ANEM – Advanced National Electricity Market (NEM 2.0)

Whitepaper on a new fundamental operating strategy to reform the NEM

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Introduction

This whitepaper outlines a plausible whole-of-system pathway to reform the NEM such that it better serves the NEM objective[1] by improving reliability, stability and security as the balance of generation shifts from large base-load synchronous generators to a more distributed, variable and renewable generation network.

Background

This transition in generation has been underway for a number of years. It is well recognised, as are the problems and risks to the existing NEM. The South Australian blackouts in 2016 are a prime example of these problems. Furthermore and alarmingly, there is no solution available using the existing NEM power system today. A major rethink is essential *now* to enable meaningful progress.

This whitepaper does not advocate any one generation technology over another. Nor does it suggest a timetable for retiring any existing infrastructure or assets. It merely proposes NEM reforms necessary to flexibly utilise *any* generation source. It aims to efficiently use all existing infrastructure and participants present and future. Fossil-fuelled generation assets will be phased out through natural attrition as they become uneconomical to operate and maintain. Further, the likelihood of any new coal-fired generation being commissioned is almost negligible, regardless of how "clean" it is; limited demand from the public or investors is expected to diminish existing political will. Generation companies such as AGL and Engie (the owners of Hazelwood power station) have already announced plans to transition to renewable generation, simply because market forces dictate that that is where future investment should occur.

The transition process is already underway and Australia has a limited window of opportunity to adapt. Obsolete industry models should not be supported and slow, incremental changes are no longer sufficient. As a nation we must embrace bolder strategies to devise a power system with limited or *no* fossil-fuelled generation. Now is the time to take this big leap.

Such a strategy will address Australia's future energy needs; and, it will also inherently establish a pathway to limit greenhouse gas emissions. This will go a long way to meeting our international obligations, possibly without the need for any form of emissions trading scheme or carbon tax.

This is a reform to the physical power system and market mechanisms. It is not just an additional layer of market trading that doesn't alter the physical system or the operation thereof.

This document proceeds as follows: page:

[1] The National Electricity Objective, as stated in the National Electricity Law *"To promote efficient investment in, and efficient operation and use of, electricity services for the long term interests of consumers of electricity with respect to price, quality, safety, reliability, and security of supply of electricity; and the reliability, safety and security of the national electricity system."*

Summary

Key elements of the reformed power system:-

1. A whole-of-system approach to coherently integrate all required elements.

2. Eliminate the variability in network frequency and all associated technical difficulties.

3. New system service category – 'Network Storage Service Provider'. Category participants are responsible for the design, installation and maintenance of energy storage systems connected to the NEM.
    a. NSSP Tier 1 – Greater than 10 MW/5 MWh capacity of instantaneous response that is capable of being 'grid forming' (requires some extra technical pre-requisites). These provide the network stability and replace the need for *all* the existing ancillary services.
    b. NSSP Tier 2 – As above but not capable of 'grid forming'. AEMO dispatchable, market based, similar role as gas peaker plants.
    c. NSSP Tier 3 – Providers with capacity between 1 MW and 10 MW. Market based, non-dispatchable. Generally for commercial self-consumption uses.

4. Generation regulated directly via line voltage, not frequency.

5. Accommodates any amount of renewables generation; no longer limited by synchronous generation providing stability.

6. Australian Energy Market Operator (AEMO) to upgrade to fully centralised and automated control of all the generation, NSSP Tier 1, transmission and distribution network elements.

7. Full Advanced Metering Infrastructure (AMI) metering and data collated and processed at centralised server point for use by AEMO, NEM, retailers and customers. Up-to-date data for all participants. Communications system allows other services potential.

8. Time of Use (ToU) tariff structures; all other tariffs phased out. Cost reflective service delivery fees. (Peak demand?) Energy must be valued the same in both directions for all participants.

9. Later develop a trading system that allows any participant, B2B, P2P trading. Facilitates wholesale pricing and private contracts.

10. Provides the flexibility for the market to more easily adapt to evolving energy environment. <u>The existing system is effectively a barrier to the future</u>.

Part 1. A change in power system technical strategy.

