ARRESTING FREQUENCY CHANGES IN A MODERN ELECTRICITY SYSTEM

CLEAN ENERGY COUNCIL

CLEAN ENERGY COUNCIL BRIEFING PAPER
MAY 2017

EXECUTIVE SUMMARY

The security of our electricity grids is essentially measured by their ability to withstand shocks. Historically, the National Electricity Market has relied on conventional coal and gas generators to provide inertia and respond rapidly to suppress rapid change in frequency following a shock or disturbance. However, as our energy mix changes with the growth of large-scale and distributed renewable energy and energy storage technologies, it is becoming clear that this cannot be taken for granted any longer. Other generation sources and enabling systems in the grid must contribute as well.

As the decarbonisation of the energy system continues, new technologies and solutions will ensure the continued level of security that is expected from a modern electricity grid. These technologies are available now and are rapidly improving. Failing to tap into them is a missed opportunity that could have significant ramifications for future energy security.

This paper explores some of these technological opportunities in order to demonstrate that transforming our energy system is not a technology problem. But it is important to ensure that regulatory and market settings provide the necessary incentives to bring new technologies into the market, rather than relying on outdated assumptions.

BACKGROUND

Keeping grid frequency as close as possible to the nominal 50 Hz operating frequency when a major disturbance occurs is an essential part of a secure power system. The ability of the system to withstand and 'ride-through' shocks has traditionally been supported by the inertia in large centralised coal and gas generators. These 'synchronous' generators have very heavy electrical rotors and turbines that spin to generate power. Traditional power grid design assumes that the system's inertia is created by the combination of these spinning masses[1].

Importantly this inertia only acts to manage the rate at which frequency changes. If the frequency moves too far from 50 Hz, special fast-acting protection schemes are in place to turn off customer supply, as a way of restoring the supply-demand balance and arresting the change in frequency. The ultimate goal of these actions is to minimise the amount that the frequency moves away from

[1] A small amount of inertia is also provided by electrical loads but this has been ignored here.

the nominal 50 Hz – termed the frequency nadir – before the system can restore the frequency back to 50 Hz.

It's fair to say that grid operators have taken this inertia service for granted to date. Because our grids were originally designed around these traditional solutions, it has been assumed that inertia is always sufficient, despite there being a track record of imperfection, and a lack of understanding of the operation of existing large generators during major disturbances.

The many changes in electricity grids across the world over the last decade clearly demonstrate that further and ongoing evolution of our power system is needed.

The average thermal coal power plant in Australia is more than 30 years old. By 2020 around 40 per cent of these plants will be over 40 years old and 15 percent will be over 50[2]. In addition to their advanced age, these assets need to be replaced because of the global effort underway to reduce carbon emissions to stall global warming to below 2 degrees Celsius. Australia's ratification of the Paris climate agreement will require the replacement of emissions-intensive generators with new renewable energy, largely wind and solar.

Although modern renewable energy generators are technologically very sophisticated, the provision of an inertia-like response to rapid changes in frequency has never been contemplated or expected by the Australian Energy Market Operator (AEMO), which is responsible for power system security[3]. However, this does not imply that these technologies cannot support the system in these events – only that the expectation has never been set by the market operator or market rules. This is an increasingly critical missed opportunity.

HOW DOES INERTIA ARREST FREQUENCY CHANGES?

The extent of inertia in a system becomes most apparent when a significant contingency event occurs. An example of this is when a large generator's protection mechanisms disconnect it without warning.

