Assessment of Potential Security Risks due to High Levels of Wind Generation in South Australia

Markus Pöller[1] Holger Müller[1] Koos Theron[2] Paul Ravalli[3] Andrew Robertson[3]
m.poller@digsilent.de h.mueller@digsilent.de koos@digsilent.com.au Paul.Ravalli@nemmco.co.au Andrew.Robertson@nemmco.co.au

1 Introduction

In February 2005, the Australian National Grid Operator NEMMCO engaged DIgSILENT to carry out power system stability studies to assess the impact of high levels of wind generation on the South Australian power transmission system. This follows indications that more than 1000 MW of wind generation capacity may be connected to the South Australian grid within the next few years. This was a concern as the South Australian load varies between a forecast peak demand of 3378 MW for summer of 2005/06 and a minimum demand as low a 900MW.

The scope of this work was to review how large amounts of wind generation could affect the stability performance of the power system, in order to determine

- What future operational and power system security issues could arise;
- In broad terms, the extent of these impacts; and
- Whether there may be a fundamental limit to the amount of wind generation that could be supported.

The scope of the work was limited to power system stability only – i.e. issues that could affect wide areas of the South Australian power system. While localised issues were noted, it was considered that these need to be managed on a case by case basis.

2 Scope of Investigation

The work was aimed at determining:

- What are the critical stability mechanisms that could significantly impact operation of the South Australian transmission system;
- Whether the existing stability mechanisms change fundamentally or new stability mechanisms emerge;
- What is the trend for increased wind installation, in order to understand what level of wind generation may cause significant changes to network limits or other operational difficulties, and whether there is a fundamental limit to installed wind capacity in South Australia.

The scope was limited to:

- An assessment of transmission system issues only – that is, impacts that can affect a wide area. While localised impacts must be dealt with, this was considered to be the subject of other, more detailed studies;
- The assessment of power system stability. Thermal limitations were not studied;
- A limited (but broad) number of scenarios and faults were studied. This is in line with the basic aims of understanding stability mechanisms and how they may change.

Simulations were conducted for high and low load cases for 0 MW; 400 MW; 800 MW and 1200 MW of wind generation respectively. The capability to transfer power between Victoria and South Australia can be used as a measure for the impact of wind generation on power system stability in South Australia. The transfer capability of the "base" case (no installed wind generation) for each major contingency is compared with the transfer capability for each of the 400MW, 800MW and 1200MW wind scenarios for the same contingencies. An increase in the transfer capability, and the extent of that increase, is a measure of the improvement in stability, whereas a decrease is a reduction in stability.

---

[1] DIgSILENT GmbH – Heinrich-Hertz-Str. 9, 72810 Gomaringen, Germany – www.digsilent.de

[2] DIgSILENT Pacific - Suite 310, 370 St Kilda Road, Melbourne, Victoria, 3004, Australia – www.digsilent.com.au

[3] NEMMCO - Level 12, 15 William St. , Melbourne, Victoria, 3000, Australia

In the development of the wind scenarios, it has been assumed that wind generation will displace the existing scheduled generators. That is, when a wind farm is generating power, the most expensive scheduled generator(s) in South Australia will reduce their output by an equivalent amount and, if necessary, will disconnect from the power system. In the scenarios, the installed wind farms are assumed to be operating at their maximum generation. Hence, in the 400MW, 800MW and 1200MW wind scenarios scheduled generation of those amounts are assumed to be disconnected from the power system. This approach could only be applied provided:

- There was sufficient scheduled generation to be displaced;
- A minimum amount of scheduled generation remained on line.

Approximately 400-500MW of scheduled generation was assumed to remain on line, operating at minimum load. This takes into account:

- Some generators remain on line at minimum load in spite of low market costs, due to the cost of restarting the unit; and
- An expectation that some generators may stay on line to protect their commercial positions under contract.

While it is more likely that South Australia would be exporting power to Victoria during high wind and access generation conditions, it was still necessary to determine the operating envelope of South Australian import limits.

For the 800MW and 1200MW wind scenarios and low load in South Australia therefore, import into South Australia is limited or no power import into South Australia will occur. For these cases, therefore, South Australian demand was increased to accommodate the minimum scheduled generation, the installed wind generation and the imported power – demand was increased in the low load cases to approximately 1600MW and 2000MW, respectively, representing conditions which would be classified as medium, rather than low, demand.

