Hydro Tasmania

Battery of the Nation

Understanding reliability in the future NEM

Challenging preconceptions and providing new understandings and clarifying language for the transformation of the NEM

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Authors: Cameron Potter, Pippa Williams, Stuart Allie

Email: batteryofthenation@hydro.com.au

Foreword

The National Electricity Market (NEM) is undergoing a transition away from the dominance of baseload fossil-fuel generation, towards greater proportions of low-cost variable renewable energy. This transformation will change some of the fundamentals of how we understand our power system. It is challenging long-held concepts and terminology.

This paper highlights that as the characteristics of the market change, the services that the market needs will also change. This change drives a need to challenge pre-conceptions, better understand what will actually be required in the future and clarify the language used to describe the system. Recently, words like “firming”, “dispatchable”, “variable” and “balancing” have become increasingly common in power systems discussions – and yet the understandings, definitions and implications of the terms are not fully agreed.

Hydro Tasmania calls upon decades of managing a power system based primarily on weather-driven renewables to take a closer look at the transformation of the NEM. This paper raises questions about the system itself, and how we understand it, to present clearer definitions for a more informed conversation about a rapidly changing market. We need to re-evaluate our understanding of what is needed to make the system work.

Steve Davy

Hydro Tasmania Chief Executive Officer

February 2019

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Executive Summary

Australia's electricity landscape is at the start of a dramatic transition. Older generators are likely to be replaced by new technologies. This transformation is challenging long-held concepts and terminology. Familiar terms often come loaded with preconceptions. Emerging terms can be elastic as the implications (and sometimes entire definitions) adjust to better reflect the purpose and need for new words. Clear definitions are required in a rapidly changing market, and we need to re-evaluate our understanding of what is needed to make the system work.

To successfully navigate this transformation we need to challenge pre-conceptions, better understand what will be required in the future and clarify the language used to describe the system. To make this discussion more accessible driving a car is used as an analogy for the electricity system.

As an industry, we need to ensure that we continue to meet the supply-on-demand challenge of the power system as it transforms. Australia's electricity is currently generated predominantly by coal, which provides baseload supply, supported by gas and hydro, which balance the inflexible supply against the variable demand. Across the National Electricity Market (NEM), wind and solar generation is modest but increasing. There will be a very different generation mix in the future. The nature of supply and demand – and how it will be balanced – will change.

Historically, the focus of balancing supply and demand has been predominantly on ensuring that variable demand is met with available supply. However, as variable renewable energy enters the system, it becomes necessary to consider compensating for variable supply. The management of variability on the supply side is broadly referred to as "firming". While firming is a concept that is relatively new to the Australian power system, the underlying principle of responding to supply-demand imbalance is core to the operation of any secure and reliable electricity system.

To meet demand in a system with significant variable renewable energy, supply options are required that can start, stop and change supply – quickly, reliably and on-demand ("dispatchable"); and sustain generation over the required period – a number of hours or days ("sustained capacity"). We will also need to support and recognise demand-side response options to cost-effectively manage the total system.

We need to develop a more nuanced view of the broad range of options to manage the supply-demand balance in the future NEM.

1. Australia's power system is changing

Australia's electricity landscape is at the start of a dramatic transition. Coal power plants built in the 1980s are expected to retire over the coming two decades. This older energy and capacity is likely to be replaced by new technologies. This transition – or transformation – is challenging long-held concepts and terminology. Familiar terms are losing clarity and new terms are being introduced. Clear definitions are needed in a rapidly changing market.

Our changing electricity system requires us to re-evaluate our understanding of what is required to make the system work. There are many factors that make even something as seemingly simple as balancing supply and demand a complex task.

It is critical to impartially reconsider our assumptions about the power system, both in terms of how it operates and what is needed. Language frames our thoughts and our vocabulary needs to evolve to help our understanding and enable clear and robust discussion to address the challenges ahead. What is the difference between energy and capacity? What is "firming"? What do we need from flexible energy generation? These concepts and others are part of a new vocabulary that needs definition.

You can compare the electricity system with the concept of driving a car.

As the driver (customer), you decide the speed (demand) and you need enough output from the engine (energy) to successfully reach your destination (reliability) without breaking down (security).

The size of the car's engine (capacity) must be big enough to meet your desired speed, even when going up a hill or overtaking (peak). The road conditions change, so to continue at the desired speed (supply-demand balance), you have to adjust (regulation, or “firming”) your foot on the accelerator (dispatchable and flexible generation).

When buying a car, there is a trade-off between cost and a bigger engine – and sometimes the most effective solution is to accept a slightly slower speed (demand-side response). Finally, a good engine doesn’t do much without the tyres (ancillary services) that grip the road.

To stretch the analogy further: we are seeing a rapid growth in hybrid and electric vehicles (the future power system).

The cars still get you to where you need to go, but they use new energy sources and different technologies to achieve the desired outcomes. As a driver of a hybrid or electric car, you need to constantly adjust your foot on the accelerator – as you have always done with fossil-fuel cars.

In reality, few customers want to think about the details of power generation. In this way, the power system is arguably more like a pizza delivery car – we don’t need to know about the car’s engine or the bumps and turns on the road; we just want our pizza to arrive when we expect it.

2. Adapting our language for the future

Our language and understanding of the power system must adapt as the power industry transforms. Familiar terms often come loaded with preconceptions. Emerging terms can be elastic as the implications (and sometimes entire definitions) adjust to better reflect the purpose and need for new words.

The following list includes familiar terms with subtle implications that are worth considering, and emerging terms that need further discussion.

Ancillary services

The services that are required to ensure the successful operation of the electricity system – beyond the commodity of energy itself. Ancillary services include frequency control, network support and control, and system restart services. Mostly these services provide reserves and capability to respond to disturbances or uncertainties.

Future implications: The options to provide ancillary services will change with the introduction of new generation technologies and decommissioning of old generation technologies. Some services may be more difficult to procure and our existing definitions and markets may need to be expanded to account for other services that may be required to help manage the power system.

