Benefits of Storing Electric Energy from Wind in Puerto Rico

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Abstract – Use of an Energy Storage System (ESS) only to convert a wind park from an energy source to a power source could have an excessive cost. On the other hand, electric energy storage could provide solutions to already identified needs in Puerto Rico's electric power network tilting the economic analysis balance in favor of eolic generation. Rapid response spinning reserve, frequency control and reactive support are three of the potential benefits of using electric energy storage in Puerto Rico.

Keywords – electric energy storage, wind generation, spinning reserve, frequency control, reactive support.

1. Introduction

Several studies have been conducted in Puerto Rico to determine wind energy potential [1], wind resources estimates [2], the viability of wind energy conversion systems [3], wind farm assessment [4], wind power capacity value [5], and wind resource maps [6]. Despite these efforts a continuous argument against eolic electric generation is the random nature of the prime energy source, the wind. The use of energy storage resolves this problem at a considerable cost since usually storing significant amounts of electricity is expensive. If the Energy Storage System (ESS) is used only to convert the wind park from an energy source to a power source the cost of the ESS could be excessive. In the other hand, using the stored energy to alleviate other problems could make the ESS economically feasible.

Rapid response spinning reserve, frequency control and reactive support are three of the potential benefits of electric energy storage in Puerto Rico. Previous studies [7,8,9] have shown that a Battery Energy Storage System (BESS) is an economic alternative to provide rapid response spinning reserve as well as frequency control [10]. Conversations with the Puerto Rico Electric Power Authority (PREPA) personnel as well as a recent study [11] indicate the need for additional reactive support on Puerto Rico system under specific circumstances. One or more properly located ESS may provide the needed reactive support.

The combination of current developments in electric generation from wind, relatively high cost of electricity and inclusion of the benefits derived from energy storage could tilt the economic analysis balance in favor of eolic generation projects in Puerto Rico. This article intent is to spur this discussion.

2. Wind Resource in Puerto Rico

All studies to determine wind energy potential in Puerto Rico indicate that the best wind resource is located in the North and East coasts of the Island as shown in Figure 1.

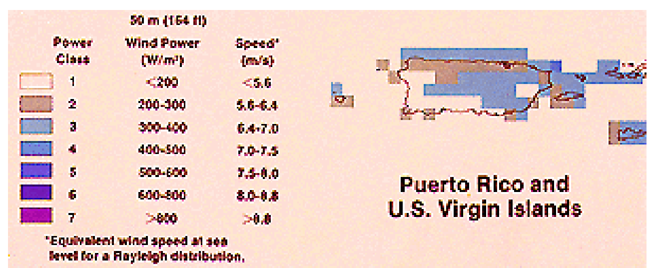

Figure 1. Annual average wind resource for Puerto Rico and the U.S. Virgin Islands (from US Wind Resource Atlas).

Most of the studies already mentioned have estimated wind energy potential using the arithmetic mean wind speed. It has been shown that a more accurate estimate of available energy can be obtained using cubic mean wind speed [12]. Equation 1.1 shows how to calculate both.

$$\overline{v} = \left[\frac{\sum_{i=1}^{N} f_i v_i^n}{\sum_{i=1}^{N} f_i} \right]^{1/n} \qquad (1.1)$$

where $\overline{v}$ is the mean wind velocity, v is the actual wind speed in m/s, f is the frequency of wind speed, n =1 for arithmetic mean, n =2 for root mean and n = 3 for cubic mean.

There is an on going effort at UPRM to use available data [1,4] to better estimate wind energy potential using cubic mean wind speed for the East coast of Puerto Rico. Preliminary results show that a single 110 kW commercially available turbine could generate from 7.4 MWh per month (May) to 28 MWh per month (November).[1] Thirty of these turbines could generate a similar amount of energy in just one day for any given month. These turbines, with 30 m rotor diameters, could be generously spaced 10 diameters apart in the prevailing wind direction and 5 diameters apart in the direction perpendicular to the prevailing wind occupying between 1 km^2 and 2 km^2.

