»

AUGMENTING WIND FARM OUTPUT WITH VERTICAL AXIS WIND TURBINES

Wind Harvest International, Inc. (WHI) (Davis, CA); Kevin Wolf

Power Generation Renewable: Wind Energy-Capture
Proposed Funds: Fed: $1,800,000 / Cost Share: $625,000/ Total: $2,425,000
Project Duration – 24 months

1. CONCEPT SUMMARY

This unprecedented research and development is needed before vertical axis wind turbines (VAWTs) can be commercialized and installed around and under horizontal axis wind turbines (HAWTs). This is because, wind farm owners won't invest in near-ground wind turbines until it is proven that the wake and turbulence they create will not harm their existing HAWTs, and the turbines are certified with a good power performance curve and validated aeroelastic model.

This R&D project will provide data and analysis on the effectiveness of the coupled vortex effect in longer VAWT arrays. In the process, the use of the WHI Harvester 70 VAWTs in the project will advance their readiness for commercial financing and large scale development.

If successful, this ARPA grant will accomplish the following major objectives:

- The Calif. Energy Commission's 1985 Wind Atlas identifies wind resource areas with 5000+ megawatts of HAWTs that have good to excellent (14-20 mph) average annual wind speeds at ~10m above ground level. With this wind resource, these wind farms could at least double their energy output by adding one or more layers of VAWTs, which would result in significant reductions of energy-related pollution, including greenhouse gases. Over 100,000 MWs of existing wind farms worldwide are projected to have similar topographically driven low wind shears, and thus profitable near-ground wind resources;
- Because WHI's U.S designed and manufactured turbines will be the first medium size, straight-bladed VAWTs to be commercialized, this grant would help ensure that the U.S. maintains a technological lead in developing and deploying utility-scale VAWTs.

VAWTs have never achieved long-term commercial success. By default, an R&D project that uses them is considered risky. VAWTs like the WHI Harvester have had a difficult time securing private-sector investments needed for them move from the prototype stage through IEC 61400 based certification to become a commercially available product. Overcoming the hurdle of proving to wind farm owners that VAWT turbulence will not harm HAWTs is an additional risk that investors find difficult to overcome. Without the possibility of near-ground wind farm development, it is hard to convince investors that VAWTs have a large market worth investing in.

Once the Harvester VAWT is certified and proven to not harm HAWTs, wind turbine suppliers will be disrupted and begin investing in their own VAWTs to compete for this new worldwide market. New investments will start fundamentally new learning curves that will reduce the cost per square meter of rotor swept area. Investment will also improve how VAWT placement will most effectively work synergistically with HAWTs in differing topographies so that their

»
interactions benefit the energy output of each other. ARPA funding will create the baseline data and modeling that the wind industry needs to trust that VAWTs will help their wind farms.

Mass manufactured VAWTs placed among HAWTs promise to result in a significant decrease in per kWh cost of wind energy when installed in good near-ground winds. It also promises dramatic increases in wind energy for places like California where new and/or denser wind farms are difficult to develop because of politics and the turbulence setbacks requirements of HAWTs.

2. INNOVATION AND IMPACT

In all of California and in other locales where wind accelerates near the ground in passes and over ridgelines, there are no commercial technologies available to wind farm owners so they can harvest these excellent rated resources. HAWTs do not operate well in the intense turbulence that accompanies energetic near-ground wind so their blade tips rarely come closer than 25m to the ground. This leaves a layer of high value wind that VAWTs not only can economically exploit, but when placed correctly, can increase the energy output of the HAWTs above.

WHI Harvester VAWTs have overcome three major barriers that have hindered VAWTs in the past with these historic advancements:

- Prototype validated aeroelastic modeling was built on the models developed and tested by Sandia National Labs and others on Darrieus-type VAWTs. With this comes high confidence that the WHI Harvester VAWTs can achieve their 20+ year fatigue life.
- In 2011, CEC funded aerodynamic modeling validated the increased energy output produced by a pair of VAWTs counter-rotating one meter apart from each because of the "coupled vortex effect." This increased output offsets the increased drag that VAWT blades create when rotating back into the wind that HAWT blades avoid.
- Use of a direct drive generator and controls perfected on and used in hundreds of similarly sized HAWTs (i.e. Northern Power Systems)

The problems still facing VAWT commercialization in existing wind farms include:

1. VAWTS need to achieve IEC 61400 based certification for safety and function, power performance, fatigue, and acoustics. The Harvester VAWT is ready for and should be undergoing certification by the time this grant is funded. If it isn't, this grant will help with the most costly part of the process, providing a 140kW pair of turbines for the R&D.
2. The need to know if the wake from VAWTs will hurt or help the HAWTs in the wind farm.
3. The need to test the hypothesis that VAWTs will be more wildlife friendly than HAWTs. *Note: WHI will fund this research separately on the same turbines on which the LiDAR data is being collected. WHI will invest in DT Bird's high definition cameras and motion detection system and third party scientists to collect and analyze the 24/7 collected data.*

The proposed effort represents an innovative and potentially transformational solution to expanding the capture of wind energy. After the ARPA R&D has been completed, the WHI Harvester VAWT will be commercially available for pilot projects in wind farms. The owners of some wind farms have already expressed interest in pilot projects after they are confident that VAWT turbulence won't harm HAWT performance. Pilot projects are the next step before a full understory build out can be advanced in wind farms: first in those with excellent wind speeds

»
(>16 mph) at 10-25m above ground level. Then, as the VAWT learning curve progresses, prices drop and synergistically driven turbine efficiencies improve, wind farms with good wind resources (14-16 mph) will be able to finance VAWT understory development.

