

Wind tunnel tests on a high rotational urban Savonius turbine

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Abstract. Savonius wind turbines are gaining attention for their low-maintenance design and suitability for small-scale distributed power generation. The THRUST (The High Rotational Urban Savonius Turbine) project focuses on a small diameter Savonius rotor designed to withstand high wind speeds without a braking system. The experimental investigation was conducted in the Giovanni Solari Wind Tunnel at the University of Genoa, under smooth and turbulent flow. In addition to assessing flow conditions, key performance parameters such as torque, voltage, current, rotational speed, and rotor-generated noise were measured in the wind tunnel. Further investigations, including CFD simulations, have allowed to explore these effects in more detail and to interpret the rate of effective wind velocity increase caused by the wind tunnel blockage due to the presence of the wind turbine. This paper outlines the activities conducted, providing the description of the model, experiments, and measurements. As an example, a selection of results is presented, including power and torque curves, as well as acoustic emission measurements recorded near the rotor. The findings indicate that the Savonius rotor can sustain energy generation even at high wind speeds and turbulence, making it a viable solution for wind energy production in challenging conditions.

Keywords: Savonius Rotor, Wind Tunnel Tests, Small Size Wind Turbines, Turbulence Intensity, Power Curves, Noise Emissions.

1 Introduction

Small size wind turbines are becoming a very popular topic due to the increasing interest in distributed power production and renewable energy communities [1] [2]. Unfortunately, during the operating conditions, they may undergo to severe vibrations induced by gusty wind, turbulence and by sudden stops of the machine [3] [4]. These phenomena, besides having a detrimental effect on the energy production, can lead to damages and even collapses that have the effect of undermining the distributed wind production market [5]. In this context, the simplified maintenance requirements of Savonius rotors offer a great advantage that sustains their appeal in the market for small size installations and makes them ideal for meeting the wind power needs of prosumers [6]. A key advantage is their self-regulating capability: as wind speeds rise, the generated power naturally stabilizes, enabling the rotor to operate safely even in high winds—unlike other turbine types that may require shutdown to prevent damage. This phenomenon occurs naturally, with power output reaching zero at a certain rotational speed (for a tip speed ratio, TSR, of approximately 2).

The proposed research considers a small diameter Savonius rotor wind turbine that is specifically engineered to withstand high rotational wind speed without being provided by any braking system [7]. During very high wind speeds, while other types of wind turbines must be stopped, this Savonius rotor is still operating. In this condition, it supplies limited power but allows producing energy without excessive concern for very high rotational speed. Given the distinctive behavior in extremely high winds and high tip speed ratio power generation, which have not been thoroughly investigated to date, there is a pressing need for detailed measurements at high wind speeds and under various turbulence conditions, including the essential measurement of rotor noise at high rotor speed of rotation.

2 Case study and Wind Tunnel set up

The experimental tests were carried out at the Giovanni Solari Wind Tunnel of the University of Genoa. It is a closed-circuit type operating at atmospheric pressure; the working section is 8.8 m long, with a cross-section of 1.70 (width) \times 1.35 (height) m. The model under investigation consists of a steel Savonius rotor, with a diameter $\Phi = 0.25$ m and a height of 1.0 m, serving as a representative segment of an actual prototype wind turbine. The model is equipped with a torque meter and incorporates essential components such as a 3-phase PMG generator (inner rotor type), a Hall sensor, and an AC/DC current transducer that can be connected to the NI PXI wind tunnel system to measure current parameters and the rotor rpm. A dedicated terminal block facilitates the acquisition of current data. Furthermore, the current transducer communicates with a resistor module capable of applying appropriate loads to the wind turbine.

Tests were conducted under both smooth and turbulence flow conditions. Flow velocities were generated with a wind tunnel rotor propulsion fan frequency ranging from 8 Hz to 40 Hz, leading to wind speed up to 21 m/s (at the inlet), while the rotor's spinning was explored up to 2500 rpm. This comprehensive approach allowed for a thorough examination of the rotor performance across a wide spectrum of operational scenarios. Turbulent flow conditions with intensities I_u of approximately 4% were achieved using a wooden static grid positioned upstream of the model. The grid featured a bar width 15 mm, and mesh size 155 mm, defined as the distance between the centrelines of the bars. For each test, the load on the rotor was varied, measuring wind velocity at the inlet, temperature, torque, voltage, current, rotational speed. Moreover, to establish baseline noise levels within the wind tunnel, measurements were conducted by microphones in different positions and under various conditions. These included the wind tunnel operating with the rotating turbine, with the rotor removed but the mounting supports in place, and with the tunnel completely empty. Fig. 1 illustrates the wind tunnel layout for the tests, showing the position of the wind turbine, the Pitot static tube at the inlet, the grid, and the microphones M1-M4.

