

Diverse, Remote & Innovative: Prospects for a Globally Unique Electricity Network and Market in Western Australia

The Network Infrastructure in Western Australia (WA)

WA's electricity industry supply infrastructure comprises the South West Inter-connected System (SWIS), the North West Interconnected System (NWIS) and 29 regional non-interconnected power systems ¹. WA exhibits a diversity of generation systems located in some of the most isolated regions of Australia, supplying a wide range of energy demand profiles. These characteristics and the unique networks that comprises WA's electricity infrastructure makes WA a unique place to research, develop and integrate new technical options within a world-class industrialised electricity system.

Around half of the total electricity consumed in WA is on the SWIS. The SWIS is a relatively small system in terms of total generation capacity by world standards (~5,100 MW in 2009/10 ²). The SWIS resembles island systems such as the Republic of Ireland prior to 2000, than the interconnected systems of Europe, North America and Asia ³. The SWIS may be small in terms of generation, but the SWIS covers a relatively large geographical area ³. The SWIS contains more than 140 major substations, 6,000 km of transmission lines (66 kV and greater) and over 64,000 km of high voltage distribution lines (33 kV and lower) ¹. However, due to significant long-term energy demand expansion in WA, there remains little spare capacity within the SWIS network to accommodate new generation without network augmentation ^{4,5}.

The transmission network in the metropolitan area of WA's capital city Perth is characterised by high loads and high fault levels near the 132 kV network design level ⁴. Additionally, generation capacity in the southern region of the SWIS is limited due to a requirement for more reactive power in the metropolitan area, as the four 330 kV transmission lines are all around 200 km long and are limited to 500 MW of transfer capacity at present ⁴. Any concentration of new generation to the metropolitan areas would increase network loading and fault levels ⁴.

The northern region of the SWIS up to Geraldton is supplied by a number of long (400 km) parallel 132 kV transmission lines and already operates close to its power transfer limits ⁴. New generation to the north of Perth will require the construction of a new 330 kV connector ⁴ or subsequent delays may occur in both some generation types and new mining developments ⁵. The eastern part of the SWIS near Northam is connected to the metropolitan area by a long and weak 132 and 66 kV transmission lines designed for relatively small loads ⁴. Any new generation in this region of the SWIS would result in significant thermal, voltage and stability issues ⁴.

Further east, Kalgoorlie (550 km east of Perth) is connected to the SWIS via a reactive compensated 220 kV transmission line from Collie (in the south) to control voltages in the 650 km line ⁴. The Kalgoorlie area also has a "remedial action scheme" to island local faults from synchronous instability of Kalgoorlie based generation capacity ⁴. This limits the capability of local generation capacity to export significant power without additional augmentation ⁴. New technical options will certainly play a role in alleviating transmission limitations to supply growing energy demands.

Electricity Demand Expansion Characteristics

Historical SWIS peak load has been increasing approximately 95 MW per year. The SWIS exhibits a high inter-annual variability highly dependent on temperature and associated air-conditioning load growth exacerbated by robust population growth ⁶. Electricity consumption and maximum demand are forecast to grow at 2.2% and 3.2% respectively per year over the period 2007/08 to 2016/17 ⁴. Ignoring increased demands that will no doubt occur from major resource development proposals proceeding, the maximum demand within the SWIS is forecast to continue growing at around 120 MW each year ⁷. In WA, the increased electricity demand, (especially from the minerals sector within the SWIS), has lead to a number of proposals for new mines that require timely construction of transmission lines and other support infrastructure ⁵. For example, the Boddington Gold Mine on the south of the SWIS accounted for around half of the total load growth in one year - an additional 3% on top of the expected 3.3% normal increase ⁵.

The single most important determinant of SWIS electricity demand is the daily temperature ^{5,7,8}. The highest maximum demands are recorded after sequentially hot days ⁵. Summer maximum temperatures can range from the mid-twenties to the mid-forties, resulting in daily peak demand fluctuations from below 2,000 MW and above 4,000 MW ⁹. Between April 2007 and March 2008, the mean load was 1862 MW, which is 55% of the maximum demand ⁵. The short-term nature of peak demand in the SWIS is also illustrated by the last 800 MW (or 23% of the total generation capacity) being utilised only 3% of the time ¹⁰.

