TRANSPOWER

Wellington Voltage Stability Study During HVDC South Transfer

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1. Purpose

The purpose of this report is to determine the system limits for powerflow from Bunnythorpe to Haywards while HVDC is in south transfer for the Wellington (GZ8) region.

The study focuses primarily on voltage stability issues in the Wellington region post the thermal upgrading of the BPE_HAY 1&2 lines, and assumes that system conditions are such that the system split of the MGM_MST circuit is in place. It also assumes all existing reactive power sources (all 4 condensers) at Haywards are available.

In addition the study takes into account 5 major 220kV circuit outages south of Bunnythorpe, namely BPE_HAY1, 2 and 3, BPE_WIL_1 and HAY_WIL 1.

Analysis has been carried out using the EMS/SCADA powerflow modelling including the VSAT tool. Both tools are as used to manage system limits in real time, hence the results are likely to be a good reflection of the actual limits in real time system operation.

2. Summary

The re-rating of the Bunnythorpe-Haywards circuits 1&2 (17 May 2006) raised the thermal rating of the 220 kV AC network into Wellington. Under typical, potential dry year conditions with a system split at Mangamaire, the new rating of these two circuits of 807/880A alleviates the previous post contingent thermal loading issues. In particular, for a tripping of Bunnythorpe-Haywards 3 circuit overloading either of the Bunnythorpe-Haywards 1 and 2 circuits in the Wellington region. This change makes the HVDC south transfer runback redundant and voltage stability now sets the SPD transfer limit at all times (summer, winter and overnight) when there is a system split at MGM and all 220 KV circuits are in service.

The *default* voltage stability limit for combined Wellington demand and HVDC south transfer (~450MW) is 868MW transfer from Bunnythorpe to Wellington will apply at all times. This transfer limit takes into account that all circuits south of Bunnythorpe are in service, with the exception of the Mangamaire-Masterton 110kV circuit, and Wilton interconnecting transformer – T8.

To ensure system security is maintained, the voltage stability limit into Wellington will be monitored in real-time using VSAT – the online voltage stability tool, and the constraint Right Hand Side (RHS) value revised as system conditions change.

Real time adjustment of constraint limits will largely be in response to variations in the amount of reactive support in service at Haywards, which varies with the HVDC configuration and level of transfer. See table 1 under the results section for the different RHS values for voltage stability.

Further details of how this transfer limit relates to previously advised limits and the limits for various circuit outages are set out in this report.

3. Background

Potential Dry Year Situations

As a response to a potential “dry year” situation and low storage in the South Island hydro lakes, the HVDC link may from time to time be required to transfer significant power in the reverse direction (Haywards to Benmore).

While overnight south transfer is common, with sustained south transfer the 220 kV AC network from Bunnythorpe to Haywards becomes a constraint. Until May 2006 the constraint was often due to the thermal rating of two of the four circuits. With recent rating changes voltage stability will set the Bunnythorpe to Haywards limits when conditions are such that the 110 kV route through Mangamarie has been split by the Grid Owner.

The nature of voltage stability and the changes in network conditions between Bunnythorpe and Haywards is outlined in italics below. This text includes excerpts from “ *Power System Stability and Control, Prabha Kundur, 1993”*

Voltage Stability

Voltage stability problems were once associated primarily with weak systems and long lines, however, they are now also a source of concern in highly developed networks as a result of heavier loadings.

Voltage stability is concerned with the ability of a power system to maintain acceptable voltages at all buses in the system under normal conditions and after being subjected to a disturbance. A system enters a state of voltage instability when a disturbance, increase in load demand, or change in system condition causes a progressive and uncontrollable decline in voltage. The main factor causing instability is the inability of the power system to meet the demand for reactive power.

Effect of shunt capacitors at Haywards

In this study, the filter banks at Haywards – commonly known as the shunt capacitors are effectively used up to a certain point to extend the voltage stability limits by correcting the receiving end power factor. They can also be used to free up “spinning reactive reserve” in generators and thereby help prevent voltage collapse in many situations.

Shunt capacitors, have a number of inherent limitations from the viewpoint of voltage stability and control:

- *In heavily shunt capacitor compensated system, the voltage regulation tends to be poor.*

- *Beyond a certain level of compensation, stable operation is unattainable with shunt capacitors.*

- *The reactive power generated by a shunt capacitor is proportional to the square of the voltage; during system conditions of low voltage, the VAR support drops, thus compounding the problem.*

Changes in Network Conditions with south transfer and limits

"Under normal system conditions, with all circuits in service, as the flow into Wellington increases, the first issue that arises is the post contingent ***thermal overloading*** *of the MGM_WDV circuit. This is managed by a permanent branch constraint being applied in SPD which limits the precontingent flow on this circuit to 95% of its thermal rating.*

As the flow into GZ8 increases further, MGM_MST circuit is split – this is a special offer by the Grid Owner to reconfigure the grid in order to maximize transmission capability. The next issue then is that WIL T8 may experience ***static violations post contingency (147MVA)*** *prior to static violation in steady state, which means it will in turn be switched out post event in real time. At this point, the binding constraint on flows into Wellington region is the* ***static limit*** *on WIL T8.*

As the load in GZ8 increases even further, WIL T8 is switched out in accordance with the offer from the Grid Owner, and the binding constraint now into Wellington is ***voltage stability****. The voltage stability limit calculated at this point will be across the 4 220kV circuits less WIL T8. The unavailability of WIL T8 reduces the voltage stability limit by around 30 MW. And as the demand in GZ8 increases further, voltage instability could occur for a contingent event.*

To conclude, under high HVDC south transfer, the MGM_MST system split would be in place – and the flows into the GZ8 region would be bound by voltage stability."

Real time Management of GZ8 Stability using VSAT:

A brief description of the SCADA/EMS system and VSAT

In realtime the SCADA/EMS system is continually analysing the impact various contingencies would have on the power system .This analysis is known as realtime contingency analysis, and reports what the post contingent loading on system components would be, and what the post contingent system voltages would be, if a contingency occurred at that time.

This realtime contingency analysis has two components. The first part is the use of an EMS powerflow application which uses a Newton Raphson loadflow solution to determine what system component loadings would be for a number of nominated contingencies. This application then reports if system components are at risk of exceeding their capability due to post contingent loading.

The second part of this realtime analysis is the VSAT application, which uses a static PV analysis to determine the post contingent system voltage for the same nominated contingent events. This analysis identifies the point at which post contingent voltage is likely to become unstable ie: the system is at risk of voltage collapse should a contingency occur.

By monitoring these applications in realtime, the System Operator is able to ensure security standards for post contingent equipment loading, and post contingent system voltage, are maintained all times.

In the event of these systems reporting that an equipment loading limit, or a system voltage limit would be violated **if** a contingency occurred, the System Operator follows a standard operating procedure to correct the situation.

