Compressed Air Energy Storage as an Alternative to Transmission for Remote Wind Energy Resources

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1. Introduction

In 2008 the U.S. Department of Energy released a report examining a scenario that provides 20% of the nation's electricity from wind by 2030 [1]. While the report found that achieving this amount of energy from wind will require no dramatic change in generation technologies or the need for energy storage, it will require substantial increase in transmission capacity, including a large number of high-capacity, long distance transmission lines. The need for transmission for wind is exacerbated by this resources' relatively low capacity factor, increasing the transmission capacity required compared to conventional resources.

Figure 1 illustrates a hypothetical transmission expansion that could accommodate the 20% wind scenario. There is a significant expansion of 765 kV AC lines, the largest (and least common) AC lines built in the U.S.

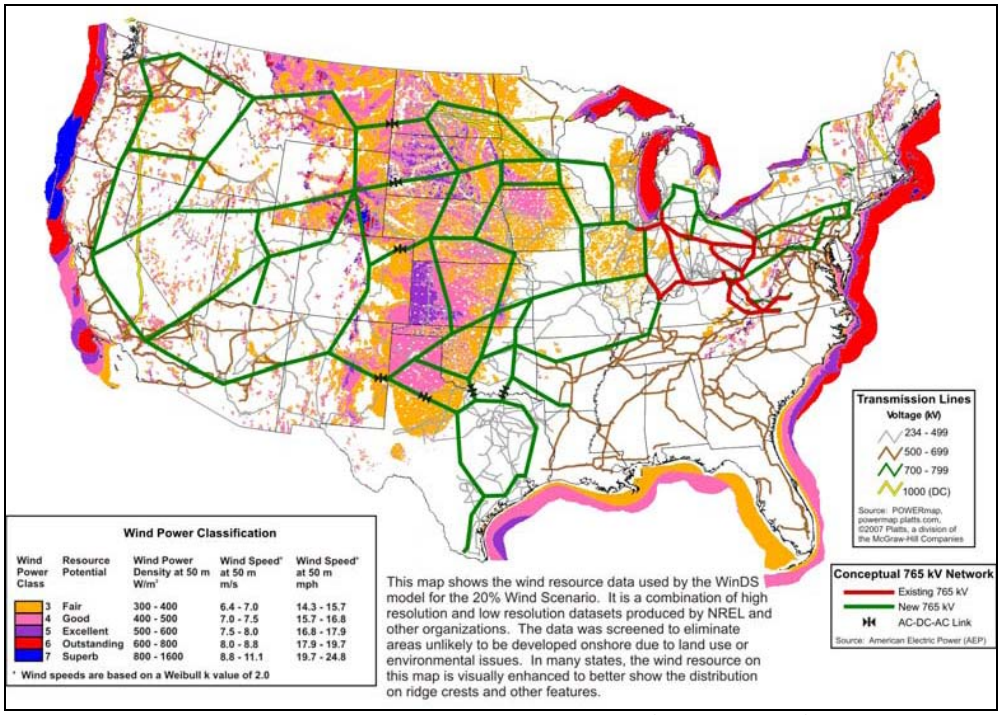

Figure 1: Conceptual transmission plan to accommodate 20% of U.S. electricity from wind [1].

Given the difficulty in siting new transmission, it is important to ensure that all mechanisms to maximize transmission utilization are considered. One option is to co-locate remote wind resources with energy storage, which can increase transmission line loading and decrease the need for new transmission. Several previous studies have suggested this concept, typically suggesting compressed air energy storage (CAES) as the most viable storage option, given its cost competitiveness compared to other bulk energy storage technologies [2-4]. CAES plants in the Midwestern U.S., such as the proposed Iowa Stored Energy Park would use underground aquifers for the air storage vessel. This could help increase the viability of wind energy as a major supplier of carbon-free energy, provided that the economic benefits of storage as an alternative to transmission are large enough to warrant this application.

Figure 2 illustrates this concept with a generation duration curve for a spatially diverse wind resource, showing and the impact of moving energy to periods of lower wind output, and the associated increase in transmission line loading.

