

BUNNYTHORPE–HAYWARDS CONDUCTOR REPLACEMENT

Major Capex Proposal

Attachment D POWER SYSTEMS ANALYSIS REPORT

Keeping the energy flowing



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1| Purpose

This document is the Power System Analysis report for the Bunnythorpe–Haywards A and B lines conductor replacement investment proposal.

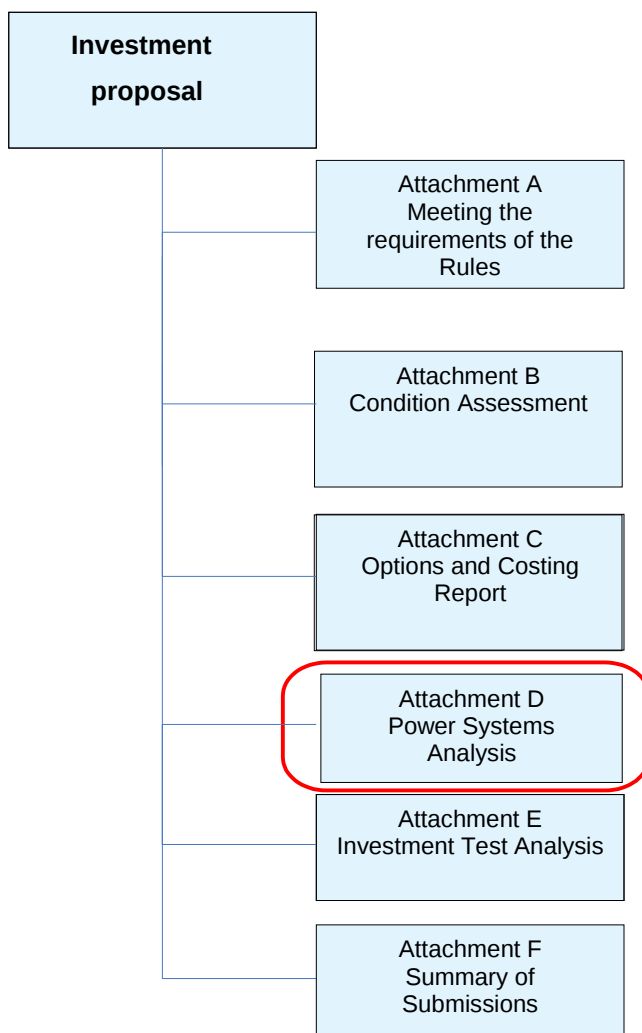
1.1 Purpose

The purpose of this report is to:

- set out the results of the power flow analysis carried out on the short-listed options
- test the feasibility of the options and to calculate the network constraint equations which to be used in the economic modelling

1.2 Document Structure

This report forms part of the Bunnythorpe–Haywards A and B lines conductor replacement investment proposal, as set out in the diagram below:



2| Executive Summary

In this report we set out the results of the power flow analysis carried out on the short-listed options. In this case the purpose of the power flow analysis is to test the feasibility of the options and to calculate the network constraint equations which were used in the economic modelling, summarised in section 5 of the main document.

The conductor being replaced is Goat ACSR/GZ. This is a type of conductor no longer available. The nearest modern equivalent conductor is Goat ACSR/AC which has a slightly higher capacity rating.¹ As such, Goat ACSR/AC is our reference case option. Our analysis considered the following short list of options:

1. Goat ACSR/AC at 80°C. This is the modern equivalent option, but with a slightly higher capacity of approximately 12 MVA with summer ratings and 13 MVA with winter ratings compared to the old GZ conductor. This is the reference case.
2. Zebra ACSR/AC at 65°C. This keeps a similar capacity as the reference case option but is a slightly larger and more efficient conductor. Compared with Goat ACSR/AC at 80°C, there is a loss of capacity of approximately 3 MVA with summer ratings and a gain of approximately 22 MVA with winter ratings.
3. Zebra ACSR/AC at 75°C. Compared with the reference case option, there is a gain of approximately 47 MVA with summer ratings and a gain of approximately 55 MVA with winter ratings.
4. Zebra ACSR/AC at 85°C. Compared with the reference case option, there is a gain of approximately 80 MVA with summer ratings and a gain of approximately 84 MVA with winter ratings.

