Investment in solar and wind generation in Australia- lessons learned

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The Australian National Electricity Market (NEM) rules and arrangements were developed in the 1990s when the majority of the energy was generated from large thermal generating units that were relatively close to the major load centres. These generation and load centres are also interconnected to allow energy to be transferred and traded to improve reliability and efficiency. New generators have open access to the network provided they negotiate their connection with the network operator and meet acceptable performance standards.

In the past decade changes in technology and climate change incentives have driven an evolution in the NEM rules and market arrangements. However, in recent years pace of change has increased and there has been a dramatic increase in the number of solar and wind generating systems installed and actively being assessed. These generating systems are smaller than the existing thermal generating units and are generally connected in more remote low voltage locations due to resource availability.

The paper will discuss how the NEM has evolved under the high volume of concurrent connection applications, including:

- **the need to coordinate generation and network investment to avoid excessive congestion, including the role of the Australian Energy Market Operator's (AEMO's) integrated system plan;**
- **the negotiation of performance standards in the presence of multiple concurrent connection applications, including the need for system strength remediation;**
- **the impact on network losses and the associated loss factors used to provide locational investment signals.**

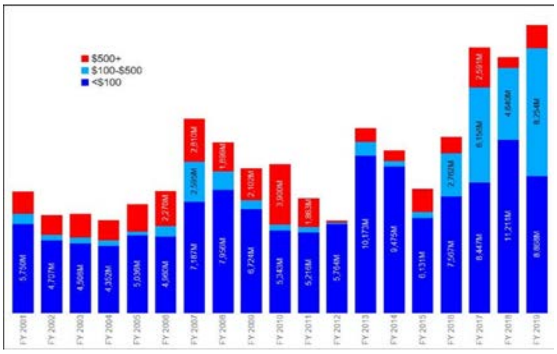
I. INTRODUCTION AND CONTEXT

Like many developed economies, Australian policy makers struggled to integrate a comprehensive climate change policy within an energy market framework. Pollitt and Haney (2013, p. 9) make the observation that when markets such as the Australian National Electricity Market (NEM) were liberalised, 'competitiveness was the overriding priority. Today, competitiveness, energy security and decarbonisation are the three main energy policy priorities.'

Without a comprehensive national framework implemented by the Commonwealth Government, a proliferation of piecemeal state-based public policies aimed at encouraging the adoption of new supply options with lower greenhouse gas emission profiles have added significantly to the existing generation capital stock. These technologies have a distinctly different cost profile structure to existing and competing thermal (coal and gas) units. Fuel is effectively free (i.e. wind and sun) but with material up-front capital costs. At a peak, there were six policies in place to drive capital substitution or addition, including: the New South Wales (NSW) Greenhouse Gas Abatement Scheme (GGAS); the Commonwealth's Large-Scale Renewable Energy Target (LRET); the Small-Scale Renewable Energy Target (SRES); the Queensland (QLD) 18% Gas Scheme; various energy efficiency policies (e.g. Victorian Energy Efficiency Target or VEET); and Victoria's premium solar feed-in tariffs (PFiT). A carbon price was also established through the Clean Energy Future package but then repealed within three-years.

Given declining demand, and significant uptake of subsidised embedded small-scale photovoltaic (PV) and large-scale renewable generation, there was an oversupply of capacity with prices well below the cost of new-entry until 2015 (see Nelson et al., 2015). This sustained low pricing resulted in several incumbent ageing coal-fired generators retiring over several years with the most capacity being retired in 2017. In most cases, less than a year's notice was provided of the generator closure. With such little time available to participants to replace the capacity being withdrawn, wholesale prices increased markedly in 2017. Prices are now at the highest they have ever been due to the disorderly transition that has occurred. This is shown in Figure 1.

FIGURE 1. VALUE OF NEM TRADING FROM 2001 TO 2019 (SEPARATED INTO PRICE BANDS)

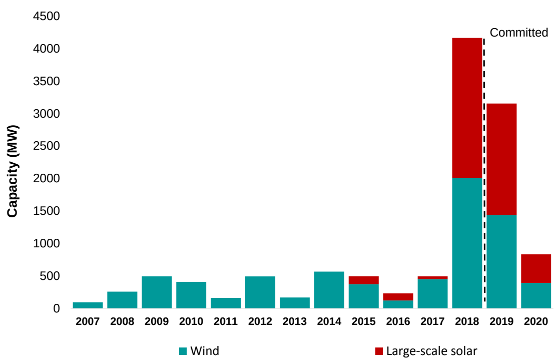


Around 5,000 MW of dispatchable generation (coal and gas) has been retired from the NEM while approximately 18,000 MW of non-dispatchable generation (wind, solar etc.) has been, or is in the process of being, commissioned. The installed capacity in the market is shifting from a small number of geographically concentrated large coal fired power stations, located within coal regions such as the Hunter Valley in New South Wales, to a large number of smaller units located throughout the system where fuel (i.e. wind and sun) is available. This has had significant impacts on both the way in which the energy-only NEM functions; and system security and reliability.

