MASSIVE ELECTRICITY STORAGE

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Summary

The United States is embarking on a number of routes to develop an electric power generation system that depends less on fossil fuels in order to conserve oil and natural gas and have a lower impact on the generation of greenhouse gases. Our nation, along with the rest of the world, is turning to renewable energy sources to hopefully generate significant portions of our national power needs. Emphasis has been placed on developing and improving the renewable energy generation systems. However, little attention has been given to Massive Electricity Storage (MES) that is a key to making the use of renewable energy possible on a broad scale. This paper puts forth the case for pushing ahead with developing and commercializing the critical MES technology.

1. Renewable Power Needs MES

Electricity is generated and consumed instantaneously. Unlike other energy supply systems--oil, natural gas, or coal–the electricity power grid or the generation plants that supply the grid have essentially no storage or “surge” capacity to smooth out peaks and valleys in demand or to provide reserve capacity during sudden spikes in demand.

Fortunately, coal-fired and nuclear power plants, as well as hydroelectric plants, have turbine generators that run continuously so that they deliver firm, continuous, and dispatchable power required by consumers. With such a steady baseload supply, power plants can meet demand shifts and daily cycles either by adding peaking generators or utilizing the available “spinning reserve,” about 13 percent today for the U.S. power industry. Thus, the balancing of power supply and demand, critical for the operation of a safe and reliable grid, is now done “on line in real time.”

Renewable power, whether generated by wind, photovoltaic, or solar thermal, is inherently intermittent, and there is no “spinning reserve.” The sun generates power 10-12 hours a day at best, and clouds can block the sun at any time. The wind changes direction and velocity on a regular basis, and loss of wind can occur at any time. Yet, power must be supplied to match load demand using a mix of baseload and dispatchable generating plants. This is the Achilles’ heel of renewable power.

Massive Electricity Storage (MES) is the critical technology needed by renewable power if it is to become a major source of baseload dispatchable power to eventually replace fossil/nuclear power plants. For system stability and load leveling, stored power of multi-MW capacity and multi-hours of application duration are needed to convert the intermittent and fluctuating renewable power that is generated into dispatchable power. Without sufficient MES, accessible online, solar/wind power cannot serve as a stable baseload supplier; it can only piggyback onto baseload fossil/nuclear generators as a small incremental supplier.

2. State of MES Today

In 2006, the U.S. renewable power from non-hydro sources--mostly solar and wind--supplied 2.4 percent of our annual electricity consumption. Hydropower is a renewable power source and it supplied an additional 7 percent as dispatchable power; but this resource is essentially “maxed out”. The 2.4 percent renewable power is simply piggybacked onto our fossil/nuclear power grid by direct connection. America’s huge grid can absorb this small intermittent incremental amount without encountering grid instability.

However, as renewable power increases its grid penetration to 15 percent or more, grid instability will rise to a level that must be controlled. For smaller and weaker grid systems on islands, such as Hawaii or Ireland, which cannot be tied into large continental grids, the sensitivity to instability is much more acute.

No U.S. renewable power generator has MES today. Among battery storage technologies, only one is operating at above 1 MW power level, the 1.2 MW NaS (sodium-sulfur) battery system with 7 hours of storage capacity at an American Electric Power facility. The purpose for this installation is to reduce peak loads for improved distribution service, and not yet for renewable power stabilization.

In America today, there is an almost total absence of public awareness of the need for MES. The prevailing public view is that renewable power can replace fossil/nuclear as power sources if enough wind farms and solar generators are built. All attention and R&D support are focused on improving the cost and performance of wind/solar electricity generators. As a result, it is not surprising that MES is not even recognized as a top priority critical technology deserving sustained attention and support by both the U.S. Department of Energy (DOE) and Congress.

Because our power grid is the backbone of our society, its reliable and safe operation is absolutely essential to our nation's well-being. The MES devices to be deployed are very large, both in size and investment. More importantly, they must be tested on a commercial scale under a wide range of operating conditions and for extended periods of time before MES can be accepted and included in our grid system. This takes time, and we, as a nation, have yet to start down the development path.

3. U.S. Power Grid and MES

In 2006, the U.S. grid had 1,076 GW (1 gigawatt = 1,000 MW) of installed capacity and delivered 4,254 TWh (1 terawatt-hour = 1,000 GWh) of electricity (1). Of that total, the energy sources were 49 percent coal, 20 percent natural gas, 19 percent nuclear, 7 percent hydro, 2.4 percent non-hydro renewable, and 2 percent oil and refinery gas. U.S. power consumption was 22 percent of the global total. The huge size of the U.S. grid with a wide diversity of power generation sources provides stability and minimizes the impact of fluctuating renewable power on the composite system load profile. In comparison, weaker grids, covering isolated areas not connected to major grids, are much more sensitive to, and less able to tolerate, the fluctuating renewable power.

To obtain an estimate of the order of magnitude of the size of the MES needed and the associated capital investment, three scenarios of renewable power penetration into the U.S. grid are examined:

a. 20 percent--MES required for grid stability

b. 50 percent--Renewable becomes the principal power source

c. 75 percent--Ultimate renewable penetration

The reason 75 percent is considered the ultimate penetration of renewable power is that both hydro and nuclear will continue to be used for a long time because they are carbon neutral, reliable, and economical.

