Project Plan - Advancing Renewables Program

Integrating energy storage into the NEM: Market design, dispatch and ancillary markets.

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Project Summary

Electricity storage on large scale is nothing short of revolutionary; it is the perfect, and very timely, complement to intermittently available renewable energy generation. The deployment of storage is therefore also the bottleneck to further penetration of variable renewable energy (VRE). Storage enhances the value of VRE assets, which are thus far non-dispatchable. In the short to medium run, storage is the key to better use currently installed VRE assets and to connecting more VRE assets to the grid. In the longer term it is essential to building more VRE generation capacity, to making Renewable Energy Zones a working reality and to realising the energy transition. While full of promise, storage also entails plenty of challenges. Chief among these is a set of market rules that is not conducive of viable investment in storage, and thus on two accounts. First, the spot-only nature of the NEM precludes the systematic intertemporal price arbitrage a day-ahead market can afford market participants. There is empirical evidence in all US markets of systematic price difference between off-peak and peak demand periods, which are exactly the source of revenue necessary to sustained deep storage (of long duration).1 Correcting this deficiency is key to foster investment in deep storage, without which a transition to VRE generation on a large scale is impossible to achieve. Second, storage allows for the use of dynamic strategies in buying and selling energy, which bidding and dispatch rules must account for in order to send the correct price signals to market participants and investors. In addition, there is a distinct risk of market manipulation. Beyond market rules, dispatching storage units in the energy market must also be amended to account for this new, dynamic behaviour. Storage is expected to play a critical role in ancillary services, old (FCAS) and new (synthetic inertia), but the details are hazy and some of these markets do not exist yet. Finally, because storage is attractive to so many market participants (arbitrageurs, generators, network services) it may reshape the industrial organisation of the electricity sector, with consequences in terms of competition policy. This project intends to study the problem of storage integration into the NEM under the lens of economics. It will assist in designing the correct incentives for storage operators competing in the market, and by extension, for investment in storage. It will deliver an updated dispatch algorithm to account for the (new) behaviour of storage as it becomes an increasingly important player in the NEM. It will also develop a new method to value new services that may be supplied by storage operators. In doing so it will contribute to increasing the penetration of renewable energy in the NEM, whose essential challenges remain intermittency and grid stability. This project is important to the success of Australia's energy transition, to emissions reduction and to further the penetration of renewable energy in the grid. There is no large-scale transition without a sizeable storage capacity; that storage capacity cannot be invested in without the correct incentives, and the current NEM market rules do not produce the right incentives. Furthermore, additional investment in VRE capacity without storage will only reduce the value of all VRE assets as prices fall when they can generate. Therefore this project is strongly aligned with ARENA's investment priorities, and it supports its mandate to facilitate the deployment of renewable energy sources. Like all studies, this project is neither a policy formulation nor a prescription. Rather it seeks to inform policy makers (such as the AEMC and AEMO) and market participants in their efforts to foster the emergence of storage and to further VRE penetration.

Deliverables	1. A manipulation-proof market design solution that specifically account for storage in the energy market 2. A dispatch rule that accounts for the dynamic strategies of storage 3. A method to value synthetic inertia, formulate a demand for inertia and a suitable market design 4. An analysis of the competitive landscape with storage, with recommendations to guide storage investments and acquisitions
Duration	Two Years
Alignment	The project strongly aligns with ARENA investment objectives as it increases the capacity of the grid to *efficiently* integrate more renewable energy production capacity by solving the intermittency problem.
Partners	Monash University, AEMO and Grid Innovation Hub (GIH)
Audience	AEMO, AEMC, AER, Market Participants (storage operators, generators, loads, consumer organizations).

