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TRANSMISSION SECURITY: INTRODUCTION TO CONCEPTS AND GOVERNANCE

SECURITY
AND
RELIABILITY
COUNCIL

This paper provides an introduction to grid security concepts and key governance arrangements.

Note: This paper has been prepared for the purpose of the Security and Reliability Council (SRC). Content should not be interpreted as representing the views or policy of the Electricity Authority.

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1. Introduction

- 1.1.1. This paper responds to an action from the Security and Reliability Council's 8 August 2019 meeting, that the secretariat should prepare:
- "..a paper that explains what the grid reliability standards are and how they were derived, how they are used, how n-security outages are decided upon and planned for, and includes any available data on the uses of n-security and any related lessons learned."*
- 1.1.2. The action follows correspondence between the SRC and the Authority regarding an 18-day period of the Wellington CBD being supplied through a single transmission circuit in March this year.
- 1.1.3. The secretariat is preparing two related papers for later SRC meetings. These will cover the way Transpower communicates outages, and lessons learned from the period of reduced security in March. These papers are timed to benefit from completion of a joint Transpower and Wellington Electricity lessons-learned exercise. This paper also uses the March event as a brief case study. Further information on related papers is provided in agenda item #16 (the SRC's work programme for 2020-23).
- 1.1.4. This paper is structured in three parts:
- a) concepts
 - b) governance
 - c) data, case studies and insights.
- 1.1.5. The paper draws on public information, meetings with Transpower staff, and documentation made available by Transpower.

2. Grid Security Concepts

2.1 Foundation concepts

- 2.1.1 This section explains grid security concepts and is organised by time horizon. It considers three horizons relevant to grid security and system operation. System operation is included because the system operator facilitates asset outage coordination.
- 2.1.2 The following table provides a guide to terminology used in this report, and how it maps to terms in the Electricity Industry Participation Code (**Code**).

Table 1: Guide to terminology used in this report

Terms	Usage in this Report	Terms used in the Code
<i>Security and grid security</i>	A key reliability strategy for the grid owner. Refers to providing redundancy in the transmission system so that supply to a point of service is resilient to failure of any single transmission asset or circuit.	N-1 criterion Secure state at GXP
<i>Stability and system stability</i>	Principal obligation of the system operator. Refers to operating the power system within required parameters to preserve power quality and avoid cascade failure.	System security Satisfactory state Principal performance obligations

- 2.1.3 The Code also uses the term *security of supply* to refer to the system operator's functions (in Part 9) in monitoring and forecasting generation fuel and generation capacity adequacy.

2.2 Security is managed over multiple time horizons

- 2.2.1 The grid owner is accountable for the capability and availability of the grid, while the system operator is accountable for the stability of the power system.¹ The system operator works with the grid (and generation) assets made available at any time to ensure generation and load remain in balance.
- 2.2.2 The following table summarises key time horizons over which grid security considerations play out for each party, noting that the system operator section focusses on roles relevant to grid outage management only.

¹ Transpower fulfils both roles but has distinct accountabilities and obligations under each role.

Table 2: Grid security time horizons

	Horizon	Description	Comments
Grid owner	Strategic planning	Long-term planning of the capacity, configuration and other performance characteristics of the transmission system.	Planning standards (including grid reliability standard) and investment frameworks are relevant here.
	Work design and scheduling	Design of projects (or programmes of work) to alter, repair or inspect grid assets, and scheduling an overall grid works programme.	Includes determining project build methodologies and coordinating required outages.
	Execution	Carrying out work on the grid.	Includes de-energising and re-energising parts of the grid.
System operator	Forecasting and coordination	Scanning ahead to identify situations where planned outages could impact stability.	Facilitative role – forecasting, assessment and information provision.
	Operational planning	Putting measures in place in advance to mitigate risks.	Grid owner and grid users can also mitigate risks.
	Real-time operation	Monitoring in real-time and acting if needed to preserve stability.	Includes emergency management measures.

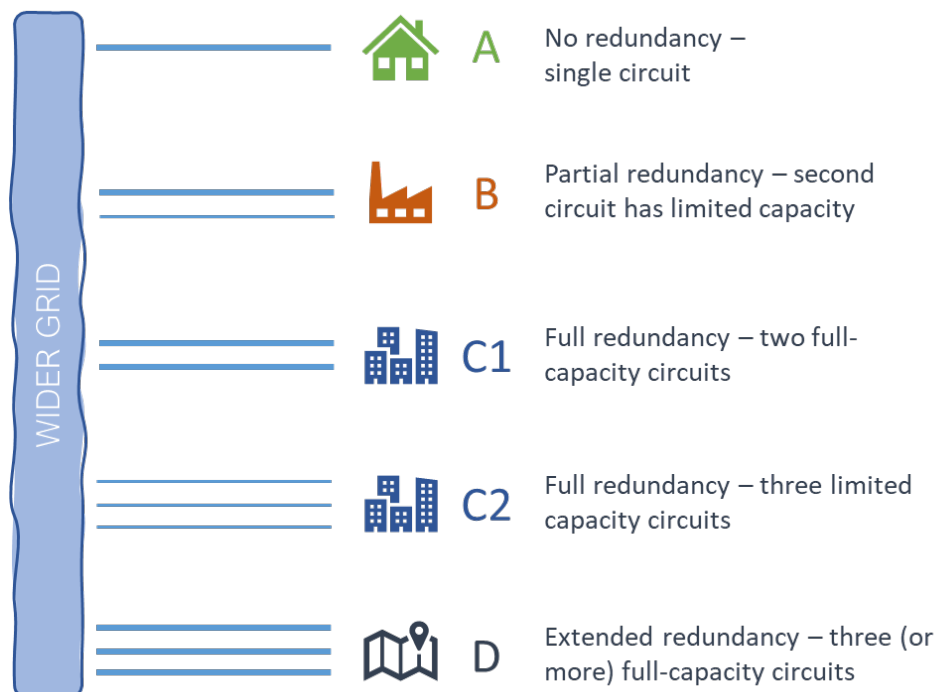
2.3 Strategic planning determines built capability

- 2.3.1 Transpower works with its grid customers to plan changes in grid capability and configuration well in advance. This includes:
- a) external drivers – forecasting when grid connections, regional networks or backbone will become more stressed or slack due to demand or generation changes and identifying how to optimise grid capability
 - b) internal drivers – identifying whether planned asset renewal or alteration works present opportunities to optimise grid capability.
- 2.3.2 Transmission grids are designed to achieve very high levels of reliability, including by:
- a) using robust, highly reliable assets and maintaining them in good condition (including by replacing them before they fail)
 - b) enhancing capacity ahead of growth, and
 - c) duplicating assets to provide redundancy.
- 2.3.3 Building too far ahead of growth and providing full redundancy everywhere are both expensive, so the amount of built redundancy varies across the grid and over time. As assets are taken out of service for maintenance, replacement or to support upgrades, the level of redundancy is temporarily reduced.

Levels of redundancy are designed into the grid

2.3.4 The following diagram illustrates five differing levels of redundancy that are useful for understanding grid security as designed (or built), and as operated.

Figure 1: Illustrative levels of redundancy



2.3.5 Case C1 is designed to provide “N-1 security”, indicating supply can withstand loss of a circuit. In contrast, Case A is designed to provide “N security”, meaning supply is always vulnerable to loss of any one asset. Case D is designed to provide “N-2 security”, indicating supply can withstand loss of two circuits.

2.3.6 Case B would also be described as an “N-security” connection, though it clearly provides better security than Case A because:

- a) loss of the lower-capacity circuit wouldn’t interrupt supply, and
- b) loss of the full capacity circuit wouldn’t interrupt supply if load is low.

