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Energy Storage

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Introduction: Use cases and user requirements for energy storage

With the emergence of variable renewable energy (VRE) sources, such as solar photovoltaics (PV) and wind power, flexibility requirements in the power system are generally increasing. However, what is not so clear yet is what "increasing flexibility requirements" actually means. In order to develop the appropriate technical solutions, it is important to first understand and differentiate between the different types of use cases from which flexibility requirements arise.

In electricity systems, the following use cases for electricity storage can be identified:

Use case	Voltage level[1]	Description
1. System-level cost/price arbitrage	TS	Storing electricity when the marginal cost of power generation is low (off-peak) and discharging when the marginal cost of power generation is high (peak periods). This is the typical use case for pumped storage schemes.
2. Balancing power *(frequency control)*	TS, DS, LV	Short-term compensating for surplus generation (negative balancing, charging) and for surplus load (positive balancing, discharging). Today, this ancillary service is supplied typically by the conventional fleet (coal and gas).
3. Power quality *(voltage- & current-quality control)*	DS	Storage as a tool in the toolkit of distribution system operators, in order to improve local power quality and local grid congestion
4. Provision of black-start	TS, DS	Utilising storage to restart a power system after a total blackout. This use case is typically supplied by diesel-fired engine-based generators and by smaller gas turbines.
5. Island and off-grid storage	DS, LV	Utilising storage to augment VRE in island and off-grid situations. The storage provides the "firm capacity", potentially in combination with conventional generators (e.g. diesel).
6. T&D deferral	TS, DS	Utilising storage in a situation where the existing grid's capacity is not enough to supply the peak demand in a certain grid area (or to evacuate the peak power supply from distributed VRE).
7. Industrial peak shaving	DS, LV	Storage used to provide power during peak periods in order to avoid penalties for exceeding the contractual peak demand.
8. Self-consumption optimisation	LV	This involves storage by residential and commercial users primarily for self-consumption, typically to increase the self-consumption ratio of own-produced solar PV energy. This use case is very similar to use case 1, just that it takes the arbitrage view of individual customers rather than that of the system.
9. Security of supply	DS, LV	To avoid load shedding for customers or for certain areas.

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[1] TS = transmission system; DS = distribution system; LV = low voltage

Public discussion around energy storage and around batteries specifically often refers implicitly to use case 1, in combination with cheap solar power. However this is the least attractive use case for batteries as they compete with other power generators to provide the power during peak periods. Batteries are in essence power generators with the fuel being electricity –compared to gas-fired power stations for which the fuel is gas. For use case 1, the competition is between charging batteries during daytime to discharge after sunset, and gas-fired power stations that kick in when the solar PV fleet stops producing power. In order to be a cost-efficient fuel saver for a gas-fired power station (fuel-cost component: 1.1 R/kWh), the investment cost of a Li-ion battery has to drop below R 1,250 per kWh of useful storage capacity.

From a use case 1 perspective, VRE do not require a significant investment into electricity storage. Use cases 2 and 3 can be relevant for electricity storage and specifically for batteries, because of their excellent dynamic behaviour and their ability to switch between charge/discharge (load/generator) with a very short timeframe. These two use cases underlie the large grid-connected investments in batteries observed in Europe and the US.

Large grid-connected batteries are often used in conjunction with VRE for use cases 2 and 3; they are used worldwide, including in the USA, Europe and Japan. However, batteries are not a technically necessary condition for high VRE penetration. Spain has a wind fleet of 23 GW at a system peak of 44 GW, supplying more than 20% of the total annual electricity demand, and no significant battery storage. Spain has however a hydro and gas fleet to balance fluctuations from the wind fleet. For use case 1, storage solutions for which power and energy-storage capacity can be dimensioned independently of each other (e.g. pumped and hydrogen storage, flow batteries) provide the best economics because of the large amounts of energy that need to be shifted in time at relatively low power capacities.

From a power-system perspective (i.e. use cases 1, 2 and 3) the inherent volatility of solar PV and wind supply is managed most cost-efficiently when:

1. Widespread spatial aggregation of both solar PV and wind leads to significant reduction of short- and medium-term volatility of both power sources (i.e. spatial distribution of solar PV and wind generators across the country and region, all connected to the same interconnected grid). This is the easiest and cheapest way of reducing fluctuations of solar- and wind-based power generation; this applies mostly to use case 1.
2. Remaining fluctuations can be managed by flexible conventional power generators (e.g. gas-fired engines, gas turbines, combined-cycle gas turbines, pumped storage). These generators are both technically flexible (fast ramp rates, good grey- and black-start capability, low min-load requirements), as well as economically flexible; their cost structure is capital-light and more fuel-heavy; this also applies mostly to use case 1.
3. In the next stage of absorbing volatility from solar PV and wind, one would bring flexible, non-essential (i.e. dispatchable / shiftable) loads into the picture; this applies mostly to use cases 2 and 3.
4. An additional mean to manage short-term fluctuations (use case 2 and 3) is needed or in cases with very high penetration of renewables and related “overshoots” of supply (use case 1), energy storage in form of batteries will be a viable option. Currently, batteries for use case 1 are still the most expensive of all the mentioned means. For use cases 2 and 3 they already start making economic sense.

