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Wind tunnel testing of scaled models of a newly developed Darrieus - style vertical axis wind turbine

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Abstract

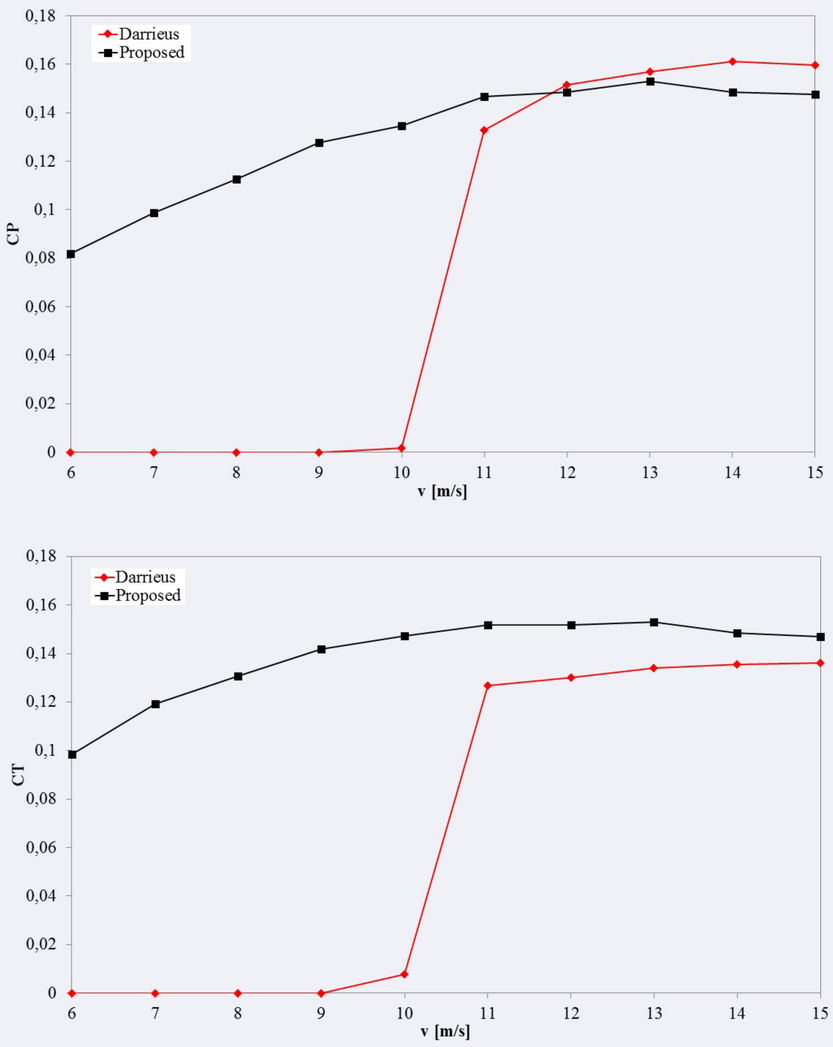
Renewable sources of energy, needed because of the increasing price of fossil derivatives, global warming and energy market instabilities, have led to an increasing interest in wind energy [1], [2]. Amongst the different typologies, small scale vertical axis wind turbines (VAWT) have the greatest potential for off grid power generation at low wind speeds [3]. In the present work, wind tunnel investigations about the performance of an innovative configuration of Darrieus-style vertical axis wind turbine has been made on scaled models specifically developed for small scale energy conversion at low wind speeds [4].