These standard procedures ensure that the system is being operated to maximum capability before further corrective action is taken.
In the situation of maximising transfer into the Wellington region, this is typically achieved through:

- Ensuring all available capacitors are connected to provide maximum voltage support.

- Transfer of HVDC south is optimised across Pole 1 and Pole 2.

- Load distribution within the Wellington region is optimised across the 220 KV and 110KV networks. ie:there is some ability to transfer load between these networks

The SCADA/EMS applications used for realtime operation also have off-line or “study time” versions. Theses offline systems are an exact replica of the realtime system, and it is these offline systems that have been used for the analysis in this report.
Consequently there is a high level of correlation between the information contained in this report, and the system limits that are expected to apply for various system conditions.

4. Assumption and methodology

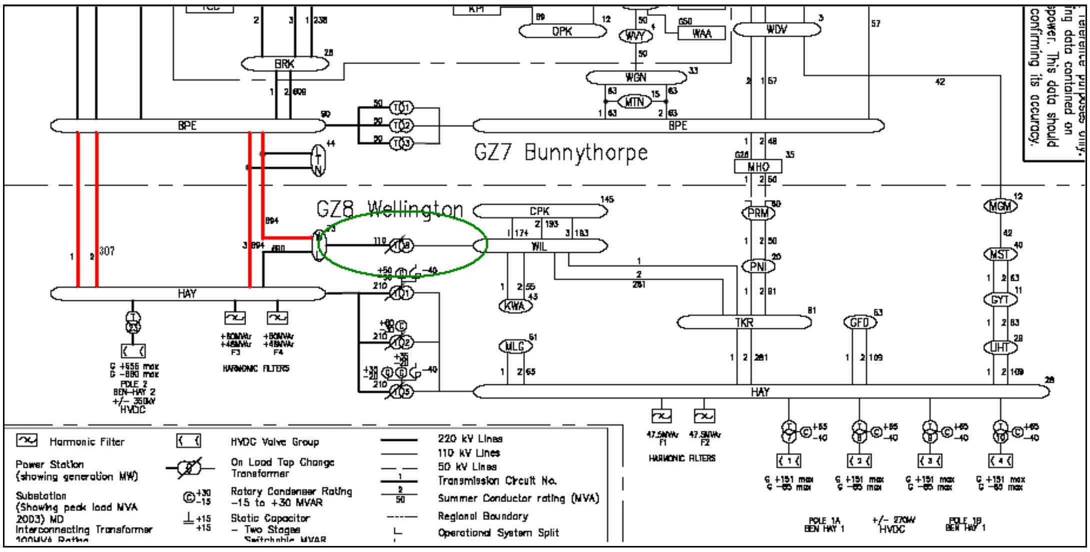
4.1 Analytical Tool

The power system package used for the study is SCADA (EMS) and VSAT.

4.2 System Conditions

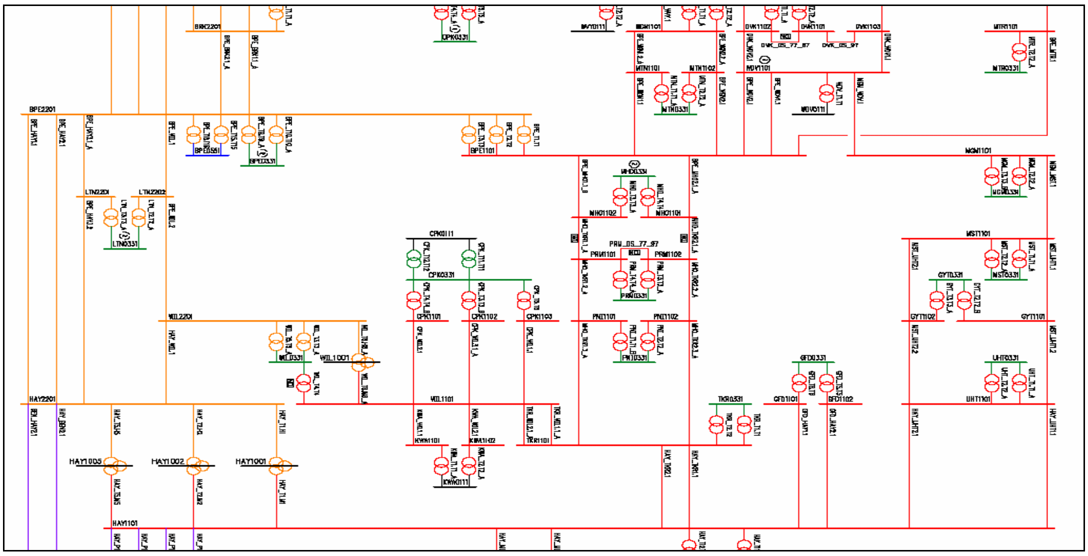
4.2.1 Network Configuration:

System diagram – single line

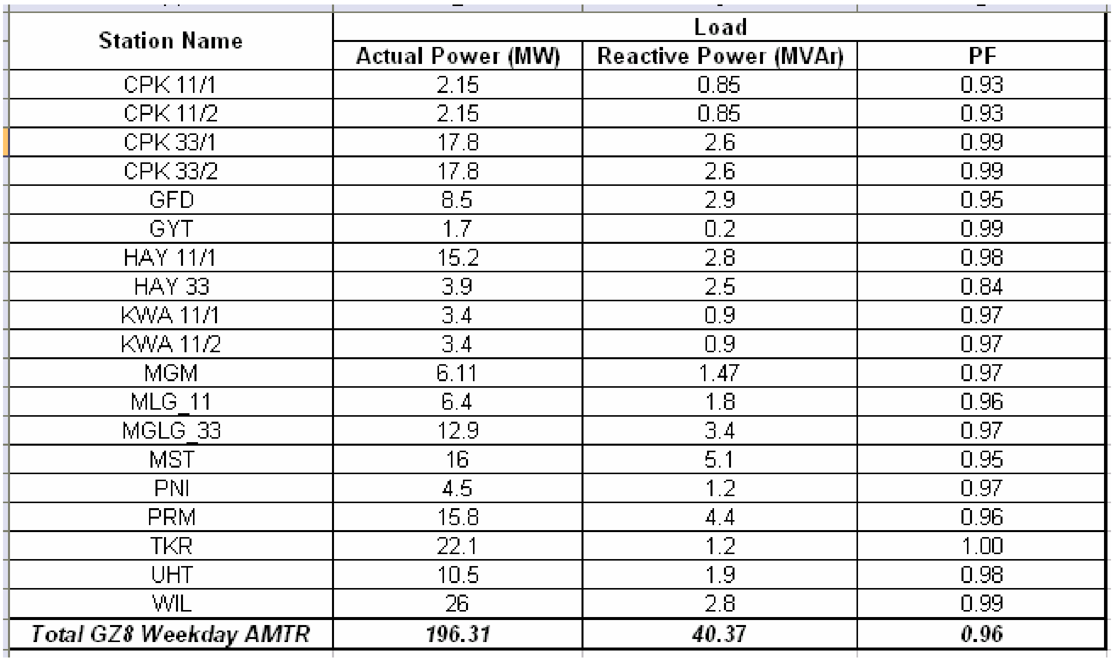


The diagram above shows the major 220kV circuits out of Bunnythorpe (highlighted red) and one of the major interconnecting transformers, Wilton T8 (circled in green).

