6 Grid Backbone

6.1 Introduction

This chapter describes the adequacy of the grid backbone to transfer energy from generators to loads now and in the future, while maintaining a secure grid.

The Grid backbone describes the bulk interconnected transmission system, primarily the 220 kV network, which connects the regions described in Chapters 7 to 19.

We identify potential grid backbone issues by studying the capability of the system to meet the forecast growth in demand (see Chapter 3) under a range of system conditions. 1 Generation development scenarios are not explicitly used, other than to note where significant issues may arise if future generation is established in particular regions. 2 Grid upgrades to resolve issues must meet the requirements of the Grid Reliability Standards. Many grid upgrades will also require submission of a Major Capex Proposal to the Commerce Commission for approval.

6.2 North Island grid backbone

The North Island grid backbone comprises the following 220 kV circuits:

- four from Wellington to Bunnythorpe
- three from Bunnythorpe to Wairakei and Whakamaru
- three from Stratford to Brunswick, two of which continue on to Bunnythorpe
- two from Stratford to Huntly
- three connecting Wairakei and Whakamaru
- ten into Auckland from Huntly and Whakamaru.

Power flows on the inter-island HVDC link vary. The net annual power flow is northwards, especially at times of North Island peak demand. However, during light load periods, power may flow southward to conserve South Island hydro storage, especially during periods of low hydro inflows in the South Island.

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1 System conditions are load and generation patterns that we use to highlight transmission issues we can reasonably expect to occur with currently available information and trends.

2 Additional ‘growth generation’ is included in our North Island models where it is required to balance load and generation. Refer to section 6.4.4.3.
The existing North Island grid backbone is set out geographically in Figure 6-1 and schematically in Figure 6-2. To help describe transmission system problems and opportunities on the backbone grid, we split the North Island transmission system into five main areas:

- Waikato and Upper North Island (WUNI) area, which encompasses everything north of Whakamaru, including the Auckland and Northland regions and most of the Waikato region\(^3\)
- Lower North Island area, which encompasses everything south of Bunnythorpe
- Central North Island area, which connects the Lower North Island area with Whakamaru and Wairakei
- Taranaki area, which encompasses the grid backbone that connects generation in the Taranaki region to the WUNI and Central North Island areas
- Wairakei Ring area, which encompasses the 220 kV circuits between Wairakei and Whakamaru connecting the major hydro and geothermal generation in the Central North Island, Bay of Plenty and Hawkes Bay regions to the transmission network.

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\(^3\) This is the same area that is the focus of the Waikato and Upper North Island Voltage Management project, which is discussed in sections 6.3.2.1 and 6.4.6.1.
Figure 6-1: North Island grid backbone map
Figure 6-2: Simplified North Island grid backbone schematic

Key:
- 220 kV Circuit
- 220 kV Substation Bus
- Generator
- Tee Point
6.3 North Island grid enhancement approach

6.3.1 Possible North Island grid backbone to 2032

Figure 6-3 provides an indication of possible North Island transmission backbone development in the medium term (the next 15 years). Assets that are new or upgraded within the forecast period (based on potential enhancement approaches set out in the following sections) are shown.

Figure 6-3: Indicative North Island grid backbone schematic to 2032
6.3.2 Enhancement approach

This section provides information about the transmission constraints on the North Island grid backbone that we will investigate or mitigate over the next few years. Constraints that are not considered at this time include those that only occur:

- for a particular generation development scenario (for example, one where most new generation is located in the Taranaki region)
- towards the end of the forecast period.

Transmission issues likely requiring E&D base capex or Major Capex Project (MCP) funded investment in the North Island grid backbone over the next 10-15 years include:

<table>
<thead>
<tr>
<th>Section number</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.3.2.1</td>
<td>Transmission constraints north of Whakamaru</td>
</tr>
<tr>
<td>6.3.2.2</td>
<td>Wairakei Ring transmission capacity</td>
</tr>
<tr>
<td>6.3.2.3</td>
<td>Central North Island and Taranaki transmission capacity</td>
</tr>
<tr>
<td>6.3.2.4</td>
<td>High voltage at light load periods</td>
</tr>
</tbody>
</table>

6.3.2.1 Transmission constraints north of Whakamaru

Waikato and Upper North Island Voltage Management

Since 2015, more than 1000 MW of generation capacity has been decommissioned in the WUNI area. The proposed closure of the remaining two Huntly Rankine units in 2022 will reduce generation by an additional 500 MW. This generation reduction, coupled with demand growth in the WUNI area, raises significant voltage stability risks.

 Enhancement approach:

The Waikato and Upper North Island Voltage Management (WUNI) investigation is considering what investment is needed in the WUNI area to maintain voltage stability following the retirement of thermal generation in the region.

Some options to manage this issue include installing a combination of:

- static capacitors in various locations in the Waikato region
- a special protection scheme to manage N-G-1 voltage stability limits
- series capacitors on the Brownhill–Whakamaru 400 kV-capable line and/or
- dynamic reactive support such as SVC and/or STATCOMs in the Waikato and Auckland regions.

Whether there is a need for these investments is highly dependent on the actions of other parties in developing non-transmission solutions, such as new generation in the WUNI area.

The WUNI project is a Major Capex Project. We are currently in the Options Analysis (Short-list) stage of the investigation, and expect to submit a proposal to the Commerce Commission in the 2018/19 year.
### Major Capex investments

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Waikato and Upper North Island Voltage Management (WUNI)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project description:</td>
<td>Waikato and Upper North Island Voltage Management</td>
</tr>
<tr>
<td>Project’s state of completion</td>
<td>Possible</td>
</tr>
<tr>
<td>OAA level completed:</td>
<td>None (OAA level 5 investigation underway)</td>
</tr>
<tr>
<td>Grid need date:</td>
<td>2023</td>
</tr>
<tr>
<td>Indicative cost [$ million]:</td>
<td>High uncertainty (scope dependent)</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### Brownhill–Whakamaru transmission opportunity

The 400 kV capable Brownhill–Whakamaru–A double circuit line was built with the intent of applying staged upgrades as warranted by demand growth in Auckland. The next stage is to install series compensation on the line while it remains operating at 220 kV.

Our economic analysis indicates that the reduction in system losses as a result of installing series compensation justifies bringing forward the investment to before the need date for transmission constraints. Once the transmission constraints need date is reached, a 220 kV bus at Brownhill Road and a third 220 kV cable from Brownhill Road north to Auckland are also required. The 220 kV bus and cable are not required if the series capacitors are installed to reduce losses rather than to meet demand growth.

**Enhancement approach:**

Series compensation will raise the limits on transmission into the WUNI area identified by the WUNI project. Approval for series compensation is expected to be sought as a part of that project. The cost of series capacitors is expected to exceed the Major Capex Project threshold by a significant amount.

### 6.3.2.2 Wairakei Ring transmission capacity

The Wairakei Ring connects the generation rich regions of the central North Island with the high load centres of the Upper North Island, Waikato and Bay of Plenty via two 220 kV transmission lines (a single and a double circuit line).

The capacity of the Wairakei–Ohakuri–Atiamuri–Whakamaru circuits may cause a transmission constraint during very high Wairakei Ring area generation. This constraint will worsen if there is a reduction in industrial load in the Bay of Plenty region, or if additional generation is developed around Wairakei or in the Bay of Plenty region (both of which have the potential for a significant increase in geothermal generation).

**Enhancement approach:**

We will continue to monitor developments in the region that may trigger the need for investments to relieve the Wairakei Ring constraints. These triggers include generation developments in Wairakei, Kawerau and the Bay of Plenty region. We will investigate investment options as one or more of these triggers emerges.

The limiting circuits have already been thermally upgraded and are using variable line ratings, so there is no scope to further increase the transmission capacity using these techniques. A possible incremental investment is a series reactor on the Wairakei–Atiamuri–Ohakuri–Whakamaru line to balance flows on the Wairakei Ring circuits. Otherwise, the next investments are likely to be major ones involving reconductoring.
or building a new line, either or which will have a cost in excess of the $20 million Major Capex Project threshold.

### Base E&D Capex investments

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Wairakei Ring transmission constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project description</td>
<td>Install Atiamuri–Ohakuri series reactor</td>
</tr>
<tr>
<td>Project’s state of completion</td>
<td>Possible</td>
</tr>
<tr>
<td>OAA level completed</td>
<td>None</td>
</tr>
<tr>
<td>Grid need date</td>
<td>Uncertain, Wairakei area generation dependent</td>
</tr>
<tr>
<td>Indicative cost [$ million]</td>
<td>10</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

#### 6.3.2.3 Central North Island and Taranaki transmission capacity

**Central North Island and Taranaki thermal capacity**

During high generation in the Wellington (including HVDC north transfers) and Taranaki regions, the Tokaanu–Whakamaru, Bunnythorpe–Mataroa, and Huntly–Stratford transmission circuits limit generation export to the WUNI area.

The limiting constraint depends on which region contributes the highest generation. When generation is highest in the Wellington region (including HVDC north transfers), the 220 kV Tokaanu–Whakamaru circuits and low capacity 110 kV Bunnythorpe–Mataroa circuit constrain generation export. When generation is highest in the Taranaki region, the 220 kV Huntly–Stratford circuit constrains generation export.

**Enhancement approach:**

We have identified a range of smaller investments that will enable us to better utilise the existing assets between Bunnythorpe and the WUNI area:

- Upgrade the Tokaanu CB128 intertrip scheme to remove the branch component limit on the Tokaanu–Whakamaru circuit, and possibly apply variable line rating on the Tokaanu–Whakamaru circuits to further increase transmission capacity.
- Install a series reactor and special protection scheme on the lower capacity 110 kV Bunnythorpe–Mataroa circuit to reduce power flow on the circuit and protect it from overloading post-contingency (see section 11.4.2.2).
- Upgrade the Huntly–Stratford protection to remove the static limit on this circuit.

We are committed to upgrading the Tokaanu CB128 intertrip scheme and installing the Bunnythorpe–Mataroa series reactor and special protection scheme. We will investigate the possible application of variable line ratings on the 220 kV Tokaanu–Whakamaru circuits to further relieve transmission constraints.

The next generation development in the Taranaki region is likely to trigger the need to upgrade protection on the Huntly–Stratford circuit to remove its branch component limit. We are monitoring triggers such as the proposed Waikato and Junction Road power stations, and will consider whether to proceed with this investment once firm proposals emerge.

Once the benefits from the incremental investments described above have been realised, a major investment will likely be required if a combination of the following factors eventuate:

- substantial generation investment in the Taranaki region
- substantial generation investment or load reduction in the Wellington region
• an increase in HVDC north transfer, which may be driven by substantial generation investment or a reduction in load in the South Island.

Possible major investments are transmission circuit thermal upgrades, reconductoring, or new transmission lines. The cost of these investments will be in excess of the Major Capex Project threshold. We will proceed with a Major Capex Project investigation when plans for development in these areas are more certain.

**Base E&D Capex investments**

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Tokaanu–Whakamaru transmission constraint</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project description</td>
<td>Upgrade Tokaanu CB128 intertrip scheme to remove branch component limit</td>
</tr>
<tr>
<td>Project’s state of completion</td>
<td>Committed</td>
</tr>
<tr>
<td>OAA level completed</td>
<td>1</td>
</tr>
<tr>
<td>Grid need date</td>
<td>2017 (December)</td>
</tr>
<tr>
<td>Indicative cost [$ million]</td>
<td>0.05</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Huntly–Stratford transmission capacity</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project description</td>
<td>Upgrade Huntly–Stratford circuit protection to duplicated differential protection</td>
</tr>
<tr>
<td>Project’s state of completion</td>
<td>Possible</td>
</tr>
<tr>
<td>OAA level completed</td>
<td>None</td>
</tr>
<tr>
<td>Grid need date</td>
<td>2022</td>
</tr>
<tr>
<td>Indicative cost [$ million]</td>
<td>1</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Brunswick–Stratford circuit consolidation**

The 220 kV single circuit Brunswick–Stratford–B line (Brunswick–Stratford–3 circuit) is due for reconductoring as a risk based condition replacement. As part of our Options Assessment Approach (OAA) we are looking at a full range of investment options to ensure our assets remain fit for purpose in the future.

**Enhancement approach:**

We are investigating the long term need for this line, including considering the following options:

- dismantling the line
- upgrading the Brunswick–Stratford–A line (Brunswick–Stratford–1 and 2 circuits) and dismantling the B line
- reconductoring the Brunswick–Stratford–B line.

An outcome of this investigation will be a preferred option and a timeframe for submission to the Commerce Commission,⁴

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⁴ The Brunswick–Stratford–B line reconductoring was included in our RCP2 submission as a listed project. The submission to the Commerce Commission may be a listed project application or a Major Capex Project proposal.
6.3.2.4 High voltage at light load periods

Waikato and Upper North Island high voltage management

During light load periods, managing high voltages issues in the WUNI area is increasingly difficult.

We primarily manage the issue by switching the 400 kV capable Pakuranga–Whakamaru circuits out of service when there are insufficient reactive power reserves on the available dynamic reactive plant in the area. In a few instances, we have also switched the Huntly–Stratford circuit out of service.

Although taking circuits out of service is an effective way to control voltages, its application is limited as we must also ensure security of supply to load in the area.

Enhancement approach:

We are currently investigating options to provide voltage support to the WUNI area during peak load periods (see section 6.3.2.1) under the WUNI project. Some of the options identified such as installing dynamic reactive plant, if implemented, will also increase the capability of the grid to absorb reactive power during light loads.

In parallel we are also investigating alternative options such as switching additional circuits out of service, or seeking voltage support contracts. We will assess the viability of these options for the interim period between now and any WUNI investments.

