THE UNIVERSITY OF QUEENSLAND
AUSTRALIA

The University of Queensland (UQ)

Submission on the

ElectraNet South Australian Energy Transformation

RIT-T Project Specification Consultation Report

27 February 2017

We are pleased to submit the following comments and suggestions on ElectraNet's Project Specification Consultation Report for their South Australian Energy Transformation Investigation [1, 2]. It is based on the findings of research and investigations into a new Trans-Australian Interconnection between South Australia and Queensland by Prof Simon Bartlett AM, Australian Chair for Electricity Transmission [3, 4]. It is supported by the work of UQ post-graduate researchers, collaboration with the China Southern Grid Research Department (a world leader in HVDC-VSC multi-terminal interconnections), CIGRE HVDC publications (based on input from the world's leading HVDC industry experts), advice from international HVDC-VSC manufacturers, consultants, HVDC operators and contributions from interested Australian companies.

The key comments and recommendation, detailed in this submission, include:

(a) All network and non-network options should be rigorously evaluated to ensure they could secure the South Australian power system following a separation event of the Heywood interconnection similar to the 28th September 2016 occurrence.
(b) The national economic benefit of unlocking renewable energy potential in South Australia and other states and along each interconnector route should be valued and included as a benefit.
(c) The investigation should assess and value the benefits of MESHING the NEM to the extent that each interconnection option alleviates power system security and high whole market prices in each of SA, Victoria, NSW and Queensland by strengthening the NEM interconnected network, especially in SA and Queensland that currently have only a single interconnector to the NEM.
(d) The investigation should assess and value the benefits of strengthening the northern and western parts of the South Australian power system to increase power system security to industry (eg near Olympic Dam and Port Piree) and providing additional network capacity for new renewable generation developments in the Eyre Peninsula and mid-north regions.
(e) The assumptions for Option 4 "SA-Qld interconnection" should be aligned with the findings on UQ investigations in terms of its capacity, route, technology, and estimated costs (capital and O&M)
(f) That the study include an assessment of NEM wide benefits for each option including changes in overall NEM interconnector stability limits, transmission losses, power security security and the full economic benefits to industry and the community of reducing wholesale pool prices in each state.

Needs Being Address by Investigation

Independent electricity market and power system security studies undertaken by University of Queensland researchers, together with observations of actual NEM events, as reported by AEMO prove, beyond reasonable doubt, that South Australia's deteriorating power system reliability and the increasing wholesale electricity prices were predictable and are avoidable.

As illustrated in the Figure 1, based on information from AEMO's third preliminary report [5], the complete blackout of South Australia on 28th September can be attributed to severe voltages on the SA power system during the few tenths of a second following the opening of the Heywood interconnector between South Australia and Victoria. The severe voltage conditions tripped four of the remaining five large gas fired generators in South Australia before the frequency collapsed, thus sealing the fate of the entire South Australian region. This serious voltage phenomena may be associated with the weakening of the SA power system due to current-limited inverter-connected PV and wind-power generators displacing conventional synchronous generators. The explanation given in the latest AEMO report on the SA blackout [5] that high ROCOF, insufficient synchronous inertia and frequency collapse tripped these remaining generators may not be supported by the facts, although plausible and another risk to be managed later in the timeframe, had the remaining South Australian generators survived the voltage challenges.

