Renewable Electricity in WA: Energy Security

Synopsis

This Briefing Note outlines how power networks with high proportions of renewable electricity (RE) generation, with appropriate design considerations, can be more secure and stable than the traditional, largely fossil-fuelled networks.

Volunteers for Sustainable Energy Now (SEN) have modelled various options for providing future electricity needs in WA's South West Interconnected System (SWIS). A wide range of technologies was assessed, and the optimum scenario is to replace the aging coal plants with solar PV, wind and biomass energy, and various storage options. This can be achieved by 2030. For more details, see SEN's "The Economic Argument for Renewable Electricity in WA" Briefing Note.

SEN's modelling shows that wind and solar PV can meet most of the expected demand, day and night, for most of the year. During periods of variable wind and solar conditions, energy security can be assured by rapid-response fuelled generation combined with several storage options. Widely-distributed generation capacity, and increasingly accurate wind and cloud prediction, can provide a renewable power network that is demonstrably *more* secure than the current electricity networks.

Mature technologies such as batteries, flywheels and isochronous spinning reserve can contribute towards power stability as effectively as the traditional means of provision of spinning reserve, eliminating the need for large, inflexible coal-fired thermal generators.

'Edge of grid' so-called micro-grids will provide stability and reduce the need for long power lines to isolated consumers, reducing the risk of associated power outage and fire hazard problems.

Security and Reliability of Electricity

A paramount requirement of a modern electricity system is that it can provide secure and stable power when needed. This means the electricity grid must be able to:

- Provide sufficient power to meet the minimum power demand at all times of the day, regardless of wind and sun conditions (***security***).
- Respond to fluctuations in frequency caused by unexpected outages or demand changes (***stability***).

Security

The variable nature of wind and solar means that, on their own, these technologies do not meet demand at all times since they are not 'load following', but depend on wind and sun conditions. During the initial stages of the renewable electricity transition, even after 75% of coal-fired stations are phased out, WA's existing gas-fuelled generators can meet the entire shortfall, based on historic peak demand records. After this initial transition period (to 2021), as more renewables are installed, some additional fast-response fuelled turbine generator capacity will need to be added to the network, for backup capacity.

As RE penetrates further into the market, SEN's modelling shows that wind and solar PV can meet most of the expected demand, day and night, for most of the year without the use of the backup generation. Because generation capacity will be spread across the entire 900km x 500km SWIS, poor wind and solar conditions in one region are usually be offset by better conditions in other regions. In unusual situations where the whole region is in lull solar and wind conditions, backup supply covers the shortfall.

Table 1 Modelled wind, solar and fuelled generation for high penetration renewable electricity (up to 90%).

	Annual hours (2014) supplied by source	% of hours in the year (8760)	% of Generation
RE (wind and solar PV) alone	5765	66%	86%
RE + Battery storage	7283	83%	92%

RE + Battery + Pumped Hydro storage	7437	85%	94%

Table 1 shows that wind and solar, with about 18,000 MWh of battery and pumped hydro storage provides 94% of total electricity demand, supplying all demand for 85% of the hours in a year. Rapid-response gas turbines, which can operate with many fuels including natural gas, diesel or bio-liquids, are used to supplement wind and solar for only 15% of the time, providing only 6% of total annual generation.

Storage

As the transition to renewables continues, it will be increasingly important to provide standby and ancillary power through various storage mechanisms, as indicated in Table 1. These storage technologies are 'charged' by excess RE when it is available, and discharged when needed.

Pumped hydro storage (PHS), is a system by which water is pumped from a lower reservoir (which may be the ocean) to a higher reservoir, which generates hydroelectricity when needed. It is a mature technology and the cheapest of all options for large scale storage. There are suitable sites within the region of the SWIS to construct such storage facilities.

Molten Salt (MS) heat storage is already being used cost effectively to provide large scale (110MW) overnight storage in Concentrated Solar Thermal (CST) plants in Nevada, California, Spain and Chile, with many more under construction. Experimental phase change, carbon block and metal hydride heat storage systems promise to be even more effective than molten salt in various situations. MS is much cheaper than batteries and will probably remain so for large scale, high capacity applications.

Utility-scale battery storage consists of large battery banks located within the grid at electricity sub-stations or in isolated micro-grids. These are charged mainly by PV, and are now common world-wide.

