likely to be cost prohibitive. The need for new services that have high availability, but low utilisation has been raised [56, p. 77]. Currently, ramping constraints that interface with EirGrid's scheduling process have been implemented to ensure a sufficient amount of system flexibility is available to cover renewable variability [81, p. 4].

Hawaii

In 2015 Hawaiian utilities were forced to restrict some customers from turning on new solar PV they had installed because the grid was unable to cope with the volume of intermittent renewable electricity that had been rapidly added to the system. They also stopped new installations from going ahead, creating a years' long waiting list for rooftop solar PV panels [57], and ended the net metering programme, which allowed customers to sell surplus electricity generated by rooftop solar PV panels back to the utilities at retail rates [58].

Singapore

Apart from space maximisation, managing the high variability from solar PV is one of the key concerns for large-scale adoption of solar PV in Singapore [83, p. 44] . However, even in Singapore's 2050 accelerated solar PV uptake scenario the current capability of generators will still be able to accommodate ramp rate impact requirements. Four potential mitigation measures were suggested to minimise any ramping requirements: operational solar forecasting, demand response, energy storage systems, and smart inverters and power electronics.

Managing Reducing System Inertia

Australia

The NEM and South-West Interconnected System (SWIS) have experienced over-frequency events [81, pp. 26-27].

AEMO has observed that an increase in penetration of wind and solar PV is pushing the system to minimum limits, which was never considered in the design of the NEM dispatch process. To address these operational issues AEMO is redeveloping the scheduling systems to better account for essential system services (incl. inertia), improving the modelling of new technologies, and assessing market mechanisms for system services to ensure system security going forward [84, p. 8].

(See comments above in *Accommodating Future Changes within Technical Requirements*).

Great Britain

As a response to high renewable generation and low demand during Covid-19 lockdowns, a super-fast acting response product called Dynamic Containment was introduced to help manage frequency on a system experiencing low inertia levels [73, p. 9]. National Grid ESO is now improving the Dynamic Containment day-ahead procurement process and launching a high frequency response service. In 2021 they will develop a new suite of reserve products [47, p. 7].

In addition, National Grid ESO has also implemented Phase 1 of its NOA pathfinder which aims to procure services that add stability to the grid without needing to add energy, allowing a higher proportion of non-synchronous generation. Phase 1 procured 12.5 GVAs of inertia without additional MWs. The capability to monitor real time inertia was expected to come online in summer 2021 [47, p. 40].

In order to operate the system with lower inertia, National Grid ESO is also implementing a Loss of Mains programme which has delivered protection changes across more than 3,000 sites so far. This will alleviate rate of change of frequency and vector shift constraints, which are now the dominant factor when managing system inertia and reduce the cost of balancing the system [47, p. 41].

Ireland

Ireland has implemented a requirement to keep a minimum of eight large conventional units synchronised to prevent low frequency from becoming an issue. They plan to reduce the minimum level of conventional synchronous generation and enable system non-synchronous penetration levels of 95% by 2030, which will also require implementing a secure rate of change of frequency of 1 Hz/s [56, p. 62].

EirGrid/SONI studies have identified "having fewer synchronous generators online decreases the synchronising torque on the system. While a system-wide scarcity has not been identified in the EU-SysFlex studies, localised scarcities have been noted. The scarcities are sensitive to specific unit commitment combinations (i.e. committing an additional Open Cycle Gas-Turbine near the unit that loses synchronism in the base case removes the instability) and certain contingencies but highlight the need for further detailed study based on future network configuration." Similar outcomes have been identified in the Australian context, where AEMO is considering development of a Unit Commitment for Security scheduling mechanism which could constrain dispatch according to number and location of connected machines, rather than simply the unit output.

Additionally, “studies from EU-SysFlex found a localised scarcity of oscillation damping. This scarcity can primarily be observed as a local oscillation in one or two units when a contingency occurs close to their point of connection. It was found that the cases with poor damping are heavily associated with quite specific contingencies and do not occur in general.” No mitigation to these events was discussed.

Hawaii

Over-frequency events have been experienced by Hawaii, resulting in simultaneous disconnection of large amounts of small-scale PV. In order to prevent future events, a large proportion of Hawaii’s older PV systems were remotely reprogrammed [81, pp. 22-27].

