Introduction

Siemens commends AEMO on the broad stakeholder engagement process it is carrying out in support of its Integrated System Plan. The energy transition is a challenge facing all modern electrical networks and a planned approach is essential if there is any chance to minimise its negative impact to either cost, security/reliability and climate.

As one of the largest global electrical engineering companies with extensive expertise in electrical generation (both fossil and renewable), transmission, distribution and efficient use of energy, Siemens has technology expertise that can be deployed at the various parts of the electrical supply chain. And while the energy transition of every country or even region may be different, there are certain learnings from others that will benefit Australia's electrical network as it navigates this fundamental change in operations.

Given the broad range of technologies in our portfolio, Siemens is technology agnostic with respect to which technologies should be promoted. Instead, it is critical that the challenge and application requirements are properly described before technology solutions are promoted. AEMO's Integrated System Plan Consultation paper describes the challenge and application requirements for the National Electricity Market and it is in response to this that Siemens would like to draw to AEMO's attention a range of technology solutions which should be further considered in the plan's development.

1. Grid Modelling

The German electricity network is amongst the most secure and reliable in the world which is a consequence not only of its interconnection with neighbouring networks but also its extensive modelling and transition planning amongst other things. Siemens collaborates actively with German grid planners and other stakeholders through software, research projects and technology to support background activities to ensure network security and reliability are maintained. See the link below for more information.

https://www.cleanenergywire.org/factsheets/set-and-challenges-germanys-power-grid

With increasing grid complexity and the exponential increase in distributed generation and power electronics in the network, advanced grid modelling, simulation and maintenance of a network 'digital twin' informed by actual grid performance, all have a role in planning for the energy transition. Figure 1 provides an illustration of the level of modelling that has been undertaken in Germany.

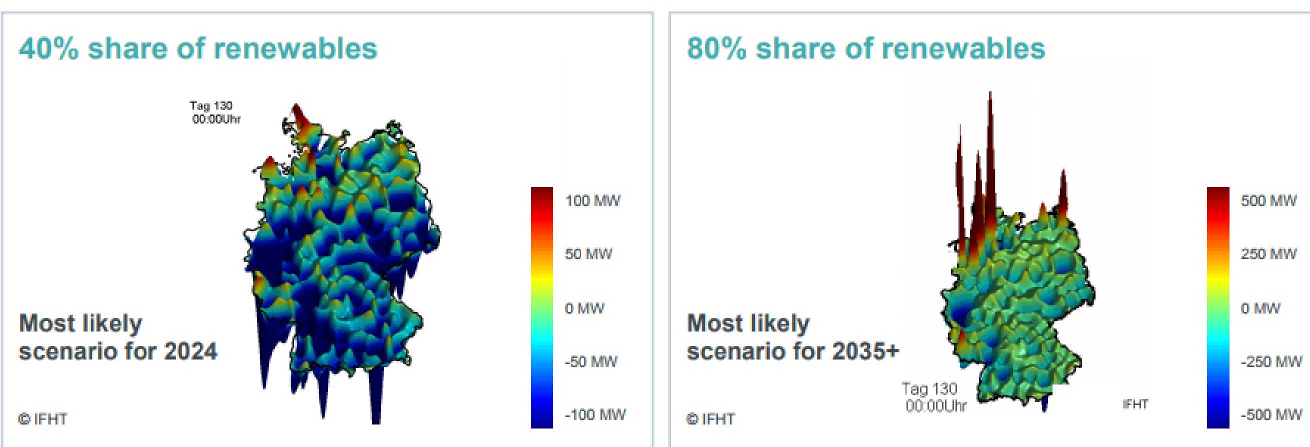

Figure 1: Germany's 'Energy Heartbeat' - Snapshot of interactive 3D video modelling of Germany's electricity sector. Source: German Power Network Development Plan

Siemens would be pleased to facilitate an introduction to some of Germany's grid modelling systems and activities to gain further insights into the approaches and activities behind Germany's renowned electricity network stability performance. This could include the following;

- Bundesnetzagentur – The agency responsible for coordinating grid planning.
- SINTEG – Research projects investigating issues relating to energy grid transition.
- Dynamic Grid Control Centre – Research project investigating control centre management of dynamic grid changes.

2. Integrated Grids and Sector Coupling

The nature of solar and wind energy is such that they can provide more energy than we can immediately use. On the other hand, there will be instances when there is not enough power available due to low winds or cloudy skies. To illustrate this, in the case of Germany, the Fraunhofer Institute for Wind Energy and Energy System Technology expects 400 GW of installed wind and solar capacity by the end of the decade, while the predicted consumption will only be 80GW. If in Germany all 40 million cars were electric with a capacity of 30 kilowatt-hours each, the overall capacity would be more than 1 terawatt-hour. On a very windy day charging this fleet would be a matter of only five hours[1].