'Micro-grids are small, autonomous grids based around utility-scale battery storage. They typically integrate storage, PV and/or wind generation, with demand management. They can range from small, farm scale units near the edge of the grid, up to community or mine-scale systems of several MW. They can also be connected to the main SWIS grid e.g. Alkimos, where they contribute to grid stability.

Behind the meter' batteries enable consumers to store their own PV electricity generation for use during evening and morning peak times when tariffs are high. Any excess stored energy can be sold to the grid at these times. Battery prices are falling steeply. For example, the Tesla Powerwall price fell by 50% in 12 months and prices are predicted to decrease dramatically over the next decade. These systems are already cost effective on some premises and hundreds have already been installed.

Other grid-based storage technologies such as flywheels and super capacitors have application in some situations, where short bursts of fast response balancing power is required.

Reliability of Renewables with Storage

Table 1 summarised the amount of generation which can be supplied by renewables. This section goes into more detail about how much electricity is generated by renewables across a 10 day period, as well as how any shortfalls can be met. Figure 1 shows modelled power generation every hour over a ten-day summer period. Output from wind and PV is shown in yellow. In this period, the minor shortfalls shown in other colours are met by battery and pumped hydro storage, and then by rapid-response fuelled turbines (fuelled by biogas/bio oil or conventional

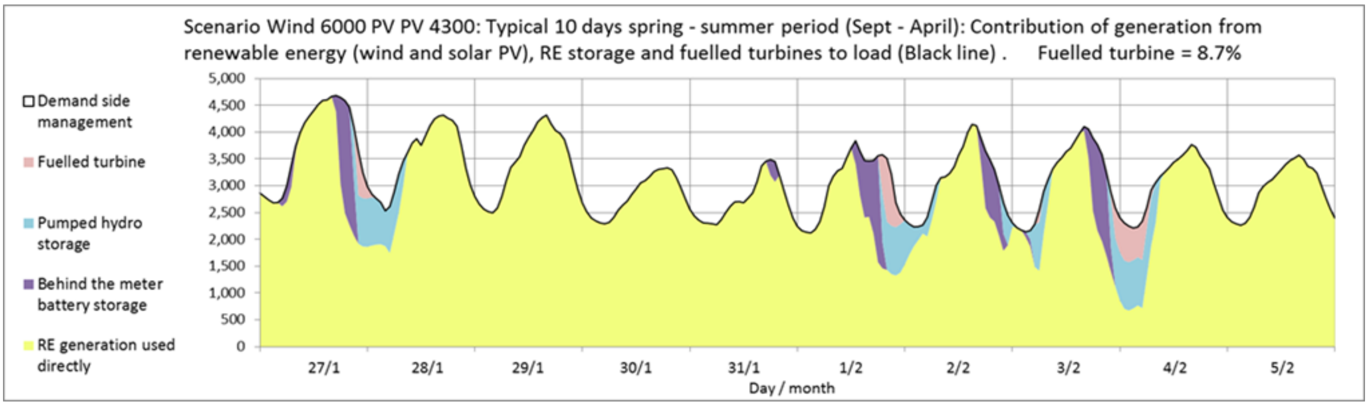

Figure 1. Modelled generation and load over 10 days in summer

Figure 2. Modelled power surplus/shortfall for renewables for every hour over a two week period in summer, 2014.

natural gas).

Similarly, in winter, wind and solar, combined with storage, can meet most of the demand most of the time. However, there are infrequent periods of up to two weeks during autumn and winter with cloud and little wind. Figure 2 shows one of these 10 day periods, once again with renewables shown in yellow. In this scenario, battery and pumped hydro storage is soon exhausted. Although most of the load is still being supplied by wind and solar, shortfalls (37% – mainly at night – shown in pink) can be met by rapid-response turbines (also known as open-cycle gas turbines).