2.3.7 The nuances of Cases B and C2 are explored further below.

Secure state depends on circuit availability and loading

2.3.8 Given the limitations of “N” and “N-1” terminology, it is helpful to introduce the concept of a ‘secure state’ – supply operates in a secure state if it is resilient to failure of any single asset, eg:

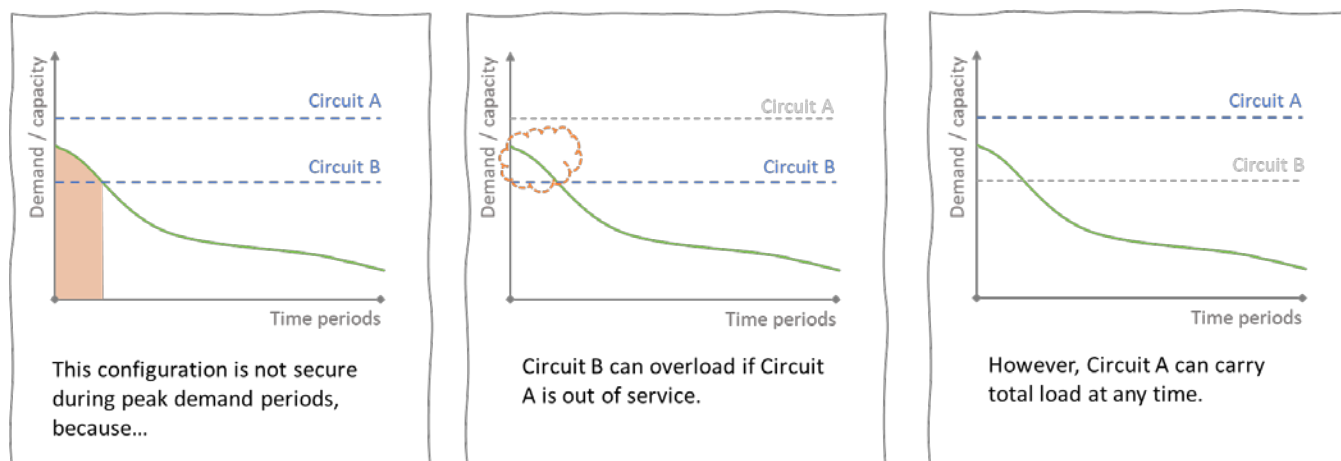
- a) Case A could operate in a secure state if local generation, battery backup or back-feed through the distribution network will cover loss of the circuit
- b) Case B will operate in a secure state whenever demand is below the capacity of the second (smaller) circuit
- c) Case C1 will normally operate in a secure state, except when one of the circuits is out of service

- d) Case C2 will be in a secure state whenever the two lowest-capacity circuits can carry the full load between them. Depending on demand, this configuration may be able to sustain secure state with a circuit on planned outage
- e) Case D can continue to operate in a secure state with any one circuit on planned outage.

2.3.9 It's also important to note that circuit configuration for a connection to the grid may be vulnerable to a single point of failure if redundancy does not extend deeper into the grid. For example, if supply to a region is not in a secure state then grid connections within that region will not be in a secure state.

2.3.10 The following diagram illustrates Case B – showing how it may operate in a secure state most of the time (whenever load is below the capacity of the smaller circuit).

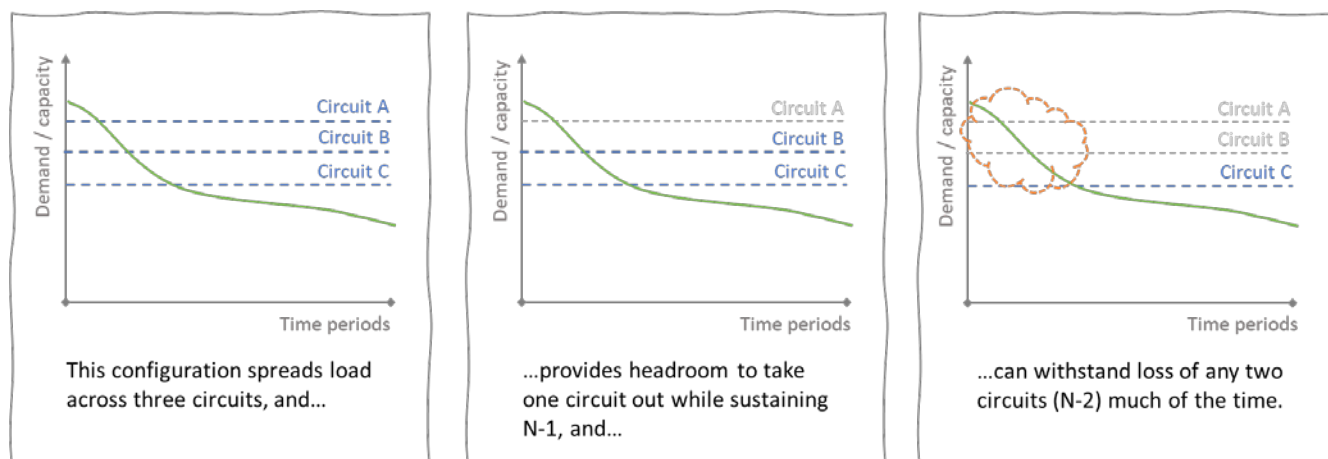
Figure 2: Case B is not N-1, but operates in a secure state most of the time



2.3.11 Over time the green line may move up to approach the higher dashed line as demand grows. This increases the probability of a circuit failure overloading the remaining circuit and causing loss of supply. As demand grows, Transpower and the connected customer will assess when (or whether) to invest in transmission or non-transmission measures to enhance grid security.

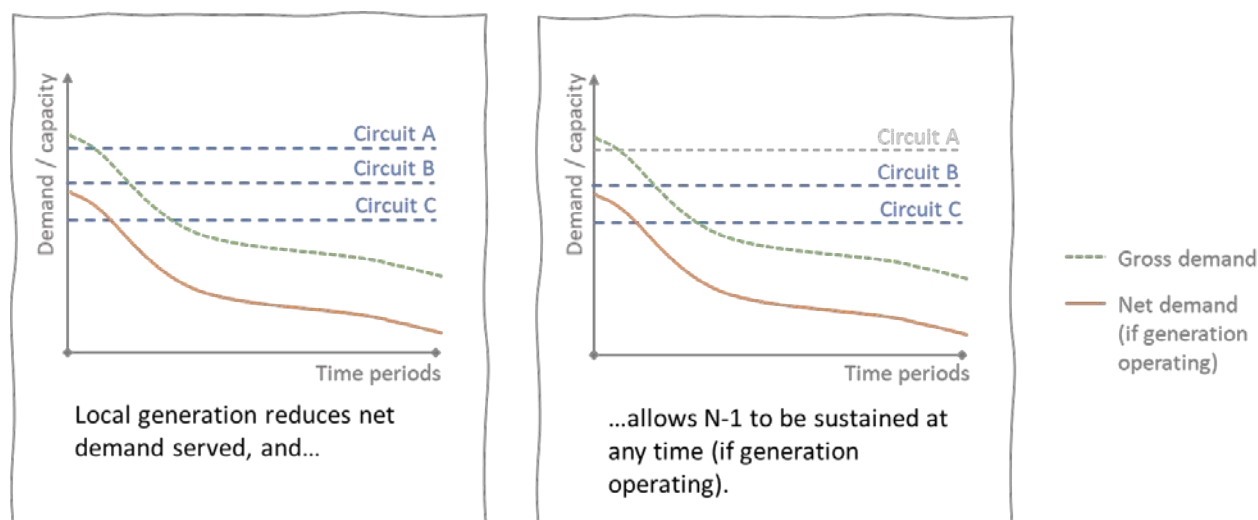
2.3.12 The following diagram illustrates Case C2 – showing how more circuits can provide enhanced security, even if the connection doesn't provide full N-2 security. Importantly, Case C2 provides headroom to maintain a secure state while taking a circuit out of service for maintenance or upgrade work. Also, this case illustrates that N-1 security can be achieved even with no single circuit able to carry peak demand on its own.

Figure 3: Case C2 provides headroom for planned outages



2.3.13 Finally, the following diagram illustrates how generation also factors into whether the grid maintains a secure state.

Figure 4: Local generation can improve security



2.3.14 In this example, generation reduces the amount of energy needing to be supplied across the grid. This increases flexibility to maintain a secure state with one circuit de-energised (but only if generation is operating as expected).

Asset outages can interrupt circuits

2.3.15 For simplicity, this paper generally refers to *circuits* and does not consider more nuanced differences in resilience that depend on how circuits are constructed.

2.3.16 A circuit includes substation assets at either end, and overhead (conductor) or underground (cable) assets in between. Substation assets include transformers, circuit breakers, switches and busses (which connect circuits together). These are all *primary* assets. The grid also has *secondary* assets (that measure and control the performance of primary assets) and *supporting* assets (such as towers, insulators, foundations and bus structures). Finally, there are *ancillary* assets such as buildings and fences.

2.3.17 A circuit may be de-energised for work on any of these assets, though supporting and ancillary assets are more often able to be worked on without de-

energising a circuit. Transpower uses the term *outage block* to refer to groups of assets that can be isolated and de-energised. A circuit may contain several outage blocks – eg, for the bus, transformer and line.

- 2.3.18 Bus assets and secondary assets can have the greatest scope to cause failure of multiple circuits at once. There is also more scope for dual-circuit failure if two circuits share common support structures (eg, failure of a tower supporting two circuits) and resilience is highest if circuits take diverse routes with no crossovers.