Baseload

The minimum demand that must be met at all times. Baseload also refers to generators, such as coal-fired power stations, that provide constant power output to meet the minimum demand. These baseload generators are typically inflexible, with expensive and inefficient start-up sequences that take many hours (sometimes days), and high capital costs that are paid off over many hours of operation. Brown coal-fired generators (predominantly in Victoria) are particularly inflexible, whereas output of power from black coal-fired generators (predominantly in New South Wales and Queensland) can be economically reduced a small amount when required.

Future implications: The concept of baseload may be less useful in the future. Customers have traditionally been incentivised to minimise the variation in the system demand. This better matched the physical characteristics of the baseload generation that could not sufficiently respond to daily variations in demand. As coal-fired generators retire, the need to encourage a flatter demand profile will reduce as well – instead promoting responsive demand that better matches weather-driven renewable energy generation patterns.

Capacity

The maximum power from generators available at any given moment. To balance the system there must be enough generation capacity available to meet instantaneous demand. Typically, flexible generators with high fuel costs are considered capacity providers (e.g. open-cycle gas turbines). These flexible generators are available to quickly provide electricity when needed, rather than providing low-cost electricity at all times. Hydro generators are also highly flexible generators that tend to act more as capacity providers due to constrained energy supply (finite water availability).

Future implications: A more variable supply will need more dispatchable, flexible capacity to fill the gaps. The gaps will also be more frequent and for longer durations meaning that pure capacity providers will be too inefficient to provide the sustained need for flexible generation.

> ***Measuring capacity***
>
> Using the car analogy, capacity is the size of the car's engine (potential maximum output at any instant) and energy is the output from the engine over time. Capacity is measured in megawatts (MW) and energy is measured in MWh (MW multiplied by time in hours).

Demand

The amount of electricity being consumed at any given time[1]. Historically, demand has not responded strongly to changes in supply. Demand varies substantially: the maximum annual demand is typically around twice the annual minimum demand, and on a daily basis changes of more than 30% are not unusual. Therefore, to achieve system balance, supply traditionally has been adjusted to meet demand.

[1] Transmission and distribution losses consume energy on the way to the customer. Sometimes this is treated as demand and sometimes it is treated as negative generation. In terms of balancing supply and demand this is irrelevant so long as it is correctly applied. Demand is usually reported as "grid-facing". This means that embedded generation such as rooftop solar photovoltaics is simply subtracted from demand. However, for the purpose of this paper, it is important to recognise the impact and value of rooftop solar as generation, and so it is explicitly included on the generation side.

Future implications: With the right market signals the responsiveness of demand would be likely to change in the future – especially with substantial energy storage acting as both supply and demand.

Demand-side response (also known as demand-side management)

The ability, and tendency, for demand to respond to the needs and signals in the market. Demand has always responded to market signals, to some extent. For example, peak and off-peak tariffs encourage a flatter energy use profile throughout the day and night, which has suited the inflexibility of coal-fired generation. However, time-based tariffs do not encourage response to real-time market signals, preferencing simplicity for the customer.

Future implications: As supply becomes more variable, the value of improved demand responsiveness will also increase to help manage the supply-demand balance, particularly the super-peaks. This will provide incentives for innovative solutions to aggregate and manage loads more actively, in order to extract some of the value inherent in the flexibility of demand. Increased value in demand-side response may lead to a shift in supply-demand economics. It is expected that demand-side response will have a range of options with different values associated. Section 3.1.3 has a more detailed discussion on the range of supply options. An indicative comparison of increased supply and demand reduction options is shown in Figure 1. It is worth noting that load-shifting will have different economics and may also influence the supply-demand balance.

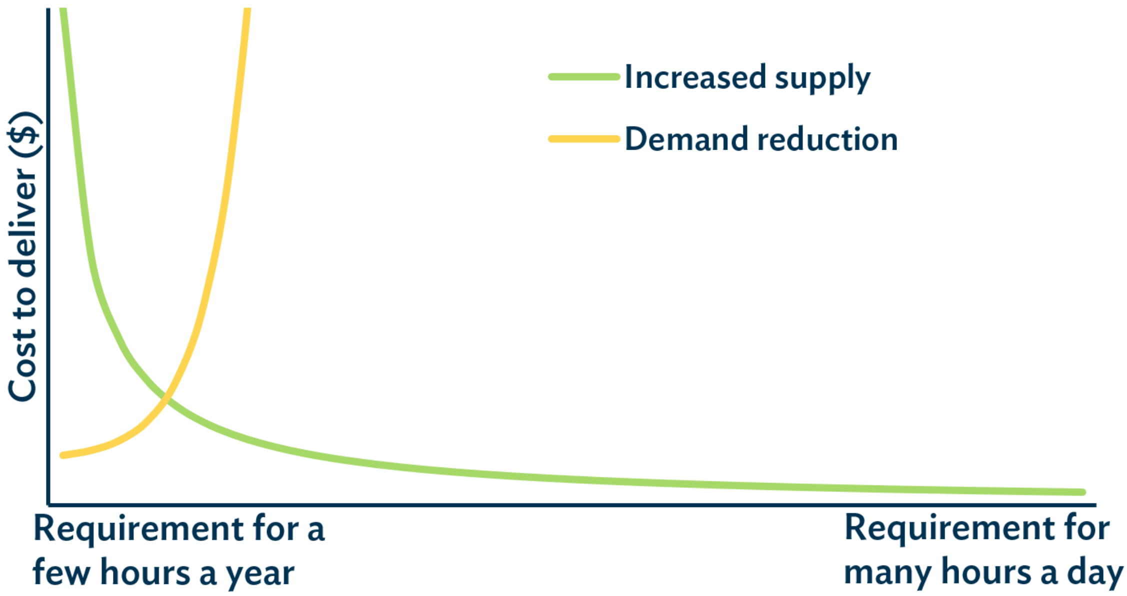


Figure 1. Representation of cost-effectiveness of options to balance supply and demand. It is likely to be more effective to manage an infrequent requirement through demand-side response and likely to be more effective to manage a frequent requirement through supply-side options.