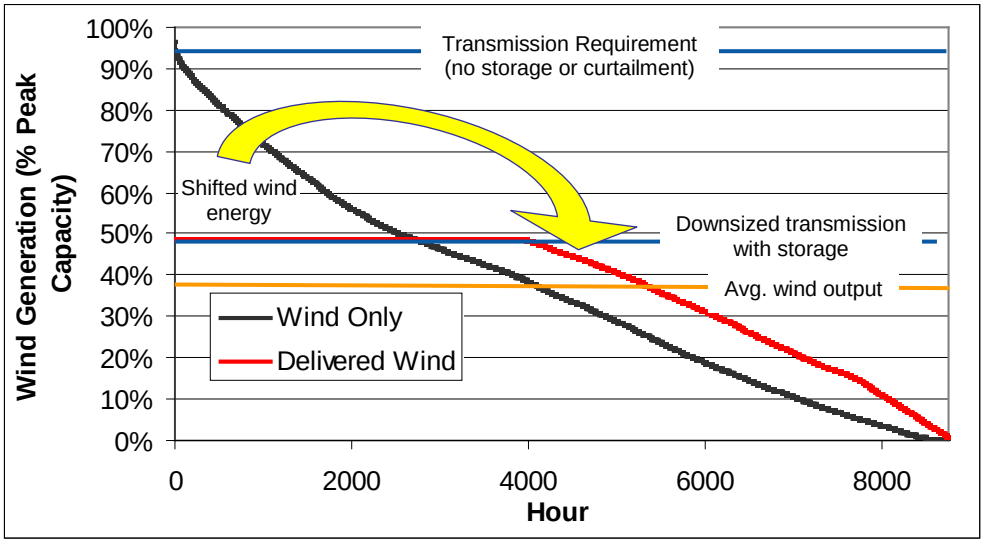

Figure 2: Co-Locating Wind and Storage to Increase Transmission Line Loading

One of the limitations of this approach is the decreased profitability of the CAES system compared to when located at the load, or otherwise unconstrained by transmission. From a merchant perspective, the CAES plant is now forced to purchase energy from the wind plant, as opposed to the larger market as a whole. This incurs opportunity costs since although wind is often somewhat anti-correlated with load (and as a result, price) there are times that the wind blows during periods of relatively high prices. From a systems perspective the question becomes whether or not the net profitability of a wind/CAES system with downsized transmission system is greater or less than a system with wind and CAES and unconstrained transmission. Essentially, the issue becomes whether or not the reduced profits from the CAES plant are greater than the reduced cost of transmission. Figure 3 compares the operation of the CAES plant in the two scenarios. The scenario to the left shows the dispatch of an unconstrained CAES system, which is able to buy and sell into the market as a whole. When the CAES plant is co-located with the wind plant, the CAES plant becomes transmission constrained and unable to take complete advantage of market opportunities (in addition to any additional transmission losses that may occur.) This is illustrated on the right side of Figure 3, which now includes a down-sized transmission line. On both occasions where the price of electricity exceeds $60/MWh in these two days, the transmission line is already largely occupied by the wind farm, and the CAES plant cannot optimally sell into the market. This reduction in profit comes with the benefit of the downsized transmission line and associated reduction in transmission costs.