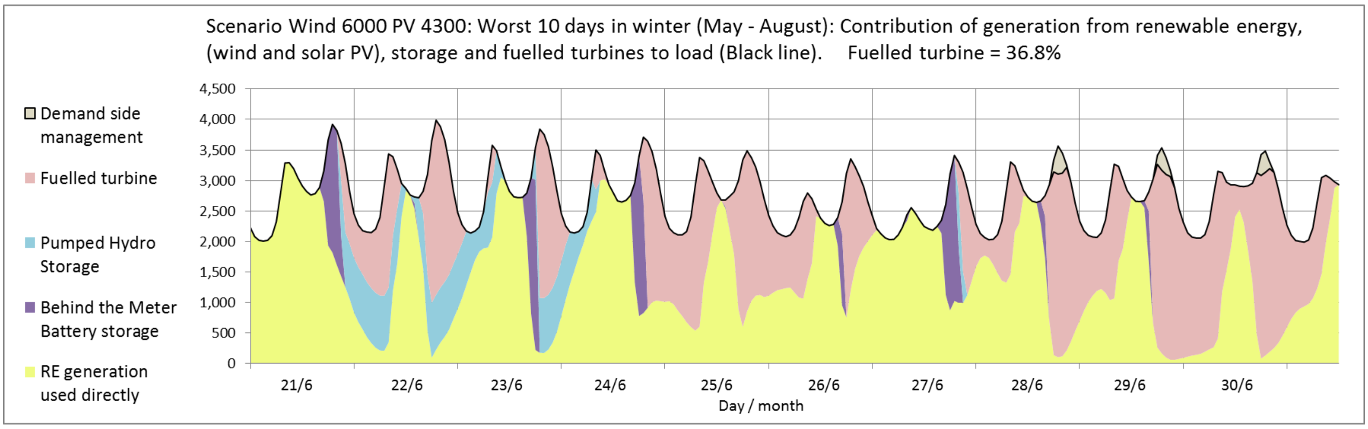

Figure 2. Modelled generation and load over 10 days for worst period in winter

While more storage technologies could be installed, SEN's modelling shows that, at present, it is prohibitively expensive to install sufficient storage to meet the worst demand scenarios, illustrated in Fig. 2. Rapid-response fuelled turbine generation capacity of about 3,000 MW (80% of the maximum load) is required to meet the maximum shortfall, assuming that 500 MW of demand side management is available (as in the current situation). This is comparable to the 1,900 MW of rapid-response (gas) for peaking, and 550 MW of gas for the baseload, augmented with 675 MW of gas co-generation available on the grid as at 2017. The rapid-response turbines require relatively low capital expenditure, but are expensive to run, because of the high cost of fuel. However, as shown in Table 1, they only supply 6 – 14% of total load, compared to nearly 50% in the current (2017) grid.

SEN's proposal is to fuel these turbines from bio-fuels from an oil-mallee biomass growing industry. This could be established in Collie (see SEN's Jobs Revolution Briefing Note), to enable coal workers to transition to alternative employment, while also addressing salinity on degraded farm lands.

The current SWIS generating system has unrealistic amounts of excess capacity. There is approximately 1,000MW of reserve coal-fired capacity over the maximum historic demand of 4,400MW. This excess capacity is kept in reserve in case of failure of one of the few large, 220-420 MW generating units. It is usually idle. With thousands of smaller wind and PV units, these large thermal plants, which are very expensive to keep in reserve, will no longer be needed. Unpredicted failure of small units is much easier to manage, and have spinning reserve coverage (see below), being in the 2-5MW capacity range. Reducing this overcapacity will put downward pressure on energy prices.

Variations in RE generation due to low wind and sun conditions are entirely predictable and covered by storage, and standby gas turbines, some of which will be on hot standby duty ready to provide 'spinning reserve'. Furthermore, the Australian Wind Energy Forecasting System (AWEFS) provides accurate forecasts of wind generation on the National Energy Market grid at 5 minute intervals, 5 minutes in advance, for individual wind farms and market regions. This accuracy of such short-term forecasting has been proven in practice world-wide to allow adequate time for dispatch of stored energy or spinning reserve to compensate for falling RE generation. Cloud-predictive technology is also coming online. These factors will contribute to even more responsive demand management.

Grid Stability

Even when generation is plentiful, an electricity grid can be blacked out by a brief disruption. This can occur when the network voltage drops rapidly, or the frequency deviates slightly from 50Hz. If a large coal or gas generation facility has to close down suddenly (caused by flooding or fire), this can have a large impact on the network, which must have provision for standby reserve capacity to meet demand in the event of a single large unit failure. In a scenario with many distributed, smaller wind and PV units, loss of units due to failure is more manageable, and its required backup is at a lower cost.

Various frequency control services are available to ensure that the system can balance load fluctuations and keep AC power frequency within a narrow tolerance range close to 50Hz. While rapid-response turbines can ramp up from cold start to full power in less than 10 minutes, this is sometimes not fast enough for frequency control and to meet large increases in demand.

