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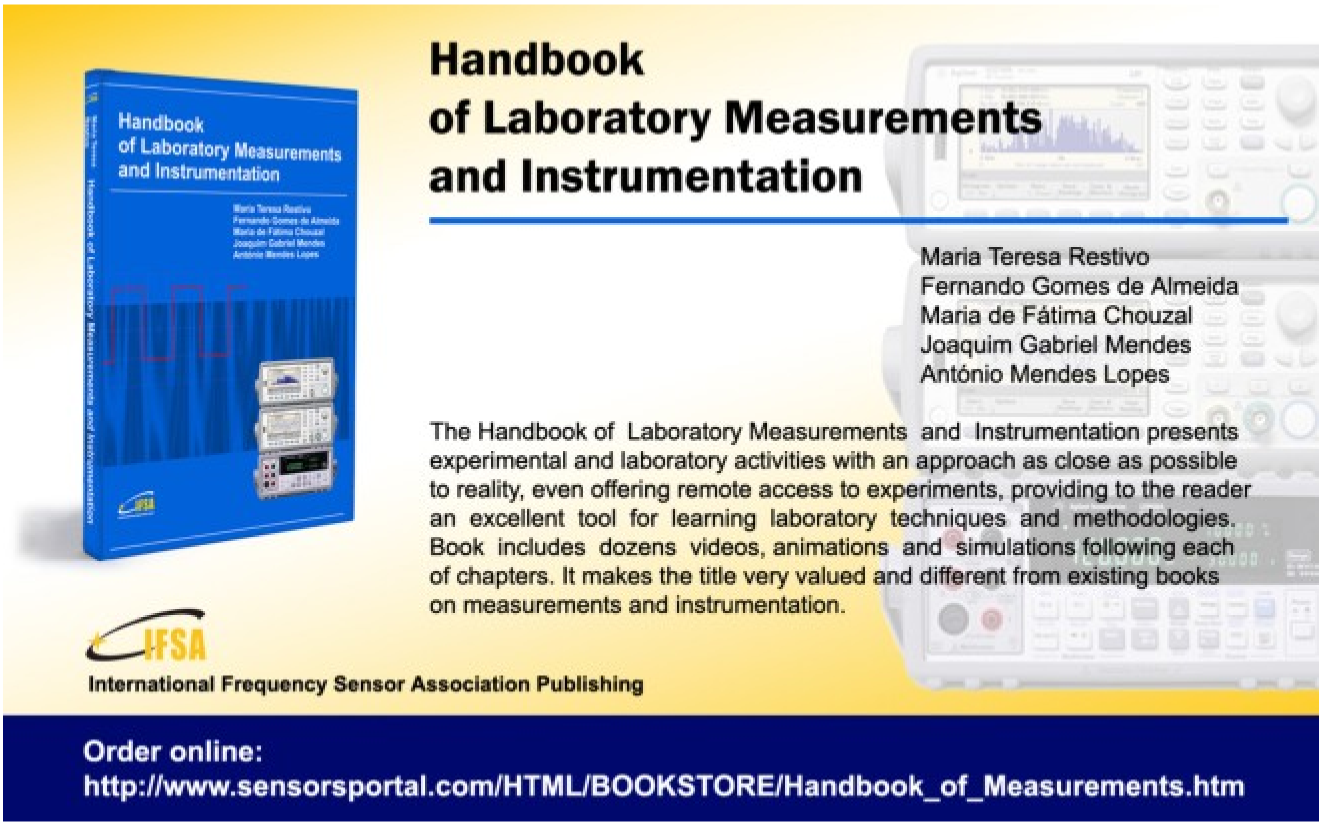

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Use of Small-Scale Wind Energy to Power Cellular Communication Equipment

[*] B. Plourde, [*] J. Abraham, [*] G. Mowry, [**] W. Minkowycz
[*] University of St. Thomas, School of Engineering, St. Paul, MN 55105-1079
[**] University of Illinois at Chicago, Department of Mechanical Engineering
Chicago, IL 60607, USA
E-mail: jpabraham@stthomas.edu

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Abstract: The recent increase in cellular communication coverage and usage has been remarkable. The increase has occurred throughout the globe, in both developed and developing regions. In fact, in some regions of the world, land-line communications are being avoided altogether as countries move into primarily mobile communication technologies. In order for cellular communication to function adequately, communication towers must be built with sufficient density to provide coverage. These towers have electrical requirements which are often not met with grid-based power. This study presents a novel design of a wind turbine which is designed to be positioned atop existing communication towers in order to provide local power for the tower. These turbines have vertical axes of rotation and other features which suit them for this highly specialized application. The study carried out here shows that these turbines are able to provide the required electrical power to fully satisfy the communication-tower electronics. *Copyright © 2011 IFSA.*

Keywords: Vertical-axis wind turbine, Communication towers, Renewable energy, Fluid modeling.