Murray link was assumed to be dispatched at 0MW, though its dynamic impacts were considered.

3 Results of Study

3.1 Impact on South Australian Export Capability

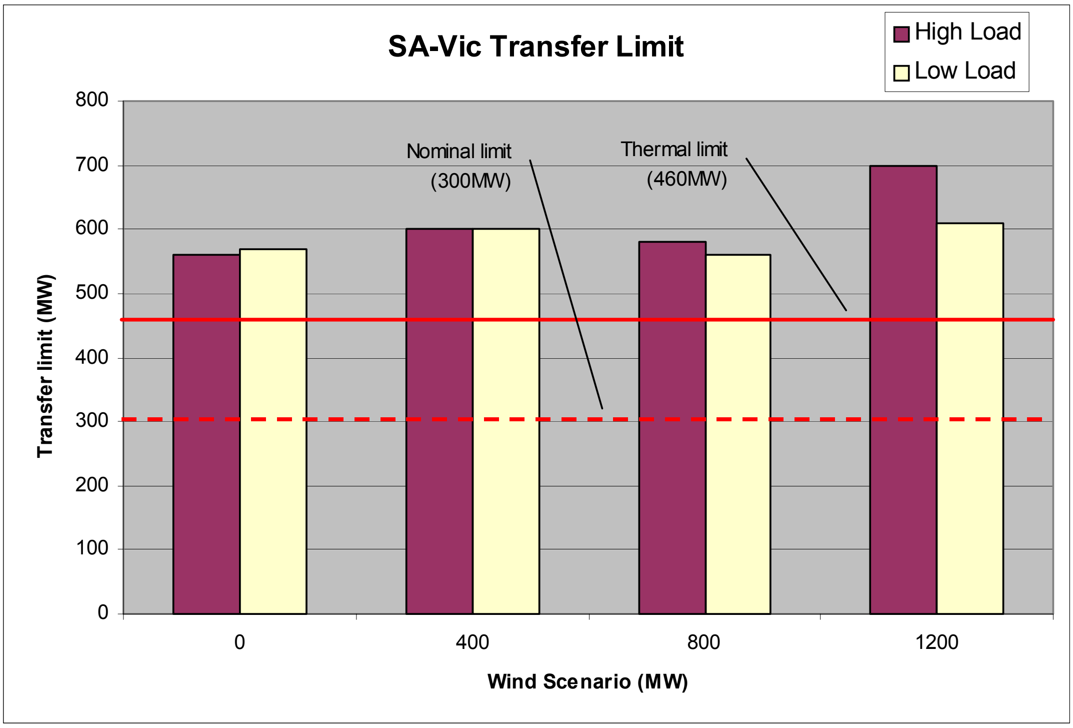

Figure 1 - South Australian export transient stability limit

During high wind generation in South Australia it is anticipated that power will be exported during most times. Therefore wind generator impact on export limits was the first issue to be addressed.

At present, power export between SA and VIC is limited by the thermal limit of the SA-VIC interconnector. A further possible limit could be due to transient stability constraints between SA and VIC.

The following contingencies have been assessed:

- Fault and trip of the Tailem Bend–South East substation 275kV transmission line; and
- Fault and trip of the Moorabool–Heywood–Alcoa Portland 500kV transmission line.

Based on the transient stability analysis, the effect of wind generation tends to have a beneficial influence on transient stability constrained export limits, as shown in Figure 1. This is due primarily to the decoupling between the mechanical components of the generator and the network resulting in a reduced increase of kinetic energy stored in South Australian synchronous generators at fault clearance.

3.2 Impact on South Australian Import Capability

Even if most cases with high wind generation in SA power will be exported to VIC, it is necessary to analyse the impact of wind generation in SA on voltage stability constraint import limits in order to determine the operating envelope of the power system.

The most severe stability effects limiting power import into SA are related to short-term and long-term voltage stability effects.

In most cases, the loss of large South Australian power plants is the critical contingency. The resulting increased power transfer can lead to the following effects resulting in a South Australian system collapse:

- Violation of static stability limits across the VIC-SA interconnector right after the generator outage and to a subsequent system collapse (time frame of a few seconds, short-term voltage stability problem)
- Violation of static stability limits across the VIC-SA interconnector in the long-term, when excitation current limiters limit the maximum reactive power output of synchronous generators and hence voltage is reduced.
- Reactive reserve problem in the Adelaide area because the reactive power of SVCs, switched shunts and remaining synchronous generators is not sufficient to provide the reactive power demand in the Adelaide area (long-term effect).