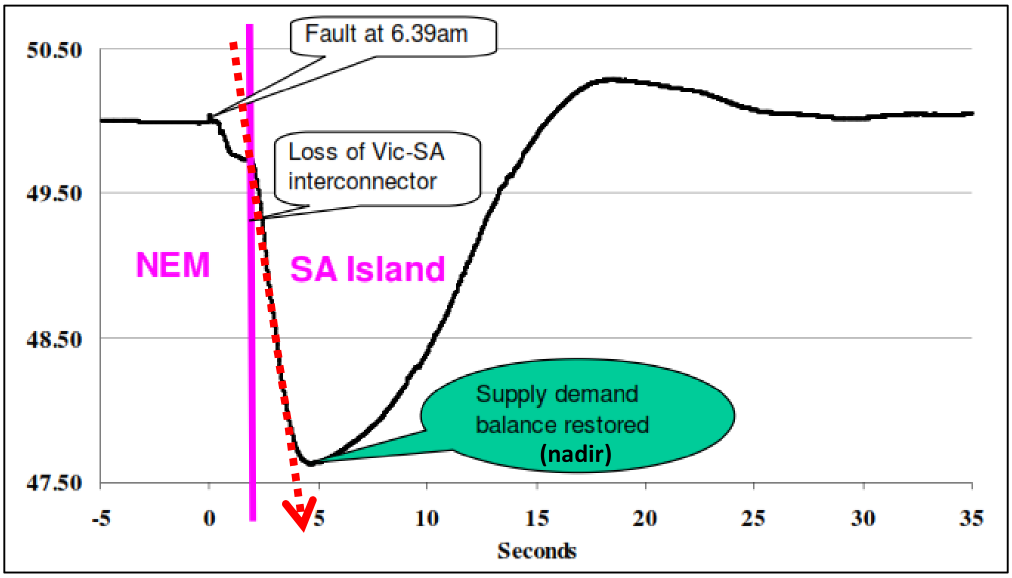
The immediate response of the power system is the *rate* at which frequency moves away from the nominal 50 Hz. During this very short time window the rate of change of frequency, or RoCoF, is determined by the size of the contingency and the system's inertia. Higher inertia slows the initial

[2] A Stock, Climate Council, *Australia's Electricity System: Ageing, inefficient and unprepared*, 2014, page 9
[3] Australian Energy Market Commission, *System Security Market Frameworks Review Consultation Paper*, July, 2016

rate of change.

Such an event can be seen in Figure 1, which shows the frequency changes following a sharp reduction in generation from the now-closed Northern Power Station in South Australia on 14 March 2005 (before significant wind power was deployed in the state). Northern Power Station reduced its output from around 500 MW to nearly zero in 0.6 seconds. Conservative protection settings were later identified as the cause.

Figure 1: Frequency deviations during the 14 March 2005 islanding event in South Australia. RoCoF was 1.6 Hz/s (measured by the red dashed line) and the nadir was 47.53 Hz[4].



The generation shortfall had to be drawn across the Heywood Interconnector from Victoria, causing the interconnector's protection to detect 'loss of synchronism' and disconnect, separating or 'islanding' South Australia from the rest of the east coast grid. Around 900 MW of imported power was lost instantaneously, sending a large shock through the islanded grid in South Australia. Two and a half seconds later the Pelican Point gas turbine generator tripped off, losing around 100 MW

[4] National Electricity Code Administrator, *Report into power system incident on 14 March 2005 in South Australia*, 2005.

of generation and compounding issues within the state. Software settings were later identified as the cause[5].

The fast-acting emergency load-shedding protection scheme disconnected around a third of the state's customer load to restore the supply-demand balance, stalling the fall in frequency. Once the supply-demand balance was restored, the governors and controllers in those gas generators that were still running acted to raise the frequency back to the nominal 50 Hz.

In this instance the 900 MW shock led to a RoCoF of 1.6 Hz per second for a period of 0.5 seconds. The frequency nadir (lowest point) was 47.53 Hz. A similar event was also caused by Northern Power Station in 2004 where a higher RoCoF was experienced[6].

Importantly, the inertia in the system is only a part of this response. The response requires many different components of the system to work together: inertia, generator governor responses and load-shedding all need to contribute towards stopping the change in frequency. The system's objective is to keep the frequency 'nadir' as close to 50 Hz as possible to minimise the impact of the disturbance.

AEMO has established that as coal generators have shut down, the energy they provided has been replaced by wind and solar power. To date the market rules and market operator have not expected these renewable energy generators to contribute towards keeping the nadir close to 50 Hz.

INERTIA FROM CONVENTIONAL GAS AND COAL GENERATORS

While it is clear that the inherent mechanical inertia from traditional generators has played an important role in Australia's power system, the performance of these generators during large disturbances is less well understood. In addition their control settings may not be tuned well enough to support the system during major events.

It is known that these generators can become unstable under some high RoCoF conditions. Currently AEMO does not have any information on how well older generators connected prior to 2007 can withstand these conditions.