1. Introduction

In virtually every region of the globe, cellular communication use and infrastructure has grown remarkably in the past decade and the growth is projected to continue at least for the coming decade. In many instances, countries are bypassing land-line communication and using mobile communication technology to meet civilian needs.

Each communication tower utilizes energy-dependent devices which must be continually powered for their operation. For rural parts of the developed world, or for either rural or urban regions of the developing world, continuous electrical power is not available. In some cases, the towers are placed in regions where grid-based electricity may not be available at all. In other cases, the grid-based electricity is unreliable and operates intermittently. For these situations, towers either utilize diesel-electric generators or they suffer from intermittent service. Reliance upon diesel power is expensive and polluting. In addition, for some regions of the world, the diesel must be protected against theft by round-the-clock guards.

In order to deal with the aforementioned limitations, a novel wind turbine was designed, constructed, simulated, and tested. The turbine is designed to be attached to existing towers so that installation costs are low. The turbine is a vertical-axis variant that is driven by drag forces. While vertical-axis turbines of this design are notably less efficient than their horizontal-axis counterparts (which are turned by lift forces), there are a number of advantages that make the vertical-axis turbine appealing for the present application. First, the geometry of a vertical-axis wind turbine (VAWT) fits nicely with the available space alongside a communication tower. Next, VAWTs are less sensitive to wind direction than their horizontal-axis counterparts (which require control systems to ensure that turbines are directed in the wind). Additionally, the VAWT begins rotating in slower wind speeds than other turbine styles. Finally, a VAWT rotates at relatively slow rates and, consequently, imparts a lessened vibrational load to the supporting tower. These four unique advantages make the VAWT appealing for use in the present application.

A complete wind turbine was designed (including structural, electrical, aerodynamic components). The prototype was constructed and tested in a large wind-tunnel facility. Simultaneously, the turbine rotor was created in a virtual environment and numerical simulation was used to estimate its performance. The turbine system was designed to be fabricated in a modular manner. The number of rotor sections would be selected based on the electrical requirements of the tower and the expected wind speed. During the design process, a number of novel features were included. First, one-way venting structures were inserted into the turbine rotor. The purpose of these venting slots was to reduce thrust loading on the tower with minimal degradation to the electrical performance. The second feature was a circular cap that was added to the upper and lower edges of the rotor. The cap was added to improve aerodynamic efficiency.

There exists a large body of literature devoted to the study of drag-based VAWTs. In the industry, these turbines are referred to as *Savonius* style turbines. In most studies, the turbines are created by bisecting oil drums or other large cylindrical structures. The halves are then slightly offset about a central axis of rotation [1-10]. The design used in this study presents a profile that is more complex than the traditional half-cylinder variant.

In order to provide perspective, Fig. 1 has been prepared. That figure shows a three-module VAWT attached to the side of a communication tower. The turbine rotor is visible as white blades which are seen in the upper part of the image.

2. Wind-Tunnel Experiments

A variant of the turbine shown in Fig. 2 was tested in a wind tunnel. A figure has been prepared which shows a single rotor of the turbine positioned within a wind tunnel. The photograph shows a person as a size reference. The figure includes callouts which highlight the venting and caps.

Fig. 1. Photograph of VAWT attached to a communication tower (from [11]).