Project Outline

The project comprises four essential areas of work: understanding storage behaviour and designing bidding, clearing and settlement rules for storage; dispatching a market with storage; new services with storage and understanding the industrial organization of a market with storage. Throughout this description remains agnostic as to technology; instead it is concerned with the problem of incentive provision in the operation of storage units. It may be helpful to first clarify what is meant by "bidding, clearing and settlement rules". At an abstract level, these consist of three sets of rules: an allocation rule, a pricing rule and an exclusion rule. In the current design of the NEM, the allocation rule is given by the merit order (modulo dispatch constraints) and is applied by clearing the market every five minutes, the pricing rule is simply the uniform clearing price and the exclusion rule states that one must be a registered participant. This approach has served consumers and suppliers reasonably well until recently, but it needs significant adjustments to the allocation rule and the pricing rule with the rise of storage. Storage behaves differently from standard generators and loads in many ways – starting with the fact it can be either at the same time. The most salient features of storage, regardless of the technology it uses (battery, pumped hydro or any other) are twofold. First, by its very nature it employs dynamic strategies. Concretely this means that choices (to charge or discharge) in the current pricing interval have consequences for the choices available in the next pricing interval; therefore the sequence of actions of storage operators are linked over time. It is easy to see that a battery that is drained at time t cannot sell more energy at t + 1 (but may buy energy). This is not true of a conventional generator (nor load), especially not VRE. Furthermore, finding the optimal sequence of charge and discharge in a highly volatile environment can be very challenging. Second, storage needs arbitrage. While a generator prefers selling at higher than lower prices, a storage operator must buy low and sell high to exist. Devising market rules is agnostic as to the engineering environment, which it can internalize as a constraint. For example, if the market operator (AEMO) determines a minimum level of inertia is required, this threshold can be introduced as constraint, just like transmission line capacity can be internalised as linear constraint in the dispatch. Thus models that we may develop can be parametrized by, or made subject to, a necessary level of inertia or system strength. As the environment changes these parameters, or constraints, can be modified. The result(s) may change, of course, but not the model. This makes for a robust analysis.

Area 1. Understanding storage and market design for storage

The current approach in the NEM is deficient when it comes to storage on two accounts: first, there is no day-ahead market and second, clearing is myopic. This part of the project seeks to find the best possible clearing and settlement rules when storage is a non-trivial player in the market.

Day ahead market. The NEM operates as a spot market only; the distribution of future prices can be forecast with varying degrees of accuracy but is always uncertain. A day-ahead market affords storage, in particular deep storage, opportunities to operate that a spot market cannot offer. In a day-ahead market a schedule based on prior-day bids is binding. Therefore it delivers a day-ahead price path and a day-ahead supply path that are committed to.2 Hence price differences become not just predictable, but known with complete certainty. In the United States, where all markets operate as day-ahead plus balancing markets, it is documented that every day of the year, the price difference between the through and the peak in the day-ahead market is strictly positive (Wolak, 2019). The figure below depicts the distributions of these price differences; there are no occurrence of negative price differences in the day-ahead market, but some in the real-time (balancing) market. In other words, there exist systematic inter-temporal arbitrage opportunities in the day-ahead market, which deep storage can readily exploit. These arbitrage opportunities are the source of revenue necessary to induce investment in these assets. Creating them only requires changing settlement rules – from spot only to day-ahead plus balancing. The investment is very small compared to the large returns it may induce in that it render deep storage viable under a short horizon. The direction of the market failure is quite obvious here, and more a matter of documentation than research. Because the spot market fails to deliver these systematic price differences, it provides insufficient opportunities for investment in (deep) storage, which in turn curtails further investment in renewable capacity.

Myopic clearing. In the current incarnation of the NEM, the merit order is applied (modulo dispatch constraints) to clear the market taking into account the current bids only – that is, discarding the fact that the actions of storage operators are linked over time. This myopic design is wholly inadequate when market participants use dynamic strategies. If starting from scratch, a market designer would devise a different clearing rule.