Siemens sees three grids playing a critical role in a future energy network which will need to become more closely integrated to support the inevitable increased uptake in variable renewable penetration; i) the electrical grid, ii) the gas grid and iii) the digital grid. While the first should need no further discussion, the second two will play an ever more essential role in energy networks of the future. Figure 2 below depicts these schematically.

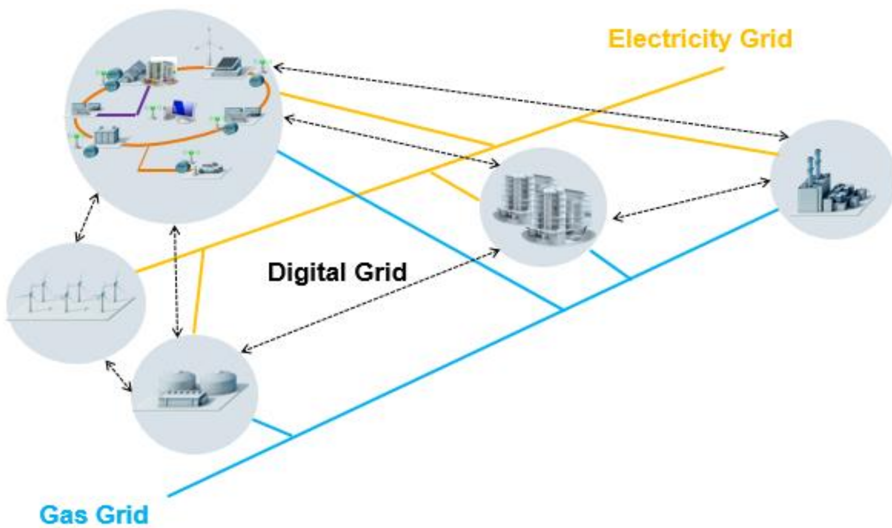

Figure 2: Illustration of the integration of the Electricity, Gas and Digital Grids to support high intermittent renewable energy penetration

The gas grid has a distinct advantage over the electrical grid in the context that it is able to not only distribute energy, but also to store it. It is this feature which will become increasingly attractive in grids with high levels of variable renewable energy. Conventional solutions to this mismatch already exist (such as gas peaking power plants, pumped hydro and / or battery storage) however the possibility to store vast amounts of energy in a chemical form through the electrolysis of water to produce hydrogen and other derivative gases or chemicals will become increasingly important.

[1] https://www.siemens.com/customer-magazine/en/home/energy/bringing-power-to-the-people/multimodal-energy-systems-on-the-rise.html

The digital grid will facilitate the high speed matching required between generation and demand, not just at a transmission level with bulk generators but increasingly for the orchestration of distributed energy resources or large scale peer-to-peer trading. With grid reliability and security increasingly important and the advance of power electronics at most new grid-connected generators and loads; digital connectivity will facilitate not only load matching but also power quality requirements. The digital grid will be underpinned by an open platform which offers a single source of truth for the energy market and facilitates secure data exchange between participants. Siemens 'MindSphere' platform has been designed for just this purpose.

Because electricity is such a versatile energy source, it will be the primary medium for achieving deep, economy-wide decarbonisation through deployment of renewable energy. This will require extensive electrification of other carbon emitting sectors such as stationary energy, industrial processes and transportation, which would also increase electricity demand.

The coupling of key sectors such as electricity, heat, cold, gas and water sectors can also be used to manage the intermittent nature of variable renewable energy. Coupling of sectors enables utilities to optimize the energy system, choosing the most suitable pathway with regard to fluctuating renewable energy sources. This is sometimes referred to as multimodal energy systems, and is represented in Figure 3 below.