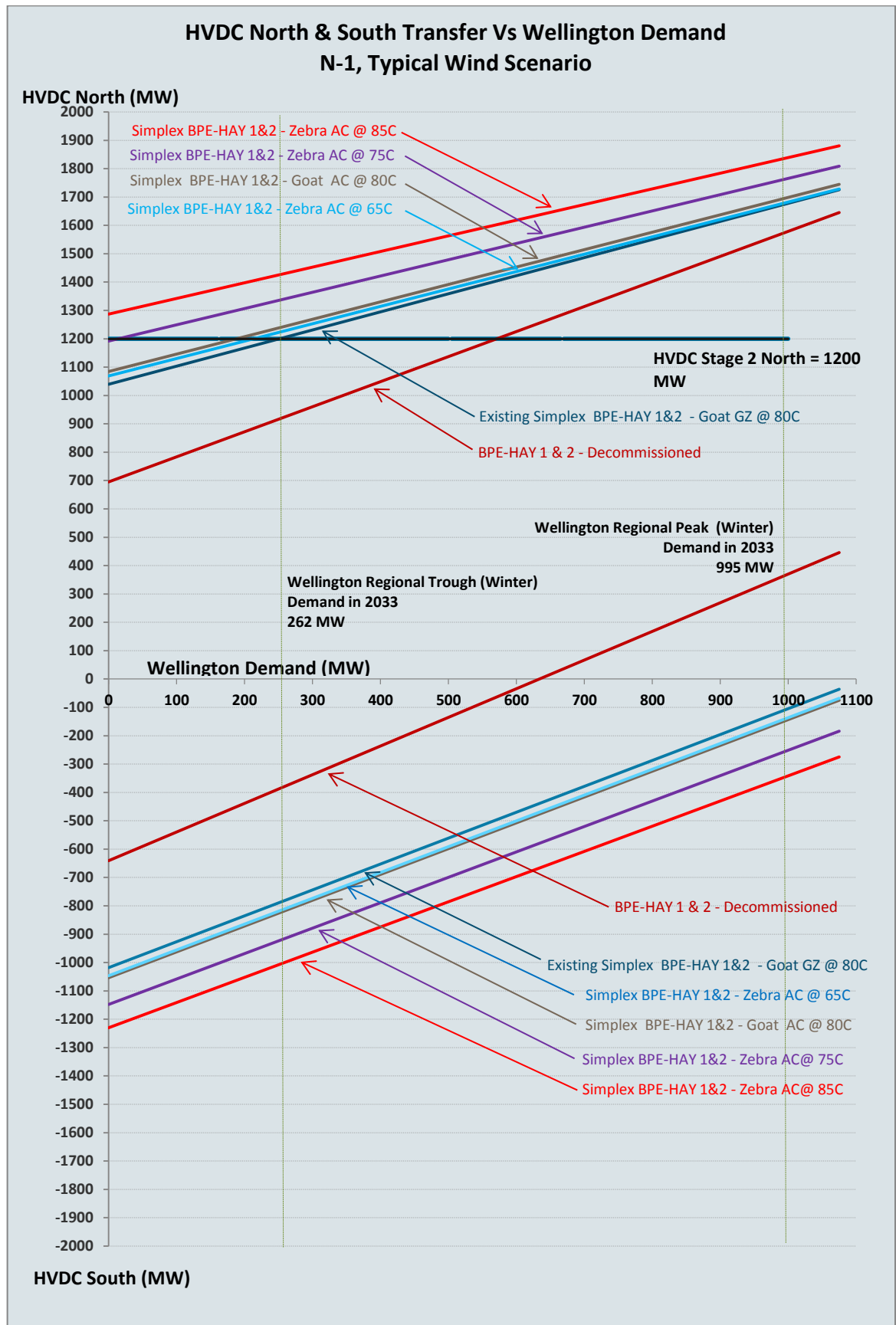
The study assumes that the Paraparaumu substation is connected to the Bunnythorpe–Haywards–A and B lines, as per the Paraparaumu 220 kV Upgrade Project presently underway.