II. RATE OF RENEWABLE CONNECTIONS SINCE 2015

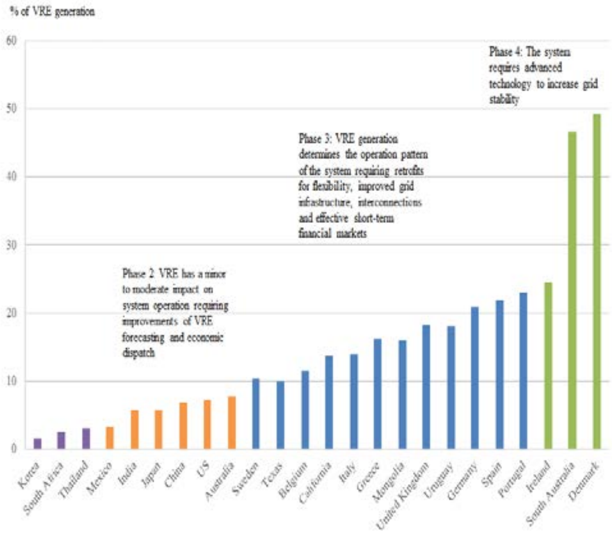
As discussed above the rate of commissioning of grid connected renewable solar and wind generation has accelerated in recent years. This can be seen in Figure 2 that shows the rate of uptake of solar and wind generation in the NEM from 2009 to 2019.

FIGURE 2. UPTAKE OF RENEWABLE GENERATION IN THE NEM FROM 2009 TO 2019



This means that the levels of variable renewable generation penetration in the NEM are amongst the highest in the world, as shown in Figure 3.

FIGURE 3. UPTAKE OF VARIABLE RENEWABLE GENERATION



As well as the nature of the generation mix changing, predominantly from coal based generation to an increased proportion of solar and wind generation, the physical location of the recently installed solar and wind generation is connecting in very different locations. Figures 4 and 5 show the changes in the generation in New South Wales, Victoria and South Australia from 2015 to 2019.

FIGURE 4. NSW, Victorian and South Australian generation IN 2015

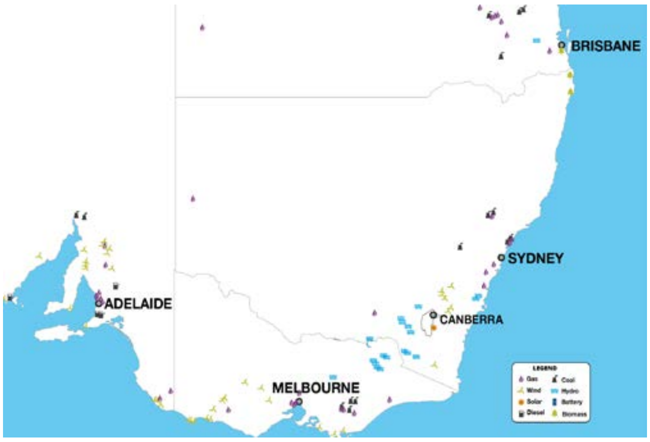
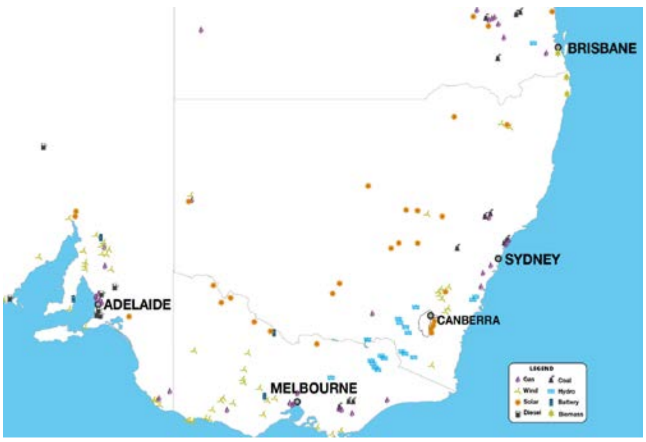