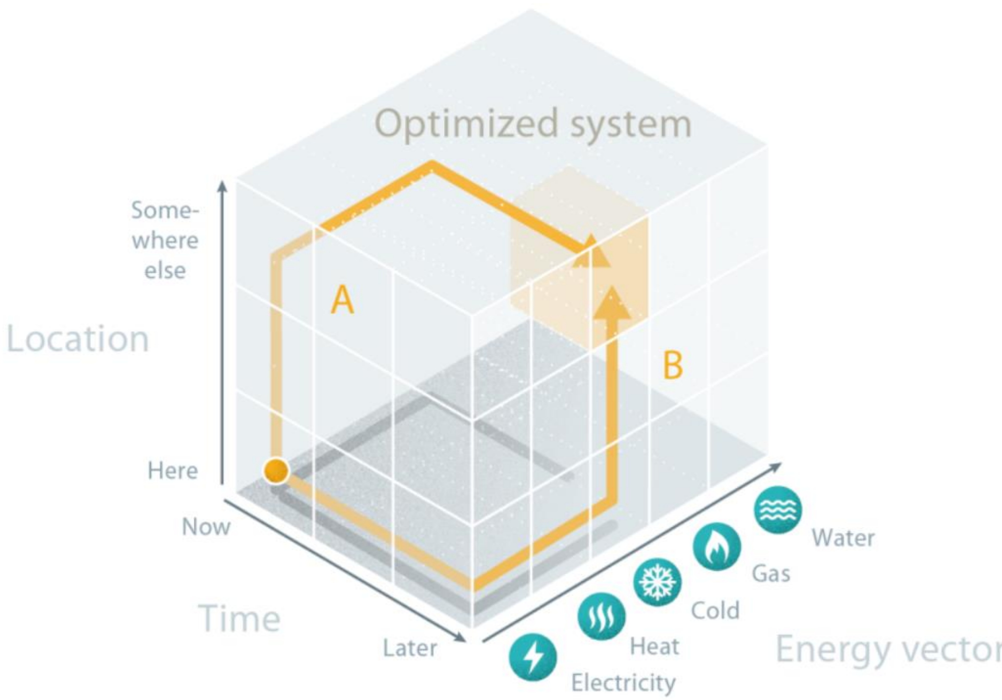

Figure 3: Multimodality optimises energy systems

Pathway (A) shows electricity transporting energy fast over long distances, i.e., in high-voltage transmission lines, while at its destination, a compression refrigeration system transforms power to cold, which can then be stored in a reservoir for later use. The same goal can be reached via pathway (B) by storing electricity in a battery or transforming power to heat and storing it in a reservoir before it is transported through long-distance heating lines to the point of consumption at the time of need.

3. Transmission

Powering the world's largest island is a complex task and unlike many other countries, Australia cannot rely on its neighbours for power in the event of significant disruptions. Our grid is also one of the longest and thinnest in the world, consisting predominantly of overhead lines, making it especially vulnerable to disruption from events such as extreme weather, bushfires etc.

A well connected, unconstrained transmission network can improve system security and reliability, provide access to a more diverse range of generation and help align prices across regions through interregional trade. The AER has noted that alignment rates in mainland NEM regions have deteriorated significantly in recent years, and that the recent deterioration in market alignment reflects a rising incidence of network congestion[2].

A certain level of congestion is expected in an efficient market where the cost of expanding the network to eliminate congestion is greater than the cost of congestion itself. However, transmission networks and interconnections are critical infrastructure and important to any national energy system plan. As the ISP consultation paper notes, the RIT-T process has previously been predicated on load growth without enough focus on system security and reliability. This investment test may also not fully recognise other benefits from interconnection. For example in assessing a second interconnection between Victoria and Tasmania, the report by Dr. John Tamlyn[3] found the RIT-T assessment did not take into account competition, some aspects of power security and reliability and options value benefits. Without additional investment to strengthen the country's transmission and interconnection infrastructure, the value of renewable energy zones and nation building projects such as the proposed Snowy 2.0 project may not be able to be fully realised. The concept of Tasmania as a 'Battery of the Nation' is simply not viable without additional interconnection between Tasmania and the mainland.

A strongly meshed network, such as that in Europe, is likely not an affordable option for the Australian power system. AEMO has assessed 5 separate interconnection options in its 2016 NTNDP, at a total estimated cost of around $3 billion at the higher end of the assessments. The total Regulated Asset Base of the NEM (Transmission plus Distribution) is around $86 billion[4]. CSIRO modelling indicates that almost $1 trillion could be spent by all parties in Australia's electricity system by 2050[5]. If all the identified interconnection options were implemented, the investment cost would amount to 3.4% of the former and much less than <1% of the latter, which would not appear excessive given the potential benefits. We fully support assessing the economics of these investments in a way which values the additional security, reliability, national interest and other benefits they would bring. For Australia, we think that there are many benefits to employing HVDC transmission technology, and we take this opportunity to provide a little more detail.

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[2] AER State of the Energy Market, May 2017
[3] Feasibility of a second Tasmanian interconnector, Final Study, April 2017
[4] Retail Electricity Pricing Inquiry Preliminary report 22 September 2017
[5] Energy Networks Australia Electricity Network Transformation Roadmap Final Report, April 2017

3.1 HVDC (High Voltage Direct Current) Transmission

Historically, when considering whether to employ HVDC or HVAC transmission technology, planners would employ a total cost (CAPEX + OPEX) view, which allows for capital expenditure, losses and operating costs over the life of the asset. This can be represented by the Total AC / DC Cost lines in Figure 4 below.

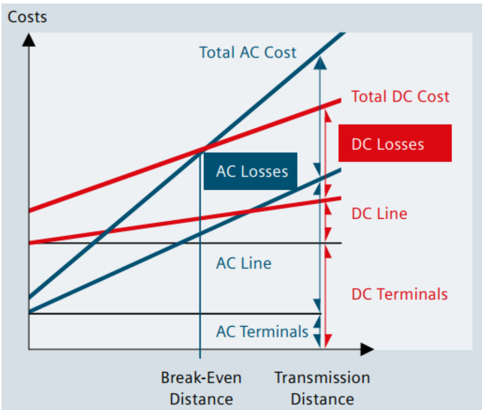


Figure 4: Typical cost comparison curve between HVDC and HVAC

The Total DC Cost curve begins at a higher point than AC as HVDC stations are more expensive than AC stations, but it is not as steep as the AC curve because of the considerably lower line costs per kilometre. For long AC lines the cost of intermediate reactive power compensation has to be taken into account.

