

Vertical-Axis Wind Turbines for Powering Cellular Communication Towers

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ABSTRACT

Cellular communications are rapidly penetrating markets across the entire globe. Very rapid adoption is occurring in developing countries such as China, India, and Brazil. In many cases, wired communication is being bypassed. The electronic equipment which is housed on communication towers requires large amounts of reliable electricity for their operation. On the other hand, in some regions of the world, continuous supply of electricity is not available. In these cases, auxiliary power is supplied by diesel generation which is polluting and expensive. In other cases where grid-connected electricity is not available, the entirety of power is provided by diesel generation.

To alleviate the issues related to power availability, a novel, vertical-axis wind turbine has been designed, constructed, and implemented to power communication towers. The turbine is specifically designed to attach to communication towers without interfering with the existing electronics. Results show that the proposed design is capable of providing for the electrical requirements of a typical communication tower.

Keywords: vertical-axis turbine, wind power, cellular communications, off-grid power, Savonius turbine

1 INTRODUCTION

This project deals with the design, development, and evaluation of a novel vertical-axis wind turbine which is particularly suited to be affixed to cellular communication towers. The turbine is a drag-type turbine (Savonius turbine) and does not rely upon lift forces for its rotation.

The goal is to provide electricity to supply the needs of the electronic equipment connected to the tower. Typical power requirements are in the 1-1.5kW range.

While vertical-axis turbines produce less energy than their more common horizontal cousins, there are a number of advantages which make the vertical-axis design more appropriate for this application. First, drag-based vertical turbines begin rotation in lower wind velocities than do horizontal variants. Second, they are less sensitive to wind direction and they do not require a control mechanism to ensure that they face the wind. Additionally, since the style of turbine blade selected for this application is driven by wind drag forces rather than lift forces, it rotates at a slower rate and thereby imparts a reduced vibration load to the tower structure.

A prototype wind turbine was designed and constructed in a modular manner to meet the power production needs of a typical communication tower. Rotor modules can be added or removed from the design to allow the device to be tailored to meet the specific needs of individual towers.

The turbine was designed, in part, through the use of computational fluid dynamic software which allowed an optimization of the turbine shape to maximize power production and limit the thrust loading which was imparted to the tower. A number of novel features were implemented to aid in the optimization. First, specially designed one-direction venting structures were utilized to reduce deleterious drag on the blade. Second, a special cap was incorporated to increase the amount of wind which was captured by the blade. Details of these features will be discussed later.

An early variant of the turbine was built and tested in a large-scale wind tunnel operated by the University of Minnesota. Results from the tests show that the venting marginally improves performance while the capping structures gave rise to a large improvement. The final design has been shown to be a viable solution to the issue of off-grid or unreliably powered communication towers.

An extensive body of literature has been devoted to the design, testing, and fabrication of vertical-axis Savonius-style turbines. That literature includes studies involving wind-tunnel tests, numerical simulation, and in-field observations [1-11]. In most cases, the turbines are fabricated by half-cylindrical drums which are offset some distance from their axis of rotation. The design utilized here is more complicated with a profile that is not half-cylindrical.

A photograph showing a three-module turbine fixed to a communication tower is presented in Figure 1.



Figure 1: Photograph of installed wind turbine.

2 ROTOR DESIGN

As mentioned in the prior section, the design used for this turbine contains novel features which improved performance and reduced thrust loading on the tower. Two of those features are vents which were aligned longitudinally along the rotor and a capping structure which was positioned above and below the rotor to minimize wind bypass around the turbine. A photograph of the turbine, installed in a wind tunnel, is presented in Figure 2.

As mentioned in Section 1, tests were performed at a large wind tunnel which is operated by the University of Minnesota. The wind tunnel possessed a test section which was large enough to accommodate a complete rotor

module. Tests were carried out with complete control over various operational parameters such as air speed and electrical load. The tests displayed the dependence of power generation on these parameters.

The turbine occupied nearly 25% of the wind tunnel cross sectional area. Consequently, when evaluating the results, account had to be made for the wind-tunnel *blockage factor* which, for our case, was estimated to be nearly 2. The blockage factor is an artificial increase in performance of an object placed in a wind tunnel. The increase in performance is caused by the acceleration of air as it passes the object. The acceleration is due to the reduced area through which air can flow (because the object blocks a portion of the tunnel).