System diagram – SPD model



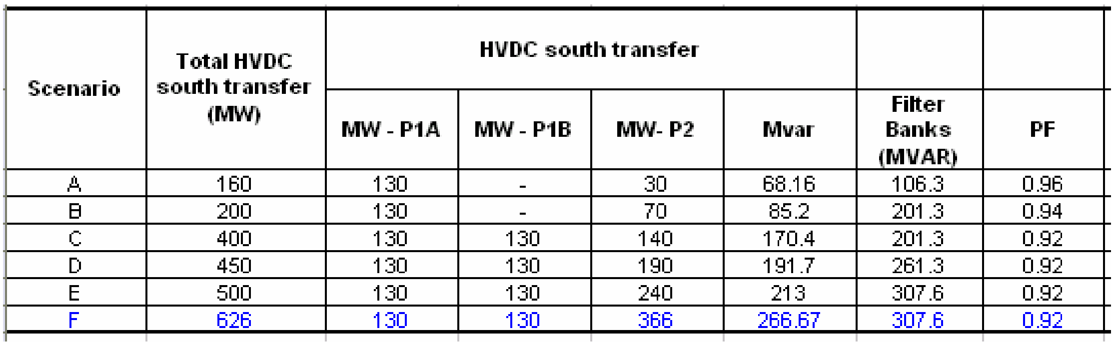
4.2.2 Initial Load Assumption



Station Name	Load		
	Actual Power (MW)	Reactive Power (MVAr)	PF
CPK 11/1	2.15	0.85	0.93
CPK 11/2	2.15	0.85	0.93
CPK 33/1	17.8	2.6	0.99
CPK 33/2	17.8	2.6	0.99
GFD	8.5	2.9	0.95
GYT	1.7	0.2	0.99
HAY 11/1	15.2	2.8	0.98
HAY 33	3.9	2.5	0.84
KWA 11/1	3.4	0.9	0.97
KWA 11/2	3.4	0.9	0.97
MGM	6.11	1.47	0.97
MLG_11	6.4	1.8	0.96
MGLG_33	12.9	3.4	0.97
MST	16	5.1	0.95
PNI	4.5	1.2	0.97
PRM	15.8	4.4	0.96
TKR	22.1	1.2	1.00
UHT	10.5	1.9	0.98
WIL	26	2.8	0.99
Total GZ8 Weekday AMTR	***196.31***	***40.37***	***0.96***

Note that with MGM_MST split the MGM load has been transferred outside of GZ8 and is no longer part of the total load.

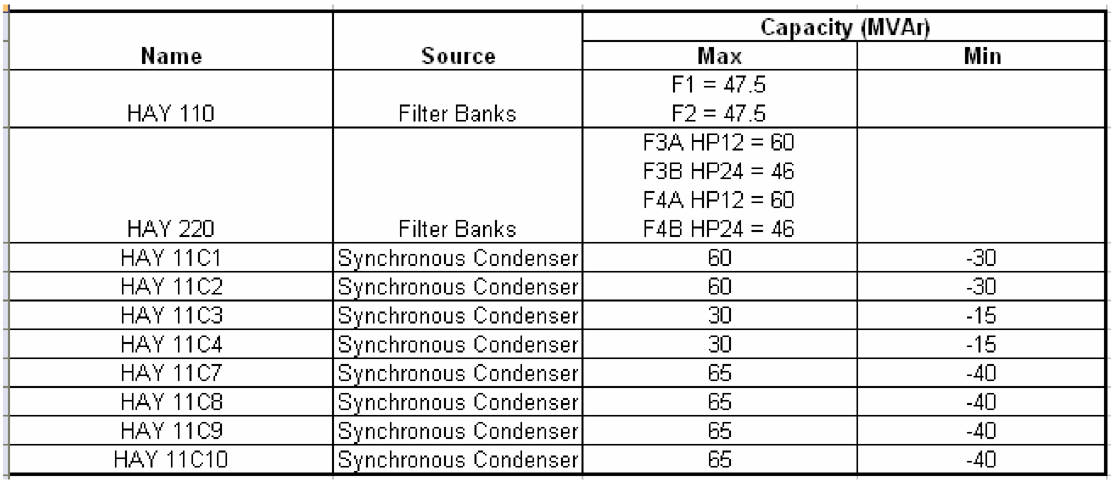
4.2.3 HVDC Transfer Levels:



Scenario	Total HVDC south transfer (MW)	HVDC south transfer					
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF
A	160	130	-	30	68.16	106.3	0.96
B	200	130	-	70	85.2	201.3	0.94
C	400	130	130	140	170.4	201.3	0.92
D	450	130	130	190	191.7	261.3	0.92
E	500	130	130	240	213	307.6	0.92
F	626	130	130	366	266.67	307.6	0.92

Note: HVDC pf is a variable that will change according to system configurations.

4.2.4 Reactive Sources at Haywards:



Name	Source	Capacity (MVAr)	
		Max	Min
HAY 110	Filter Banks	F1 = 47.5 F2 = 47.5	
HAY 220	Filter Banks	F3A HP12 = 60 F3B HP24 = 46 F4A HP12 = 60 F4B HP24 = 46	
HAY 11C1	Synchronous Condenser	60	-30
HAY 11C2	Synchronous Condenser	60	-30
HAY 11C3	Synchronous Condenser	30	-15
HAY 11C4	Synchronous Condenser	30	-15
HAY 11C7	Synchronous Condenser	65	-40
HAY 11C8	Synchronous Condenser	65	-40
HAY 11C9	Synchronous Condenser	65	-40
HAY 11C10	Synchronous Condenser	65	-40

Haywards Pole 1 AC Filters:

There are 2 × 47.5 MVAr 110kV AC harmonic filters associated with Pole 1 at Haywards, F1 and F2.

Under normal conditions the Haywards RPC will automatically connect one filter when Pole 1 is started and connect the other when the Pole 1 DC current reaches about 300 A. The second filter will be disconnected if the current falls below about 250A [1].

Haywards Pole 2 AC Filters:

There are 2 × 220kV AC harmonic filter banks associated with Pole 2 at Haywards, F3 and F4. Each bank is divided into 2 sub-banks.

