D4.3i. A detailed description of the capability of STORES to provide ancillary services

Matt Stocks and Andrew Blakers
Australian National University
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Provision of ancillary services is likely to be an important part of the economics of future storage plants. As noted by Kirby (2012), "*The fast and accurate control capability available from most pumped storage plants and many hydro plants make them ideal providers of ancillary services*"

AEMO has a guide for ancillary services in the NEM that provides an overview of these services in Australia.

The existing pumped hydro facilities in Australia are typically not providing ancillary services as a major part of their operation. In the current market, pumped hydro sites are primarily used as peaking plant, generating in the early evening demand peak and pumping in the early morning demand trough. They are located in regions dominated by conventional thermal and hydro generation assets. Consequently, systems are not operating most of the time and are not providing significant ancillary services.

The histogram in Figure I shows the pumping and generating operation at five minute intervals of the Wivenhoe pumped hydro scheme in Queensland over the summer of 2017/18. In this 3 month period, a frequency of 90 would represent 100% operation at that time period. The highest usage is less than 10% for generation around 4pm and pumping at 4am with an average operation frequency of about 3.3%. In Queensland, the existing fossil fuel generation suite are dispatchable and provide most of the ancillary services.

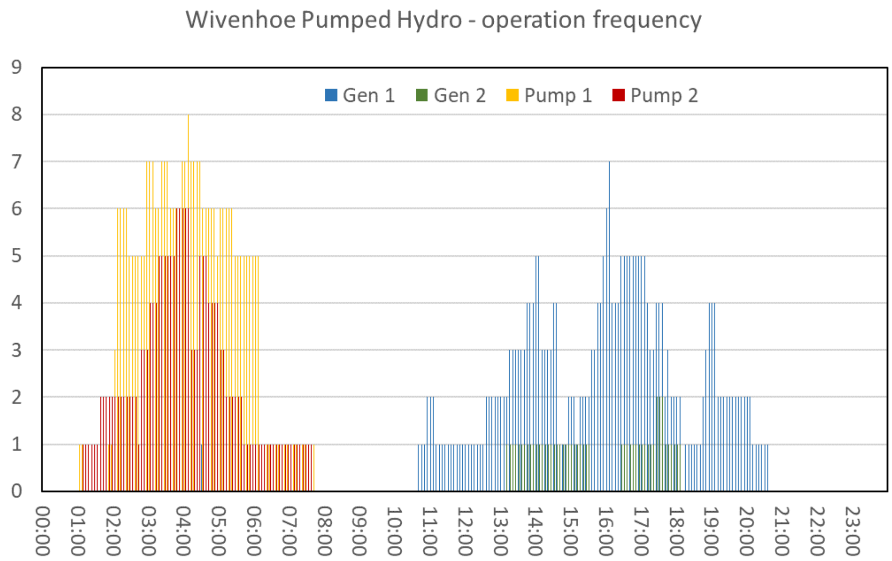

Figure I. Frequency distribution of generating and pumping operations for Wivenhoe pumped hydro for summer 2017/18. (Data from AREMI)

The situation is similar for the Shoalhaven Scheme as can be seen in figure II for the same summer period. This scheme is operated by Origin Energy in the NSW market. The scheme generates in the evening peak and pumps in the morning in a similar profile to Wivenhoe but with a higher overall usage fraction. The scheme is operation in the early evening peak (57pm) almost 50% of the time during this period. This scheme is currently not operating 75% of the time. Pumping time is greater than generating times, due to the efficiency of the pumping and the dual use of the system for water supply.