Singapore

Studies in Singapore have determined that rate of change of frequency is unlikely to occur before 2030, and only beyond about 4 GWp of installed capacity, compared to the estimated installed capacity of only 400 MWp in 2020 [83, p. 51].

Operating with Low System Strength

Australia

AEMO has worked with local TNSPs to address system strength shortfalls in South Australia, Tasmania, Victoria, and Queensland. Localised system strength challenges are also creating increasing hurdles for generators seeking to connect in weaker parts of the grid.

A lack of system strength in parts of Australia's grid has seen grid connected solar PV being constrained.

Decreasing system strength and voltage dip propagation with increased IBR (wind and solar PV generation) has also been observed by both Ireland and Australia [81].

A review of the system strength framework is underway which may result in changes to the System Strength Requirements Methodology and System Strength Impact Guidelines [84, p. 11].

Great Britain

Great Britain has experienced issues with high voltage caused by reduced demand on the bulk power system as the result of increased residential PV and improved energy efficiency. In 2020 National Grid ESO in Great Britain constrained conventional plant in order to provide voltage support. The additional power delivered because of the constraints meant reducing the output of renewables [81]. To mitigate this issue in future, National Grid ESO is running NOA (Network Operations Assessment) Mersey pathfinder. In 2020, the Mersey short-term pathfinder solution was used on 76 per cent of overnight periods, reducing the requirement for additional synchronous machines. They are also running a Power Potential project to access services from a reactor, at battery and distributed energy resources [47, p. 54].

Ireland

An observed lack of dynamic voltage stability is occurring because of fewer synchronous generators being online. This has resulted in a degradation of dynamic voltage performance. At times this is system-wide, but it occurs more regularly in local instances [56, p. 79].

Hawaii

Hawaii identified high voltage as a result of reduced demand as a potential issue as part of a solar PV integration study [80, p. 23]. It proposes lowering the minimum power level of thermal generation resources in order to reduce the curtailment required from wind and solar PV generation.

Singapore

In modelling a typical distribution network in Singapore no immediate voltage concerns were observed [83, p. 50].

Accommodating Future Changes Within Technical Requirements

Australia

The rapid uptake of inverter-based generation technology and consequential impacts on system operation led to an initial rule change requiring transmission network service providers (TNSPs) to 'do no harm' – requiring them to support system strength and fault tolerance despite new connections on their network. This led to slow and inefficient investment in primary assets such as synchronous condensers, where in some parts of the network it was shown that similar improvements were achieved through reconfiguration of wind turbine operation settings. In co-ordination with the ESB, the Australian Energy Market Commission determined to change the 'do no harm' rule, instead developing a framework for TNSPs and AEMO to agree system strength requirements and a compensation mechanism, and access standards with connected parties. This determination dovetails with the market design work being undertaken by the ESB [85].

Great Britain

The ESO identified a need to develop interoperability standards for existing technology types to be able to interact as well as adopting a whole of system approach when planning new DER, with sufficient visibility of potential impacts, so assets are designed to help manage local flexibility [73].

In an interesting strategy, ESO is paying for generation connected prior to 1 February 2018 to upgrade their Loss of Mains Protection settings to the new standard [86].

Ireland

As part of their future planning EirGrid and System Operator of Northern Ireland (SONI) have included technical standards as "Pillar 1" of their Operational Pathways to 2030 programme, recognising the key need to clarify technical systems and standards to ensure ongoing system stability [56].

Loss of Control Due to Cyber Security

Australia

Several Australian industry and government stakeholders –AEMO, Australian Cyber Security Centre (ACSC), Critical Infrastructure Centre (CIC), and the Cyber Security Industry Working Group (CSIWG) – have collaborated to develop the Australian Energy Sector Cyber Security Framework (AESCSF). This leverages frameworks already implemented in other countries such as the US Department of Energy's Cybersecurity Capability Maturity Model, and global best practices [45].

Great Britain

In its 2021-26 business plan, the National Grid includes a specific stakeholder priority on external threats such as cyber security [53, p. 108]. It currently monitors cyber threats 24/7 and use threat intelligence from specialist agencies to inform cyber security and investment plans. It is currently trialling solutions and vendors in preparation for the next investment cycle [53, p. 110].

