UPPER SOUTH ISLAND RELIABILITY MCP STAGE 1

ATTACHMENT B TECHNICAL ANALYSIS

Transpower New Zealand Limited

June 2012

Keeping the energy flowing

TRANSPOWER

TABLE OF CONTENTS

1| Executive Summary

Purpose of this document

This report documents the power system analysis for Transpower's USI Grid Upgrade Plans for reactive support.

Purpose of the analysis

The purpose of the analysis is to determine the need dates for new dynamic and static reactive support and thermal upgrades.

Need summary

By winter 2014 the USI network is at risk of cascade failure and voltage collapse. The figure below shows the USI dynamic voltage response in winter 2013 and 2014 respectively. This shows how a small increase in load results in a dramatically different dynamic response, changing from acceptable voltage recovery to voltage collapse which is unacceptable.

ES Figure 1: USI dynamic voltage performance for credible contingency event

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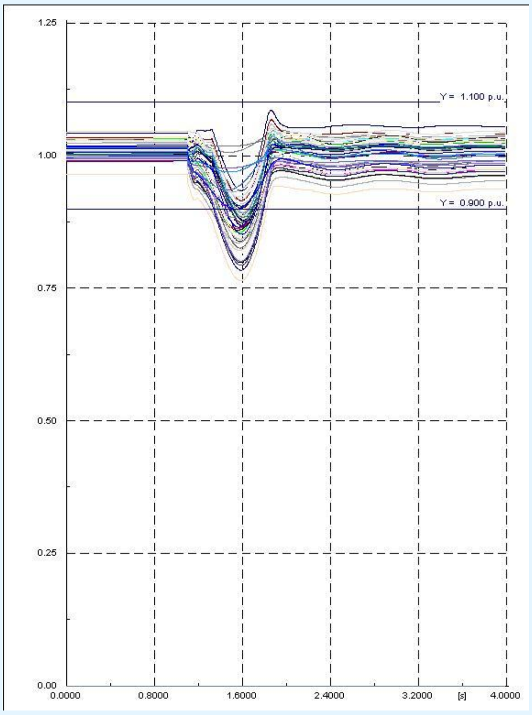
<tr>
<td>Winter 2013 – acceptable voltage recovery


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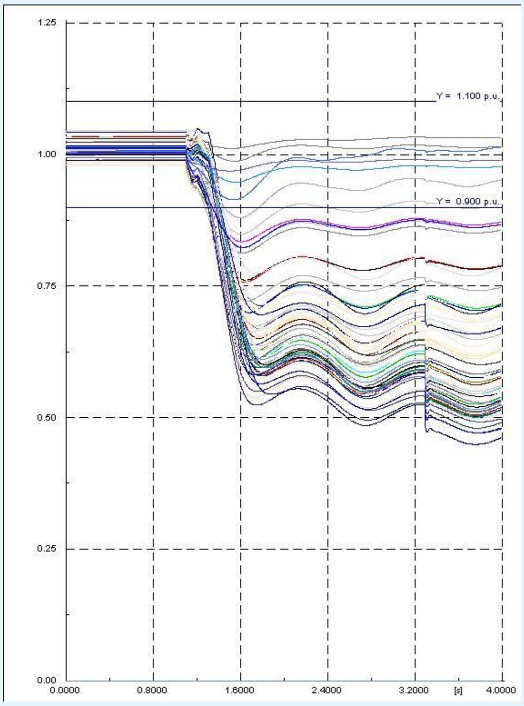
<td>Winter 2014 – voltage collapse, not acceptable


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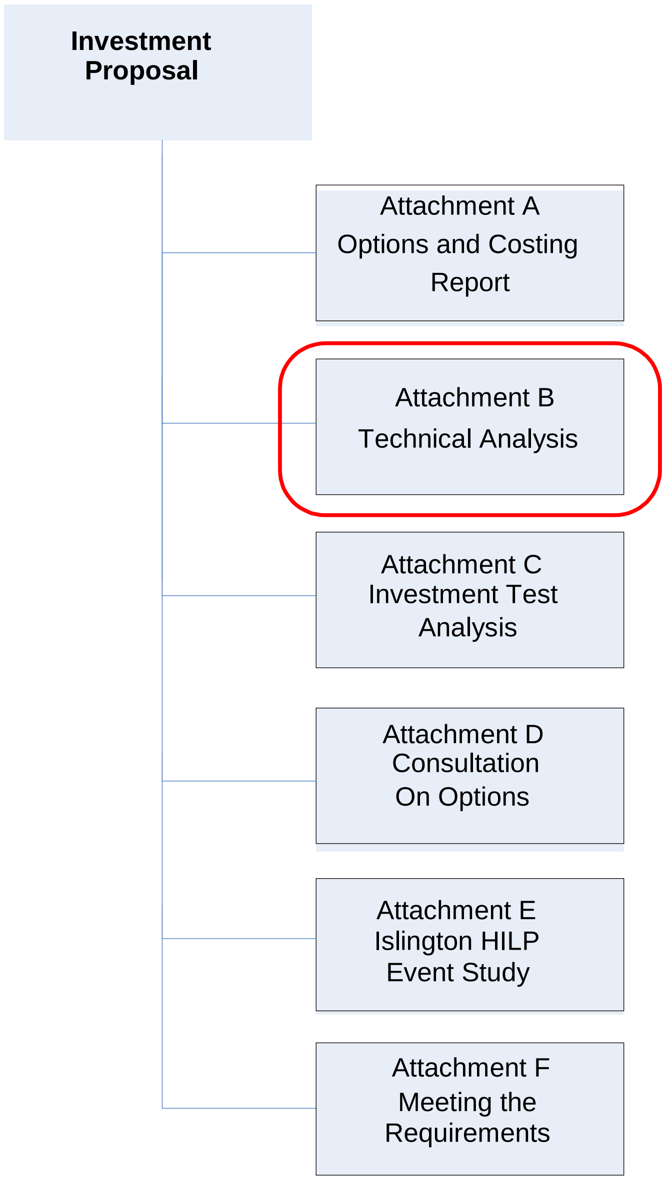
In addition, the need analysis shows that additional capacitive static reactive support is required by winter 2017. After that, studies indicate 75 Mvars additional static support is required approximately every 4 years.

We’ve also looked at the thermal loading on transmission circuits into Christchurch. The need date for thermal upgrades between Waitaki valley and Islington is around 2028 if no new generation is commissioned in the upper South Island prior to that.

2| Introduction

2.1 Document structure



2.2 Upper South Island Overview

Figure 2-1 shows the geographical area of the USI north of the Waitaki Valley. The loads above a hypothetical line drawn between Twizel and Timaru are included in the USI load area. Timaru is included in the USI region but Twizel is excluded.

Figure 2-1: USI geographic region.