Figure 1 shows the system thermal limits that arise with the short-listed options. The “constraint” lines are shown relative to the load in Wellington region and HVDC transfer levels. The analysis assumes the network topology remains as it exists today. Operational measures such as the future use of variable line ratings have not been assessed. Figure 1 also shows the effect of decommissioning the Bunnythorpe–Haywards A and B lines².

¹ Modern equivalent Goat has a summer/winter rating of 319/348 versus 307/335MVA for GZ conductor

² This assumed the operation of a System Protection Scheme (SPS) on the 110kV circuits between Upper Hutt and Woodville substations.

Figure 1 - Constraint limits for the short list options



3| Introduction

The Bunnythorpe–Haywards–A and B lines form part of the transmission backbone to:

- supply power for North Island demand (north of Bunnythorpe) during HVDC north transfer; and
- supply Wellington and South Island demand during dry years (HVDC south transfer).

3.1 The existing system

The existing transmission network between Bunnythorpe and Haywards is shown geographically in Figure 2 and the 220 kV transmission network is shown schematically in Figure 3.

Figure 2: Wellington 220 kV and 110 kV network

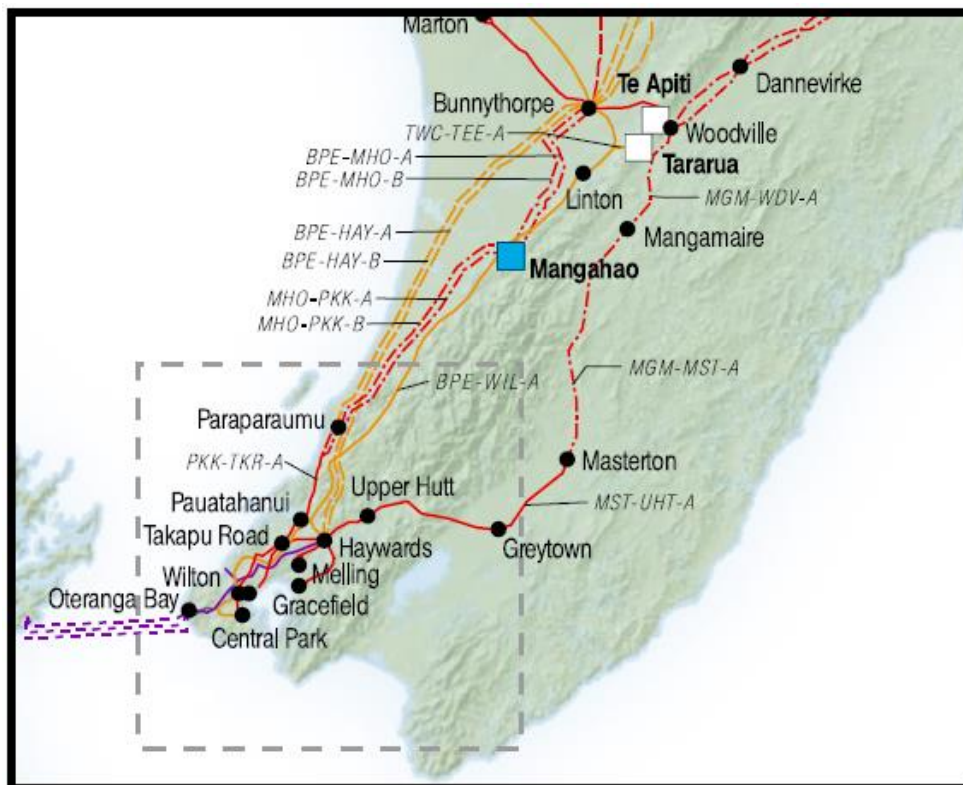
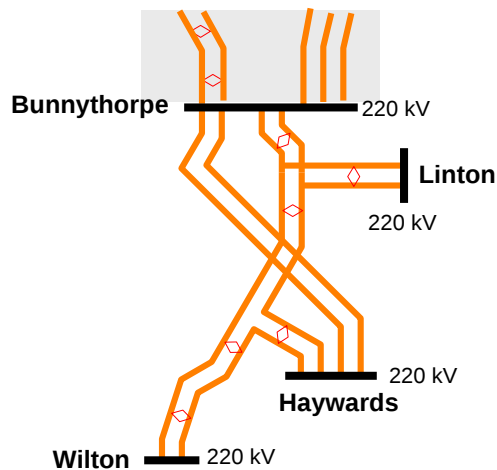