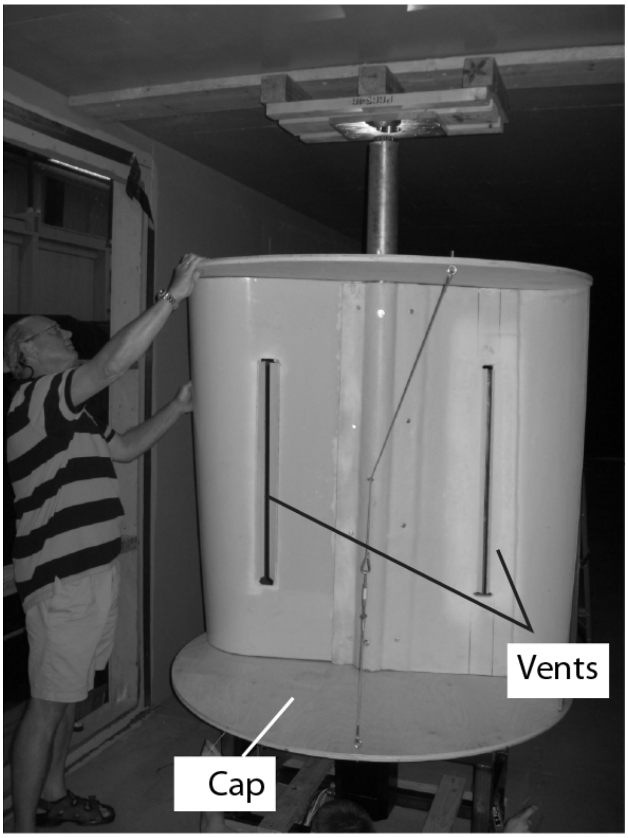

Fig. 2. Photograph showing a single-rotor section of VAWT prior to testing in a wind tunnel (from [11]).

An cross-sectioned image of the rotor shape is shown in Fig. 3. It can be seen that the rotor consists of two arcs connected by a straight segment. The figure includes annotations of the defining dimensions. Values of the dimensions are shown in Table 1.

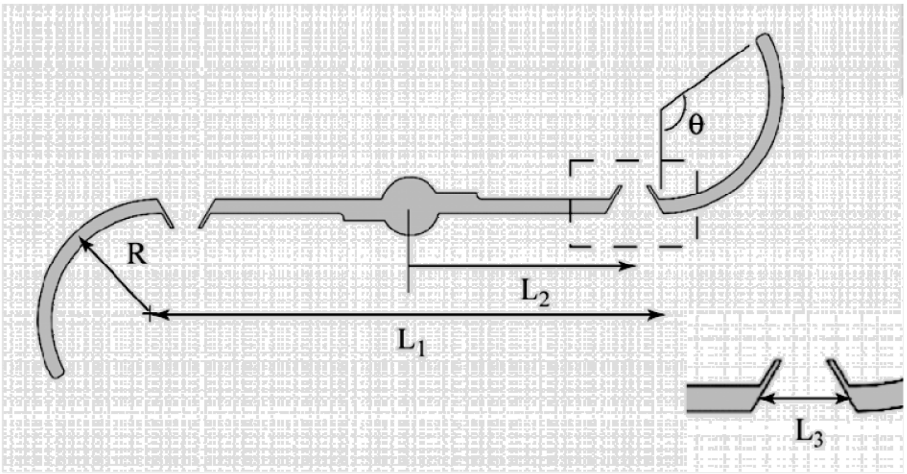

Fig. 3. Cross section of turbine rotor with dimensional nomenclature (from [12]).

Table 1. Relevant dimensions for the turbine blade.

L_1	0.92 m (36 in.)
L_2	0.41 m (16 in.)
L_3	0.10m (4 in.)
R	0.20 m (8 in.)
θ	120 degrees

The wind tunnel used in the tests was located at the St. Anthony Falls Laboratory in Minneapolis, MN. That wind tunnel contains two test sections, the larger of which spanned 2.44 m by 2.44 m. At this location, the maximum wind-tunnel air speed is 19 m/s. A schematic of the wind tunnel is presented in Fig. 4.

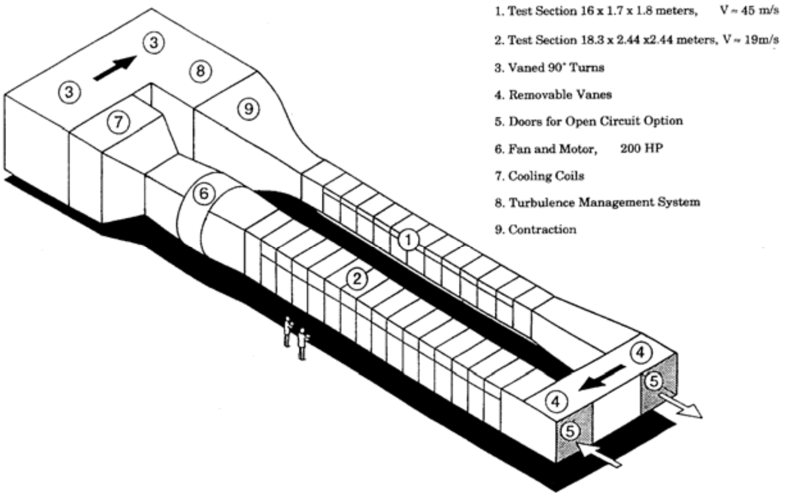

Fig. 4. Schematic diagram of the wind tunnel used in experiments (from [12]).