[5] National Electricity Code Administrator, *Report into power system incident on 14 March 2005 in South Australia*, 2005.
[6] Australian Energy Market Operator, *The Future Power System Security Program: Frequency Control*, presentation by Jenny Riesz, August 2016

Recent research into the Irish electricity grid has found that RoCoF in the ranges shown in Figure 1 caused ‘pole-slipping’ for some gas generators and could lead to both costly damage to these machines[7] and grid instability. No such studies have been undertaken for Australian generators.

At present there is no available information on the expected performance or stability limits of thermal gas and coal generators commissioned prior to 2007. This includes those in operation in South Australia. It is absolutely critical to develop a greater understanding of the operation of these machines. Mandatory testing by their operators is advised to obtain this information.

The initial response of synchronous generators to rapid frequency changes is autonomously delivered by the generator governors based on response frequency set points. However, in response to incentives created by the Frequency Control Ancillary Services (FCAS) market many of these set points have been set with wide response ‘deadbands’ that delay response times. This delay increases the severity of high RoCoF events and results in a frequency nadir that settles further from 50 Hz. In effect the market mechanism that controls frequency has created perverse outcomes that undermine system security. The Clean Energy Council understands that no other jurisdiction in the world has allowed this to happen.

In an environment where new technologies are being driven to support the security of the grid, it is essential that the settings of the existing generation fleet are reviewed and revised to ensure that these synchronous generators are contributing effectively to arrest rapid changes in frequency.

As the energy market transitions from old conventional technologies to new renewable technologies, it is critical that all forms of generation work in concert to support power system security. The market has to look beyond these conventional technologies. Some key alternative options for renewable energy and energy storage to support the grid are included below.

FAST FREQUENCY RESPONSE FROM WIND TURBINE GENERATORS

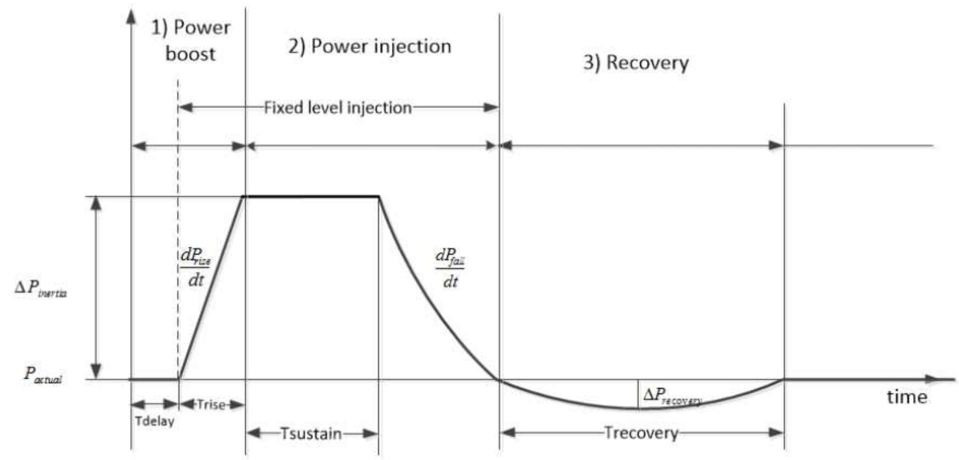
Wind turbines are frequently cited as being ‘decoupled’ from the grid frequency and therefore provide no inertia to the system. Modern wind turbine generators incorporate highly sophisticated electronics and control systems that are capable of transferring their inertia to the system to assist in arresting changes in frequency.

[7] Australian Energy Market Operator, *International Review of Frequency Control Adaptation*, page 29, October 2016.

To achieve this, the wind turbine generator can draw upon the kinetic energy stored in the generator and rotating blades to provide a boost of power if triggered by a system disturbance. This higher output can be sustained for a short period. The power injection acts to arrest the change in frequency and the precise response can be shaped to suit the local grid requirements[8]. Figure 2 shows how this response works conceptually at the generator level.

Quebec has been paving the way with wind turbines being used in this way. Although wind penetration in the Canadian province is below that of South Australia, Quebec established a standard that demanded an 'inertial' response from wind turbines in 2006. The first of such systems were installed in 2011 and were tested when a major transformer failure led to the loss of 1600 MW of generation. In this instance the response from the fleet of wind turbines was as expected and comparative to the synchronous generators online at the time[9].