F3A	HP12	60MVAr	11/13 th harmonic
F3B	HP24	46.3MVar	24th harmonic and high pass
F4A	HP12	60MVAr	11/13 th harmonic
F4B	HP24	46.3MVar	24th harmonic and high pass

Under normal conditions the Haywards RPC will automatically connect one 11/13th sub-bank and one 24th/HP sub-bank when Pole 2 is started. The second 11/13th sub-bank will be connected when the Pole 2 current reaches 720A and the second 24th/HP sub-bank will be connected when the current reaches about 1000A.

As the DC current falls the sub-banks are disconnected in reverse sequence at about 50 A below their respective connection levels [1].

4.2.5 Haywards Synchronous Condensers

Condensers C1, C2, C3, and C4 control the HAY 220kV voltage. Condensers C7, C8, C9, C10 are part of the HVDC system and perform the task of controlling the firing angle at 15 degrees at Haywards. In the load flow case, these condensers control the pole 1A and 1B DC voltages.

4.2.6 Circuit Outages

The following circuit outages are considered:

- No circuit outage
- BPE_LTN_HAY_3 circuit outage
- BPE_HAY_1 circuit outage
- BPE_HAY_2 circuit outage
- BPE_LTN_WIL circuit outage
- HAY_WIL circuit outage

Note, MGM_MST system split is considered in place.

The above circuit outages are considered most critical in terms of voltage instability in the Wellington region. The outage of BPE_LTN_HAY_3 being of particular concern.

4.3 Constraints

Whenever the 110 kV route between Masterton–Managmaire is split out of service, higher levels of transfer on the 220 KV network can occur. For this condition of higher transfer, it is voltage stability which sets the transfer limit into GZ8. In this situation, voltage stability constraints are applied in SPD to regulate the amount of scheduled transfer into GZ8. These constraints are classified as “outage” constraints and are to be applied whenever there is an outage of either the Mangamaire–Masterton circuit or the Managmaire-Woodville circuit. These constraints include all grid exit points south of and including Masterton and Paraparaumu on the 110kV system, and all grid exit points south of and excluding Linton on the 220kV system.

Mangamaire-Masterton outage constraint:
MGM_MST_1_WELLINGTON_STABILITY_O_1

MDE ID 23427

1 * BPE_HAY1.1 + 1 * BPE_HAY2.1 + -1 * BPE_HAY3.2 + 1 * BPE_WIL.2 <= 868 MW

The effect of this constraint is to manage flows through Bunnythorpe_Haywards 1 and 2, Bunnythorpe_Linton_Haywards 3 and Bunnythorpe_Wilton 1 circuits for a contingency of Bunnythorpe_Linton_Haywards 3 circuit during high HVDC south transfer for stability reasons when Mangamaire_Masterton is out of service. This voltage stability constraint covers all grid exit points south of and including Masterton and Paraparaumu on the 110kV system, and all grid exit points south of and excluding Linton on the 220kV system.

Mangamaire-Woodville outage constraint:
MGM_WDV_1_WELLINGTON_STABILITY_O_1

MDE ID 23428

1 * BPE_HAY1.1 + 1 * BPE_HAY2.1 + -1 * BPE_HAY3.2 + 1 * BPE_WIL.2 <= 868 MW

The effect of this constraint is to manage flows through Bunnythorpe_Haywards 1 and 2, Bunnythorpe_Linton_Haywards 3 and Bunnythorpe_Wilton 1 circuits for a contingency of Bunnythorpe_Linton_Haywards 3 circuit during high HVDC south transfer for stability reasons when Mangamaire_Woodville is out of service. This voltage stability constraint covers all grid exit points south of and including Mangamaire and Paraparaumu on the 110kV system, and all grid exit points south of and excluding Linton on the 220kV system.

Note: The RHS value of 868 MW allows for combined Wellington off-take and HVDC transfer of 820 MW, plus 48 MW of transmission losses.

4.4 Method of Conducting Studies

The variables in the study are the HVDC transfer levels and filter bank configurations which varied with the different HVDC transfer level. The Wellington load is increased at a step of 10MW (assuming constant power factor). All generation in the Northland (GZ1), Auckland (GZ2), Hamilton (GZ3), and Edgecumbe (GZ4) areas are increased to make up the load increase. The study is continued until load flow non-convergence is obtained where it is then assumed that load flow non-convergence is due to static voltage instability. The final load at which the load flow converged is considered the point of collapse (PoC) and sets the limit. This is standard practice for conducting a static PV analysis, and is the same method used in the “Revised Study on HVDC South Transfer” report [3].

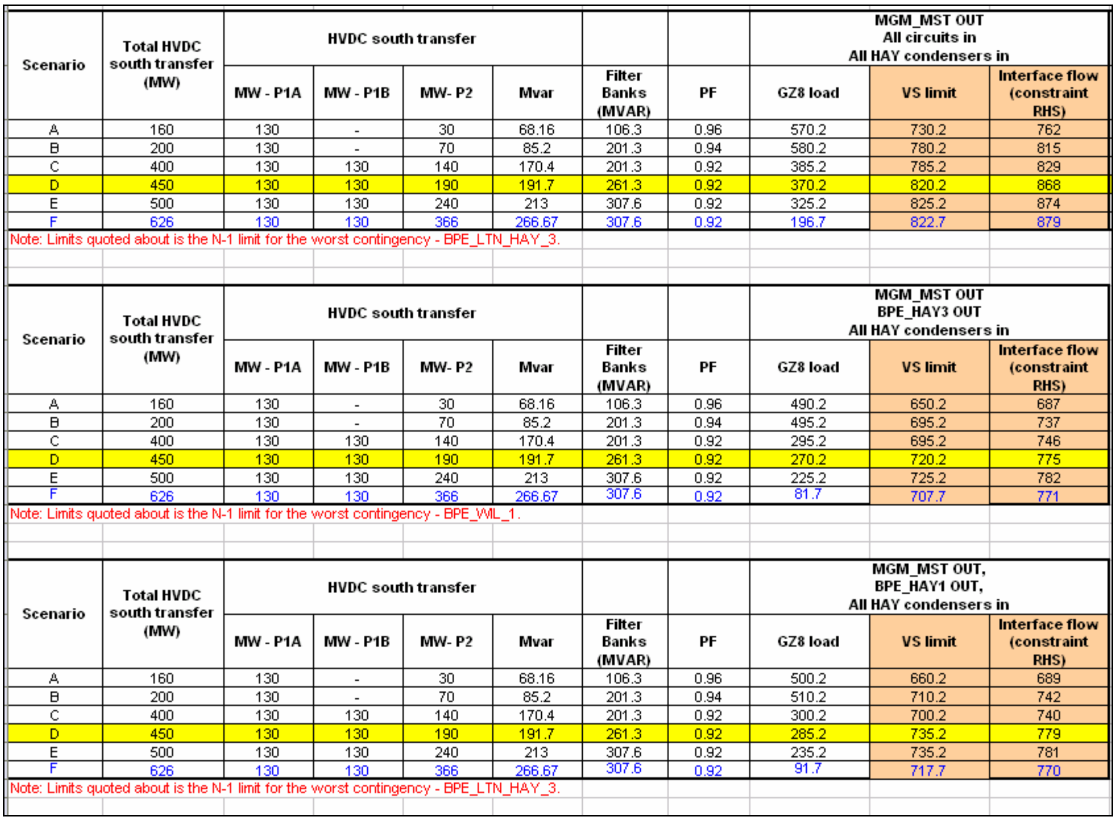
4.5 Voltage Stability Security Margin

A safety margin of 5% has been applied to these studies which is good electrical industry practice.