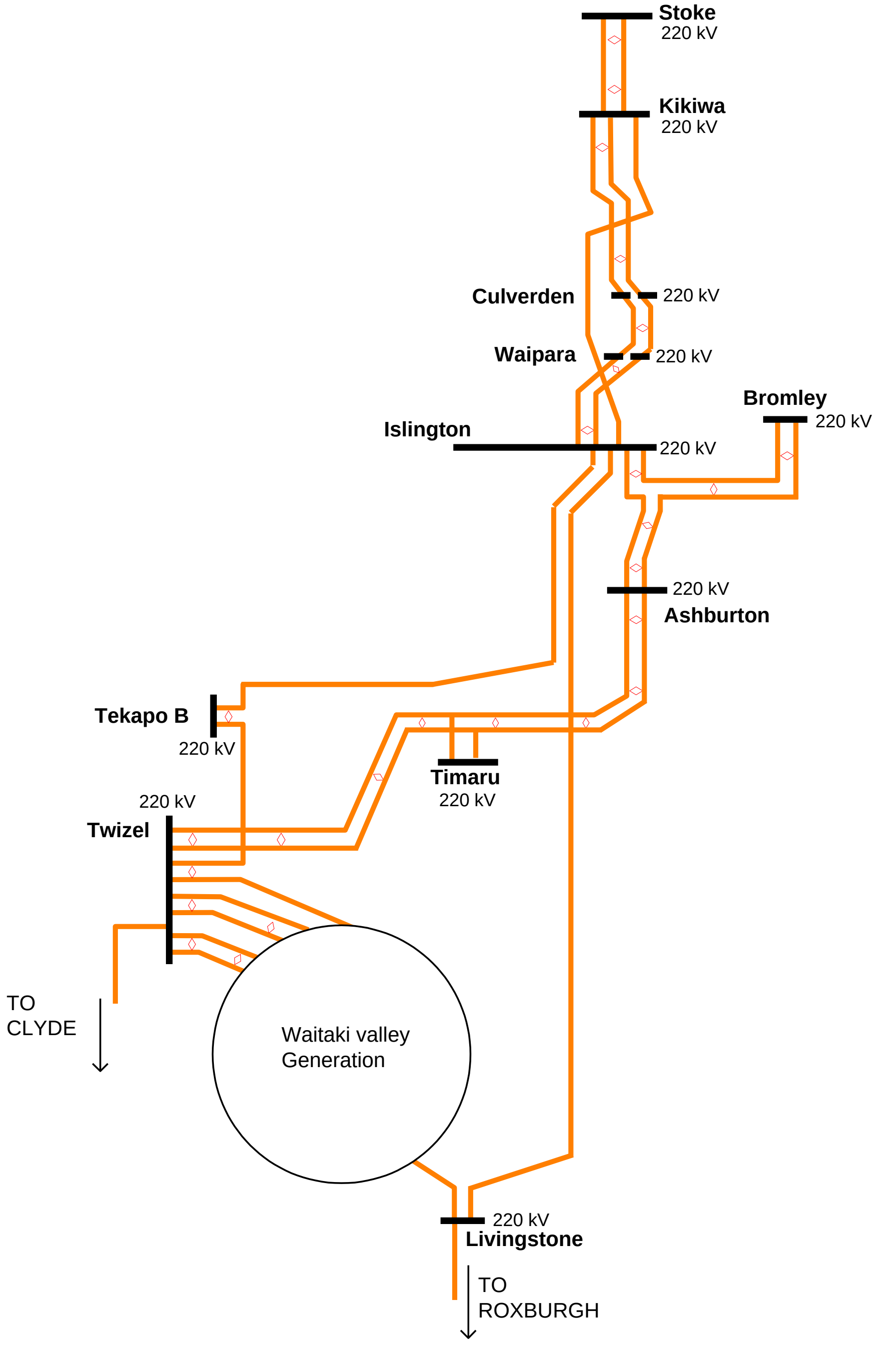
The USI region consumes a major portion of the generation in the South Island and is supplied by the 220 kV network from the Waitaki Valley in the middle of the South Island.

More specifically, four 220 kV circuits connecting to Islington supply the upper half of the South Island as shown in Figure 2-2. They are:

- a single circuit line from Benmore to Islington
- a single circuit line from Roxburgh to Islington
- a double circuit line from Twizel to Christchurch

Figure 2-2: USI 220 kV transmission network as of March 2012.

(Note: A list of substation abbreviations for the USI is given in an Appendix A)



Three 220 kV circuits from Islington to Kikiwa supply the entire Nelson–Marlborough region and part of the West Coast region. The West Coast region is also supplied by two smaller 66 kV circuits from Islington to Hororata. However, their contribution is negligible compared to the 220 kV circuits.

There are also two 220 kV circuits from Kikiwa north towards Stoke. Stoke is also supplied via the 110 kV network from Kikiwa.

2.2.1 Circuit ratings

Table 2-1 lists the transmission lines between the Waitaki Valley and Christchurch, along with their summer, shoulder and winter ratings.

Table 2-1: Conductor thermal ratings of the 220 kV Christchurch - Waitaki Valley circuits.

Circuit	Conductor	Configuration	Temp. (ºC)	Length (km)	Rating, MVA		
					Summer	**Shoulder**	**Winter**
Ashburton – Bromley	Zebra	Duplex	75	92.7	694	730	764[1]
Ashburton – Islington	Zebra	Duplex	75	79.8	694	730	764[2]
Ashburton - Opihi 1[6]	Zebra	Duplex	75	69.2	694	730	764
Ashburton - Opihi 2[6]	Zebra	Duplex	75	69.2	694	730	764[1]
Bromley – Islington	Zebra	Duplex	75	28.1	694	730	764[2]
Islington – Livingstone	Goat	Duplex	50/75[3]	283.3	404	451	493[4]
Islington – Tekapo B	Goat	Duplex	70	213.6	557	589	620[5]
Opihi - Timaru 1[6]	Zebra	Simplex	50	32.4	239	266	292
Opihi - Timaru 2[6]	Zebra	Simplex	50	32.4	239	266	292
Opihi - Twizel 1[6]	Zebra	Duplex	75	75.0	694	730	764
Opihi - Twizel 2[6]	Zebra	Duplex	75	75.0	694	730	760[1]
Tekapo B – Twizel	Goat	Duplex	70	25.7	557	589	620

[1]Winter rating is presently limited by a substation component to 760 MVA.

[2]Winter rating is presently limited by a substation component to 762 MVA.

[3]Islington - Rangitata section is rated to 50ºC (114.3 km) and Rangitata – Livingstone section is rated to 75ºC (169 km).

[4]Winter rating is presently limited by a substation component limit to 476 MVA.

[5]Winter rating is presently limited by a substation component limit to 610 MVA.

[6]Ashburton - Opihi 1 / Opihi - Timaru 1 / Opihi - Twizel 1 is one circuit. (Ashburton - Twizel 1) The circuit is divided into sub circuits in Table 6 to show the rating and length of each sub circuit. This is also true for the second circuit (Ashburton - Twizel 2).

Table 2-2 lists the transmission lines from Islington to Kikiwa and from Kikiwa to Stoke, along with their summer, shoulder and winter ratings.

Table 2-2: Conductor thermal ratings of the 220 kV Islington - Kikiwa and Kikiwa - Stoke circuits.

Circuit	Conductor	Configuration	Temp. (ºC)	Length (km)	Rating, MVA		
					Summer	**Shoulder**	**Winter**
Culverden - Kikiwa 1[1]	Zebra	Simplex	75	136.3	347	365	382
Culverden - Kikiwa 2[1]	Zebra	Simplex	75	136.3	347	365	382
Culverden - Waipara 1[1]	Zebra	Simplex	75	30.9	347	365	382
Culverden - Waipara 2[1]	Zebra	Simplex	75	30.9	347	365	382
Islington - Kikiwa 1	Zebra	Simplex	50	229.6	239	266	292
Islington - Waipara 1[1]	Zebra	Simplex	75	60.9	347	365	382
Islington - Waipara 2[1]	Zebra	Simplex	75	60.9	347	365	382
Kikiwa - Stoke 1	Zebra	Simplex	50	52.4	239	266	292
Kikiwa - Stoke 2	Zebra	Simplex	50	52.4	239	266	292

[1]Islington - Waipara 1 / Culverden - Waipara 1 / Culverden - Kikiwa 1 is one circuit (Islington - Waipara – Culverden – Kikiwa 1). The circuit is divided into sub circuits in Table 7 to show the rating and length of each sub circuit. This is also true for the second circuit (Islington - Waipara - Culverden - Kikiwa 2).

2.2.2 Existing USI generation

Table 2-3 details the main installed generation in the USI. The forecast winter peak demand for 2012 exceeds local generation by almost 1100 MW.

Table 2-3: USI grid connected generation.