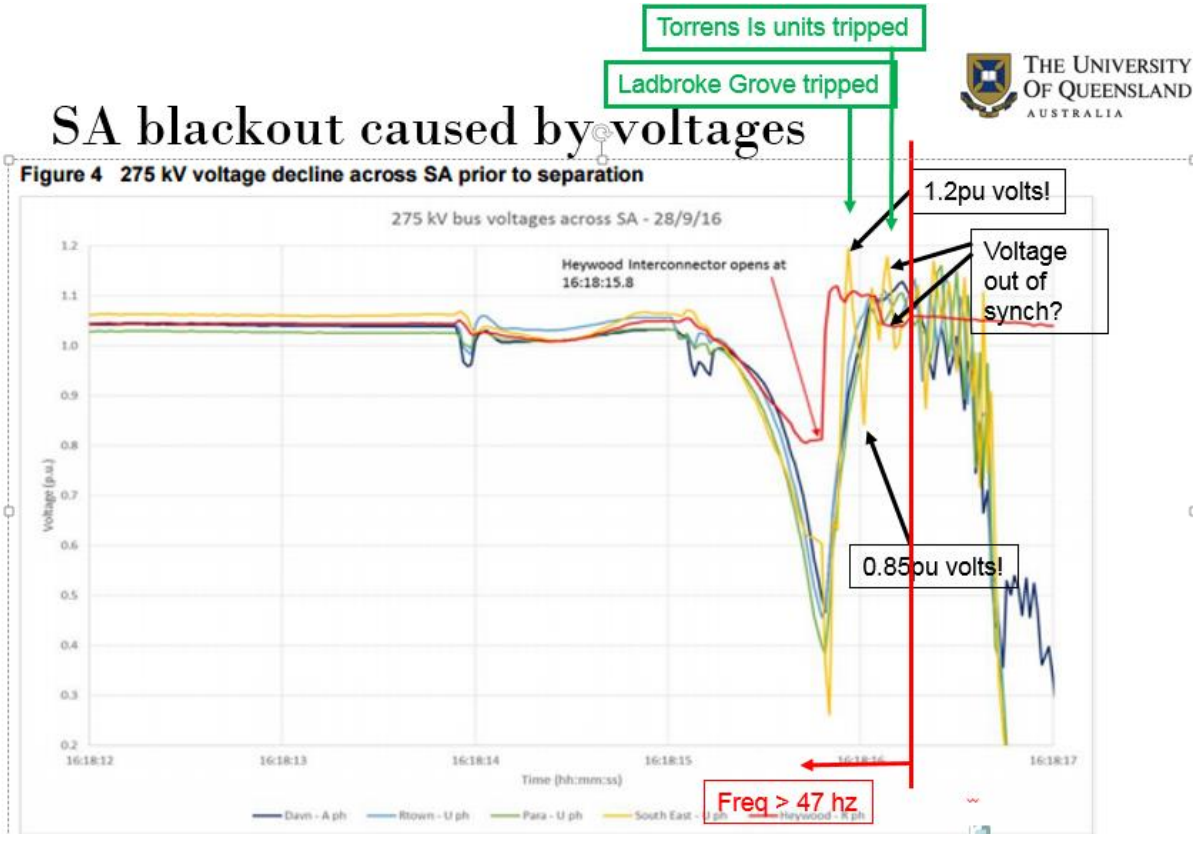

Figure 1 Severe Voltages after Heywood Separated tripped SA generators before frequency collapsed

It is critical that ElectraNet investigate both the voltage stability issues and subsequent power system frequency issues when designing short term, mid-term and long term measures to secure the South Australian power system as renewable penetration increases, otherwise electricity costs to

South Australian customers may increase unnecessarily and a re-occurrence of the SA blackout may not be prevented.

As illustrated in Fig 2 AEMO's published data [6], shows that wholesale electricity prices in SA and Qld have averaged some 30% higher than those in NSW and Victoria for the last 4 years, and the price difference is increasing.

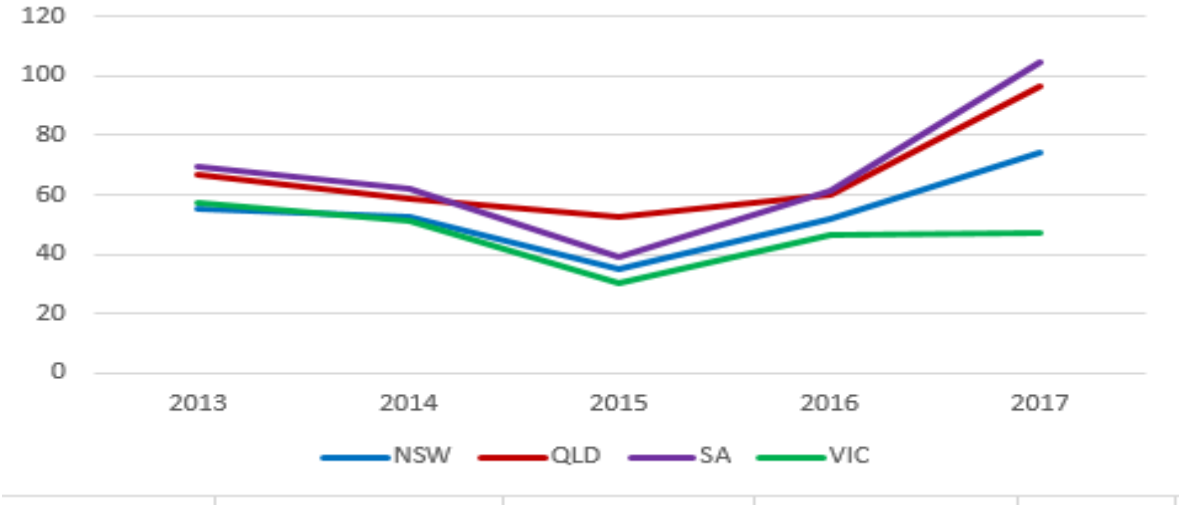

Figure 2 Average Wholesale Electricity Prices ($/MWH) [6]