The National Electricity Network has historically operated under a conventional principal where large synchronous generators determined the characteristics of the energy provided. In particular, the frequency of the network is a direct result of the rotational speed of the generators. Despite adoption of best practice control mechanisms, frequency variation still occurs, especially at times of sudden load change. Such changes can cause parts of the network to fail and damage to customers equipment. “Inertia” is a term used to imply a *resistance* to such variation. But the existing system can *never* be immune to such variations.

Therefore, the existing system architecture relies upon a significant/dominant proportion of synchronous generation inertia within the system to maintain stability. Thus this dependence is in itself a barrier to incorporating high levels of renewable generation.

A large number of issues related to frequency control and inertia arise because there is no means to automatically and instantaneously respond and adjust to variations in supply and demand.

<u>However, there is a solution.</u>

There are a number of energy industry providers that utilise various technologies to provide support to electricity networks, to reduce the effects of these compromises and deficiencies. However, due to the regulatory environment they are currently all only permitted to be ‘supplementary’ services.

The most prominent and flexible technology is solid-state power conversion technology (inverters) with battery storage. If such a system was scaled sufficiently, it would provide the exact instantaneous response necessary to smooth out supply and demand in real time, thus providing the required stability.

However, for this technology to be effective it needs to be used as the core controller of the physical network, not just supplementary. This is a fundamental shift in thinking for the industry; the aforementioned regulations do not even consider the viability of this option. Or the concept of utility scale battery storage for that matter.

Technologically it is not difficult, merely an adaptation of the control logic programming of currently available technology. But, the whole industry and the regulatory framework in which it operates must change to allow this.

To conclude, changing from a network ‘formed’ by synchronous generation to a network ‘formed’ and controlled by <u>solid-state power conversion technology (inverter/battery)</u> is the key element needed to enable transition from fossil-fuelled generation to a network fuelled by a diverse range of distributed renewable sources.

Such a system can be implemented as follows:

At the core of the network, connected at transmission switching sub-stations in each NEM region/sub-region, NSSP entities would install inverter banks with attached battery storage. Similar projects around the world have shown significant benefits with storage capacities of just 5 to 10% of the network capacity.[1]

However, such inverter/storage systems will not address asynchronous system frequencies. For this to be enabled, greater network inverter capacity, perhaps 20% of total network capacity will need to be established. Such capacity would need to be calculated in the same way that reserve capacity is currently calculated. This being equivalent to the two largest generators or loads in each region. This inverter capacity would equal approximately 1500 MW for Qld, NSW and Vic, and 500 MW each for WA, SA and Tas. A total of 6 GW of tier 1 NSSP.

Available battery storage would be required to ensure sufficient supply for 30 minutes, or 50% of the inverter's capacity. Approximately 3 GWh of battery storage. Tier 1 is not intended to perform large load shifting. It is mainly for grid forming and stability. Less storage may be possible, but there must be enough to provide generators sufficient time to adjust output to demand. The more storage there is, the easier this will be.

Regions with high amounts of variable generation would further benefit with increased storage via Tier 2 NSSPs that can perform bulk load shifting, particularly where inter-connector capacity constrains supply from adjoining regions.

The use of such inverters enables instantaneous access of their full capacity in either direction to the network. Variations in supply and demand can be met instantaneously, maintaining power quality and stability. Crucially, such a system is immune to frequency variations. There is no "inertia", or more accurately, it has *infinite inertia*.

Each inverter is also able to synchronise to another Tier 1 NSSP inverter already running in adjoining regions; and, it can also lock and hold control individually in the event it becomes isolated from the network.

All monitoring and control of transmission and distribution networks needs to be centralised. The current system, managed by multiple entities is by nature a largely un-coordinated operation with inherent delays and inefficiencies.

The operation process of such a system is as follows:

Starting from a completely black system, all lines would be open. Inverters would start, and transmission lines to areas with substantial generation capacity would be connected to provide power for this generation to start. Such generation would then be synchronised to the inverter, with initial power used to charge the battery storage. Loads can be progressively connected as more capacity becomes available.

Each individual segment would have a known expected demand so that they will only be connected if there is sufficient capacity. There should never be an opportunity to overload supply due to a controllable event such as connecting a transmission line or sub-station.

This process continues to propagate at a controlled rate until the entire network is connected; but, only as generation capacity is able to ramp up to meet additional loads. Ideally this process would continue down to individual MV feeders at sub-station level to provide a smooth ramping up of generation.