USI Generation	Capacity, MW
Arnold	3.0
Argyle	3.8
Cobb	34.0
High Bank	22.0
Lake Coleridge	39.5
Kumara	10.0
Tekapo A	25.0
Wairau	7.0
Total	**144.3**

2.2.3 Existing USI Reactive compensation

Table 2-4 summarises the presently installed reactive compensation (static and dynamic) in the USI region. The table does not include reactive compensation in the distribution networks, except for Hokitika and Greymouth, whose capacitor banks are under the control of the System Operator. There is a total of 610 Mvar of capacitors, -30 Mvar of inductors and +310/-201 Mvar of dynamic compensation presently available.

The dynamic reactive compensation consists of two Static Var Compensators (SVCs) and two synchronous condensers at Islington substation and a Static Synchronous Compensator (STATCOM) at Kikiwa.

Table 2-4: Static and dynamic reactive compensation in the USI.

Substation	Voltage level	Capacitors	Reactors	Dynamic support (Mvar)		
	(kV)	(Mvar)	(Mvar)	Synchronous Condenser	SVC	STATCOM
Islington	220	4 x 60			+150/-75	
		1 x 75				
	66	3 x 38				
	11			2 x +30/-18		
	11				+60/-50	
Kikiwa	11					+40/-40
Stoke	33	4x10				
	11	4 x 5[1]	2 x -5			
Blenheim	33	4 x 5				
Bromley	11	2 x 30	1 x -30[2]			
Greymouth	11	1x1, 1x2 & 1x4				
Hokitika	11	1x1, 1x1.4, 1x2, 1x2.8, 1x4 & 1x8				
Southbrook	66	1 x 35				
	TOTALS	**610**	**-40**	**+60/-36**	**+210/-125**	**+40/-40**

[1]Stoke 11kV capacitors are reaching their end of life and are due to be decommissioned (with an indicative date of 2015). They are assumed to be unavailable in the analysis that underpins this report's conclusions.

[2]Bromely reactor is reaching its end of life and is due to be decommissioned (with an indicative date of 2012).

2.3 Report outline

The rest of this report is structured as follows:

Section 2 discusses the main assumptions including forecast demand, committed projects, USI generation dispatch and the dynamic behaviour of SVCs, STATCOMs and motor loads.

Section 3 outlines the planning requirements and performance criteria for the dynamic voltage stability studies.

Section 4 presents the need analysis based on dynamic voltage stability and thermal constraints.

3| Modelling assumptions

The following section lists the assumptions used in the analysis including:

- forecast demand
- USI generation and dispatch
- committed projects
- load model
- Islington synchronous condensers
- supply transformer upgrades and other details

3.1 Forecast demand

The forecast demand was based on the 2010 Annual Planning Report forecast, and has been modified following feedback from lines companies in the USI region for the 10 year period to 2020. See Attachment C for details.

The winter forecast is for the period 10 May – 20 October. The summer forecast is for the period 1 December – 15 March. The rest of the year is the shoulder period. A shoulder forecast is not included in this report as it is known that the need date for dynamic voltage stability is determined by the winter forecast and the need date for thermal capacity is determined by the summer forecast. The forecasts are based on the 10 per cent Probability of Exceedance (PoE) criterion.

The 2010 regional peak forecast from the 2010 APR was applied to all loads in the rest of the South Island. These loads were kept constant throughout the analysis of the USI.

3.2 Upper South Island Generation Dispatch

The USI installed generation mainly consists of limited storage and run of river hydro plant. Hence the available generation is significantly dependent on the prevailing hydrological conditions.

The USI generation dispatch was chosen using 9 years of historical generation data from 2003 to 2011. The raw data was filtered into seasons (summer and winter, as defined in Section 2.1), and years. The data was further filtered, keeping only the generation data which corresponded to the top 10% of the USI load for each year. This provides a realistic generation dataset which can be used for summer and winter dispatch scenarios.

The total USI dispatch for the summer and winter seasons was chosen as the 5th percentile of this filtered generation data (i.e. there is a 95% probability that the total USI generation over the historical period was greater than or equal to the chosen dispatch level).

This exercise was repeated taking the 50th percentile, which represents an average generation year.

The scenarios of the Electricity Commission's 2010 Statement of Opportunities predict some generation in the USI [1], although at this stage there is no new grid-connected generation committed in the region. We have identified two committed embedded generation schemes on the West Coast (Amethyst and Kawatiri) and included these in the modelling. In the absence of historical data, they are both dispatched at 50% of their rated capacity.

Table 3-1 shows the USI generation dispatch assumptions.

Table 3-1: USI generation dispatch assumptions (based on 5th percentile of historical data).

Station Name	Code	Machines	Station Capacity (MW)	Winter Scenario (MW)	Summer Scenario (MW)
Amethyst[1]	-	1 x 6	6	3	3
Arnold	ALD	2 x 1.5	3	2.8	2.8
Argyle	ARG	1 x 3.8	3.8	1.7	1.4
Cobb	COB	4 x 3	32	23.7	10.9
		2 x 10			
Highbank	-	1 x 25	22	17.9	-
Lake Coleridge	COL	1 x 9.5	39.5	26.9	27.5
		2 x 12			
		2 x 3			
Kawatiri[2]	-	1 x 4	4	2	2
Kumara	KUM	1 x 10	10	2.3	2.1
Tekapo A	TKA	1 x 25	25	10.9	10.3
Wairau	WAU	1 x 7	7	3.2	2.5
Generation Total			**152.3**	**94.4**	**62.5**

[1]Amethyst is a committed project and is assumed to be available from Winter 2014.
[2]Kawatiri is a committed project and is assumed to be available from Winter 2013.

3.3 Load model

Load is modelled at each GXP using a composite load model. The model consists of static and dynamic motor loads and the proportions of each load type are set according to a recent survey of the region, which includes data at a GXP level [3]. The composite load model is described in Appendix B.

Table 3-2 lists the aggregate load composition in the USI.

Table 3-2: Aggregate load composition in the USI.

Season	Load composition, %			Survey period
	Static load	Small motors	Large motors[1]	
Winter	77.4	20.2	2.4	June – August
Summer	61.4	35.0	3.6	mid March – mid May
Irrigation	59.2	37.0	3.8	November – mid December

[1]Large motors are defined as those with ratings greater than 150 kW.

The seasons of Table 3-2 do not correspond with the seasons of the forecast demand (see Section 2.1). For a winter demand forecast the load composition of the winter load survey is used. For a summer demand forecast, studies are repeated using the summer and irrigation load composition surveys and the most pessimistic result is used.

3.4 Islington synchronous condensers

The analysis assumes that both Islington synchronous condensers are out of service. Their condition has deteriorated to the point where refurbishment is not longer economic.

3.5 Supply transformer upgrades

It is assumed that transformers can be cyclically loaded up to 120%. Therefore the supply transformers will be upgraded when their n-1 capability is matched by the predicted load for that particular point of supply.

3.6 Voltage profile

Pre-contingency voltages in key parts of the USI network are maintained at set values as per Table 3-3.

Table 3-3: Pre-contingency voltage set-points in the USI.

Substation	Bus	Set point, pu	Method of achieving set-point
Islington	220 kV	1.04	SVC9 controls set-point. SVC3 is set to 0 Mvars. Islington 220 kV and 66 kV capacitors are switched to adjust SVC9 output to near zero Mvars pre-contingency.
Stoke	220 kV	1.04	Stoke 33 kV capacitors
Blenheim	110 kV	1.01	Blenheim 33 kV capacitors
Hokitika	66 kV	1.02	Hokitika 11 kV capacitors
Greymouth	66 kV	1.02	Greymouth 11 kV capacitors

Set-points for the USI generators are controlled to a voltage set-point. These set-points are assumed values. The actual set-points do vary with loading.

Table 3-4: Voltage set-points for USI generators.