Figure 3: 220 kV Circuits between Bunnythorpe and Haywards



The network between Bunnythorpe and Haywards comprises the following:

- two single circuit lines connecting directly between Bunnythorpe and Haywards (Bunnythorpe–Haywards–A and B); and
- the Bunnythorpe–Wilton–A line that runs in parallel to the Bunnythorpe–Haywards–A and B lines, connecting Bunnythorpe to Wilton (in Wellington). The Bunnythorpe–Wilton–A line is made up of two circuits, on double circuit towers. On route between Bunnythorpe and Wilton they connect through Linton (near Bunnythorpe) and Haywards substation.

The magnitude and direction of power flow on these lines depends on the direction (north or south) and quantity of HVDC transfer at Haywards, the demand in Wellington and the quantity of wind generation within the Wellington region.

The two circuits within the Bunnythorpe–Wilton–A line have greater capacity than the Bunnythorpe–Haywards lines. They supply power into the Wellington region via the Wilton–T8 interconnecting transformer and the Haywards interconnecting transformers. The Bunnythorpe–Wilton line is not part of this study.

Table 3-1 lists the individual circuit ratings.

Table 3-1: Details of circuits between Bunnythorpe and Haywards

Line	Circuit(s)	Conductor	Conductor Rating	
			Summer Rating	Winter Rating
Bunnythorpe–Haywards–A	BPE–HAY–1	Simplex Goat ACSR-GZ @ 80oC	307 MVA, 807 A	335 MVA, 880 A
Bunnythorpe–Haywards–B	BPE–HAY–2	Simplex Goat ACSR-GZ @ 80oC	307 MVA, 807 A	335 MVA, 880 A
Bunnythorpe–Wilton–A	HAY–WIL–1 BPE–LTN–WIL–1 BPE–LTN–HAY–3	Duplex Zebra ACSR-GZ @ 75 oC	695 MVA, 1822 A	765 MVA, 2006 A

The two key constraints that limit power flow are:

- The capacity of the Bunnythorpe–Haywards–1 and 2 circuits (A and B lines) limits HVDC north transfer to a maximum of 1140 MW during trough Wellington demand in summer. The capacity of the Bunnythorpe–Haywards–1 and 2 circuits does not limit HVDC north transfer during regional trough demand in winter after stage 2 of the HVDC upgrade is completed, allowing up to 1200 MW of HVDC north transfer. Without additional wind generation in Wellington region the capacity limit on the Bunnythorpe–Haywards 1 and 2 circuits is unlikely to be reached.
- The Bunnythorpe–Haywards–1 and 2 circuits can on occasion constrain HVDC south transfer to a maximum of 402/559 MW (winter/summer) during peak Wellington regional demand and to a maximum of 913/867 MW (winter/summer) during trough Wellington regional demand. However, this constraint can only be reached during Wellington peak demand if sufficient generation is operating in the lower North Island. HVDC constraints during times of light Wellington demand are subject to other technical constraints such as reserves, overvoltage etc.

3.2 Short List of Options

The Short List of Options (see Attachment B: Options and Costing Report) is found in Table 3-2.

Table 3-2 Short List of Options

Short List Option
Simplex Goat ACSR/AC at 80°C
Simplex Zebra ACSR/AC at 65°C
Simplex Zebra ACSR/AC at 75°C
Simplex Zebra ACSR/AC at 85°C

4| Power flow analysis of options

We have used power flow analysis to study the capability of the Bunnythorpe–Haywards A and B lines with each short-listed option.