Since the turbine occupied approximately 25 % of the wind tunnel cross section, it was necessary to account for the *blockage effect.* The blockage effect refers to the acceleration of air which must occur as it passes over objects which present a blockage to a wind tunnel. Here, three independent estimates of blockage are used. First, in the literature, one study considered blockage of these types of turbines in wind tunnels [13]. Information from that study leads to the following estimate of blockage (F)

$$F = \frac{Power_{tunnel}}{Power_{free\ space}} \sim 2 \tag{1}$$

A second method to estimate blockage is to recognize that the velocity in a wind tunnel varies inversely with the open area. Since there is a 25 % reduction in open area, it follows that the effective velocity which impacts the turbine is 25 % higher than in the wind turbine proper. Inasmuch as wind power varies as the cube of velocity, it follows that

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

A third method of estimating blockage is to perform computational fluid dynamic simulations of a wind turbine inside and outside of a wind tunnel. A comparison of the rates of power generation provides estimates of blockage. Since power extraction is found by multiplication of the turbine rate of rotation and the torque generated by the turbine, it follows that

$$F = \frac{Torque \cdot rpm_{tunnel}}{Torque \cdot rpm_{freespace}} = 1.85 \ , \tag{3}$$

where the value of 1.85 was obtained from the fluid simulations. These three, independent estimates of blockage provide complementary and reinforcing evidence of the true blockage effect. It is clear that if the impact of blockage were ignored, errors of nearly 100 % would occur. In the subsequent presentation of data, a blockage factor of two will be employed for all experimental results.

3. Numerical Simulations

Numerical simulations were performed on a blade whose diameter and height are 1.33 m and 1.29 m, respectively. The height was not critical to the simulation because the calculations were carried out using the two-dimensional projection of the blade shown in Fig. 3. Calculations spanned a range of wind speeds from 4-15 m/s which are the expected ranges for operation of the turbine. Simulations were carried out for four complete rotations so that quasi-steady results could be obtained. For the quasi-steady results, torque and rate of rotation were determined which, in turn, allowed a calculation of the extracted mechanical power.

The simulations were completed with prescribed rates of rotor rotation. Multiple rotational rates were used for each wind speed. From the data, it was possible to extract a functional dependence of extracted power with rotor rotation rate so that for each wind speed,

$$power = function\ (turbine\ rpm) \tag{4}$$

In turn, this functional dependence was used to extract the maximum power generation for the wind speed under consideration. In the following section, the results from the simulations will be compared with experimental values which were determined from wind-tunnel tests. Reference [14] contains more details on the numerical simulations.

4. Results and Discussion

4.1. Unvented/Uncapped Rotors

The first set of results to be presented corresponds to power generation from an unvented and non-capped rotor blade. The rotor was connected to various electrical resistances which were used to simulate different electrical loads on the turbine. Results from the experiments are shown in Fig. 5. A few features are immediately apparent. First, the power rises with wind speed as expected, approximately as the cube of the velocity. Second, the performance of the device does not strongly depend on the electrical load.

4.2. Vented/Uncapped Rotors

The next set of results to be presented is shown in Fig. 6. These data correspond to a vented, uncapped rotor. A comparison between Figs. 5 and 6 reveals that the two rotors perform similarly with respect to power generation.

