Assessment of grid-based energy storage technologies

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In today's electric grid, which has essentially no ability to store energy, the balance between energy supply from generators and energy demand from electricity customers must be maintained consistently in real time. The stability of this balance between generation and load is exacerbated as the amount of intermittent renewable energy resources on the grid increases. Large-scale energy storage has been proposed as a solution to this problem of matching load to generation. Large-scale storage has the ability to decouple generators from load, making the grid fundamentally more stable and enabling the use of large quantities of intermittent, renewable energy. Despite the potential advantages of large-scale energy storage, there are a number of barriers to its widespread adoption.

Energy storage technologies such as compressed air energy storage (CAES) and pumped hydroelectric energy storage have geographic requirements that make them infeasible for widespread use. Emerging large-scale electrochemical storage options such as flow batteries and sodium-sulfur batteries have not been widely adopted because, as new technologies, they have prohibitively high costs that limit their marketability. So far, installations have been limited to the demonstration scale. Unlike the geographic constraints that limit adoption of pumped-hydro and CAES energy storage systems, the cost of large-scale electrochemical energy storage systems will decrease as technology matures. In order to determine how the cost of different electrochemical energy storage technologies must change in order increase marketability, we analyze the potential value of energy storage systems serving different applications on the electric grid.

In order to determine the potential value of different energy storage technologies, we utilize an optimization algorithm that uses a gradient-based solver utilizing sequential quadratic programming implemented in Matlab. The optimization algorithm takes in the specifications of the hypothetical energy storage system, such as energy conversion efficiency, rated power, and energy storage capacity, and then uses relevant market prices, grid conditions, and other factors to determine an economic storage dispatch strategy. In general, the objective function of the optimization is the economic benefit of the hypothetical storage system as it performs one or more grid applications. The optimization problem is constrained by a linear inequality constraint function that limits the storage power dispatched within the rated power of the storage technology in question. The optimization is also constrained by a smooth, non-linear constraint function that maintains the state of charge of the hypothetical storage system within specified limits while taking into account the storage energy conversion efficiency.

For the purpose of our current analysis, we utilize the optimization algorithm in order to assess the potential value of energy storage used for two separate applications: frequency regulation and utility bill management. Frequency regulation is a service required to maintain the frequency of the electric grid at a constant 60 Hz. As customer demand fluctuates on small time scales (on the order of a few seconds) generators either increase their power output to the grid (up regulation), or decrease their output the grid (down regulation) in order to maintain a constant grid frequency. Energy storage is well suited for frequency regulation because it can provide up *and* down regulation alternately by discharging or charging respectively. Fossil-fuel generators, on the other hand, cannot alternate from ramping up to ramping down. We utilize historic market prices from the Electric Reliability Council of Texas (ERCOT) for 2007-2010 and historic ERCOT regulation signals from the same years in order to determine the potential value of existing energy storage technologies providing frequency regulation service. We also discuss how changing energy storage system specifications and changing electricity market rules affect the potential value of energy storage used for regulation.

Electrochemical energy storage offers a number of desirable features, including pollution-free operation, high charge/discharge efficiency, flexible power and energy characteristics to meet different grid functions, long cycle life, and low maintenance. So far, they do not comprise a significant portion of capacity in the grid, due largely to their high costs. As we consider the evolution of the smart grid, we seek to understand which batteries are best suited for which grid management applications, and to guide research and development of electrochemical systems. The scaleability and relatively small sizes of battery installations makes the well suited for use at distributed locations to address a number of grid management issues, ranging from arbitrage to frequency regulation to peak shaving. While today's prices are still too high, modularity and scalability of different battery systems provide the promise of selling into niche applications with substantial reduction in prices as large-scale battery manufacturers achieve economy of scale. In this presentation, we consider some of the most likely battery technologies: lithiumion, sodium-sulfur, flow batteries, and novel chemistries/designs. We assess which battery technology pathways are most likely to ensure niche acceptance followed by wider acceptance with cost reductions. We attempt to identify what the key technology limiters are, and how they might be addressed.