To put a boundary around the study there are some aspects of the power flow analysis that are outside the scope of this study:

- Potential wind farm development in the Wellington region. This study focuses only on committed and in-service wind farms. However, any wind farm development connected directly into the Wellington load area will act as a net reduction in the load. The impact of the additional wind generation is covered by assessing the impact of different levels of Wellington demand.
- The study does not address any of the network north of Bunnythorpe. Anything north of Bunnythorpe is independent of the proposed conductor replacement.

4.1 Assumptions

To set up the model for power flow analysis we need to make certain assumptions about the power system. These are described below.

4.1.1 Study Timeframe

The study period for the power flow analysis is from 2013 to 2033.

4.1.2 Wind Generation Contribution Scenarios

The study considered three wind generation contribution scenarios:

- 1) Typical Wind Contribution: As wind generation is unpredictable, and often does not coincide with peak demand periods, the wind contribution is assumed to be 20% of the maximum output capacity³.
- 2) No Wind Contribution: This is a sensitivity study where key wind generation (see Table 4-1) is turned off.
- 3) Maximum Wind Contribution: This is a sensitivity study where key wind generation (see Table 4-1) is operating at full output.

Table 4-1 lists the key wind generation that affects the level of power flows in the Bunnythorpe–Haywards A and B lines.

³ Electricity Commission, Statement of Opportunities 2009, wind generation assumption for peak demand periods.

Table 4-1: Key Wind Generation

Name	Grid Injection Point	Installed capacity (MW)
Te Rere Hau	Linton	33.5
Tararua Wind North & South	Linton	68
Tararua Wind Central	Linton	90
Te Apiti	Woodville	90
West Wind	Central Park	144
Mill Creek	Wilton	60

4.1.3 Demand

The study is based on the 2013 Annual Planning Report (APR) demand forecast. The Wellington regional peak demand during winter is forecast to grow on average by 1.6% annually over the next 20 years, from 756 MW in 2013 to 995 MW by 2033. The study uses the winter and summer regional peak and regional trough diversities.

4.1.4 Voltage Support

Presently, all voltage support in the Wellington region is provided by both the HVDC reactive plant at Haywards substation and by West Wind. Table 4-2 lists the reactive plant at Haywards substation with reference to the two stages of the HVDC Pole 3 project.

Table 4-2: Reactive plant at Haywards substation including new plant of the HVDC Pole 3 project

HVDC Development Stages	Year	Reactive Support at Haywards Substation
Stage 1	2013	Pole 2 filters 3 and 4 (2 x 106.3 MVar). Ex Pole 1 condensers, C7 – C10 (relocated to 110 kV bus) Pole 2 condensers, C1 – C4 2 x 40 Mvar shunt reactors 2 x 60 MVar filters 1 x 49 MVar filter 2 x 16 Mvar capacitor (110 kV)
Stage 2	2013	As above, plus Dynamic reactive device (1 x +/- 60 MVar Statcom).

We have assumed the reactive plant listed in Table 4-2 maintains the Haywards 220 kV bus voltage at 227.7 kV (or 1.035 pu) and there is sufficient reactive support to maintain the Bunnythorpe 220 kV bus voltage at 231 kV (or 1.05 pu). This means that Bunnythorpe is maintained as a strong bus by the rest of the system north of Bunnythorpe.

4.1.5 HVDC Transfer levels

Pole 1 is assumed to not be available in all cases. Maximum HVDC transfer is assumed to be 1000/750 MW (north/south) respectively when stage 1 is commissioned (December 2013) and 1200/850 MW (north/south) when stage 2 is commissioned.

4.1.6 System Configuration

The system configuration used is the existing configuration as at November 2010. The following upgrades are included in the Wellington regional network:

- Replacing the existing conductors (from Pigeon ACSR/GZ @ 50°C to Nobelium AAAC @ 75°C) on Mangamaire–Masterton–Woodville–A line by 2011.

- Paraparaumu substation is teed off the Bunnythorpe-Haywards–A and B lines. The tee point is located approximately 23 km and 96 km from Haywards and Bunnythorpe substations respectively. This 220 kV connection is expected to be completed in early 2015.

There are no other committed plans to upgrade the Wellington regional network.