Excepting areas isolated due to line faults, an entire region could be restarted in considerably less time and more efficiently than is currently achievable. What currently can take many hours could be done within an hour. Each connection/disconnection would be managed such that the change in demand or supply is less than the capacity of the inverter. Thus, each switching is not dependant on, nor has a direct effect on, any of the generation. Centralised control programming would incorporate this as part of its' operating logic, virtually eliminating operational imbalances.

The sequencing and dispatch process for the generators would remain similar to the existing model. But the dispatching need not define exactly how much each generating unit is to produce. It only needs to manage the sequencing; which units need to operate according to demand and forecasting. What is different is that the units would be told what mode of operation to use:

- Renewable generation units would be given priority to generate whatever they can.

- The first synchronous units incorporated would run in base-load mode as they do now ('passive mode').
- The next units, the ones that make up the required capacity within the range the inverter can cover above the first passive units would run in true automatic voltage regulation mode ('active mode').
- These units are the ones that are currently dispatched with specific capacity requests less than their rated capacity. Their output will be governed by the actual line voltage. If the Tier 1 NSSP inverter allows the voltage to sag*, the generators governing system will sense this and increase output, and vice-versa. But it is programmed to adjust safely within the units ramp rate so that it does not influence frequency at any time. (*-The inverter would strictly maintain voltage within +/-4% of target voltage.)
- Finally, the next group remains on standby ready to connect when forecast demand indicates they'll be needed. They immediately run in active mode also.
- When these units are running, some of the second group that have been running in active mode will now be operating continuously at full capacity and can switch to passive mode the same as the earlier units. In this way, only a generation capacity approximately the size of the inverter bank needs to operate in active mode.
- As overall demand reduces, the sequence is reversed.

Additionally, the capacity of the battery bank can be treated as both a generation source or a load depending on which way the energy is flowing. Whilst it balances out overall and does not need to be included in any financial transaction for the energy transferred, the amounts do need to be considered within the forecasting and sequencing process to manage battery state of charge. This can be achieved by altering the line voltage to which the active generator units AVRs respond. Just the information needs to be forwarded for inclusion in calculations. This can be finitely controlled and timed to allow generation to respond accordingly. This can be further optimised with load profiling which would significantly improve generation scheduling too.

For example, if a little more supply is required, this can be supplied by battery alone, should forecasting indicate this extra load is only for a short time. This would negate the need to start additional generator units just to satisfy the short term extra demand. Conversely, the battery could also be used to take extra supply for a time, negating the need to shut down a generator when it will be needed again within hours. This is similar to peak-shifting but optimised to suit network activity.
The inherent flexibility within such a system is highly beneficial. It removes the 'tight-rope walk' balancing act of supply and demand that is currently used; and it provides far greater stability and reliability of supply.

Some coal-fired units, particularly the ones that wish to run continuously and are always needed at a constant capacity may not need to run in active mode and therefore not need to have the modern governor controller that is required to run in active mode. So they will be able to continue to operate without any changes or upgrades. But in time when renewable generation starts displacing even these units, they will also need to be able to run in active mode too.

From this, all generating units only get paid for the MWh's that they actually deliver into the grid. Those that are on standby will likely expect a flat fee for remaining in a state of readiness.
Note too that they will no longer be required to participate in any ancillary market process to respond to frequency variations – simply because frequency is no longer a variable that needs to be managed by them. Frequency control is not something the existing system manages very well at all. Synchronous generators are not particularly good at responding to frequency variations. Further, the use of synchronous condensers, flywheels or any other technology that uses inertia are all defunct if the system is properly and accurately controlled by inverter and battery systems. And there would not be any need to require wind generators to undergo any refits to provide any extra inertia response, something they're not really

designed to do. It is important that resources are not wasted on such technologies that will be obsolete with this system.

The network control systems will require substantial updating in order to prevent network failures and black system events as experienced in South Australia, *irrespective* of whether the system is designed around 'inertia' or inverters.
This will focus primarily on the software and system controls processes rather than augmenting the network with more transmission capacity.

This investment is essential and inevitable.

Investing in augmenting a network designed around the notion of 'inertia' will result in money being wasted and not achieve the desired result of this transition. Worse, it will defer the inevitable and require a rushed conversion in the future and that becomes even more expensive.