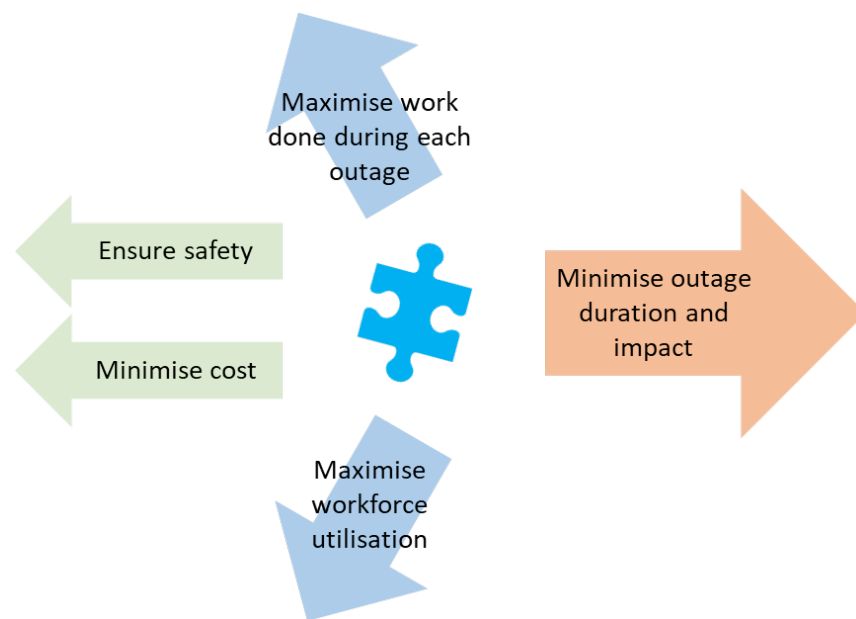
Voltage performance can also determine security

- 2.3.19 The examples above all consider the more common (and simpler to conceptualise) situation where thermal capacity is the limiting factor for grid supply. In practice, voltage performance can sometimes be the limiting factor and must be considered alongside thermal limits.

2.4 Works design and scheduling

- 2.4.1 Taking a circuit out of service always impacts grid security in some way, so it is an important consideration when planning how to undertake a project – including the construction methodology, coordination and timing, and risk management.
- 2.4.2 To illustrate how construction methodology can play a part:
- a) work on the grid can sometimes be done without de-energising – eg, by using specialised live-line technicians, or by only working outside safe approach distances
 - b) recall time (ie, how quickly an asset can be brought back into service) can be influenced by project staging – eg, reconductoring span-by-span may be more costly and time-consuming than stringing several spans at a time, but can reduce recall time
 - c) outages can be avoided through bypass – eg, using mobile substation equipment or building a temporary line can significantly reduce outage times.
- 2.4.3 Typically, there are trade-offs involved in measures that would minimise outage duration and impact. These are illustrated in the diagram below.

Figure 5: Outage optimisation involves multiple trade-offs



2.4.4 The blue arrows indicate work programme optimisation challenges. For example:

- a) if outages were costless then work plans would be designed to minimise work crew downtime, with priority given to the most costly or difficult to obtain resources
- b) at the other extreme, if outages were the only concern then each outage would be arranged to support the maximum possible amount of work on the de-energised assets (with work crews moved around to suit).

2.4.5 Grid customers also have a key role in the design and scheduling of work, including because customers:

- a) can help determine the lowest-risk timing, or can contribute to risk mitigation (eg, by back-feeding through a distribution network)
- b) may wish to coordinate work on their own assets (or additional work on grid assets)
- c) have roles in field, operations, and end-user communications.

2.4.6 Finally, as outages are moved around to optimise the work programme against the considerations above, there is also an ideal timeframe for each work item. For example:

- a) replacing (or maintaining) assets earlier (or more often) than needed is expensive, while acting later increases the risk of unplanned failure (or more costly remediation work)
- b) upgrading capacity earlier brings forward costs, while upgrading later may reduce grid security (or leave less headroom for outages)
- c) costs escalate if delays extend the total elapsed time of a project, or if resources are mobilised and stood down multiple times

- d) some work has seasonal windows of opportunity for completing work efficiently and safely – eg, reconductoring work is stood down in winter months, and rural line access can be unavailable during lambing.

2.5 Project execution

- 2.5.1 As work moves into execution, outages are confirmed, contingency measures are put into effect (if applicable) and assets are switched out of service.
- 2.5.2 Planned outage windows can be disrupted due to factors such as:
 - a) delays to construction readiness (eg, due to procurement delays, resource unavailability, or unanticipated design challenges)
 - b) interdependencies with other work (including customer and third-party work)
 - c) unfavourable weather conditions (eg, high winds or snow) or other difficulties accessing work sites, or
 - d) unfavourable system conditions (eg, higher than forecast grid flows).
- 2.5.3 Disruptions can ripple through the work programme as work is rescheduled and optimised.
- 2.5.4 Once an outage is underway, the duration may be extended (if more time is needed to safely complete planned work) or reduced (if work is completed more quickly than anticipated).
- 2.5.5 If an outage takes supply out of secure state, then failure of an in-service asset may cause interruption to supply. The system operator's concern is to ensure this does not then lead to cascade failure of the system, whereas the grid owner will focus on quickly and safely restoring supply to affected points of service.
- 2.5.6 Recall times can vary considerably, depending on the work required to reattach or reassemble components and ensure workers are clear of the circuit, and in some cases, it may be quicker to restore the other circuit.
- 2.5.7 An unplanned return to service can disrupt the wider grid work programme, particularly if it detains specialist workers or causes loss of access to specialist resources.

2.6 System operator horizons

- 2.6.1 This section summarises the system operator's role across the time horizons introduced earlier.

The system operator assesses and advises to facilitate coordination

- 2.6.2 As a central party with an interest in the overall power system, the system operator assesses outages and provides advice to asset owners to support an iterative process of planning and re-planning amongst asset owners – including the grid owner, generation asset owners, distributors and major users.
- 2.6.3 The system operator cannot direct asset owners to change their planned outages.
- 2.6.4 The system operator assesses the potential impact of planned outages and advises (through the NZ Generation Balance) or directly requests asset owners

to adjust their plans if it identifies potential problems. Publishing the assessment gives asset owners opportunity to reschedule outages to avoid deficiencies.

The system operator can put measures in place to reduce risk

- 2.6.5 The system operator does have a range of measures it can put in place or request before a planned outage to mitigate risk:
- a) system reconfiguration – for example, putting in place “system splits” that leave a circuit open to prevent knock-on impacts if an asset fails
 - b) protection schemes – configuring systems that will respond automatically in the event of an asset failure (eg, by implementing a system split or disconnecting demand)
 - c) ancillary services – procuring standby resources (eg, reserve generation) or power quality support (eg, voltage support)
 - d) security constraints – defining grid limits within the generation dispatch software to limit loading on a circuit or group of circuits
 - e) requesting additional generation or load control – eg, by publishing grid emergency notices.
- 2.6.6 While the system operator’s actions are focused on grid stability, these measures can complement actions taken by asset owners or end users to mitigate the risk or consequences of unplanned interruptions.

The system operator can also act in real-time

- 2.6.7 The system operator monitors system conditions in real-time and maintains communication with asset owners. If a problem arises, the system operator can request outage recalls, or changes in generation or load, and works with asset owners on reconfiguration and restoration.
- 2.6.8 As a last resort, the system operator can instruct managed shedding of load to avoid cascade failure if there is insufficient supply to meet demand in real time.