Besides loss of a large power station in SA, the trip of lines importing reactive power from VIC to SA can be critical too.

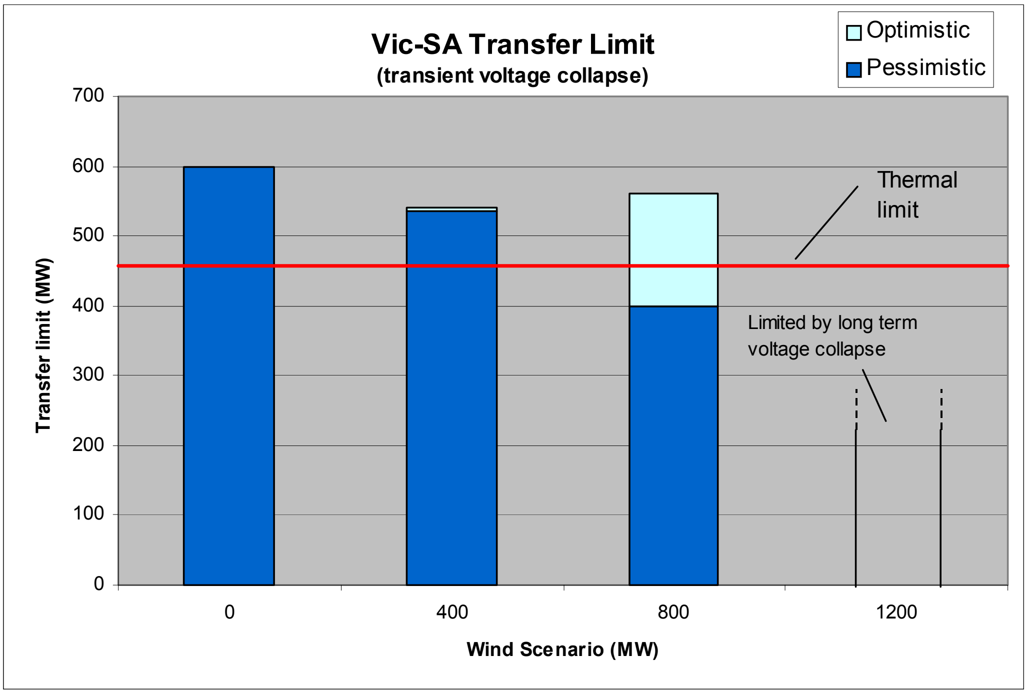

Figure 2 – Impact on short-term voltage stability constrained import limits (high-load case)

3.2.1 Impact on Short-Term Voltage Stability Limits

The following disturbances were analysed for analysing short-term voltage stability effects:

- Trip of a Northern Power Station generator (near Davenport) (operating at maximum output prior to the trip).
- Fault and trip on the Davenport to Northern Power Station line feeding the Northern Power Station generator

Figure 2 shows that there is a trend towards lower import limits with increasing amount of wind generation in South Australia. In the 1200MW case, the long-term voltage stability limit is reached without contingency before any short-term voltage stability problem can be observed due to the described reactive power deficit in SA.

The different results for “Optimistic” and “Pessimistic” refer to optimistic and pessimistic assumptions with regard to wind generator behaviour and local problems that have been found in sub-transmission networks surrounding the wind farms leading to the disconnection of wind-farms following the initial contingency.

The “optimistic” results assume that all wind generators behave as designed and that the sub-transmission networks will be properly designed.

“Pessimistic” results were obtained using preliminary modelling data of the subtransmission networks and wind-farms.

Hence, with regard to “feasibility” the “optimistic” results are relevant. “Pessimistic” results especially highlight the relevance of “low voltage ride-through capability” of all wind farms under all voltage variations that can occur if the system is operated close to voltage stability limits.