Station	Controlled bus	Voltage set-point, pu
Arnold	ALD_33	1.000
Argyle / Wairau	ARG_110	1.033
Cob	COB_66	1.040
Coleridge	COL_66	1.045
Tekapo A	TKA_110	1.023

3.7 Embedded generators

Embedded generators can be dealt with implicitly by reducing the demand at the Grid Exit Point or explicitly by including the generator in the power system model. The advantage of explicitly modelling embedded generators is that the dynamic performance of the generator and AVR will help to increase the USI transfer limit (which is bound by dynamic voltage stability constraints).

The benefit of explicitly modelling an embedded generator depends on the generator size and the impedance between the embedded generator and the Transpower network. Details of the distribution network are not normally available to Transpower. A nominal impedance of 10% is assumed between the Grid Exit Point and the embedded generator. Embedded generators are modelled as per Figure 3-1 where '*x*' indicates the generator dispatch in MW.

Figure 3-1: Modelling of embedded generators.

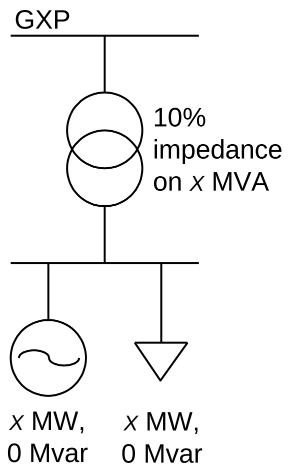


Table 3-5 lists the embedded generators which are explicitly modelled in the analysis.

Table 3-5: Embedded generators explicitly modelled in the analysis.

Embedded generator	Capacity, MW	Grid Exit Point
Amethyst(*)	6	HKK_11
Arnold	3	DOB_33
Highbank	22	ASB_66
Kawatiri(*)	4	ROB_33

(*) Committed generation projects, available from 2013 (Kawatiri) and 2014 (Amethyst). Grid Exit Points are estimates only.

3.8 Other assumptions

3.8.1 HVDC link operation

It is assumed that there are no new generation projects in the USI region for the planning horizon and the system studies assume that the demand growth in the South Island will be met from HVDC transfer from the North Island. The HVDC link at Benmore is represented as a single lumped equivalent at the Benmore 220 kV bus. During the dynamic studies it is modelled as a PIQZ load equivalent.

3.8.2 Stoke 11 kV capacitor banks

The four 11 kV capacitor banks at Stoke are 1960s vintage and plans are in place to decommission them in the near future (indicative date is 2014 / 2015). For this analysis the capacitors are assumed to be out of service.

3.8.3 Bromley 11 kV reactor

The Bromley reactor R5 (BRY R5) is a 30 Mvar reactor used to manage high voltages in the upper South Island during low load periods. Typically it is used for four to five hours a night, most nights of the year. The age and condition of the reactor is such that it is scheduled to be decommissioned in May 2012. Thus for this analysis the reactor is assumed out of service. Our stage two proposal will address this issue. Prior to this Islington SVC3 and SVC9 can be operated inductively to reduce the high voltage issue at light load.

3.8.4 Islington SVC3

In 1996 a +60/-50 Mvar SVC (SVC3) was commissioned and connected to the 11 kV tertiary winding of ISL T3 interconnecting transformer.

Transpower typically specifies primary equipment, e.g. the high power components, for a lifetime of 40 years. Secondary equipment, which includes control and protection systems, cooling system is typically specified for 20 year life. SVC3 is now about 16 years old. Therefore mid life refurbishment / replacement is required soon. The alternative is to decommission it. The development plans consider these alternatives.

3.8.5 SVC and STATCOM modelling

SVCs and STATCOMs are power electronic devices that can supply dynamic reactive power to the AC system. The USI network has two SVCs (Islington SVC3: +60 / -50 Mvar and SVC9: +150 / -75 Mvar) and one STATCOM (Kikiwa STC2: + / - 40Mvar).

Kikiwa STC2 has a 2-second current overload of 2.5 pu capacitive or 2.0 pu inductive. The increased output capability for short durations provides significant reactive support during voltage dips to re-accelerate stalled motors and to further aid voltage recovery.

The SVCs and STATCOM are dispatched at 0 Mvar pre-contingency so the devices can respond fully to system events.

4| Planning requirements and performance criteria

This section details the planning requirements and performance criteria which are used to assess the steady state voltage stability, dynamic voltage stability, and thermal need of the USI power system.

4.1 Planning requirements

The key planning guidelines used in assessing voltage stability and calculating dynamic voltage stability limits are listed below:

The power system remains in a satisfactory state during and following a single (N-1) credible contingency event occurring on the core grid.

a) Single credible contingency events (defined in the EIPC [4]) are:

- a single transmission circuit interruption
- the failure or removal from operational service of a single generating unit
- an HVDC link single pole interruption
- the failure or removal from service of a single bus section
- a single interconnecting transformer interruption
- the failure or removal from service of a single shunt connected reactive component.

b) In determining the N-1 dynamic voltage stability limit, a dynamic load margin not less than 5% of the total regional load shall be provided. For these studies all loads were set to 105% of their nominal forecast values.

The key thermal planning guidelines (under n-1 conditions) are listed below:

a) transmission lines are limited to 100% of their respective winter, summer, and shoulder rating with no short term overload capability

b) existing transformers are limited to 120% of their continuous rating assuming the transformers are cyclically loaded

c) voltages at all generator busses are maintained at set values. This indicates that the generators operate within their reactive capability limits

d) acceptable voltage levels are maintained on the grid (pre and post contingency), i.e. not outside the limits below.

Nominal grid voltage, kV	Voltage limits			
	Minimum, kV		Maximum, kV	
220	198	-10%	242	+10%
110	99	-10%	121	+10%
66	62.7	-5%	69.3	+5%
50	47.5	-5%	52.5	+5%

4.2 Voltage performance criteria

The EIPC references system instability as meaning operating conditions under which it is reasonably likely that 1 or more generating units may cease to be synchronised with the grid. System instability can result from a number of causes:

- large disturbances on the power systems resulting in frequency excursions, voltage excursions or power oscillations
- steady state instability.

The transmission system is considered to be in a 'steady state' when it has reached a point of stable operating equilibrium. The transmission system is usually in a steady state under normal operating conditions (all or most of the equipment in service). It will also settle to a steady state following a disturbance (e.g. an outage) if the post-disturbance system is stable.

System instability can occur during voltage excursions following the switching of grid assets or during the occurrence and clearance of short circuit faults on the power system. Momentary high or low voltages can result in generating units disconnecting from the power system. Motor loads may also disconnect during voltage excursions.

Voltage stability refers to the ability of the transmission system to maintain control of the voltage after a disturbance, avoiding either an uncontrolled voltage drop (potentially leading to a blackout) or uncontrolled high voltages (potentially leading to damage to end user or transmission system equipment).

The voltage recovery criteria are based on avoiding operating conditions where it is reasonably likely that one or more generating units may cease to be synchronised with the grid.

The following recovery criteria are applied:

- Voltage must be greater than 0.5 pu following a single credible contingency on the core grid which removes an item of equipment from service without a transmission system short circuit fault. For modelling purposes, all load is assumed to stay connected during and following the event;
- Voltage must recover to above 0.8 pu in less than 4 seconds following a credible contingency on the core grid. This requirement is to ensure that voltages have recovered to the extent that under-voltage based protection relays on grid connected generating units do not operate which would cause the units to disconnect from the power system;
- Voltage must not be greater than 1.3 pu. This applies for areas that are remote from the HVDC link terminals such as the upper North Island and Upper South Island. This requirement is to ensure that overvoltage based protections on generating units do not operate which would cause the generating unit to disconnect from the power system and;
- Voltage must not be greater than 1.1pu after 0.9 seconds. This requirement is based on the normal operating range for voltages in the Part 8 of the EIPC.
- There is no pole slipping on grid connected generating units. This requirement is to ensure that protection relays on generating units do not operate to remove the unit from the power system.

