FOSSIL FUEL-BASED ENERGY STORAGE

As the penetration of variable renewable energy (VRE) such as solar and wind power increases, energy storage is needed for the successful development of a resilient and flexible electricity network. Energy storage systems can provide services to support the grid and address some of the new challenges that increasing VRE introduces into the power system. There has been a significant increase in the application of utility-scale energy storage systems in many regions. This fast growth rate of the deployment of grid storage is set to continue. Total global installed energy storage capacity was about 186.1 GW in 2020.

Energy storage can operate as a standalone system or be co-located with power generation facilities. There is an option with coal power plants to integrate a storage system with generating units to obtain some operational advantages and benefits such as improved flexibility. Integration with energy storage could also eliminate the need for excessive flexible operation of coal power plants, enabling them to operate at optimal output and efficiency with reduced environmental impacts. R&D of hybridising energy storage and fossil-fuelled power plants have been conducted for decades. In 2020, the USDOE announced federal funding of up to $6 million for cost-shared R&D projects under its Energy Storage for Fossil Power Generation programme to explore technology approaches to integrate fossil fuel assets with potential energy storage applications.

ENERGY STORAGE TECHNOLOGIES

Various energy storage systems are commercially available and in operation. More are emerging. There are five different types of storage technology based on their working principles:

- *Mechanical storage systems* store energy as either potential or kinetic energy, and include pumped hydro (PHS), compressed air (CAES) and flywheel storage systems;
- *Electrical energy storage systems* store electricity directly in the form of electric current or electric charges with a potential difference. The two forms are superconducting magnetic energy storage (SMES) and supercapacitors;
- *Electrochemical energy storages* involve storing electricity in chemical form. They include batteries and are one of the most traditional energy storage technologies;
- *Thermal energy storage (TES) systems* heat or cool a storage medium such as water, rocks and molten salts to store thermal energy. High temperature TES is used for electricity storage. The stored heat can be converted back into electricity using a conventional steam turbine;
- *Chemical storage systems* convert electric energy to chemical energy via production of a chemical such as hydrogen, methane, syngas ($CO + H_2$) and ammonia, usually based on electrolysis technology. The chemical can later be used as a fuel.

Some of the storage technologies such as PHS are well-established and have long been applied to provide various services to the grid. Others such as batteries have recently found application in grid-scale storage and their use here is accelerating. Each system has different capabilities and parameters that make it suitable for particular support services to the grid. In general, PHS can provide high power and energy capacity and long-term storage, and can be used for time shifting and reserve generation. Flywheels, SMES and supercapacitors are high power, short duration storage systems and can be used for frequency regulation, voltage stability and power quality management. CAES, TES and batteries can have power and energy capacity of multi MW and MWh and discharge durations of up to several hours. They can provide a range of ancillary services and can be used to smooth out VRE power generation, thus stabilising the grid. Chemical storage systems can provide long-term storage and flexibility with the end use of the chemicals produced.

INTEGRATING ENERGY STORAGE SYSTEMS WITH FOSSIL FUEL POWER PLANTS

From an engineering viewpoint, TES, batteries and chemical energy storage systems can all be combined with coal power plants to provide flexibility in different ways. It is technically feasible to integrate TES into the water-steam cycle of a coal power plant and it is well-suited for this purpose. Analyses showed that an integrated TES-coal power plant had enhanced flexibility, faster dynamic responses to load demand changes and performed better in grid frequency services than a coal power plant.

Existing coal power plants retrofitted with battery storage systems are already in operation in China, and dozens of hybrid battery-renewables, battery-gas turbines and battery-natural gas combined cycle power plants are operational elsewhere. Successful integration depends on the development of interfaces connecting the coal power plant and a battery pack with a control system that brings the two systems together to work harmoniously. No modifications to the power generation process are required. In a hybrid battery-coal power plant, the battery pack works as a supplement to the operation of the generating units, enhancing the plant flexibility and overall performance as well as offering enhanced ancillary services such as frequency regulation, spinning reserve without fuel burn, higher peak power output, instant power to grid, and faster start-up.

Similarly, effective connection of coal power generation units with water electrolysers using a dynamic control system is key to their successful integration, which can learn from the knowledge and experience gained from the extensive R&D and demonstration of nuclear-electrolysis hybridisation in the USA and elsewhere. In an electrolyser-coal power hybrid plant, the electrolysers do not necessarily inject the stored energy back to the grid, nor provide any ancillary services. The electrolysers enhance the flexible generation of coal power plants by absorbing the excess electricity whenever it is generated. The major advantages of hydrogen for energy storage are the length of time of storage that is possible and the bulk energy storage capacity.

Techno-economic analyses show that molten salt TES is the choice of technology for integration, especially for retrofit projects due to its lower cost and greater maturity than the competing TES technologies. Li-ion batteries have advantages over other batteries of commercial acceptance, high energy and power capacity, high efficiency and availability, and a longer cycle/calendar life although they are expensive. Polymer electrolyte membranes are preferred technology choice as they have a compact design and better overall performance than alkaline electrolysers although they cost more. Depending on the technology choice and storage capacity and duration requirements, the integration of storage system into a coal power plant could be expensive. Preliminary analysis showed that retrofitting a coal power plant with TES is less costly than batteries or electrolysers with hydrogen storage. Hybridising Li-batteries and a coal plant requires a capital investment substantially higher than that of coal power-TES and coal power-electrolyser integration. Li-batteries and water electrolysers also have a higher reinvestment cost due to the need to replace cells that degrade. In addition, the need to process and store the hydrogen produced on-site increases the complexity of the operation, and the capital and O&M costs of electrolysers with hydrogen storage. Nevertheless, it is technically feasible to integrate energy storage with coal power plants. A hybrid storage-coal power plant can have enhanced flexibility and other operational advantages, which can support the grid to adopt more renewable power.

Each executive summary is based on a detailed study which is available separately from: www.sustainable-carbon.org. This is a summary of the report: Fossil fuel-based energy storage by Dr Qian Zhu, ICSC/314, ISBN 978-92-9029-637-9, 94 pp, August 2021.

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