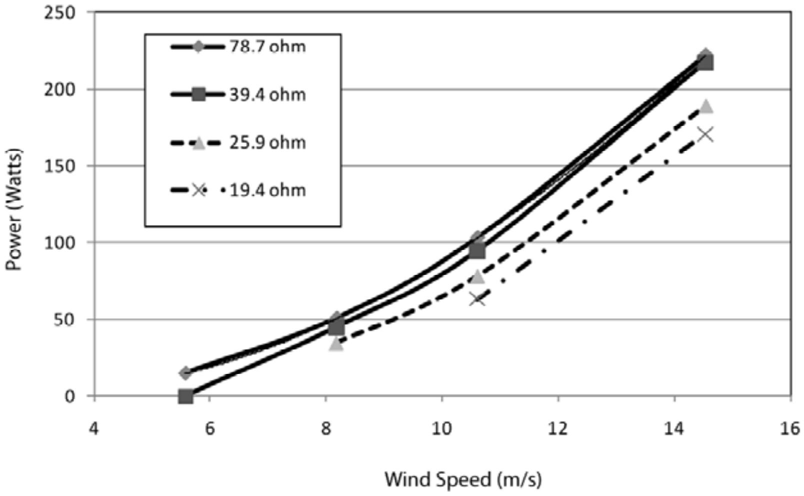

Fig. 5. Power extraction for a single section of an unvented, uncapped rotor (from [14]).

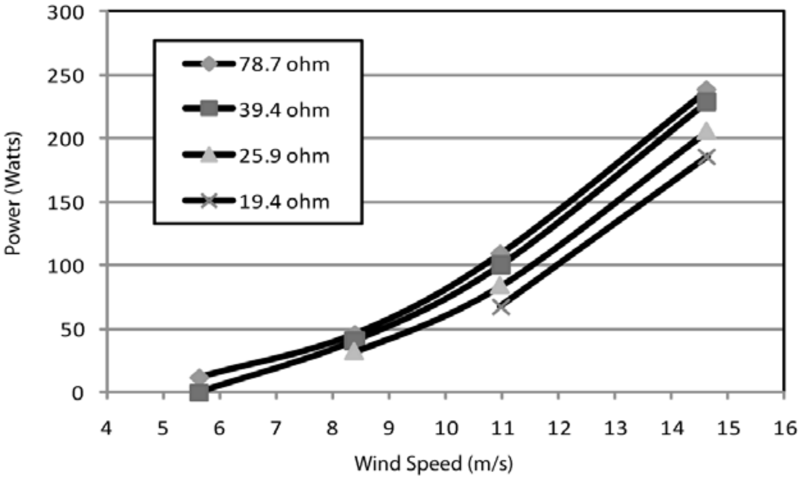

Fig. 6. Power extraction for a single section of a vented, uncapped rotor (from [14]).

4.3. Vented/Capped Rotors

The final set of results, presented in Fig. 7, is from a vented and capped blade. Along with these results, numerical simulations are shown. A few key features are immediately apparent from the graph. First, the performance is significantly higher than for the rotors discussed in Figs. 5 and 6. Second, the performance depends strongly on the electrical load. For the data presented in the figure, performance increases with electrical resistance. Also shown is the simulated maximum which was based on the discussion from Section 3. It is not surprising that the simulated maximum performance is slightly greater than the results from experiment.

Based on the results set forth in Fig. 7, it is apparent that a multi-stage vented and capped rotor has the potential to supply in excess of 1kW of power for wind speeds that reach values of ~10 m/s.

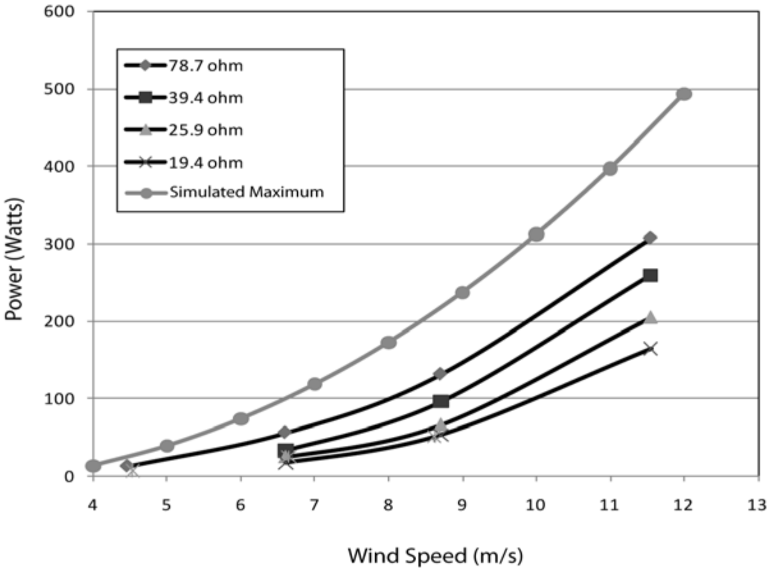

Fig. 7. Power extraction for a single section of a vented and capped rotor along with predicted maximum performance, based on simulations.