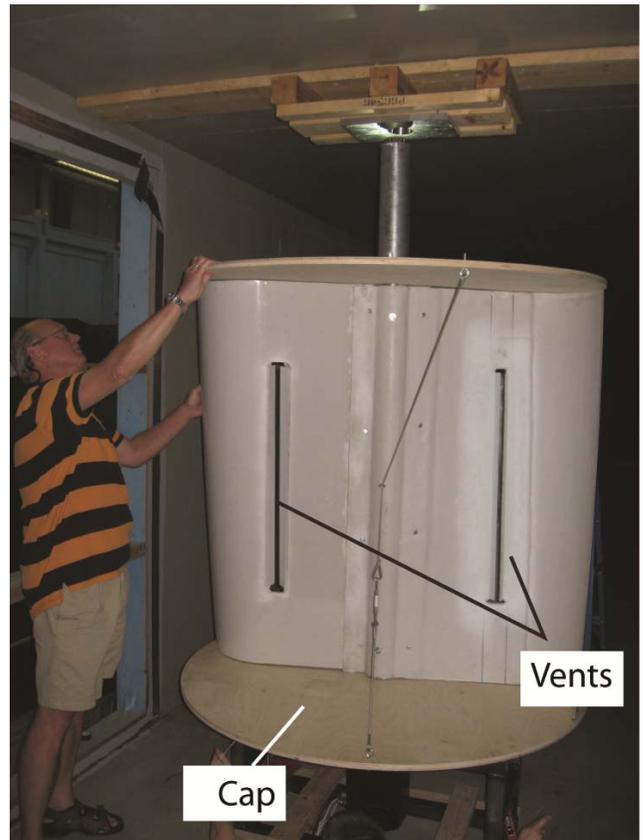


Figure 2: Photograph showing turbine cap and venting slots for a rotor positioned in a wind tunnel.

Blockage effects are defined as the power generated within a wind tunnel relative to the power generated in a free-space region. Mathematically, the expression is

$$F = \frac{Power_{tunnel}}{Power_{free\ space}} \quad (1)$$

Since power varies with the cube of velocity (which varies inversely with area), it can be expected that

$$F \sim \frac{V_{tunnel}}{V_{free\ space}} = 1.25^3 = 1.95 \quad (2)$$

A verification of the numerical simulations was made by independently calculating the blockage effect. Those calculations, which were performed for wind speeds of 12 m/s and rotational rates of 60 rpm, showed

$$F = \frac{Torque \cdot rpm_{tunnel}}{Torque \cdot rpm_{free\ space}} = 1.85 \quad (3)$$

This value of the blockage effect is in close agreement with that set forth in Eq. (2). The agreement provides strong support for the computational method.

3 RESULTS

The experiments were performed on the rotor which is depicted in Figure 2. Additionally, experiments were carried out on rotors which did not contain vents or caps. Finally, simulations were completed using finite-element commercial software. A collection of these three results are shown in Figure 3. For the results which correspond to the vented and capped rotor, it was found that the electrical resistance setting significantly impacted the amount of power which was generated. On the other hand, for rotors which did not have venting slots or caps, the power generated was much less dependent on electrical load. The data which is termed *simulated maximum* are the predicted results from numerical simulations for an optimized electrical resistance setting.

The results from Figure 3 are all obtained for a 1.3 m tall, single rotor design. If multiple rotor modules were to be used, the predicted power generation would scale linearly with the number of modules.

The quantity of power generated by the novel turbine is seen to be sufficient to provide power to cellular communication towers which require 1-1.5 kW of power. For times when the generated power exceeds that required by the electrical components, excess energy could be stored in a battery array for later use.

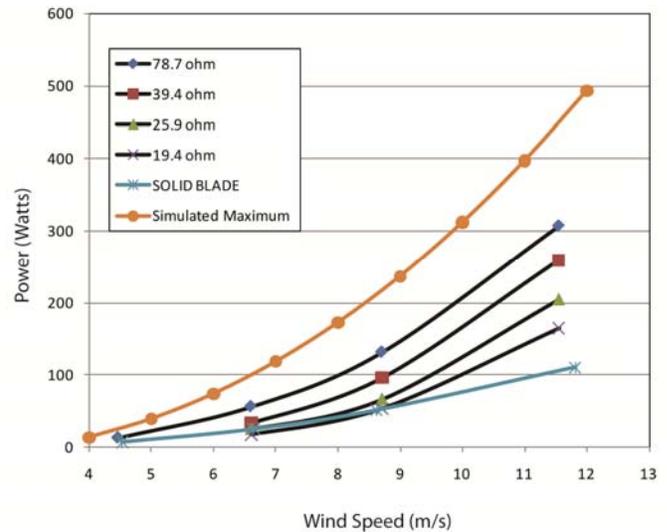


Figure 3: Comparison of experimental results with simulated maximum.

4 CONCLUDING REMARKS

This research project demonstrates that a vertical-axis wind turbine has the potential to provide electricity to cellular communication towers. The turbine is well-adapted for the environment because its rotation will not interfere with the tower's structure, it is able to operate independent of wind direction, and it imparts a lesser vibrational load to the structure compared to horizontal turbine designs.

Two novel design features were incorporated into this turbine. First, venting slots were added to reduce thrust loading on the tower. Second, caps were affixed to the upper and lower edges of the rotor to prohibit air from bypassing the turbine. Together, these features were found to significantly increase performance of the turbine. They also greatly increased the dependency of the performance on the electrical load.

Numerical simulations were performed using finite-element techniques. Those simulations provide an upper bound on the performance (theoretical optimum).

The results, when taken together, demonstrate that this turbine design is a viable candidate for powering cellular communication towers.

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