UQ investigations into the causes of the higher wholesale electricity prices in South Australia and Queensland show that extreme prices of up to $14,000/MWh are more likely to occur in SA or Qld when the single interconnector to either state reaches full load, thereby preventing competitive bids from generators in the rest of the NEM participating in the SA or Qld wholesale electricity markets. This is an outcome of a seemingly fatal flaw in the design of the National Electricity Market (NEM); by having only a single interconnection to each of South Australia, Queensland and Tasmania. As soon as that single interconnector is fully loaded, wholesale electricity prices in that state skyrocket as competitive interstate bids are excluded, and in the case of South Australia, if the interconnector trips under full load, the entire state can blackout due to inadequate network strength, as occurred on 28th September 2016.

Options for Addressing Needs

One solution to this fatal design flaw is to "MESH the NEM" by forming a secure interconnected loop between the mainland NEM regions; Qld - SA – Vic – NSW – Qld by simply interconnecting South Australia to Queensland across central Australia [3, 4]. In addition to strengthening the SA network; MESHING the NEM would provide both South Australia and Queensland with dual redundant interconnectors to the rest of the NEM. This would address both power system security and high wholesale electricity prices that are impacting industry and society, in both states and particularly in South Australia and which are expected to grow with increasing renewable generation. Preliminary power system stability studies indicate that MESHING the NEM would also increase the existing interconnections limits between Qld – NSW and possibly between NSW – Vic – SA, provided HVDC-VSC technology is used to achieve a dynamically controllable and stabilising effect on power flows across the existing NEM interconnectors.