4.2.1 Contingencies

The following contingencies are evaluated:

- The failure or removal of a single item of equipment with and without a fault.
- The failure or removal from service of a single 220 kV bus section with single phase to ground fault cleared in 100 msec.
- A single phase to ground fault (cleared in 100 msec) on a 220 kV transmission circuit followed by a failed attempt to auto-reclose.

The Islington 220 kV bus and the connecting 220 kV circuits are part of the core grid. The removal from service of a single bus section at Islington, which presently leads to loss of multiple circuits, is the most onerous case for voltage recovery.

5| Need Analysis

The need date is changed from that reported in the Need Report in June 2011 [5]. Since the need report was published there have been changes made to our assumptions. The winter and summer local generation are updated as discussed in Section 2.2. In addition, our voltage performance criteria and credible contingencies are updated as discussed in Section 3.2.

5.1 Dynamic reactive support

The results of the dynamic voltage stability studies are summarised in Table 5-1. The year indicated is the first year in which the voltage performance criteria of Section 3.2 are breached. The USI load limit is also shown (rounded to the nearest 5 MW). The results assume Islington SVC3 is in service. The total capacitive dynamic reactive support available from Transpower equipment is 250 Mvar (from Islington SVC3 and SVC9, and Kikiwa STC2).

Table 5-1: Need dates for winter and summer

Case	First year criteria is breached	USI load limit, MW
Winter	2014	1245
Summer	2016	1240

Figure 5-1 illustrates the dynamic response of the USI voltage in winter 2013 and 2014 respectively. The voltages plotted are all of Transpower's 220 kV, 110 kV, 66 kV and 33 kV buses. The figure shows how a small increase in load results in a dramatically different dynamic response, changing from acceptable voltage recovery to voltage collapse.

The need is driven by the criteria that voltage must be greater than 0.5 pu following a single credible contingency on the core grid which removes an item of equipment from service without a transmission system short-circuit fault and where all load is assumed to stay connected during and following the event.

The results show that by winter 2014 the USI network is at risk of cascade failure and voltage collapse. The need date to address the dynamic voltage stability issue is therefore prior to winter 2014.

For reference, the voltage performance at the terminals of the USI generators is shown for the same contingency in Figure 5-2.

Figure 5-1: USI voltage performance for Transpower's 220 kV, 110 kV, 66 kV and 33 kV buses in the USI in a) 2013 and b) 2014 for Islington Bus A contingency (without a fault and all load remaining connected)

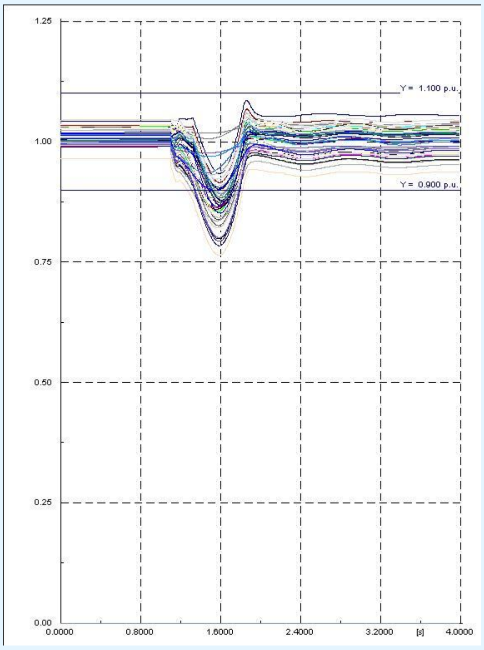
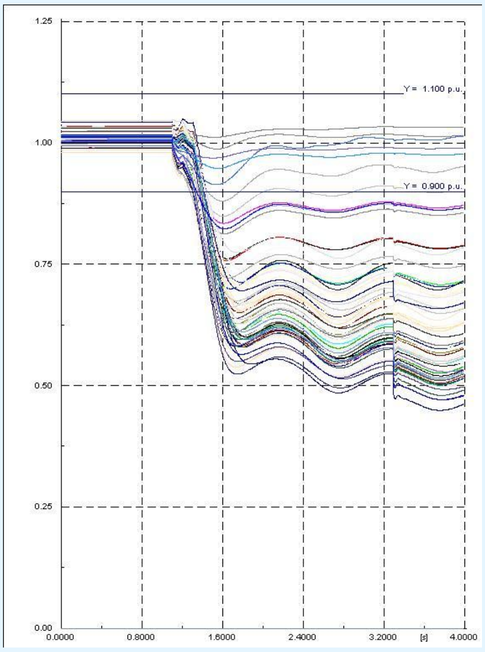
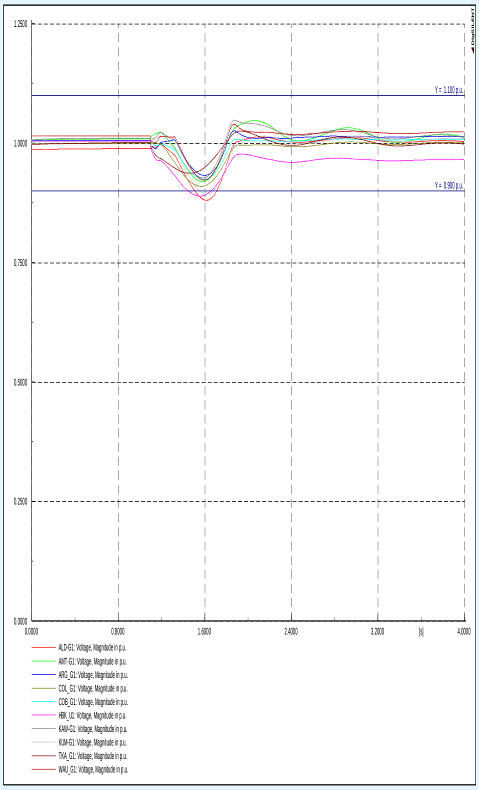
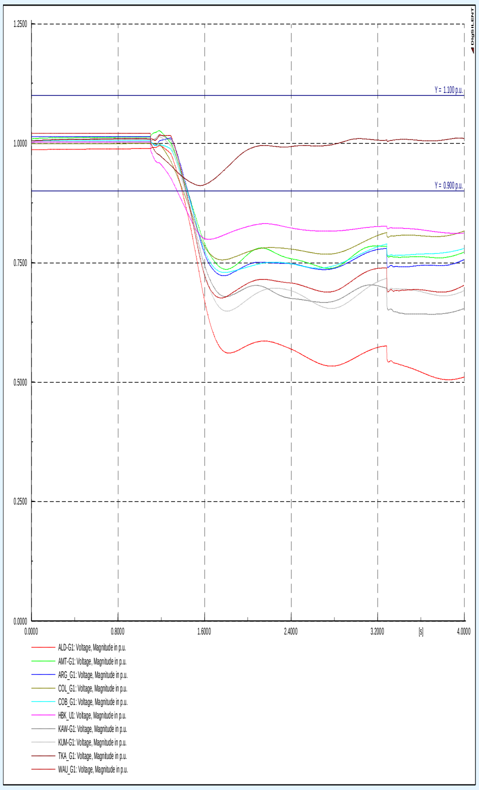
Winter 2013 – acceptable voltage recovery	Winter 2014 – voltage collapse, not acceptable
	

Figure 5-2: Voltage performance at the terminals of the USI generators in a) 2013 and b) 2014 for Islington Bus A contingency (without a fault and all load remaining connected)

Winter 2013 – acceptable generator voltages



Winter 2014 – unacceptable generator voltages



5.1.1 Sensitivity to assumptions

Table 5-2 shows the results of a sensitivity analysis to the base case load limit of 1245 MW.

Item 1 shows the load limit reduces when existing dynamic plant is out of service. Items 2 and 3 show the sensitivity to load assumptions.

Table 5-2: Need date sensitivity analysis.