It was noted in the findings of the Power Potential project (using DER to provide reactive support) that "Software development can be a headache (issues such as cyber security, confidentiality and access to data are a hidden complexity)" [76, p. 8].

Ireland

EirGrid tested its cyber security by contracting experts in cyber security to try and hack through EirGrid's cyber protections [87].

Hawaii

Hawaiian Electric notes a 20 per cent year-on-year increase in their cyber security costs. They have formed partnerships with related industry peers to share information and collaborate on solutions. Hawaii was one of five US jurisdictions which took part in a two-day energy security exercise which simulated a cyberattack [88].

Singapore

Singapore has developed a five-year roadmap for how it will improve the cyber security for PV integrated power grids. The plan is divided into stakeholder engagement, including the establishment of public-private partnerships, working groups, educational activities and incident planning and R&D, which focuses on new research on cyber security for securing PV components [65, p. 18].

Co-ordination of Increased Connections

Australia

Australia is experiencing significant volumes of new generation connections, principally IBR, which are having real-time operational impacts, including significant delays in connecting new generation. In response, AEMO developed the Integrated System Plan (ISP) [89], which endeavours to co-ordinate investment across Australia's electricity industry to maximise value and reduce operational and investment risk.

The ESB has proposed further enhancements to the ISP "to provide an interim framework for Renewable Energy Zones (REZ). REZ schemes can promote efficient location decisions by making it more attractive for generators to invest in certain parts of the network where resources are plentiful, and the grid has capacity." [71]. In the longer term a congestion management model is proposed, which is intended to encourage new generation and storage to locate in the REZs and mitigate risks of degraded access to the grid by connection of other resources outside the REZs.

Great Britain

In Great Britain most connections are occurring on the distribution network. The ESO has a Distribution System Operator (DSO) strategy in place which notes the need for greater information sharing and coordination between the parties. It also notes the benefits of common standards and frameworks for scenario planning [47].

Ireland

Managing new connections in Ireland is contingent on mitigating their impacts on key operational parameters including inertia/rate of change of frequency, and system strength. By evolving capabilities in ancillary services to support these operational parameters, Ireland is planning on enabling new generation and penetration of intermittent generation of up to 95 per cent [79].

Growing Skills & Capabilities of the Workforce

Australia

In Australia, AEMO runs a number of courses that cover all aspects of the energy industry, including the markets, participants, governing bodies and regulations [90], but doesn't specifically call out development of skills for a low-carbon electricity future.

Great Britain

The National Grid has published the Net Zero Energy Workforce report, which sets out how the energy sector can build a workforce that is able to transform the UK's energy system so that it can meet its net zero target. It outlines the required size, skills and spread across the UK of the future workforce [91, pp. 4, 14]. The report identifies four strategic challenges: losing existing talent, competition for talent, the 'STEM pipeline challenge', and lack of diversity in the sector and goes on to detail solutions to address those challenges [91, pp. 9, 18-23].

Ireland

As part of its Operational Pathways to 2030 programme, EirGrid has defined four key pillars. One of these, Operational Policies and Tools, includes training its people to ensure that the system can be safely and securely operated using new capabilities available [56, p. 103].

Hawaii

Hawaiian Electric runs a career and technical programme to help students transition from high school into employment in the energy sector with work-based learning and other organised activities [62], but this isn't aimed at developing additional skillsets needed for moving to a low-carbon future.

Singapore

The Energy Market Authority (EMA) in Singapore partners with industry, institutions of higher learning, government agencies and the Union of Power and Gas Employees to encourage the development of innovative energy solutions through grants and test-beds in the areas of smart grids, power utilities and energy storage [66, p. 8]. It also offers a suite of programmes for both individuals and organisations to promote training in relevant fields. Current initiatives include a data analytics bootcamp, fellowships, internship programme, monetary awards for students training in relevant fields, and a young talent programme for students to study overseas [66, pp. 10-11]. Going forward, it has called out the need to equip its engineers with new skills in data analytics and cyber security as new technologies and digitisation become more important to manage the power system [66, p. 7] . It also published a list of specific in-demand skills [66, p. 9].

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