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Design of a novel open space test rig for small scale wind turbine

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Abstract

In the present paper, an innovative and cost-effective open test rig for small and medium wind turbines is proposed. The main aim is to develop a valid alternative to wind tunnels, which present unresolved problems such as the unmatched Reynolds numbers for downscaled wind turbine tests. The proposed test bench concept is an open field, subsonic facility for horizontal and vertical axis wind turbines. The core of the test bench is a cluster of axial fans, positioned at a given height from the ground, which generate an air flow suitable for testing a wind turbine placed in front of the fans. The present work aims at investigating the feasibility of this novel concept of test rig for small wind turbines having a rotor diameter smaller than 5 m. A thorough CFD analysis is performed in this paper in order to assess the characteristics of the wind generated by the fans in terms of uniformity and intensity, even in case of atmospheric disturbances. The developed CFD modelling is also instrumental in both determining the maximum rotor diameter that can be tested and selecting the correct position for a wind turbine in the proposed open test rig.

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Keywords: Small scale wind turbines; Test rig in open field; CFD Simulations; Energy microgeneration.

1. Introduction

Energy production is changing in the world because of the need to reduce the greenhouse gas emissions, and the dependence on carbon/fossil sources [1,2]. Renewable energy sources have become one of the most important focus for the development of new energy concepts [3].

The reasons that can explain the increasing attention to renewables are the depletion of fossil fuels and the necessity of offering a best future to 4,5 billion of people who today have limited access to energy resources, and this is also in line with the international environment treaties aimed at reducing world pollution and global warming, i.e. Kyoto

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Protocol and EU 2020 [4]. In the next future, it is expected that most industries will produce energy for their own use by means of renewable sources, coupling the energy production with storage systems [4] to overcome the discontinuity in the availability of renewable sources.

One of the most promising and useful strategy consists in the employment of small size wind turbines, thus installing decentralized grid systems [5,6]. Small-scale wind turbines can be used as a reliable source of energy if they are properly sized. They are suitable for some autonomous applications that require a very high level of reliability; moreover, they can also become a generation source of socio-economically valuable energy for most of the developing Countries [5]. In addition, thanks to their small dimensions and attractive geometries, small/medium scale wind turbines are suitable for an urban environment because of their cut-in wind speed, which is lower than that of large wind turbines. This peculiarity shows good compatibility with different scenarios of application.

Most of the development of the design concepts for modern wind turbines is achieved by wind tunnel testing. Wind tunnel investigations present important features, such as the reproduction of a broad range of well-characterized wind conditions. However, in many cases this experimental approach has been hindered by the large size of blade models. As an example, a turbine generating power of the order of some MWs, has blades with a diameter larger than 50 m; on the other hand, the conventional wind tunnel facilities have diameters smaller than 10 m. Therefore, a scaled down model for the experimental studies of wind turbine blades is needed. This leads to the scaled effect, which comes from the fact that the Reynolds number in the experiment is significantly smaller than the real value [7][8][9]. In addition, the natural variability in the Atmospheric Boundary Layer flow, such as variations in wind velocity and direction, turbulence intensity, spatial heterogeneity and thermal stability, is difficult to be entirely reproduced through wind tunnel experiments [10]. Moreover, the wind tunnel walls do not allow one to reproduce the characteristic conical shape of the flow around the turbine rotor disk. The walls around turbines are geometrical constraints forcing the stream lines direction. As a result, the test section should be designed much larger than the turbine diameter to reproduce an open field condition.

Several research studies have been carried out to date in order to solve the problem related to the unmatched Reynolds numbers for downscaled wind turbine tests in wind tunnels. Makita and Sassa [11] proposed to employ a turbulence generator capable of inducing a certain degree of turbulence in the flow. An active grid system was used in [12] as a turbulence generator in an attempt to minimize the impact of the unmatched Reynolds number [12]. Turbulence grids were also used in [13] to adjust the turbulence intensity.

Rather than focusing on improving wind tunnels to overcome the above-mentioned limits, this paper proposes an innovative way of testing wind turbines, which consists on using cost-effective, open field test rigs, very different from conventional ones. As to date, the scientific literature has not highlighted effective wind tunnel tests capable of reproducing an open bound test rig, the task is very challenging and, at the same time, can represent a great innovation in wind turbine tests.

Comparing conventional systems (wind tunnels) with the proposed one (open test rig), it is clear that the latter can eliminate a lot of elements that induce a major usage of resources in term of both costs of installation and time for designing the facilities. In fact, a typical wind tunnel mainly consists of a convergent duct followed by a divergent one, which are usually equipped fans, honeycombs, and other channels to guide the air. Furthermore, typical wind tunnels are usually characterized by large lengths which can be as high as 30 m [14,15]. The main advantage of the proposed solution over common wind tunnels is the possibility of analysing the real effect of open field surroundings and all the associated phenomena, such us the real wind speed, turbulence effects and atmospheric conditions. Moreover, another important advantage is the absence of the scale effect because rotors can be tested with their real geometry. In addition, as confirmed by [16,17], the blockage effect would not be encountered, therefore the turbine power output would not be affected by any increase in velocity due to the wind tunnel walls.

The realization of such a system will be part of a net of laboratories called "Zero Emission Research Option" (ZERO), which the Polytechnic University of Bari and Apulia Region decided to found in order to study the conversion and management of energy obtained from renewable sources. In addition, the laboratory will work to promote the development of the smart grid technology in a smart city context. In this regard, lab-ZERO will be integrated with a micro co-generative heat and power plant [18–21] fuelled with carbon-neutral biomass (such as pruning residues [22]) to provide energy to all of the facilities.

In the present work, a thorough 3-D Computational Fluid Dynamics (CFD) approach has been employed with the aim of accurately predicting the air flow generated by the fans and its interaction with the external environment. This analysis aims at determining the correct distance at which the wind turbine must be placed in the proposed open test rig and the maximum diameter of the rotor that can be tested.