Comparative Analysis of a Novel Approach to Economical Wind Energy

Verterbi School of Engineering Research & Innovation Fund Final Report
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Summary of the research project:

Conventional wind energy generation is obtained from "wind farms" that are in high-wind remote regions. Large Horizontal Axis Wind Turbines (HAWT) are mounted on towers spread far apart and supported on large piers to resist large overturning forces of the tall wind catching propellers. The cost of the infrastructure and land required to construct the towers has limited the use of this system.

A new cable based installation of vertical as well as conventional horizontal shaft windmills for electric power installation as shown in Figure 1 was proposed. In the proposed methods a multitude of vertical turbines and their corresponding generators may be suspended on one, two or more strands of cables on available natural or manmade infrastructures. It was expected that the proposed approach would reduce the cost of wind energy generation. The energy output of an array of smaller vertical turbines was to be matched to a single large HAWT for cost comparison incorporating turbine and generator costs and installation costs. The goal of our study was hence to model each new configuration to compute the cost of implementation given the weight of the turbine/generator assemblies and the wind load.

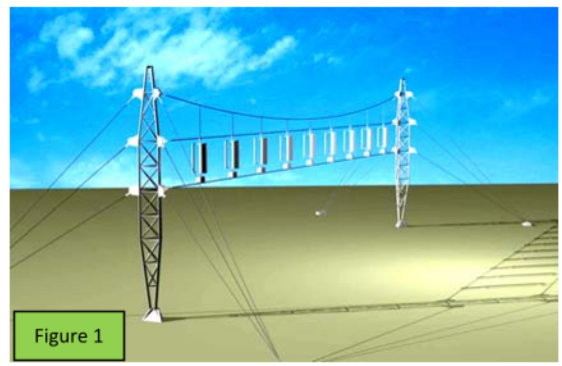
Figure 1

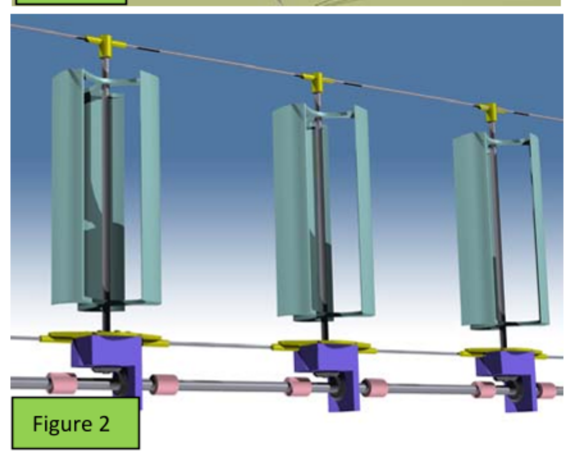
Figure 2

New outcomes and impact of the spent funds:

We created several alternative design configurations for cable suspended vertical axis wind turbines, such as the one shown in Figure 2 where the torque generated by each turbine is aggregated through a horizontal shaft and delivered to a stationary generator. Other designs incorporated hydraulic pumps powered by each turbine to force hydraulic fluid to a hydraulic motor turning a stationary generator. To establish the technical feasibility of suspending several turbines on the same cable set without generating adverse oscillation and harmonic effects we built the scaled physical simulator shown in Figure 3. The model demonstrated flawless performance under a variety of simulated wind conditions.

To assess the economic viability of this new approach, preliminary designs had to be analyzed and sized to develop realistic costs. We considered a vertical axis turbine currently available in the market with diameter and height of 11 meters. To minimize costs, the distance between centerlines of turbines was set to 22 meters (the minimum distance recommended). We had to assume 33 small vertical axis turbines to match the 1.8 MW output of the horizontal axis wind turbine for which we had cost data. The 33 turbines span vertically between two sets of cables that are attached to two steel truss towers. The towers are stayed by additional cables requiring foundations for the two towers and eight stays (two pairs at each tower to stabilize tension in the two spanning cables). This system was analyzed using software developed at UC Berkeley, SAP2000 by Computers & Structures, Inc. The software can accurately model large geometric nonlinearities such as cable sag under loading that was required for our analysis.