In RE scenarios, instantaneous frequency control can be provided by:

- 'Spinning reserve' – fuelled generators running at low load, as also deployed in traditional fuelled grids.
- Dedicated on-grid, bi-directional inverter-connected batteries
- Bi-directional, inverter-connected flywheel systems.
- Synchronous generator-connected pumped hydro systems can respond instantly to demand fluctuations
- Wind and solar farms can manage weather-related variations through their own computer control systems
- Micro-grids

A complementary approach to grid stability is demand-side management, where end-users are paid to shed load during high demand periods. This is already utilised on the SWIS, with industrial users providing about 500 MW. Demand-side management can also be deployed at the domestic level, with behind the meter battery storage. Approximately 1000 MW of demand-side management could be provided by domestic and commercial users through appropriate incentives and roll-out of bi-directional smart meters.

Additionally, there are a growing number of innovative technologies and business models that can contribute to network stability, and reduce consumer costs and peak demand on grid infrastructure:

- Time-of-use tariffs enable end-users to re-charge their batteries in periods of low demand/price and draw on this electricity in times of high demand/price;
- Smart metering and appliances can be used to adjust demand to better match renewable generation;
- Peer-to-peer trading, enabling end users with distributed energy resources to trade between each other;
- Virtual Oscillator Control, where new-generation smart solar inverters contribute to network stability by following a network frequency signal, thereby stabilising the network.

The 2016 shutdown of the South Australian grid, during a storm event, was incorrectly attributed to a rapid shut down of wind generation. In fact, it was caused by the severing of High Voltage transmission lines (>20 pylons blown over), the inability of gas turbines to compensate rapidly enough, and the 'tripping' of the high voltage interconnector transmission line. This 'adverse load cascade event' could probably have been averted by better management of the protection settings on the generating assets and having adequate standby generation policies in place.

Electricity networks evolving to large RE penetrations are now requiring a more modern, responsive approach to system management and control. Events in early 2017 in South Australia and NSW further emphasise the need to modernise network management, highlighting the need for a government transition plan.

The impact of increasing domestic solar PV penetration

An emerging energy security scenario is evolving as consumers on the SWIS install solar PV. As solar generation capacity increases, it can provide the majority of electricity demand during daylight hours. This is illustrated in Fig. 3, which shows the predicted average amount of electricity supply required from the grid over the period from 2007 to 2025.

Because domestic rooftop solar PV is growing, it supplies much of the daytime electricity for households. This will reduce baseload demand from the grid. Fig. 3 shows that, from 2021, domestic solar generation will reduce the daytime demand below the night-time baseload, to near zero by 2025.

This will present a serious technical and political problem for coal-fired power generation. Coal-fired generation assets require a constant baseload demand to reduce the need for them to 'ramp' up and down – a slow and inefficient process. While there will be low demand for grid power during the day, there will still be a demand for high levels of generation in the evening peak times. Coal-fired power stations simply cannot adapt to this change in demand. This scenario does not consider any commercial solar installations, which will accelerate the impact. Without government intervention, the situation will inevitably arise that coal-fired generation will only be needed during certain periods (therefore raising consumer costs), or Government will need to legislate against consumer-generated solar electricity (causing political unrest). Governments will need to respond nimbly.