Trends in technical solutions for Electrical Energy Storage

The Energy Storage (ES) market and the demand for cost effective technological solutions are drivers. Electric Energy Storage (EES) is the capability of storing electricity or energy to produce electricity and releasing it for use during other periods when its utilisation is more beneficial. EES is however requires bulky, costly equipment.

There is a large variety of ES technical solutions including various form of energy including potential-, kinetic-, chemical (including electrochemical), electrostatic, magnetic-and thermal- energy as shown in Figure 1. When establishing the viability of an energy storage technology two categories should be considered:

1. Technical viability, which includes energy density (kWh/kg or m^3), power-density (kW/kg or m^3) and response time (s), reliability, self-discharge rates and
2. Economic viability which is determined by:
   - Capital cost (materials and construction, Rand per useful kWh),
   - Operational cost (Rand per useful kWh per year)
   - Interest rates
   - Operational life time (cycle life and calendar life)
   - Round Trip Efficiency including self-discharge
   - Scalability (Batteries scale different than pumped hydro stations)

Viability of each storage technology is changing constantly as new and more effective designs, production methods and materials are developed that decrease construction cost and increase the operational lifetime and efficiencies. Simultaneously, viability is strongly related to the use case. There is a high degree of variance in technological and economic battery data, as schematically represented by Figure 2

In commercial arena, the most recent developments in EES are in electrochemical storage, singling out Li-ion batteries and Vanadium Redox flow batteries, while power-to-gas/-fuels (electrolysis of water into hydrogen and subsequent methanisation or synthetisation of liquid fuels) offers an interesting link between the electricity and the transport sector. Batteries consisting of abundant low cost materials drive R&D for grid scale storage, specifically metal air, molten-salt thermal energy storage, Na-ion (Aquion) and Na-MetalHalide batteries.

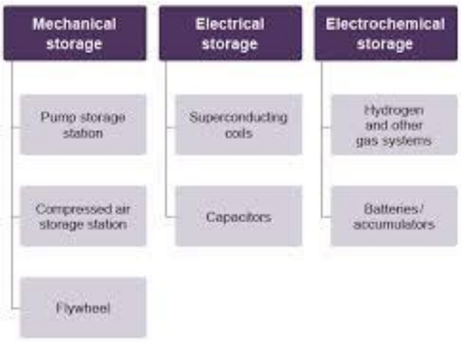

Figure 1

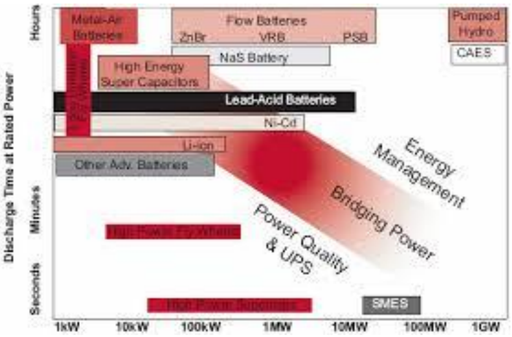

Figure 2

Matching use cases with technologies

Batteries

The business case for relative expensive batteries today lies in the combination of services they can provide, for example ancillary services like balancing power (use case 2) to deal with short-term imbalances of supply and demand, and/or for managing local grid congestion problems (use case 3), and/or for peak-shaving for commercial/industrial customers (use case 7). Batteries also play a role in the residential market (use cases 8 and 9); however the market forces to drive this segment are different from those of a pure system-optimising central planner. In off-grid situations (use case 5), batteries will be an important tool in the toolbox of system designers – together with primary energy providers solar PV, wind, biogas and potentially backup through diesel-based generators. Outside the electricity sector, eMobility will largely drive the demand for battery storage.

Power-to-Fuel (via H2)

With declining electricity costs (from solar PV and wind), producing carbon-neutral, synthetic fuels from these cheap VRE will become increasingly attractive over the next decade. One example is in the EU, where synthetic fuels from renewables are now counting towards the mandatory bio-blending requirements for diesel and petrol. As electrolysers are very flexible loads, they can contribute to system-cost arbitrage and balancing power (use cases 1 and 2). Power-to-Fuel is, together with eMobility, the connector between the historically separated electricity and transport sector.

Challenge Questions

- What will drive the future battery market?
- Is energy storage a necessary condition for a large uptake of VRE in South Africa?
- Will solar PV and batteries be the only components of the future power system?
- What impact would a steep cost reduction of utility scale batteries have on the energy mix?
- What are the major barriers to the uptake of battery storage for various applications?