The cables, cable stays, and steel truss towers were analyzed and designed using SAP2000 for loading including self weight and high wind loads. The height of the tower was a variable since the length of the cables and the mass loading them determines the sag in the cables. To ensure the lowest turbines near the middle of the span were high enough to achieve expected wind speed levels, the tower height had to be adjusted for the sag. The final model resulted in 100 mm diameter cables with 10 m sag from support to midspan and 99 m tall towers. Foundations were sized based on the reactions of the stay cables and towers.

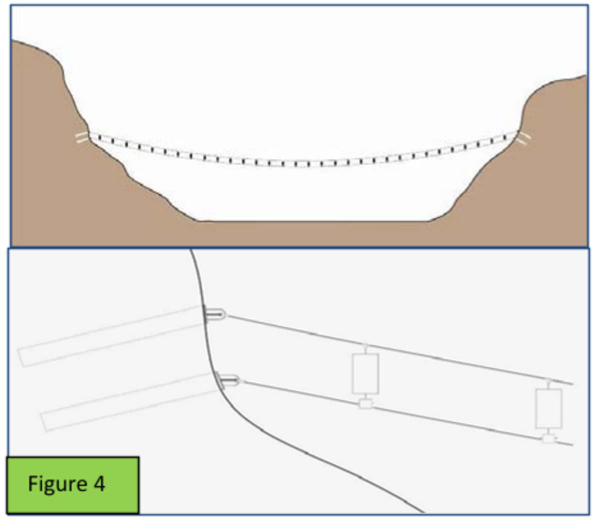

Figure 4

The resulting structure costs were estimated with advice from a reputable construction cost estimating firm to estimate an overall construction cost related to the output of the turbines. We evaluated the advantages and disadvantages of having the heavy generators supported with turbines or placed remotely using power transfer mechanism to minimize the weight supported. Ultimately, the structure required was governed more by the wind loads than the self weight and there was not enough savings to offset the reduced efficiency of remotely placed generators.

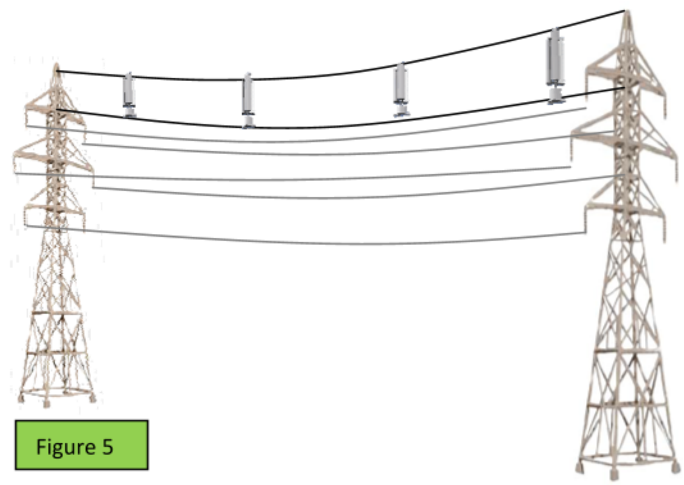

Figure 5

Unfortunately it was determined by our model that the per KW cost of cable suspended multiple turbines was higher than what is yielded by the conventional practice where each single turbine is supported by a dedicated tower. The excess cost of the new approach is primarily due to the cost of the two towers and their foundation as well as the guy wires and their stays needed to support the towers.

Continued directions for the project:

We anticipate that the proposed method will be profitable in situations where tower construction can be avoided altogether by utlizing natural features such as canyons and cliffs, as shown in Figure 4. Also installation of smaller turbines on man-made structures such as power transmission towers and bridges as shown in Figures 5 and 6 as well as between tall buildings could prove to be profitable as well.

Figure 6

We intend to continue our study toward determination of scenarios in which tower construction would not be necessary. We will repeat our cost comparison analysis for a variety of realistic scenarios and will possibly implement the concept at a test site using small commercial vertical axis wind turbines. We will use our findings in future proposals to receive support to continue our research in this potentially rewarding direction.