The break-even distance is usually in the range of 500 to 800 km depending on a number of other factors, like country-specific cost elements, interest rates for project financing, loss evaluation, cost of right of way, etc. It is very likely that in Australia, with our vast geography, power will have transfer distances >500km, and therefore DC transmission technology could be the preferred option.

However with the increasing penetration of renewables, and the need for grids to become ‘smarter’ to support the energy transition, network stakeholders globally are adopting a more holistic cost / benefit approach that accounts for the additional benefits of DC technology, preferencing the DC technology choice even over shorter distances.

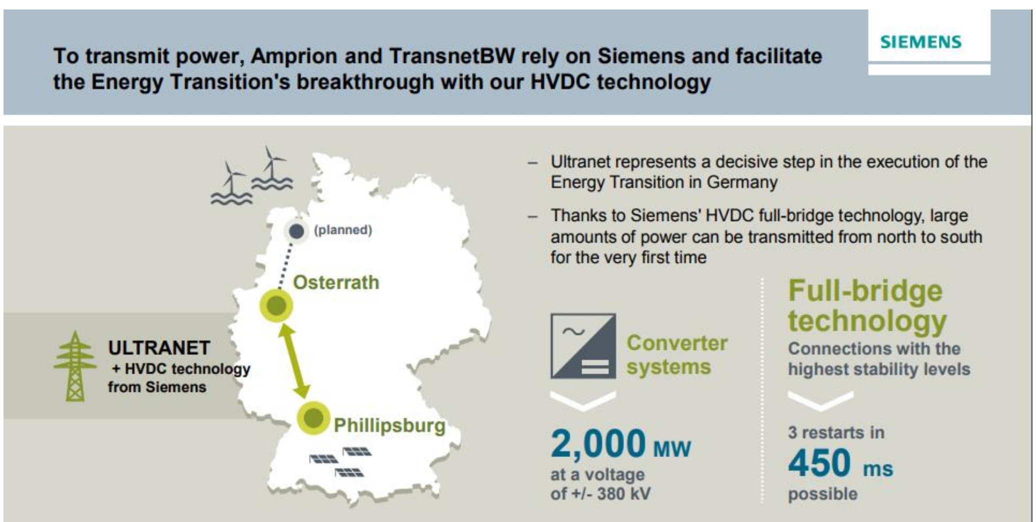
The key advantage of HVDC over HVAC is power controllability. This controllability is beneficial for:

- Precise power flow control, in either direction, dynamic and steady state
- Enhancement of AC system stability
- Reactive power control / support of AC voltage
- Frequency control
- Overload capability
- Emergency power functions, including black start capability
- Power oscillation damping

Importantly, HVDC also acts as a Firewall against cascading disturbances.

With the growing renewables share in the overall generation mix, new HVDC links in Europe are now being built mainly for controllability. This is illustrated by a number of projects from around the world that Siemens is involved in.

In this example, although the distance involved was only 75 km of overhead lines which would ordinarily involve an AC interconnection based on the traditional CAPEX / OPEX model, the extra level of controllability and system security benefits of an HVDC interconnection outweighed the additional up-front CAPEX cost of the AC option. Two AC interconnector options are being evaluated for South Australia by AEMO. The lengths involved are around 300 and 450 km, depending on route. A DC link would provide AEMO additional controllability in the form of dispatchable power in any direction at any power level (up to its capacity) inclusive of black start capability.



The ULTRANET project in Germany involved the conversion of one of the four existing AC links to DC. The same towers and conductors were kept, with only the tower bushings needing replacement to cope with DC insulation levels. Apart from increased control and system security benefits provided to the adjoining AC links, a 20% increase in total power transfer on the DC circuit is achieved. This technology could be particularly relevant for the Qld / NSW interconnection (QNI). This 330kV link has a stability constraint, as well as a thermal overload constraint. Converting one of the AC circuits to DC would provide more stability on the AC network and increase the power throughput capacity on the interconnection.

3.2 MVDC (Medium Voltage Direct Current) Transmission

As has been noted, the grid is moving away from unidirectional energy flows following the High Voltage → Medium Voltage → Low Voltage pathway via alternative current (AC), to omnidirectional energy flows that will require more control. In addition, renewable energy is often produced at a low voltage level, and we are seeing an increasing number of DC consumers, such as electric cars / e-mobility, and data centres.

Siemens has developed the MVDC transmission system for grid operators who need to enlarge their infrastructure to handle the increasing volumes of power fed into the distribution system from distributed and renewable energy sources and also keep their network stable.

MVDC can be an efficient transmission link in AC medium-voltage networks of 33 to 132KV. It allows power to flow in all directions and like HVDC it enables seamless control of the active power flow. It helps manage short-circuit currents and optimise networks through a hybrid approach, using a mix of AC and DC. It could be more economical than MVAC networks as it offers a higher capacity at lower voltage. See Figure 5 for more details.