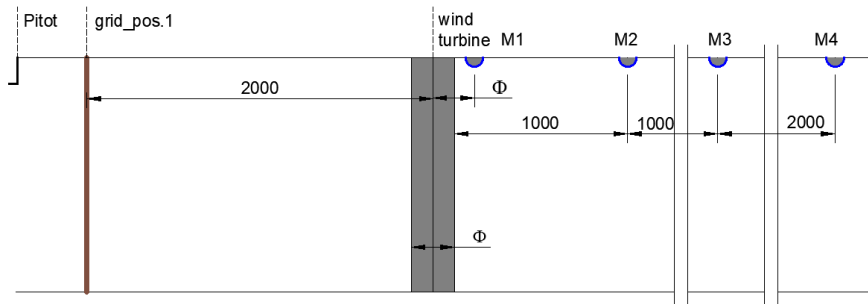


Fig. 1. Wind tunnel test layout (dimensions in mm)

Fig. 2a illustrates the steel rotor, the pivotal component of the experiment; Fig. 2b provides a glimpse into the wind tunnel, showcasing the model's placement; Fig. 2c highlights the wooden grid positioned upstream.

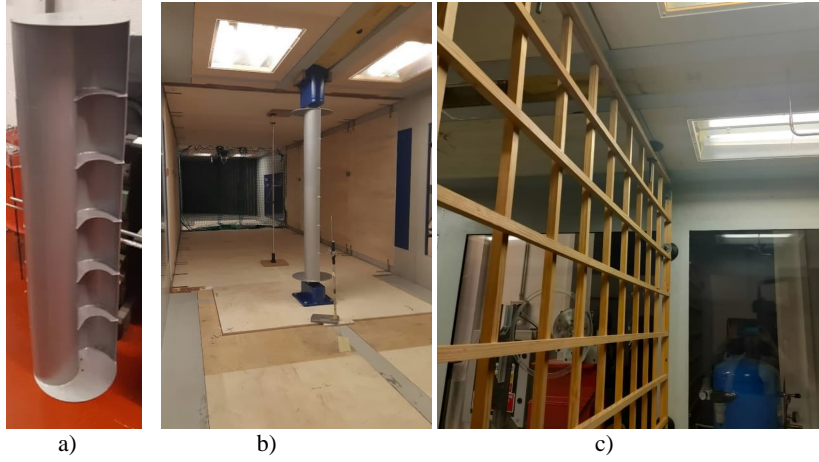


Fig. 2. Savonius rotor (a), model in the wind tunnel with the generator (b); the wooden grid for turbulence generation (c)

3 Wind Tunnel results

For each test run at a fixed propulsion fan frequency of the wind tunnel, f , experiments were conducted by varying the load applied to the rotor. At each load setting, the wind tunnel velocity—measured by the Pitot tube at the inlet—was stabilized to a steady-state value. Once the turbine reached a steady rotational speed, data was recorded for one minute. The load on the rotor was then varied, and new measurements were taken after reaching steady-state conditions. Fig. 3 reports an example of the measurements of the generated power, P , and torque, T , at different rotational speed ω (in rpm) of the turbine for $f=24$ Hz in smooth flow and with the wooden grid. In both conditions, the Pitot tube recorded a wind speed $v=12.3$ m/s. The Reynolds number is calculated as $Re = 3.9 \times 10^4$.

The measured data points establish the relationship between the extracted power and the measured torque versus the corresponding rotational speed of the rotor. The whole set of tests carried out at different wind velocities allows deriving the power curve of the turbine.

Referring to the flow velocity measured at the inlet section, the power coefficient c_p and torque coefficient c_T are obtained:

$$c_p = \frac{P}{\frac{1}{2} \rho v^3 A_s}; \quad c_T = \frac{T}{\frac{1}{2} \rho v^2 R A_s}; \quad (1)$$

where A_s is the turbine swept area, $R=\Phi/2$ is the turbine external radius, ρ is the density of the air. Fig.4 reports the diagrams of c_p and c_T versus the tip speed ratio $TSR=\omega R / v$.

Conversely, conducting experimental investigations of the rotor in a wind tunnel requires careful consideration of the blockage effect. Blockage correction for Savonius rotors [8] typically involves accounting for both solid object blockage and wake blockage. However, assessing these factors can be challenging due to the rotor's motion, which adds complexity to the analysis. Considering that the model frontal area is 0.25 m^2 and the wind tunnel cross section is 2.3 m^2 , the ratio of these surfaces yields a static blockage ratio of $S/C= 11 \%$. Following the approach of Pope and Harper [9], the power curve can be corrected considering an increment for the free stream velocity of about 3.5%, while the use of Maskell relationship [10] supplies a correction coefficient of about 16%. The use of one corrective coefficient over another leads to significant variations in the results. CFD analyses, carried out for the investigated set up, have shown that the method by Pope and Harper effectively adjusts the results to match those of an unconfined wind field.