3. Governance

3.1 Introduction

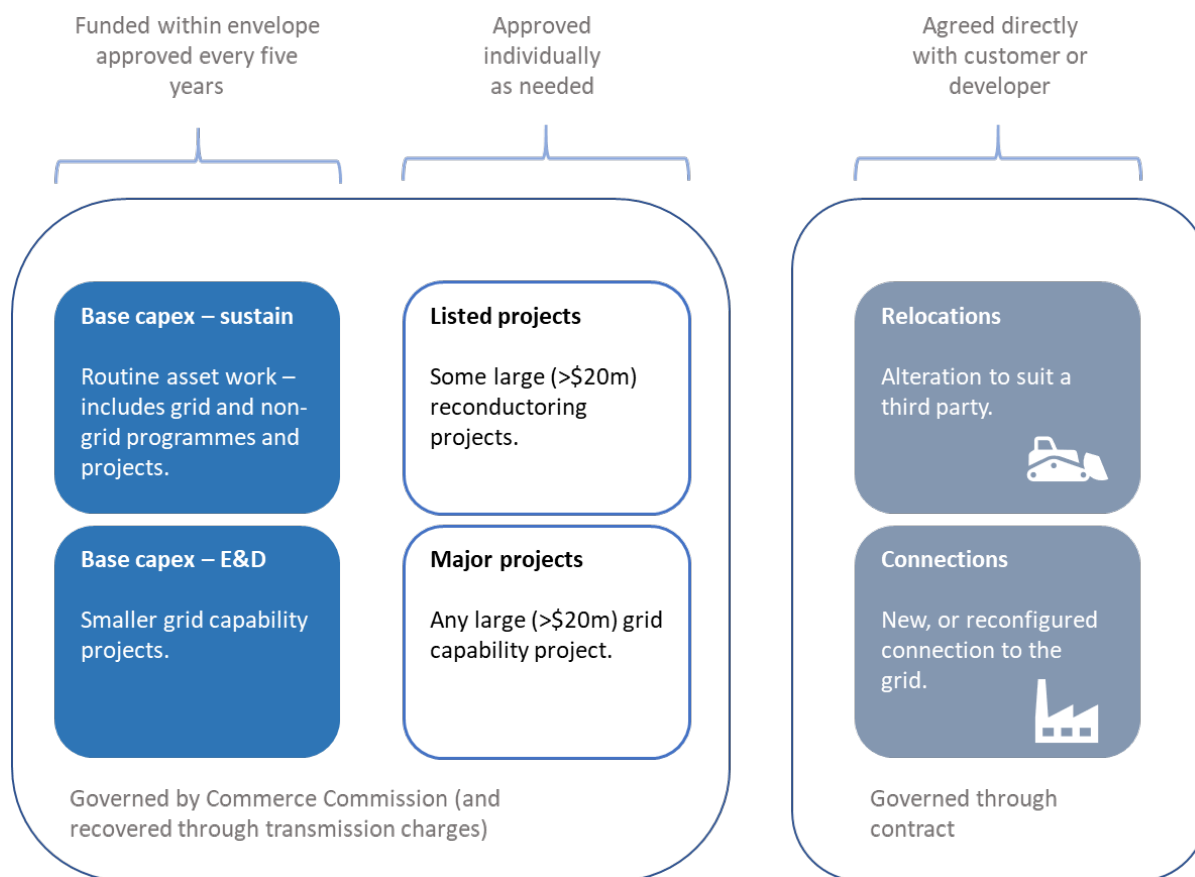
3.1.1 This section surveys regulatory frameworks governing grid security, as well as key non-regulatory governance measures such as Transpower's internal policies and processes. This section is in two parts:

- a) grid capability – arrangements governing how much capacity and redundancy is built into the grid
- b) grid availability – arrangements governing how built capacity is removed from service.

3.2 Built capacity is governed through investment arrangements

3.2.1 The following diagram illustrates classes of grid investment.

Figure 6: Classes of grid investment



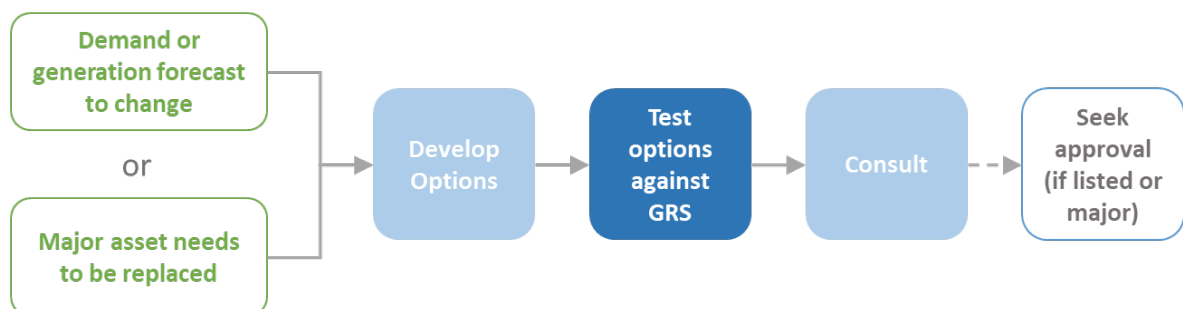
3.2.2 Investments in the left box are initiated by Transpower, governed by the Commerce Commission and have their costs recovered through charges set under the transmission pricing methodology. Investments in the right box are initiated by a customer or third party (such as a developer) and have their costs recovered directly from that party.

- 3.2.3 The Commerce Commission does not individually approve ‘base capex’ projects. Instead, it scrutinises a full regulatory proposal every five years and approves a funding envelope within which Transpower can reprioritise as required. In contrast, large (>\$20m) grid enhancement projects (termed *major projects*), and some large renewal projects (termed *listed projects*), are individually reviewed and approved.
- 3.2.4 The largest share of the grid work programme falls within the *base capex – sustain* class. Transpower justifies this work on the basis it will support least-cost delivery of grid services, where this can encompass:
- a) optimising direct costs— such as replacing bolts before they become too rusty and difficult to remove
 - b) reducing service risks— such as replacing an ageing transformer before its risk of failure starts to climb too high
 - c) eliminating safety risks— such as replacing unsound structures or contaminated materials.
- 3.2.5 Listed projects are similar but cover large (>\$20m) projects that are too uncertain (regarding timing or cost) to approve within the base capex envelope. Transpower is still required to consult on other large renewal projects, even though they’re not subject to individual approval.
- 3.2.6 These classes of work can be thought of as *renewal* or *sustaining* investments. They are not prompted by a need to change the capability of the grid but can become opportunities to reassess capability—especially when replacing large primary assets, such as conductors or transformers.
- 3.2.7 In contrast, the *enhancement and development* classes of Transpower-initiated work are prompted by a need or opportunity to alter the capability of the grid. This usually arises because demand or generation is forecast to grow (though the same assessment can be prompted by a decline in generation or demand).

Investments are tested against the grid reliability standards

- 3.2.8 The following diagram illustrates how grid reliability standards (**GRS**) help guide selection from a range of investment options. The GRS are relevant whether a change in grid capability is prompted by major asset renewal, or directly by an opportunity or need to adjust capability.

Figure 7: The GRS is a reference point for assessing changes to the grid



- 3.2.9 The GRS are defined and governed in Part 12 (Transport) of the Code.

- 3.2.10 Clauses 12.55 to 12.62 of the Code set out the purpose of the GRS, content requirements, and the processes for amending them. This includes a process where any interested party can request a review of the GRS, and a process where the Authority can initiate its own review. The GRS in force at any time are incorporated into Schedule 12.2 of the Code.
- 3.2.11 The GRS can include differing standards for different regions of the grid, including one or more standards for the “core grid”. Sections 12.63 to 12.69 of the Code define the purpose of the core grid determination (and some restrictions on the definition) and provide processes for amending the determination. The core grid determination in force at any time is incorporated into Schedule 12.3 of the Code.
- 3.2.12 The GRS and core grid determination have not been altered since they were established by the Electricity Commission in 2005. The key operative part of the GRS is as follows:
- 2(2) ...the **grid** satisfies the **grid reliability standards** if—
- (a) the power system is reasonably expected to achieve a level of reliability at or above the level that would be achieved if all **economic reliability investments** were to be implemented; and
- (b) with all **assets** that are reasonably expected to be in service, the power system would remain in a **satisfactory state** during and following a **single credible contingency event** occurring on the **core grid**.
- ...
- satisfactory state** means that none of the following occur on the power system:
- (a) insufficient **supply** of **electricity** to satisfy **demand** for **electricity** at any **grid exit point**:
- (b) **unacceptable overloading** of any **primary transmission equipment**:
- (c) **unacceptable voltage conditions**:
- (d) **system instability**
- 3.2.13 Subclause 2(2)(b) provides an ‘N-1 backstop’ for the core grid. This is a form of *deterministic* planning standard, in that the grid owner tests how to meet the defined standard at least cost but does not have to question whether a standard below N-1 could be justified.
- 3.2.14 In contrast, subclause (a) provides for the grid owner to use economic analysis:
- a) everywhere outside the core grid, and
- b) if considering whether to build capacity beyond N-1 within the core grid.
- 3.2.15 The core grid determination contains a list of transmission ‘links’ that generally (but not exclusively) cover assets that were servicing more than 150 MW of load when the determination was made in 2005. It has not been updated to include

assets built since 2005, or to account for demand growth and changes in generation.

- 3.2.16 The Electricity Commission initially favoured having no deterministic backstop in the GRS, but most submitters preferred a more cautious approach. After accepting inclusion of a deterministic backstop, the Electricity Commission initially favoured a higher (more restrictive) 300 MW threshold for inclusion in the core grid. Most submitters again favoured a more cautious approach, which led to the current arrangements.
- 3.2.17 The Code refers to *investment test* rules set out in the Commerce Commission's capital expenditure input methodology² for guidance on how the grid owner should apply economic testing. The investment test:
- a) directs Transpower to use Ministry of Business, Innovation & Employment forecasts of demand and generation (but allows, with justification, substitution with its own forecasts)
 - b) directs Transpower to use a figure from the GRS for assessing the value of reliability (but allows, with justification, substitution of its own views)³
 - c) lists other classes of costs and benefits that can be counted and provides guidance on analytical techniques Transpower can use.
- 3.2.18 The GRS and investment test also direct Transpower to test whether *transmission alternatives* are more economic than traditional grid solutions. This could encompass measures such as building or contracting for generation, batteries, demand control or substitution (such as fuel switching).