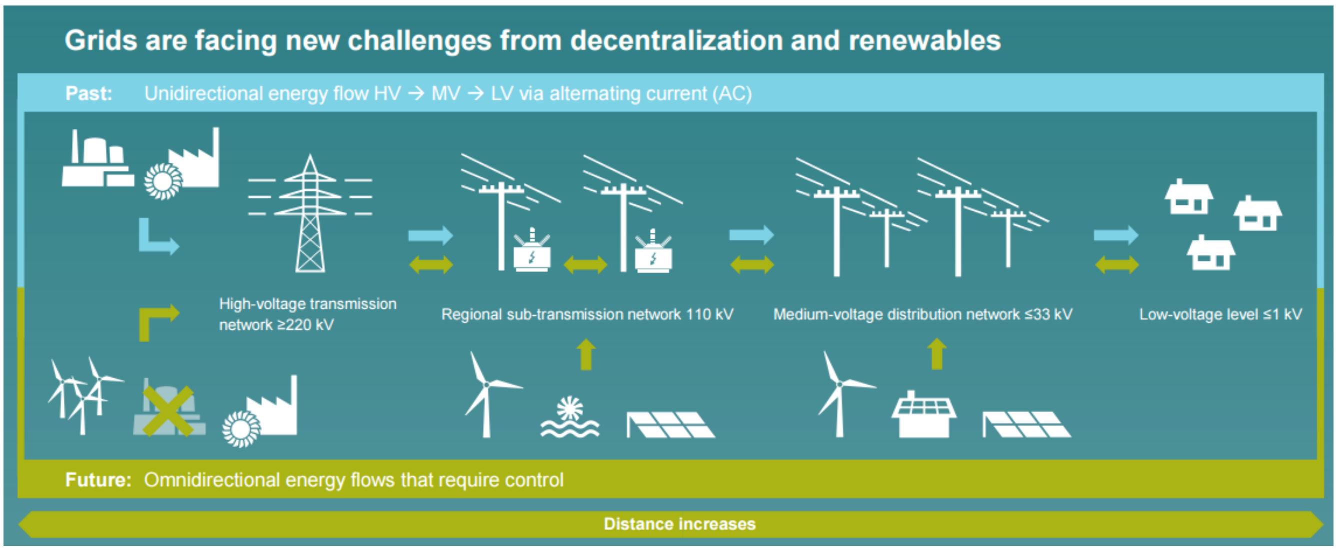


Figure 5: In the past (arrows shown in blue), power has typically flowed from conventional generation source to consumer in one direction via AC. The MVDC solution system (arrows in green) could allow for omnidirectional energy flows over larger distances.

In addition, MVDC can cost effectively connect islands, autonomous systems and regional medium-voltage networks, which could help networks such as Microgrids that supply themselves with wind or solar power, or through their links with each other be better managed, controlled and optimised.

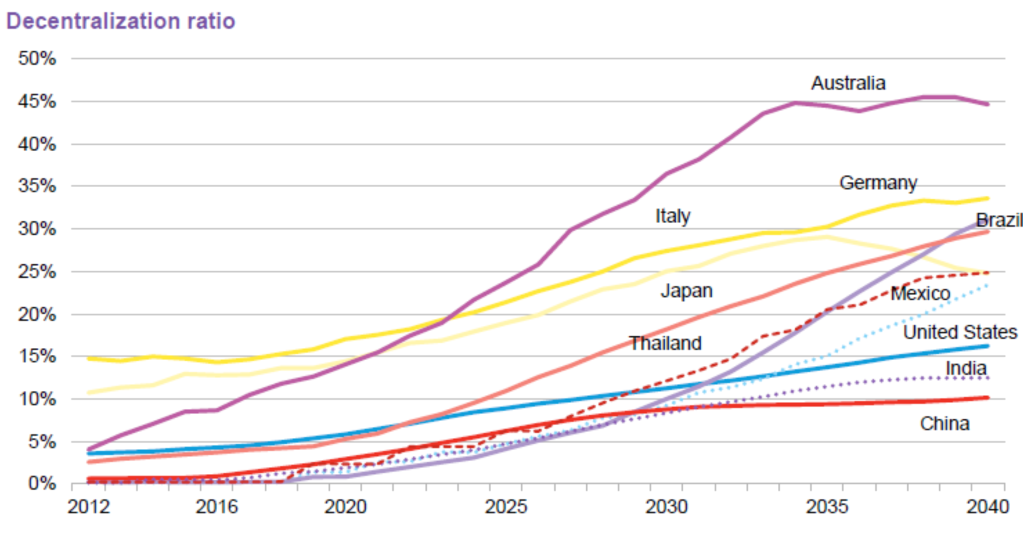
The basic version of the system can be used over a distance of up to 200 kilometres, and in a power range of 30-150 megawatts.