5. Results

5.1. Results for setting the constraint RHS for HVDC scheduling purposes:

The following results are **the security limits** for the given system configuration. The worst contingent event for each configuration is noted below each table.



Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT All circuits in All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	570.2	730.2	762
B	200	130	-	70	85.2	201.3	0.94	580.2	780.2	815
C	400	130	130	140	170.4	201.3	0.92	385.2	785.2	829
D	450	130	130	190	191.7	261.3	0.92	370.2	820.2	868
E	500	130	130	240	213	307.6	0.92	325.2	825.2	874
F	626	130	130	366	266.67	307.6	0.92	196.7	822.7	879

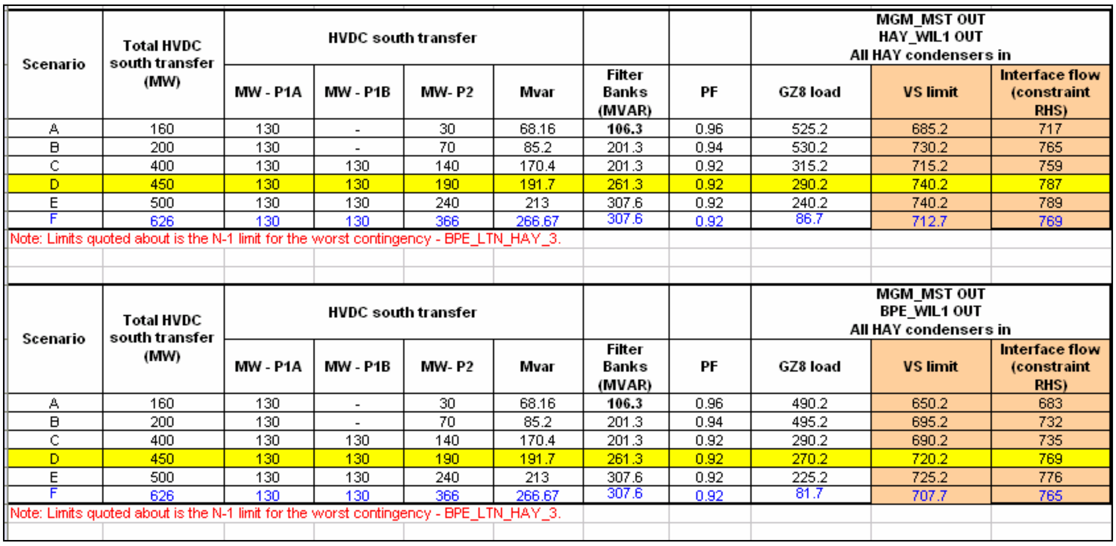
Note: Limits quoted about is the N-1 limit for the worst contingency - BPE_LTN_HAY_3.

Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT BPE_HAY3 OUT All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	490.2	650.2	687
B	200	130	-	70	85.2	201.3	0.94	495.2	695.2	737
C	400	130	130	140	170.4	201.3	0.92	295.2	695.2	746
D	450	130	130	190	191.7	261.3	0.92	270.2	720.2	775
E	500	130	130	240	213	307.6	0.92	225.2	725.2	782
F	626	130	130	366	266.67	307.6	0.92	81.7	707.7	771

Note: Limits quoted about is the N-1 limit for the worst contingency - BPE_WIL_1.

Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT, BPE_HAY1 OUT, All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	500.2	660.2	689
B	200	130	-	70	85.2	201.3	0.94	510.2	710.2	742
C	400	130	130	140	170.4	201.3	0.92	300.2	700.2	740
D	450	130	130	190	191.7	261.3	0.92	285.2	735.2	779
E	500	130	130	240	213	307.6	0.92	235.2	735.2	781
F	626	130	130	366	266.67	307.6	0.92	91.7	717.7	770

Note: Limits quoted about is the N-1 limit for the worst contingency - BPE_LTN_HAY_3.



Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT HAY_WIL1 OUT All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	525.2	685.2	717
B	200	130	-	70	85.2	201.3	0.94	530.2	730.2	765
C	400	130	130	140	170.4	201.3	0.92	315.2	715.2	759
D	450	130	130	190	191.7	261.3	0.92	290.2	740.2	787
E	500	130	130	240	213	307.6	0.92	240.2	740.2	789
F	626	130	130	366	266.67	307.6	0.92	86.7	712.7	769

Note: Limits quoted about is the N-1 limit for the worst contingency - BPE_LTN_HAY_3.

Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT BPE_WIL1 OUT All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	490.2	650.2	683
B	200	130	-	70	85.2	201.3	0.94	495.2	695.2	732
C	400	130	130	140	170.4	201.3	0.92	290.2	690.2	735
D	450	130	130	190	191.7	261.3	0.92	270.2	720.2	769
E	500	130	130	240	213	307.6	0.92	225.2	725.2	776
F	626	130	130	366	266.67	307.6	0.92	81.7	707.7	765

Note: Limits quoted about is the N-1 limit for the worst contingency - BPE_LTN_HAY_3.