Dispatchable

Generators which can be turned on and off when required. The technical definition simply covers power stations that can be operated to a schedule.

Future implications: "Dispatch" is a familiar term – but the concept of "dispatchable" only really gained relevance with increasing variable generation, see Section 3.

Energy

The amount of supplied and/or consumed electricity over the time it is delivered. Generators with a low fuel cost (e.g. coal, wind and solar) are considered to be bulk energy providers, as opposed to capacity providers ("peakers"). Some hydro generators are considered to be bulk energy producers.

Future implications: As coal generators retire, progressively more energy will be provided by wind and solar. This will change the nature of the supply.

Hydropower energy and capacity

Energy and capacity are related: capacity is required to deliver energy and energy is required to deliver capacity. However, the two concepts are different: Tasmania's hydropower portfolio is less than half the capacity of the mainland hydropower assets, yet produces 50% more energy, see Figure 2.

Hydropower generators can provide capacity to the market, although the economics of hydropower are different to gas-fired capacity providers. Higher capital costs are mitigated by free "fuel" (water). The availability of water becomes the limiting factor to operations: less water availability raises the effective price of the service, while more plentiful water reduces the effective price.

In Tasmania, the weather and topography is ideal for hydropower, which has been sufficiently cost-effective to fulfil the bulk energy demand as well as the flexible capacity requirement. This is not the most efficient use of these valuable assets[2].

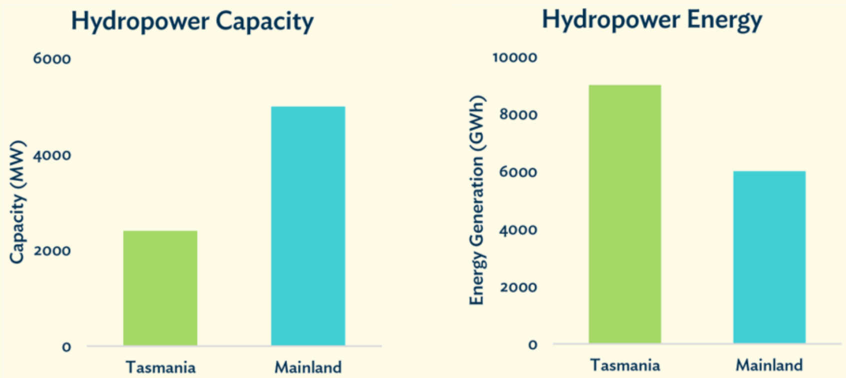


Figure 2. Tasmania's hydropower has less capacity than those across the rest of the NEM, but produces more

[2] This concept is discussed in detail in the White paper *Unlocking Tasmania's Energy Capacity* (https://www.hydro.com.au/docs/default-source/clean-energy/battery-of-the-nation/unlocking-tasmania's-energy-capacity_december-2018.pdf?sfvrsn=8d159828_6)

Firming

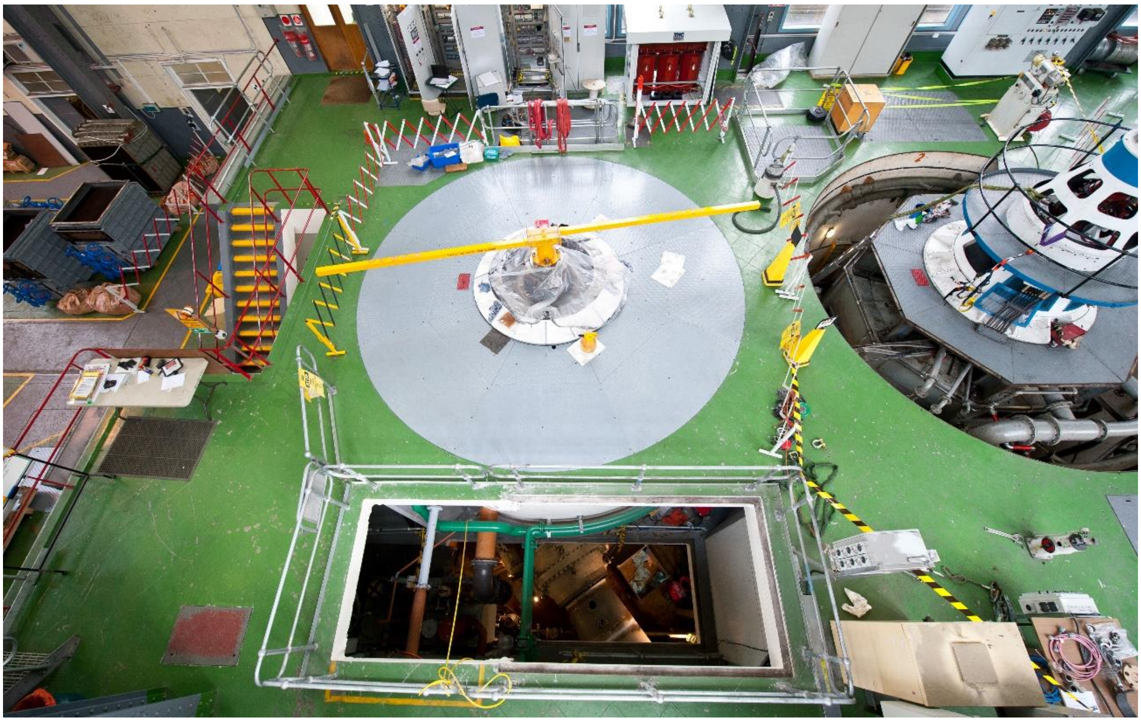
Firming is an emerging term with subtly different meanings depending on the context. Broadly, it describes a mechanism for achieving reliability of supply by supplementing variable renewable energy.

Future implications: As more renewable energy enters the system, it will become necessary to balance the supply side by considering compensation for variable supply, see Section 3.1.1 for a more detailed discussion.