Several small wind farms like this could be installed in the North and East coast of Puerto Rico. Wind farms could be installed inland, in the Islands of Culebra and Vieques for instance, or offshore in the North coast. The cost of using energy storage to convert these wind farms from energy producers to power producers can outweigh the benefits. Therefore it is necessary to consider other benefits of the ESS to make them economically feasible.

3. INMEDIATE BENEFITS OF ENERGY STORAGE FOR PUERTO RICO

We have noted that rapid response spinning reserve, frequency control and reactive support are three of the potential benefits an ESS for Puerto Rico. We elaborate our argument in the following sections.

3.1. Rapid Response Spinning Reserve

In any power system, the failure of a generator unit changes the ratio of demand to on-line generation capacity instantaneously. This change causes a corresponding decline in the speed of the remaining generators and consequently in the frequency of the electricity that these generators produce. Uncorrected, the decline in frequency can damage the remaining generators and within a few seconds, cause the collapse of the entire power system [13]. Unless sufficient generation with the ability to rapidly increase output (rapid response spinning reserve) is available, the decline in frequency will be largely determined by frequency sensitive characteristics of the loads and by the magnitude of the overload. In many situations, the frequency decline may reach levels that could lead to tripping of steam turbine generating units by under frequency protective relays. To prevent extended operation at lower than normal frequency, load-shedding schemes are employed to reduce the connected load to a level that can be safely supplied by available generation [14].

The Puerto Rico Electric Power Authority (PREPA) identified its island condition and the relatively large size and slow response of its generating units as main factors leading to unacceptable system performance (blackouts) when generation deficiency occurs. The study described in [8,9] evaluated possible energy storage solutions, Battery Energy Storage Systems (BESS) vs. Superconducting Magnetic Energy Storage (SMES), to Puerto Rico's rapid response spinning reserve insufficiency under generation deficiency conditions.

The combined results of our study showed that the most economical solution to the problem was a BESS unit with stored energy requirement of 7.7 MWh. This capacity is sufficient to allow the start-up of gas turbine units to maintain the reserve power of the BESS.

A SMES plus diesels option, a combination that will keep the required power output over a five minutes period or more, will also solve the problem. The SMES plus diesels solution present value was calculated as \$133 million. The 60 MW BESS present value was calculated as \$104 million, \$29 million less than the SMES plus diesels solution.

Note that the required 7.7 MWh of stored energy could be produced from a relatively small wind park as noted before.

3.2. Frequency control

Frequency control is a critical operating problem on any island electric utility. The lower inertia of island systems causes frequency to deviate rapidly as the load and topology of the system changes. These deviations have a negative effect on the quality of power. Therefore, means for fast acting frequency control are required.

An ESS can be very useful executing frequency control. The following example, taken from [10], will illustrate this point. Allow only the ESS to perform frequency control. All the other system governors will have a large deadband so that they will not respond to normal frequency deviations. A deadband of frequency error is defined for each ESS, which is ±0.05 Hz and maximum ESS power for frequency control is set to ± 30 MW. Figure 2 shows the frequency error function for the ESS [10].

[1] From “Study of Wind Resource for the Fajardo Zone”, INEL 6025 homework by José A. García-Pérez, October 2002.

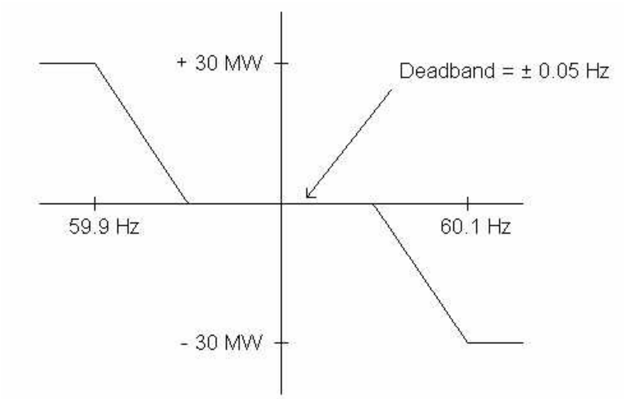

Figure 2. Frequency error function.