Reliability standards are implemented via reporting obligations

- 3.2.19 The Code defines the GRS as a reference point for Transpower to use when considering changes to the capability of the grid, including:
- a) contracting – Transpower and a connected customer can agree to depart from GRS for connection assets, but must either notify the Authority (if intending to exceed GRS) or seek approval (if intending to fall short of GRS) (12.35, 12.36)
 - b) grid reliability report (**GRR**) – Transpower must regularly report on any instances where capability is forecast to fall short of an N-1 standard within the coming 10 years, and has an obligation to invest to a level that will satisfy GRS (12.114)
 - c) shared connection assets – the Code provides backstop authority to pursue investments required through the GRR process in cases where Transpower cannot reach agreement with multiple parties who share connection assets (12.40)
 - d) grid economic investment report (**GEIR**) – Transpower must regularly report on other investments that would satisfy GRS but is only required to *consider* whether to make those investments (12.115).

²

Input methodologies are the Commerce Commission's upfront rules governing how it regulates suppliers.

³

This appears to override a provision in the Code that allows for the Authority to approve an alternative value.

- 3.2.20 In effect, the GRR filters the GRS so that an obligation to invest (and access to backstop authority) only applies to a subset of potential investments. Situations where a site is already at N-1 but would require further investment to satisfy the GRS are not captured by the obligation to invest.
- 3.2.21 This means the mechanisms through which the GRS operate are less likely to drive an outcome where major demand centres have a grid configuration that would allow major work to be completed in a secure state.
- 3.2.22 Transpower publishes the GRR and GEIR, and an overview of its grid enhancement and development plans, in its Transmission Planning Report.⁴
- 3.2.23 The cost of Transpower investing in connection assets to meet or exceed the GRS is recovered from the customers using those connection assets. This means connected customers internalise the trade-offs involved in determining an appropriate level of grid security. This includes deciding whether to accept a given level of security, pay Transpower for better security or put their own mitigations in place (such as backup generation or back-feed capabilities).
- 3.2.24 On a related point, Transpower and distributors can also agree to transfer the ownership of connection assets. If Transpower sells assets to a distributor, those assets are no longer subject to GRS requirements.
- 3.2.25 Finally, there are two situations where Transpower must use a different net benefit test (specified in clause 12.43):
- a) removing shared interconnection assets from service (12.41) or changing their configuration (12.42), and
 - b) temporary (12.116AA) or permanent (12.117) removal or reconfiguration of interconnection assets.
- 3.2.26 The clause 12.43 net benefit test is similar to the input methodology investment test incorporated into the GRS but is tailored to the costs and benefits that flow from removing an asset.

Obligations operate within the context of incentives and quality standards

- 3.2.27 From the description above, the GRS does not fully dictate how the grid should be built. In practice:
- a) GRS investment obligations are not comprehensive, and
 - b) Transpower and connected customers must deal with considerable uncertainty and complexity when assessing whether the GRS will be (or is) met – ie, GRS compliance is not clear-cut in practice.
- 3.2.28 Given these factors, it's useful to consider the wider context in which Transpower applies the GRS. Key elements of the Commerce Commission's regulations are:

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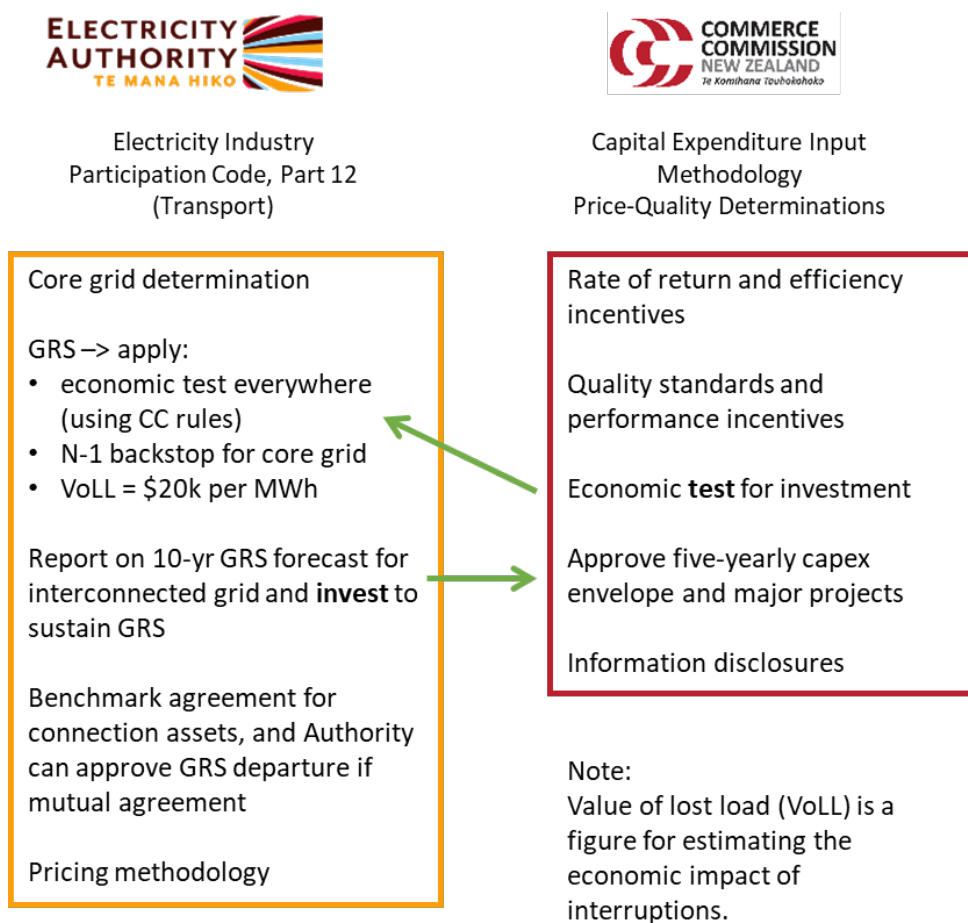
Transpower (2018), *Transmission Planning Report*,
https://www.transpower.co.nz/sites/default/files/uncontrolled_docs/Transmission%20Planning%20Report%202018%20-%20FINAL%20-%2022%20Nov%202018.pdf

- a) uplift – regulated returns include an uplift aimed at reducing the risk of returns being below actual capital costs. This aims to mitigate the risk of suppliers (including Transpower and regulated distributors) being unwilling to invest
- b) efficiency incentives – Transpower can enhance its return on investment by controlling its costs, including the cost of meeting GRS. This encourages Transpower to find the least-cost means of satisfying GRS and deters an overly conservative assessment of whether GRS are satisfied
- c) resets – the Commission resets funding every five years based on an assessment of the prudence and efficiency of Transpower's forecasts. This establishes an incentive for Transpower to guard its credibility and trustworthiness
- d) performance incentives – Transpower has regulatory incentives to outperform targets for the number and duration of interruptions to supply
- e) quality standards – Transpower can be penalised for allowing performance, including the number and duration of interruptions, to drop below minimum standards
- f) transparency – the Commission requires Transpower to disclose performance information and can elect to carry out investigations or publish summaries and analysis.

GRS were derived prior to Commerce Commission regulation

- 3.2.29 The transport rules framework in Part 12 of the Code has not changed materially (nor been subject to substantive review) since its initial development by the Electricity Commission.
- 3.2.30 The GRS and core grid determinations were in place when the Electricity Commission had a role approving grid investments. Responsibility for investment regulation shifted to the Commerce Commission in 2010 (with new input methodologies developed by 2012), while the GRS remained the responsibility of the Authority.
- 3.2.31 The GRS now effectively spans the Code and Commerce Commission rules, as shown in the diagram below.

Figure 8: The GRS is split across the Code and input methodologies



- 3.2.32 The hybrid structure of the GRS is a pragmatic compromise between traditional deterministic standards (which are easy to apply and arguably help capture non-quantifiable benefits of grid security) and more sophisticated economic standards (which would give the 'right' answer with perfect information and unlimited analytical capacity).
- 3.2.33 The other operative elements of the GRS framework are:
- a) core grid determination was developed by applying a 150 MW rule-of-thumb, with some added demand centres that were judged to warrant N-1 supply
 - b) the \$20,000 per MWh default value for assessing the economic impact of interruptions was based on the limited evidence available in 2005.
- 3.2.34 The value for assessing the impact of interruptions has had some attention in recent years but has not been changed in the Code. The Authority commissioned work on survey methodologies and obtained sectoral estimates in 2015. In 2018, Transpower extended this work to obtain updated estimates that it has begun to use within its asset management framework.
- 3.2.35 This more recent work has begun to develop insight into how the economic benefit of reliability varies:
- a) across sectors – for example, small businesses experience a much higher impact per unit of energy than residential consumers (on average)

b) depending on duration – for example, a half-hour interruption has a much bigger impact per unit of energy than a two-hour interruption.