Currently, the supply of auxiliary services (FCAS, SRAS) is provided by a number of the existing power stations. The proposed inverter and battery system would take over all these roles, allowing the generators to simply provide energy without any complication.

Some of the TNSP's and DNSP's are currently considering similar installations, but the full benefit will not be achieved if they each go their own way, they still allow frequency variation because they are only supplements to the network.

Ultimately, it is important that AEMO has the operational control of the entire national network. It is essential to eliminate frequency as a variable so control must be centralised. Having this function performed by multiple existing entities will lose the co-ordinated coherent control that is required. Only then will it work at best possible productivity and efficiency.

This is a fundamental change in strategy, which will significantly improve efficiencies. Eliminating the requirement to maintain a "spinning reserve" or FCAS, which are dependent on the inertia of the generators. Master inverters can perform all these functions with much greater accuracy.

A system that is *not* dependent on "inertia" at all will be a far more reliable and secure network. Such a system and mechanism will also accommodate the full transition from fossil-fuels to renewables.

Other matters.

There should not be arbitrary limitations on the size of a customer's solar or wind generation capacity. Customers should be able to export at the same capacity as their connection allows them to import. Monitoring network energy flows can easily determine when any component is reaching capacity and constraints need to be imposed. And even then a customer should be allowed larger systems - it is the rate of transfer into the grid that may need to be constrained. Customers should be free to generate and store anything in excess of that.
Being able to export like this is another key element to transitioning to a decarbonised energy network. Existing limitations due to system stability provided by synchronous generation are a significant barrier to this.

Part 2. Market management.

1. For true genuine market operation all electricity energy must be valued the same to all participants at any point in time regardless of whether a participant is a generator or a consumer.

2. At the existing wholesale market participant level, this could remain at the 5-minute spot pricing, but given the far superior management of the network it would be preferable to be longer periods. Possibly even 30-minute periods.

3. With true advanced metering infrastructure (AMI) and supporting systems, there is no practical reason why all consumers couldn't be billed on the same 30-minute pricing. This would provide the natural variation in market value that then allows all participants to engage in the market. They can all manage their energy generation, consumption and storage according to market pricing signals. This would further smooth out network stability and security. As well as providing a genuine level playing field. The existing regulated flat tariffs do not provide any incentive to change consumer energy use behaviour.

4. The existing offer/bidding and dispatch process had worked reasonably until recent years. The generator companies have spot trading experts that have worked out how to manipulate the process and exploit the market.[2] It is therefore no longer a viable true market mechanism and must be reformed as a matter of urgency irrespective of other reforms.

5. Upon reading the rules one would think they are fair and sound, but in practice there are opportunities for exploitation. This was never intended to be possible and is completely contrary to the NEO.

6. Whilst a generator can not alter the offer price in the re-bidding process, they can adjust the volumes of energy within price bands in the bid. Which simply makes a mockery of the rule preventing price adjustments.[3] This practice must be removed.

7. A market offer should only have a single price for the period in the market. The units output capacity for that period should be stated. The operator needs to indicate relevant constraints such as minimum capacity and applicable ramp rates. And if its performance characteristics mean that its output is reduced for any reason, the operator must indicate this by reducing the offers capacity appropriately. For example; during high ambient temperatures experienced during a heatwave the output may need to be reduced to 90% of rated capacity.

8. No re-bidding in last 24 hours. An offer must not be able to be re-bid in the last 24 hours prior to coming into effect at all. There should not be a variety of capacity bands associated with a bid as is currently the case. It must only be a single monetary value for each MWh generated during that period.

9. Failure to supply. If less than 80% of the dispatched volume of energy is generated, they are penalised by double the value of the offered bid. This is important because it provides a strong incentive to fulfil their bid offer and not withdraw it to artificially induce more dispatch from AEMO. It also means they need to be thorough with maintenance and have reliable plant.

With these rules, the process is simplified and opportunities for exploitation are removed. Which will make the market much easier, fairer and less volatile than it currently is; all improving adherence to the NEO.

As an interim methodology, AMI can be used with Time-of-Use as is currently available using time periods as used in NSW currently.

The peak and off-peak prices is a simple multiplying factor of the base price. eg. 1.8x and 0.6x respectively.

The peak/off-peak multipliers are essential to provide the incentive to;-

- Reduce demand during periods of high demand, smoothing overall network capacity, delaying or avoiding network augmentation.
- Encourage the use of and investment in ESS and self-generated energy.