Further assume that system redispatching will be performed every 3 minutes, with a load pick-up rate of 15 MW/min. In this example the load is increased by 20 MW two minutes after the last redispatching, frequency decreases to 59.895 Hz, after a minute the system is redispatched again through the AGC and frequency returns to 60 Hz. After two minutes of the last redispatch the load is decreased by 20 MW, frequency increases to 60.106 Hz. A minute after the change in load, the system is redispatched again and the frequency is corrected to 60 Hz.

Figure 3 shows the frequency control performed by the ESS. The frequency stays between 59.94 Hz and 60.06 Hz. Figure 4 shows the output power of the ESS.

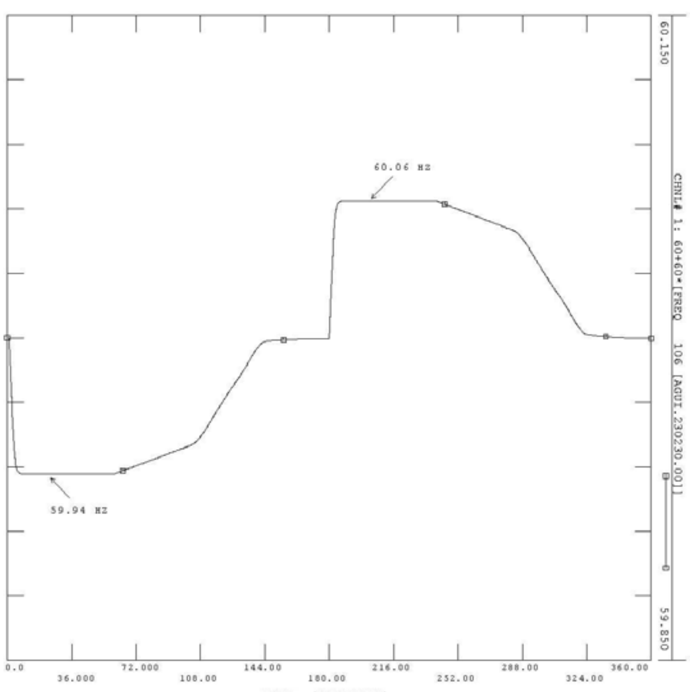

Figure 3. Frequency control

Such control action can be performed with a fraction of the 60 MW needed for rapid response spinning reserve.

3.3. Reactive support

SMES store electrical energy as a dc current, while the electrical grid is connected to operate with ac currents. BESS stores energy chemically but the electric reaction at the battery terminal is also DC. Hence, for these two ESS an intermediary must be inserted between the ESS and the electrical system — a Power Conditioning System (PCS).

The PCS acts as the power interface between the energy store and the utility system by performing a bidirectional energy transfer between the two as is schematically depicted in Figure 5. The PCS can also generate or absorb reactive power from the utility system concurrently with the real power exchanged. The ratio of real and reactive power exchanged at any instant can adjusted by an external system controller in response to system conditions. The PCS could be designed with the capability to deliver any combination of real and reactive power instantaneously within its rating envelope (and capacity of the energy store) as illustrated in Figure 6.

