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

M. Scungio [a,*], F. Arpino [a], V. Focanti [b], M. Profili [b], M. Rotondi [b]

[a] Department of Civil and Mechanical Engineering, University of Cassino and Southern Lazio, via G. di Biasio 43, 03043 Cassino, FR, Italy
[b] Arken S.p.A. - Gymnotus S.a.s., via Stazione 182, 03013 Ferentino, FR, Italy

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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. Among the different typologies, small scale Vertical Axis Wind Turbines (VAWT) present the greatest potential for off grid power generation at low wind speeds. In the present work, wind tunnel investigations about the performance of an innovative configuration of straight-blades Darrieus-style vertical axis micro wind turbine, specifically developed for small scale energy conversion at low wind speeds, has been made on scaled models. The micro turbine under investigation consists of three pairs of airfoils. Each pair consists of a main and auxiliary airfoil with different chord lengths. A standard Darrieus configuration, consisting of three single airfoils, was also tested for comparison. The experiments were conducted in a closed circuit open chamber wind tunnel facility available at the Laboratory of Industrial Measurements (LaMI) of the University of Cassino and Lazio Meridionale (UNICLAM). Measured data were reported in terms of dimensionless power and torque coefficients for dynamic performance analysis and static torque coefficient for static performance analysis. The adoption of auxiliary airfoils has demonstrated to give more dynamic torque at the lower wind speeds with respect to a standard Darrieus rotor, resulting in better performance for all the wind speeds considered. In terms of dynamic power coefficient, the standard Darrieus configuration presented slightly better performance for the highest wind speed analyzed. The proposed configuration showed also an higher value of static torque coefficient with respect to the standard Darrieus micro turbine, resulting in a better self-starting ability.

1. Introduction

Wind energy, as other renewable energy sources, has gained high interest by the scientific community in the last years [18,11,29,2]. The increasing prices of fossil derivatives is pushing industrialized countries to the diversification of energy sources, also raising awareness to environmental issues related to the exploitation of traditional non-renewable energy reserves. In this context, the interest in developing wind energy technology is growing significantly since its potential in power generation is unaffected by political and economic instabilities [1,22,12,32].

The conversion of wind energy is obtained through wind turbines, which are mainly classified in two categories: Horizontal Axis Wind Turbines (HAWT) and Vertical Axis Wind Turbines (VAWT). Even if considerable progress has been achieved with HAWT, a lack in the available technical design of VAWT for small scale power generation at low wind speeds is still to be bridged, and more attention by scientific community and dedicated industry is needed in order to develop low cost reliable wind energy converters [5,10]. One of the aerodynamic issues of the VAWT is its continuously variable angle of attack of the blades with respect to the incoming wind [7]; this aspect, along with the high turbulence that the blades encounter passing in the leeward side of the turbine, make the VAWT configuration less efficient than the HAWT counterpart. The power generation cost of a 500 kW variable pitch VAWT at mean wind of 5.4 m/s, in fact, was found to be about 18–39% less than the HAWT [13].

Darrieus VAWTs, invented and patented in 1925 by Georges Jean Marie Darrieus, a French aeronautical engineer, who adopted airfoils for the blades, result to be particularly suitable for

* Corresponding author.
E-mail address: m.scungio@unicas.it (M. Scungio).

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residential applications or remote zones, since they can overcome limits such as blades size, rotational speed and building integration. In addition, in the case of small power generation, this kind of turbines can be cheaper than HAWT and can work with a comparable efficiency, which is higher than other VAWT such as the Savonius turbines. On the other hand, the main issue of the Darrieus turbines is related to their scarce performances at low wind speeds. For these reasons, in the authors opinion, studies aimed at developing small Darrieus-style vertical axis wind turbines for home applications with improved efficiency at moderate or low wind speed conditions, can result very useful for sustainable energy consumption.

Darrieus VAWT, was intensely investigated for about two decades, mainly by National Research Council (NRC) in Canada, Sandia National Laboratories (SNL) in the US, and The Carmarthen Bay Wind Energy Demonstration Centre in the UK, while recent innovations on this wind turbine configuration improved their reliability and performance [6,32,27]. In particular, Zamani et al. [35] and Bedon et al. [8] numerically investigated a Darrieus type wind turbine by means of computational fluid dynamic (CFD) tool, analyzing the static and dynamic performance of the turbine in relation to the blade profile, while the self-starting ability of VAWTs was recently analyzed by Worasinchai et al. [34] and Singh et al. [30] by means of numerical CFD approach.