The numerical solutions provide information which is not made available through experiment. For instance, from the simulations, it is possible to obtain continuous values of pressure and velocity at all points within the fluid region. A typical example of the results is set forth in Fig. 8. There, a series of images has been prepared which show velocities by contour color. Images are extracted at a sequence of positions during a blade rotation with air moving from bottom to top in each figure. The presentation in Fig. 8 is intended to be representative of the entire set of simulations. In all cases, a large, low-speed wake region was seen downstream of the VAWT. A more detailed discussion of the simulations is provided in [14].

5. Concluding Remarks

In this study, a detailed investigation has been completed which evaluates the viability of powering communication towers with VAWTs. The VAWTs are designed to be attached to existing towers and consequently, the cost of installation is minimized. The VAWTs provide local power for the electronics and can supplant or complement other electrical sources of power. Currently, many towers are in off-grid areas where power is produced entirely by diesel power. In other cases, particularly in the developing world, towers are positioned in regions where grid-based power is not continuously available. In these cases, the VAWT would complement the grid-based power and would allow continuous operation, even when power was not available.

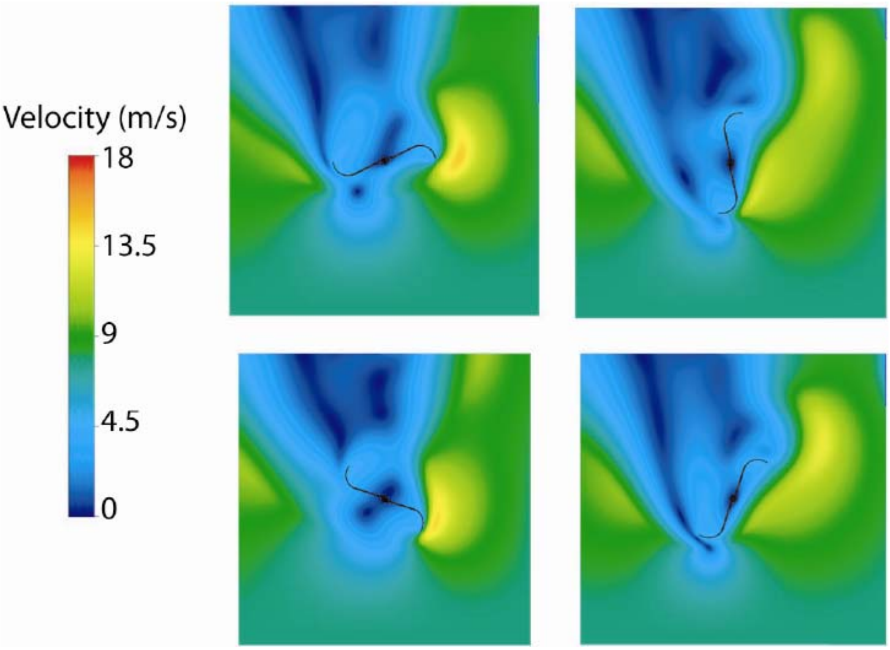

Fig. 8. Color contour presentation of air velocity in the vicinity of a rotating wind turbine. Results were extracted from a wind speed of 8 m/s.

The VAWT developed here has three variants: (1) a solid, unvented rotor, (2) a vented rotor, and (3) a vented rotor with caps attached to the top and bottom edges of the turbine. All three variants were tested in a large wind tunnel over a range of wind speeds that was expected in practice. It was found that both non-capped variants behaved similarly with respect to their power generation performance and the insensitivity of their performance with electrical load. On the other hand, the capped variety performed significantly better than the earlier models. Additionally, the capped rotor exhibited a much stronger dependence on electrical load.

Numerical simulations were performed on a two-dimensional version of the vented rotor. Inasmuch as a two-dimensional simulation does not allow wind to pass over or under the blade, it is expected to behave similar to a capped rotor. The simulations showed that the expected optimal rotor performance was slightly higher than the rotors which were tested in the wind tunnel. This results was expected and it allows the conclusion that this style of rotor is capable of producing more than 1 kW of power in wind speeds that are ~10 m/s or higher.

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- Smart sensors and systems;
- Sensor instrumentation;
- Virtual instruments;
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