More information regarding Siemens MVDC PLUS offering can be found via this link:
https://www.siemens.com/global/en/home/products/energy/medium-voltage/solutions/mvdc.html

4. Microgrids and 'Island Capable' Demand Centres

Microgrids are the building blocks of our energy future. As small-scale electricity networks that can operate independently of the surrounding grid, they present a potentially cost effective solution to promoting system resilience in the face of Australia's vulnerability to environmental hazards such as bushfires and cyclones. Benefits include the ability for them to expand incrementally and quickly on account of renewable embedded generation and energy storage having relatively short delivery times. In addition, they facilitate the ability to integrate a diverse generation mix as new technologies become available and to incorporate potential co-generation and efficiency measures such as Combined Cooling / Heat & Power, Hydrogen production, e-Vehicle charges or fuel cell vehicles. By intelligently networking and managing distributed energy resources and loads, they can achieve efficiency dividends, capture new revenue streams and support the utility network they are connected to.

Australia is no stranger to off-grid generation, accounting for an estimated 17% of total generation in 2014/15[6]. Bloomberg New Energy Finance suggests Australia will lead the world in distributed energy per Figure 6.



Source: Bloomberg New Energy Finance Note: decentralization ratio is the ratio of non-grid-scale capacity to total installed capacity.

Figure 6: Decentralisation ratio projection for various countries

There is significant scope for the many weakly grid connected locations in Australia, particularly in Western Australia and Queensland, to move to a more reliable independent form of embedded generation via Distributed Energy Systems (DES), most likely in some form of hybrid plant consisting of renewable generation backed up by storage and fossil fuel generation. Advanced control systems are employed to properly manage the microgrid. Figure 7 show the display dashboard from one such system.

[6] Office of the Chief Economist, Australian Energy Update 2016

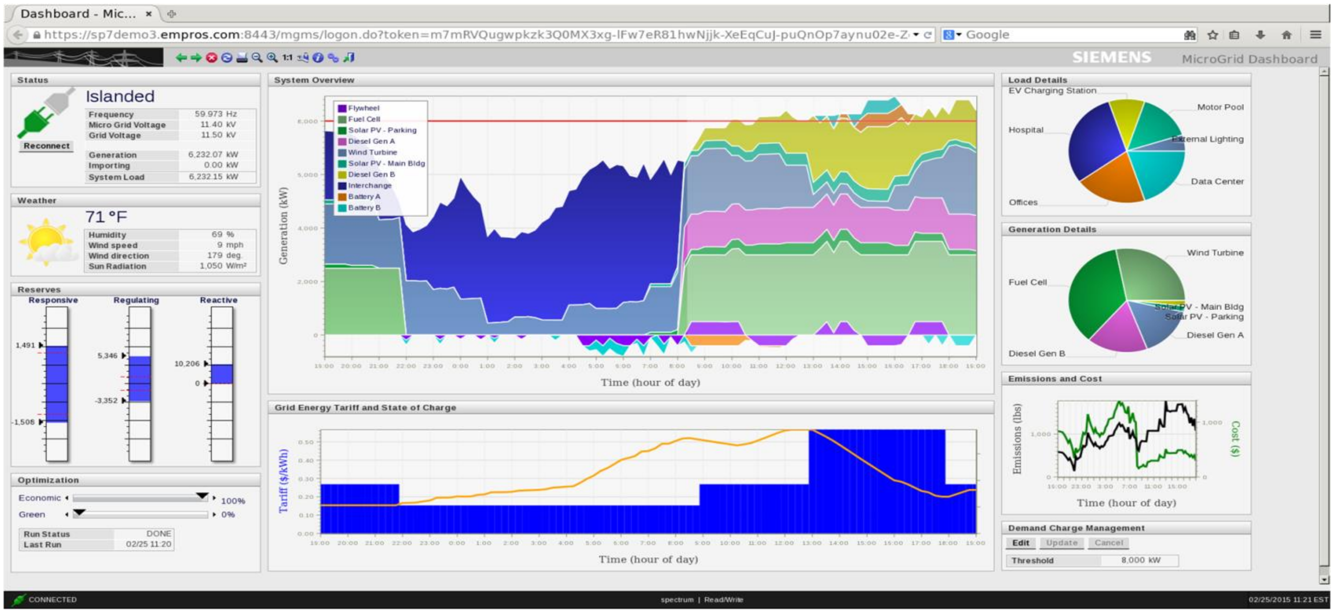


Figure 7: Spectrum Power Microgrid Management System dashboard provides complete situational awareness of the microgrid's operation. See also Blue Lakes Rancheria MicroGrid case study video. https://www.youtube.com/watch?v=MvdJBBekqoc

There are a number of these types of 'islanded' grids already in operation in Australia and around the world. For example, Horizon Power manage approximately 30 islanded microgrids with a program underway to increase the renewable penetration within each of these isolated grids. Western Power have started to introduce medium sized battery storage into their remote grid connected towns, including Perenjori and Kalbarri that are connected to the Western Power SWIS.
https://www.youtube.com/watch?v=Bg3M3wXRp3g.

