THERMAL ENERGY STORAGE AS AN ENABLING TECHNOLOGY FOR RENEWABLE ENERGY

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The ultimate limit to supplying a large fraction of the nation's electricity demand from variable generation sources such as wind and solar is the supply/demand characteristics of the renewable resource. In many parts of the United States there is limited correlation between the solar resource and demand, while the wind resource is often anti-correlated with demand. At low penetration, wind and solar generation can be accommodated and make a valuable contribution to the electricity supply during all periods. However, at higher penetration, variable generation may need to be curtailed due to lack of demand during some hours, while meeting only a small fraction of demand during others.

Energy storage is commonly seen as an important enabling technology for large-scale deployment of variable renewable energy sources such as wind and solar. However, many energy storage technology assessments ignore the potential use of thermal energy storage (TES) as a method of increasing the penetration of solar and other renewables.

There are two forms of thermal storage we examine in this work. The first is the use of TES with concentrating solar power (CSP). CSP/TES is a highly dispatchable source of energy, with high ramp rates and range. This feature allows it to increase the flexibility of power systems, enabling greater use of other variable generation sources such as photovoltaics (PV) and wind.

The second technology examined is TES for space cooling. Space cooling is a significant use of energy in the United States, representing about 10% of total demand. Cooling also drives the peak electricity demand and the need for peaking generation capacity. Potentially a large fraction of this cooling electricity demand could be shifted via cold storage in ice or chilled water. End-use thermal storage could be dispatched to maximize the use of renewable sources and also to provide ancillary services.

Both forms of TES add several advantages over conventional electricity storage technologies. Storing thermal energy is often more efficient than storing electrical energy. In CSP plants, TES can achieve efficiencies well over 90%. End-use thermal storage can also achieve very high efficiencies and has the ability to be sited at the load, avoiding losses in the transmission and distribution network. The primary disadvantage of TES is that it is tied to a single application, and cannot be used to store grid electricity. (While theoretically it could be used for grid storage, the round-trip efficiency of this use would be well under 50%.) CSP can only be deployed in locations with significant direct solar radiation, restricting its application in the United States largely to the desert southwest. Cold storage is economically restricted to locations with significant cooling demand. As a result, there are significant geographical restrictions on the use of TES as a renewable enabling technology.

This study examines the system flexibility that can be realized by deploying concentrating solar power with TES, focusing on the southwestern United States. Simulations of large-scale deployment of combinations of CSP/TES, PV, and wind were performed, examining the feasible contributions of renewable sources, considering the limits of thermal generation and system flexibility.

Figure 1 illustrates several of the challenges of deploying large amounts of wind and solar without enabling technologies such as thermal storage. The figure is a dispatch stack in the western United States, considering a future scenario where PV provides 15% of the annual energy demand and wind provides an additional 15%. The period is May 1 through 4 based on weather conditions in 2005. During each day the large amount of mid-day PV generation forces conventional units to cycle over a large range. Even nuclear plants are forced to reduce output to accommodate PV production. Given the limited ability to ramp large thermal units, this would likely result in curtailed PV generation to avoid excessive cycling of coal and nuclear plants.

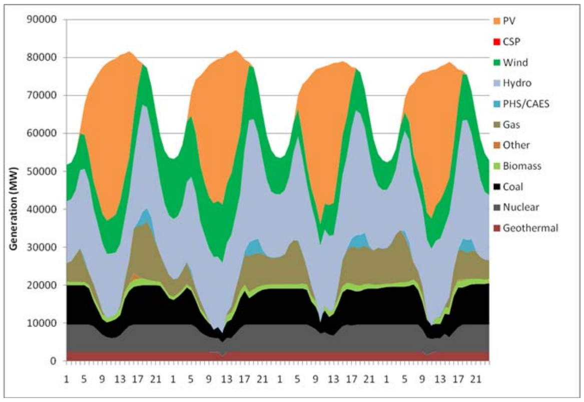

Fig. 1. Dispatch of the western U.S. grid where renewables provide 30% of annual demand.

Figure 2 illustrates how replacing some PV generation with dispatchable CSP could be used to shift solar generation and reduce ramping requirements. Solar still provides 15% of the total energy demand, but requires far less ramping of large thermal units.