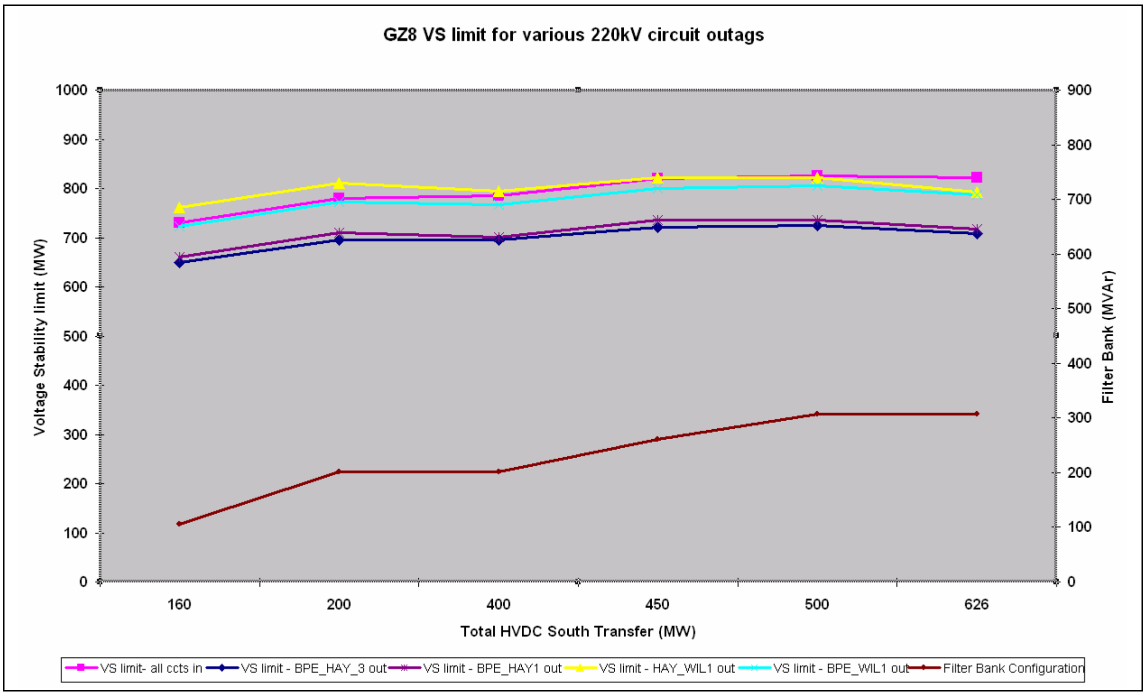


Figure 4.1: GZ8 voltage stability limit curve

Figure 4.1 shows the voltage stability limit curve. The limits are derived by balancing the GZ8 load and the HVDC level of transfer at the time.

From the above figure, it suggests that as the HVDC south transfer level and GZ8 load level increase, more filter banks are required to help with reactive support, which in turn increases the voltage stability limit for the region. However, one of the main characteristics of shunt capacitors is that beyond a certain level of compensation (~400MW south transfer in this case), stable operation is unattainable with shunt capacitors – meaning that as the HVDC south transfer increases up to and beyond this point (~400MW), the effect of the shunt capacitors providing more reactive support into the system is minimal.

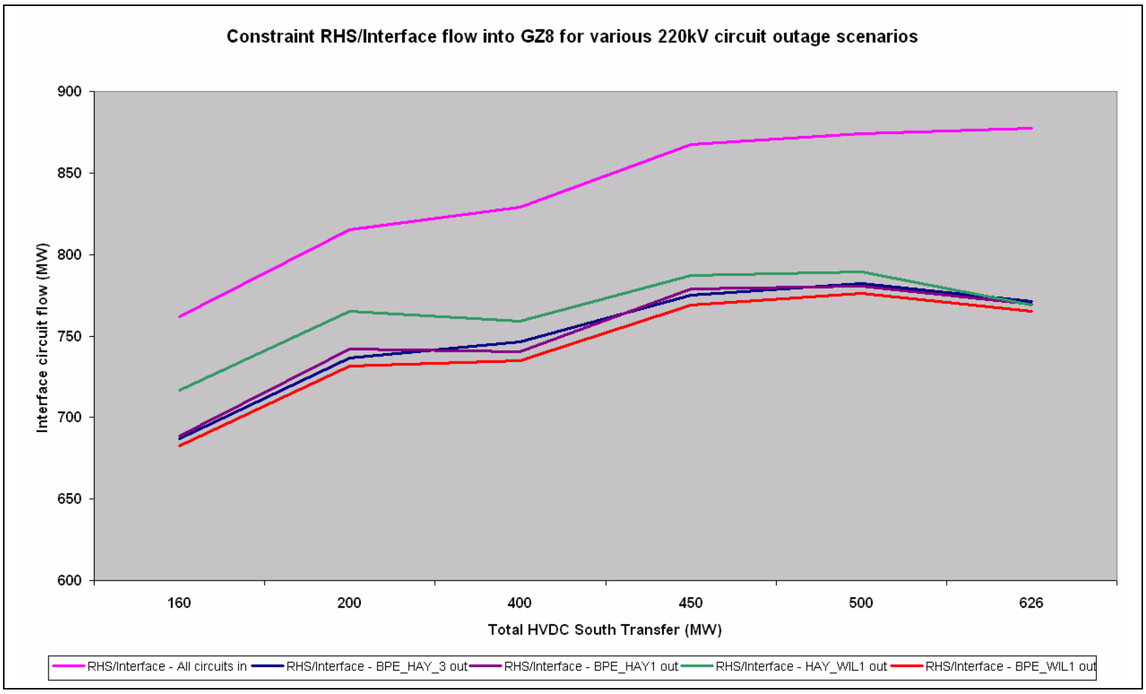


Figure 4.2: Constraint RHS/Interface flow into GZ8 for various 220kV circuit outage scenarios

The constraint RHS figure equates to the interface flow defined (circuits into GZ8 from BPE). In this case: BPE_HAY1&2, BPE_LTN_WIL, BPE_LTN_HAY3 and HAY_WIL circuits/segments.

5.2. Theoretical limits into Wellington with all equipment in service except for the 220kV circuit outages noted below

						Winter Transfer Limit		Summer Transfer Limits	
BPE_HAY_1	**BPE_HAY_2**	**BPE_HAY_3**	**BPE_WIL_1**	**MGM_WDV.1**	**MGM_MST.1**	**Thermal**	**Stability**	**Thermal**	**Static**
1	1	1	1	1	1	846		655	
1	1	1	1	1	out		868		868
out	1	1	1	1	1	705		560	
1	out	1	1	1	1	705		560	
1	1	out	1	1	1	650		520	
1	1	1	out	1	1	670		530	
out	1	1	1	1	out		779		779
1	out	1	1	1	out		779		779
1	1	out	1	1	out		775		775
1	1	1	out	1	out	690		660	

Notes:

1. All transfer limits given are pre-event transfer to meet the requirements of the SO Policy Statement for the worst contingent event.
2. In some of the scenarios WIL_T8 exceeds it's MCR but is still within its 24 hour rating. WIL_T8 rating is 110/139/147.
3. All **thermal** limits prevent MGM_WDV from overloading in steady state.
4. These limits are applicable from 17 May 2006 (new ratings of BPE_HAY_1&2 implemented).
5. These limits account for **all equipment** being available, i.e. all Haywards condensers. Outages are as noted in the table.
6. For concurrent BPE_WIL and MGM_WDV outage, thermal limit is based on BPE_HAY_3 contingency overloading BPE_HAY_1 or 2.
7. Stability limits assume 450 MW HVDC South transfer and HAY filter bank availability of 261 MVAr.
8. These are **transmission transfer** limits into GZ8 which summate the line loadings on MGM_WDV, LTN_WIL, HAY_LTN_3, BPE_HAY_1, and BPE_HAY_2 during HVDC south transfer.