Item	Description	First year criteria is breached	load limit, MW
	Base Case (winter)	2014	1245
1	Islington SVC3 out of service	2012	1200
2	Pike River mine demand does not return	2014	1245
3	Christchurch load down 10% due to 2011 earthquakes	2017	1310

5.2 Static reactive support

Capacitive static reactive support is switched in pre-contingency to meet the grid reactive needs and allow the dynamic devices to operate near 0 Mvar pre-contingency. This allows the dynamic devices to maintain maximum reactive reserves to respond to system events.

The analysis shows that additional capacitive static reactive support is needed by winter 2017. After that, studies indicate 75 Mvars of additional static support is required approximately every 4 years.

Presently under light load conditions (e.g. during the night time), the dynamic reactive plant at Islington (and Kikiwa) absorbs Vars to hold the voltage down. SVC9 and SVC3 can absorb 75 and 50 inductive Mvars respectively giving a combined inductive capability of 125 Mvars at Islington.

Even with SVC3 and SVC9 in service, and without the Bromley reactor, there will still be some occasions where additional inductive Vars are required. When additional reactive absorption is required then switching out the Islington–Kikiwa 1 circuit can be effective by increasing system reactive losses and removing the natural capacitive support effect of the line. Switching out the Islington-Livingstone circuit is a further step than can be taken in extreme cases such as when SVC9 (or SVC3) is out of service.

If SVC3 is decommissioned (and not refurbished or replaced) then there is 50 Mvars inductive less available to hold voltage down during light loads. While the system will remain secure, switching out multiple circuits would become a routine occurrence during light loads overnight. Therefore for development scenarios where SVC3 is decommissioned, and SVC9 is the only dynamic reactive plant in Christchurch area, then a 30 Mvar shunt reactor (connected at 11 kV) is added in the development plans to help manage voltage during light load conditions.

5.3 Thermal Capacity

Our planning studies [2] have shown that, assuming no new generation is commissioned in the USI, the region has sufficient thermal transmission capacity to maintain n-1 security, until 2028. After that, new transmission capacity into Christchurch from the south, will be needed.

The 2028 date assumes existing lines can be maintained right up to that date, but this may not be possible. As demand in the USI increases and flows on the existing lines increase, it becomes more difficult to remove a circuit from service for maintenance and continue to maintain n-1 supply security. In such circumstances, live transmission line maintenance work can be considered, meaning that all circuits can remain in service, but this is not always possible. The availability of maintenance windows and possibilities for live line maintenance will need to be considered for the circuits into Christchurch. If not feasible, the need date of 2028 may need to come forward.

In developing options for new transmission capacity, we always consider whether existing assets can upgraded (by reconductoring existing lines with higher rated conductor for example) to defer the need for a new transmission line. The circuits that define the n-1 USI capacity need date are the Ashburton–Twizel 220 kV circuits on the Christchurch–Twizel A line and both circuits would need upgrading to extend the 2028 date.

Similarly as for maintenance, reconductoring requires lines to be taken out of service, but for longer periods of time. If the outage window or windows need to be large (6 continuous weeks allows for 24 km of reconductoring as a general rule and is regarded as an efficient practical minimum), then adequate windows of opportunity may not exist for reconductoring without constructing temporary bypass lines.

Investigation will be required to determine whether there are sufficient outages available to enable reconductoring work. If not, bypass lines or live line reconductoring could be considered. We have little experience in live line reconductoring and the double circuit Christchurch–Twizel A line will almost certainly involve tower modification work to accommodate heavier conductor load, which complicates the issue.

If upgrading options are not feasible for existing lines, we will need to consider a new line.

A detailed investigation into options for increasing transmission capacity into the USI will likely be required within the next five years.

6| References

[1] 2010 Statement of Opportunities, September 2010, Electricity Commission. Available online at http://www.ea.govt.nz/industry/ec-archive/soo/2010-soo/

[2] Planning and Development, Annual Planning Report 2012, Transpower, March 2012. Available online at www.transpower.co.nz

[3] Upper South Island voltage stability study – information collation, SKM, April 2008.

[4] Electricity Industry Participation Code 2010. Available online at The Electricity Authority's website: http://www.ea.govt.nz/act-code-regs/code-regs/the-code/

[5] Upper South Island Grid Upgrade Investigation Project – Need Analysis, Report NP 499, Transpower NZ Ltd. Available online at: http://www.gridnewzealand.co.nz/f4827,54611853/need-analysis-june-2011.pdf

[6] Taylor, C.W., *Power system voltage stability*, McGraw-Hill, New York, 1994.

[7] Investigation into heat pump power quality under-voltage and transient operation, Electric Power Engineering Centre, Version 2.1, September 2008.

Appendix A Abbreviations

AVR – Automatic voltage regulator

GXP - Grid eXit Point

IGE – Interim Grid Expenditure

MCP – Major Capex Proposal

OEL - over excitation limiter

PIQZ - load with a constant real current and constant reactive impedance characteristic to variations in voltage.

PPQQ - load with a constant real power and constant reactive power characteristic to variations in voltage.

RPC – Reactive Power Controller

SKM - Sinclair Knight Merz (Consultancy)

SVC - Static Var Compensator

STATCOM - Static synchronous compensator

TCR – Thyristor Controlled Reactor

USI - Upper South Island

Appendix B Load Modelling

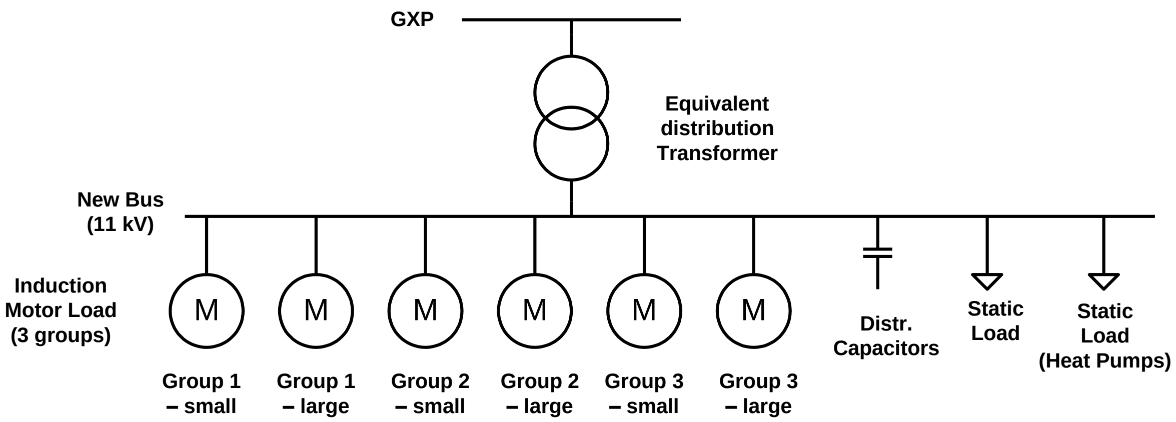
The dynamic load model is assumed to comprise of non-rotating "static" loads and induction motor loads, forming a composite load model. A composite load model is assumed for all loads in the USI.

B.1 Composite load model

The individual motor load composition for each GXP was set according to a 2008 SKM survey of the USI [3]. The survey includes the Winter (June to August), Summer (mid March to mid May) and Irrigation (November to mid December) windows.

The motors are split into three different protection groups (groups one, two and three). Each group is further subdivided into groups based on motor sizes (large and small[1]) as shown in Figure 6-1.

Figure 6-1 Composite load model.



The load composition for each GXP for the winter, summer and irrigation periods is shown in Table 6-2, Table 6-3, and Table 6-4. The term 'G1 Large' means Group 1 large motor. Similarly, 'G3 Small' means Group 3 small motor.

The Pike River and Logburn Road GXPs were not included in the original SKM survey. These GXPs supply the Pike River Mine which is assumed to have a high motor load component. These GXPs are therefore assumed to have the same motor load composition as the GXP in the USI which has the highest percentage of group one large motor load.