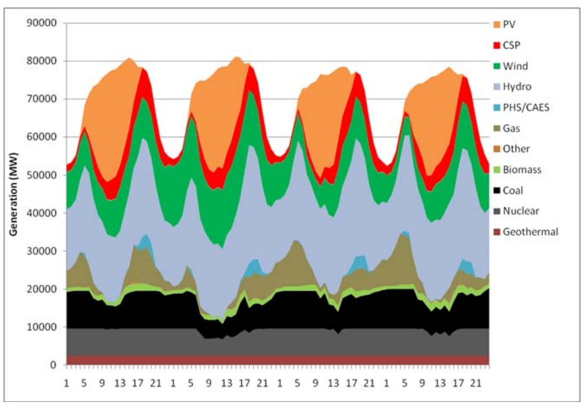

Fig. 2. Dispatch of the western U.S. grid where renewables provide 30% of annual demand, but including CSP/TES.

An important component of adding CSP/TES is the rapid ramping capability, firm capacity, and the ability to provide operating reserves. This means that CSP/TES can be complementary to wind and solar, and actually enable greater use of these variable resources. Since it provides firm capacity, CSP/TES can replace conventional thermal generators that may have less ramping rate and range. Figure 3 illustrates the ramping requirement in a high renewable scenario. If not dispatched, the production of CSP and PV would obviously coincide during the middle of the day. This would produce excess solar generation. This can be observed by comparing the output of a CSP plant if it did not have storage (blue line) with the CSP/TES generation as dispatched (red line). Furthermore, the rapid ramping requirements, minimum generation constraints, and reserves requirements may require some of the solar generation to be curtailed. However, adding TES to CSP allows nearly all the CSP generation to be shifted and provide rapid ramping to follow the significant increase in net load variability introduced by solar and wind. This can potentially reduce renewable curtailment. By providing these services with fast-response CSP, TES can reduce the integration challenge introduced by variable wind and solar PV.

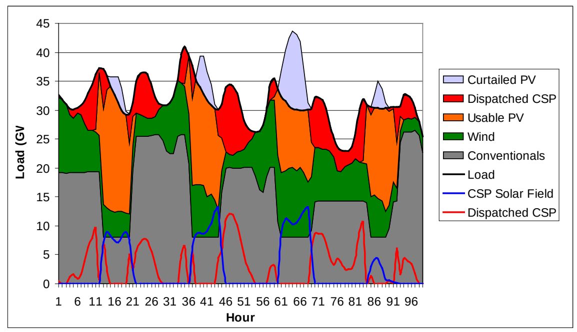

Fig. 3. Dispatch of CSP/TES to provide ramping services to enable greater use of wind and solar.

Similarly, cold storage can potentially provide similar benefits to wind and solar. Figure 4 illustrates the limited coincidence of wind and solar patterns during four summer days in the western United States. Demand due to cooling loads peaks at about 4 to 6 p.m., while solar peaks at about 1 p.m. This results in limited capacity benefits of solar and wind, and the need for large amounts of conventional generation. Cold storage can potentially add loads during periods of high wind and solar output, reducing cycling impacts on conventional generators, and reducing the need for peaking capacity.

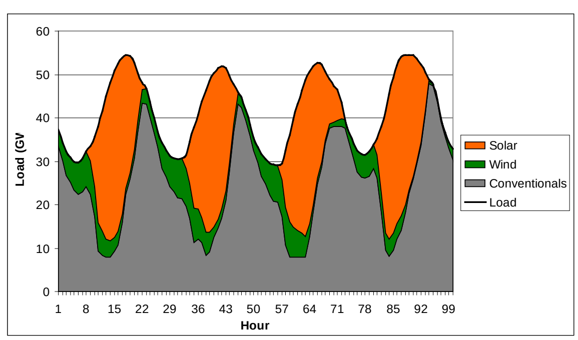

Fig. 4. Limited coincidence of solar and wind with demand patterns that could be improved by use of cold storage.

BIOGRAPHICAL NOTE

Conference presenter: Paul Denholm is a Senior Energy Analyst in the Strategic Energy Analysis Center at the National Renewable Energy Laboratory. His research interests include examining the technical, economic, and environmental benefits and impacts of large-scale deployment of renewable electricity generation, including the role of enabling technologies such as energy storage, plug-in hybrid electric vehicles, and long-distance transmission. His analysis focuses on modeling electric power systems using grid simulation tools with an emphasis on bulk storage technologies, including compressed air, pumped hydro, long-duration batteries and thermal storage. He holds a B.S. in physics from James Madison University, an M.S. in instrumentation physics from the University of Utah, and a Ph.D. in environmental studies and energy analysis from the University of Wisconsin–Madison.