We will reassess the issues (both interim and longer term) when a preferred solution is identified under WUNI. An alternative option, if the preferred WUNI option does not remove the high voltage issue, is installing shunt reactors.

Base E&D Capex investments

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Waikato and Upper North Island high voltage management</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project description:</td>
<td>Waikato and Upper North Island high voltage management - shunt reactor</td>
</tr>
<tr>
<td>Project’s state of completion</td>
<td>Possible</td>
</tr>
<tr>
<td>OAA level completed:</td>
<td>None</td>
</tr>
<tr>
<td>Grid need date:</td>
<td>2021</td>
</tr>
<tr>
<td>Indicative cost [$ million]:</td>
<td>5</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>No</td>
</tr>
</tbody>
</table>

6.3.3 North Island grid backbone beyond the planning horizon (2032)

Figure 6-3 provides an indication of the possible North Island transmission backbone development in the longer term (beyond 2032).

6.3.3.1 Increased operating voltages from Whakamaru to Brownhill Road

The operating voltage on the overhead transmission line from Whakamaru to Brownhill Road may be increased to 400 kV. This will also require additional 220 kV cables from Brownhill Road north into Auckland. Ultimately, we may also require a new transmission line from Whakamaru to Auckland, but both of these upgrades are highly dependent on future load and generation growth, and the viability of alternatives.
6.3.3.2 Wairakei Ring upgrade options

Upgrade options for the Wairakei Ring include reconductoring part or all of the existing single circuit Wairakei–Ohakuri–Atiamuri–Whakamaru line or replacing it with a new double circuit line. A new double circuit line has the added advantage of increasing security to the Bay of Plenty region during maintenance outages.

6.3.3.3 Transmission capacity north of Bunnythorpe

Transmission capacity north of Bunnythorpe may be increased through the central North Island to Whakamaru and/or through the Taranaki area with a new line from Taranaki to Whakamaru. Ultimately, we may also require a significant increase in transmission capacity from Wellington to Bunnythorpe. These upgrades are highly dependent on significant new generation being developed south of Taupo.

6.3.3.4 Reinforcing Hamilton and the Waikato region

Reinforcing the transmission capacity into Hamilton may be justified in the longer term to provide security to the Waikato region during maintenance outages. One option is a new 220/110 kV connection to the east of Hamilton, supplied off the 220 kV Ohinewai–Whakamaru circuit and connected to the 110 kV Hamilton–Piako–Waihou circuits to backfeed Hamilton and the rest of the Waikato region.
Figure 6-4: Longer-term indicative North Island grid backbone schematic (beyond 2032)

Although this diagram shows a few possible development paths for the future North Island grid backbone transmission system, it is not intended to indicate a preference. Any option will be finalised closer to the date that transmission reinforcement is needed.

* Another possible option is a new HVDC link into Auckland.

** Connection point for 110 kV Valley Spur circuits

*** The Wairakei-Whakamaru C line has been positioned to allow connection of Mokai generation in the future.
6.4 North Island asset capability and management

We have assessed transmission capacity and reactive support requirements on the North Island grid backbone for a range of system conditions over the next 15 years. When a problem or opportunity is likely to arise, we have examined initial options and actions that may be taken to address it. Grid Enhancement Approaches (refer to section 6.3) have been developed to address problems or opportunities that require action within the forecast period and where investment is a valid option.

6.4.1 Changes since the 2015 Transmission Planning Report

Changes since the 2015 TPR include:

- A lower load forecast, with low or almost zero load growth forecast for most regions and high load growth forecast for a few ‘hot spots’ (e.g. the Waikato region).
- A detailed dynamic voltage analysis was completed to establish the impact of thermal generation decommissioning in the WUNI area. That work has resulted in the WUNI Major Capex Project.
- An additional system condition for the 2017 TPR to demonstrate the significance of the 110 kV network operating in parallel with the grid backbone between Bunnythorpe, Waikato, and Otahuhu.
- Removed the system condition from the 2015 TPR that demonstrated the impact of the south Waikato 110 kV network on the grid backbone if the Arapuni bus split was closed. We intend to retain the Arapuni 110 kV bus split.

6.4.2 Committed Projects

Projects that are not complete at the time of publication but which are included in the analysis modelling are:

- installation of a 110 kV series reactor and special protection scheme at Mataroa, which is programmed for commissioning by summer 2018
- reconductoring of the Bunnythorpe–Haywards–A and B lines, which is programmed for completion by winter 2020.

6.4.3 Line conductor replacements

Table 6-1 lists the major grid backbone line conductor replacement projects expected to be undertaken between 2017 and 2022.

<table>
<thead>
<tr>
<th>Line</th>
<th>Affected circuits</th>
<th>Note</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bunnythorpe–Haywards–A</td>
<td>Bunnythorpe–Paraparaumu–Haywards–1</td>
<td></td>
</tr>
<tr>
<td>Bunnythorpe–Haywards–B</td>
<td>Bunnythorpe–Paraparaumu–Haywards–2</td>
<td></td>
</tr>
<tr>
<td>Bunnythorpe–Wilton–A</td>
<td>Bunnythorpe–Linton–Wilton–1</td>
<td></td>
</tr>
<tr>
<td>(Bunnythorpe–Judgeford section)</td>
<td>Haywards–Wilton–1</td>
<td></td>
</tr>
<tr>
<td>Bunnythorpe–Wilton–A</td>
<td>Bunnythorpe–Linton–Wilton–1</td>
<td></td>
</tr>
<tr>
<td>(Judgeford–Wilton section)</td>
<td>Haywards–Wilton–1</td>
<td></td>
</tr>
<tr>
<td>Brunswick–Stratford–B</td>
<td>Brunswick–Stratford–3</td>
<td></td>
</tr>
<tr>
<td>Otahuhu–Whakamaru–A</td>
<td>Otahuhu–Whakamaru–1</td>
<td></td>
</tr>
<tr>
<td>Otahuhu–Whakamaru–B</td>
<td>Otahuhu–Whakamaru–2</td>
<td></td>
</tr>
</tbody>
</table>
These line conductors are all approaching risk based condition replacement criteria, which provides the opportunity to review the circuit capacities and whether they are still required in future. Options providing the greatest net benefit will be implemented, optimising the conductor types and operating temperatures, circuit capacities, losses, the cost of replacing conductors and strengthening towers, market benefits, and future maintenance costs.

6.4.3.1 North Island grid backbone asset feedback register

The Asset Feedback Register includes no entries related to E&D that are specific to the North Island grid backbone.

6.4.3.2 Bunnythorpe–Haywards–A and B line conductor replacement

This is an approved project. The existing Goat conductor is being replaced with Zebra conductor, providing a moderate increase in rating of 45–55 MVA per circuit. Although the project is not complete at the time of publication, the analysis assumes the new line conductor is commissioned.

6.4.3.3 Bunnythorpe–Wilton–A line conductor replacement

This conductor replacement is being investigated. A Listed Project, or if required a Major Capex Project proposal, will be submitted to the Commerce Commission. The project involves reconductoring the Judgeford–Wilton section by 2020 and the Bunnythorpe–Judgeford section in 2020–2025. The analysis referred to in this TPR uses the existing line conductor and circuit configuration.

6.4.3.4 Brunswick–Stratford–B line conductor replacement

This replacement will be investigated this year and, if required, a listed project submission or Major Capex Project proposal submitted to the Commerce Commission. Options include dismantling the line, upgrading the Brunswick–Stratford–A line and dismantling the B line, and reconductoring the Brunswick–Stratford–B line. The analysis referred to in this TPR uses the existing line conductor.

6.4.3.5 Otahuhu–Whakamaru–A and B line conductor replacement

This replacement is currently being investigated as part of the Auckland Strategy. We anticipate including an option to address reconductoring of the northern section (approximately 30 km) of the Otahuhu–Whakamaru–A and B lines in our RCP3 submission, as a base capex or a Listed Project. Options being considered include dismantling these lines north of Ohinewai, or reconductoring with a modern equivalent conductor or a larger conductor.

This work is closely linked to the WUNI Project and the Auckland Strategy. For more details, refer to sections 6.3.2.1 and 8.4.2, respectively.
6.4.4 Methodology

6.4.4.1 System conditions

A small number of realistically challenging system conditions are used to assess the capability of the existing North Island grid backbone (including the committed projects discussed in section 6.4.2). They provide snapshots to identify transmission constraints that may require minimum or maximum generation limits to avoid overloading the power system following an outage. From these we can identify transmission upgrades that will alleviate the constraints, allowing lower minimum and higher maximum generation limits.

6.4.4.2 Development uncertainty

Until recently, load in the upper North Island was partially supplied by local generation at Otahuhu, Southdown and Huntly. However, the recent decommissioning of more than 1000 MW of thermal generation in the WUNI area has resulted in advancement of voltage stability and thermal issues in the area, despite a reduction in forecast load growth.

Decommissioning of the remaining Huntly Rankine units (scheduled for 2022) will further increase this impact.

These changes cause considerable uncertainty for transmission planning because more generation is required to meet load balance. However, it is unclear as yet where new generation development will occur. Therefore, at this stage it is not possible to assess the likelihood and location of future thermal constraints on the North Island grid backbone with any certainty. A preferred option has not yet been selected under the WUNI project which further increases uncertainty.

Because of this uncertainty, system analysis beyond 2022 is of limited value. All the results presented below that deal with the period beyond 2022 should be used with caution.

6.4.4.3 Growth generation

Existing generation is insufficient to supply the forecast load for some system conditions. Additional generation is required to securely supply the forecast load. We model this using ‘growth generation’.

Depending on the system conditions, assumed ‘growth generation’ can exceed:

- 1000 MW by Winter 2032.
- 500 MW by Summer 2032.

In the North Island we model the growth generation as 50 MW generating units added sequentially at Stratford and Wairakei, as they are centrally located in gas and geothermal rich areas respectively. Growth generation at Stratford is capped to prevent overloading the conductor on the long Huntly–Stratford circuit. Heavily loading this long circuit results in high reactive power absorption, which can lead to unmanageable voltages in the Waikato region.

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5 This matches assumptions regarding future generation used in the WUNI project.
The system conditions will identify transmission constraints that can occur as a result of the growth generation.

6.4.4.4 Limits in the Electricity Market

Transmission constraints identified by the system conditions do not always cause minimum or maximum generation limits in the wholesale electricity market. The System Operator’s management of a transmission constraint depends on the type of outage that causes the constraint:

- Circuit outages are managed as contingent events requiring pre-contingent management (for example, by using market security constraints to apply a maximum generation limit or pre-contingent load management).
- Other outages (for example, bus-sections) may be managed using pre-contingent or post-contingent actions, depending on the extent and magnitude of the system impact resulting from the outage.

6.4.5 Overview of results

Key findings for the North Island grid backbone are:

- A reduction in thermal generation in the WUNI area may require immediate investment in both dynamic and static reactive support. Reduced generation will also worsen, or bring forward, the transmission constraints into the WUNI area.
- Transmission in the Wairakei Ring area is nearing capacity, despite commissioning of the high capacity Wairakei–Whakamaru–C line in 2014. The Wairakei–Whakamaru–A line will become a transmission constraint if there is further significant geothermal generation development around Wairakei and/or in the eastern Bay of Plenty.
- The 110 kV Bunnythorpe–Mataroa circuit may limit transmission in the Central North Island area. We have already committed to implementing, in 2018, a low cost solution to alleviate (but not eliminate) the transmission constraint.
- The 220 kV Tokaanu–Whakamaru and Huntly–Stratford circuits may cause transmission constraints between Bunnythorpe and the WUNI area following commissioning of the Mataroa series reactor and special protection scheme.
- During extremely dry North Island hydro conditions (low North Island hydro generation) the Otahuhu–Wiri circuits may limit the load that can be supplied in the Waikato region.

6.4.6 North Island grid backbone capability and constraints

The system conditions that provide snapshots of the capability of the North Island grid backbone to transfer energy from generators to the loads while maintaining a secure grid are:

- low WUNI generation and winter peak load (section 6.4.6.1)
- low WUNI generation and summer peak load (section 6.4.6.2)
- HVDC south transfer (winter) (section 6.4.6.3)
- HVDC south transfer (summer) (section 6.4.6.4)
- low eastern Bay of Plenty industrial load (section 6.4.6.5)
- impact of extremely low North Island hydro generation on the parallel 110 kV network (section 6.4.6.6)
- light load (section 6.4.6.7).
6.4.6.1 System condition 1: low WUNI generation (winter peak)

This system condition (SC1) tests the case where thermal generation in the WUNI area is low during a period of high load (winter peak). It represents generation development scenarios where the two remaining Huntly Rankine units are not available during the winter peak and are replaced with ‘growth generation’ elsewhere in the North Island. The specific assumptions for this system condition are:

- North Island winter peak load
- thermal generation in the WUNI area is limited to one combined-cycle generating unit and one small open-cycle gas turbine at Huntly
- high geothermal and hydro generation in the Bay of Plenty, Central North Island and Hawke’s Bay regions
- maximum thermal generation in the Taranaki region (including the combined-cycle generating station and the gas peaking generators)
- maximum wind generation in the lower and central North Island regions
- high HVDC north transfer up to 1000 MW
- for the thermal analysis, a dynamic reactive power source that provides enough reactive support to maintain the voltage at Otahuhu to 1.02 pu
- generation and load balance is achieved using growth generation at Wairakei and/or Stratford (see section 6.4.4.3 for details).

Transmission constraints are addressed by trading off lower North Island and South Island generation with WUNI area generation.

Studies of this system condition focus on the thermal issues that occur when large amounts of growth generation is transported from remote areas in the lower North Island to Whakamaru and Huntly. In order to prevent major voltage stability problems in the WUNI area (which are specifically covered by the WUNI section) and at the same time avoid extremely high levels of “growth generation”\(^6\), we assume that Huntly unit 5 is available.