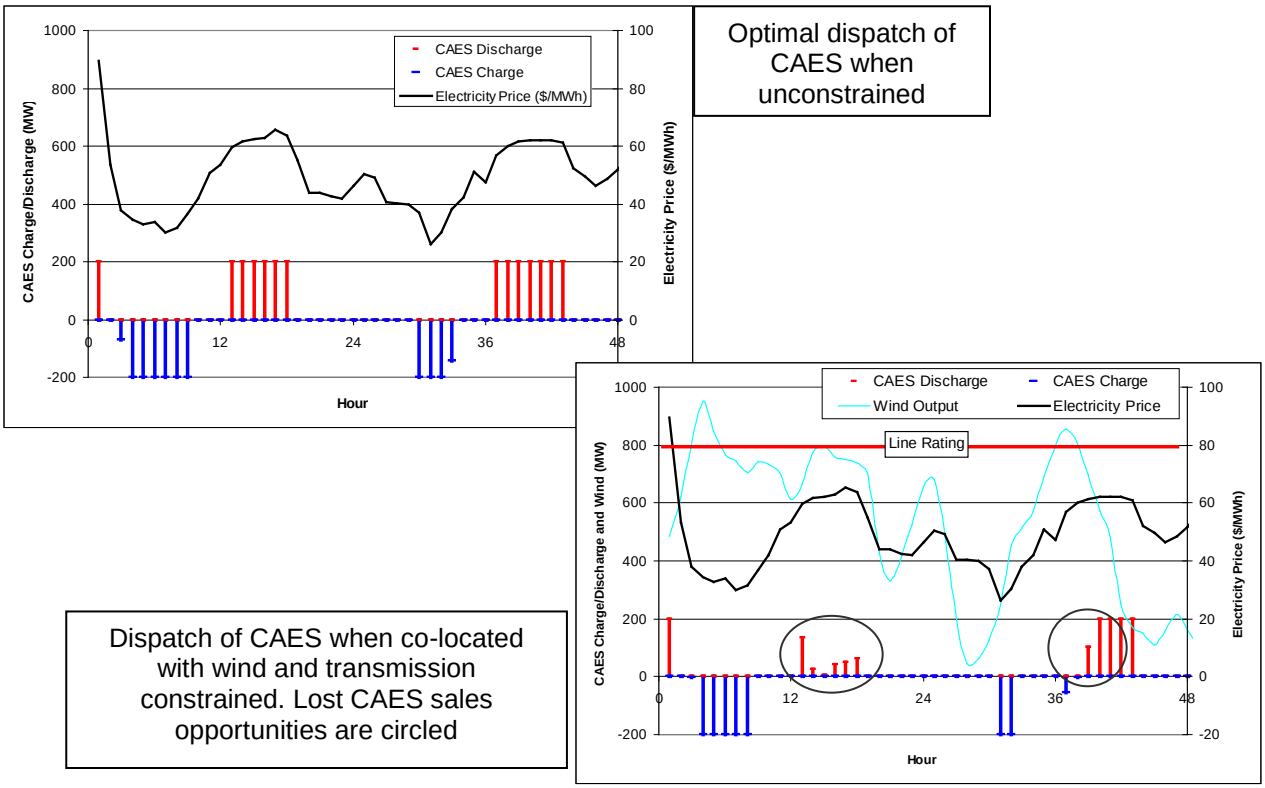

Figure 3: Lost CAES Revenue when Co-Located with Wind and Constrained Transmission

2. Analysis

To analyze this net profitability of the downsized transmission scenario, we evaluated three remote wind scenarios, where a long distant transmission line is constructed to deliver remote wind to major load centers. Three locations were analyzed – the Midwestern U.S., (assuming a line from the Dakotas to Chicago), Texas (assuming a line from West to East Texas) and the Western U.S. (assuming a line from Wyoming to Northern California). In each case, we used historical wind and market data in several locations in the U.S. and examined the value of a wind/CAES/transmission system as a function of such factors as electricity prices, wind resource, storage capacity and natural gas price. The CAES system was dispatched to maximize profits by optimally buying grid and selling grid electricity. When co-located with wind, the CAES plant was constrained by transmission availability under a variety of combinations of transmission and CAES sizes. Additional details are provided in [5]. Figure 3 illustrates the three evaluated scenarios.