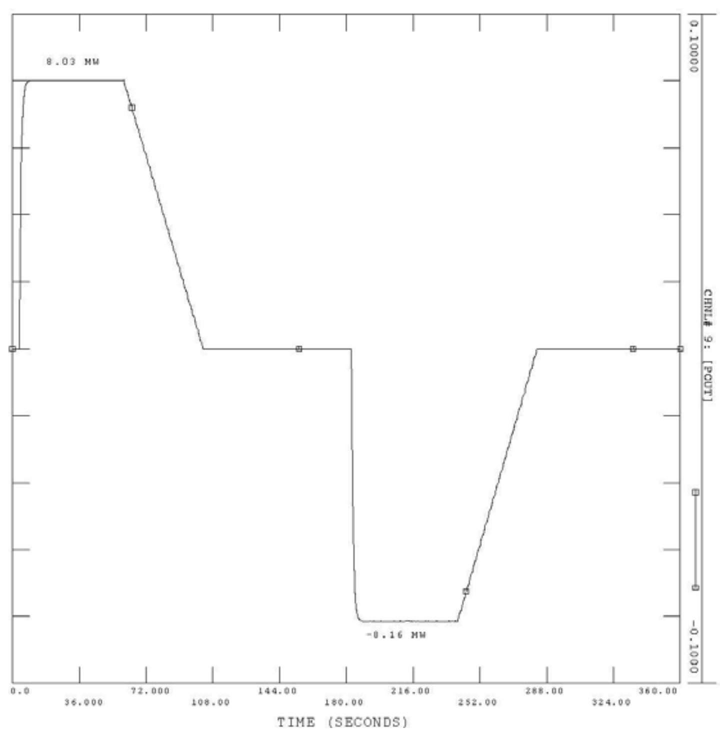

Figure 4. ESS power output.

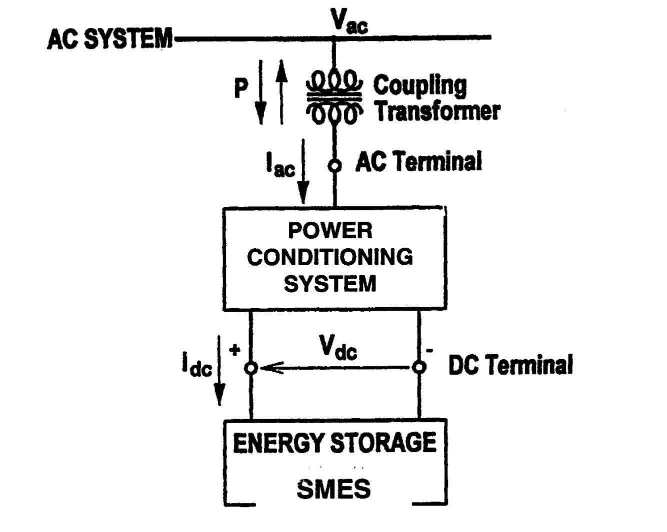

Figure 5 PCS Controls Power Flow Between Energy Storage and Utility Systems

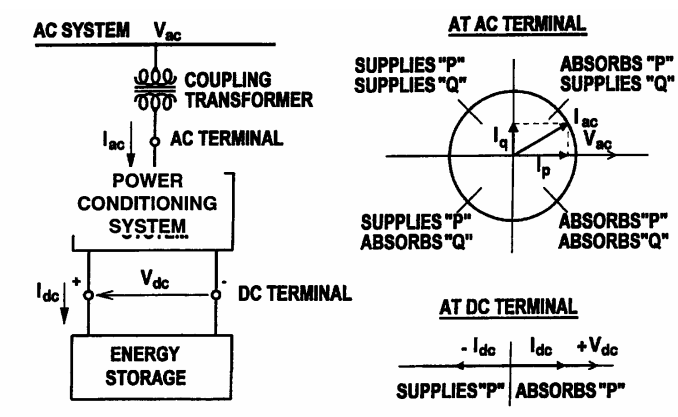

Figure 6. Four Quadrant Power Control by PCS

This capability of injecting either active or reactive power as needed makes the ESS very useful against voltage instability, a condition usually associated to reactive support inadequacy. In [11] we identified that a weak connection between the load center, in the North of Puerto Rico, and the major generation centers, in the South, combined with generation decrease could lead to insufficient reactive margin in the buses near the North load centers. The reactive power margin in a bus indicates its actual reactive power reserve. It has to be negative in order to operate without shunt compensation [14].

If shunt compensation is required a properly located ESS (near these load centers) could inject the required reactive support. The amount of reactive support required and the duration of the injection will vary with the system operating conditions. This function is compatible with the use of the ESS for rapid response spinning reserve and frequency control.

V. Conclusions

The cost of using energy storage to convert wind farms from electric energy producers to electric power producers could be too expensive. In order to justify the investment on a ESS multiple uses for it may be required. We propose the use of ESS to provide rapid response spinning reserve, frequency control and reactive support in the island of Puerto Rico as well as to promote the use of eolic generation.

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VII. BIOGRAPHY

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