Figure 2: Conceptual fast frequency response from a wind turbine[10].



T_{delay}: Adjustable initial delay.
T_{rise}: The time it takes to reach the needed boost level. The rate of power change is adjustable.
$T_{sustain}$: Adjustable maximum boosting time.

---

[8] Diverse Fast Frequency Response Services in Systems with Declining Synchronous Inertia, N Miller, S Pagic, 15th Interational workshop on Large-Scale Integration of Wind Power

[9] P. Fairley, IEEE Spectrum, *Can synthetic inertia from wind turbines stabilise grids?,* November 2016, accessed at http://spectrum.ieee.org/energywise/energy/renewables/can-synthetic-inertia-stabilize-power-grids.

[10] Vestas, *Wind Power Plant Frequency Control to Support the Penetration of High Levels of Renewable Sources*, presentation by Antonio Martinez, March 2016.

One of the challenges faced by this approach is that drawing power from the rotating blades slows their rotation, leading to a recovery period of reduced power output after the fault while the blades accelerate back to the wind speed. The recovery period can depend on how fast the blades are rotating before the event.

All generation technologies have to recover after a major disturbance in the system and the grid operator in Quebec is working towards improving its technical standards to better manage operation during this period. Wind turbine suppliers are responding with even more sophisticated generator performance solutions[11].

The lessons learned here could easily be translated to Australia's grids.

FAST FREQUENCY RESPONSE FROM INVERTER-BASED GENERATION AND STORAGE

As with wind turbines, both solar PV and energy storage inverters are decoupled from the grid frequency. These are static devices which have no rotating parts, from which extra energy can be drawn when needed. However, the solid state nature of power inverters provides these systems with an ability to switch and change operation almost instantaneously. Where storage is included or where generation is available, the energy injection is highly controllable.

Recent work by the Australian Energy Market Operator has identified the potential for these devices to provide support during frequency disturbances. Termed 'Fast Frequency Response' (FFR), the technology works by continuously measuring frequency. Where RoCoF exceeds a pre-set limit, these devices inject or absorb power in an attempt to slow the change in frequency and control the frequency nadir.

Inverter-based or solid state devices can respond to a frequency event very quickly if triggered. As with fast frequency response from wind turbines, the response can be tailored to suit Australian grid conditions. However, technical challenges are present in the measurement of the frequency deviation[12]. On one hand, a fast detection in the order of 100ms is possible and is needed to quickly suppress a frequency change. On the other, detecting the change too quickly may lead to a

[11] Australian Energy Market Operator, *International Review of Frequency Control Adaptation*, October 2016, page 95-105.
[12] Australian Energy Market Operator, *Future Power System Security Program Progress Report*, August 2016

disproportionate response to a minor disturbance or erroneous triggering. Demonstration and experience is needed to gain a better understanding of these technologies.

Although there are no examples of FFR being applied at scale in overseas grids, initial trials and procurement mechanisms have been put in place on some grids to draw this technology into the market. These solutions must form an integral part of the future design of Australian grids.

INTEGRATING MODERN CAPABILITIES INTO A CONVENTIONAL GRID

There are clearly opportunities to tap into new technologies that are being missed in Australia. Collectively, these opportunities and continued technological advancements show that it is not technology per se, but the failure to prepare for technological change that will impact system security.

There is currently no standard for inertia or inertia substitutes in the National Electricity Market, nor have expectations been placed on new renewable energy generators or storage technologies to provide it. In order to progress the market it is critical that market operators fully appreciate the current state of play across the existing generation fleet.

The following actions should be pursued to achieve a modern energy system that calls upon the diverse technological solutions available to support it:

1) Establish appropriate standards for frequency conditions that apply to all technologies and focus on the speed and accuracy of their contribution to arresting the change in frequency following a disturbance.

2) Accelerate trials of fast frequency response from inverter-based technologies to further prove this solution in the context of the NEM.

3) Review legacy synchronous generators and undertake testing to demonstrate the performance and capability of the fleet under high rates of change of frequency.

4) Undertake a detailed review of generator governor settings and opportunities to refine the power system's performance, while understanding and addressing the drivers that have resulted in a poorly tuned power system.

Both new and old technologies need to contribute positively towards supporting a secure energy system. These steps will address the current state of play, while tapping into the opportunities presented by an evolving power system.