In winter, peak demand is also strongly influenced by the weather, but primarily determined by heating requirements ⁵. As electricity competes directly with gas and other energy sources for heating in WA, there is a lower peak electricity demand compared to summer cooling loads that are almost exclusively supplied by electricity ⁵. Winter peak demand is forecast to be almost 4000 MW by 2018, which is 60% of the forecast summer peak demand in that same year ⁵. In addition to seasonally dependent demand changes, the SWIS overnight loads are markedly lower than daytime loads ⁵. This extreme seasonal, inter and intra-day demand variability provides an excellent baseline to explore new technology investments, demand side management techniques, and electricity market options.

New major industrial loads and electricity infrastructure augmentation are generally required to mirror one another, especially in WA's remote areas ⁹. Establishing a new transmission line can take seven to ten years from conception to commissioning while the construction phase of a generation project can take less than two ³. This is a temporal investment issue that may constrain the options for generation capacity under the WA Wholesale Electricity Market's (WEM) Reserve Capacity Mechanism.

Electricity Market Establishment and Opportunities

Electricity trading on WA's WEM commenced on 21 September 2006 ². The WEM is a net pool electricity market where suppliers are paid for electricity sold, with an additional reserve capacity/demand management market called the Reserve Capacity Mechanism (RCM) ¹¹. The RCM aims at ensuring adequate generation capacity available each year to meet SWIS peak demand forecasts and an additional reserve margin of around 10% ^{7,12}. The RCM achieves adequate capacity by placing a value on the capacity provided by generation, demand side management, or variable generation capacity ¹³. The total capacity assigned in the RCM on the SWIS for 2009/10 was 5136.43 MW ².

Base-load capacity is better placed to compete in the WEM by trading contracts to supply electricity demand, while peak-load capacity investments are competitive because of the RCM ¹⁴. The WEM rules set an electricity cap for non-liquid fuelled power plant sales and a higher cap (both per MWh) for liquid fuelled power plants ⁷. The relatively low electricity market price caps require peak-load capacity to enter the RCM to recover costs.

As demand side management (DSM) and demand response (DR) mechanisms can also balance electricity supply and demand akin to additional generation capacity ¹⁵, these services are able to participate in the RCM. Thus there is significant scope for exploration to foster technological and continued regulatory and market evolution of electricity systems in terms of greater energy efficiencies, new market possibilities, high quality power provision, and enhanced supply security in WA ¹⁶.

The RCM value that is allocated to variable renewable energy generation is based on the average output of the generator(s) over the previous three years, or an estimate of the average if the generator(s) have not yet operated for three years ^{7,14}. For example, Emu Downs wind farm has an installed capacity of 80 MW and was assigned 31.1 MW under the RCM ⁷. It is generally acknowledged that the RCM certification method used for wind farms is currently generous, and this method is likely to be modified to reduce the RCM capacity ⁶. In contrast, solar thermal generation is strongly correlated with peak load intervals on the SWIS, which is unrecognised in the RCM at present ⁸. Similarly, it is expected that solar thermal generation capacity value on the SWIS will be amended to enable capacity providers to capture this value in the RCM.

While remotely installed variable generation will provide system diversity, it may require substantial network augmentation to connect to the SWIS to maintain supply security. At present, remote generation investors would be required to bear the costs of such network augmentation ⁸. It could be argued that this investment should be rewarded in relation to the subsidy it provides to additional generation investment that occurs in the region subsequently, and the diversified security benefit that it provides to the network ⁸.

Electricity Quality and Supply Security

Power quality involves current and voltage waveform disturbances, the presence of momentary steady-state voltage variations, harmonic variations, and distortion ¹⁷. Both quality and reliability of electricity in the timeframes of seconds and even cycles is becoming increasingly important to customers ¹⁸. Power quality is therefore an increasing concern for utility, facility and consulting engineers, as end use equipment is more sensitive to disturbances that arise both on the supply side and within facilities ¹⁷.

Complex correlations between reliability and price in electricity markets arise because of random system failure uncertainties and variable demand responses in different nodal regions ¹⁹. In the majority of electricity systems, more than 80% of all faults occur in distributions systems with 80% of these faults being grounding faults, of which 90% of these grounding faults are instantaneous faults ²⁰. Despite the exceptionally large geographical area of the SWIS relative to capacity, the SWIS has significantly lower generation unit outage rates than other systems and well-established benchmarks ²¹.