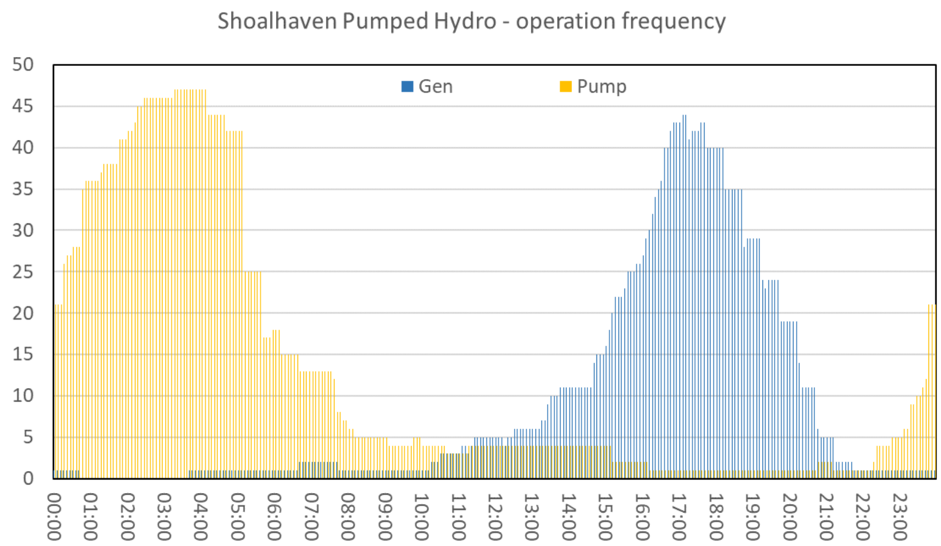

Figure II. Frequency distribution of generating and pumping operations for Shoalhaven pumped hydro for summer 2017/18. (Data from AREMI)

Currently, existing dispatchable fossil fuel provide and conventional hydro generating assets in New South Wales and Queensland provide most ancillary services. The marginal cost for providing ancillary services is low when these assets are generating. The operation of storage is likely to change significantly as the amount of dispatchable generation decreases in future. As current fossil fuel generators retire and are replaced by variable generators, the expectation is that sources of storage will need to operate at higher frequency and will be more available to provide these services.

This is highlighted in simulations by Koraitarov et al 2014. This work showed that the value of ancillary services provided by pumped hydro increased by more than 60% in a high wind scenario relative to a base renewable scenario. The importance of using advanced (variable speed) pumped hydro units due to their ability to regulate in pumping mode was also highlighted.

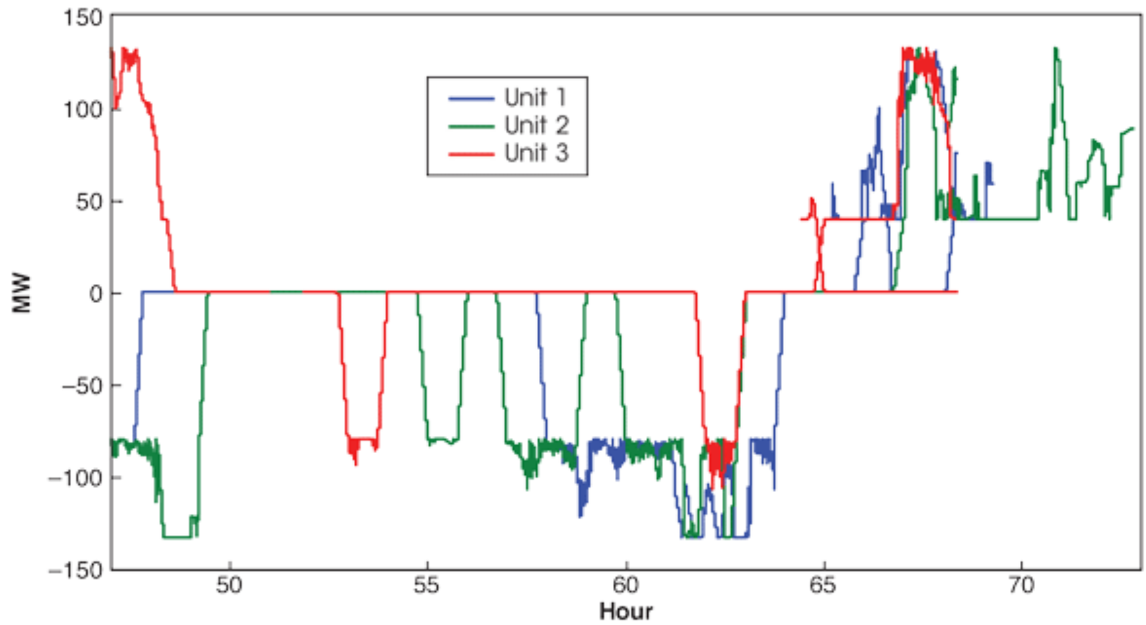

Figure III. Simulations of variable speed pumped hydro unit operation. This shows the ability of these pumped hydro units to rapidly change supply/demand and to provide ancillary services both when pumping and generating. (Koritarov 2014)