For each scenario, an "upper bound" estimate for the magnitude of MES is calculated in terms of MW storage power and MWh of storage discharge capacity. An estimate of the corresponding capital investment puts in context the immensity of the challenge ahead.

To meet a 100 MW of firm demand with wind power, 286 MW of nameplate wind power capacity must be installed because the capacity factor for wind is at best 35 percent today. Only 35 percent of a wind farm's nameplate capacity can be considered firm for reliable and economic load dispatch due to the inherent variable and intermittent nature of wind power, and even then storage is required. Current design calls for installing storage capacity equal to about 20 percent of the nameplate capacity, or 57 MW, to achieve a 95 percent assurance that the 286 MW of wind farm capacity can deliver 100 MW baseload power. The amount of storage needed is 6-8 hours, or 342-456 MWh (2).

With solar power, a typical annual average of 10 hours per day is available for power generation, immediately cutting the capacity factor to 40 percent. Add to this the variable nature of solar power due to seasonal changes and cloud cover and the overall capacity factor drops to around 20 percent. Fortunately, power consumption at night is typically much lower than during the day, so that with sufficient storage capacity it is possible to cover the demand during off-peak hours without generation.

As a basis for our “upper bound” analysis, solar and wind generation are both treated with a 35 percent capacity factor. So, to meet a 100 MW firm demand, 286 MW of nameplate generation capacity must be installed, plus 57 MW of storage power for 8 hours of storage, or 456 MWh of storage capacity.

Knowing what each 100 MW of firm demand would require in terms of wind power installed capacity and the MES required to deliver 100 MW of dispatchable power supply, we can complete the calculations for the three scenarios above to produce Table 1 below. For example, Scenario (a) of 20 percent renewable power grid penetration means 200 GW of firm capacity. This would require the installation of 572 GW of nameplate capacity of solar/wind, plus 114 GW of MES storage power with 912 GWh of storage capacity. Similar calculations are made for Scenarios (b) and (c).

For capital cost calculations, best current estimate shows installed wind capacity at $1500/kW (3) and solar at $3600/kW (4). For MES, American Electric Power estimates $3000/kW for a NaS battery system (5).

Table 1 summarizes the current “upper bound” conservative estimates for the needed MES capacity under the 3 scenarios of grid penetration.

Table 1. "Upper Bound" Estimate of U.S. MES Size and Cost

Grid Penetration By Renewable Power, %	20	50	75
Firm Renewable Demand, GW	200	500	750
Nameplate Renewable Installed Capacity, GW	570	1430	2150
Capital Investment for Installed Capacity, $ billion	860	2150	3220
MES Power Capacity, GW	114	285	428
MES Storage Capacity, GWh	912	2280	3424
MES Capital Investment, $ billion	342	855	1284

4. **Action Needed**

To make a renewable energy electric power system a reliable reality it will be necessary to ensure that MES options are developed. This is the critical path to harnessing renewable energy. To achieve this goal in the time required, the following actions must be undertaken:

a. Inform the public of critical MES need through papers, meetings, briefings, media, and conferences. Decision makers must be informed that without MES, renewable power cannot become the principal supplier of baseload dispatchable power. Without MES, renewable power can only be piggybacked onto the U.S. grid to supply not more than 15 percent of the power at best. America and the world must rely on renewable power for the future. We must place the highest priority on MES technology development.

b. DOE is the logical agency to stimulate MES development, from basic science to R&D and the subsequent demonstration stages. By recognizing the vital role of MES, DOE should place top priority on MES R&D for the transition to renewable power. With DOE's interest and support, Congress then has a solid basis to weigh in with its support.

c. Congress enacted The Energy Independence and Security Act of 2007, including specifically a title on "Energy Storage Competitiveness" (P.L. 110-140, Title VI, Subtitle D, Section 641). This new law establishes a major electricity-storage program to support the ability of the U.S. to remain globally competitive in energy-storage systems for electric-drive vehicles, stationary applications, and electricity transmission and distribution systems.

   The Act authorizes for the next 10 years $50 million per year for the basic research program, $80 million per year for the applied research program, and $100 million per year for the demonstration program. Not all of the funding will be applied to MES, because development efforts for mobile-source and stationary-source energy-storage systems are also included in this program. Congress viewed the combination as being mutually reinforcing to the betterment of both. But, the emphasis on MES is new and undeniable.

d. The 2007 Act is only a funding authorization. What will actually happen depends on how much money is ultimately appropriated. Heightened public awareness of the critical role of MES will be a powerful incentive to the decision-makers to take action as Congress addresses the appropriation issue.

References:

(1) BP, “Statistical Review of World Energy 2007”; EIA Electric Power Annual with data for 2006, Table 2.2 Generator Nameplate Capacity

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(3) “Biennial Review of the Cost of Wind Power”, Northwest Power & Conservation Council, 7-13-2006

(4) “Gila Bend 280-MW APS Solana Solar Thermal Plant”, Arizona Republic, 2-21-2008

(5) Nourai, Ali, “Sodium-Sulfur Batteries for Bulk Energy Storage”, AIChE Spring National Meeting, New Orleans, 4-2008