Not using the best clearing rule induces a market failure in the sense that social welfare can be improved precisely by modifying the clearing rule. In other words, by using a suboptimal clearing rule the market operator does not minimize system costs over time. As alluded two in Section 2, the source of this market failure lies in the fact that the current myopic clearing is oblivious to the future behaviour of the market participants. It may also preclude the market operator from accessing services, such as reliability services, in the future because that capacity has already been used. Using a more sophisticated approach, this behaviour can be anticipated by a market operator. Given a forecast environment, the combination of the current state of charge of a storage unit and of the current bid conveys sufficient information to estimate its future actions. It is possible precisely because these actions are linked over time – that is, they cannot be arbitrary. This information should be used by the market operator to decide whether to accept a bid and dispatch a storage unit, precisely because dispatching (or not) a unit at t defines what is feasible at t + 1 for the operator too.

This market failure may induce too little or too much investment in storage. In either case market participants are made worse off: with insufficient storage capacity there is insufficient price smoothing, peak prices are too high for consumers and off-peak prices too low for VRE producers, volatility remains large and the bottleneck for VRE remains. In addition, insufficient storage capacity may result in inefficiently frequent blackout. With excessive storage there is insufficient spread between peak and off-peak prices to remunerate the investment in storage, and so capital investment is wasted. We note that insufficient storage capacity and insufficient competition in storage is the more likely outcome if staying with the current design; the reason is that ignoring the future behaviour of market participants leaves them more opportunities to behave strategically and exert their market power. The consequence is then lower returns to VRE generators, and therefore lower investment in VRE. Here too, correcting the market failure is both feasible and inexpensive; it requires minimal investment and mostly some research. Implementing the correct clearing rule is the necessary ingredient to send investors the correct price signals to guide their decisions. While day-ahead markets are well known, the details of a day-ahead market with storage are not. This part of the project will investigate exactly these details, and in particular how the day-ahead and the spot balancing market co-exist. This aspect is particularly important to induce the correct balance between long-term storage, which mostly relies on the day-ahead market for revenue, and short-term storage, which mostly relies on the balancing market for revenue.

Market manipulation. The dynamic nature of storage trading strategies also creates new opportunities for market manipulation that a market operator should reasonably anticipate. In peak demand time storage units can not only exert market power, it is easy to anticipate they can abuse it in the many ways; here are two examples. **Example 1: intertemporal capacity choices.** Storage operators can control their available capacity at peak time. To do this, they can decide to not (fully) charge up before the peak and sell their curtailed capacity at inflated prices during the peak; the very fact they have less to sell increases the clearing price. The converse is also possible when storage buys energy, so that prices remain depressed. This is not true of conventional generation, whose capacity is installed and (almost) always available, and therefore the temptation to use it always present. Instead, emptying a storage unit is a commitment to not use it. Likewise, conventional loads, such as households, commercial loads and some industrial processes, typically cannot delay their purchase. **Example 2. Storage operators can easily manipulate prices.** Take two storage units wanting to sell; one bids a small quantity to sell while the other one makes aggressive bids to buy. The price effect increases prices to all participants. When the price is sufficiently high, they can sell. This kind of strategy is common on securities markets and rests on the fact that storage units can build inventory. Conventional generators and loads cannot do this; in addition, generators and loads sit on either side of the market, while storage units may be on the same side – hence have the same incentives to manipulate the market in the same direction.

Area 2. Clearing and dispatching a market with storage

The dispatch algorithm must reflect the market clearing rule and the settlement rule. Dispatching a day-ahead schedule is common in US markets, however dispatching storage units that employ dynamic strategies cannot be achieved using the current dispatch engine (NEMDE), which is a linear programming engine. Instead, we suggest NEMDE should be modified on two account: 1) to reflect the day-ahead settlement and 2) to internalise these dynamic strategies by adopting an approach based on dynamic programming, rather than linear programming. A new dispatch algorithm must be designed for this task, and a new numerical implementation must be created. This is essentially a problem of mathematics and computer science. The computational burden may be very large but tremendous progress has been made in the numerical implementation of stochastic games. The goal is not just to find a solution to this problem, but to also develop a numerical implementation that is fast enough to be practical.