Electricity systems are at most risk of failure in times of highest load when a generator failure may decrease reliability of load provision ²². However, there are also occasions when the fuel supply chains are interrupted, which lead to electricity supplies being at risk. The June 2008 Varanus Island gas explosion in WA was one such occasion. The gas used in the SWIS generators is mainly transported by the Dampier to Bunbury Natural Gas Pipeline and the Goldfields Gas Pipeline, with some additional gas sourced from the Parmelia Pipeline ²³. The Dampier to Bunbury Pipeline limited the SWIS gas-fired generation capacity until the Stage 5B expansion, but further gas supply and price increases may constrain the continued expansion of SWIS gas capacity ⁵.

The Varanus Incident lead to supply loss to pipelines and subsequent RCM changes required generators to provide details of their fuel supply and transport arrangements ⁵. In the months after the gas explosion, electricity supply integrity was maintained by the dual fuel and liquids-only capacity ⁹. Increasing the percentage of gas/liquid, liquid-only, or DSM capacity decreases reliance of gas supplies ⁶. However, the recent electricity generation investment in the RCM has

seen the SWIS dual fuel capacity decreasing ⁹, while gas-only capacity has expanded to around 40% as of 2010/11 ⁶.

As Australian R&D policies tend to focus on individual companies, system-wide energy sector innovation has been under-represented ²⁴. Therefore, an active exploration of options to incentivise network operators to undertake research and development is required ²⁵. The positive externality of innovation is derived from the public-good nature of new knowledge as innovating firms cannot exclude other firms from also benefiting from their new knowledge ²⁶. As the reliability of electricity supply and available transmission capacity are interchangeable, both can be enhanced with new investment to improve overall system integrity during a period of major expansion ¹⁸. However, the lack of R&D, changing economics between various fuel types, and high levels of interest in clean energy generation makes it difficult to determine the likely location and size of future generation capacity ⁵.

Solar and Wind Integration

International experience has shown that when variable renewable electricity generation penetration approaches 20%, additional frequency control ancillary services (FCAS) are required ³. When this penetration reaches 30% the total cost incurred by market participants is generally around 2% of the retail price of electricity, as conventional generators run at less than full output or are idle ³.

In WA, renewable electricity sources of all types supplied only 3.1% of total consumption in in 2008/09, with more than half sourced from two wind farms, Emu Down and Walkaway, and one fifth from one hydro station, the Ord ²⁷. On the SWIS, the same year recorded 5.0% of electricity was sourced from renewables ²⁷, mostly from wind farms. In GWh terms for the period, renewable energy sold by retailers on the SWIS totalled 755 GWh, while regional grids totalled 81 GWh, and other systems were an estimated 143 GWh ²⁷.

Minimum frequency keeping capacity in the SWIS has increased from 30 MW up to 50 MW, and then again increased to 60 MW to cater for wind farm output ^{5,9}. Further variable generation capacity may require additional load following capacity and associated costs ²². However, an important determinant of the contribution of the renewable capacity to system reliability (and associated ancillary capacity) are correlations between variable generation and peak load ²².

Historical wind generation capacity output on the SWIS shows high variability in periods of peak demand ⁸. Nonetheless, in 2009 a Senergy report stated that wind generators on the coastal areas of the SWIS had a slight positive correlation trend for above average generation in peak load periods ⁸. Thus, regionally specific weather patterns are important, which is demonstrated by wind farms in the south around Esperance, Albany, and Margaret River exhibiting different characteristics than wind farms north of Perth ⁸. Various Bureau of Meteorology wind mast locations and existing generation from wind farms distributed around the SWIS demonstrate no material weather-based correlations of simultaneous low outputs in specific WEM trading intervals ⁸. Thus, additional distributed wind generation capacity on the SWIS increases wind generation reliability as an aggregate technology in the SWIS and the WEM ⁸. While wind is less predictable than solar radiation, wind capacity remains a challenge for day-ahead system adequacy planning, and results in a lower value to system operators than dispatchable generation ¹⁵.