3.2.36 These studies have not explicitly tested the wider economic impact of extended outages in major centres (where the question of N-1 vs. N-2 security is most obviously pertinent).

3.2.37 Finally, clause 12.114(1)(c) of the Code requires Transpower to submit a proposal to the Commerce Commission for any projects it is obliged to make due to the GRR process. This obligation does not comfortably align with the Commerce Commission's input methodologies, because any such project with a forecast cost of less than \$20m would be funded through Transpower's base capex arrangements rather than a project-based proposal mechanism.

3.3 Available capacity is governed through outage arrangements

3.3.1 The sections above describe how the GRS play a key role in shaping Transpower's strategic planning, which in turn determines the designed (and built) capability of the grid.

3.3.2 The Code also requires the grid owner to make assets available to the system operator (12.111). However, exceptions to this obligation include (12.112):

- a) planned outages, but only if the outage is permitted under the outage protocol
- b) urgent outages taken to ensure safety of people or to protect the safety and integrity of an asset
- c) urgent outages directed by the system operator to help prevent an energy shortage from arising (9.13B), and
- d) permanent removal of an asset from service, provided the grid owner can demonstrate removal is beneficial.

3.3.3 In addition to these planned or urgent outages, unplanned outages can arise due to environmental conditions (eg, lightning or contact with vegetation), asset failure or human error (eg, misconfiguration of protection systems).

3.3.4 This paper focusses on planned outages.

Outage protocol governs outage planning

3.3.5 The Code provides for Transpower to develop an outage protocol covering how planned outages (and recovery from unplanned outages) are coordinated. The Authority has an approval role and can request Transpower to review the protocol. The Code also specifies high-level and detailed requirements and incorporates the current outage protocol by reference.

3.3.6 Key elements of the outage protocol include:

- a) annual planning preparation cycle – this includes requirement for customers to advise Transpower of their planned outages by December each year, and for Transpower to publish an annual plan for consultation by February each year

- b) planning consultation – Transpower must hold regional forums each year and provide participants with an opportunity to meet and discuss outages that may impact them
- c) net benefit test – parties can object to a planned outage if they consider taking the outage will not result in a net benefit. Transpower is then required to assess the net benefit. Transpower can also apply a net benefit test as a backstop if it cannot achieve agreement with a connected party to take an outage
- d) variation notification – Transpower must provide notice if it intends to amend a planned outage and must publish any decision to cancel a planned outage.

3.3.7 The grid outage plan is published as a spreadsheet on Transpower's website. The spreadsheet lists outages by outage block and indicates planned timeframes as well as information about the nature and purpose of each outage. The outages are also uploaded into the industry's planned outage coordination process (POCP) website, alongside other asset owner outages. In practice, most participants use this website for information on Transpower's outages.

3.3.8 The outage protocol and the Code require the grid owner, system operator and connected customers to work together in good faith to coordinate outages.

3.3.9 The Part 12 (Transport) section of the Code works with Part 7 (System Operator), Part 8 (Common Quality) and Part 9 (Security of Supply). Across the sections, asset owners have obligations to ensure their assets perform acceptably and to work with and be responsive to the system operator in supporting the security of the power system.

Industry coordinates outage planning

3.3.10 Part 8 requires all asset owners (including the grid owner and generators) to advise the system operator of planned outages.

3.3.11 Over time, the industry has developed and refined processes for sharing information to facilitate enhanced joint outage planning. At the centre of these efforts, system operator hosts the POCP database and provides web access. Anybody can access planned outage data through the website, and registered market participants can also access security assessments.

3.3.12 The POCP processes have been regularly reviewed and refined over time, and the system operator is currently convening a review that will be completed in February 2020.

3.3.13 Transpower runs more extensive engagement and analysis processes for exceptional outages, such as those planned for HVDC life extension work in early 2020.

Commerce Commission incentivises grid asset availability

3.3.14 Commerce Commission regulation includes several elements relevant to asset availability:

- a) grid performance incentives (GP1 and GP2) – Transpower can be penalised (or rewarded) up to ca. \$8m each year for under (or over)

performing against targets for the frequency and duration of unplanned interruptions. Placing points of service on N-security heightens the risk of interruptions, so this incentive encourages management of this risk

- b) asset availability incentive (AP1 and AP2) – more directly incentivises availability. Transpower has a \$2m incentive each year to out-perform targets for the availability of the HVDC link and selected HVAC assets. The applicable assets were selected due to their market impact, so this incentive is not directly focussed on security but has an indirect impact. From 2020 this incentive will extend from 27 circuits to 71 assets (including some bus sections and interconnecting transformers)
- c) return to service reporting (AP3 and AP4) – from 2020, Transpower will be required to report on instances of the 71 selected assets being returned to service more than two hours later than planned and on late notification of any change in planned return to service time
- d) time on N-security (AP5) – from 2020, Transpower will be required to report annually on the extent to which it has placed customers on N-security.

3.3.15 The new AP5 requirement follows a limited trial in 2016 where Transpower tested methods for determining and comparing forecast and actual time on N-security. The trialled methods were found to be resource intensive and Transpower is currently working through whether it can develop a suitably streamlined methodology for meeting its new obligations.

Grid owner monitors scheduled outages

3.3.16 The grid owner monitors outages weeks ahead to identify significant outages, which it defines as including any outages that:

- a) place large loads on N-security
- b) will require supply to be interrupted (eg, because a customer has an N-security connection)
- c) have a long recall time, or
- d) impact one of the AP1 (HVDC) or AP2 (selected HVAC) circuits.

3.3.17 This process is designed to:

- a) support situational awareness amongst people managing outages
- b) identify outages that require additional risk mitigation planning, and
- c) support communication planning.

3.3.18 The risk mitigation mentioned above can include measures such as:

- a) patrolling lines or inspecting key primary equipment to provide additional confidence that in-service assets are in good condition and clear of environmental hazards
- b) stationing additional service staff in locations that will expedite return to service
- c) staging key spares in locations that will reduce recall times.

- 3.3.19 Around six to 10 weeks out from each outage, the grid owner sends a notice to connected customers or interested parties for each outage to notify them of planned asset outages or confirm acceptance of outages where the grid owner needs the customer to take action, or where they are expected to be on reduced security.
- 3.3.20 The outage monitoring process described above tests each planned outage to assess whether it is likely to place demand on N-security, but it does not involve running power system simulations to determine whether the combined effect of coincident outages may expose further sites to N-security.

4. Data, Case Studies and Insights

4.1 Data

4.1.1 This section provides a selection of data to help illustrate the prevalence of N-security.

N-Security standard is common

4.1.2 Transpower's RCP3 regulatory proposal breaks down its 222 points of service (**POS**) into service categories, with one dimension being whether the POS ordinarily provides N security.

Figure 9: One-fifth of grid points of service are built to N-security

	<u>Number of interruptions (Target)</u>	<u>Average load (MW)</u>	<u>Number of sites</u>
N-1 Security High Economic Consequence	7	57.0	48
N-1 Security Material Economic Consequence	24	12.1	95
N Security High Economic Consequence	6	17.8	12
N Security Material Economic Consequence	23	3.0	21
N-1 Security Generator	9	92.0	44
N Security Generator	12	28.6	9
			222

4.1.3 This shows that almost 20% of sites are built to an N-security standard, with no material difference in this proportion between generator-only and general POS. N-security POS carry less load on average, but there is clearly a substantial overlap in sizes.

4.1.4 Transpower's proposed performance targets indicate a 15% to 25% probability of experiencing an unplanned interruption each year for N-1 POS, and a 50% to 133% probability for N-security POS – ie, an N-1 standard significantly improves expected performance. In addition, N-security POS are much more likely to experience planned interruptions to supply.