4.1.7 Power Systems Analysis Software

DIgSILENT PowerFactory version 14.0.520 was used to carry out the study. The study used the APR 2010 base case.

4.1.8 Component Ratings

Transmission lines are limited to 100% of their respective winter or summer rating with no short term overload capability.

4.2 The study methodology

We used the following methodology to conduct the power flow analysis for each short listed option:

- 1) Vary the HVDC transfer in both north and south directions during both peak and low demand periods with “typical” contributions from wind generators.
- 2) Identify when the thermal capacity limits on the lines between Bunnythorpe and Haywards for HVDC north and south transfer under an N-1 security standard would be exceeded.
- 3) Limit HVDC transfer to ensure post contingent loading on the AC transmission lines remain within 100% of their thermal capacity limits.
- 4) Repeat steps 1 – 3 for wind contribution sensitivity studies (i.e. no wind generation contribution and maximum wind generation contribution).

5| Results of power flow analysis

We have developed three graphs (Figure 4 to Figure 6) to summarise the results of the analysis for each short list option.

With the HVDC transfer capacity at 1200 MW (when stage 2 is completed), the capacity of the Bunnythorpe–Haywards A and B lines will only constrain the HVDC for north transfer during times of light Wellington demand or high Lower North Island wind generation.

Figure 4 shows that the reference case option (Goat ACSR/AC at 80°C) and the Zebra ACSR/AC at 65°C conductor option only constrain HVDC north transfer if the net Wellington demand is less than approximately 200 MW. We note that high Wellington wind generation will have the same effect of lowering the net Wellington load. This is because the key wind generation in the Lower North Island, i.e. West Wind and the Tararua wind farms, reduce the need for power flow through the Haywards interconnecting transformers to supply the Wellington 110 kV demand during HVDC north transfer. This reduces the level of HVDC north transfer that can be delivered before the Bunnythorpe–Haywards A or B lines constrain.

Figure 4 demonstrates that the conductor replacement options progressively reduce the constraint on HVDC north transfer. There is no longer any constraint with a Zebra ACSR/AC at 75 °C conductor.

The capacity of the Bunnythorpe–Haywards A and B lines may constrain the HVDC south transfer during times of high Wellington demand or low Lower North Island wind generation. The conductor replacement options progressively reduce the constraint on HVDC south transfer.

The graphs also show that with higher wind generation in the Lower North Island the higher the HVDC south transfer capability. During HVDC south transfer, the higher wind generation adds to the amount of power flowing through the 220 kV lines allowing for a higher HVDC south transfer.

Hence, the addition of any new wind generation south of Bunnythorpe may:

- increase the power flow through the Bunnythorpe–Haywards A and B lines during HVDC north transfer causing the HVDC to be more constrained; and
- decrease the power flow through the Bunnythorpe–Haywards A and B lines during HVDC south transfer causing the HVDC to be less constrained.

The short-listed options can be further compared by looking at the differences in HVDC transfer capability. This has been done by comparing the HVDC South Transfer capability of each option during the 2033 Wellington Peak Demand when there is no wind contribution from the existing wind farms.

Table 5-1: Comparison of the short listed options with the reference case option

Short List Options	HVDC South Capability (MW) for short listed options		Gain/Loss between reference case and other options (MW)	
	Winter	Summer	Winter	Summer
Goat ACSR/AC 80°C – Modern equivalent reference case option	177	404	-	-

Short List Options	HVDC South Capability (MW) for short listed options		Gain/Loss between reference case and other options (MW)	
	Winter	Summer	Winter	Summer
Zebra ACSR/AC 65°C	205	397	28	-7
Zebra ACSR/AC 75°C	293	508	116	104
Zebra ACSR/AC 85°C	365	596	188	192

The comparison shows that the Zebra ACSR/AC at 65°C option has a similar capacity to the Goat ACSR/AC at 80°C (reference case option). There is a small loss of HVDC transfer capability with summer ratings of approximately -7 MW but a gain of approximately 28 MW with winter ratings. The table clearly shows the progressively higher gain in HVDC transfer capability with the higher temperature Zebra conductor options compared to the reference case option. For example, with Zebra ACSR/AC at 75°C, there is a gain of approximately 116 MW in HVDC transfer capability in winter compared to the reference case option of Goat ACSR/AC at 80°C

Graphs for typical wind, no wind and high wind cases follow.