In contrast to wind where the most prospective sites are exploited first, solar electricity marginal costs are likely to continually decrease as the resource does not suffer from the same constraining limits. Additionally, unlike the complex correlation with wind and temperature, in practical terms there is a clear relationship between average solar generation and temperature in WA ⁸. More precisely, there are regionally differentiated positive correlations between the peak electricity demand and solar generation output. As an example, there is a better match between the solar resource with peak loads in Geraldton compared to Kalgoorlie ⁸.

In general, large scale variable renewable penetration in WA will benefit from improved weather forecasting, geographic distribution, energy storage, DSM, DR, variable curtailment, additional reserves, and renewable source complementarity ¹⁵. Renewable energy complementarity can be assessed over different timescales including hourly, daily, seasonally, or annually, and multiple variable capacity can be optimised for technical supply stability if primary data exists, and for cost-effectiveness ¹⁵.

New Options for Clean Technology & Resource Security

A pressing issue is for regulatory frameworks to adapt to the rapid expansion of variable renewable energy generation technologies that are not fully dispatchable at all times ⁸. The new and renewable energy sector is diverse with a range of technologies at different stages of development ²⁸. If incentives for decreasing distribution network losses, deferring network investment, load shifting, or improving service quality are too high or low then the provision of these and other performance indicators will be higher or lower than is economically reasonable ²⁵.

Transmission line nearing capacity in several locations ⁹. Therefore, network expansion needs to be compared against energy efficiency, and alternative supplies, fuel switching, and demand management ²⁹. The application of DSM and DR technologies and policies, it is possible to influence load profiles to balance electricity supply and demand ¹⁵. DG pose new challenges to network operators and planners, who are notoriously risk-averse ²⁵.

The greater penetration of DG requires more cost-reflective connection charges, use-of-system charges, and incentives for ancillary services ²⁵. Conversely, high levels of automated electricity demand responsiveness to price can offset high penetration of variable generation capacity ¹⁵. Network planning should be undertaken that considers the possibilities offered by DG, and incentive regulation by itself is inadequate to attract appropriate forms and scale of DG integration ²⁵. As some reinforcements and upgrades are normally required to connect DG, reducing discrimination of DG connection by system operators can be achieved by regulating an averaged and shallow connection charges ²⁵. The remaining network costs can be recovered by time dependent and location-specific cost reflective network charges to reduce difficult negotiations between system operators and DG providers ²⁵.

Akin to peak shaving from DR measures, electricity storage can increase system efficiency by keeping system ratings lower than would be required otherwise and achieve higher marginal economic efficiencies ³⁰. While batteries are popular technology for small scale systems, thermochemical reformation or decomposition processes can be utilised to pre-process fuels to improve thermal performance downstream to utilise solar thermal energy or mid-to-low temperature heat at larger storage scales ³⁰. Syngas can store low temperature heat to be converted at a later date ³⁰, or other options such as steam injected gas turbine (STIG) technology ³⁰, are potential areas of interest. The availability of both prospective gas and excellent solar resources in the north of WA in terms of storing and using renewable solar energy will likely attract such investigations.

The solar resource itself may be better matched to the evening electricity peak demands on the SWIS via the use of steam storage. Modern actuators are available to store steam under pressure and can shift output of solar thermal steam turbines to match evening peak periods, and also requiring lower turbine ratings and associated capital expenditures for solar thermal generation investments.

Furthermore, integrating renewable energy, desalination and water purification is becoming increasingly attractive in terms of maximising infrastructure economies to supply growing state demands ³¹. The two existing desalination plants in WA consume around 385 GWh annually, with further expansion planned ³². This infrastructure offers another economic efficiency akin to energy storage, as a DR peak shaving method to go offline in high demand periods to be reimbursed under the RCM.

New energy saving, storage, or generation technologies with diverse primary energy requirements are leading to many alternatives for sustainable energy and water infrastructure designs and are expanding the boundaries for multi-distributed generation (MDG) system planners ¹⁶. While MDG planning encompasses additional energy and material streams other than simply electricity, profitable deployment of MDG systems in specific locations depends on the parallel demand for particular outputs over the year ¹⁶, and energy resource availability.