FIGURE 5. NSW, VICTORIAN AND SOUTH AUSTRALIAN GENERATION IN 2019



The figures show that the majority of the generation that was connected in 2015, much of which was operating at the commencement of the NEM in 1998, were large coal units located relatively close to the major load centres in the state capitals. These coal-fired power stations were connected to strong high voltage networks (275kV, 330kV and 500kV) with multiple parallel circuits. The Snowy scheme located on the New South Wales and Victoria boarder also strongly connected to major load centres of Sydney and Melbourne (330kV). Additional gas powered intermediate and peaking generation is also generally located near the state capitals and strongly connected to the transmission network. The flows on the transmission networks generally followed well-defined patterns throughout the day, between the seasons and from one year to the next.

In the 2000s large-scale wind generation started being commissioned for the first time. This generally occurred in in relatively remote locations associated with a good wind resources and comparatively inexpensive land. However, these wind farms were not located near the strong parts of the existing transmission network, rather were connected to lower voltage parts of the transmission and distribution networks. In more recent years grid connected solar generating systems have also been commissioned.

From 2015 the rate at which grid connected solar and wind generation entered the market began to accelerate with most of this generation connected in remote parts of the network. This was largely due to a tight supply/demand dynamic indicating resource scarcity and policy uncertainty in relation to the Large-Scald Renewable Energy Target being resolved. In particular:

- large quantities of grid connected solar and wind generation have been connected in north-western Victoria and south-western New South Wales;
- there is now around 1,500 MW of wind in rural South Australia and, at times of minimum demand, South Australia sometimes produces so much wind energy, the residual energy is exported to Victoria; and
- several large grid connected solar generation have been connected in northern Queensland.

In each case, these generating systems were connected to the existing networks that were originally commissioned to supply rural cities and towns remote from the state capitals, generally with limited or no local generation. The commissioning of large quantities of this grid connected variable renewable generation at these remote locations in the network, and the associated reduction in the output from the existing thermal generation, has dramatically changed the flows of energy in the transmission and distribution networks. This has caused a range of problems including:

- over-loading of the associated transmission and distribution networks, resulting in periods where the output of this generation is constrained during periods of high wind or solar radiation
- low fault level, often referred to as low system strength, resulting in potential system instability and increased numbers of generating systems being commissioned with synchronous condensers
- the losses in the associated networks have increased, especially due to the long distances between most of the new generation and the major load centres of the state capitals.

These problems are discussed further in the following sections.

III. COORDINATION OF GENERATION AND NETWORK INVESTMENT

The NEM is made up of five pricing regions, which approximately follow the political boundaries of the states of South Australia, Victoria, Tasmania, New South Wales and Queensland.

Under the existing transmission access regime in the NEM, all generation and load which participates in the wholesale market is settled on a region-wide price for its physical output or consumption (net of losses), regardless of its location in a region. This region-wide price is called the 'regional reference price'. When the physical output of a generator is reduced - for example, due to the presence of a transmission constraint - its revenue is similarly reduced.

While this approach is relatively simple, it also abstracts away from the technical and economic realities of the system. When constraints arise on the transmission network within a region, the underlying cost of an additional unit of generation to serve an additional unit of load at a particular location (known as the 'locational marginal cost' of generation) differs from location to location. The marginal cost of an additional unit of generation tends to be relatively low in areas which have an abundance of generation versus load and limited ability for generation to flow to other areas of the network, and vice versa.

Economic efficiency is promoted when prices reflect the marginal cost of the provision of a particular product or service. Numerous issues are arising in the NEM because of the incentives created by the difference between the locationally specific cost of an additional unit generation and its region-wide price. Furthermore, because prices for electricity are not locationally specific, the difference in cost between locations (and hence the value of transmission capacity) is not explicitly valued.

A foundational principle of the NEM when it was created was that decisions to invest in generation capacity are made by businesses operating in a competitive environment, rather than by vertically integrated monopolies. Investment in generation assets is market-driven and takes account of expectations of future demand, the location of energy sources, access to land and water and access to transmission. The result is that risks associated with generation investment rest with those businesses.