Figure 4 - Constraints with typical wind contribution

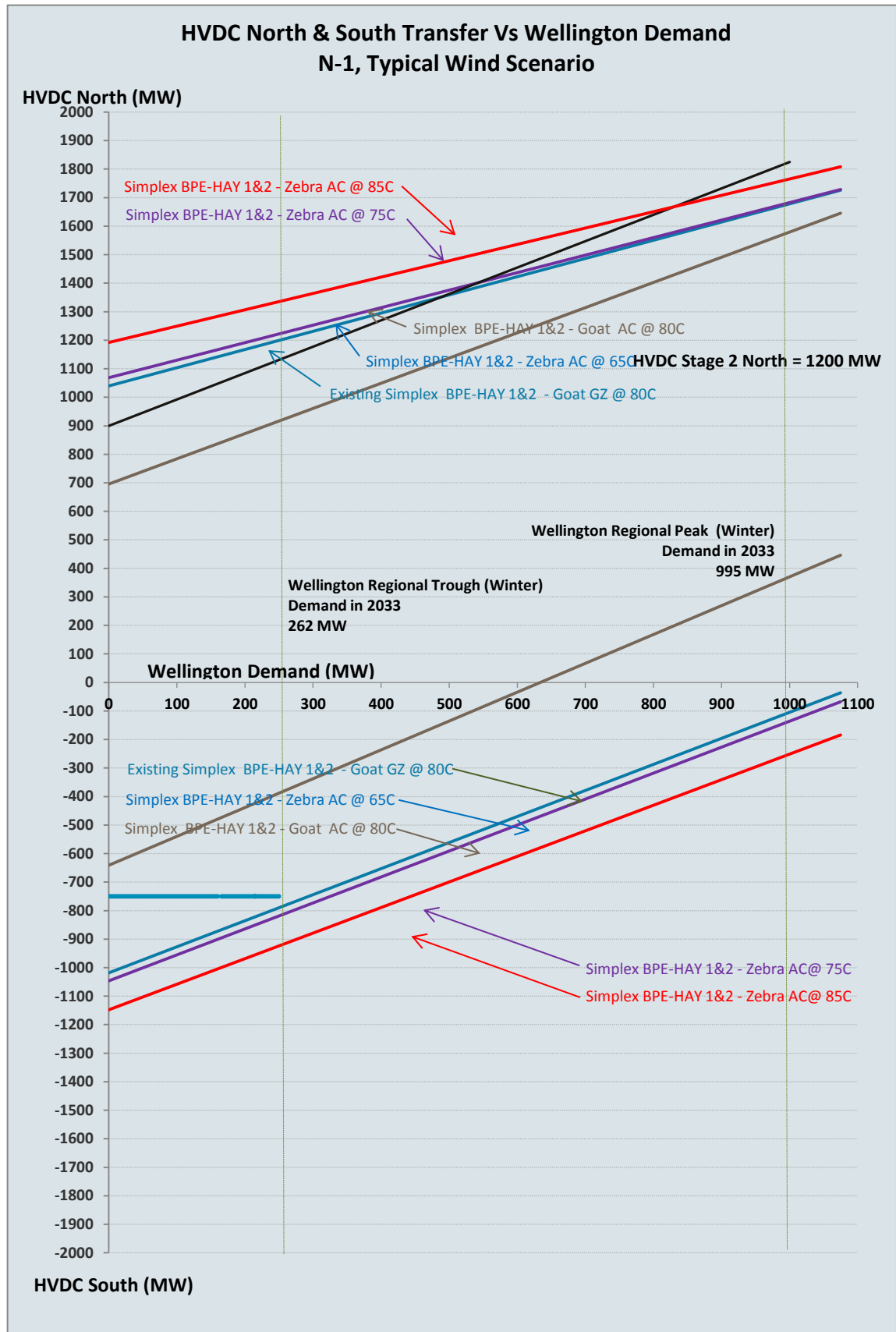


Figure 5 - Constraints