Distributed power generation located close to energy demand delivers electricity with minimal losses. Typical thermal efficiency for centralised coal fired power generation is around 33%, whilst distributed energy resources embedded within microgrids could be greater than 80% efficient if designed properly. This power then has a higher value than power coming from large centralised conventional generators through the traditional utility transmission and distribution infrastructure.

There is therefore the potential for even strongly grid connected regional demand centres, such as small to medium sized towns throughout Australia, to develop their own generation capacity including renewable generation, and be managed as a microgrid. Integrating these distributed generation 'nodes' or embedded networks into the main grid in a way that allows the market operator to manage them for load, power and FCAS, could improve the reliability of the whole power supply system. This can be represented schematically in Figure 8.

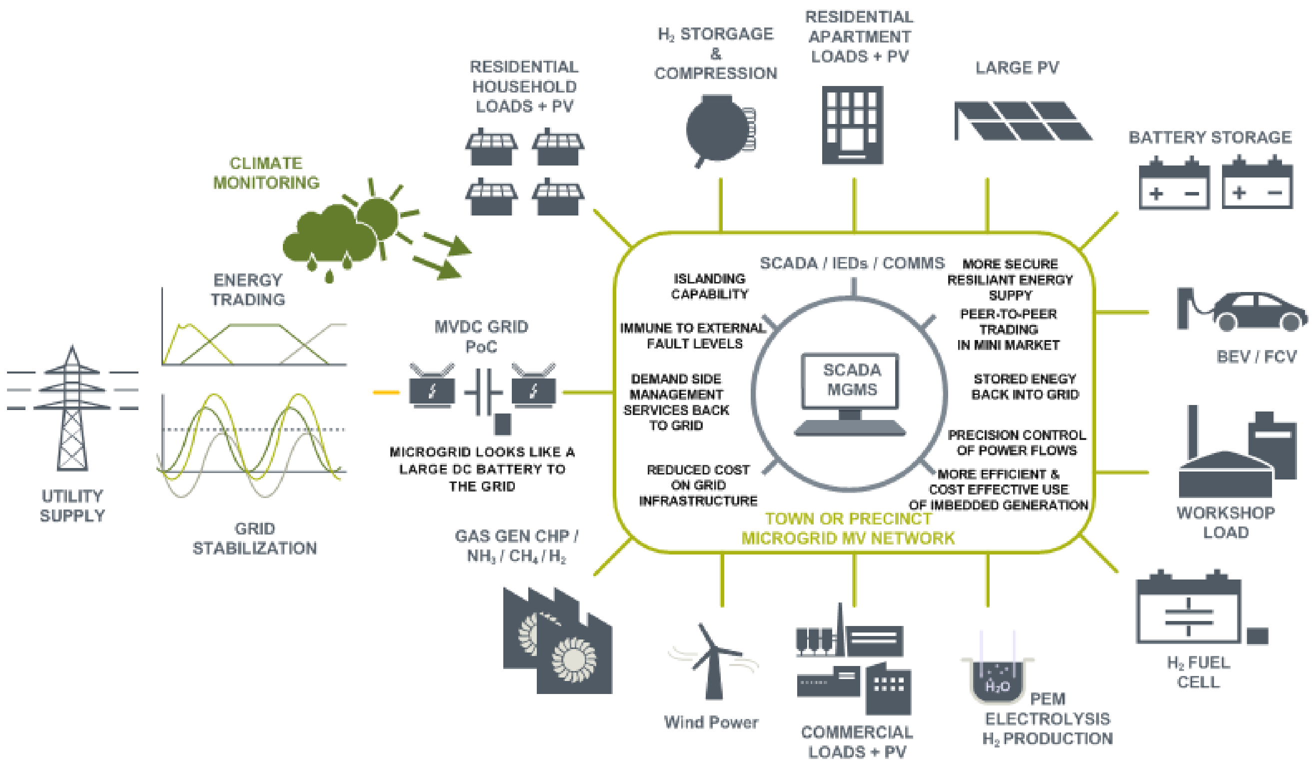


Figure 8: Grid integrated town or precinct microgrid MV network model (MVDC connection shown)

In Germany there are towns and villages that have embraced the microgrid concept, two such examples are Feldhiem and Wildpoldsried.

The Feldheim microgrid, originally developed as a standalone network due to regulatory challenges, is now connected to the HV network and trades much of its excess renewable energy with the market. In addition to its 47 wind turbines, biogas generators and a district heating system, the village has also installed a large 10MWp / 10.8MWh battery storage system, with its role to provide Frequency Controlled Ancillary Services to the grid (primary reserve). The market operator can call on this energy for a period 15 minutes 3 to 4 times a day and has some 30 other battery storage systems dispersed throughout Germany that it can call upon when required. https://cleantechnica.com/2015/09/21/new-10-mw-storage-plant-opened-feldheim-germany-europes-largest/

The provision of these primary reserve services is incentivised by the energy market. The provision of this service has to be guaranteed when it is called upon and if it is unable to provide the service there are penalties. This mechanism enables this type of service to be both economically viable for the provider of the service and the market operator.