Summary of transmission constraints

Possible transmission constraints include:

- WUNI Voltage Management
- constraints north of Whakamaru
- Central North Island area constraints
- Taranaki area constraints
- Wairakei Ring area constraints.

The 110 kV and 220 kV circuits in the Central North Island area will overload under this system condition. If most of the new generation locates in the:

- Taranaki area, then the Huntly–Stratford circuits will also overload within the forecast period
- Wairakei area, then the Wairakei Ring circuits and some circuits between Whakamaru and Auckland will also overload within the forecast period.

\(^6\) Including very high levels of ‘growth generation’ will result in exaggerated thermal constraints on the transmission system south of the WUNI area.
**SC1: Waikato and Upper North Island Voltage Management**

The WUNI voltage management project analysed the voltage issues in detail and identified that for a scenario where Huntly unit 5 is unavailable:

- the limitation in the WUNI area is voltage stability
- there will be low voltage in the Waikato region, requiring static capacitors to lift the voltage plane
- the Otahuhu–Whakamaru and Hamilton–Whakamaru 220 kV circuits are likely to overload for parallel 220 kV circuit outages.

**SC1: North of Whakamaru constraints**

The 220 kV Hamilton–Whakamaru and Otahuhu–Whakamaru–1 and 2 circuits may overload from 2032. These overloads could be managed operationally for the forecast period and beyond by increasing generation in the WUNI area.\(^7\)

Transmission constraints will arise on the 110 kV circuits between Otahuhu and Bombay before they appear on the 220 kV transmission system. (See section 6.4.6.6 for information on 110 kV circuit constraints.)

Detailed dynamic voltage stability studies identified the need for substantial transmission investment to manage both the dynamic and static voltage stability following the decommissioning of the remaining Huntly Rankine units (currently scheduled to occur in 2022).

**SC1: Central North Island area constraints**

The most prominent transmission constraint is the loading on the 110 kV Bunnythorpe–Mataroa circuit.

In winter 2017 the Bunnythorpe–Mataroa will overload for a:

- Whakamaru 220 kV bus outage, if HVDC north transfer exceeds about 540 MW
- 220 kV Tokaanu–Whakamaru circuit outage, if HVDC north transfer exceeds about 660 MW.

The analysis assumes that from winter 2019 there is a series reactor at Mataroa and the Bunnythorpe–Mataroa circuit can be loaded up to 100 per cent pre-contingency because there is a special protection scheme to open the Mataroa–Ohakune circuit if the Bunnythorpe–Mataroa circuit overloads.

Once the series reactor and special protection scheme are installed, the next limitation on the Bunnythorpe–Mataroa circuit is pre-contingency overloading from around 2024.

At present, a Tokaanu–Whakamaru circuit may overload following the outage of the other Tokaanu–Whakamaru circuit for this system condition. This transmission constraint is alleviated (but not resolved) by the special protection scheme at Tokaanu.\(^8\) Limits on maximum generation at or south of Tokaanu will reduce loading

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\(^7\) This solution assumes that there is at least one generating unit in addition to the assumed 440 MW at Huntly still available to relieve the overload.

\(^8\) The special protection scheme at Tokaanu reconfigures the grid by splitting the 220 kV Tokaanu bus. This redistributes the power flow within the power system, reducing the loading on the in-service Tokaanu–Whakamaru circuit. This scheme may operate for a Tokaanu–Whakamaru circuit or 220 kV Whakamaru bus outage.
with the most effective place to reduce generation being Tokaanu. This is nearly twice as effective as reducing HVDC transfer and two and a half times as effective as reducing Taranaki generation.

In Winter:

- 2019, Tokaanu–Whakamaru will overload for a parallel circuit outage if Tokaanu generation exceeds around 200 MW
- 2022, Tokaanu–Whakamaru will overload for a parallel circuit outage if Tokaanu generation exceeds around 150 MW
- 2032, HVDC north transfer is limited to 850 MW to prevent Bunnythorpe–Mataroa from overloading pre-contingency and Tokaanu generation is limited to 220 MW to prevent Tokaanu–Whakamaru from overloading for a parallel circuit outage.

SC1: Taranaki area constraints

The Huntly–Stratford circuit may overload for a parallel circuit outage from about 2020, when the first 50 MW ‘growth generator’ is installed at Stratford. The Huntly–Stratford circuit is limited to 354 MVA.\(^9\)

The Bunnythorpe–Mataroa and Tokaanu–Whakamaru circuits will overload before a Huntly–Stratford circuit. The Huntly–Stratford circuit overload will only occur if transmission through the central North Island is upgraded. This constraint is most effectively managed operationally, by limiting generation in the Taranaki area. This is one and a half times as effective as reducing HVDC transfer.

SC1: Wairakei Ring area constraints

With growth generation connected near Wairakei:

- the Wairakei–Ohakuri–Atiamuri circuits will overload from 2020 following a Whakamaru 220 kV bus section outage
- the Wairakei–Ohakuri–Atiamuri circuits will overload from 2022 following a Te Mihi–Whakamaru circuit contingency
- the high capacity Wairakei–Whakamaru circuit will overload from 2029 following a Wairakei 220 kV bus section outage
- by 2029, all existing thermal generation north of Whakamaru\(^10\) is required to be operating to prevent the Atiamuri–Ohakuri circuit from overloading for a Whakamaru 220 kV bus section outage
- by 2032, all existing thermal generation north of Whakamaru\(^10\) is required to prevent the Atiamuri–Ohakuri circuit from overloading for a Te Mihi–Whakamaru circuit outage.

The transmission constraints caused by the overloads can be most effectively managed operationally by reducing generation injection into the Wairakei 220 kV bus. This is around four times as effective as reducing HVDC transfer.

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\(^9\) The circuit’s capacity is limited by protection equipment. With this limit resolved, capacity will be 469/492 MVA (summer/winter).

\(^10\) This solution assumes all the existing generation at Huntly is available, including retaining two Rankine units beyond 2022.
What next?

Presently, transmission constraints can be managed operationally through generation dispatch in the WUNI area.

We are studying investment options to alleviate or remove the transmission constraints following decommissioning of the remaining Huntly Rankine units. For more specific information on our enhancement approach for the:

- Central North Island 110 kV constraints see section 6.3.2.3
- transmission capacity between Bunnythorpe and Whakamaru see section 6.3.2.3
- transmission capacity between Stratford and Huntly see section 6.3.2.3
- transmission capacity in the Wairakei Ring see section 6.3.2.2
- transmission capacity into the WUNI area, see section 6.3.2.1.

6.4.6.2 System condition 2: low WUNI generation (summer peak)

This system condition (SC2) tests the case where there is low thermal generation in the WUNI area during summer peak load. This is similar to system condition 1, but with summer circuit ratings. It considers the case where the two remaining Huntly Rankine units are not available at summer peak time, replaced with ‘growth generation’ elsewhere in the North Island. The specific assumptions for this system condition are:

- North Island summer peak load in the year the transmission constraint is identified
- thermal generation in the WUNI area is limited to one combined cycle generating unit at Huntly
- maximum geothermal generation in the Bay of Plenty, Central North Island and Hawke’s Bay regions
- average summer hydro generation in the Central North Island, Hawkes Bay, Bay of Plenty, and Waikato regions
- low Taranaki generation, with no generation on the Stratford 220 kV bus
- maximum wind generation in the lower and central North Island
- generation and load balance is achieved by increasing HVDC north transfer, up to 1000 MW. This is followed by growth generation at Wairakei and Stratford (see section 6.4.4.3 for details)
- transmission constraints are addressed by trading off lower North Island and South Island generation with WUNI generation.

Summary of transmission constraints

Possible transmission constraints include:

- Central North Island area constraints
- 110 kV constraints
- WUNI area voltage stability
- Wairakei Ring area constraints.

In general, the 220 kV network is more capable of supplying the summer peak load than winter peak load without thermal constraints. Voltage stability limits are expected in the WUNI area once the remaining Huntly Rankine units are decommissioned.
The 110 kV Bunnythorpe–Mataroa circuit in the central North Island may limit the maximum HVDC north transfer.

**SC2: Central North Island area constraints**

The most prominent transmission constraint is the loading on the 110 kV Bunnythorpe–Mataroa circuit.

In summer 2017 the Bunnythorpe–Mataroa will overload for:

- Hamilton 220 kV bus outage if the HVDC north transfer exceeds about 510 MW
- 220 kV Hamilton–Whakamaru circuit outage if the HVDC north transfer exceeds about 590 MW
- 220 kV Tokaanu–Whakamaru circuit outage if the HVDC north transfer exceeds about 600 MW.

The analysis assumes that from summer 2019 there is a series reactor at Mataroa and the Bunnythorpe–Mataroa circuit can be loaded close to 100 per cent pre-contingency because there is a special protection scheme to open the Mataroa–Ohakune circuit if the Bunnythorpe–Mataroa circuit overloads.

Once the series reactor and special protection scheme are installed, the next limitation on the Bunnythorpe–Mataroa circuit is pre-contingency overloading from around 2022. The Bunnythorpe–Mataroa circuit overloads pre-contingency earlier in summer due to the lower conductor rating, lower Arapuni North bus generation, and summer peaking loads in the Waikato region, particularly at Hangatiki.

From 2019, a Tokaanu–Whakamaru circuit may overload following the outage of the other Tokaanu–Whakamaru circuit. This transmission constraint is managed with the existing special protection scheme at Tokaanu. However, from around 2019 and as HVDC north transfer and the Stratford (growth) generation increases, an outage of a Tokaanu–Whakamaru circuit will operate the Bunnythorpe–Mataroa and Tokaanu special protection schemes. Even after both special protection schemes have operated, the Tokaanu–Whakamaru circuit will still overload from around 2021.

In summer:

- 2022, HVDC north transfer is limited to around 960 MW to prevent Bunnythorpe–Mataroa from overloading pre-contingency and Tokaanu generation is limited to around 160 MW to prevent Tokaanu–Whakamaru from overloading for a parallel circuit outage
- 2032, HVDC north transfer is limited to 600 MW to prevent Bunnythorpe–Mataroa from overloading pre-contingency and Tokaanu generation is limited to 230 MW to prevent Tokaanu–Whakamaru from overloading for a parallel circuit outage.

**SC2: 110 kV constraints**

From 2018 when the Bunnythorpe–Mataroa constraint is addressed, the limitation in the parallel 110 kV network is the Otahuhu–Wiri circuits. See section 6.4.6.6 for more information.
In addition, the Bunnythorpe–Woodville circuits will overload following the outage of the other Bunnythorpe–Woodville circuit. However, this transmission constraint can be managed with the existing special protection scheme at Woodville.\footnote{11}

**SC2: Waikato and Upper North Island voltage stability**

Dynamic voltage stability studies have identified the summer peak period as having a lower risk of dynamic voltage collapse than winter peak. The analysis confirmed that a voltage stability limit will bind once the remaining Huntly Rankine units are decommissioned, presently scheduled for 2022.

**SC2: Wairakei Ring area constraints**

The Atiamuri–Ohakuri–Wairakei circuits may overload for a:

- 220 kV Whakamaru bus section outage from around 2024
- 220 kV Te Mihi–Whakamaru circuit from around 2027.

**What next?**

The transmission constraints identified by this system condition are similar to those in system condition 1.

Presently, the transmission constraints can be managed operationally through generation dispatch in the WUNI area.

We are studying investments to alleviate or remove the transmission constraints following decommissioning of the remaining Huntly Rankine units. For more specific information on our enhancement approach for the:

- Central North Island 110 kV constraints see section 11.4.2.2
- transmission capacity between Bunnythorpe and Whakamaru see section 6.3.2.3
- transmission capacity between Stratford and Huntly see section 6.3.2.3
- transmission capacity in the Wairakei Ring see section 6.3.2.2
- transmission capacity into the WUNI area see section 6.3.2.1.

**6.4.6.3 System condition 3: HVDC south transfer (winter)**

This system condition (SC3) tests the case where there is extremely low generation in the South Island, requiring high HVDC south transfer during periods when winter loads in the North Island are relatively high. This system condition represents a ‘dry’ period in the South Island together with low North Island wind generation. The specific assumptions for this system condition are:

- load is 80 per cent of North Island winter peak load
- thermal generation in the WUNI area is up to 960 MW including all remaining Huntly Rankine units
- maximum geothermal and hydro generation in the Bay of Plenty, Central North Island, and Hawkes Bay regions
- maximum thermal generation in the Taranaki region, including the Taranaki combined cycle unit

\footnote{11 The special protection scheme at Woodville detects an outage of a Bunnythorpe–Woodville circuit and, if the other circuit is overloaded, reconfigures the grid by opening the Mangamaire–Woodville circuit at Woodville. If the overload remains, the scheme will also reduce Te Apiti generation.}
- no wind generation in the lower and central North Island
- high HVDC south transfer up to voltage stability limits
- generation and load balance is achieved using growth generation at Wairakei and Stratford (see section 6.4.4.3 for details)
- transmission constraints are addressed by trading off South Island generation with North Island generation.

The HVDC control system prevents voltage stability issues by automatically reducing HVDC transfer, if required, following a power system fault. The reduction in HVDC transfer depends on how many circuits, transformers, synchronous condensers and filters are available in the lower North Island. The largest reduction will occur for 220 kV bus faults at Bunnythorpe or Haywards. The reduction in HVDC transfer also limits thermal issues within the North Island grid backbone.

The transmission constraints arising from these assumptions are based on the capacity of the existing grid.