Coastal areas with high wind resource availability are preferred locations for desalination ³³. Links between suitable resource availability and energy supply security requirements has stimulated exploration into localised efficiency gains for energy supply chains ¹⁶. Regional DMG can enable parallel planning approaches that clearly demonstrate energy, water, and carbon accounting in regionally specific industries and lead to integrated developments ¹⁶. Xu *et al.*, 2009, proposed a small scale system that combined distributed energy systems for refrigeration, heating, electricity generation, and seawater desalination ³⁰. Waste heat from electricity generation was used to drive an absorption refrigerator or heat pump, and in times of low refrigeration or heat demand a multi-effect distillation engine produced freshwater to produce energy savings ³⁰.

Renewable energy is more cost-effective for autonomous desalination systems in arid and coastal areas where conventional energy sources are unavailable ³¹. A main concern with large-scale desalination is the highly concentrated brine discharge ³³. Zero brine discharge from desalination processes by creating a secondary salt product, and powered by renewable energy is a highly sought scenario, especially if cost effective ³³. A possibility in areas with good wind resources is hybrid mechanical vapour compression (MVC) from turbines in combination with solar thermal collectors to supply multi-effect distillation (MED), as a two step process ³³. Salt and water separation in a centrifugal MVC based cycle operating at 185 -190 °C, consumes around 1.2 MWh and can produce 7.5 tonnes of salt each hour ³³. Salt as a co-product may partially offset higher costs of totally removing salt through MVC and MED ³³.

There are a range of energy, water, and carbon opportunities in WA, especially since the state is a net exporter of oil and gas. Water-to-oil production ratios exceed 10:1 by volume at many wellsites and are a cost burden and environmental issue for companies ³⁴. Oil and gas producers must dispose of wastewater and there is potential to use redundant electricity capacity in times of low demand to process this water to enhance regional water security and reduce wastewater volumes ³⁴. Arid region production could greatly benefit if oilfield brines could be processed to supply agricultural, industrial, or potable use ³⁴. This will require desalination, and using renewable energy to supply power to these facilities is becoming more attractive ³¹.

Conclusion

Transmission network expansion to remote regions of Australia is required to develop a large-scale renewable energy industry ³⁵. Providing incentives to promote geographic and technological diversity of variable generation could offset network augmentation requirements for projects in remote locations to increase system security ⁸. A strong domestic clean energy industry is a strategic investment for increased energy independence and security, and also provides environmental benefits and economic growth through innovation ³⁶. WA exhibits a diversity of generation technologies, networked systems, electricity markets, renewable energy resources, and a range of energy demand profiles, both large and small. WA is a unique place to undertake research, assess new technology performance, and their integration with other options - all within a world-class and growing electricity system.

Discussion paper prepared by Mr Mark McHenry, School of Engineering and Energy.

Contact **Professor David Doepel**

Director of the Institute for Resources Technology
Murdoch University, South Street, Murdoch WA 6150