Frequency control services

The Australian electrical system is designed to operate in a tight band of frequency around 50Hz. Difference in the balance between supply and demand leads to changes in the frequency with the rate of change of frequency proportional to the size of the supply/demand difference and the rotational inertia of synchronous generators in the system.

Regulation frequency control

Regulation frequency services are the primary tool used to maintain frequency. Small deviations in the balance between supply and demand lead to variation in frequency as synchronous generators' rotational speed varies to maintain energy balance. The rate of change of frequency is inversely proportional to the amount of inertia provided by synchronous generators for a given difference between supply and demand in the system.

Generators that provide regulation services (raise or lower) respond to signals from AEMO to increase or decrease their power output on time frames of less than 6 seconds based on changes in frequency.

Wind and PV generations can provide these services but are typically not designed to be operated in this manner at present. These variable generators usually aim to provide all available energy into the network. There are several ARENA trials underway at Hornsdale and Woolnorth investigating the potential for wind farms to provide FCAS services remotely controlled by AEMO.

Output from variable speed wind farms with electronic power conversion are constrained between zero and the maximum available wind power. In order to provide *raise services*, the generator needs to be operating below maximum available power energy so that the energy supply can be increased when necessary. This is inefficient for wind and PV generators, requiring curtailment of some potential power in order to be available to provide these services. Provision of *lower services* only require reduction in power (curtailment) at the time of provision of the services. If there is no generation due to an absence of wind or sunshine, then neither of these (raise nor lower) services are available.

Pumped hydro systems, both synchronous and variable speed, can be used to provide these services when in generation mode. Generation can be rapidly adjusted through changes of water flow, provided that the system is not operating at the extreme of its operational range. For example, Dinorwig pumped hydro plant was primarily designed to provide these services and can transfer from 0MW (spinning in air) to 1320MW in less than 12 seconds. In operation, tests of Ohkawachi pumped hydro was reported to achieve changes of 32MW in 0.2 seconds and accurate achievement of power targets throughout the frequency regulation time frames.

Variable speed systems can also effectively provide these services in pumping mode. The speed of the pump can be raised or lowered leading to a corresponding change in the demand. An increase in demand is equivalent to a decrease in supply and acts as a lower service and vice versa for a decrease in demand. The earlier mentioned report on Ohkawachi pumped hydro system demonstrates that fast accurate changes in power are achievable (e.g. raise and lower of 80MW in 0.2s in pumping mode). Synchronous systems are less flexible with the pumping demand only varying with changes in frequency of the network.

Other sources of energy storage can also effectively provide these services. Batteries are very effective in achieving rapid increases or decreases in power, as demonstrated by the 100MW Tesla battery installed at the Hornsdale wind farm in South Australia. AEMO has reported the very high accuracy of the Hornsdale Power Reserve to signals from the AEMO's Automatic Generation Control in comparison to services provided by a conventional steam turbine.

Contingency frequency control

Contingency frequency control services are used to correct supply/demand imbalances after a major contingency event. These events include tripping of a major load, loss of a generator or failure of a transmission line. AEMO's planning process includes identifying the scale of a reasonable contingency events (typically loss of the largest generator and load in the system), and then procuring the contingency frequency support services to enable the system to return to stability if this event was to occur.

These services are procured based on different time frames. These are fast raise/lower (6 second), slow raise/lower (60 seconds) and delayed raise/lower (5 minutes). These different time periods reflect the response times of different generators. For example, an OCGT gas turbine can respond to requests to changes in supply much more rapidly than a thermal generating unit.

If it is already operating in generation mode, a pumped hydro plant in generating mode can provide all of these services effectively for all times frames within the limits of its generation range due to its ability to rapidly change the flow of water through the turbine).