Inertia

An ancillary service that helps maintain a stable frequency for the power system. This non-market form of frequency control is provided by the physical mass of spinning generators that are rotating at a frequency proportional to the alternating current (AC) electricity supply (nominally 50 Hz). Their spinning mass resists instantaneous changes to the frequency of the AC electricity in the network.

Future implications: Inertia was readily available with traditional generators, and is not monetised in the current market. Non-synchronous generators (e.g. wind and solar) do not provide inertia, and as these technologies begin to account for larger proportions of the supply, the availability of inertia is reducing[3]. Recognising, and remunerating, the value of inertia will be important to provide incentives for this critical ancillary service.



[3] As inertia reduces there is a need to find alternative options to manage the system. Fast frequency response (FFR) is sometimes called “synthetic inertia”. Fast response power electronics can rapidly change output to help manage frequency variations, but is not a complete replacement for true inertia. Synthetic inertia is limited by the speed of observation, processing, command signal and response; it reacts to a change in frequency. True inertia physically resists changes to the frequency immediately and at all times. FFR has value in helping to manage the system, but it can never completely replace physical inertia.

Peak

The maximum demand – usually in a half-day, day, season or year. Some generators that operate only at times of maximum demand are referred to as “peakers”. By definition, peakers are infrequently operated and operate only at high prices – typically due to high fuel costs or constraints on energy availability. “Peak” can also be shorthand for “peak periods”, which are defined in the market. These periods are aligned with historical times of higher price (driven by higher demand).

Future implications: The future peak (high price) periods are expected to be defined less by times of high demand and more by times of scarce wind and solar generation. Lack of low-cost generation will require more support from more expensive flexible generation sources and is expected to be much more relevant than the magnitude of the demand. The relevance of the current definitions of peak and off-peak periods will reduce.

Regulation

An ancillary service that controls frequency where generators change their output to meet the fluctuations in demand. In a broader sense, regulation is a key element to firming the system.

Future implications: Regulation is already recognised in today’s market, but as supply starts to vary more, so too does the need for regulation provided by flexible generation options.

Reliability

The ability of the system to continually meet the energy requirements of consumers under normal asset operations. In Australia, reliability (the longer-term need for reliable energy delivery) is differentiated from the instantaneous need for security against an event.

Future implications: The need for the differentiation between reliability and security is a direct consequence of increasing reliance on variable generation. The challenge of reliability highlights the benefits of storing low-cost energy during times of plentiful supply, for use during times of lower variable generation. Australians expect electricity to be available when it is needed most. Rolling residential brownouts during a heatwave do not meet that expectation. Contracted reduction, or even shutdown, of flexible industrial loads is expected to be part of the most cost-effective solution during times of exceptional demand.

Security

The ability of the system to meet demand during system events such as asset failures.

Future implications: As Australia’s coal generation assets age, generator events have begun to occur more frequently, which places more stress on system security. Smaller and more distributed generation, and a more interconnected electricity system, reduces the impact from a single asset event.

Supply-demand balance

The power system is a true supply-on-demand system. Transmission and distribution lines cannot store electricity, so power supply must always equal demand – even at time scales of less than a second. The Australian Energy Market Operator (AEMO) is responsible for ensuring that supply and demand are constantly matched: to continue the car analogy, AEMO is the driver of the pizza delivery car with responsibility to deliver a quality and reliable outcome for the power system.

Future implications: As supply begins to vary more, the challenge to balance supply and demand will increase. In late 2017, AEMO needed to call on the Reliability Emergency Reserve Trader (RERT) mechanism to ensure supply-demand balance. The RERT mechanism allows for tendering of reserve supply contracts as a safety net. Markets and regulations must continue to adapt to support the development of the assets required to help manage this increase in variability.

Sustained capacity

A response to the challenge of cost-effectively delivering reliability in the context of increasing variable supply. This is a new concept that is still emerging and not yet part of the common vocabulary.

Future implications: Extended periods with low output from wind and solar are expected to be more impactful. Managing a varying supply-side and a varying demand-side will need cost-effective and responsive supply options that can provide energy for extended periods when needed, see Section 3.

Variable generation

Generation where the actual power supplied is limited by the resource available at the time[4]. This is typically used in the context of variable renewable energy generation (wind and solar[5]). Sometimes these energy sources are also referred to as intermittent – although this is not a preferred term as it incorrectly implies that the energy is entirely unpredictable.

Future implications: Across the NEM, wind and solar generation is presently modest but rapidly increasing. During high wind and solar periods, the baseload generators are already having to change the operation of their assets, and this is likely to increase.

[4] All generation is constrained to some extent by the resource available. With fossil fuel-based generation there is usually an assumption that the fuel is stockpiled and can be purchased as required. With hydropower there is usually some storage that can hold the water for use at a more suitable time.

[5] In this document, unless otherwise stated, solar generation includes both utility-scale and rooftop solar photovoltaic generation.

3. Delivering reliable supply in the future NEM

We need to ensure that we continue to meet the supply-on-demand challenge as the power system transforms. This will require us to develop new services, or at least to reconsider existing concepts, to enhance our ability to respond. Most people in the industry are now familiar with the concepts of "dispatchable" and "firming", yet quantifying these terms is challenging.

Australia's electricity is currently generated predominantly by coal, which provides baseload supply, supported by gas and hydro, which balances the inflexible supply against the variable demand. Across the NEM, wind and solar generation is presently quite modest, but rapidly increasing. Figure 3 illustrates the generation mix, using the first week of December 2018 as an example. During periods of high wind and solar, the baseload generators are already having to change the operation of their assets. Black coal can economically accommodate some small level of variation, and even the substantially inflexible brown coal generators are starting to be partially dispatched.