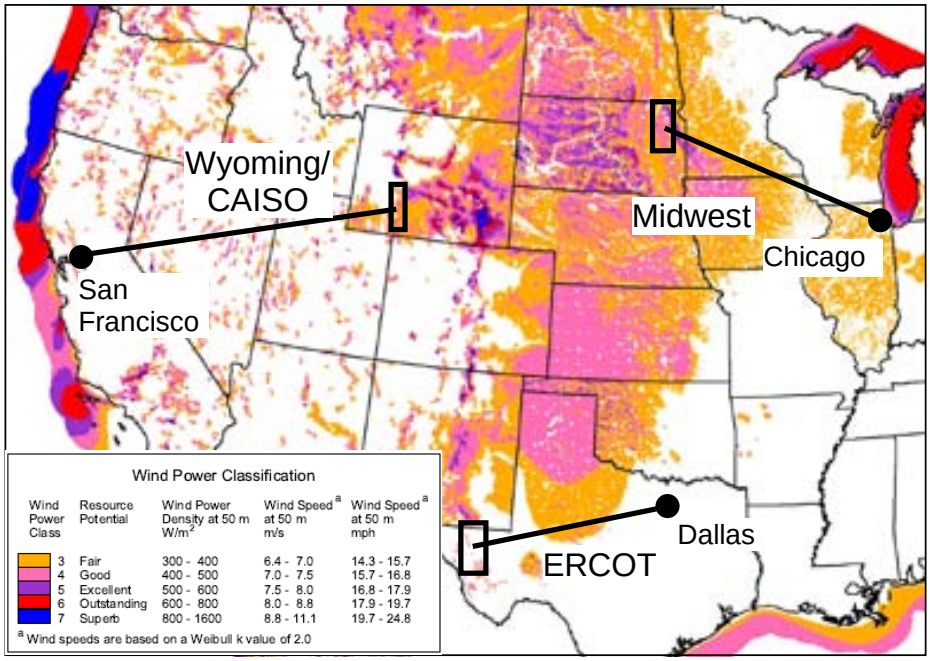

Figure 4: Evaluated Wind/CAES Scenarios

3. Results

In general, the analysis shows that in the historical markets, the co-located CAES facility loses significant revenue opportunities when sharing the line with a wind power plant. Figure 5 illustrates the results for the Midwest and ERCOT scenarios, for a variety of transmission and CAES sizes (relative to the size of the wind farm). As the transmission size is decreased, the annual revenue losses are increased. Over the range of cases evaluated, co-locating wind and CAES and downsizing transmission results in annual lost revenue of up to about 18% per year relative to a full sized transmission line and unconstrained CAES.

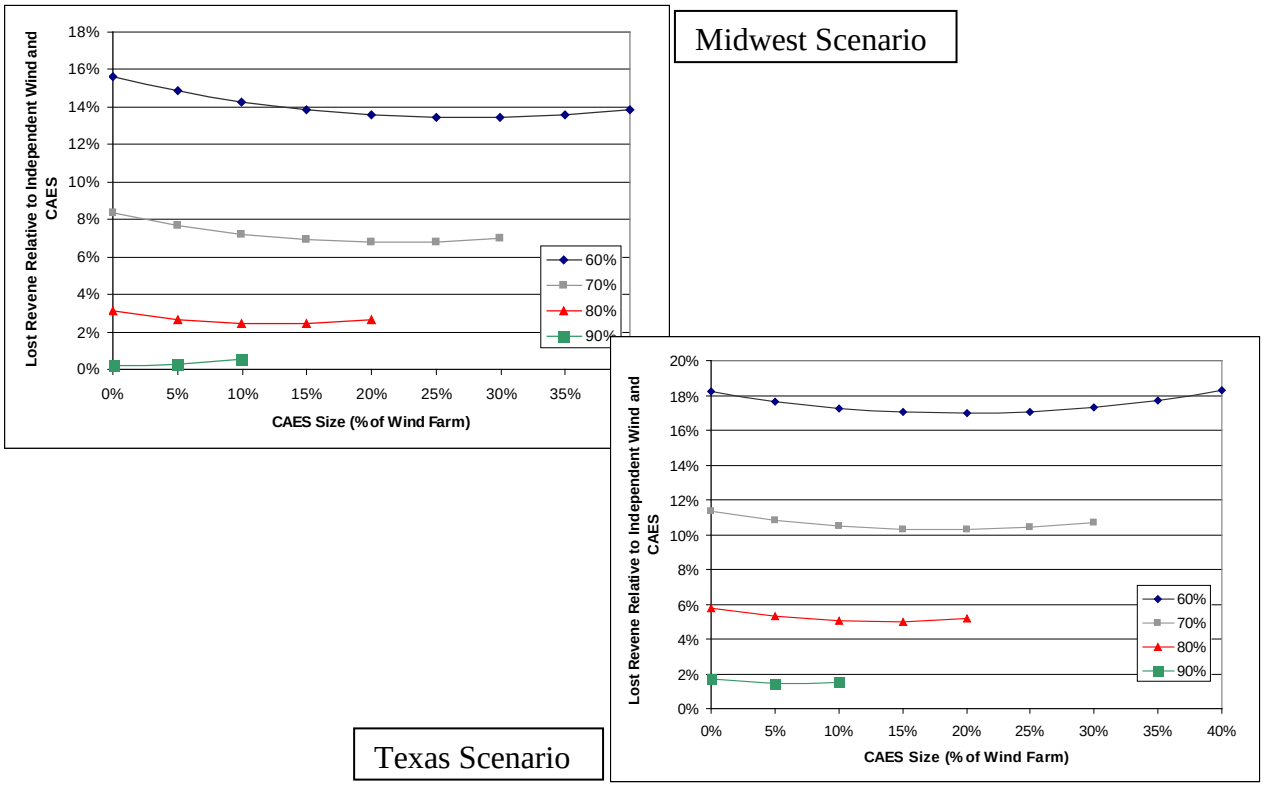

Figure 5: Lost Revenue Associated with Co-Locating Wind and CAES and Downsizing Transmission Compared to an Un-Constrained Wind/CAES System.