**Summary of transmission constraints**

Possible transmission constraints include:

- 110 kV regional constraints
- Haywards HVDC power limits
- Central North Island area 220 kV constraints
- Lower North Island area 220 kV constraints
- Brunswick–Stratford constraints.

The 110 kV and 220 kV circuits in the Central and Lower North Island areas will overload during the forecast period under this system condition. There are also likely to be low voltages in the central North Island driven by low voltage at the Bunnythorpe 220 kV bus.

Some transmission constraints are managed by the HVDC control system as described above.

**SC3: 110 kV regional constraints**

The most serious issues seen under this system condition occur in the 110 kV regional network. There are two main issues: Bunnythorpe–Woodville overload and regional low voltage.

**Bunnythorpe–Woodville overload**

The Bunnythorpe–Woodville circuit will overload if HVDC south transfer exceeds around 60 MW during an outage of the other Bunnythorpe–Woodville circuit. The existing special protection scheme at Woodville\(^\text{12}\) will manage this transmission constraint. However, if HVDC south transfer exceeds 450 MW, the Bunnythorpe–Woodville circuits will overload for a Haywards 220 kV bus outage. This limit is similar to the HVDC runback limit for the outage. The special protection scheme at Woodville will not operate to manage the overload on the Bunnythorpe–Woodville circuits as neither of them is out of service. The transmission constraint can be managed by the HVDC control system.

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\(^{12}\) The special protection scheme at Woodville detects an outage of a Bunnythorpe–Woodville circuit and, if the other circuit is overloaded, reconfigures the grid by opening the Mangamaire–Woodville circuit at Woodville. If the overload remains, the scheme will also reduce Te Apiti generation. This prevents power from flowing to the Wellington area through the lower capacity 110 kV network.
operationally if there is generation at Te Apiti and/or by temporarily reconfiguring the grid to split the 110 kV system.

**Regional low voltage**

Low voltages may occur in the central North Island during a Bunnythorpe 220 kV bus outage when there is HVDC south transfer. Waipawa is likely to be the first supply bus to fall below 0.95 pu. Other supply buses with voltages outside the acceptable voltage operating range include Brunswick, Wanganui, Mataroa, and Marton.

**SC3: Haywards HVDC power limits**

The maximum pre-contingency HVDC south transfer is about\(^{13}\):

- 760 MW in 2017 with Wellington load of about 460 MW (assuming no generation injection into the Wellington 110 kV network)
- 710 MW by 2022 with Wellington load of about 500 MW
- 620 MW by 2030 with Wellington load of about 560 MW.

**SC3: Central North Island area 220 kV constraints**

From 2017, the:

- Rangipo–Tangiwai circuit may overload during an outage of a Bunnythorpe or Tokaanu 220 kV bus, or an outage of a Bunnythorpe–Tokaanu circuit for HVDC south transfer above about 360–410 MW
- Bunnythorpe–Tangiwai circuit may overload during an outage of a Tokaanu 220 kV bus or an outage of a Bunnythorpe–Tokaanu circuit for HVDC south transfer above about 450–500 MW
- Bunnythorpe–Tokaanu circuits may overload during an outage of a Bunnythorpe 220 kV bus, the other Bunnythorpe–Tokaanu circuit, or the Rangipo–Tangiwai circuit for an HVDC south transfer above about 490–580 MW
- Rangipo–Tangiwai circuit may overload pre-contingency for HVDC south transfer of more than about 600 MW.

By 2022, the:

- Rangipo–Tangiwai circuit may overload during an outage of a Bunnythorpe or Tokaanu 220 kV bus, or an outage of a Bunnythorpe–Tokaanu circuit, for HVDC south transfer above about 400–450 MW
- Bunnythorpe–Tangiwai circuit may overload during an outage of a Tokaanu 220 kV bus or an outage of a Bunnythorpe–Tokaanu circuit for HVDC south transfer above about 490–540 MW.

By 2032, the:

- Rangipo–Tangiwai circuit may overload during an outage of a Bunnythorpe or Tokaanu 220 kV bus, or a Bunnythorpe–Tokaanu circuit for HVDC south transfer above about 300–340 MW
- Bunnythorpe–Tangiwai circuit may overload during an outage of a Tokaanu 220 kV bus or an outage of a Bunnythorpe–Tokaanu circuit for HVDC south transfer above about 360–410 MW.

\(^{13}\) These limits are set by HVDC power limits, reactive reserve limits may result in lower values.
These transmission constraints, which can be managed operationally by increasing or reducing generation in the Taranaki area and the South Island, depend on the amount of generation at Rangipo. If Rangipo generation is traded off with generation:

- north of Rangipo, the HVDC south transfer can be increased by less than 1 MW for every 1 MW reduction at Rangipo
- in the Taranaki area, the HVDC south transfer can be increased by more than 4 MW for every 1 MW reduction at Rangipo.

**SC3: Lower North Island area 220 kV constraints**

From 2017:

- the Bunnythorpe–Paraparaumu Tee–2 circuit may overload during an outage of a Bunnythorpe 220 kV bus for HVDC south transfer above about 250 MW
- the Bunnythorpe–Paraparaumu Tee circuits may overload during an outage of a Haywards 220 kV bus, or the Bunnythorpe–Taranaki–Taranaki or Haywards–Linton circuit, for HVDC south transfer above about 450 MW
- the Haywards–Paraparaumu Tee circuits may overload for a Haywards–Linton circuit outage for an HVDC south transfer above 520 MW
- a Bunnythorpe–Paraparaumu Tee circuit section may also overload for an outage of the other Bunnythorpe–Paraparaumu–Haywards circuit for an HVDC south transfer above about 550 MW.

We are currently reconductoring the Bunnythorpe–Paraparaumu–Haywards circuits and this is due for completion by 2020. Following completion of this work, the capacity of those circuits will increase slightly.

There is also a transmission constraint due to dynamic voltage stability for HVDC south transfer. After the Bunnythorpe–Paraparaumu–Haywards circuits are reconductored, the thermal transmission limit due to the capacity of the Bunnythorpe–Paraparaumu–Haywards circuits and the dynamic voltage stability limit are similar.

**SC3: Brunswick–Stratford constraints**

From 2017, the Brunswick–Stratford circuits may overload for an outage of one of the other Brunswick–Stratford circuits for HVDC south transfer above about 490-530 MW.

By 2022, the Brunswick–Stratford circuits may overload for an outage of one of the other Brunswick–Stratford circuits for HVDC south transfer above about 330-370 MW.

By 2032, the Brunswick–Stratford circuits may overload for an outage of one of the other Brunswick–Stratford circuits for HVDC south transfer above about 80-120 MW.

These HVDC south transfer limits will decrease if we relax the maximum ‘growth generation’ assumption at Stratford.

**What next?**

In the short term, the transmission constraints described above can be addressed by dispatch of additional generation in the Lower North Island area or South Island.

We consider that the existing Bunnythorpe–Woodville special protection scheme is sufficient to manage the Bunnythorpe–Woodville issue for the forecast period, and have not planned any investments to change this.

In the medium to long term, the central North Island regional low voltage constraints will be alleviated (but not completely removed) when the existing supply transformers
are replaced (due to risk based condition replacement), as the replacement transformers will have on-load tap changers.

We consider that the HVDC controls are sufficient to manage dynamic voltage stability in the Lower North Island area for the forecast period, we have not planned any investments to change this.

In the longer term, we may consider transmission upgrades to alleviate or remove the transmission constraints. For more specific information on our enhancement approach for the:

- transmission capacity between Whakamaru and Bunnythorpe see section 6.3.2.3
- transmission capacity between Stratford and Bunnythorpe see section 6.3.2.3
- limiting 220 kV Bunnythorpe bus section outage, see section 11.5.5.2.

6.4.6.4 System condition 4: HVDC south transfer (summer)

This system condition (SC4) tests the case with extremely low generation in the South Island requiring high HVDC south transfer close to the time of summer peak load. Similarly to system condition 3, it represents a dry period in the South Island with low wind generation in the North Island. The specific assumptions for this system condition are as follows:

- load is 80 per cent of North Island summer peak load
- thermal generation in the WUNI area is up to 960 MW including all remaining Huntly Rankine units
- maximum geothermal and hydro generation in the Bay of Plenty, Central North Island, and Hawkes Bay regions
- low Taranaki generation, with no generation on the Stratford 220 kV bus
- no wind generation in the lower and central North Island
- high HVDC south transfer up to voltage stability limits
- generation and load balance is achieved using Huntly (to the extent it is available), followed by growth generation at Stratford and Wairakei (see section 6.4.4.3 for details).

Summary of transmission constraints

Possible transmission constraints include:

- 110 kV regional network
- 220 kV thermal overloads.

Thermal issues arise before HVDC voltage stability runback levels. This means that the most onerous Bunnythorpe and Haywards 220 kV bus outages can occur with relatively high HVDC south transfer.

SC4: 110 kV regional network

The Bunnythorpe–Woodville circuits may cause a transmission constraint during south transfer for a parallel circuit outage. This transmission constraint is managed by the existing special protection scheme at Woodville. The Bunnythorpe–Woodville

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14 The special protection scheme at Woodville detects an outage of a Bunnythorpe–Woodville circuit and if the other circuit is overloaded, it reconfigures the grid by opening the Mangamaire–Woodville
circuits may also cause a transmission constraint for HVDC south transfer exceeding 470 MW (in 2017) for a 220 kV bus outage. This transmission constraint is not addressed by the special protection scheme at Woodville. The issue can be managed if there is generation at Te Apiti and/or by temporarily reconfiguring the grid to split the 110 kV system.

SC4: 220 kV thermal overloads

With high HVDC transfer, the 220 kV circuits reach their thermal capacities in the following order:

- Rangipo–Tangiwa
- Bunnythorpe–Tangiwa
- Bunnythorpe–Tokaanu
- Bunnythorpe–Paraparaumu–Haywards
- Rangipo–Tangiwa (pre-contingency).

What next?

In the short term, these transmission constraints can be addressed with additional generation dispatched in the lower North Island or South Island.

We consider that the Bunnythorpe–Woodville special protection scheme is sufficient to manage the central North Island 110 kV issue for the forecast period, and we have not planned any investments to change this.

In the longer term, we may consider transmission upgrades to alleviate or remove the transmission constraints. For more specific information on our enhancement approach for the:

- transmission capacity between Whakamaru and Bunnythorpe, see section 6.3.2.3
- limiting 220 kV Bunnythorpe bus section outage, see section 11.5.5.2.

6.4.6.5 System condition 5: low eastern Bay of Plenty industrial load

This system condition (SC5) tests the effect on the grid backbone of high generation export from Kawerau. It represents a summer peak period where there is low thermal generation in the WUNI area, high generation in the eastern Bay of Plenty, and no industrial load at Kawerau. The specific assumptions for this system condition are:

- North Island summer peak load, with all directly connected industrial load on the Kawerau 110 kV and 220 kV buses turned off
- Kawerau–T13 is replaced with a new transformer bank identical to the existing Kawerau–T12

15 The HVDC south transfer limit increases following Bunnythorpe–Paraparaumu–Haywards reconductoring.

16 An alternative to this development is to enable the existing Kawerau–T13 Overload Protection Scheme, which reduces Kawerau 110 kV generation if Kawerau–T13 overloads and Kawerau–T12 is out of service. However, this system condition is intended to highlight constraints on the grid backbone, which the special protection scheme does not illustrate.
• thermal generation in the WUNI area is limited to one combined cycle generating unit at Huntly
• maximum geothermal generation in the Bay of Plenty, Central North Island, and Hawkes Bay regions
• hydro generation at average summer dispatch levels, with the exception of Matahina and Aniwhenua, which are operating at 100 per cent of capacity
• low Taranaki generation, with no generation on the Stratford 220 kV bus
• maximum wind generation in the lower and central North Island
• generation and load balance is achieved using HVDC north transfer.

Summary of transmission constraints
Possible transmission constraints include:
• 110 kV regional network
• 220 kV Bay of Plenty network
• Atiamuri–Ohakuri constraints
• other transmission constraints.

The 110 kV network between Kawerau and Owhata may overload for parallel 220 kV circuit outages. Special protection schemes exist to address these overloads, though their operation may cause the Atiamuri–Ohakuri circuit to exceed its summer rating.

SC5: 110 kV regional network
A number of contingencies will result in 110 kV circuit thermal overloads (see section 10.5.4.1, for more information). A number of special protection schemes will operate to remove overloaded 110 kV circuits: the special protection scheme on the Edgecumbe–Owhata circuit is most relevant to the grid backbone.

SC5: 220 kV Bay of Plenty network
The 220 kV Bay of Plenty circuits that may overload are the:
• Edgecumbe–Kawerau–3 or Kawerau–Ohakuri circuit, which may overload for an outage of the other circuit, particularly if the special protection scheme on the 110 kV Edgecumbe–Owhata circuit operates
• Edgecumbe–Kawerau–3 circuit, which may also overload for an Atiamuri–Ohakuri circuit outage
• Atiamuri–Tarukenga circuit, which may overload for a Tarukenga 220 kV bus outage.

See Chapter 10 for more information about these transmission constraints.

SC5: Atiamuri–Ohakuri constraints
The Atiamuri–Ohakuri circuit may overload for:
• an Edgecumbe–Kawerau–3 circuit outage followed by operation of the Edgecumbe–Owhata special protection scheme, for Kawerau generation of more than 250 MW in 2018, 210 MW in 2022, and 175 MW in 2032

17 The Edgecumbe–Owhata special protection scheme detects an overload on the Edgecumbe–Owhata–2 circuit, and then reconfigures the grid by opening the Edgecumbe–Owhata–2 circuit.
an Edgecumbe 220 kV bus outage followed by operation of the Edgecumbe–Owhata special protection scheme, for Kawerau generation of more than 280 MW in 2018, 250 MW in 2022 and 225 MW in 2032

a Kawerau 220 kV bus outage followed by operation of the Edgecumbe–Owhata special protection scheme, for Kawerau generation of more than 250 MW in 2018, 210 MW in 2022, and 175 MW in 2032.