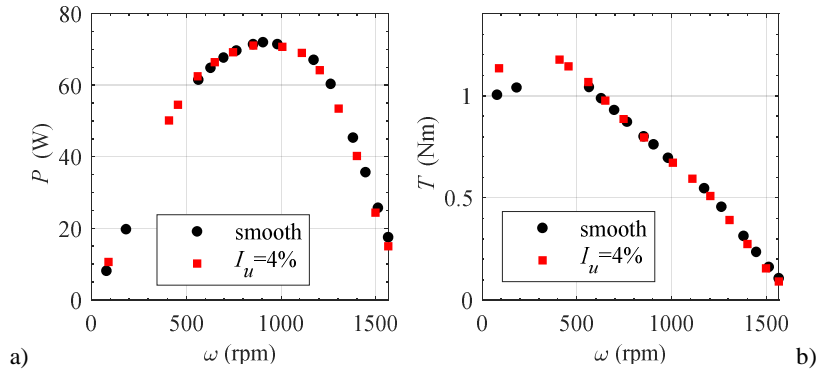


Fig. 3. Power (a) and torque (b) versus rotational speed (a) at different flow conditions for same propulsion fan frequency

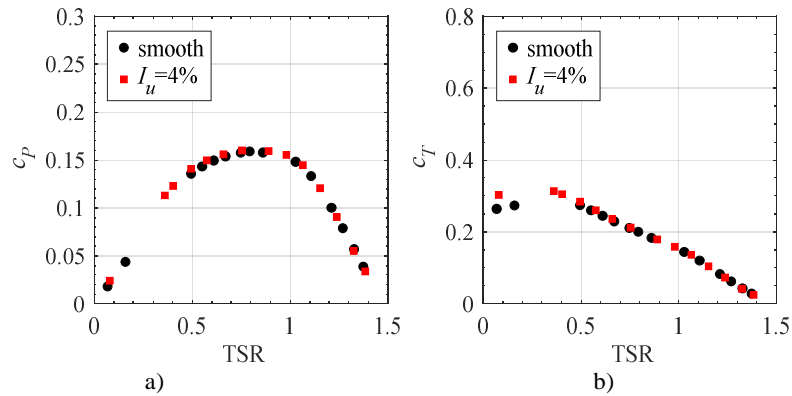


Fig. 4. Power (a) and torque (b) coefficients versus the tip speed ratio; the reference velocity is measured at the wind tunnel inlet.

Fig. 5 reports the power spectrum density (PSD) of the noise, in smooth flow, recorded by the microphone just behind the rotor (position M1, see Fig. 1) for the static condition in empty wind tunnel (i.e., without the model) and for the wind turbine in operation when it produces the maximum power. In this condition, the turbine rotates at $\omega=934$ rpm, that corresponds to frequency $1P=15.6$ Hz. Peaks in the PSD are clearly related to the spinning frequency and its multiples. Fig. 6 shows the noise variation during the tests at different tip speed ratio (a), rotational velocity (b) and generated power (c); the diagrams also report values in turbulent flow $I_u=4\%$.

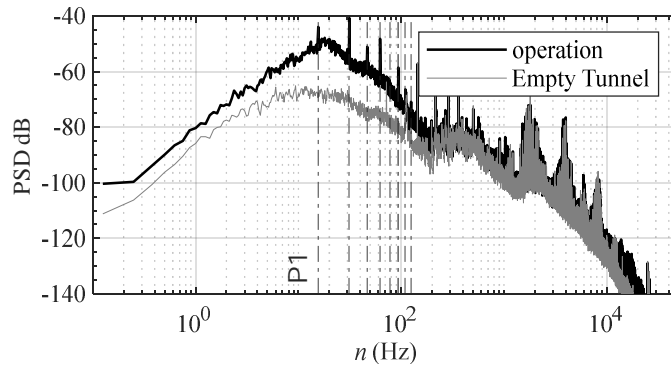


Fig. 5. Noise spectra in smooth flow at a fan frequency of 24 Hz, for the rotating turbine and in the empty wind tunnel.

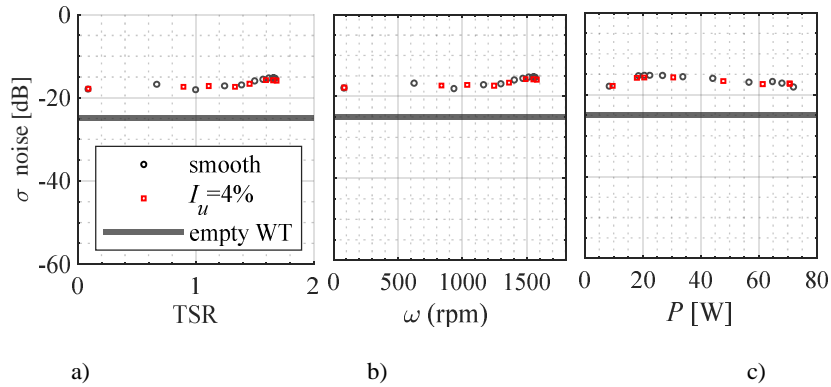


Fig. 6. Noise pressure level for the rotating turbine in smooth flow versus tip speed ratio (a), rotational velocity (b) and mechanical power (c).

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