Planned outages routinely place sites on N-Security

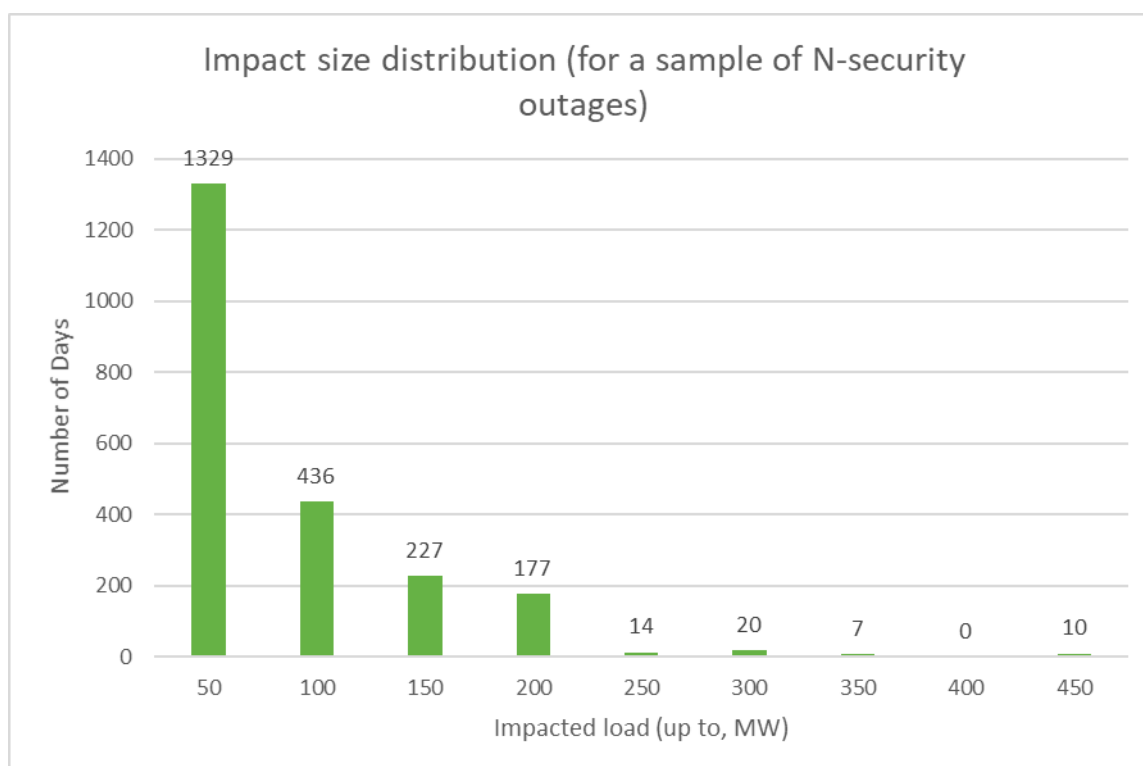
4.1.5 For the year to 30 June 2019, Transpower's published work plan indicated just under 2,000 outages. As the work plan was built further during the year, and plans were adjusted, the number of outages grew to just over 6,000 outages and ca. 18,000 outage days⁵.

⁵

This figure is the total hours of outages, divided by 24. These figures include urgent outages, though these account for only a small portion of the total.

- 4.1.6 For the same year, nearly 1,300 outages accounting for 2,900 outage days were flagged through Transpower's internal monitoring of N-security outages. This is around 20% of outages and 16% of outage days.
- 4.1.7 These figures are not definitive and should be treated with caution. In particular:
- some outages flagged as N-security will not have taken POS out of secure state in practice due to demand (or grid flows) being low, or non-transmission security measures being in place, and
 - some outages not flagged as N-security will have taken POS out of secure state due to the cumulative impact of individual outages.
- 4.1.8 The following analysis of a sample of N-security outages indicates that they are heavily weighted toward smaller POS.⁶

Figure 10: N-security outages mostly impact smaller points of service



- 4.1.9 For context:
- the Central Park substation in Wellington has a peak demand of less than 200 MW
 - peak demand across POS built to an N-security standard is estimated to be on the order of 15 MW and would collectively account for a further 12,000 days (across 33 POS) – i.e. sites permanently on N significantly outweigh sites temporarily on N.

⁶

Note: this analysis uses a sample of outages, so figures do not correlate directly to the earlier figures.

Transpower's work programme is growing

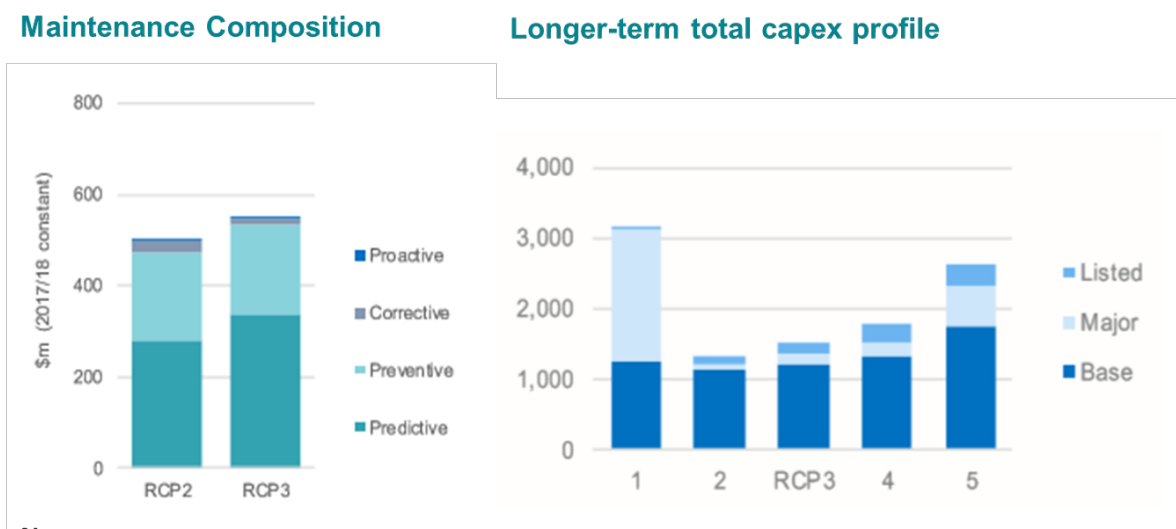
4.1.10 In 2017/18, Transpower's work programme included⁷:

- a) \$100m of grid maintenance opex
- b) \$180m of grid base capex, and
- c) ca. \$40m of major capex projects

4.1.11 In total, the grid works programme was ca. \$320m. While this will have included many projects that did not require outages (including most of the \$40m tower painting programme), the size and mix of Transpower's work programme does ultimately drive the scale of required outages.

4.1.12 Transpower's RCP3 proposal indicates that the scale of the grid works programme is forecast to increase over the coming 15 years, as shown below

Figure 11: Transpower expects work on the grid to grow



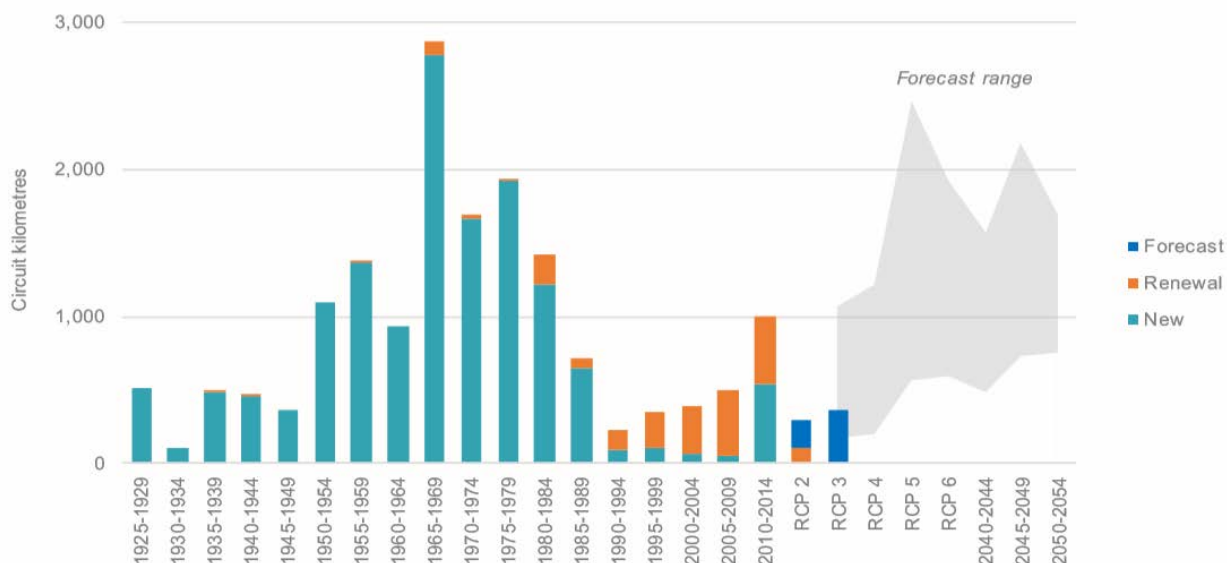
Notes:

- RCP3 refers to the five years to 30 June 2025
- RCPs 2-5 each span five-years
- Figures are expressed in constant FY18 prices (ie, exclude price escalation)

4.1.13 A key driver of this increase is the age profile of conductor, as shown by the following chart from Transpower's proposal.