The rules governing the market are complex, and would likely need to be modified to enable the implementation of the full suite of capabilities outlined above. We note that both the AEMC[7] and the AER[8] have identified some of the regulatory framework gaps, and made some recommendations.

[7] AEMC Consultation paper on stand-alone energy systems, 12 October 2016, ref ERC0206
[8] AER: Issues Paper, Regulating innovative energy selling business models under the NER law, January 2015

5. Australia as a renewable energy superpower

As has been noted by many industry participants and commentators, Australia is very well positioned to manage the transition to a carbon neutral energy environment, with world class renewable resources, skills and industrial capacity and importantly land availability. One or more of these is not readily available in many other countries.

However, our historical competitive advantage as a relatively low cost energy economy is being eroded. Both electricity and gas domestic pricing have increased significantly over the last decade, and Australia has moved up the cost curve relative to other OECD countries[9].

Siemens sees an opportunity for Australia to restore its competitive advantage as a low cost energy producer as the world makes the transition from fossil to renewable energy. Renewable energy cost projections position Australia favourably against key trading partners, as per Figure 9.

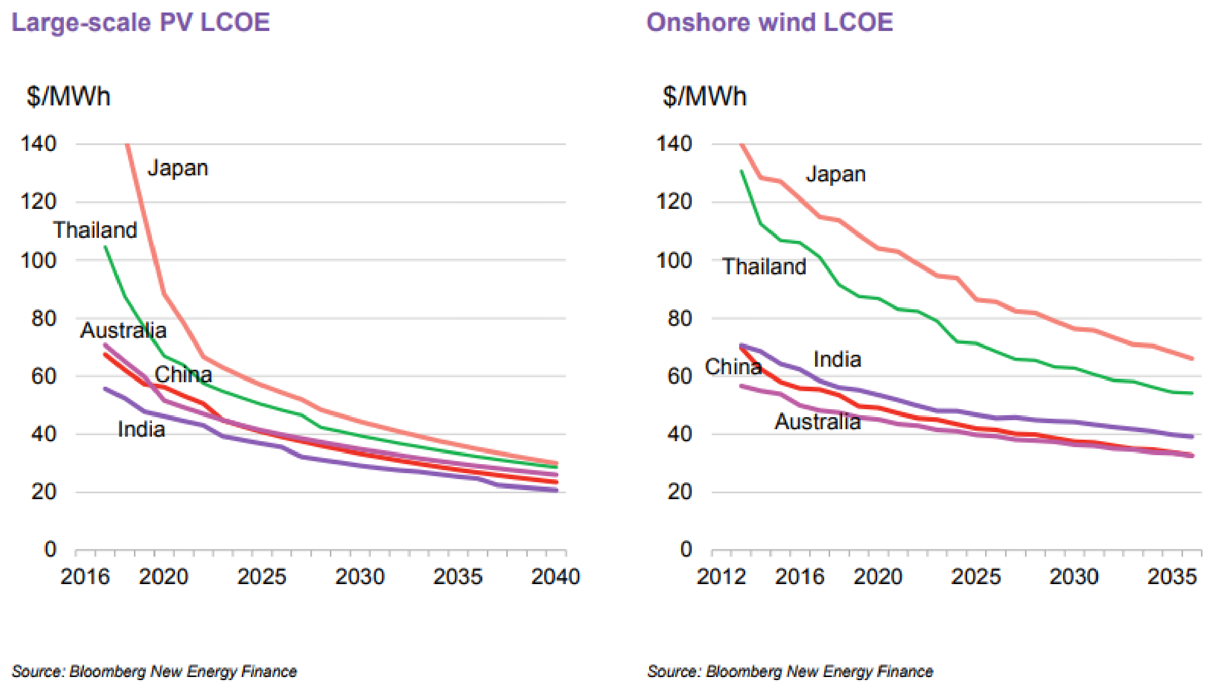


Figure 9: Large scale renewable energy cost projections for major Asia Pacific economies

The current AEMO NEM 20 year demand forecast is for a flat demand profile in the neutral scenario. We would invite industry stakeholders to consider the possibility for Australia's electricity demand to significantly increase, say more than quadruple, through the growth of energy intensive industries that exploit our natural resource base, effectively exporting our renewable energy capacity.

Zero Carbon Australia's report "Renewable Energy Superpower"[10] provides some compelling reasoning supporting this position.

Properly managed, a significant increase in the scale of electricity production through an increased energy intensive industry base, together with electrification of key carbon intensive sectors such as stationary energy and transportation, could further reduce the overall system-wide energy costs driven by a large but sparsely populated geography.

[9] ACCC Retail Electricity Pricing Inquiry, Preliminary Report, 22 September 2017

[10] bze.org.au/renewable-energy-superpower/