3.2.2 Impact on Long-Term Voltage Stability Limits

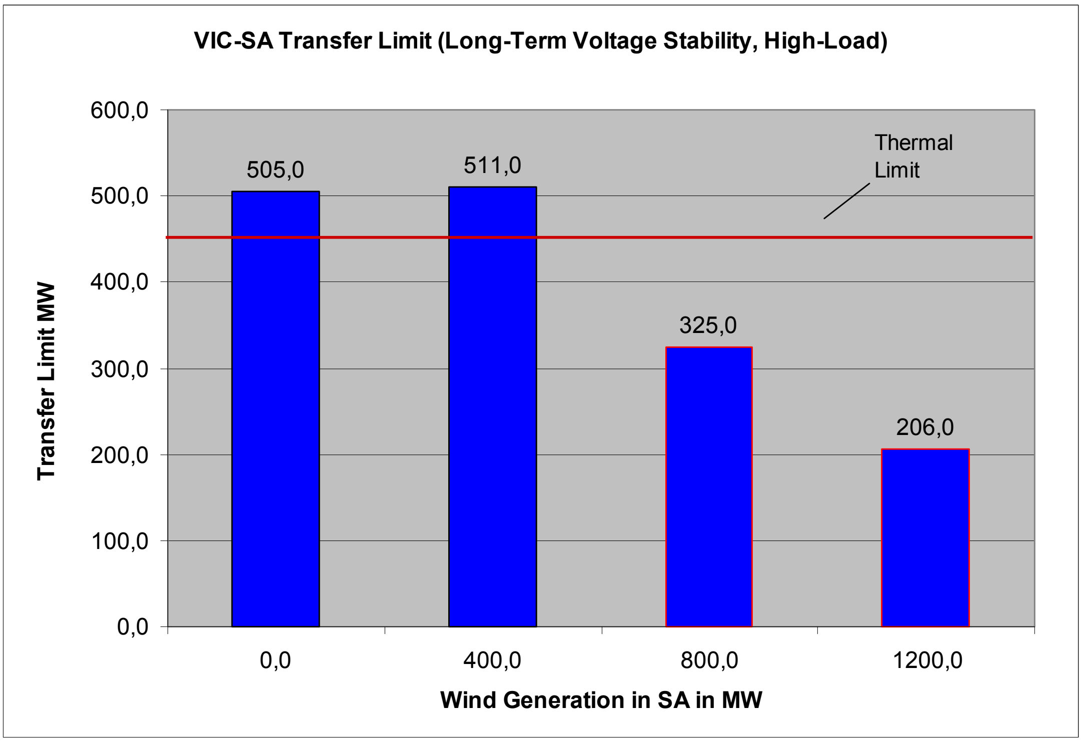

Figure 3: Impact on Long-Term Voltage Stability Constrained Import Limits

In the long term, reactive power output of synchronous generators is mainly limited by excitation current limiters of synchronous generators. Hence, reactive power output of synchronous generators is substantially lower in the long-term than in the short-term, which can drive the system into a long-term voltage collapse, even if it survives a contingency in the short-term. On the other hand, the system is supported by switchable shunts providing additional reactive power, which is not available in the short-term. Hence, both effects, long-term and short-term effects have to be analysed.

Long term voltage stability was analysed using PV-curves. It was assumed that no wind generator trips off and that a power outage is entirely compensated by generators outside SA. (ie.: across Heywood)

Long term voltage stability was investigated for the following disturbances:

- Trip of a Northern Power Station generator (near Davenport) (operating at maximum output prior to the trip).
- Trip of a Torrens B Power Station generator (near Adelaide) (operating at maximum output prior to the trip).
- Trip of a Tailem Bend to South East Substation 275kV transmission line in South Australia;
- Trip of a Moorabool-Heywood-Alcoa Portland 500kV line in Victoria.

The lowest transfer limit determined for all of these disturbances for each of the scenarios is shown in Figure 3.

There are three important features of the trend shown:

- There is a steady reduction in transfer capability as more wind generation operates;
- The critical contingency changes from the current critical contingency of loss of a Northern Power Station generator to transmission related contingencies for higher levels of wind generation; and
- Under the high demand and 1200MW wind scenario the stability mechanism changes from being managed through interconnector transfers to being a voltage collapse in the Adelaide metropolitan area.

These effects are due to the steady depletion of reactive power reserves available to the 275kV network. The displacement of scheduled generators mentioned above results in the removal of the static and dynamic reactive support provided by those generators. Reactive power reserves and the ability of the system to regulate the voltage are reduced because of the limited ability of generators embedded in sub-transmission systems to provide reactive power for supporting the voltage at the transmission level.

3.3 Impact on South Australian Frequency when Suddenly Islanded

The loss of the Vic-SA interconnector is a credible contingency event under some conditions. This occurs, for example, during storm activity in the vicinity of the interconnector, or when there is a critical line out of service (as a forced or planned outage). During these times, if the South Australian import is greater that 250MW, the transfer is reduced to 250MW. Should the interconnecter be tripped under these conditions, the frequency in the South Australian power system will drop rapidly.