The pumped hydro system can also be operating in spinning reserve mode. The generator is synchronised to the grid but the turbine is spinning in air (no water supplied). The turbine can then rapidly transition to full generation. As reported earlier, Dinorwig Power Station can change from 0 to 1,320 MW in 12 seconds.

Variable speed pumped hydro units can also provide raise or lower services during pumping operation with the ability to quickly and flexibly adjust the pumping demand as can be seen in figure III. Fixed speed (synchronous units) can only switch off to reduce demand to provide raise services.

Batteries can also provide these services at all these time intervals across the full range of the charging/discharging power of the system.

System Restart Services

System Restart Ancillary Services (also known as Black Start) are provided by generators which are capable of providing the initial power required to enable synchronisation of the grid.

Conventional hydro is generally considered an ideal black start generator as it requires minimum auxiliary power (usually provided by a local diesel generator) to enable the re-energisation of the local network. A hydroelectric station needs very little initial power to start (just enough to open the intake gates and provide excitation current to the generator field coils), and can put a large block of power on line very quickly to allow start-up of fossil-fuel or nuclear stations (Black Start).

The same service can be provided by pumped hydro plants in the same manner as conventional hydro plants provided that there is water remaining in the upper reservoir to enable generation.

The total value of system restart services in Australia is relatively modest at approximately $21M across the NEM as reported by AEMO in the NMAS cost report. This is not expected to change significantly in the future.

System strength

System strength is a measure of the ability of the system to remain stable in the presence of faults. Synchronous generators contribute significantly to system strength due to their ability to inject significant additional current in response to changed conditions within the network. This provides negative feedback reducing the rate of change in the system. They can also provide sufficient current to enable the triggering of protection devices in the network. However, the further these generators are from the source of the fault, the less their impact due to the impedance of the transmission network. Further explanation of the importance of system strength can be found in the ACIL Allen Renwables SA report (2016)

Batteries and other inverter based generators (e.g. PV and most wind generators and variable speed pumped hydro) are not effective at providing system strength. These systems rely on monitoring the voltage in the external system and injecting power in response to the characteristics of the network at the point of connection. In the presence of a significant system fault, inverter based systems are limited in the amount of current they can supply to the network without damage. Generation from non-synchronous sources is growing rapidly in the National Electricity Market (NEM). South Australia (SA) currently has 1,700 megawatts (MW) of non-synchronous generation registered (currently all wind generation), which is above SA's average operational demand (from AEMO 2017).

Unlike batteries, synchronous pumped hydro storage systems can provide system strength. This may be particularly important in regions like northern South Australia where closure of synchronous generators (e.g. Northern Power Station) and increasing wind and PV generation are reducing system strength. Electranet are looking to install synchronous condensors in South Australia to improve system strength, a service that could instead be provided by the various pumped hydro announcements in South Australia.

Network Support Ancillary Services

There are a range of other ancillary services which are used to manage the network. These can be provided by pumped hydro systems when operating in synchronous condenser mode. The generator is synchronised to the network but the turbine spins in air (no water flow). In this mode, the generator can absorb reactive power to improve the local power factor. This helps to maintain voltage and reduce impedance loss in the network.

The need for this service is highly location specific and dependent on the topology of the network.

Economics

The value of the ancillary services that pumped hydro can provide is beyond the scope of this work and will depend on accurate modelling of the system.

Modelling of a 100MW plant in the US by Kirby (2012) indicated that optimised operation of a pumped hydro plant could provide significant ancillary service revenue. The revenue of the plant was derived from the plant selling up to 100 MW energy while generating, sell 51 MW of energy and 49 MW of spinning reserve, sell 76 MW of energy and 12 MW of + and – regulation, or a combination of the above. Non-spinning reserve could be sold when the plant was not generating or pumping. Sale of ancillary services during pumping was not modelled since most current pumped storage plants (synchronous) have limited flexibility to control the pumping load. This work indicated that ancillary services would generate 25% of its revenue.

As mentioned earlier, Koraitarov et al 2014 showed that the importance of ancillary services increases as the amount of variable generation (wind and PV) increases. Given the long pumped hydro asset life, future changes in the system will need to be considered when valuing the ancillary service value of a pumped hydro asset.

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