A simple introduction to the economics of storage: shifting demand and supply over time and space

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David Newbery

The electricity system has to balance supply and demand every second, a task that becomes increasingly difficult as intermittent renewables increases its penetration and the amount of inertia on the system falls. Wind and solar PV can be both highly variable over time periods of a day and hard to forecast accurately more than a few hours ahead, making storage appear increasingly attractive as a key element in an electricity system. Much of the discussion of electrical energy storage (EES) is highly technical, reporting the results from small model networks or individual experiments, and published in electrical engineering journals. More ambitious attempts at forecasting EES requirements or optimal EES volumes summarise the results of complex simulation/optimal dispatch models at a rather high level (e.g. the demand for and potential savings afforded by generic storage devices of given costs and storage/output ratios).

This paper takes a bottom-up approach to compare the likely ranges of costs and benefits of different solutions to the various problems facing the evolving electricity system. It describes the relevant characteristics of different solutions to balancing supply and demand with high levels of intermittent generation, their costs and value, as well as constraints on their supply. It draws on day-ahead and balancing market price data to assess the arbitrage benefits of EES, comparing that with alternatives such as back-up generation and interconnection, to give a sense of the role that EES might play in an integrated system.

The benefits of storing currently excess or very cheap electricity for later more valuable use is not new. As Britain (and other countries) developed significant shares of nuclear power, it became clear that the opportunity cost of that power in periods of excess supply, usually at night, was zero (or negative, if costs would be incurred in shutting down and restarting), while later in the day high variable cost power would be called on to meet peak demands. Storage was an obvious method of shifting surplus supply to later periods, and many pumped (hydro) storage plants, or PSPs, like Dinorwig in Wales, were built to allow nuclear power to continue to run at full output at essentially zero variable cost for later use.

More recently, rapid falls in the cost of batteries have raised hopes that chemical rather than water storage offers a new and attractive storage option. Batteries are typically of modest size (10 MW) and likely to be connected to distribution networks, where improved network management (smart grids) allows them to realise a variety of services locally and to the national grid. Smart metering also offers the prospect of accessing smaller decentralised EES units, for example that embodied in Battery Electric Vehicles (BEVs), which are projected to increase their penetration as battery costs fall.

The overwhelming (99%) share of conventionally defined EES is provided by pumped storage plants (PSPs), in which water is pumped to an upper reservoir from which it can be released through turbines to generate electricity when needed. Apart from the scarcity of suitable sites, the main drawback of PSPs is that potential or gravitational energy is remarkable weak compared to chemical energy. Thus the energy contained in 1 litre of gasoline is the same as 7 tonnes of water raised 500 meters (Dinorwig has a head of around 500 meters). Even the lowly AA battery has the same energy as 100 kg raised 10 meters.

World PSP operating output capacity in 2016 was 164 GW. Data on storage capacity is incomplete but for the 45 GW of PSPs for which capacity is available, total storage is 1.7 TWh (although the top four by capacity have 75% of this total and a very low output, corresponding more to storage hydro). The other PSPs have 10.9 hrs, duration so if this is representative of the remaining PSPs, the total global storage capacity is 2.9 TWh (compared to roughly 70 TWh in dams in Norway alone). Germany, for example, has 6.8 GW output capacity and stores 50 GWh, or 7.4 hrs on average while Britain with 2.86 GW output stores 26.7 GWh, or 9.3 hrs (the range over the four PSPs is from 3.6-25 hrs).

World hydro capacity in 2012 was 979 GW, generating 3,288 TWh/yr or 16% of world total electricity output at a capacity factor of 38%. Again, data on its storage capacity is not readily available, but assuming the capacity factor is related to storage capacity as in Norway, the capacity would be 3.7 months. At 3 months, storage capacity would be 2,144 TWh, or 2,700 times the global PSP capacity. Ignoring hydro capacity, PSP comprises 99.7% of world electrical energy storage and electro-chemical (dedicated) storage only 0.1%.

PSP costs are very site specific and the more attractive range from £50-250/kWh capacity, giving overhead costs of £30-80/MWh delivered, to which must be added the cost of purchasing power. Batteries are considerably more expensive per unit of capacity and even 2020 low-end forecast costs are $390/kWh for Lithium-ion,

$420/kWh for sodium-sulphur batteries. Their much shorter cycle life gives overhead costs even at 2020 low forecast costs at $175/MWh (Li-ion) or $260/MWh (Na-S), again excluding electricity purchase costs.

Balancing demand and supply can also be achieved by exporting surpluses and importing deficits over interconnectors, or by having back-up flexible generation. Interrupting the charging of electric vehicles, or delaying the use of stored hydro-power in dams can be far cheaper than putting power into EES for later use.

In conclusion, storage for the high tension grids appears expensive compared to alternatives such as spilling wind in surplus and providing peaking plant for shortfalls, unless it can sell other ancillary services of sufficient value. DC Interconnectors can provide similar functions and can also deliver flexibility services, while their ability to continue to deliver for lengthy periods gives them (and peaking generation) an additional edge. Batteries may be very useful when strategically deployed in distribution networks where expansion can be very costly and disruptive. Widening the range of demand-side responses increases potential competition to network-provided storage – and indeed EVs offer the potential through the smart timing of charging to gain some of the same benefits of storage without actually having to make use of the battery as a source of network storage. This underlines the importance of indirect storage, where interconnectors can provide access to Norwegian storage hydro for European electricity systems.

Contact dmgn@cam.ac.uk
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