with no wind contribution

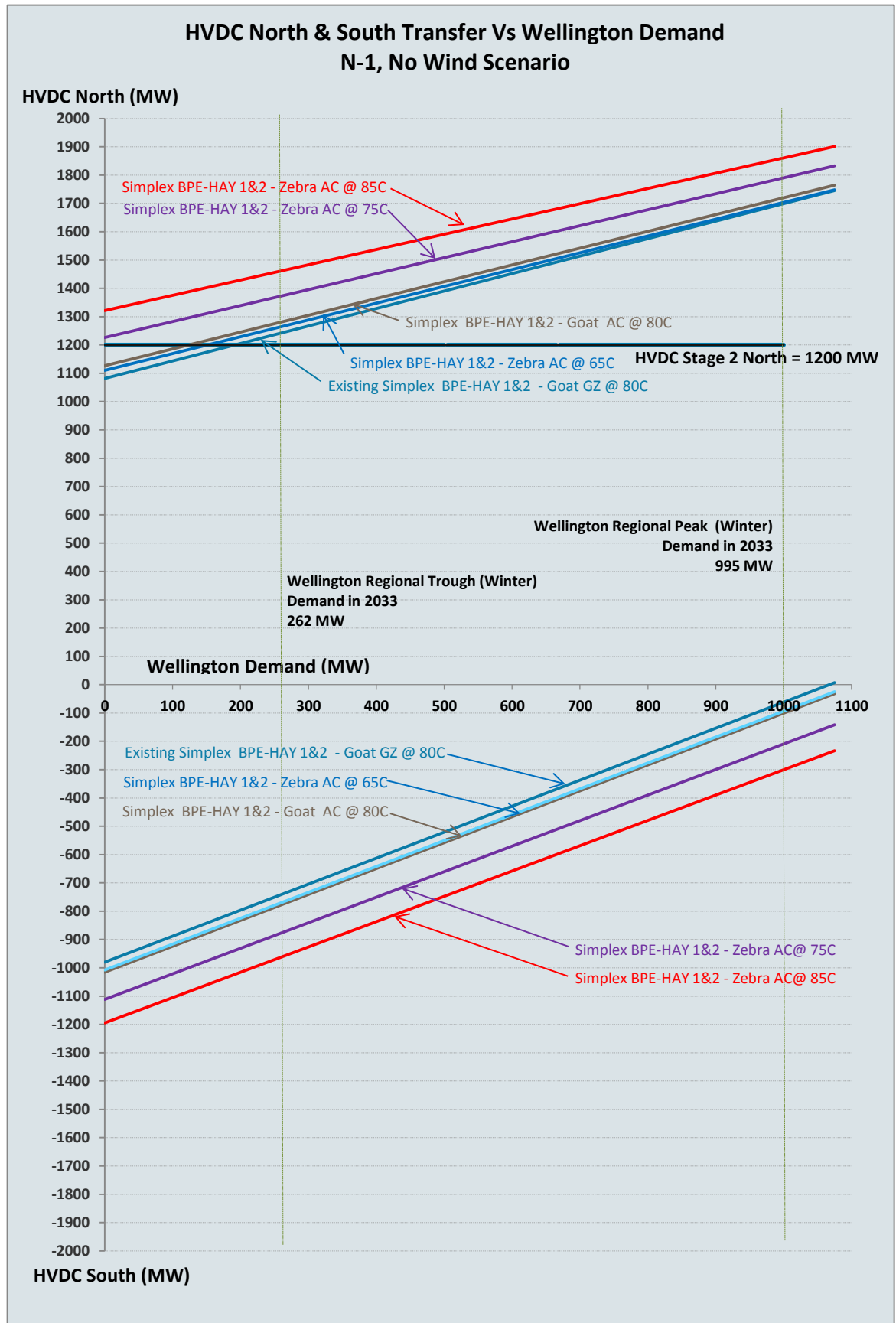


Figure 6 - Constraints with Maximum Wind Contribution