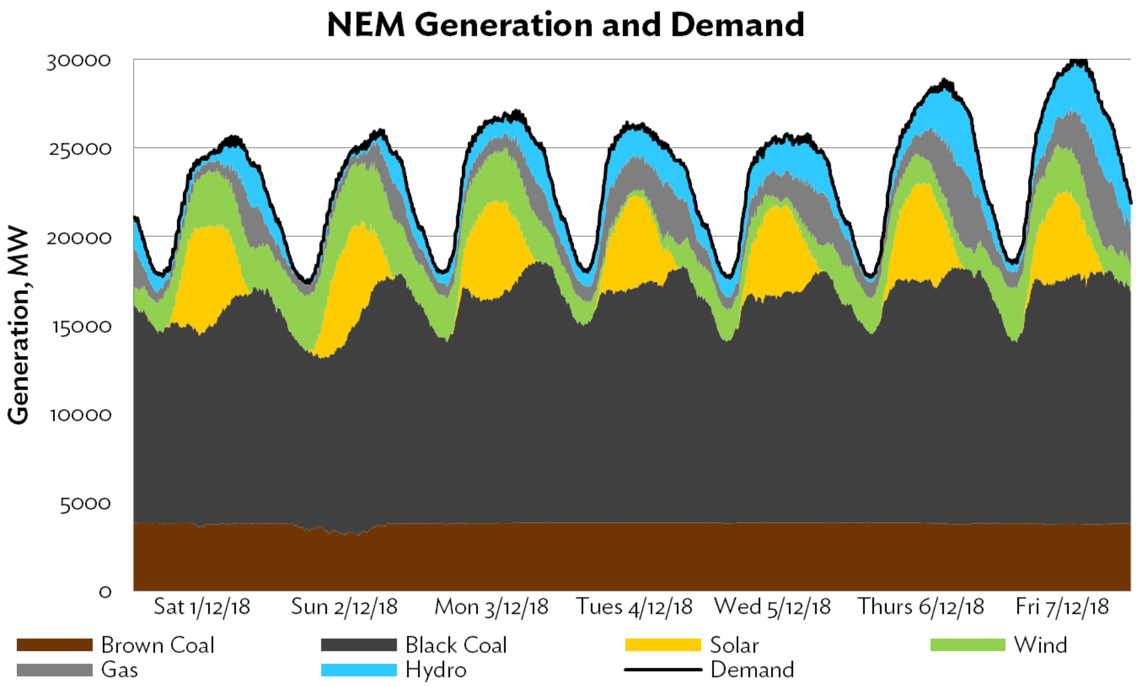


Figure 3. NEM-wide generation and demand during the first week of December 2018

Wind and solar developers continue to identify cost-savings and produce energy at ever lower costs. This significant shift in economics is forecast to drive a very different generation mix in the future. AEMO's first Integrated System Plan[6] found that the least-cost solution was reached by interconnecting the regions more strongly, and leveraging diverse wind and solar generation balanced by substantial growth of storage.

The change in the generation mix has raised questions about both security and reliability as the conventional thermal generators exit the market and are replaced by

6 Integrated System Plan, 2018 (see https://www.aemo.com.au/Electricity/National-Electricity-Market-NEM/Planning-and-forecasting/Integrated-System-Plan)

newer technologies with different characteristics. However, the existing system works because the rules, regulations and tariffs have been designed to make it work – not because it is an easy system to operate. The opposite challenge of coping with today's inflexible constant-output generation would be just as daunting if the industry was accustomed to a system with substantial flexible storage to help manage supply-demand imbalance – and yet that is our system today. Change can be challenging, especially for utility services with long-life assets and an expectation of being highly reliable, yet the most effective power system for the future will be different from today.

3.1 Emerging terminology

In the future, energy generation sources will shift from large-scale baseload to variable renewables. Both supply and demand will vary and this will change the nature of the balance as well as how the balance must be managed. In fact, supply-side variation may be much larger than the demand-side variation, causing greater requirement for flexible supply and demand options. These flexible options must be able to respond to market signals very rapidly and also be able to cost-effectively support the supply-demand balance not just for minutes or a few hours, but several hours or even days.

3.1.1 Defining "firm"

"Firm" is a seemingly simple term, but is used to mean subtly different things. AEMO defines firmness[7] as,

> *The resource's ability to confirm its energy availability. For example, how long can the source provide a requested amount of energy once dispatched, and how far in advance can the energy be guaranteed by the source?*

However, this definition does not capture the full range and depth of meanings ascribed to the term.

Firmness typically has an implication regarding the *consistency* of the availability of supply, not just the ability to commit to being available. For example, solar generation can reasonably be predicted (energy will be produced during daylight hours and not at night), but cannot guarantee firm supply at evening peaks.

The power system is a true supply-on-demand system – at all times the supply must balance the demand. Consequential surpluses or deficits of power will disturb the electricity voltage and frequency.

7 Power system requirements (see https://www.aemo.com.au/-/media/Files/Electricity/NEM/Security_and_Reliability/Power-system-requirements.pdf)

Customers turn on their home appliances without requesting permission and without causing a noticeable disturbance in the grid. This is because of an integrated system with many customers and generators all connected with transmission and distribution lines. The diversity of the changes in demand, coupled with constant adjustment of generator output, act to smooth out the impact of individual actions. Only the largest changes are material to the system.

Historically, the focus of supply-demand balancing has been predominantly on ensuring that variable demand is met with available supply. However, as more variable renewable energy enters the system, it becomes necessary to compensate for variable supply. This supply-side consistency is generally referred to as "firming".