Even though CFD investigations, if properly validated, represent a very powerful tool for wind turbine characterization and optimization, such investigation technique cannot be used without experiments. Unfortunately, on-field experiments can result very challenging because of the high variability of the meteorological conditions, and local wind speeds. In order to keep the testing conditions constant, it is then essential the use of a wind tunnel equipment. Wind tunnel experiments on Darrieus wind turbine were carried out by Khadir and Mrad [20], while Bianchini et al. [9] conducted wind tunnel experiments on different NACA airfoils to study the aerodynamic behavior of the same blades in curvilinear flow in Darrieus-like motion. Looking at the vertical axis micro wind turbines, the dimensions of the measurement section of the wind tunnel determines the possibility to perform the experimental investigations on a real scale wind turbine or on a scaled version. Anyway, it is crucial to use a wind tunnel that allows a good velocity uniformity of the flow in correspondence of the measurement section in order to get the more accurate data possible in terms of dimensionless parameters such as power and torque coefficients, with the corresponding measurement uncertainty [23,31,14,15].

In the present work, wind tunnel experiments on scaled models of an innovative straight-blades Darrieus-style configuration of vertical axis micro wind turbine, obtained with 3D fused deposition modelling printer, were made at different wind speeds and with a specifically designed measurement system, in order to characterize the turbine performance in terms of power and torque. In addition, the effect of the blade surface roughness on the turbine performances was investigated. Measurements on a standard Darrieus configuration of scaled micro turbine were also performed with the same experimental apparatus and under identical conditions, comparing its performance to the proposed innovative configuration.

2. Characteristics of the turbine blades

The proposed micro wind turbine configuration is composed of three pairs of airfoils placed at 120° each other. Each pair is composed of two airfoils, whose features are reported in Fig. 1a. The blades are a modified version of the DU 06-W-200 airfoil [17]. The angle of attach, α is equal to 13° for both the main and auxiliary airfoils; the ratio between main and auxiliary airfoils chord lengths, C_2/C_1, is equal to 0.57; the distance between the two airfoils, y, is equal to $0.29 \times C_1$ while the longitudinal distance between the airfoils, x, is equal to $0.38 \times C_1$.

In order to fit the micro turbine model into the wind tunnel measurement section, it was scaled and printed in PLA (polylactic acid) through a Fused Deposition Modelling (FDM) technique using a 3D printer. Referring to Fig. 1a, the main dimensions of the obtained printed rotor are the following: main and auxiliary airfoil chord lengths, C_1 and C_2, equal to 47.2 mm and 26.9 mm, respectively; distance between the two airfoils, y, equal to 13.7 mm; longitudinal distance between the airfoils, x, equal to 17.9 mm; angle of attach, α, equal to 13° for both the main and auxiliary airfoils. The height and diameter of the micro turbine model are equal to 150 mm and 200 mm, respectively.

Besides, a standard Darrieus rotor model composed of the main airfoil only was realized with the same characteristics, in order to compare its performance to the proposed VAWT. A drawing of the standard Darriues turbine is reported in Fig. 1b.

3. Experimental setup

Experimental investigations were carried out in the wind tunnel of the Laboratory of Industrial Measurements (LaMI) of the Department of Civil and Mechanical Engineering (DICeM) at the University of Cassino and Lazio Meridionale. In Fig. 2 a scheme of the wind tunnel is reported.

In particular, the wind tunnel used is of a closed circuit and open chamber typology, in which the air circulation is provided by a fan directly connected to a synchronous electric motor, con-

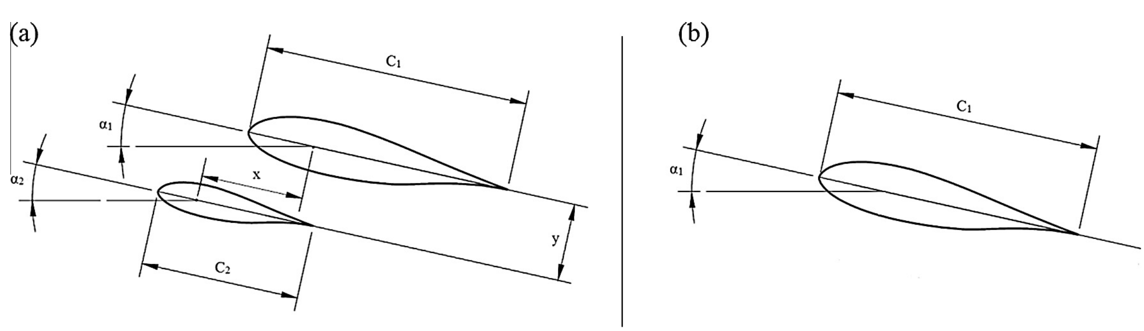

Fig. 1. Geometrical details of the analyzed micro turbine configurations: proposed (a), standard Darrieus (b).