SC5: other transmission constraints

The following transmission constraints are not specifically caused by high generation export and no industrial load at Kawerau, but do eventuate under system condition 5. The transmission constraints occur later in the forecast period, as HVDC transfer requirements increase. These are the same transmission constraints identified in system condition 1 and 2, in particular:

- the 110 kV Bunnythorpe–Mataroa circuit may overload during some central North Island 220 kV outages (from 2018, this will be managed with the special protection scheme that opens the Mataroa–Ohakune circuit if the Bunnythorpe–Mataroa circuit overloads)
- the 110 kV Otahuhu–Wiri Tee circuits may exceed their minimum summer variable line rating for an outage of the other Bombay–Wiri–Otahuhu circuit. This issue is discussed in section 6.4.6.6
- a Tokaanu–Whakamaru circuit may overload for an outage of the other Tokaanu–Whakamaru circuit. This will be managed with the existing special protection scheme at Tokaanu.

What next?

In the short term, these transmission constraints can be managed operationally by limiting generation on the Kawerau 110 kV bus during low industrial load periods. In the longer term, we may consider transmission upgrades to alleviate or remove the transmission constraints. For more specific information on our proposed approach for:

- increasing the 220 kV capacity out of Kawerau, see section 10.4.2.1
- increasing the capacity in the Wairakei Ring, see section 6.3.2.2.

6.4.6.6 System condition 6: Extreme low North Island hydro generation

This system condition (SC6) tests the adequacy of the parallel 110 kV circuits between Bunnythorpe, Hamilton and Otahuhu during very low generation from the Waikato River stations. These circuits supply load in the Central North Island and Waikato regions and the Bombay and Wiri grid exit points. The specific assumptions for this system condition are:

- North Island summer peak load
- maximum geothermal and wind generation in the North Island
- at least one combined-cycle generating unit and one small open-cycle gas turbine at Huntly

Assuming the special protection scheme at Tokaanu is in service reduces the reliance on generation in the WUNI area. However, because of high minimum generation requirements at Arapuni, a high level of generation at Karapiro is also assumed to balance water flow between power stations.
very low hydro generation in the North Island with all of the stations in the Waikato, Tongariro, and Waikaremoana schemes limited to 1-2 generating units. In particular there is one generating unit connected at each of Karapiro and the Arapuni North bus

- maximum thermal generation in the Taranaki region, including the Taranaki combined-cycle unit
- HVDC north transfer is up to 700 MW, limited as required by the loading on the 110 kV Bunnythorpe–Mataroa circuit
- as this system condition represents a dry year in the North Island, generation and load balance is achieved by dispatching the Huntly Rankine units, followed by Whirinaki generation and growth generation at Stratford and Wairakei as required.

**Summary of transmission constraints**

In 2017, the limiting thermal constraint is the Bunnythorpe–Mataroa 110 kV circuit for a 220 kV circuit outage.

Once the Mataroa series reactor and Bunnythorpe–Mataroa circuit overload protection scheme is commissioned, by summer 2018, the limiting thermal constraint becomes the minimum summer variable line rating on the Otahuhu–Wiri circuit for a Bombay–Wiri–Otahuhu outage.

A Hamilton 220 kV bus outage will also cause low voltages in the Waikato 110 kV network, and overload the Bunnythorpe–Mataroa and Otahuhu–Wiri circuits and the remaining Hamilton 220/110 kV interconnecting transformer.

Low voltages can also occur in the Waikato 110 kV network for 220 kV Huntly–Ohinewai circuit outages.

**SC6: summer 2017**

In summer 2017, HVDC north flow is limited to manage the loading on the Bunnythorpe–Mataroa circuit.

The Bunnythorpe–Mataroa circuit will overload:

- for a Hamilton 220 kV bus outage, for HVDC north transfer above about 270 MW
- for a 220 kV Tokaanu–Whakamaru circuit outage, for HVDC north transfer above about 320 MW
- pre-contingency, for HVDC north transfer above about 500 MW.

There will be low voltages at:

- Hinuera, Hangatiki, Waihou, and Waikino for a Hamilton 220 kV bus outage
- Hinuera and Hangatiki for a 220 kV Hamilton–Ohinewai circuit outage.

**SC6: summer 2018**

By summer 2018, a series reactor will be installed on the Bunnythorpe–Mataroa circuit and the Bunnythorpe–Mataroa circuit overload protection scheme will open the Mataroa–Ohakune circuit if the Bunnythorpe–Mataroa circuit overloads. Therefore, the HVDC is limited to manage only the pre-contingency overloading on Bunnythorpe–Mataroa circuit.

The Bunnythorpe–Mataroa circuit will overload pre-contingency for the HVDC north transfer above about 700 MW.
The Otahuhu–Wiri Tee circuits will exceed the circuits’ minimum summer variable line rating for a Bombay–Wiri–Otahuhu circuit or Hamilton 220 kV bus outage followed by operation of the Bunnythorpe–Mataroa special protection scheme.

The 110 kV Bombay–Wiri Tee circuits will overload for a Hamilton 220 kV bus outage followed by operation of the Bunnythorpe–Mataroa special protection scheme.

The 220/110 kV Hamilton–T9 interconnecting transformer will exceed the transformers’ summer capacity for an outage of the other 220/110 kV Hamilton interconnecting transformer or an outage of a Hamilton 220 kV bus section, followed by operation of the Bunnythorpe–Mataroa special protection scheme.

The voltage at Hinuera will fall below 0.9 pu for a Hamilton 220 kV bus section outage followed by operation of the Bunnythorpe–Mataroa special protection scheme.

The voltage will fall below 0.95 pu at Hinuera, Hangatiki, Waihou, and Waikino for an outage of a Hamilton 220 kV bus section or an outage of the 220 kV Hamilton–Ohinewai circuit followed by operation of the Bunnythorpe–Mataroa special protection scheme.

**SC6: summer 2022**

Summer 2022 is the last period that is considered for this system condition. This is the latest timing we expect for transmission developments to address the WUNI voltage management issues.

The Bunnythorpe–Mataroa circuit will overload pre-contingency for HVDC north transfer above about 690 MW.

In addition to the issues identified in summer 2018:

- the Otahuhu–Wiri Tee–1 circuit will exceed its minimum summer variable line rating for an outage of the 220 kV Hamilton–Ohinewai circuit or an outage of a Hamilton 220/110 kV interconnecting transformer, followed by operation of the Bunnythorpe–Mataroa special protection scheme
- the Bombay–Wiri Tee circuit will overload for an outage of a Bombay–Wiri–Otahuhu circuit or an outage of a Hamilton 220/110 kV interconnecting transformer, followed by operation of the Bunnythorpe–Mataroa special protection scheme for power flow from Wiri to Bombay
- the 220/110 kV Hamilton–T6 interconnecting transformer will exceed its summer capacity for an outage of the other interconnecting transformer (T9) or an outage of a Hamilton 220 kV bus section, followed by operation of the Bunnythorpe–Mataroa special protection scheme
- the voltage at Hangatiki, Waihou, Waikino, Te Awamutu, and Hamilton will fall below 0.9 pu for a Hamilton 220 kV bus section outage, followed by operation of the Bunnythorpe–Mataroa special protection scheme.

**What next?**

A bus outage is an extended contingent event. Therefore, constraints caused by a Hamilton 220 kV bus outage will be managed operationally, post-contingency.

Presently, more generating units will need to be dispatched at Karapiro and Arapuni North to manage the:

- Otahuhu–Wiri thermal constraint, for the parallel Bombay–Wiri–Otahuhu outage
- 220/110 kV Hamilton–T9 thermal overload, for the parallel interconnecting transformer outage
• low voltage, for a 220 kV Hamilton–Ohinewai outage.

We are studying investment options to alleviate or remove the transmission constraints following decommissioning of the remaining Huntly Rankine units. For more specific information on our proposed enhancement approach for the:

• WUNI Voltage Management, in particular the installation of reactive support in the Waikato region, refer to section 6.3.2.1
• Otahuhu–Wiri circuit capacity, refer to section 8.4.2.3
• Waikato 220/110 kV interconnection capacity, refer to section 9.4.2.6
• Hangatiki transmission capacity, refer to section 9.4.2.5
• Bunnythorpe–Mataroa 110 kV transmission capacity, refer to section 11.4.2.2 for details of the Mataroa series reactor and Bunnythorpe–Mataroa circuit overload protection scheme committed for installation by summer 2018

• Low voltages at:
  o Hangatiki and Te Awamutu, refer to section 9.4.2.5
  o Waihou, refer to section 9.4.2.13
  o Waikino, refer to section 9.4.2.14
  o Hamilton are expected to be addressed by the WUNI Voltage Management proposal.

At this stage, we do not anticipate that any other transmission investments will be required specifically to manage the issues discussed in this scenario within the forecast period. We will continue to monitor developments to ensure the timing of our proposed investments to address regional 110 kV issues is appropriate.

6.4.6.7 System condition 7: light load

This system condition (SC7) tests the effect of low load on the grid backbone. It represents a realistic summer night light load period and is designed to highlight high voltage issues. The specific assumptions for this system condition are:

• North Island trough summer night load
• thermal generation in the WUNI area is limited to one combined cycle generating unit at Huntly
• maximum geothermal in the Bay of Plenty, Central North Island and Hawkes Bay regions
• low hydro generation, with many stations having only one unit in service, the exceptions being Arapuni, Maraetai, Rangipo, and Tokaanu
• no Taranaki area generation
• low wind generation in the Wellington region and no wind generation in the Central North Island region
• low HVDC north transfer of 140 MW representing low levels of South Island hydro generation.
• generation and load balance is achieved by altering Whakamaru generation.

Summary of transmission constraints

Possible transmission constraints include:

• WUNI area high voltages
• Te Kowhai and Taumarunui high voltage
• Lower North Island area high voltages.

The main concern during light load periods is high post-contingency voltages. These are dependent on load power factor and voltage profile across the North Island. The voltage profile can be maintained at around 1.0 pu at most generating stations. However, this requires generation and North Island dynamic reactive plant to absorb a high level of reactive power pre-contingency, limiting the available response to a post-contingency event.

**SC7: Upper North Island area high voltages**

Keeping the WUNI area voltages within acceptable limits with all circuits in service requires high levels of reactive power absorption from available units at Huntly and dynamic reactive plant in the region at Penrose, Albany and Marsden. If this reactive power absorption is not available or insufficient, circuits such as Pakuranga–Whakamaru–1 and/or 2 may need to be removed from service to maintain voltages.

Over the years, the high voltage issue has continued to worsen, so there is an increasing need to remove circuits from service overnight to manage the issue. A variety of factors have exacerbated the high voltage issue including the use of long transmission cables, an increasing amount of distribution network being converted to underground cables, and load characteristics becoming generally more capacitive.

**SC7: Te Kowhai and Taumarunui high voltage**

If a 220 kV Huntly–Te Kowhai circuit outage occurs at light load periods, the Te Kowhai and Taumarunui 220 kV bus voltages can exceed 1.10 pu. This is more likely to occur when generation is unavailable in the Taranaki region as there are no means to absorb the excess reactive power. The extent of the high voltage at Te Kowhai and Taumarunui also depends on the response from the two generating stations embedded at Te Kowhai (Te Rapa and Te Uku).

**SC7: Lower North Island high voltages**

Keeping the Lower North Island area voltages within acceptable limits with all circuits in service requires high levels of reactive power absorption from the Haywards synchronous condensers at light load times. HVDC transfer may also be limited for harmonic performance if the number of filters must be reduced to prevent high voltages.

**What next?**

At present, the high voltages are managed via operational measures including removing circuits from service, (particularly in the WUNI area), and in more severe cases by bringing on generators in the region.

We consider the operational measures we have identified are sufficient to manage the high voltage issue in Taumarunui, Te Kowhai, and the Lower North Island area. We will continue to monitor the issue and investigate options as the need arises.

In addition, we are investigating investment options to resolve high voltage issues during light load in the WUNI area, as discussed in section 6.3.2.4.
6.5 South Island grid backbone

The South Island grid backbone comprises the following 220 kV circuits:

- three from Islington to Kikiwa
- four from Twizel and Livingstone to Islington
- nine between Twizel and Livingstone, which connect six large Waitaki Valley hydro generation stations and the HVDC link
- three from Roxburgh to Twizel and Livingstone
- four from Roxburgh to Invercargill and North Makarewa (two of which run via Three Mile Hill)
- nine connecting Manapouri and Tiwai to Invercargill and North Makarewa.

Power flows on the inter-island HVDC link vary. The net annual power flow is northwards, especially at times of North Island peak demand. However, during light load periods, power may flow southward to conserve South Island hydro storage, especially during periods of low hydro inflows in the South Island.

The existing South Island grid backbone is set out geographically in Figure 6-5 and schematically in Figure 6-6.

To help describe transmission system problems and opportunities on the backbone grid, we split the South Island transmission system into three major areas:

- Clutha Upper Waitaki Valley area, which encompasses the transmission system between the Clutha area (Clyde and Roxburgh) and the Waitaki Valley area (Twizel and Livingstone)
- Upper South Island area, which encompasses everything north of the Clutha Upper Waitaki Valley area
- Lower South Island area, which encompasses everything south of the Clutha Upper Waitaki Valley area. Within the Lower South Island area, we also refer to the area south of Invercargill and North Makarewa as the Southland area.
Figure 6-5: South Island grid backbone map
Figure 6-6: South Island grid backbone schematic
6.6 South Island grid enhancement approach

6.6.1 Possible South Island grid backbone to 2032

Figure 6-7 provides an indication of possible South Island transmission backbone development in the medium term (the next 15 years). New assets and upgraded assets, (based on potential enhancement approaches set out in the following sections) are shown.