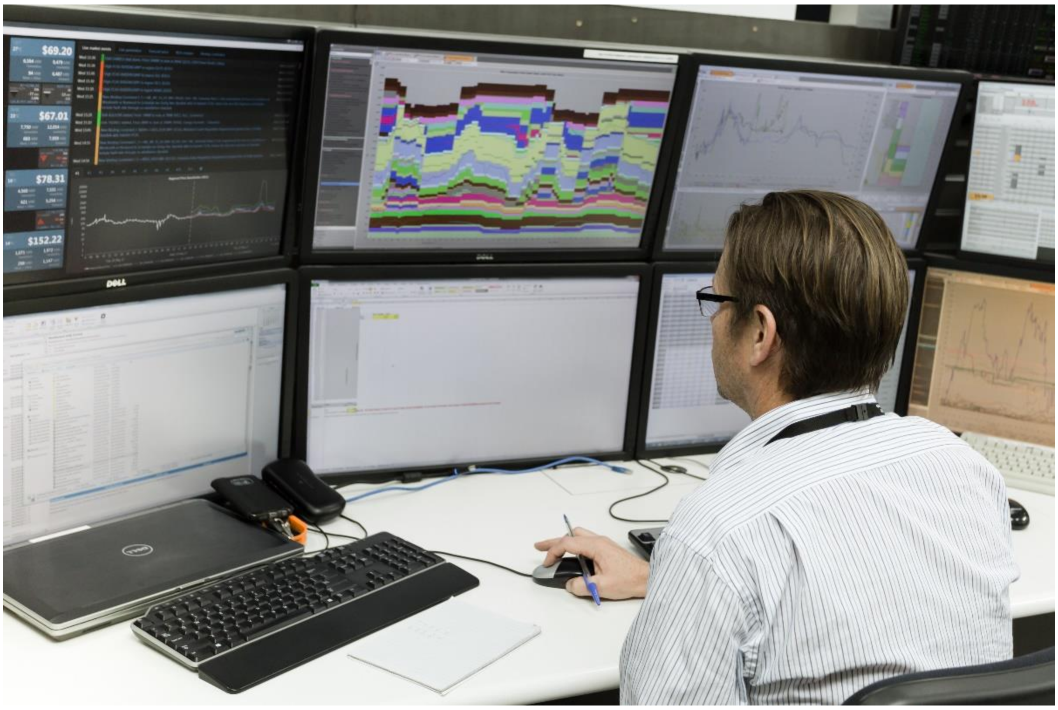
Within this broad definition, different people (e.g. retailers, operators, traders, generators) assign subtly different meanings to the term:

- Physical vs financial

  To some, "firm" is a financial concept: a contractual guarantee to provide a consistent supply of energy. Firming then becomes a financial service to help manage the risk of exposure to spot prices in supplying that energy.

  For other people, "firm" is a physical concept: the ability to generate the required supply of energy. Firming then becomes a physical service to help manage times of shortfall in energy production.

  Both definitions of firm relate to protecting the customer from variability: one achieves this through price guarantees and the other achieves this through energy generation.



- Asset vs system

  Some view firmness as a property of an asset, or a group of assets. The idea is that such an asset, or group of assets, would produce consistent output, regardless of market requirements.

  There may be valid market and financial reasons to provide incentives for a generator, or group of generators, to provide firm supply, but there is no technical reason why any given generator, or group of generators, must be independently firm. The system requirement is that supply balances with demand. Sharing resources throughout the system is more efficient than requiring individual generators to be independently firm. Just as it is clearly more efficient to share resources across the grid instead of having a separate generator in each house, sharing firming resources throughout the system is more important than assigning (and even co-locating) individual firming options with individual variable generators.

- Degree of firmness

  Generally, a baseload power station would be considered firm. However, even baseload power stations don't always generate to their full capacity – they have planned and unplanned (emergency) outages[8] which means the plant is unavailable. Requiring new assets to be 100% firm is an unrealistic expectation. There is yet to be a generally agreed definition of what level of unavailability is acceptable while still being considered firm.

In light of the varying interpretations of "firm" and "firming", it is important to consider what is fundamentally required to meet demand in a system with significant variable renewable energy. Energy sources are required to:

a. Start, stop and change supply – quickly, reliably and on-demand ("dispatchable")
b. Sustain generation over the required period of time – a number of hours or days ("sustained capacity").

The provision of these characteristics can be considered firming services. The requirements, and the way they are met, will change over time and as the generation mix changes.

[8] As assets age, they are increasingly unreliable and more likely to suffer 'events'. These baseload coal assets are sufficiently large to be noticed at the system level. This is causing some commentators to cast some doubt on the asset's firmness at this stage in their life.

3.1.2 Defining "dispatchable"

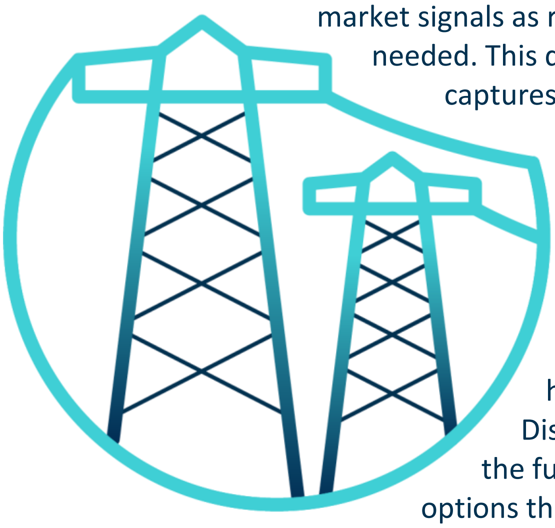
Technically, "dispatchable" may be defined as being able to generate when directed, with the caveat that generation is constrained by technical limitations. The caveat is the key issue in defining dispatchability. AEMO's *Advice to Commonwealth Government on Dispatchable Capability*[9] includes the following:

> *The NEM is not delivering enough investment in flexible dispatchable resources to maintain the defined target level of supply reliability, as the transition from traditional generation to variable energy resources proceeds.*

While the document's title focussed on dispatchable, the key word in the statement above is "flexible". This highlights that for most uses of dispatchability there is an implicit assumption that the generator has the technical ability to be able to respond when needed.

Generation assets that are traditionally baseload providers (such as coal and nuclear) are inflexible and slow to start. Combined cycle gas turbines and most biomass generators are marginally better, but still take many hours to start. This means that in the context of needing to respond to variations in the supply-demand imbalance, these technologies are not truly dispatchable – at least not in the context that the word is normally used.

The flexible dispatchable technologies in the NEM include open-cycle gas turbines (OCGT), diesel generators, hydropower and storage (including pumped hydro and electrochemical batteries). These technologies are typically capable of responding to market signals as required – thus able to be dispatched when needed. This definition of flexible dispatchable generation better captures the need for controllability that is typically assumed when discussing the need for dispatchable generation.