References

- 1 Government of Western Australia. 2005. Application to the National Competition Council for a recommendation on the effectiveness of the Western Australian Third Party Access Regime for electricity networks. Perth.
- 2 Independent Market Operator Western Australia. 2007. Summary of Capacity Credits assigned for the third Reserve Capacity Cycle. Perth.
- 3 Morton, A, Cowdroy, S, and Stevens, D. 2005. Maximising the penetration of intermittent generation in the SWIS - Econnect project no. 1465. Econnect,
- 4 Independent Market Operator Western Australia. 2007. 2007 Statement of Opportunities Report. Perth.
- 5 Independent Market Operator Western Australia. 2008. 2008 Statement of Opportunities Report. Perth.
- 6 Independent Market Operator Western Australia. 2009. Public Reserve Capacity Mechanism review report. Perth.
- 7 Independent Market Operator Western Australia. 2006. Statement of Opportunities report. The South West Interconnected System. Perth.
- 8 Senergy Econnect. 2009. The treatment of intermittent generation in the SWIS capacity market. Review of certified reserve capacity calculation methodologies for intermittent generators. Senergy Econnect project No. 2413 Version 003.
- 9 Independent Market Operator Western Australia. 2009. Statement of Opportunities, July 2009.
- 10 Independent Market Operator Western Australia. 2007. Annual Report 2006/07. Perth.
- 11 Independent Market Operator Western Australia. 2007. Wholesale Electricity Market. Six months of electricity trading. Perth.
- 12 Government of Western Australia. 2005. Application to the National Competition Council for a recommendation on the effectiveness of the Western Australian Third Party Access Regime for electricity networks. Perth.
- 13 Independent Market Operator Western Australia. 2006. Opportunities for renewable energy and demand side management to participate in the Wholesale Electricity Market. Perth.
- 14 Independent Market Operator Western Australia. 2006. The South West Interconnected System Wholesale Electricity Market: an overview. Perth.
- 15 Moura, P S and de Almeida, A T. 2010. Multi-objective optimization of a mixed renewable system with demand-side management. Renewable and Sustainable Energy Reviews DOI:10.1016/j.rser.2010.01.004.
- 16 Chicco, G and Mancarella, P. 2009. Distributed multi-generation: a comprehensive view. Renewable and Sustainable Energy Reviews 13, 535-551.
- 17 Golkar, M. A. 2004. Presented at the 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, Hong Kong.
- 18 Kazemi, A. and Andami, H. 2004. Presented at the IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, Hong Kong.
- 19 Ding, Y. and Wang, P. 2006. Reliability and price risk assessment of a restructured power system with hybrid market structure. IEEE Transactions on Power Systems 21 (1), 108-116.
- 20 Zeng, X., Li, K. K., Chan, W. L., and Yin, X. 2004. Presented at the 2004 IEEE International Conference on Electric Utility Deregulation, Restructuring and Power Technologies, Hong Kong.
- 21 Thorpe, G., Chattopadhyay, D., and McCail, K. 2007. Review of the planning criterion used in the South West Interconnected System. CRA International, Melbourne.
- 22 Sustainable Energy Development Office. 2009. Senergy Econnect report (2009), The treatment of intermittent generation in the SWIS capacity market. Report Summary. Government of Western Australia, Perth.

- 23 Office of Energy. 2004. Wholesale Electricity Market Reserve Capacity Mechanism - Request for
expressions of interest information package.
- 24 Longo, A and Markandya, A. 2005. Identification of options and policy instruments for the
internalisation of external costs of electricity generation.
- 25 Cossent, R, Gomez, T, and Frias, P. 2009. Towards a future with large penetration of distributed
generation: Is the current regulation of electricity distribution ready? Regulatory
recommendations under a European perspective. *Energy Policy* 37, 1145-1155.
- 26 Jaffe, A. B., Newell, R. G., and Stavins, R. N. 2005. A tale of two market failures: technology and
environmental policy. *Ecological Economics* 54, 164-174.
- 27 Office of Energy. 2010. Electricity from renewable energy, January 2010. Government of Western
Australia, Perth.
- 28 Foxon, T J, Gross, R, Chase, A, Howes, J, Arnall, A, and Anderson, D. 2005. UK innovation systems
for new and renewable energy technologies: drivers, barriers and system failures. *Energy Policy*
33, 2123-2137.
- 29 Remmer, D P and Kaye, J. 2001. Institutional uncertainty and its effect on electricity supply
choices for fringe of grid consumers. *Renewable Energy* 22, 361-368.
- 30 Xu, J, Sui, J, Li, B, and Yang, M. 2009. Research, development and the prospect of combined
cooling, heating, and power systems. *Energy* DOI:10.1016/j.energy.2009.03.019.
- 31 Eltawil, M A, Zhengming, Z, and Yuan, L. 2009. A review of renewable energy technologies
integrated with desalination systems. *Renewable and Sustainable Energy Reviews* 13, 2245-
2262.
- 32 Parliament of Western Australia. 2007. Question on notice no. 2483 asked in the Legislative
Assembly.
- 33 Fernandez-Lopez, C, Viedma, A, Herrero, R, and Kaiser, A S. 2009. Seawater integrated
desalination plant without brine discharge and powered by renewable energy systems.
Desalination 235, 179-198.
- 34 Barrufet, M A and Mareth, B CC. 2009. Presented at the Latin American and Caribbean
Petroleum Engineering Conference, Cartagena de Indias, Columbia.
- 35 Buckman, G and Diesendorf, M. 2010. Design limitations in Australia renewable electricity
policies. *Energy Policy* DOI: 10.1016/j.enpol.2010.02.009.
- 36 Wei, M, Patadia, S, and M, Kammen D. 2010. Putting renewables and energy efficiency to work:
How many jobs can the clean energy industry generate in the US? *Energy Policy* 38, 919-931.