Area 3. New services with storage

Most of this proposal is concerned with the use of storage in the energy market. However it is not the only market that may be served by storage. At present, storage is used primarily in the FCAS market, but this market is rapidly nearing saturation. It may be important, especially in a transition phase, to develop other (new) markets in which storage can play a role in order to spur investment in storage capacity. This is particularly important as the physical inertia of the NEM declines with each conventional generator retiring. If inertia becomes too low, additional VRE integration is compromised. Synthetic inertia is already identified as a new service that can be supplied by batteries thanks to their rapid response. Inertia, in particular synthetic inertia, is of great concern to AEMO, which is closely monitoring the stability of the grid. It is also of importance to the AEMC for two reasons. First, it is a complement to the further integration of renewable capacity in the NEM. Second, it is a complement to the more extensive use of the existing interconnector capacity (between States), which are conservatively constrained at the moment. Better use of the interconnector capacity benefits VRE producers, and therefore their investors, who can sell more of their cheap energy to large demand centres across (State) borders – for example, from solar farms in Queensland to Sydney. Finally, we know from recent experience with the Callide incident, that synthetic inertia responds well and effectively. During that incident the Hornsdale Power Reserve successfully supplied virtual inertia responses. Conceiving of a market for (synthetic) inertia first requires valuing inertia (mapping inertia into tradable units) and then devising a market design to supply synthetic inertia services, noting that this market is obviously linked to the energy market. It is not enough to just copy what is currently done with the FCAS market, for there is no proper demand side of FCAS. Valuing services and constructing demand function is the bread and butter of economists, and this team is particularly well placed to perform this work. At a conceptual level, the value of one unit of inertia (which can be readily measured on a grid) is its price impact: if adding inertia allows more VRE to be traded over the inter-State connectors and decrease the clearing price in a pricing zone, its value is the price difference over the total energy traded. These gains may be large, but are not currently realised because procuring inertia services is not yet feasible. The demand for inertia is then the difference between the level of inertia available and the level of inertia required to target a price reduction. This leg of the project will deliver a precise method to value (synthetic) inertia, and other services, construct a demand function for (synthetic) inertia and suggest a market design to address this demand at lowest possible cost. It will take into account the connection to the energy market and the FCAS market in order to provide the correct balance of incentives between supplying inertia and supplying energy.

Area 4. Industrial organization with storage

Because of large returns to scale, the electricity generation sector is highly concentrated. The benefit of this concentration is a low average cost to deliver energy, but its downside is that generators routinely exercise their significant unilateral market power. Whether storage features significant returns to scale depends on the technology. Pumped hydro likely is an increasing-returns-to-scale technology. Batteries do not possess significant returns to scale – the developer adds battery packs to increase size. So there is no social benefit to large battery units: increasing size does not lower average costs. However the risk of exercising unilateral market power remains. We know from the work of Andres-Cerezo and Fabra (2020) that letting storage operators hold market power – which has no social benefit here – leads to underinvestment in storage, so in lower VRE penetration in the long run because too much of their energy is spilled. This area of work will study this, and other, problems in the details necessary for the competition authorities to be informed. It will also study the problems arising from owning multiple batteries; it should be intuitive to see that the sole owner of multiple batteries can easily engage in market manipulation, such as coordinating capacity levels to drive prices up or down. It will also investigate whether batteries and other assets such as solar farms should be jointly owned (vertical integration) or separated. Finally, because storage is also attractive to manage congestion on networks, this area will also revisit the structural separation between NSPs and energy supply. What are the consequence of allowing NSPs to invest in storage units? Does the structural separation need to be maintained? If mandating so, a third party may own and operate (a) storage unit(s) on the network, which may create local monopolies at certain nodes. Then what is the remedy? The AEMC is particularly interested in these questions, which go to the core of the construction of the NEM.

References

This bibliography is far from exhaustive. It lists only the relevant literature on storage as well as a minute sample recent publications on combinatorial approaches to market design.

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