The lost revenues can be translated into a transmission "breakeven cost" or the point where the cost of transmission exceeds the lost revenue of co-locating wind and CAES. Figure 6 illustrates the size of the CAES plant that would be optimal to co-locate with wind as a function of transmission costs for the three scenarios. In this scenario, the CAES plant is sized relative to the wind plant. For example, at a transmission cost of $1000 per MW-km of transmission capacity, the optimal CAES size for a 1000 MW wind plant in the Midwest case would be 20% of this rating, or 200 MW.

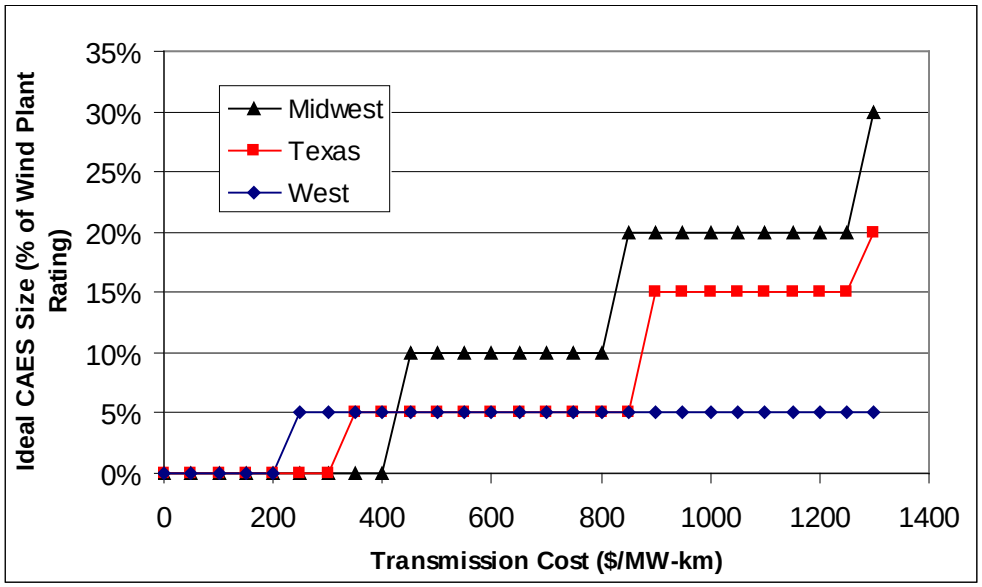

Figure 6: Optimal Co-located CAES size as a function of transmission cost for the three evaluated scenarios

Figure 6 illustrates that the amount of CAES that is optimal is relatively small compared to the overall size of the wind plant, and that transmission costs must be fairly high to justify co-locating wind and CAES. This result is from several factors. First, the CAES configuration is not optimal for co-located wind applications. In the base analysis, we assumed that the CAES expander and compressor are identically sized, as presently configured in the 110 MW Alabama plant which uses a common turbo-machinery train. In reality, it is possible to separate the compressor and expander, as was proposed for the Norton Ohio plant plant. We found a small increase in net wind/CAES revenue with an expander to compressor ratio of >1. In addition, the base analysis uses a storage time of 20 hours. Longer times may be possible in aquifers, and while longer storage times are of little value in typical arbitrage applications, longer storage times are of significant value in wind/CAES applications. We found a decrease in breakeven transmission costs of about 20% for storage times of 120 hours. Finally, and most importantly, the scenarios and markets evaluated did not consider increased penetration of wind and its effect on energy prices. In the years evaluated (2005 and 2006) the penetration of wind energy was a very small part of the system's energy, and not a primary driver of prices. As wind penetration increases, periods of high wind output will begin to drive down prices, and the dispatch of a co-located wind/CAES system will begin to converge with an unconstrained CAES system. This should improve the economics of a co-located wind/CAES system, but further analysis will be necessary to evaluate the economics of co-located wind/CAES systems at greater penetration of wind energy.

References

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