Ultimately the aim is to not require any form of emissions trading scheme or carbon tax. However, if a market incentive scheme is required, the following is a simple method to implement.
A penalty rate is deducted off the revenue to the generators that emit greenhouse gases. Say 5% for natural gas powered plant, 10% for black coal powered plants, and 12.5% for brown coal powered plants. The actual amounts should be proportional to the emissions emitted. The revenue from this penalty rate can be used to fund further network transition investment and continue the RET scheme. The RET should fund energy storage systems as well as, or instead of, solar PV panel, encouraging private investment. This scheme would effectively be the financing that incentivises decarbonising the energy industry. It is important that it be kept as simple as possible so that it is administered as efficiently as possible. All other schemes proposed are unnecessarily complex and expensive to administer.
Modelling work will be required in order to get this underway and determine the initial base price.

The cost of delivering energy is a substantial part of the equation.

The revenue for the Tier 1 NSSPs could be calculated in a similar way as is used for the TNSPs and DNSPs. The other tiers should be able to operate simply on trading time-shifted energy. Buying and charging batteries when prices are low and exporting when prices are high. Thus effectively being paid to smooth out supply and demand fluctuations.

Micro-grid operators are a single customer connection in so far as the network is concerned. How it is operated behind that connection point should not be of concern to the network or market. This freedom allows micro-grids to establish and operate as they see fit.

The concept of a peak demand charge is sound and provides an equitable means of charging for a customer's impact upon the network with regard to supplying their energy needs. This has been a major influencing factor on the expense of network expansion over the last decade, which could potentially be avoided if customers changed their usage patterns in order to reduce their peak demand on the network. This is sensitive to variation and should not be the sole charge in order to generate revenue for the TNSP's and DNSP's. Customers changing their usage patterns will dramatically alter the revenue stream and therefore some revenue will be required from a kWh delivered basis, modelling will determine the rates charged.
Metering and Data service providers will be a key element to modernising the network operations. Simple price per day per meter serviced is the only requirement and a simple $1/day for electricity meter, includes the communications and administration of data and an additional 50c each for water and gas. The same communications and administration can be used for all utility meters.

Fully implemented meters need only record energy transfers both imported and exported at time of use (ToU). There will be no requirement for controlled load tariffs as this functionality can be provided using a different method that can be built into the AMI.

Methodology adopted can take advantage of different rates for ToU – base, peak and off-peak prices as described previously.

In the future, after or independently from the reforms of this paper, “block chaining” software technology may be developed to determine market energy prices.[4] This software has the capacity to undertake calculations, factoring in numerous conditions and can accommodate individual contracts between any combination of participants. The price determined could therefore become the base price for all market participants, from the big generators, large industrial and commercial customers, to the individual residential customer. This base price should be fixed for three months at a time, aligning with the seasons. It would also incorporate two multipliers to determine a daily peak period price and a daily off-peak period price. These prices are applied to all energy traded by all participants whether consumed or fed into the network, from any and all sources of generation or storage. These multipliers may be reviewed and adjusted once per year to remain relevant and effective as the industry evolves over the longer term.

Part 3. Governance

For any particular public service industry, it is imperative that the governance and management of it operates with complete integrity and transparency, and is free from any possible conflicts of interest. To this end it can not have people on the various boards that have any ties past, or present, in any corporate enterprise associated with the industry. ie. we can not have the wolves in charge of the hen house. Such conflicts of interest clearly have potential for decisions being made to benefit these interests.

Whilst the experience some industry people can bring to a board is useful it is also inherently biased and not necessarily of a balanced view. Such positions can be used to suppress progress, clearly contrary to the NEO.

All of this whitepaper is to support and better fulfil the NEO, which is for all Australians.

[1] https://www.aiche.org/chenected/2017/02/teslas-new-battery-storage-farm-california-big-deal
[2] http://reneweconomy.com.au/regulators-wake-up-call-fossil-fuel-majors-are-gaming-markets-18995/
https://www.aer.gov.au/system/files/State%20of%20the%20energy%20market%2C%20May%202017%20%28A4%20format%29.pdf
[3] http://reneweconomy.com.au/regulators-wake-up-call-fossil-fuel-majors-are-gaming-markets-18995/
[4] https://powerledger.io/ is one example business developing such software.