In contrast, transmission investment decisions remain the responsibility of regional transmission network businesses, guided by the Australian Energy Market Operator’s

(AEMO's) Integrated System Plan.[1] Transmission businesses are subject to incentive-based economic regulation of their revenues for the provision of transmission services, as well as various other obligations relating to reliability, safety and investment decision-making processes.

Generation, transmission and storage are complements and substitutes. They are part of an integrated system. This implies that investment and operational decisions by generators, storage proponents and transmission businesses should work together to achieve overall economically efficient outcomes.

Current locational signals such as transmission losses, congestion and inter-regional price variation do provide a degree of incentive for efficient generator and storage location. However, these signals are blunt, incomplete and imprecise.

Due to the current lack of locational price signals in the transmission framework, investors are locating their generation assets where the network has limited or no capacity for the additional generation capacity to be dispatched. Increasingly, storage may play an important role in managing both transmission congestion and variability in supply from generation, but storage is similarly not subject to the locational price signals.

Further, having made a locational decision, a generator or storage unit is not readily able to manage the risks arising from transmission losses, congestion, and to a lesser extent, inter-regional price variation.

In turn, a generator or storage unit which connects in a fuel-rich area may influence the investment case for a transmission upgrade, even if the lowest overall cost solution was to invest in a less fuel-rich area with better transmission infrastructure.

This situation is likely resulting in higher overall system costs, and ultimately elevated consumer bills.

In the past, this and other problems relating to regional pricing have tended to be modest, and so the cost of change has outweighed the benefits. In an environment of relatively low levels of generation and transmission investment, the benefits of improved investment efficiency and coordination are necessarily relatively low. Such an environment also means that transmission risks faced by generators are relatively predictable and stable. However, for the reasons outlined, this is no longer the environment that the NEM finds itself in.

These issues are being considered in Australia in order to promote better coordination between investment in generation by competitive entities and the regulated monopoly network businesses. Therefore, different design choices and trade-offs better suited to the current environment may need to be made.

[1] The exception is Victoria where decisions to augment the transmission network are made by the Australian Energy Market Operator (AEMO).

IV. NEGOTIATION OF PERFORMANCE STANDARDS CONCURRENT CONNECTION APPLICATIONS

The connection of new generating systems in the NEM can be very competitive. This means that the individual generator proponents treat their projects as commercial in confidence and generally release little information on their projects. This has become very difficult to manage in the current environment where many connecting generating systems are being developed and connected concurrently and within close proximity.

New generators connecting the NEM must meet the required technical performance standards, which were updated in 2018 to reflect the lessons learned from a 2016 black system event in South Australia and to better reflect the characteristics of asynchronous generation including inverter based plant. The proponents of the connecting generation must perform connection studies to demonstrate that their performance meets the required standards, based on the range of system conditions that apply at the time of connection.

At the same time, the effective short circuit ratios (SCRs) in the network where new generating systems are connecting have been dropping due to their remote location and the retirement of existing synchronous (coal) generation. These trends have raised stability concerns and a system strength "do no harm obligation" was placed on connecting generators from July 2018. This requires the connecting generator to mitigate any system stability issues that occur as a result of connecting their generating system.

In addition, traditional power system modelling tools are often no longer fit for purpose due to the reducing SCRs. This means that electro-magnetic transient (EMT) modelling is required to assess both the technical performance and do no harm obligations of connecting generating systems.

This combination of performance and system strength requirements, in the context of more intensive modelling requirements, has become very challenging for generator proponents in the current environment where multiple concurrent projects are being assessed at once. This can mean that a generator proponent needs to repeat many EMT studies when a competitor's project is connected nearby, thus required their existing assessment to be updated.

V. IMPACT ON NETWORK LOSSES

The prices received by generators, and paid by loads, are the product of the price calculated at the regional reference node (located at the largest load centres in each state) and the static marginal loss factor (MLF) for that connection point. The prices at the regional reference nodes are calculated from the offers submitted by the generators and represent the cost of meeting an additional MW of load at each of the regional reference nodes. Thus, when comparing an increment of output from a generating system it is necessary to also consider its marginal impact on the losses in the transmission network, hence the use of MLFs. As well as promoting efficient dispatch and pricing, the use of MLFs also provides longer-term locational investment signals that incentivise generators to connect near loads, and visa versa.