The confusion between the technical term and the intent of the language reduces the clarity of industry discourse. Depending on the timeframe of the required response, different technologies have different levels of dispatchability. Dispatchability alone is not a guarantee of meeting the future system requirements – the system requires options that can be responsive and flexible.

3.1.3 Reliable energy supply: defining "sustained capacity"

"Sustained capacity" is a response to the challenge of reliability. There is a need for services that can effectively balance the system, especially with a changing technology mix. Specifically, sustained capacity addresses the need for cost-effectiveness, not just

9 Advice to Commonwealth Government on dispatchable capability (see https://www.aemo.com.au/-/media/Files/Media_Centre/2017/Advice-To-Commonwealth-Government-On-Dispatchable-Capability.PDF)

for an hour or two, but for extended periods of time, such as operating throughout the night when there is no solar generation or during days of minimal wind generation.

This gives rise to the need to develop a more nuanced view of the old paradigm of baseload energy providers and short-term capacity providers. Sustained capacity is essentially a new category of dispatchable supply – sitting on the dispatchable energy delivery continuum between an energy provider and a capacity provider. This is illustrated in Figure 4. The key options to deliver from 6 to 48 hours are OCGT and hydropower (either pumped storage or conventional). To deliver in this range, the cost per MW and the cost per MWh are critical to the cost-effectiveness.

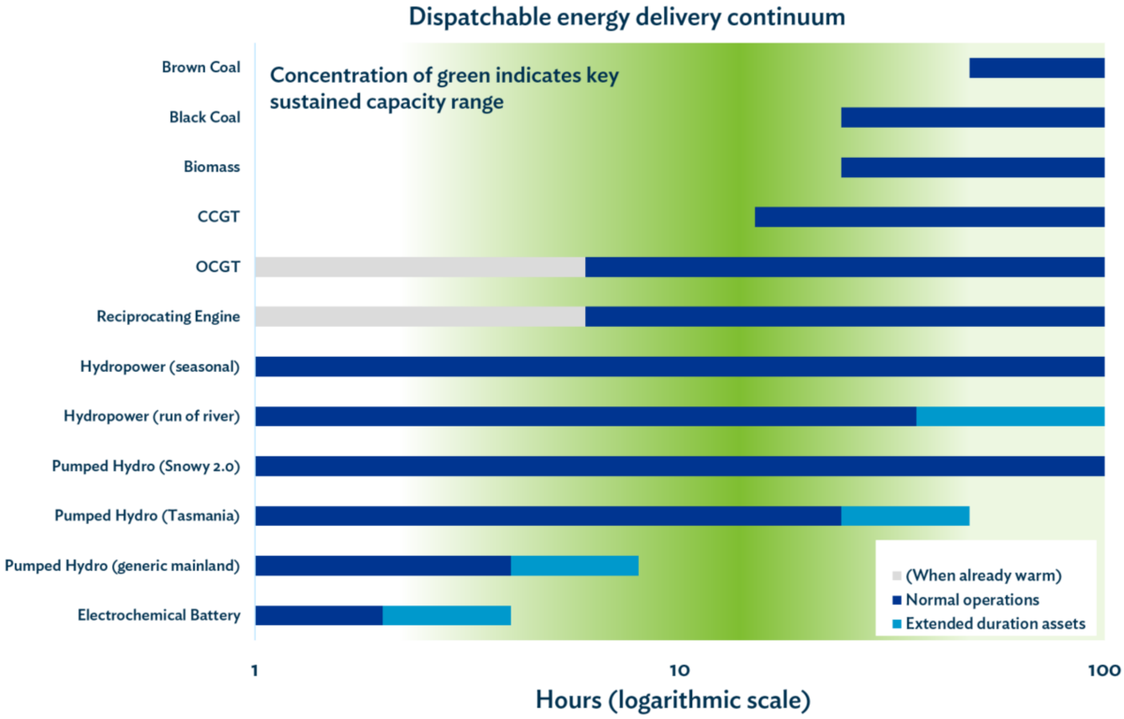


Figure 4. A demonstration of the ability of different dispatchable technologies to deliver energy continuously from time of request. The conceptual "sustained capacity" range is highlighted in green. The x-axis is a logarithmic scale to compress the range of operations.

This paper does not attempt to quantify the specific value of sustained capacity, nor how much sustained capacity is needed. Such quantification relies on the actual generation mix, the load profile and a range of other system-wide variables. However, even observing the market today, it is possible to see extended periods with low output from wind and solar and geographic resource diversity will only address part of this challenge. Managing a varying supply-side as well as a varying demand-side will need supply options that are responsive, sustained and cost-effective for extended durations. This is particularly relevant to energy storage, and challenges the simple classifications of long-term energy and instantaneous capacity – recognising that there is actually a continuum of supply options required to ensure reliability.

3.2 Firming services

Firming will be most efficiently delivered through an integrated system that leverages resource-sharing. The market must value firming services to achieve their efficient delivery.

Table 1 shows an indicative range of challenges that will cause system supply-demand imbalance if not addressed with firming services.

Table 1. The challenges that the power system is likely to face

Example challenges to system supply-demand balance	Indicative duration of impact
Brief variations in load or supply	0-1 hrs
Contingency events causing brief spikes in supply-demand imbalance	0-2 hrs
Managing load uncertainty and supply constraints (transitional)	6-8 hrs
Daily balancing of solar cycle	10-14 hrs
Large cloud bands in a system with substantial solar reliance	24-48 hrs
Successive days of minimal wind generation	24-72 hrs

3.2.1 Existing firming services

While firming is a concept that is relatively new to the Australian power system, the underlying principle of responding to supply-demand imbalance is core to the operation of any secure and reliable electricity system.

In the NEM, electricity is traded on a spot market with a 5-minute dispatch interval. Generators bid the minimum price at which they are willing to generate at each interval. The price can change significantly from one interval to the next, depending on the most expensive generation required to meet demand at that time.