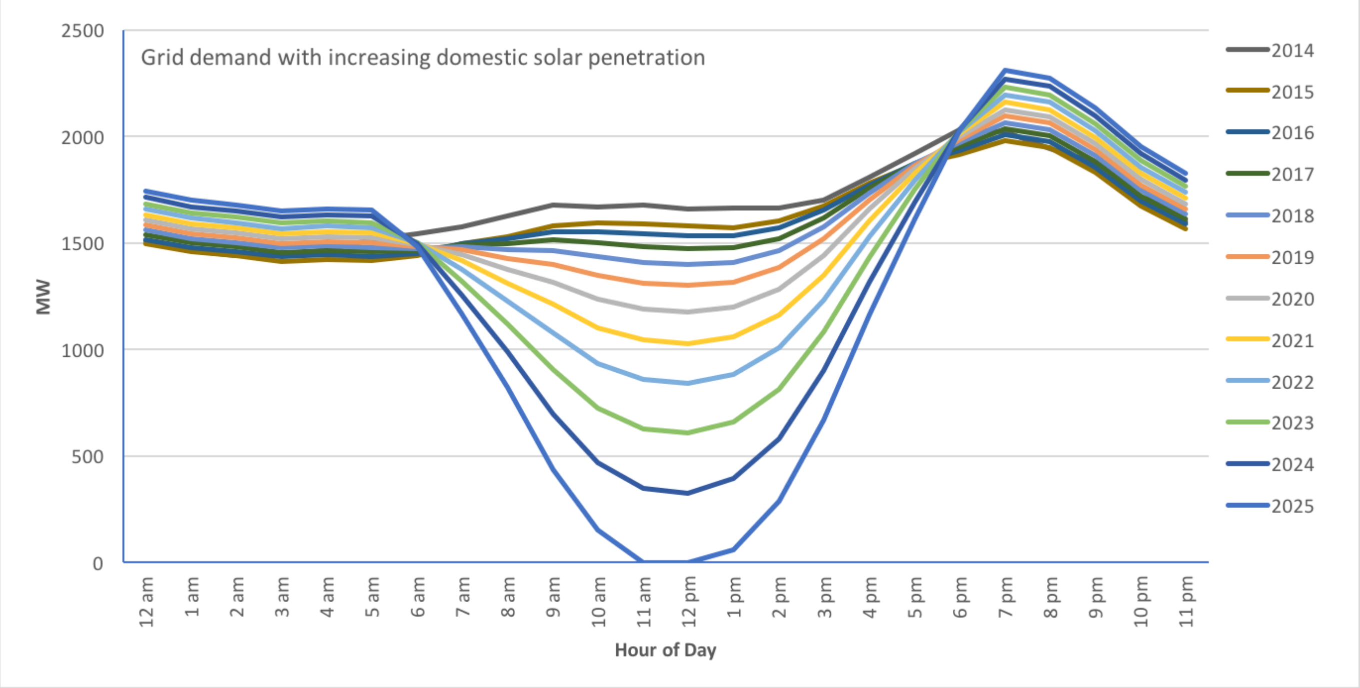

Figure 3. Predicted average amount of electricity supply required from the grid over the period from 2007 to 2025, showing how domestic solar production will decrease demand for centrally-provided power during the day.

Transition Plan

The key to a just transition towards a secure renewable electricity grid in WA is to develop a coordinated transition plan (for further details see SEN's "Role of Government" Briefing Note).

This transition plan needs to consider the numerous emerging technical issues, informed by best-practice engineering already implemented in the rest of the world. It also needs to be implemented prudently, in a staged manner, with corresponding change in management practices by utilities and regulators.

SEN recommends that regulators should provide access to, and incentivise the installation of, energy storage (batteries, etc.), smart meters (with bi-directional power and control capabilities) and smart appliances. The incentive costs can be offset by lower costs arising through reductions in peak infrastructure costs.

Conclusions

This Briefing Note has addressed renewable electricity security and stability over a 14 year transition towards 100% renewables on the SWIS by 2030. SEN's modelling shows that wind and solar PV can meet most of the expected demand, day and night, for most of the year. During periods of intermittent wind and solar conditions, energy security can be assured by rapid-response fuelled generation. Over time, some of this backup capacity can be met by various storage options. The distributed nature of a renewable grid will also contribute to energy security.

The variable nature of renewable electricity sources will require more responsive approaches to network management, and these are well established in other countries. Technologies such as flywheels, spinning reserve, batteries and appropriate energy storage mediums, micro-grids, wind and cloud prediction, and innovative business models can lead to a renewable grid which, for the reasons identified herein, will be more secure than the current electricity network.

SEN’s Modelling

SEN’s Integrated Renewable Energy Network (SIREN) software was developed to model renewable power and storage technologies. SIREN uses NASA weather data, Geographical Information System data and the US Dept. of Energy technology models. SIREN accuracy has been verified against existing wind and solar PV generation on the SWIS.

A variety of scenarios were modelled using SIREN. These include the cost of new transmission lines. Conservative assumptions have been made about the costs of renewables, which are continually decreasing. Future changes in prices will influence the optimum mix of wind and solar PV.

Sustainable Energy Now (SEN) is a voluntary group of some 200 members and associates, many of whom are professionals in the engineering, science, educational, business and IT fields. Its goal is to promote renewable energy in Western Australia.

Contact details:
PO Box 341
West Perth
WA 6872
contact@sen.asn.au
www.sen.asn.au