⁷ Figures for 2018/19 have not been disclosed yet.

Figure 12 – Transpower expects reconductoring activity to increase



4.1.14 Conductor renewal can involve:

- targeted or piecemeal replacements, which minimise outage durations but is often not optimal in terms of total cost or community disruption
- full reconductoring, or
- grid reconfiguration (eg, building or upgrading a line to allow another to be removed).

4.1.15 Full reconductoring projects typically involve extended outages. For example – Transpower’s \$66m project to reconnector lines between Bunnythorpe and Haywards has involved three summers with extended outages.

4.2 Case Studies

4.2.1 This section briefly describes some case studies selected to help illustrate the material covered in this paper.

Waikato and Upper North Island (WUNI)

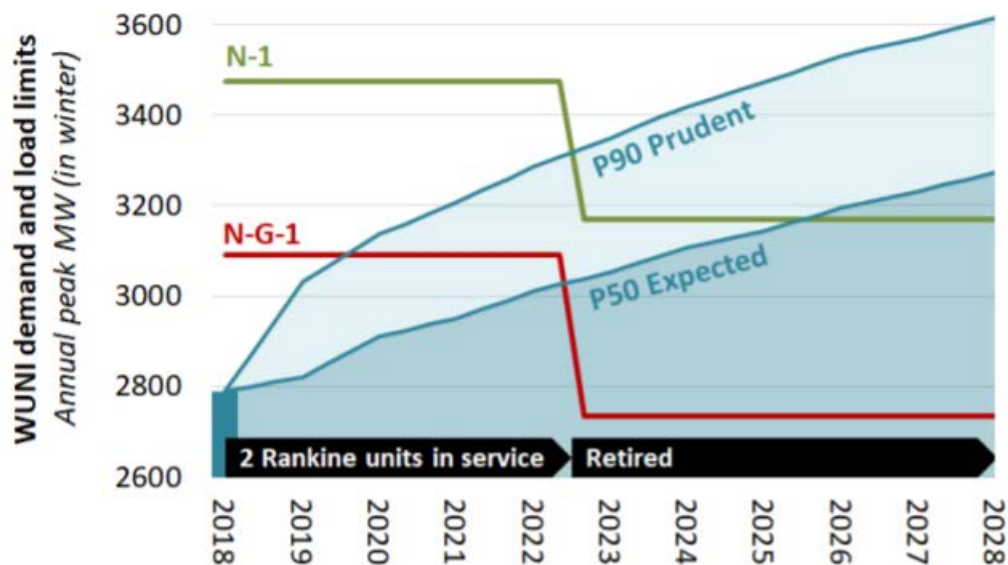
4.2.2 Transpower is developing a major capex proposal for investment of ca. \$140m to sustain an economic level of reliability in the WUNI region. The project is interesting in the context of this report because it is an example of:

- generation changes being the biggest driver for investment – several UNI generators were decommissioned in recent years, and there is the prospect of two units at Huntly being removed from service in coming years
- voltage stability being the key driver – investment to resolve voltage issues will allow for many more years of demand growth before demand approaches thermal limits

- c) Transpower considering transmission alternatives – the first stage of the project may include measures to attempt procurement of non-transmission voltage support services, and
- d) staging approval – Transpower is planning to defer approval of series capacitors to a later major capex application.

4.2.3 The following diagram, taken from Transpower's recent consultation on a short-list of investment options, shows consideration of demand growth and generation scenarios when assessing grid security.

Figure 13 – Voltage security is impacted by growth and generation changes



4.2.4 In the diagram above, the green line shows system security should a fault occur, and the red line shows system security should a fault occur while a critical generation asset is out of service. The step down at 2022 shows the impact on both measures of the units at Huntly being removed from service.

Central Park Reconductoring

4.2.5 In June 2017 the Commerce Commission approved a \$11.6m project to replace 12km of corroded conductor on one of the two lines between Wilton and Central Park substations in Wellington (Central Park – Wilton B line). The line has two circuits. A third circuit links the two substations via the separate Central Park – Wilton A line (but shares a tower at the Central Park end).

4.2.6 The project is relatively small for a reconductoring project because:

- a) the total circuit length is relatively short, and the line is relatively accessible (though does traverse steep terrain), and
- b) double-strand *duplex* conductor was replaced with lighter *simplex* conductor, removing the need for expensive tower and foundation strengthening.

- 4.2.7 Transpower planned a four-month construction programme beginning February 2019. The planned construction methodology involved keeping one circuit on the B line live while working on the other circuit. This project would have been flagged as significant in Transpower's internal reporting due to the long recall time for reconductoring projects. However, the project would not have flagged as placing the POS on N-security because the live B circuit and the A circuit would provide N-1 cover.
- 4.2.8 After completing replacement of several spans, Transpower found that the lighter simplex conductor moved out of sync with the heavier duplex conductor in strong winds. This was judged to pose a risk to the line crew, so the construction methodology was amended so that both B line circuits were de-energised while crews were working (with the second circuit re-energised overnight).
- 4.2.9 The amended methodology meant placing the Central Park substation – which serves Wellington CBD, hospital and airport – on N-security for 18 days (non-continuous). Communications between Transpower and Wellington Electricity from that point will be the subject of a future SRC paper.

HVDC outages

- 4.2.10 In October 2018 the Commerce Commission approved a \$23.5m project to replace 9.5km of conductor on the Churton Park section of the HVDC link between Haywards and Oteranga Bay. The reconductoring involves interrupting availability of HVDC link, which can have significant impacts on the electricity market.
- 4.2.11 The project is interesting in the context of this report, because Transpower consulted on several construction methodology options for limiting planned outages. Transpower found that:
- a) using two wiring teams was a feasible option but using three was not. Even with two teams, a construction period of 13.3 weeks was expected
 - b) a temporary bypass line was not feasible. Full bypass was estimated to add more than \$12m of direct costs, which would exceed the market benefit under most hydrological conditions. Property rights and project delays were also identified as significant impediments to this option
 - c) splitting the project over two summers to better target low-demand periods was found to be uneconomic.

4.3 Insights

- 4.3.1 This section summarises key insights from the material above.
- a) There are many variations on N-1. The standard can be met with two full-capacity circuits, or with a larger number of smaller circuits. Similarly, there are dual and single-circuit variants of N-security.
 - b) An N-1 planning standard does not typically provide headroom to sustain a secure state during planned outages.

- c) There is no obligation on Transpower to make investments beyond the least-cost variant of N-1, even if a higher standard may be needed to satisfy the grid reliability standard. This is because the obligation to invest applies via the grid reliability report, which filters out some cases where investment could be economic.
- d) It is relatively commonplace for outages to put points of service on N-security. This is an expected outcome of the GRS as defined and applied.
- e) Whether the cost of providing enough redundancy to ensure a secure state during planned outages could be justified is not clear cut, even for nationally important load centres. While operating on reduced security is commonplace, the duration of extended outages over the life of key assets is short (eg, three to nine months of reconductoring across a 40 to 80-year conductor life).
- f) The core grid definition has not been revisited since it was made in 2005. A review could usefully consider demand growth, generation changes, grid reconfiguration, regulatory changes and lessons learned since 2005.
- g) The economic value of reliability (called value of lost load, or VoLL) in the Code has also not been reviewed. A review could usefully consider recent research findings, and the merits of moving away from a single figure.
- h) The interface between Part 12 of the Code and the Commerce Commission's capital expenditure input methodology is workable but includes some mismatches (such as a requirement in the Code for Transpower to seek investment project approval from the Commission, and a redundant provision for the Authority to determine an alternative VoLL value).
- i) For connection assets, connected customers internalise trade-offs between the capital costs of Transpower providing higher grid security and the cost of risk to their supply (or the costs of mitigating those risks).
- j) Coordination challenges and time on N are likely to increase over coming decades as Transpower forecasts demand to grow, connection activity to step up, and its work programme to increase and rebalance from substation to lines work.
- k) Generally, considerable effort and goodwill is evident across the industry in tackling the challenges of coordinating, optimising, and mitigating the risks of necessary outages.

5. Questions for the SRC to consider

5.1.1 The SRC may wish to consider the following questions.

Q1. What further information, if any, does the SRC wish to have provided to it by the secretariat? For example:

- a. Would the SRC like to learn more about Transpower's reconductoring plans and challenges?**
- b. Does the SRC have an interest in the work Transpower is doing to meet its new obligation to the Commerce Commission to report 'time on N'?**

Q2. What advice, if any, does the SRC wish to provide to the Authority?