Figure 6-7: Possible South Island grid backbone schematic in 2032

* Although this diagram shows new static reactive support installed at Islington, and new switching stations and GXPs, this is indicative only.
6.6.2 Enhancement approach

This section provides information about the transmission constraints we will investigate or mitigate over the next few years.

Transmission issues likely requiring E&D base capex or Major Capex Project (MCP) funded investment in the South Island grid backbone over the next 10-15 years include:

<table>
<thead>
<tr>
<th>Section number</th>
<th>Issue</th>
</tr>
</thead>
<tbody>
<tr>
<td>6.6.2.1</td>
<td>Upper South Island transmission capacity</td>
</tr>
<tr>
<td>6.6.2.2</td>
<td>Otago-Southland and Waitaki Valley transmission capacity</td>
</tr>
<tr>
<td>6.6.2.3</td>
<td>Upper South Island high voltage during light load</td>
</tr>
</tbody>
</table>

6.6.2.1 Upper South Island transmission capacity

The Upper South Island is a major load centre (dominated by Christchurch load) with very little local generation. Almost all of the load in this part of the Island is supplied from the Waitaki Valley, making it heavily reliant on the transmission system. This reliance on imported power from the Waitaki Valley makes it essential that we:

- maintain sufficient voltage support equipment and ensure voltage stability limits are not exceeded
- ensure there is sufficient thermal capacity to import the required power.

Upper South Island voltage support

As there are few synchronous generators in the Upper South Island, maintaining voltage stability and quality requires us to have an extensive fleet of reactive support equipment in the area. As demand in this part of the South Island grows, we need to ensure that there continues to be sufficient voltage support equipment in the area.

We have studied the Upper South Island voltage stability issue extensively and have an investment program over the next 10-15 years to address the forecast issues. Our preferred options for the next investment phases (based on our 2013 analysis) are:

- sectionalising the 220 kV circuits from the Waitaki Valley to Islington by bussing them at new switching stations at Orari and Rangitata
- installing additional reactive support equipment, towards the end of the forecast period.

The Commerce Commission has approved the enabling works for the Orari and Rangitata switching stations. Enabling work consists of developing the detailed design for the works and procuring the necessary designations, easements, and property. This work is currently underway. Due to changing land use in the region and the use of central pivot irrigation we consider it is economically prudent to secure the necessary property rights for the switching stations now. This will ensure the option of building new switching stations is feasible in the future and reduce lead times for the delivery of the project when it is needed.

Once this enabling work is completed, the timing of the build phase will be confirmed. The build-phase will require a separate approval from the Commerce Commission.
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Enhancement approach:

- We are currently reviewing the need date for the build-phase for the Orari and Rangitata switching stations due to changes in forecast demand since our 2013 studies. Once the need date is determined we will:
  
  o determine whether there is a need to refurbish Islington SVC–3 and Islington–C15 (both to be funded under base capex replacement and refurbishment). See section 6.7.4 for further discussion.
  
  o schedule the build-phase for Orari and Rangitata and submit a Major Capex Project proposal to the Commerce Commission for approval.

- Upper South Island voltage stability will be an ongoing issue due to the lack of synchronous generation in the area. We will monitor the need for additional reactive support as the area's load continues to grow.

**Major Capex investment**

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Upper South Island Voltage Stability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project description:</td>
<td>Build Orari and Rangitata switching stations, bussing 220 kV circuits from the Waitaki Valley</td>
</tr>
<tr>
<td>Project's state of completion</td>
<td>Proposed</td>
</tr>
<tr>
<td>OAA level completed:</td>
<td>OAA level 4p</td>
</tr>
<tr>
<td>Grid need date:</td>
<td>2023 (under review)</td>
</tr>
<tr>
<td>Indicative cost [$ million]</td>
<td>$24</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>No</td>
</tr>
</tbody>
</table>

**Waitaki Valley to Christchurch transmission capacity**

In addition to the voltage constraints, the Upper South Island load is also expected to exceed the n-1 transmission capacity between the Waitaki Valley and Islington from 2030. The thermal capacity is limited by a Timaru–Twizel circuit section overloading for an outage of the other Ashburton–Timaru–Twizel circuit.

Enhancement approach:

- The next phase of investment to resolve the voltage stability issue will increase thermal transmission capacity into Christchurch.

- We will investigate longer-term options to increase the n-1 thermal transmission capacity which is likely required beyond the forecast period (see section 6.6.3).

**6.6.2.2 Otago-Southland and Waitaki Valley transmission capacity**

A significant portion of the South Island's generation lies in the Otago-Southland region. The region is connected to the Waitaki Valley by three 220 kV circuits (Clyde–Cromwell–Twizel–1 and 2 and Livingstone–Naseby–Roxburgh–1).

Much of the region's substantial hydro generation is consumed locally by the Tiwai Point aluminium smelter which operates year round. Other major load centres include Dunedin and Invercargill.

The combination of hydro generation and a very large continuous load in the region means that the need for transmission into and out of the region is very susceptible to local hydrology. During ‘dry’ hydro conditions the transmission system is constrained by the need to import power from the Waitaki Valley (including HVDC south transfers) while in ‘wet’ hydro conditions it is constrained by the need to export power to the Waitaki Valley (including HVDC north transfers).
The Clutha-Upper Waitaki Lines Project (CUWLP) is an approved suite of projects to increase transmission capacity between the Clutha and the Waitaki Valley. The first tranche of CUWLP has been implemented and included:

- duplexing the Clyde–Roxburgh–1 and 2 circuits
- duplexing the Aviemore–Waitaki circuit
- duplexing the Livingstone–Waitaki circuit.

The second tranche of CUWLP, which is yet to commence, involves:

- thermally upgrading the Cromwell–Twizel circuit sections
- duplexing the Roxburgh–Naseby–Livingstone circuits
- duplexing the Aviemore–Benmore–1 and 2 circuits.

Figure 6-8 shows the circuits between Roxburgh and Twizel following completion of both tranches of CUWLP.

**Figure 6-8: 220 kV circuits between Roxburgh and Twizel after CUWLP upgrade**

The primary justification for the second tranche work is to increase transmission capacity for power flow from the Otago-Southland region to the Waitaki Valley, which will be required if there is a significant increase in generation or reduction in load in the region. The second tranche of the CUWLP will also substantially increase transmission capacity for southward power flow from the Waitaki Valley to Otago-Southland, for periods when there is low generation in the region.

We periodically review the need to implement the second tranche of CUWLP. We do not currently consider that there is sufficient certainty regarding new generation or load reductions in the Otago-Southland region to justify proceeding with the work.

The Roxburgh Export Overload Protection Scheme (REOLPS) provided a small increase in generation export capacity from the Otago-Southland region. The scheme is designed to reconfigure the grid post-contingency in two stages but the second stage is not yet in operation, pending completion of the Gore interconnection project to reinforce the Southland 110 kV network.
Enhancement approach:

To enable us to optimise the timing for the second tranche of CUWLP in response to changes in market conditions we have:

- Completed the detail design for the Roxburgh–Naseby–Livingstone duplexing and Cromwell–Twizel thermal upgrade. We will review our decision about whether to proceed with these upgrades as new information becomes available.
- We also identified some lower cost investments that incrementally increase the transmission capacity between the Lower South Island and the Waitaki Valley. We are investigating if it is justifiable to implement some or all of these lower cost incremental upgrades which could include:
  - installing a Naseby–Roxburgh series reactor, coupled with the Cromwell–Twizel thermal upgrade or
  - implementing changes to special protection schemes and;
  - installing a special protection scheme on the Aviemore–Benmore circuits.

Base E&D Capex investments

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Benmore–Roxburgh transmission capacity</th>
</tr>
</thead>
</table>
| Project description:                     | Naseby–Roxburgh series reactor and Cromwell–Twizel thermal upgrade
| Project’s state of completion:            | Possible                               |
| OAA level completed:                      | None                                   |
| Grid need date:                           | 2020                                   |
| Indicative cost [$ million]:              | 10                                     |
| Part of the GEIR?:                        | Yes                                    |

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Aviemore–Benmore circuit special protection scheme</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project description:</td>
<td>Install Aviemore–Benmore circuit overload protection scheme</td>
</tr>
<tr>
<td>Project’s state of completion:</td>
<td>Possible</td>
</tr>
<tr>
<td>OAA level completed:</td>
<td>None</td>
</tr>
<tr>
<td>Grid need date:</td>
<td>2020</td>
</tr>
<tr>
<td>Indicative cost [$ million]:</td>
<td>0.5</td>
</tr>
<tr>
<td>Part of the GEIR?:</td>
<td>Yes</td>
</tr>
</tbody>
</table>

19 Note that this thermal upgrade may be undertaken as an incremental measure, or alternately included in the Clutha Upper Waitaki Lines Project (Stage 2)

20 Note that this special protection scheme may be implemented as an incremental measure, or alternately included in the Clutha Upper Waitaki Lines Project (Stage 2)
Major Capex investments

<table>
<thead>
<tr>
<th>Project Name</th>
<th>Clutha Upper Waitaki Lines Project (2nd tranche)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Project’s state of completion</td>
<td>Possible</td>
</tr>
<tr>
<td>OAA level completed:</td>
<td>OAA level 4p</td>
</tr>
<tr>
<td>Grid need date:</td>
<td>Uncertain, Otago-Southland generation or load dependent</td>
</tr>
<tr>
<td>Indicative cost [$ million]:</td>
<td>$96.5 ($6m for Cromwell–Twizel transmission thermal upgrade, $90m for Roxburgh–Naseby–Livingstone duplexing, $0.5m for Aviemore–Benmore special protection scheme)</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

6.6.2.3 Upper South Island high voltage during light load

The load in the Upper South Island is not dominated by heavy industrial loads, making it highly changeable throughout the day, with very low loads overnight, especially in summer. There are long transmission lines into the area and little generation. The long transmission lines produce significant amounts of reactive power during light load periods (increasing the voltage) and there is little generation to absorb reactive power (to reduce the voltage).

We currently resolve the high voltage issue in the Upper South Island by switching off the 220 kV Islington–Kikiwa–1 circuit and, on occasion, the Islington–Livingstone–1 circuit overnight when load in the area is low. This operational measure significantly reduces the amount of reactive power produced without compromising security of supply (n-1 security) to our customers.

There are no other circuits in the region that can be switched off during light load without compromising security of supply. On some light load occasions, especially when the HVDC is operating in round-power mode (where filter banks need to be in service), we have needed to bring on generation units at Benmore to absorb the excess reactive power from the grid.

Unlike in the Upper North Island, the voltage stability load limit in the Upper South Island is set by bus section outages. This means that the most economic investment to resolve the voltage stability issue is to reduce the impact of a bus outage, rather than installing more dynamic reactive support equipment. Therefore, there are no synergies between the investment to control high voltages during light load and investments to maintain voltage stability during peak load in the Upper South Island.

Enhancement approach:

- We are investigating a range of investment options to increase the capability of the grid to absorb excess reactive power during light load periods, to prevent supply voltages exceeding statutory limits. We expect that installing a new shunt reactor in the Upper South Island area will be our preferred approach, though as we are in the early stages of investigation we have not confirmed this with economic analysis.
6.6.3 South Island grid backbone beyond the planning horizon (2032)

Figure 6-9 provides an indication of the possible South Island transmission backbone development in the longer-term (beyond 2032). Additional transmission capacity upgrades into Christchurch will likely be required just beyond the end of the forecast period, which can be achieved with one or more of the following options:

- reconductoring existing 220 kV lines into Christchurch
- an HVDC tap-off from the existing HVDC line north of Christchurch
- a new transmission line to Islington (which can be built in stages) terminating at Orari (if built) or Ashburton.

The preferred option will be determined closer to the need date.
6.7 South Island asset capability and management

We have assessed transmission capacity and reactive support requirements on the South Island grid backbone for a range of system conditions over the next 15 years. When an issue or opportunity is likely to arise, we have examined initial options and actions that may be taken to address it. Grid Enhancement Approaches (refer to section 6.6) have been developed to address issues or opportunities that require action within the forecast period and where investment is a valid option.

This section discusses the main inputs to the E&D process. These are:
- transmission capability (taking into account forecast demand and generation and possible technological changes)
- customer requests
- generation proposals and opportunities
- risk based replacements
- significant upcoming work planned over the period
- asset feedback (information on assets or issues submitted through the asset feedback process)

### 6.7.1 Changes since the 2015 Transmission Planning Report

Changes since the 2015 TPR include:

- low or almost zero load growth continues to be forecast for most South Island regions with the exception of a few 'hot spots' where high load growth is forecast, for example, in the South Canterbury region (where high growth is bringing forward the South Canterbury summer voltage stability limit binding)
- completion of the Aviemore–Waitaki–Livingstone line (duplexing) capacity upgrade.

### 6.7.2 Committed Projects

Projects that are not complete at the time of publication but which are included in the analysis modelling are:

- installation of a 220/110 kV interconnection at Gore and implementation of a system split at the Gore 110 kV bus, which is programmed for commissioning in 2018.

### 6.7.3 Line conductor replacements

No line conductor replacements are expected in the South Island during the forecast period, based on risk based condition.

### 6.7.4 South Island grid backbone asset feedback

The Asset Feedback Register includes the following entries related to E&D that are specific to the South Island grid backbone:

- To review the need for Islington 66 kV capacitor bank C15
- To review the need for Islington–SVC3.