The inertia in South Australia is significantly reduced under high wind generation conditions. This will have an influence on the rate of change of power system frequency for the loss of the interconnector. An analysis has been carried out to determine the impact on frequency rates of change under the various wind scenarios, compared with the base (no wind) case. The results are shown in Table 1.

Table 1 - Frequency rates of change in South Australia for loss of the Vic-SA interconnector

Scenario		Base (0 MW)	400 MW	800 MW	1200 MW
High Load	Rate of frequency decline (Hz/sec)	0.30	0.34	0.38	0.42
	Increased rate (compared to Base)		13%	27%	40%
Low Load	Rate of frequency decline (Hz/sec)	0.54	0.70	0.74	0.84
	Increased rate (compared to Base)		30%	37%	55%

There is no specific comment that can be made at this stage in terms of any impact in South Australia due to the increased frequency rate of change, except that this effect would need to be taken into account in any review of under-frequency load shedding arrangements for South Australia.

3.4 Impact on Other NEM Inter-connectors

A review of the effect on several other inter-connectors has also been undertaken, to determine whether there may be significant issues for other NEM regions.

3.4.1 Impact for faults outside of South Australia

Several inter-connectors have constraint equations for transient stability limits, with explicit terms associated with South Australian inertia. These are the Vic-Snowy interconnector and the NSW-Snowy interconnector. According to the constraint equations, a reduction in the South Australian inertia will reduce the transient stability limits of both of these inter-connectors, although the Vic-Snowy interconnector shows a higher sensitivity. The results showed that the impact on the Vic-Snowy is a slight reduction for increased wind generation, as expected from the constraint equation, and relatively small (around 60-70MW).

3.4.2 Impact on inter-area oscillatory modes

The least damped NEM inter-area oscillatory mode is the one associated with the Queensland–New South Wales interconnector (QNI). This mode has been assessed using eigenvalue analysis, and the contingency in this case was the loss of one of the parallel Queensland–New South Wales lines.

The damping criterion for inter-area oscillatory stability requires that oscillations be damped with a 5 second halving time [1].

The results show that under high load conditions there may be some reduction in damping, although relatively small (less than 0.01nepers/s). In order to put this into perspective, the Inter-Regional Planning Committee guidelines for material inter-network impacts for network augmentations [2] nominates that a material impact is a shift of 0.01nepers/s or more towards the unstable half-plane (to the right of the y-axis). While the guidelines apply to network augmentations only, it indicates that the installation and operation of 1200MW of wind generation in South Australia would not be considered as a “material impact”. Under light load conditions, there is a significant improvement to the QNI mode.

4 Conclusion

The report analysed the impact of wind generation in South Australia on different stability effects. The impact on the following stability effects that have been analysed are:

1. Transient stability constrained export limits SA->VIC
2. Short-term voltage stability constrained import limits SA <-VIC
3. Long-term voltage stability constrained import limits SA <-VIC
4. Frequency stability in SA in case of loss of the VIC-SA AC-interconnector
5. Oscillatory stability (QNI mode)
6. Transient stability transfer limits outside SA (VIC-Snowy interconnector)

Potential security risks could be identified in case of 2.) and 3.) (voltage stability problems during high import conditions), which are mainly related to reduced reactive power voltage control capability in SA as more synchronous generators are substituted by wind generators. It is also shown that item 4.) (frequency stability) can potentially become a critical issue but more analysis has to be carried out in this regard.

The report found that the introduction of wind generation has a limited impact on system stability that can be managed through the introduction of suitably design reactive power support systems. Voltage ride-through of generators is of critical importance to transmission systems.

5 References

[1] “National Electricity Code” Version 1 Amendment 9.6, National Electricity Code Administrator, May 2005.

[2] “Final Determination: Criteria for Assessing Material Inter-Network Impact of Transmission Augmentations”, Material Inter-network Impact Working Group, Inter-Regional Planning Committee, October 2004.

[3] “Assessment of Potential Security Risks due to High Levels of Wind Generation in South Australia - Stage 1.1”, DIgSILENT, June 2005.

[4] “Assessment of Potential Security Risks due to High Levels of Wind Generation - Stage 1.2”, DIgSILENT, September 2005.