Prospects for Large-Scale Energy Storage in Decarbonised Power Grids

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Summary of Key Points

This paper focuses on the potential role that large-scale energy storage systems can play in future power systems. The starting point and basis for simulations is the Energy Technology Perspectives 2008 (ETP) BLUE scenario for power supply (IEA, 2008). According to the scenario, increased use of renewable energy and nuclear technologies can play an important role in reducing CO_2 emissions dramatically in the power sector. Through the increased use of these technologies, the use of fossil fuel powered plants, and consequent CO_2 emissions, will be reduced. Wind power and solar power provides 12% and 11% of global electricity generation by 2050 in the BLUE Map scenario. Variable output renewable technologies such as wind and solar are not dispatchable. With large shares of these technologies, steps would need to be taken to ensure the continued reliable supply of electricity.

While related issues include voltage and frequency variations, inter alia, this report focuses on frequency stability. Constant balance of demand and supply is essential to achieve this, and, in the majority of today's power systems, mid load technologies such as coal and gas and in some cases hydro, play the chief role in this regard. The main focus of this paper is to investigate the storage growth and total global storage capacity needed between 2010 and 2050, to assist in the balancing of power systems with large shares of variable renewables.

Variable renewable energies are associated with weather-related power output variations, which consist of short term variations on a scale of seconds to several minutes, superimposed on long term variation on the scale of several hours. Frequency change depends on the short-term variation, therefore this report focuses on short-term variations.

Although the output of individual wind or solar plants can vary considerably, wide geographical dispersal of wind power and PV plants reduces the net variation of many plants as seen by the system as a whole. The net output variation of renewables is an important parameter in this analysis. To date, the impact of this smoothing effect varies from region to region. If the outputs of individual wind and PV plants are uncorrelated, the extent of variation decreases with the inverse square root of the overall number of plants. On the other hand, over relatively small areas with large numbers of wind and PV plants, plants may show strong correlation with each other. In such situations a significant net variation will remain.

The extent to which a power system can accommodate variations in supply is governed to a large extent by its flexibility – a measure of how fast and how much the system can quickly increase or decrease supply or demand, to maintain balance at all times. A range of measures exist to increase the flexibility of power systems, and thus the extent to which they can accommodate variable renewables. This paper looks at one of these measures – storage.

Another option is to interconnect among adjacent power systems. For instance, in Western Europe (WEU), interconnected power grid and electricity trading play an important role.

Flexible power plants such as gas and hydro can act as reserves to provide for deficits in wind power generation across the interconnected area, while at the same time the geographic smoothing effect is increased because the total area is larger. At present, in Denmark, where the average share of wind power is approximately 20%, effective balancing of supply and demand is facilitated through electricity trade with other Scandinavian countries.

However, taking for example a cluster of interconnected systems lying under a single weather system, all with a high share of variable renewables, trade of electricity may not be relied upon for fast access to additional electricity during low wind / solar periods, nor to dispose of surpluses, because deficits and surpluses among all such systems will coincide to a large extent. Moreover, reduced flexible power plant capacity over the entire region in 2050, due to partial displacement by renewables and nuclear, as seen in the BLUE Scenario, may lead to a lack of flexible reserves. To provide for such cases, internal solutions are needed to be in place. Balance will not be maintained by interconnectors alone, and system designers and operators should look at additional measures such as energy storage, as well as load leveling and plug-in electric vehicles (the latter are not the focus here).

By way of illustration, the analysis estimated the required capacity of energy storage in WEU. Recent measurements of wind power variation in WEU show that the maximum net variability over 10-15 minutes is 6-12% and the average variability is perhaps 20-30% of that value. The analysis shows that if a 5% net variation were to be maintained then even at the high wind and solar shares projected for 2050 under the ETP BLUE scenario, no energy storage capacity would be required in the WEU. However, in areas in which the smoothing effect is limited, net output variation larger than 5% would be seen in some parts of WEU. Simulations of wind power variation levels between 5% and 30% yield estimates of energy storage capacity in the WEU ranging from 0GW to 90GW in 2050. The balance between the demand and the supply was calculated for every 0.1 hr (i.e., 6 minutes). To estimate energy storage worldwide, net variations were assumed as 15% and 30%. Simulations undertaken suggest that worldwide energy storage capacity ranging from 189GW to 305GW would be required. Under smaller variations, the capacity will decrease as in the WEU case. Rather than specific numerical values, it is the relative amounts of storage against net variability that is most important. Therefore high quality assessment of the net variation, taking into account the output of power plants across the entire system as well as demand variation, is fundamental to accurate identification of required storage capacities.

As mentioned above, as each storage system has different specifications, the optimal arrangement of these systems depends on circumstances in individual countries. In Annex 1, the current technical potential of NaS cells, pumped hydro, redox flow cells, Compressed Air Energy Storage (CAES), electric double-layer capacitors, Li-ion batteries, Superconducting Magnetic Energy Storage (SMES) and flywheel systems is reviewed. Reducing costs of such storage technologies may be a key to expanding the use of energy storage technologies to keep pace with the growth of variable renewables.