To help smooth price volatility, and ensure system balance, firming services in various guises have always existed. These largely cover the first three challenges raised in Table 1. Existing firming services include:

Regulation Services – used to constantly manage the balance of supply and demand within a dispatch interval (5 minutes). The more contemporary use of “firming” is essentially considering regulation at a much larger scale.

Swap contracts – long-term commitments to a set price for a set level of energy. Parties – typically a generator and a retailer – agree to reimburse one another the difference between the spot price and the swap price. While a swap contract is purely financial, the presence of swap contracts does drive a degree of physical firming.

Tariffs – set prices at which a consumer may buy energy. These are essentially open-ended volume swap contracts between the retailer and the customer. Time-based tariffs provide a coarse demand-side response mechanism.

$300 cap contracts – an insurance product of sorts ensuring that the purchaser will never be exposed to prices above $300. Much like a swap contract, the sellers of these contracts typically have a physical backing to protect against the risk of the extreme prices – a form of firming.

Other contract mechanisms – a range of mechanisms typically used for managing risk. For example, there are already some demand-side response options that are contracted under various mechanisms or exposed to spot prices through a limited swap contract.

There are many mechanisms to support firming, and yet there is a fresh debate about the firming services that are needed for the market and the system. The generators selling these contracts typically have large portfolios and profit from higher prices. Research into energy markets[10] has shown that relying on a market response alone is likely to result in continued under-investment in capacity to maintain prices and profits. A transforming market puts further pressure on capacity, and the need for proactive investment under conditions that reward under-investment will cause substantial stress and result in higher prices across the NEM. De-risking and/or provision of incentives will increase investment, increase capacity and reduce the cost to the customer.

[10] The Inevitability of Price Spikes and Tight Capacity in Competitive Electricity Markets (see https://tad.colman.ac.il/paper-all/134052.pdf)

3.2.2 Potential future services

While there are existing mechanisms that encourage firm supply options, the market is transforming and the nature of the requirements will change. The last three challenges listed in Table 1 all relate to increased reliance on variable supply through wind and solar. To manage these challenges the services in the market will need to adapt.

Cap contracts with lower strike prices – as the market transforms, the energy delivery options will change and this will alter the price duration curve. Historically, the NEM has experienced a fairly flat energy price (somewhere around the cost of coal) with price spikes during times of less plentiful energy. With more variable renewable energy, this flat energy price is expected to separate into two price categories: extended periods at very low prices with plentiful wind and solar, and higher firming prices when other services are required to meet demand. New cap contracts could be made to protect against high prices from gas-fired generation, which will occur more often than the $300+ price spikes of today. This would provide incentives for firming options that can cost-effectively supply energy for extended periods, identified as "sustained capacity" in Section 3.1.3.

Regulated capacity provision – some markets around the world use mechanisms to allow the system operators to define a minimum level of capacity to ensure reliability and security. There are a range of options to implement this approach. The key to the success of these mechanisms would be to sufficiently determine what is actually required with enough time to implement the most cost-effective solutions. Short-term capacity alone is unlikely to successfully meet the future market needs.

Firm energy market – the NEM is largely an energy market, with some trading in ancillary services. There is no financial reward for day-ahead commitment of firm generation in the NEM. Some markets use a two-tier energy market with a day-ahead firm energy market being traded separately from a spot price energy market. A firm energy market encourages individual generators to provide a firm service to the market. It may be more efficient to source this as a system service, although having a clear market mechanism to reward firming may deliver additional benefits through innovation and risk management. If such a market were to be created, it would provide incentives for new reliable firming options that could either procure variable energy and sell a firm product, or sell a firming service to the variable energy generator to value-add to their product.

New demand-side response – new opportunities will exist for customers with flexible demand. The mechanisms are not yet clear, particularly in defining the response against some baseline of expected consumption. This difficulty is likely to be addressed through policy and rules along with technology solutions, and some customers with flexible demand will be able to actively respond to market signals for firming.

Surplus variable generation - wind and solar are the lowest-cost forms of new energy generation. AEMO's Integrated System Plan identified that a system with wind, solar and firming options can produce the most cost-efficient outcome. However, wind and solar development may also reach financial limits from coincidental surpluses, driving the prices in the spot market to zero (or even substantially negative under a power purchase agreement). Table 2 highlights the challenges that may face developers due to value-suppression of their product. In this situation, it is expected that flexible demand that is able to ramp up to consume the surplus generation will be required to firm the supply-demand balance and leave sufficient profitability for new variable generators to be developed. Ideally, this flexible demand would be in the form of storage that can cost-effectively address the supply-side firming needs as well.

Table 2. The challenges that developers of wind and solar likely to face

Challenges for new development of wind and solar	Indicative duration of impact
Surplus solar generation (daily pattern)	8-10 hrs
Surplus wind generation (low pressure systems)	24-72 hrs

The firming services that will be required to manage the low-cost variable renewable energy sources will need to be more flexible than existing baseload generation, and operate more often than existing fossil-fuel capacity options. Sustained generation over a period of several hours to even a few days will be critical to successfully manage the transformation of the NEM when maintaining reliability, security and affordability.

3.2.3 Market redesign

As the physical power system transforms, the market must be adapted to optimise the use of the new assets and manage the physical and financial outcomes. New services will be required, and these are likely to require additional incentives outside the existing market to support the proactive investment needed to best manage the market risk.[11]

The market presently rewards capacity shortfall with high prices – a disincentive to introduce new generation to the market. To achieve the best price for the customer, it will be essential to introduce long-term mechanisms to encourage the development and utilisation of flexible supply options in the market that can and do respond to the market signals.

[11] This is a topic for a future White Paper in Hydro Tasmania's Future State of the NEM analysis series.

As the energy market transforms, our understanding of the market and the language we use to describe it must evolve. We need to progress thinking beyond our present views. Dispatchable energy generation may not be flexible. Capacity options may not be able to cost-effectively sustain supply. Firming services exist in the market today and new services will be needed to continue to balance more variable supply and demand. The exact nature of these new requirements changes the nature of the solution and the options that can best meet those requirements.