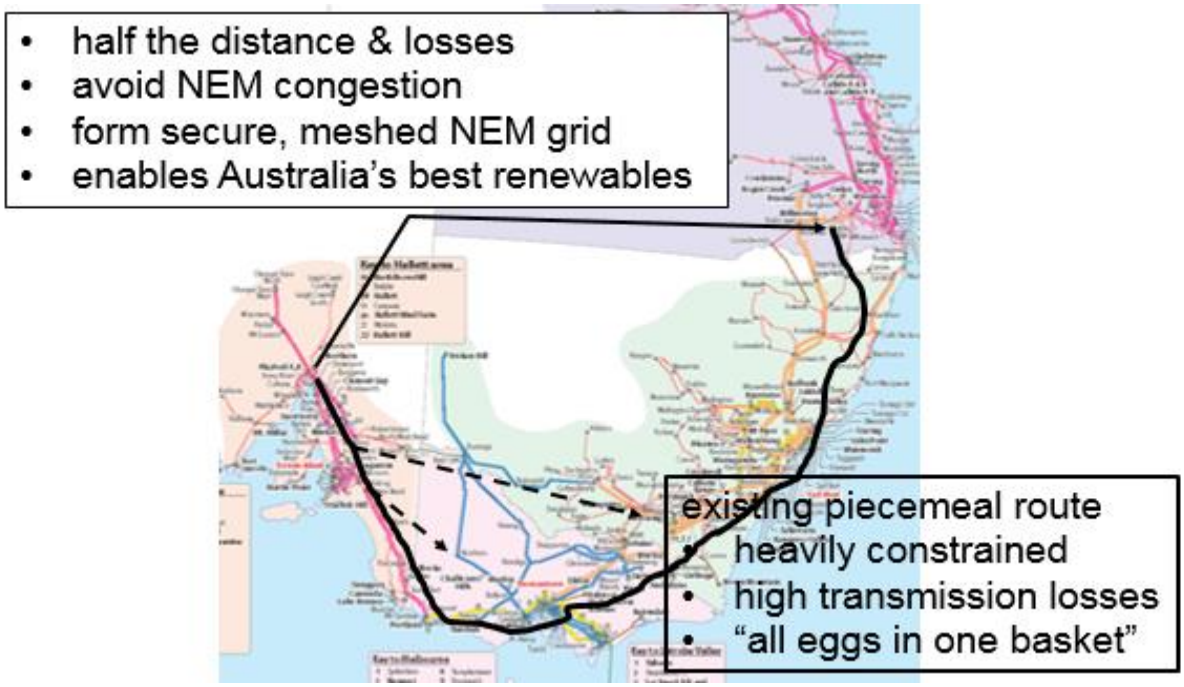

Figure 3MESHING the NEM

Only option 4 meshes the NEM between the northern part of South Australia and Southern Queensland by using HVDC-VSC technology that would deliver these additional NEM benefits. Preliminary assessments by UQ [4] indicate that the estimated value of the benefits of option D would exceed its estimated costs, warranting further investigation. As illustrated in Figure 3, the other interconnection options being considered by Electranet use HVAC technology to strengthen the existing link between South Australia and south-east Australia though Victoria or southern NSW. They provide only limited meshing of the NEM and provide minimal benefit to Northern NSW or Queensland.

System Reliability Test for Adequacy of Each Option

All interconnector options together with non-network options such as battery storage, demand management, synchronous condensers, artificial inertia etc must be rigorously evaluated and tested to ensure they would maintain South Australian power system security in circumstances similar to those that occurred on 28th September, without tripping. Fig 1 illustrates that four of the five large and robust remaining synchronous generators in South Australia tripped to prevent plant damage on 28th September. It is unclear whether ElectraNet's proposed Minimum and Preferred Targets for Power System Security [2] will be applied to all interconnection options and non-network options and how this will ensure that a re-occurrence of an event similar to that illustrated in Fig 1 will not result in a complete black-out of South Australia given that five synchronous generators were on-line but tripped from voltage phenomena on 28th September.

Preferred Technology for Addressing Reliability Needs

International research and global operating experience reported by CIGRE Study Committee B4 HVDC [7, 8] confirms that HVDC-VSC interconnector technology is well suited to stabilising existing AC power systems weakened by the integration of large amounts of intermittent renewable generation. This underpins European and Chinese investments in new HVDC VSC interconnectors to

strengthen their existing power systems as renewable generation increases [8, 9, and 10]. Further publications, can be provided. Whilst UQ and international research and experience [7- 9] confirms that HVDC-VSC technology would best address the power system security triggers for the Electranet South Australian Energy Transformation Study, a rigorous comparison of other technologies should be undertaken to verify that they are indeed feasible and economic solutions.

NEM Wide Benefits

The ElectraNet study must evaluate and compare all feasible interconnector options and non-network options from a national perspective taking into account NEM wide benefits including improved power system security, the economic benefits of lower wholesale prices and enabling the development of Australia's renewable energy resources. UQ research has identified that an interconnector across central Australia would enable the development of Australia's best renewable energy resources, including the nation's better solar energy potential and potentially geothermal resources, as well as undeveloped gas resources."

Recent announcements in Queensland indicate that around 1,000 MW of large-scale renewables (mostly PV) are proposed for construction in North Queensland. UQ research has identified a risk of increased market pressures on existing coal-fired and gas-fired power stations in Southern Queensland increasing the likelihood of early closure as occurred in South Australia. Research into the impact on power flows and security for the Queensland grid has identified that the peak electricity demand of Southern Queensland could exceed its available generation and transmission capacity, thereby creating a need to augment electricity supply capacity to Southern Queensland. Meshing of the NEM between South Australia and South Queensland could eliminate the need for that investment, thereby providing benefits under the AER RIT-T in Queensland that need to be included for Option D.

Assumptions for Option 4 SA – Qld Interconnection

The PSCR assumes that Option 4 would run 1,400kms from Davenport in SA to Bulli Creek in Queensland directly via north-western NSW, with a capacity up to 2,000MW and a cost of up to $2.5billion using either HVAC or HVDC technology.

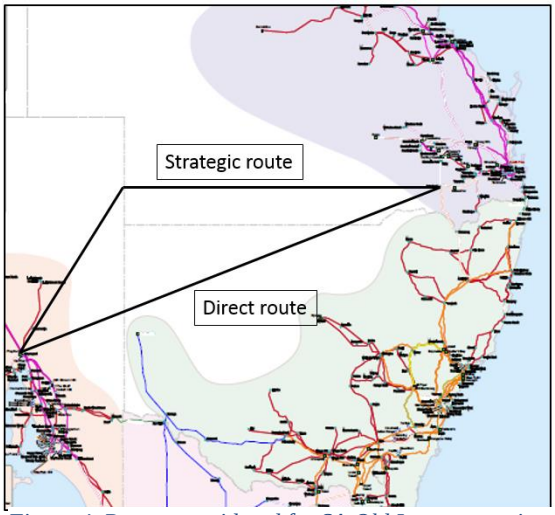

Figure 4 Routes considered for SA Qld Interconnection

As illustrated in Fig. 4 UQ, research has investigated two alternative routes:

(a) Direct route from SA to Qld passing through north-west NSW over a distance of 1,400kms.