#### 6.7.4.1 Review the need for Islington capacitor bank C15

**Issue**

Islington C15 is a 38 Mvar 66 kV capacitor that is due for risk based condition replacement. We need to confirm whether there is a future need for the capacitor.

**What next?**

We are refreshing our Upper South Island peak load voltage stability analysis. This work will confirm the future reactive support requirements in the region. See section 6.6.2.1 for our enhancement approach.
6.7.4.2 Review the need for Islington–SVC3

Issue
Islington–SVC3’s electronic components are nearing end of life. However, our operations team is heavily reliant on SVC3 to maintain voltages during both light load and peak load periods.

In addition, SVCs take a long time to repair for some types of fault. For example, SVC9 was recently forced out of service for an extended period due to component failure, and SVC3 provided some redundancy.

What next?
We are investigating voltage stability in the Upper South Island during peak loads, and high voltages during light load in the Upper South Island. Both investigations will take into consideration the future need for Islington–SVC3. See sections 6.6.2.1 and 6.6.2.3 for our enhancement approach.

We will also consider the economics of providing n-1 capacity while an SVC is out of service.

6.7.5 Methodology

6.7.5.1 System conditions

A small number of realistically challenging system conditions are used to assess the capability of the existing South Island grid backbone. They provide snapshots to identify transmission constraints that may require minimum or maximum limits to be applied to generation and/or load to avoid overloading the power system following an outage. From these we can identify transmission upgrades that will alleviate the constraints, allowing lower minimum and higher maximum limits for generation and load.

6.7.5.2 Limits in the electricity market

Transmission constraints identified by the system conditions do not always cause minimum or maximum generation limits in the wholesale electricity market. The System Operator’s management of a transmission constraint depends on the type of outage that causes it:

- Circuit outages are managed as contingent events requiring pre-contingent management (for example, by using market security constraints to apply a maximum generation limit, or by pre-contingent load management).
- Other outages (for example, bus-sections) may be managed using pre-contingent or post-contingent actions, depending on the extent and magnitude of the system impact resulting from the outage.

6.7.6 Overview of results

Key findings for the South Island grid backbone include:

- Transmission capacity to the Upper South Island is first limited by a voltage stability constraint, and later by thermal constraints on the Ashburton–Timaru–Twizel circuits.
• Transmission of generation from the Lower South Island area to the Waitaki Valley is first limited by the capacity of the Livingstone–Naseby–Roxburgh circuit, and later by the thermal capacity of the Cromwell–Twizel sections of the Clyde–Cromwell–Twizel circuits.

• The limit on transmission from the Waitaki Valley to the Lower South Island area depends on the generation source. With high Waitaki Valley generation, the Livingstone–Naseby–Roxburgh circuit sets the transmission capacity limit. With high HVDC south transfers, the Aviemore–Benmore circuits set the limit, followed by the Benmore–Twizel circuit.

• With the above constraints between the Waitaki Valley and Lower South Island area resolved, higher transmission between them will cause constraints within the Waitaki Valley and into the Southland area to appear.

• Transmission out of the Waitaki Valley will then be limited by the Benmore–Twizel circuit capacity. Transmission capacity into the Southland area will be limited by voltage stability in the area and later, by the thermal capacity of the Invercargill–Roxburgh circuits.

• During light load periods, the high voltage issues in the Upper South Island area will become increasingly difficult to manage. We are running out of operational measures to resolve the high voltage issue if it continues to worsen.

### 6.7.7 South Island grid backbone capability and constraints

System conditions are load and generation patterns that we use to highlight transmission issues we can reasonably expect to occur, given currently available information and trends. The analysis under each of the system conditions provides a snapshot of the capability of the South Island grid backbone to transfer energy from generators to the loads while maintaining a secure grid. The four system conditions that we anticipate we could reasonably encounter in the South Island are:

- Low Upper South Island generation (see section 6.7.7.1)
- High Lower South Island generation (see section 6.7.7.2)
- Low Lower South Island generation (see section 6.7.7.3)
- Light load (see section 6.7.7.4).

#### 6.7.7.1 System condition 1: low Upper South Island generation

This system condition (SC1) examines the effect of extremely low generation in the Upper South Island area during a South Island summer peak load period. It is designed to highlight the transmission issues into the Upper South Island from the Waitaki Valley area. Although the Upper South Island has relatively little generation compared with its load, generation still has a noticeable effect on transmission constraints. The specific assumptions for this system condition are as follows:

- South Island peak load
- Low generation in the Upper South Island
- High generation in the Clutha Upper Waitaki Valley and Lower South Island areas
- Generation and load balance is achieved using the HVDC.

The transmission constraints arising from these assumptions are based on existing grid capacity.
Summary of transmission constraints

There is insufficient transmission capacity to supply Upper South Island loads for the forecast period under this system condition. The transmission capacity into the Upper South Island is constrained by voltage stability from 2022 and by transmission thermal capacity from 2030.

Possible transmission constraints include:

- Upper South Island voltage stability constraints
- Upper South Island transmission thermal limits.

SC1: voltage stability constraints

Voltage stability within the Upper South Island area is influenced by:

- reactive power losses
- reactive power demand due to load composition (in particular the proportion and type of motor load)
- generation level in the Upper South Island.

Reactive support for the Upper South Island is provided by:

- two SVCs\(^{21}\) at Islington
- a STATCOM at Kikiwa
- grid backbone capacitor banks at Islington
- regional grid capacitor banks at Islington, Bromley, Southbrook, Blenheim, Stoke, Greymouth and Hokitika
- regional and embedded generation in the Upper South Island.

Based on the voltage stability studies we completed in 2013, the outages that may cause a voltage stability constraint at peak load periods are:

- Ashburton bus section C\(^{22}\) from winter 2022
- Islington bus section A\(^{23}\) or Ashburton bus section A\(^{24}\) from winter 2023
- Islington bus section B\(^{25}\) from winter 2024.

Any new generation or demand-side reduction in load within the Upper South Island will improve voltage stability. Depending on the amount, this may defer or replace the need for transmission investment.

\(^{21}\) Islington–SVC3 is due for major refurbishment if it is to be retained in service.

\(^{22}\) An Ashburton bus section C outage disconnects the Ashburton–Timaru–Twizel and Ashburton–Islington circuits.

\(^{23}\) An Islington bus section A outage disconnects the Islington–Tekapo–B circuit and Islington–T7 (220/66 kV) transformer.

\(^{24}\) An Ashburton bus section A outage disconnects the Ashburton–Timaru–Twizel–1 circuit and the Ashburton–Bromley circuit.

\(^{25}\) An Islington bus section B outage disconnects the Islington–Livingstone circuit and Islington–T6 (220/66 kV) transformer.
SC1: transmission thermal constraints

An outage of an Ashburton–Timaru–Twizel circuit will cause the Timaru–Twizel section of the other Ashburton–Timaru–Twizel circuit to overload from summer 2030 (South Island summer peak load).

What next?

The Upper South Island voltage stability issue has been extensively studied and we have an investment program over the next 10-15 years to address the forecast issues. Refer to section 6.6.2.1 for our enhancement approach.

6.7.7.2 System condition 2: high Lower South Island generation

This system condition (SC2) tests the case where there is either significant new generation developed or a significant reduction in load in the Lower South Island area (south of Roxburgh). It represents a South Island peak load period with very high generation in the Lower South Island and is designed to highlight issues with northward transmission through the Clutha Upper Waitaki Valley area. The excess power not consumed within the South Island is assumed to be exported to the North Island via the HVDC link. The specific assumptions for this system condition are:

- forecast 2018 South Island summer peak load for summer transmission constraints and forecast 2018 South Island winter peak load for winter transmission constraints
- high generation from the Clutha hydro system and moderate generation from the Waitaki, Ohau, and Tekapo hydro systems
- high HVDC north transfer of up to 1,200 MW
- generation and load balance is achieved by trading off generation south of Roxburgh with generation in the North Island.

Summary of transmission constraints

Possible transmission constraints include:

- Livingstone–Naseby–Roxburgh constraint
- Clyde–Cromwell–Twizel constraint.

The identified constraints are highly sensitive to the generation assumptions, especially at Clyde and Roxburgh. Generation constraints in the Lower South Island do not occur frequently with current load and generation levels, but will become frequent if:

- a significant reduction in load occurs
- a significant amount of new generation is developed in the area to supply future demand growth or replace retiring stations in the North Island.

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26 The generation at Roxburgh has the biggest effect on export limits from the Lower South Island as the Roxburgh Export Overload Protection Scheme effectively splits the generating station into two, with one side connected to the Clyde–Roxburgh circuits and the other side connected to the Naseby–Roxburgh circuits. The export limit will decrease if more Roxburgh generation is connected to the same side as the Naseby–Roxburgh circuits.
SC2: Livingstone–Naseby–Roxburgh transmission constraint

In most normal operating scenarios, the capacity of the Livingstone–Naseby–Roxburgh circuit constrains the maximum generation export limit from the Lower South Island.

The Livingstone–Naseby–Roxburgh circuit operates in parallel with the higher capacity Clyde–Cromwell–Twizel–1 and 2 circuits, and will overload for a Clyde–Cromwell–Twizel circuit outage if northward transfer from the Lower South Island exceeds approximately 640 MW in summer and 800 MW in winter27 (with both stages of the Roxburgh Export Overload Protection scheme operating).

SC2: Clyde–Cromwell–Twizel transmission constraint

The Clyde–Cromwell–Twizel circuits are usually next to constrain the maximum generation export from the Lower South Island, the limiting factor being the Cromwell–Twizel sections, which have a lower capacity than the Clyde–Cromwell sections.

The Cromwell–Twizel section will overload for an outage on the other Clyde–Cromwell–Twizel circuit if generation export from the Lower South Island exceeds approximately 660 MW in summer and 830 MW in winter (with both stages of the Roxburgh Export Overload Protection scheme operating).

This maximum generation export limit is very close to the one for the Livingstone–Naseby–Roxburgh transmission constraint.

What next?

These transmission constraints are presently managed operationally by limiting the maximum generation in the Southland area.

Refer to section 6.6.2.2 for our enhancement approach, including the second tranche of CUWLP.

6.7.7.3 System Condition 3: low generation south of Clyde (summer)

This system condition (SC3) tests the impact of extremely low generation in the Lower South Island (south of Clyde). It represents a summer peak load period with very low Lower South Island area generation and is designed to highlight the transmission issues into the Southland area from both the Waitaki Valley and Roxburgh. The power required to meet load comes either from generation in the Waitaki Valley or the North Island (via HVDC southward flow). The specific assumptions for this system condition are:

- South Island 2018 summer forecast peak load
- low generation at Clyde and Roxburgh
- high HVDC southward flow28
- generation and load balance is achieved by trading off generation south of Clyde with generation in the North Island or Waitaki Valley.

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27 These limits are the pre-contingency power flows measured across the Naseby–Roxburgh circuit and Cromwell–Clyde sections so they include generation from Clyde and Roxburgh.

28 The HVDC link has a south flow rated capacity of 850 MW but has only been tested to 750 MW (at the sending end), therefore this value was assumed as the maximum for this analysis.
Summary of transmission constraints

The transmission constraints differ depending on whether the balance of generation is supplied from:

- high Waitaki Valley generation
- high HVDC southward flow, or
- high Clutha generation.

With the present levels of load and generation in the Lower South Island, transmission constraints for power flow into the region do not occur frequently. However, transmission constraints into the Lower South Island could occur frequently if there were a significant increase in load or reduction in generation in the area.

SC3: high Waitaki Valley generation

With high Waitaki Valley generation and either northward or low southward HVDC transfer:

- the Livingstone–Naseby–Roxburgh circuit will overload for a Clyde–Cromwell–Twizel outage if the Lower South Island import\(^ {29} \) exceeds approximately 465 MW
- the Aviemore–Benmore circuit will overload for an outage on the other Aviemore–Benmore circuit if the Lower South Island import exceeds 620 MW.

SC3: high HVDC southward flow

With moderate Waitaki Valley generation and very high levels (up to 750 MW) of HVDC south transfer:

- an Aviemore–Benmore circuit will overload for an outage of the other Aviemore–Benmore circuit if the Lower South Island import exceeds approximately 215 MW
- the Benmore–Twizel–1 circuit will overload for a Ohau B–Twizel–3 outage if the Lower South Island import exceeds 345 MW.

SC3: constraints south of Roxburgh

With high Clutha (Clyde and Roxburgh) generation and low Manapouri generation:

- voltage stability in the Otago-Southland region sets the minimum number of generating units required at Manapouri\(^ {30} \)
- an Invercargill–Roxburgh circuit will overload for an outage of the other Invercargill–Roxburgh circuit.

What next?

These transmission constraints into the Lower South Island can be managed operationally by requiring minimum levels of generation in the region.

The second tranche of CUWLP will significantly increases southward transmission thermal capacity (see section 6.6.2.2 for more information).

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\(^{29}\) This limit is the pre-contingency power flow measured across the Livingstone–Naseby circuit and Cromwell–Twizel sections.

\(^{30}\) The maximum import limit is calculated by reducing Manapouri generation, therefore the voltage stability limit binds first as generating units are taken out of service, which also reduces the amount of voltage support available in the Southland area.
We will continue to monitor transmission constraints into the Lower South Island and investigate investment options as the need arises.

### 6.7.7.4 System Condition 4: light load

This system condition tests the effect of low load on the grid backbone. It represents a realistic summer night light load period and is designed to highlight possible high voltage issues. The specific assumptions for this system condition are:

- South Island trough summer night load
- very low HVDC transfers.

#### Summary of transmission constraint

The main concern during light load periods is high post-contingency voltages, particularly in the Upper South Island area. The high voltages are dependent on load power factor and voltage profiles across the South Island.