6. Results Validation.

This study has been validated against a previous study of transfer limits into Wellington undertaken by Ruth English and Bhujanga B Chakrabarti, July 2003 [3].

In validating these results a comparison was made between the two studies using the power system limit for a contingency of the BPE_HAY_3.

The key differences are summarised in the following table and are attributed to:

1. Wilton T8. Current practice is to remove WIL T8 from service pre-event to ensure the post contingent rating is not exceeded. Load growth of the Wellington 110 kV region in recent years can require WIL T8 to be removed from service, particularly at times of DC transfer south coinciding with high Wellington region load.

2. Capacitors connected at limit of transfer. Haywards capacitor switching is regulated by the HAY RPC. The point at which maximum transfer is achieved into GZ8 corresponds to a DC south transfer of approx 450 MW (noting higher levels of transfer can be achieved for lower Wellington load). At this level of DC transfer the minimum capacitor requirement of the RPC is for +261 MVArs. An additional +46 MVar’s can be connected for higher levels of DC transfer, however this can only be achieved with lower Wellington load, hence the connection of the last +46 MVAr’s assists DC transfer south but provides minimal benefit for overall transfer into GZ8.

3. Mangamaire – Masterton reconfiguration. To maximise transmission capacity into GZ8, the Grid Owner can seek agreement to reduce MGM & MST to single circuit supply by removing the MGM_MST cct at times of sustained high DC south transfer. This is assumed in this study. The trade off with achieving a higher level of transfer into GZ8, is that MGM_MST connection is no longer available to provide post contingent voltage support into GZ8 following a contingency of BPE_HAY_3.

4. New Plymouth generation. While some NPL generation could be expected during a DC south scenario the decommissioning of unit 1 means maximum availability is now 337 MW. Actual peak NPL generation would be determined by the combined effect that regional load and local generation has on transmission constraints out of Taranaki. The benefit of NPL generation to GZ8 voltage stability limits is minimal

Other sources of mismatch (-25 MW) are expected from the difference between the two modelling systems (PSS/E and EMS/SCADA with VSAT). While both conduct static PV analysis, the method in which they scale load and generation to find the voltage point of collapse (PoC) is different. The generation and load scenarios used in these studies have been selected to minimise these differences whilst retaining an accurate account of current system conditions.

Validation Table

	Note	**2003 Report**	**2006 Report**	**Delta transfer limit (2006 report)**
Analysis Tool used		PSS/E	VSAT	
1.Load	Loaf pf	WGTN 0.97	WGTN 0.96	
		HVDC 0.92	HVDC 0.92	
	Load increased	Scaled both loads together, constant pf, HVDC:WGTN=3:2 ratio	HVDC fixed, WGTN load scaled	
2. Caps at limit		305	261.3	-5 MW
3. Contingent Event		BPE_HAY_3	BPE_HAY_3	
4. Outages		Nil	WIL T8 MGM_MST re-configuration.	-30 MW -5 MW
5.Gen scenario		NPL = 450 MW (4 units) SFD = 350 MW	NPL = 0 MW (3 units) SFD = 380 MW	-5 MW
Difference Total				-45 MW
VS Limit Comparison	Load Limit = PoC-Safety margin	Load limit = 890 MW	Load limit = 820 MW	-70 MW
Mismatch*				-25 MW (-3%)

***Mismatch = VS Limit Comparison-Difference Total**

Table 6.1: Comparison of two studies

7. Summary

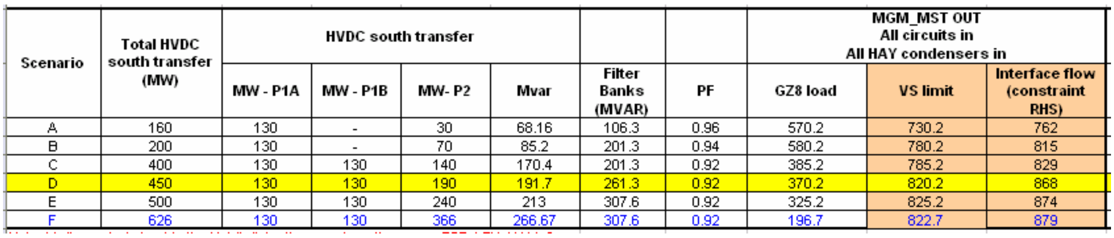
7.1 Overall Limits

<u>With no circuit outage:</u>

The voltage stability limit ranges from 730MW to 825MW depending on the HVDC transfer level and the reactive support availability. This then corresponds to total interface flow ranging from 762MW to 874MW, allowing for losses in the network of around 40MW.

<u>All circuits in service:</u>

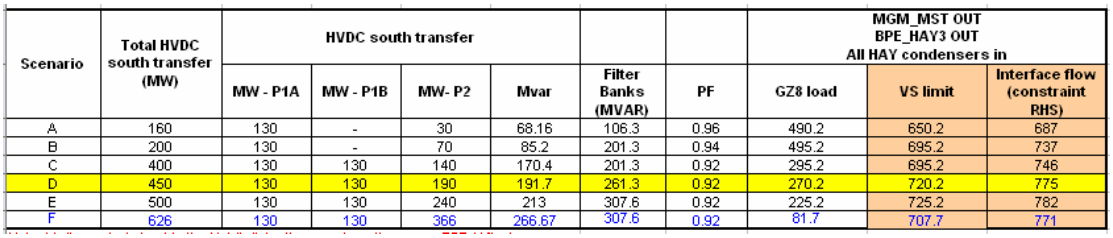
The limits below are the voltage stability limit for GZ8 covering for a contingent event of BPE_HAY_3.



Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT All circuits in All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	570.2	730.2	762
B	200	130	-	70	85.2	201.3	0.94	580.2	780.2	815
C	400	130	130	140	170.4	201.3	0.92	385.2	785.2	829
D	450	130	130	190	191.7	261.3	0.92	370.2	820.2	868
E	500	130	130	240	213	307.6	0.92	325.2	825.2	874
F	626	130	130	366	266.67	307.6	0.92	196.7	822.7	879

<u>With BPE_HAY_3 outage:</u>

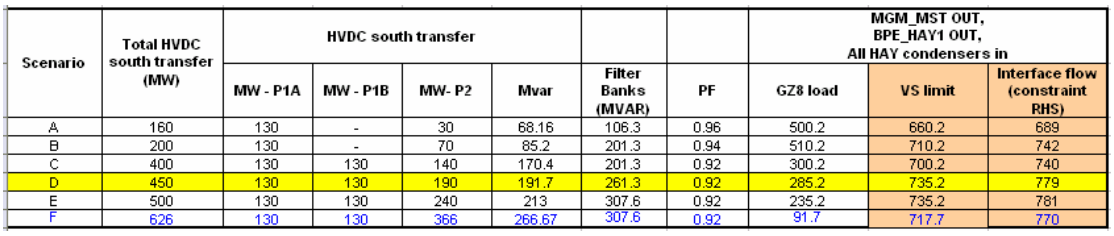
The voltage stability limit ranges from 650 – 725MW depending on the HVDC transfer level and the reactive support availability. This then corresponds to total interface flow ranging from 687 – 782MW, allowing for losses in the network of up to 63MW.



Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT BPE_HAY3 OUT All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	490.2	650.2	687
B	200	130	-	70	85.2	201.3	0.94	495.2	695.2	737
C	400	130	130	140	170.4	201.3	0.92	295.2	695.2	746
D	450	130	130	190	191.7	261.3	0.92	270.2	720.2	775
E	500	130	130	240	213	307.6	0.92	225.2	725.2	782
F	626	130	130	366	266.67	307.6	0.92	81.7	707.7	771

<u>With BPE_HAY_1 or 2 outage:</u>

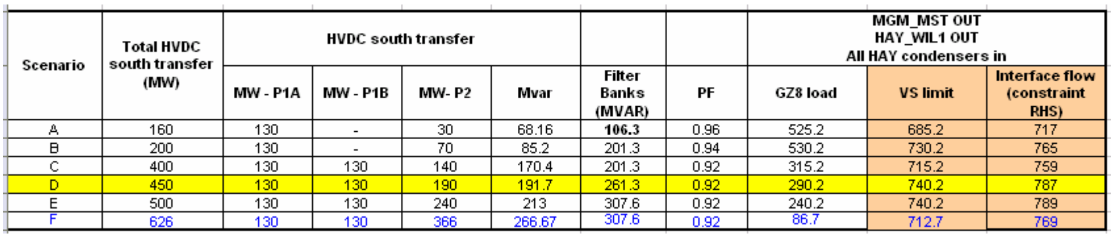
The voltage stability limit ranges from 660 – 735MW depending on the HVDC transfer level and the reactive support availability. This then corresponds to total interface flow ranging from 689 – 781MW, allowing for losses in the network of up to 53MW.



Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT, BPE_HAY1 OUT, All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	106.3	0.96	500.2	660.2	689
B	200	130	-	70	85.2	201.3	0.94	510.2	710.2	742
C	400	130	130	140	170.4	201.3	0.92	300.2	700.2	740
D	450	130	130	190	191.7	261.3	0.92	285.2	735.2	779
E	500	130	130	240	213	307.6	0.92	235.2	735.2	781
F	626	130	130	366	266.67	307.6	0.92	91.7	717.7	770

<u>With HAY_WIL_1 outage:</u>

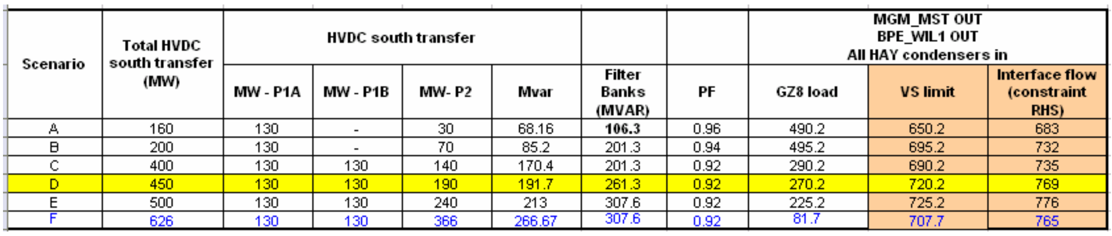
The voltage stability limit ranges from 685 – 740MW depending on the HVDC transfer level and the reactive support availability. This then corresponds to total interface flow ranging from 717 – 789MW, allowing for losses in the network of around 57MW.



Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT HAY_WIL1 OUT All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	**106.3**	0.96	525.2	685.2	717
B	200	130	-	70	85.2	201.3	0.94	530.2	730.2	765
C	400	130	130	140	170.4	201.3	0.92	315.2	715.2	759
D	450	130	130	190	191.7	261.3	0.92	290.2	740.2	787
E	500	130	130	240	213	307.6	0.92	240.2	740.2	789
F	626	130	130	366	266.67	307.6	0.92	86.7	712.7	769

<u>With BPE_WIL_1 outage:</u>

The voltage stability limit ranges from 650 – 725MW depending on the HVDC transfer level and the reactive support availability. This then corresponds to total interface flow ranging from 683 – 776MW, allowing for losses in the network of around 60MW.



Scenario	Total HVDC south transfer (MW)	HVDC south transfer						MGM_MST OUT BPE_WIL1 OUT All HAY condensers in		
		MW - P1A	MW - P1B	MW- P2	Mvar	Filter Banks (MVAR)	PF	GZ8 load	VS limit	Interface flow (constraint RHS)
A	160	130	-	30	68.16	**106.3**	0.96	490.2	650.2	683
B	200	130	-	70	85.2	201.3	0.94	495.2	695.2	732
C	400	130	130	140	170.4	201.3	0.92	290.2	690.2	735
D	450	130	130	190	191.7	261.3	0.92	270.2	720.2	769
E	500	130	130	240	213	307.6	0.92	225.2	725.2	776
F	626	130	130	366	266.67	307.6	0.92	81.7	707.7	765

Note: These RHS figures will be used in real time for scheduling purposes.

To conclude, outages on BPE_HAY_3 and BPE_WIL 1 have the largest effect on voltage stability on GZ8 as expected being the largest circuit out of BPE. Outage of this circuit drops the voltage stability limit by ~ 60MW.

Outages on BPE_HAY 1 and 2 are not as significant as the previous two circuits as they have a lower rating, nevertheless, outages on these two circuits drops the voltage stability limit by up to ~ 45MW.

7.2 Options to enhance limits

There are some further options available which may provide an incremental increase in GZ8 transfer limits, which would require further investigation. Initial options to consider would be the manual connection of HAY capacitors at certain times to provide additional reactive support to GZ8. Another option is the use of an intertrip scheme for WIL T8 to manage post contingent loading. This would allow WIL T8 to remain in service at times of higher system loading.

8. References

[1] HVDC: Bipole Operating Policy, revision 4, 29 April 1998

[2] Power System Stability and Control – Prabha Kundur

[3] Revised Study on HVDC South Transfer – Voltage Stability and Thermal Overload Limits with Outages of Synchronous Condensers. Prepared by Ruth English and Bhujanga Chakrabarti, 2004.