Model specifics are further discussed below.

B.2 Induction motor protection behaviour

In practice the group one motors are connected with electromagnetic contactors. These contactors may open and stay open when the motors experience transient voltage dips (e.g. during grid faults) or low voltage conditions. This contactor action is modelled by assuming that a portion of group one USI motor loads will disconnect during a fault and stay disconnected.

[1] Large motors are defined as those with ratings greater than 150 kW.

It is assumed that 50% of group one motor loads at each GXP disconnect during a severe fault. Sensitivities on the amount of Group 1 motors that disconnect may be performed from 25% to 90%. When less motors disconnect (i.e. 25% case) then voltage recovery is slower and more capacitive dynamic reactive support is necessary to meet the voltage performance criteria. When more motors disconnect (i.e. 90% case) then the system is susceptible to over voltage and therefore more inductive reactive support may be necessary to meet the performance criteria.

The remaining group two and group three motor loads are assumed to either remain connected, or reconnect shortly after the fault. The group two and group three motors have a combination of over-voltage and over-current protection.

B.3 Induction motor parameters

The parameters assumed for the large and small motors (single cage) are given in Table 6-1. The mechanical load torque is assumed to be proportional to the speed squared for both large and small motors.

Table 6-1: Induction motor parameters [6].

Electrical Parameters	Small Motor	Large motor
Rs (pu)	0.079	0.013
Xs (pu)	0.12	0.067
Xm (pu)	3.2	3.8
Rr (pu)	0.052	0.009
Xr (pu)	0.12	0.17
H (sec)	0.28	1.5
Load Factor	0.6	0.8

B.4 Static load

Heat pumps are an emerging trend in the USI. The percentage of heat pumps for each Lines Company was found by a customer survey in 2009. They are modelled as a separate item at each GXP and are assumed to have a PPQQ characteristic [7]. 'PPQQ' denotes that the active load portion is represented by constant power characteristic and the reactive component is represented by constant MVA characteristic.

The remainder of the static load in USI GXPs is assumed to have a PIQZ characteristic. 'PIQZ' denotes that the active and reactive load components are represented by constant current and constant impedance characteristics respectively.

Note that loads in the rest of the South Island are assumed to have a PIQZ characteristic (i.e. no motor loads represented).

B.5 Distribution impedance

The composite load model of Figure 6-1 also includes a transformer to represent the distribution network impedance. The transformer impedance is assumed to be 10% for the studies.

The transformers associated with the composite loads are configured with on-load tap changers and control the composite load voltage to 1.0 pu +/- 0.01 pu. The transformer taps have a range of +/- 7.5% in 0.25% steps.

Table 6-2: Winter load composition for each USI Grid Exit Point.

GXP	Load composition							
	Static load		Motor load					
	PIQZ	PPQQ	G1 Large	G1 Small	G2 Large	G2 Small	G3 Large	G3 Small
1	18.3	0.0	6.3	42.8	1.4	24.2	2.8	4.3
2	18.5	3.9	28.6	17.5	6.5	10.5	12.6	2.1
3	18.5	3.9	28.6	17.5	6.5	10.5	12.6	2.1
4	19.4	3.0	28.6	17.5	6.5	10.5	12.6	2.1
5	21.0	4.6	27.9	16.3	7.0	9.3	11.6	2.3
6	38.5	10.4	3.5	25.6	0.8	15.9	1.6	3.7
7	49.8	4.3	14.0	11.6	3.2	7.9	6.3	2.9
8	49.8	4.3	14.0	11.6	3.2	7.9	6.3	2.9
9	53.1	4.3	12.0	11.6	2.7	8.6	5.3	2.4
10	56.4	8.0	2.2	16.6	0.5	12.3	1.0	3.0
11	56.9	5.6	1.4	16.2	0.3	11.2	0.6	7.8
12	56.9	5.6	1.4	16.2	0.3	11.2	0.6	7.8
13	59.2	12.5	0.6	12.3	0.0	7.2	0.3	7.9
14	59.2	12.5	0.6	12.3	0.0	7.2	0.3	7.9
15	63.2	12.4	0.8	9.4	0.2	8.8	0.4	4.8
16	63.2	12.4	0.8	9.4	0.2	8.8	0.4	4.8
17	63.2	12.4	0.8	9.4	0.2	8.8	0.4	4.8
18	63.2	12.4	0.8	9.4	0.2	8.8	0.4	4.8
19	66.7	4.3	7.0	7.8	1.6	7.0	3.1	2.5
20	67.2	12.0	0.8	8.0	0.2	8.2	0.4	3.3
21	67.4	12.1	0.1	6.7	0.0	7.3	0.0	6.4
22	67.4	8.0	1.4	10.6	0.3	9.7	0.6	2.0
23	67.7	12.1	0.0	6.6	0.0	7.0	0.0	6.7
24	68.2	12.0	0.0	6.1	0.0	7.0	0.0	6.6
25	68.6	12.4	0.0	4.8	0.0	7.1	0.0	7.1
26	68.9	12.4	0.7	6.9	0.2	7.8	0.3	2.9
27	68.9	12.4	0.7	6.9	0.2	7.8	0.3	2.9
28	68.9	12.4	0.7	6.9	0.2	7.8	0.3	2.9
29	68.9	12.4	0.7	6.9	0.2	7.8	0.3	2.9
30	69.5	8.0	1.0	9.7	0.2	8.1	0.4	3.2
31	69.8	12.4	0.2	6.3	0.0	6.1	0.1	5.1
32	70.2	12.0	0.3	5.9	0.1	7.1	0.1	4.3
33	72.2	12.4	0.4	5.0	0.1	7.0	0.2	2.6
34	72.2	12.4	0.4	5.0	0.1	7.0	0.2	2.6
35	72.2	12.4	0.4	5.0	0.1	7.0	0.2	2.6
36	73.2	12.5	0.0	4.1	0.0	6.1	0.0	4.1
37	73.3	12.4	0.0	3.6	0.0	7.1	0.0	3.6
38	74.5	9.7	0.4	5.3	0.1	6.8	0.2	3.0
39	74.9	8.5	0.8	6.2	0.2	7.5	0.3	1.5
40	77.8	12.4	0.0	2.0	0.0	5.7	0.0	2.2
41	77.8	12.4	0.0	2.0	0.0	5.7	0.0	2.2
42	77.8	12.4	0.0	2.0	0.0	5.7	0.0	2.2
43	79.5	3.9	2.5	4.4	0.5	6.0	1.1	2.1
44	79.5	3.9	2.5	4.4	0.5	6.0	1.1	2.1
45	81.2	9.9	0.0	2.4	0.0	5.1	0.0	1.5
46	82.5	7.7	0.0	1.8	0.0	5.5	0.0	2.5
47	83.3	4.3	1.2	2.8	0.3	5.2	0.5	2.4
48	84.0	7.9	0.0	1.9	0.0	5.2	0.0	0.9
49	85.9	8.0	0.0	0.6	0.0	5.0	0.0	0.6

Table 6-3: Summer load composition for each USI Grid Exit Point.