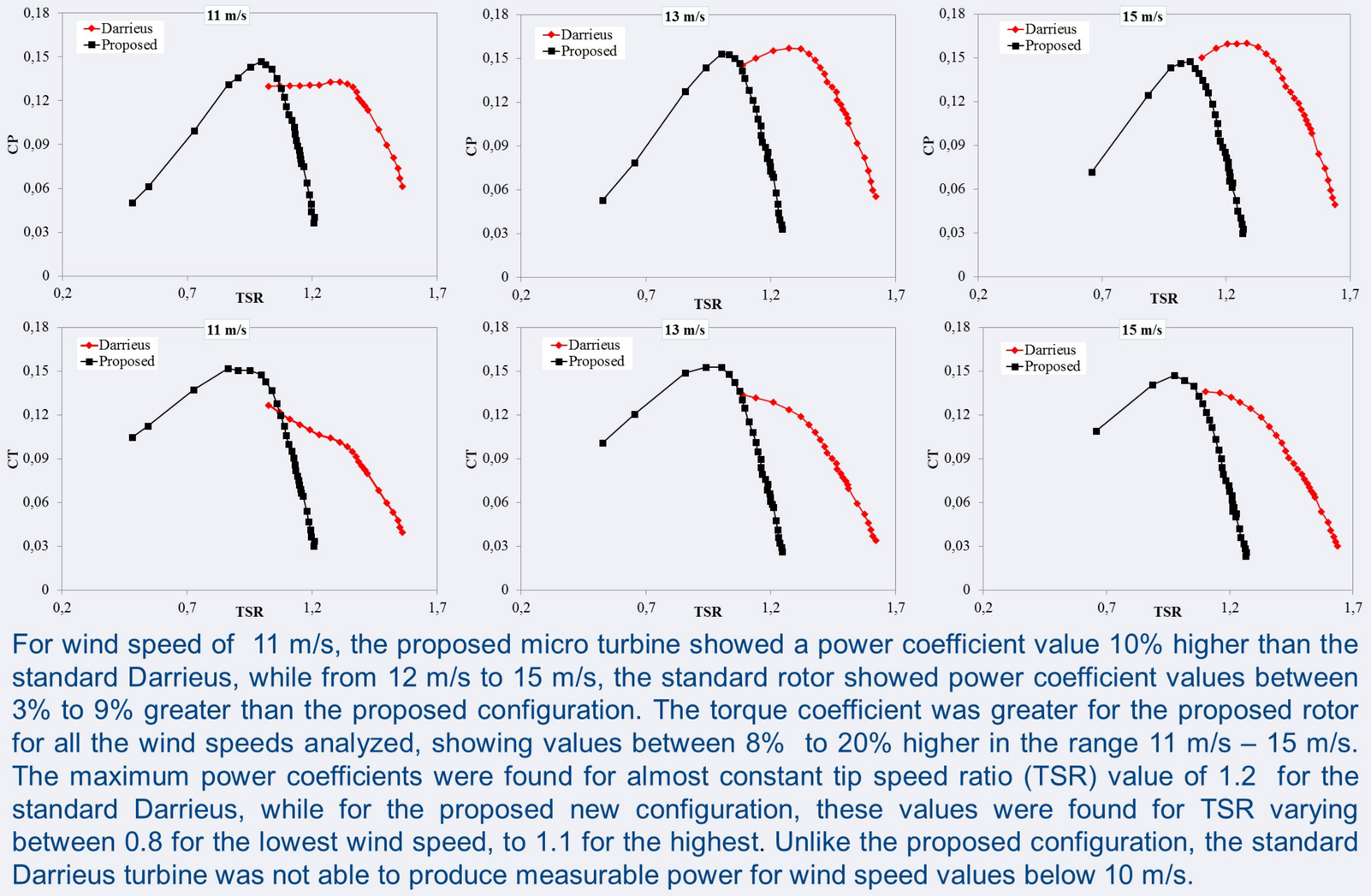
Objectives

The micro turbine under investigation consists of three pairs of airfoils. Each pair consists of a main and auxiliary airfoil with a chord length of 47 mm and 27 mm, respectively, the angle of attach is 13° , the auxiliary airfoil is placed in advanced position with respect to the main one. A standard Darrieus configuration, consisting of three single airfoils, was also tested for comparison. The length of the blades and rotor diameter are 150 mm and 200 mm, respectively. The experiments were conducted in a closed circuit wind tunnel facility available at the Industrial Measurement Laboratory (LaMI) of the University of Cassino and Lazio Meridionale. A brushless motor, acting as a generator, was directly connected to the wind rotor; series of resistors were used to simulate a variable load; electrical power and rotational speed was measured by a power analyser. From these data, power and torque coefficients were calculated.

Methods

The results of the experimental campaign are reported in terms of non dimensional parameters: power and torque coefficients versus wind speed curves, and power and torque coefficients versus tip speed ratio curves. The experiments were conducted for wind speeds ranging from 6 m/s to 15 m/s.





For wind speed of 11 m/s, the proposed micro turbine showed a power coefficient value 10% higher than the standard Darrieus, while from 12 m/s to 15 m/s, the standard rotor showed power coefficient values between 3% to 9% greater than the proposed configuration. The torque coefficient was greater for the proposed rotor for all the wind speeds analyzed, showing values between 8% to 20% higher in the range 11 m/s – 15 m/s. The maximum power coefficients were found for almost constant tip speed ratio (TSR) value of 1.2 for the standard Darrieus, while for the proposed new configuration, these values were found for TSR varying between 0.8 for the lowest wind speed, to 1.1 for the highest. Unlike the proposed configuration, the standard Darrieus turbine was not able to produce measurable power for wind speed values below 10 m/s.

An uncertainty propagation analysis on the measured data was made based on technical data of the instrumentation used and on repeated measurement series, showing a maximum relative uncertainty value below 14%, assuming a coverage factor k=2 (95% confidence level).

$$CP = \frac{P}{\frac{1}{2}\cdot\rho\cdot V^3\cdot A} \Rightarrow u_{CP}^2 = \left(\frac{\partial CP}{\partial P}\right)^2 u_P^2 + \left(\frac{\partial CP}{\partial \rho}\right)^2 u_\rho^2 + \left(\frac{\partial CP}{\partial V}\right)^2 u_V^2 + \left(\frac{\partial CP}{\partial A}\right)^2 u_A^2 + \left(\frac{\sigma}{\sqrt{N}}\right)^2$$

$$CQ = \frac{Q}{\frac{1}{2}\cdot\rho\cdot V^2\cdot A\cdot R} u_{CQ}^2 = \left(\frac{\partial CQ}{\partial Q}\right)^2 u_Q^2 + \left(\frac{\partial CQ}{\partial \rho}\right)^2 u_\rho^2 + \left(\frac{\partial CQ}{\partial V}\right)^2 u_V^2 + \left(\frac{\partial CQ}{\partial A}\right)^2 u_A^2 + \left(\frac{\partial CQ}{\partial R}\right)^2 u_R^2 + \left(\frac{\sigma}{\sqrt{N}}\right)^2$$

V (m/s) / U_r [%]	6	11	15
$U_{r,\,CP}$	7	9	14
$U_{r,\,CQ}$	5	8	12

Conclusions

From the wind tunnel measured data, it was found that the proposed newly developed rotor has a better performance in terms of torque coefficient with respect to a standard Darrieus configuration for all the wind speeds considered, while in terms of power coefficient, the standard Darrieus configuration has a slightly better performance for the highest wind speed analyzed. The proposed micro turbine configuration showed very good performance for the lower wind speeds (below 10 m/s) for which the standard Darrieus was not able to produce power. In conclusion, the proposed new micro turbine configuration showed an overall better performance, compared to a standard Darrieus rotor, which result in a better conversion of wind energy for very low wind speeds.

References

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