#### SC4: Upper South Island high voltage

The load north of the Waitaki Valley is not dominated by heavy industrial loads, making it highly changeable throughout the day with very low loads overnight, especially in summer. There are long transmission lines into the Upper South Island that produce significant amounts of reactive power during light load periods (increasing the voltage) and there is little generation to absorb reactive power (to reduce the voltage).

Over the years, the high voltage issue has continued to worsen, so we have increasingly needed to switch off transmission lines overnight to manage the issue. A variety of factors have exacerbated the high voltage issue such as an increasing proportion of distribution networks being under-grounded and the load characteristics generally becoming more capacitive.

Three dynamic voltage control plants north of the Waitaki Valley can be used to control voltages by absorbing reactive power during light load periods:

- two SVCs at Islington
- one STATCOM at Kikiwa.

Their combined reactive power absorption capacity is 185 Mvar. Generation in the Waitaki Valley can also be used to absorb some reactive power, which reduces loading on the SVCs at Islington but has very little effect further north.

#### What next?

We are studying investment options for managing high voltages during light load periods. Refer to section 6.6.2.3 for our enhancement approach.

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31 Cables are naturally more capacitive than overhead lines therefore they produce more reactive power during light loads.
6.8 HVDC link

The High Voltage Direct Current (HVDC) link connects the North and South Islands, providing:

- the North Island with access to the South Island’s significant hydro generation capacity, which can be important for supplying the North Island during peak winter periods
- the South Island with access to the North Island’s thermal generation, which is important for supplying the South Island during dry hydrological periods.

The HVDC link effectively reduces the need for extra generation investment in each island, facilitates price competition between all generation sources, and plays an important part in managing renewable energy sources.

6.8.1 HVDC link configuration

Figure 6-10 shows a simplified schematic of the HVDC link, which comprises:

- two ±350 kV thyristor bipole converters (Pole 2 and Pole 3), each rated 700 MW, with converter stations and protection and control systems at Benmore in the South Island and Haywards in the North Island
- two 350 kV bipolar transmission lines. These comprise a 535 km length from Benmore to Fighting Bay (on the shore of Cook Strait in the South Island) and a 37 km length from Haywards to Oteranga Bay (on the shore of Cook Strait in the North Island)
- three 350 kV, 500 MW, 40 km long undersea cables, with cable terminal stations at Fighting Bay and Oteranga Bay
- a land electrode at Bog Roy near Benmore in the South Island and a shore electrode at Te Hikowhenua near Haywards in the North Island
- AC filters to reduce harmonic distortion and provide static reactive support at both Benmore and Haywards
- eight synchronous condensers and a STATCOM at Haywards to supplement the dynamic reactive support available from the AC transmission system.
Figure 6-10: Existing HVDC link schematic
6.9 HVDC link enhancement approach

6.9.1 Possible future HVDC link to 2032

Figure 6-11 shows a simplified diagram for a possible expansion of the HVDC link to 1,400 MW north capacity. This configuration is based on potential enhancement approaches set out below.

Figure 6-11: Possible future HVDC link configuration

6.9.2 Enhancement approach

This section provides information about the transmission constraints and condition based risks we will investigate or mitigate over the next few years.

Issues likely requiring E&D base capex or Major Capex Project funded investment in the HVDC link over the next 10-15 years include:

- HVDC link’s submarine cable strategy, reliability, and capacity increase (6.9.2.1).

6.9.2.1 HVDC link cable strategy, reliability, and capacity increase

We are scheduling an investigation that will cover several issues that could impact the HVDC submarine cables. The issues will be considered together, because of the high cost and long lead times associated with any works involving submarine cables.

The investigation will cover the following elements:

- Analysis of the risk based condition of the existing cables. We will review their condition and use this information to develop a strategy to manage the condition-based risks, including the timing of cable replacement.
- HVDC link reliability requirements. The current focus of the HVDC link is on energy transfer, but future use may primarily be to provide reliability of supply to
the North Island. We will consider the future reliability requirements of the HVDC link, and in particular the submarine cables, given the potentially very long repair time of a cable fault.

A possible expansion of the HVDC link to 1,400 MW northward capacity. This could be required if the Tiwai Point aluminium smelter closed and large amounts of power needed to be transferred to the North Island. This expansion would involve installing:

- an additional (fourth) submarine cable and expanding the cable stations
- additional filters at both Benmore and Haywards
- additional dynamic reactive support at Haywards.

Timing for our investigation timing is driven by two factors: the need for information on the risk based condition of the cables (to support strategy development), and to support development of a strategy to manage a possible exit of the Tiwai aluminium smelter.

Enhancement approach:

- We anticipate starting an initial investigation towards the end of 2017
- If we determine that there is an economic need for a capacity upgrade this will be a Major Capex Proposal and form part of the GEIR. If both cable replacement and an upgrade are warranted, the works will be co-ordinated.

**Major Capex investments**

<table>
<thead>
<tr>
<th>Project Name</th>
<th>HVDC cable strategy, reliability and capacity increase</th>
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<tr>
<td>Project description:</td>
<td>Possible capacity increase, risk based replacement of existing cables, and improve link reliability.</td>
</tr>
<tr>
<td>Project’s state of completion</td>
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</tr>
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<td>OAA level completed:</td>
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<tr>
<td>Grid need date:</td>
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</tr>
<tr>
<td>Indicative cost [$ million]:</td>
<td>$300 for cable replacement, $150 (additional) for capacity increase,</td>
</tr>
<tr>
<td>Part of the GEIR?</td>
<td>Yes</td>
</tr>
</tbody>
</table>

### 6.10 HVDC link asset capability and management

This section provides existing capability information details for the HVDC link and sets out significant upcoming work on the HVDC link.

#### 6.10.1 Changes since the 2015 Transmission Planning Report

The only change since the 2015 TPR is the modification of the HVDC link controls, during 2016, to allow configurable unbalanced operation.

#### 6.10.2 HVDC capacity

The nominal rating of the Pole 2 converter is 560 MW, with a continuous overload of 700 MW. However, the nominal end-to-end capacity of Pole 2 is limited to 500 MW by the rating of the single HVDC cable connected to the pole.

The nominal rating of the Pole 3 converter is 700 MW, with a continuous overload of at least 770 MW within the design ambient temperature range and with all cooling
systems available. There are two 500 MW HVDC cables connected to Pole 3, so the nominal end-to-end capacity is 700 MW.

The HVDC overhead transmission line has a nominal rating of 700 MW per pole.

The HVDC link as a whole has a capacity of up to 1,000 MW in balanced 500/500 MW bipole operation and up to 1,200 MW\(^{32}\) in unbalanced 500/700 MW bipole operation.

To reduce the system reserves required to cover a trip of Pole 3, the HVDC link controls were modified. When this control is used, Pole 2 is usually limited to 420 MW. Pole 3 then meets the rest of the bipole capability, so 1000 MW is sent as 420/580 MW and 1200 MW is sent as 420/780 MW.

**Issue**

The possible retirement of the Tiwai Point aluminium smelter and the announced retirement of the remaining Huntly Rankine units in 2022 may result in an increase in the need to transfer power from the South Island to the North Island.

Following upgrades in the HVAC networks in the South and North Island’s, the HVDC link’s capacity will limit the ability to transfer power to the North Island. This will increase the risk of spilling in the South Island hydro lakes which can have a significant opportunity cost to the New Zealand.

**What next?**

The HVDC submarine cables are also nearing their risk based condition replacement criteria. We will coordinate our investigation for the cable’s risk based condition replacement and the need to upgrade the HVDC link’s capacity. See section 6.9.2.1 for our approach.

**6.10.2.2 HVDC reserves**

The HVDC link capacity can be limited by the availability of instantaneous reserves in the AC system to cover for a pole or bipole outage. In bipole operation, if one pole fails the remaining pole can increase its power transfer to provide partial or full self-cover depending on pre-fault power flow on the remaining pole.

To assist with the reserve cover, both Pole 2 and Pole 3 have short-term ratings higher than their nominal ratings to reduce the overall reserve requirements. The duration of the short-term ratings depends on the pre-contingency loading (temperature) of equipment and the post-contingency loading, and may be available for several seconds to several minutes.

The Pole 2 short-term capacity with a single DC cable is 2400 A for five seconds and is then limited by the maximum temperature of the single cable connected to the pole. From a constant pre-fault loading of 420 MW the 15 minute overload capability is 700 MW. The HVDC controls:

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\(^{32}\) This capacity is not always available. Power transfer may be limited by the capacity of the AC transmission systems in the North and South Islands (see sections 6.4 and 6.7, respectively, for more information). In particular, maximum south transfer capability varies significantly with demand in the Wellington region because of AC system limitations or lack of offered instantaneous reserves.
• calculate the maximum current that the cable can sustain for 15 minutes without exceeding the cable’s design temperature limit, based on its design parameters and its pre-fault loading
• reduce Pole 2 power transfer to 500 MW when the 15 minute overload period has expired or if the design temperature is reached.

The Pole 3 short-term capacity is limited by either the rating of the converter (1000 MW for 30 minutes), or the rating of the other AC or DC equipment (for example, the overhead transmission line, smoothing reactor or converter transformer). The HVDC controls:

• measure the temperatures in the Pole 3 converter equipment and calculate the line’s temperature based on its design parameters
• will reduce Pole 3 power transfer to the maximum continuous power capability after 30 minutes of operation above this value.

The maximum continuous power capability of Pole 3 is in the 700–840 MW range, and depends on the ambient temperature and the cooling systems that are available. 780 MW is available up to an ambient temperature of 31.4 degrees at Benmore with redundant cooling systems available.

No self-cover is possible in monopolar operation (with only one pole in service) or for a bipole trip.

6.10.2.3 Transient overvoltage

There will be a temporary or transient overvoltage (TOV) following a bipole trip. The transient recovery voltage is limited at Haywards by the synchronous condensers and STATCOM. However, at times the HVDC power transfer may need to be limited to prevent an excessive transient recovery voltage following a bipole trip.

6.10.2.4 HVDC power limits

The HVDC controls will automatically reduce HVDC capability (i.e. apply power limits) for equipment outages in the North and South Island AC transmission systems to:

• ensure stable operation of the HVDC link
• ensure harmonic performance requirements are met
• prevent AC system over voltages during fault events
• reduce or prevent overloading of AC transmission system circuits.

6.10.2.5 HVDC runbacks

The HVDC controls will automatically reduce HVDC transfer for certain system conditions. These runbacks are usually 100 MW reductions in the power transfer and are initiated when reactive power margins have been eroded, when AC system voltages are below the required levels for a sustained period, or when AC system equipment overloading is detected.

The HVDC controls also allow the transfer of reserves through the national instantaneous reserves market and of frequency keeping between the North and South Islands.

The HVDC controls are flexible, and additional control functions can be implemented in future if required. However, extensive testing will be required before any new
control features are implemented. To assist with this, we have a Real Time Digital Simulator (RTDS) to represent the AC transmission system, interfaced to a complete spare HVDC control hardware suite.

### 6.10.3 HVDC significant upcoming work

We look for opportunities to integrate our capital project and maintenance works to enable system issues to be resolved, if possible, when assets are replaced or refurbished. Significant upcoming work\(^{33}\) proposed for the HVDC link during the next 15 years that may significantly impact related system issues or connected parties is discussed below.

#### 6.10.3.1 HVDC undersea cable condition-based risk assessment

**Issue**

The existing undersea cables are expected to reach replacement criteria in the mid to late 2020's. Cable failures will reduce HVDC capacity and take an extended time to repair or replace.

**What next?**

We will coordinate our investigation into the cables' condition-based risk and our investigation to possible increase in the HVDC link’s capacity. See section 6.9.2.1 for our approach.

#### 6.10.3.2 HVDC Pole 2 mid-life replacement of selected components

**Issue**

The Pole 2 valve base electronics system, fiber optic cables, and snubber capacitors will reach their 30 year life span\(^{34}\) in 2022, which is also close to the mid-life of Pole 2. It is necessary to replace these end of life components as operating them beyond their recommended life will increase the risk of failures which impacts the reliability and availability of the HVDC link.

Due to extensive outage requirements, this work must be undertaken prior to the planned North Island thermal generation decommissionings (scheduled for 2022) and possible exit of the Tiwai Point aluminium smelter, which could occur at any time with a year's notice.

**What next?**

An investigation is underway to determine the best timing for the asset end of life replacement work.

A second tranche of work is proposed for the next 5-10 years to upgrade some of the oil-filled HVDC bushings and capacitors associated with Pole 2.

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\(^{33}\) This may include replacement of the asset due to its risk-based condition assessment.

\(^{34}\) These components life span is recommended by the manufacturer.
6.10.3.3 Oteranga Bay–Haywards–A line reconductoring

**Issue**

The conductors on a section of the Oteranga Bay–Haywards transmission line will reach our risk based condition replacement criteria within the next 3-5 years. Failure of the conductor will cause an unplanned outage and disruption to the electricity market, as well as presenting a safety risk.

**What next?**

We are investigating the reconductoring of a section of the Oteranga Bay–Haywards transmission line. We expect to submit a listed project application to the Commerce Commission in 2018.

6.10.3.4 HVDC controls replacement

**Issue**

The HVDC control systems have a shorter life span (around 15-20 years) than the main HVDC converter equipment because of obsolescence. At least one full replacement of the control systems is required during the life of the converter equipment. The HVDC controls and protection for Pole 2 – excluding the valve-based electronics for thyristor control – were replaced in 2013. The Pole 3 controls and the bipole control systems were installed in 2013.

**What next?**

We will investigate the timing and need for the replacement of the control systems in 10-15 years.