GXP	Load composition, %							
	Static load		Motor load					
	PIQZ	PPQQ	G1 Large	G1 Small	G2 Large	G2 Small	G3 Large	G3 Small
1	16.3	0.0	6.4	43.8	1.5	24.8	2.8	4.4
2	18.7	2.9	28.8	17.6	6.6	10.6	12.7	2.1
3	18.7	2.9	28.8	17.6	6.6	10.6	12.7	2.1
4	18.7	2.9	28.8	17.6	6.6	10.6	12.7	2.1
5	20.4	3.4	28.6	16.7	7.1	9.5	11.9	2.4
6	23.9	9.3	1.9	35.8	0.1	8.0	1.1	19.8
7	23.9	9.3	1.9	35.8	0.1	8.0	1.1	19.8
8	25.1	4.2	2.4	37.7	0.3	9.9	1.3	19.1
9	25.1	4.2	2.4	37.7	0.3	9.9	1.3	19.1
10	27.0	7.3	3.8	34.3	0.8	15.9	1.8	9.1
11	40.6	9.3	1.2	25.5	0.1	7.6	0.7	15.1
12	41.2	9.0	1.1	24.4	0.0	7.9	0.7	15.7
13	43.2	5.9	2.1	25.8	0.4	10.8	1.2	10.6
14	45.4	3.3	16.2	12.5	3.7	8.8	7.2	2.9
15	45.4	3.3	16.2	12.5	3.7	8.8	7.2	2.9
16	47.8	3.3	14.6	12.7	3.3	9.5	6.4	2.5
17	49.6	9.0	1.0	19.5	0.1	8.6	0.6	11.5
18	50.6	9.0	1.5	18.9	0.3	10.4	0.7	8.6
19	54.1	5.9	2.5	18.4	0.6	14.3	1.1	3.1
20	54.3	9.0	0.5	15.7	0.0	8.2	0.4	11.8
21	56.2	7.3	1.0	18.0	0.0	7.3	0.5	9.7
22	56.3	5.9	1.7	17.6	0.4	11.2	0.9	6.0
23	56.7	9.0	0.5	14.1	0.0	8.8	0.3	10.5
24	58.4	9.3	1.2	12.9	0.3	11.3	0.5	6.0
25	58.4	9.3	1.2	12.9	0.3	11.3	0.5	6.0
26	58.4	9.3	1.2	12.9	0.3	11.3	0.5	6.0
27	58.4	9.3	1.2	12.9	0.3	11.3	0.5	6.0
28	58.4	5.9	2.1	16.3	0.5	12.6	0.9	3.4
29	63.2	9.3	1.1	10.8	0.2	10.6	0.5	4.2
30	63.2	9.3	1.1	10.8	0.2	10.6	0.5	4.2
31	63.2	9.3	1.1	10.8	0.2	10.6	0.5	4.2
32	63.2	9.3	1.1	10.8	0.2	10.6	0.5	4.2
33	64.2	7.3	1.2	12.4	0.2	9.8	0.6	4.3
34	65.7	7.2	1.0	11.0	0.2	9.9	0.5	4.5
35	65.8	3.3	7.4	8.1	1.7	8.0	3.2	2.6
36	66.5	9.2	0.0	6.1	0.0	9.1	0.0	9.1
37	68.6	9.3	0.7	7.6	0.2	9.6	0.3	3.7
38	68.6	9.3	0.7	7.6	0.2	9.6	0.3	3.7
39	68.6	9.3	0.7	7.6	0.2	9.6	0.3	3.7
40	69.6	5.9	0.6	10.0	0.0	7.2	0.6	6.1
41	71.3	9.3	0.0	5.6	0.0	8.3	0.0	5.6
42	73.1	9.4	0.0	5.0	0.0	7.5	0.0	5.0
43	76.9	9.3	0.0	2.9	0.0	7.7	0.0	3.2
44	76.9	9.3	0.0	2.9	0.0	7.7	0.0	3.2
45	76.9	9.3	0.0	2.9	0.0	7.7	0.0	3.2
46	78.1	7.3	0.0	3.5	0.0	7.6	0.0	3.5
47	78.8	2.9	2.7	4.6	0.6	7.2	1.1	2.2
48	78.8	2.9	2.7	4.6	0.6	7.2	1.1	2.2
49	82.8	3.3	1.3	2.8	0.3	6.4	0.5	2.4

Table 6-4: Irrigation load composition for each USI Grid Exit Point.

GXP	Load composition							
	Static load		Motor load					
	PIQZ	PPQQ	G1 Large	G1 Small	G2 Large	G2 Small	G3 Large	G3 Small
1	16.2	0.0	6.4	43.8	1.5	24.8	2.9	4.4
2	18.8	1.9	28.9	17.9	6.5	10.9	12.7	2.4
3	18.8	1.9	28.9	17.9	6.5	10.9	12.7	2.4
4	18.8	1.9	28.9	17.9	6.5	10.9	12.7	2.4
5	19.2	2.2	28.6	16.7	7.1	11.9	11.9	2.4
6	22.2	6.3	2.1	38.8	0.1	8.0	1.2	21.2
7	22.2	6.3	2.1	38.8	0.1	8.0	1.2	21.2
8	23.1	2.8	2.5	40.2	0.3	9.4	1.4	20.3
9	23.1	2.8	2.5	40.2	0.3	9.4	1.4	20.3
10	24.7	4.9	4.1	36.9	0.8	16.9	1.9	9.7
11	37.3	6.3	1.4	29.3	0.1	7.7	0.9	17.0
12	41.9	4.0	3.6	26.4	0.8	17.4	1.6	4.4
13	42.5	2.2	16.5	13.8	3.7	9.8	7.3	4.2
14	42.5	2.2	16.5	13.8	3.7	9.8	7.3	4.2
15	45.8	2.2	14.8	13.7	3.4	10.2	6.5	3.5
16	46.1	4.0	3.2	23.8	0.7	16.6	1.4	4.1
17	51.8	4.9	1.1	21.9	0.0	7.7	0.7	11.9
18	55.4	4.0	1.7	18.9	0.2	11.1	0.9	7.8
19	60.5	6.3	1.3	13.5	0.3	11.6	0.6	6.0
20	60.5	6.3	1.3	13.5	0.3	11.6	0.6	6.0
21	60.5	6.3	1.3	13.5	0.3	11.6	0.6	6.0
22	60.5	6.3	1.3	13.5	0.3	11.6	0.6	6.0
23	60.6	4.9	1.1	15.4	0.2	9.7	0.6	7.6
24	62.8	6.0	0.4	12.8	0.0	8.1	0.3	9.5
25	62.9	2.2	7.4	9.5	1.7	9.1	3.2	4.1
26	63.6	4.9	1.2	13.9	0.2	10.3	0.6	5.3
27	63.6	6.3	1.3	12.1	0.3	11.3	0.6	4.5
28	63.6	6.3	1.3	12.1	0.3	11.3	0.6	4.5
29	63.6	6.3	1.3	12.1	0.3	11.3	0.6	4.5
30	63.6	6.3	1.3	12.1	0.3	11.3	0.6	4.5
31	65.3	6.0	1.1	11.6	0.2	10.6	0.5	4.6
32	67.6	6.0	0.6	10.2	0.1	9.0	0.3	6.2
33	68.1	4.0	1.1	11.6	0.0	10.0	0.5	4.7
34	69.7	6.0	0.2	8.5	0.0	8.1	0.1	7.5
35	69.7	6.3	0.8	8.4	0.2	10.3	0.3	3.9
36	69.7	6.3	0.8	8.4	0.2	10.3	0.3	3.9
37	69.7	6.3	0.8	8.4	0.2	10.3	0.3	3.9
38	69.8	6.0	0.3	8.3	0.0	8.6	0.1	6.8
39	71.8	6.4	0.0	6.3	0.0	9.4	0.0	6.3
40	72.1	4.0	1.1	8.9	0.0	10.0	0.6	3.3
41	73.2	6.2	0.0	5.9	0.0	8.8	0.0	5.9
42	75.2	6.3	0.0	5.3	0.0	7.9	0.0	5.3
43	75.7	1.9	2.7	5.9	0.6	8.3	1.2	3.8
44	75.7	1.9	2.7	5.9	0.6	8.3	1.2	3.8
45	78.2	4.9	0.0	4.6	0.0	8.5	0.0	3.8
46	79.0	6.3	0.0	3.1	0.0	8.2	0.0	3.4
47	79.0	6.3	0.0	3.1	0.0	8.2	0.0	3.4
48	79.0	6.3	0.0	3.1	0.0	8.2	0.0	3.4
49	79.1	2.2	1.3	4.6	0.3	7.6	0.5	4.3