(b) Strategic route via the undeveloped renewable energy resources in central Australia over a distance of 1,600kms.

The strategic route was found to be preferable [3, 4] to the direct route as

(a) The strategic route would share established access tracks for interstate gas and oil pipelines for much of the route, reducing costs and environmental impacts
(b) Land use along the strategic is compatible with the use of innovative guyed cross-rope transmission structures as the route mostly passes through sparse grazing leasehold land rather than highly cultivated freehold land (as is the case for the direct route in the Goondiwindi – Moree area) which increases costs, environmental and social impacts.
(c) The strategic route would enable the development of central Australia's PV, geothermal and gas resources, thereby providing additional benefits to help justify Option D along the Strategic route.

UQ comparisons of HVAC, HVDC-LCC (line-commutated converter) and HVDC-VSC (voltage source converter) technologies for the SA-Qld interconnection [3, 4] conclude that HVAC would be uneconomic and that HVDC-VSC would provide additional reliability benefits compared with LCC for this application. HVDC VSC is proven globally to have superior flexibility, dynamic responsiveness, controllability, multi-terminal capability, black start capability [7- 9]. Since 2010, more than fifteen HVDC-VSC schemes have been installed or committed in more than ten countries with voltages up to 350kv, capacities up to 2000MW and transmission distances up to 1000km. It is the interconnector technology of choice for long distance integration of renewables across the existing HVAC grid in Europe and China. [7 – 11]. Further references can be provided, some written in Chinese.

The optimal capacity for the SA – Qld interconnector was determined to be 700MW – 1,000MW, operating at +-320 to 400kV [3]. The estimated capital cost is $1.4billion at current price levels, with annual operation and maintenance costs of $1.5m pa and total transmission losses of around 10% [4]

Conclusions

It is concluded that the evaluation criteria proposed in ElectraNet's PSCR for the RIT-T assessment in its South Australian Transformation Investigation, needs to be broadened to include all NEM wide benefits of the proposed four interconnection options.

The power system reliability test to assess the adequacy of each interconnection and non-network option should ensure that the recommended option from the RIT-T analysis will withstand both the voltage phenomena and subsequent frequency collapse following a Heywood separation event similar to that occurred on 28th September 2016.

The assumptions for option 4 "SA-Qld Interconnection" should be aligned with the findings of research undertaken for that option by University of Queensland.

1. ElectraNet, *South Australian Energy Transformation RIT-T,* November 2016*,* *http://www.electranet.com.au*
2. ElectraNet, *South Australian Energy Transformation RIT-T, Supplementary Information Paper, 13th* February 2017*, http://www.electranet.com.au*

3. S.C Bartlett, Trans-Australian HVDC *Interconnection Investigation*, IEEE-PES APPEEC, Xi'an China, October 2016, paper 377
4. S.C. Bartlett, Inve*stigation of Trans Australian Interconnections*, Techcon Aus-NZ, April 2017 proceedings (awaiting publication – advance copy attached)
5. AEMO Energy Market Operator, Black System South Australia 28th September 2016, Third Preliminary Report, December 2016, , http://www.aemo.com.au/-/media
6. AEMO Energy Market Operator, Average Electricity Prices Data Dashboard, Annual Prices, mid February 2017, http://www.aemo.com.au/electricity
7. Dirk Westerham et al, *Voltage Source Converter (VSC) HVDC for Power Transmission – economic Aspects and Comparison with other AC and DC Technologies*, CIGRE April 2012, Report 494, Working Group B4.46.
8. J. F.Nolasco, J.A. Jardini, J.F. Graham et al, *Impacts of HVDC Lines on the Economics of HVDC Projects,* CIGRE Aug 2009, JWG B2/B4/C1.17
9. P.L. Francos, S.S, Verdugo, C.l. Viejo, L. C. Hernandez, *Drivers for technology selection in an embedded HVDC link. Case Study: France-Spain Eastern Interconnection,* CIGRE 2014 Report B4-110
10. Dr. Junzheng Cao, Mr. Jim Y Ca, *HVDC in China*, 2013 HVDC & FACTS Conference, August 2013
11. JIN Yiding , LIANG Zhifeng, *The Operation Statistics and Analysis of HVDC Transmission Systems in State Grid Corporation on China 2006 – 2012*, CIGRE 2014, paper B4-106