This table predicts changes in wind farm statistics possible with VAWTs.

Ex.[1] Mtn. View Power Partners *See more details on this wind farm this paper.*	**HAWTs alone**	**HAWTs with VAWTs**	**Harvester VAWTs with HAWTs**	**Totals**
Density (MWs / sq. mile)	64	64	133	200
Rotor swept area (m2) / sq. mi	156,000	156,000	314,000	470,000
Capacity Factor[2]	25%	26-30+%	23-28%	25-30%
Cost per kWh[3]	$.06	$.057[4]	$.047[5]	$.05

1. This wind farm has >2X density than wind farms with turbines laid out to 3x10 Rule of Thumb
2. 25% is the average CF for wind farms in CA.
3. This would be a good PPA in CA.
4. Assumes a 5% increase in HAWT energy output.
5. Assumes more expensive VAWTs/MW than HAWTs, but much lower costs for permits, land, and infrastructure in existing wind farm along with lower costs for installation and transportation per MWs. It assumes the coupled vortex effect raises VAWT efficiencies to those of HAWTs and wind shears are <.06.

3. PROPOSED WORK

First two then four WHI Harvester 70kW VAWTs will be installed in a linear array with one meter between the counter-rotating blades of each pair. The 25m then 50m wide array will create a blockage effect and speed up the wind over its top such that the HAWT rotor above will realize a faster average wind speed and produce more energy. The counter-rotating VAWT rotors produce downwind turbulence from the blade tip and edge vortices they shed. The blade edge vortices differ based on whether the blades in the gap between a pair go into or with the wind. A scanning Doppler LiDAR will be placed 500m downwind of the VAWTs with its pulsed laser beam pointed upwind collecting changes in wind speed and turbulence created by the VAWTs at 20m intervals. After sufficient data is collected, the blades will be reversed to collect data on the opposite rotational direction. A portable 32 m meteorological tower will be moved around the test field to collect wind speed, wind direction, and turbulence data to validate the LiDAR datasets. A meteorological tower upwind of the VAWTs will collect incoming wind data (Vw).

The field data will then be analyzed to determine how far downwind and above the ground the VAWT created turbulence extends. The LiDAR data collected directly above the VAWT array will document the intensity and spatial extent of the wind speedup effect that occurs above their rotors. The data will be used by Stanford University's publically available Large Eddy Simulation CFD model to predict how the VAWT wake would interact with and affect HAWT created wake and turbulence in different topographies. The data will also be available to the wind industry and universities interested in determining how VAWTs could benefit HAWT performance.

Installation of VAWTs and LiDAR data collection in existing wind farms was considered but rejected for two reasons:

»

- The data would not be clean because VAWT wake and turbulence would be difficult to extract from the turbulence data created by the HAWTs.
- Owners of wind farms are reluctant to allow R&D on VAWTs without first knowing that the new turbulence they create won't harm their existing investment in HAWTs.

Dr. John Dabiri's team has done extensive field research showing how counter-rotating VAWTs can replenish near-ground wind speeds and bring faster moving wind at higher elevations down into the rotors of downwind HAWTs. Dr. Marius Paraschiviou's modeling shows that there will be a wind speed up effect over the top of VAWT arrays. This increase in wind speed over the VAWTs can either be channeled into a HAWT rotor, or can be used directly downwind of a HAWT to change the pressure difference and thus the speed of the wind that moves through the bottom sweep of the HAWT rotor. Both of these beneficial effects can be evaluated using LiDAR.

The project requires a new technology: cantilevered medium sized, straight-bladed VAWT arrays that can be installed anywhere in a wind farm and at differing heights above ground level. The risk associated with using uncertified wind turbines is a major hurdle stopping investors from taking on such a project. The risk is mitigated because the WHI Harvester VAWT was created from a prototype from which strain gauge and other sensor data was collected and used to validate the Sandia-based suite of "aeroelastic" models that WHI's engineers used.

The economic challenge is to develop enough demand for VAWTs to decrease their cost of goods sold through mass manufacturing. This R&D project will lead to pilot projects in wind farms in different topographies. The success of the pilot projects will create the demand that will drive the expected 14% learning curve in price reduction per kWh that HAWTs realized in their early years.

The project cost of four WHI Harvester 70 VAWTs, a new LiDAR and other sensors, Stanford's LES CFD modeling, San Jose State's field work and analysis, project management and related work will be approximately $2.425 million, of which ~$1.8 million would come from the ARPA Open funds.

4. TEAM ORGANIZATION AND CAPABILITIES

Kevin Wolf, WHI's Chief Operating Officer will be the Lead Investigator and project manager. His experience with VAWTs and knowledge of the involved science will be important.

Dr. Craig Clements, professor in the Dept of Meteorology and Climate Science at San Jose State University has extensive experience with LiDAR and the sonic anemometers and transportable met mast. He will lead the meteorological field measurements and related data analyses.

Dr. Sanjiva Lele, Professor of Engineering at Stanford University will be the Principal Investigator on the modeling. He and his Stanford team have extensive experience in Large Eddy Simulation CFD modeling of wind turbines, and the computer power to do the analysis.

This team worked together to present a proposal for a similar project to the CEC EPIC grant program in 2017. That and all other proposals involving VAWTs were not funded.