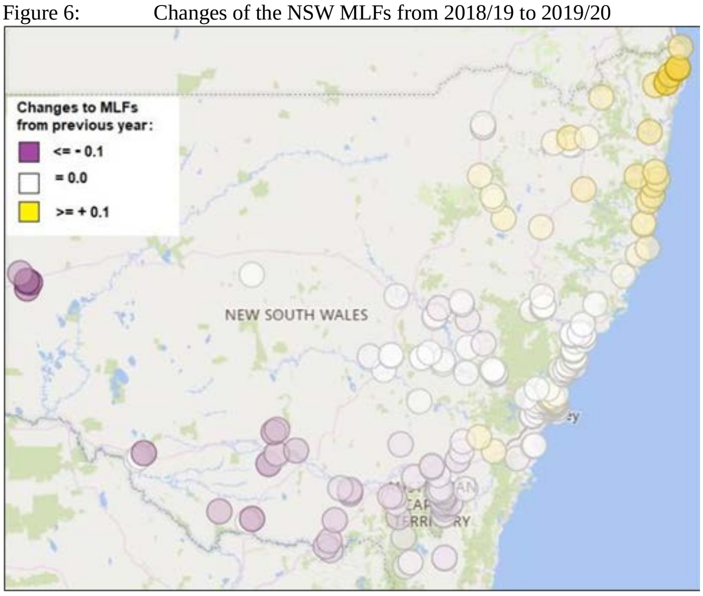
Rather than recalculating the loss factors for every 5-minute dispatch interval, a single static MLF value is calculated that is estimated to represent the impact of that generating system on losses for the financial year (July to June). These static MLFs are calculated annually by AEMO using the generation and load patterns anticipated for the next financial year, volume weighted by the generation or load pattern of the generating system in question. Using annual static MLFs, rather than real-time loss factors, is expected to increase the liquidity of the markets for financial derivative contracts and hence to facilitate efficient investment in new generation. However, using annual static MLFs can compromise the efficiency of dispatch and locational pricing.

As discussed above, much of the new generation that has been commissioned in the last few years has connected in the lower voltage network and much further away from the major load centres. This change to the generation mix has resulted in a significant increase in the losses in the transmission network, with an associated decrease in the MLFs (and hence the effective price received) for this new generation. Figures 6 and 7 show the changes in the MLFs for New South Wales and Victoria from 2018/19 to 2019/20.

The MLFs for south-western New South Wales and north-western Victoria fell significantly for 2019/20 due to the dramatic increase in solar and wind generation in that area. In one case, the MLFs of a new solar generator dropped by approximately 25%, with a corresponding decrease in the generator’s revenue. This has become a serious concern for many developers and investors in these renewable generating systems.

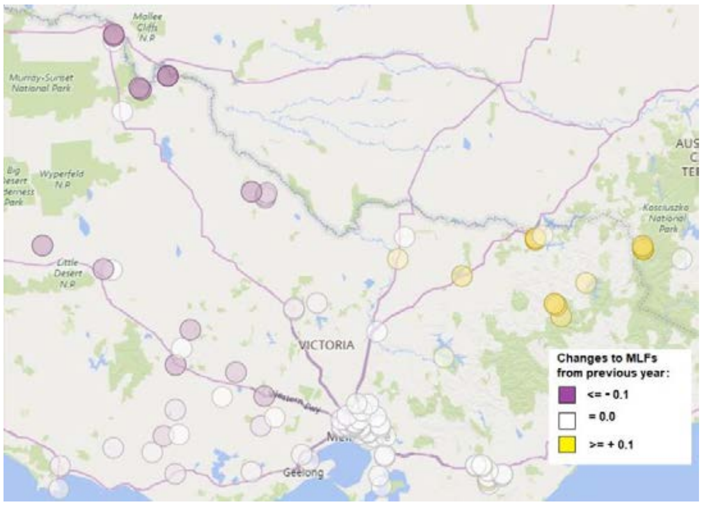
The AEMC is currently considering whether there is a better approach to calculating MLFs, while retaining the locational nature of the current approach.

Figure 6: Changes of the NSW MLFs from 2018/19 to 2019/20



source: AEMO

Figure 7: Changes of the Victorian MLFs from 2018/19 to 2019/20



source: AEMO

VI. CONCLUSION

The paper has considered how the NEM is evolving under the high volume of concurrent connection applications for new generation, including:

- the need to coordinate generation and network investment to avoid excessive congestion, including the role of the AEMO integrated system plan;
- the negotiation of performance standards in the presence of multiple concurrent connection applications, including the need for system strength remediation;
- the impact on network losses and the associated loss factors used to provide locational investment signals.

VII. REFERENCES

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