International Conference on Renewable Energies and Power Quality (ICREPQ'14)
Cordoba (Spain), 8th to 10th April, 2014
Renewable Energy and Power Quality Journal (RE&PQJ)
ISSN 2172-038 X, No.12, April 2014

Wind Tunnel Experiments on Vertical-Axis Wind Turbines with Straight Blades

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Abstract. This paper gives the experimental performances obtained in a wind tunnel for a flexible experimental model of vertical axis wind turbine (VAWT) with straight blades. The effects of blades arrangement in one or two stages, of setting angle and of blade numbers influences on the output performance were analysed. The results showed that the VAWT developed torque at low speeds is greater when the setting angle of blades is greater but the VAWT developed torque at higher speeds is greater when the setting angles of blades is less.

Key words

H-rotor VAWT, NACA Airfoils, Wind-Tunnel Experiment.

1. Introduction

The development of high performance VAWT is a recent requirement of the strategies in renewable energy. This research focuses on the experimental studies of VAWTs which can work under an average velocity of wind that is very low, as is the case of most places in Romania. There are many types of VAWTs, which is categorized by the shape of the blades. Basically there are two different shapes of blades; straight blades and curved blades. Curved-bladed VAWTs is rarely applied due to its difficulties in manufacturing. For a small scale wind power generation, straight-bladed VAWTs is more popular because of its design simplicity, low manufacturing cost and also good maintenance. This is why among VAWTs; the straight-bladed type is often called as the conventional type. At present, most of the commercial VAWT systems on the market have the output power of 1÷5 kW and blade chord length of 0.2÷0.3 m. They are designed for wind speed between 3÷15 m/s and its associated Reynolds numbers are low ($Re < 10^5$). There are few research publications that focus on optimal structure of VAWT with straight blades [1-7].

The purpose of this work is to explore the effects of blades arrangement in one or two stages, of setting angle of blades and of blades numbers influences on the output performance of a VAWT system. A small versatile VAWT system which allows the study of several VAWT configurations was manufactured in this aim. The experiments were performed at a low speed wind tunnel on the basis of developed torque and rotational speed. The experimental results showed that the VAWT developed torque at low speeds is greater when the setting angle of blades is greater but the VAWT developed torque at higher speeds is greater when the setting angles of blades is less. The effects of doubling the number of blades on the torque was also investigate and it was found that it is equivalent with doubling the total height of the rotor. For application of VAWT system it is suggested that the straight blades rotor in two stages is suitable for electrical power generation.

2. VAWT Experimental Model

The VAWT model developed for experimental studies is shown in Fig. 1 and 2. The turbine rotor comprises two vertically arranged stages. A total of six blades, three in each stage, form the basic configuration of the rotor. Each stage contains three straight blades arranged symmetrically at 120 degree-angle. Geometrically, the vertical planes which enclose the blades in the one stage make a spatial 60 degree-angle with the vertical planes which enclose the blades in other stage. The rotor stages are separated by circular endplates where each blade is hinged. The blades can be arranged at 0, 3, 6, or 9 setting (pitch) angles. Also, on a stage can be mounted 6 blades.

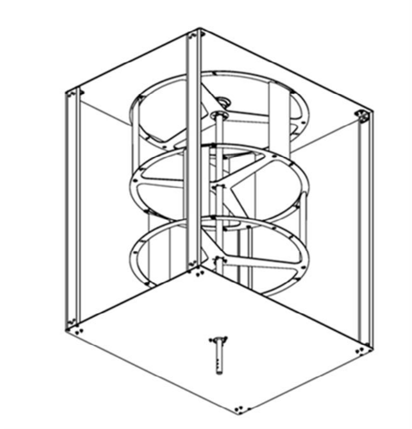

Fig. 1. Schematics of the two stages VAWT experimental model.

Fig. 2. A view of the VAWT experimental model mounted in the low speed wind tunnel

Table 1. Geometrical dimension of VAWT experimental model

Blade air foil type	NACA 0018
Number of blades/stage, B	3
Blade chord (constant), c [m]	0.08
Blade span, h [m]	0.30
Rotor diameter, D [m]	0.50
Rotor height (two stages), H [m]	0.60
Number of stages	2
Rotor solidity, $\sigma = B \cdot c / D$	0.48

3. Experimental results

A. Self-starting performances

A VAWT is considered to be self-starting only if can accelerate from rest to the point where it starts to produce a useful output or, more specific, if the rotor has accelerated from the rest to a steady speed that exceed the wind speed, i.e. the tip-speed ratio[1] $TSR > 1$, when the transition from the drag driving to the lift driving take place [8], [9].

[1] $TSR = \Omega \cdot R / v$, where Ω is the angular speed of the turbine, R is its rotor radius and v is the wind speed.

In order to obtain information about the start-up behaviour of the turbine, the wind tunnel's speed was stabilized to a predetermined value and each trial began from a random angular starting position of the turbine rotor.

In Fig. 3 is shown the evolution of the instantaneous values of the rotation speed and of the delivered torque for a wind speed of 11.7 m/s. These wind tunnel repeatable starting characteristics obtained on the model confirm that a Darrieus turbine with symmetrical air foils is capable of self-starting in a steady airflow. According to these starting characteristics, the turbine starting process has the following phases: initially the rotor speed has a small linear acceleration, then it receives a higher acceleration and finally its speed reaches a constant value. Slopes of the curves of Fig. 3 are similar to those given by Hill and others [10].

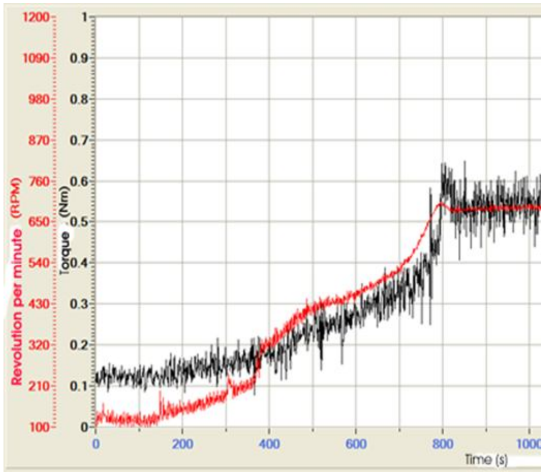

Fig. 3. Evolution of the rotation speed and of the torque for a two stages turbine model with a setting blade pitch angle of 3 deg., for a wind tunnel's speed of 11.7 m/s.

A lot of starting curves were generated for the analysed turbine model. The summarized results of these experiments are shown in Fig. 4, where the measured tip speed ratio (TSR) is plotted as a function of wind speed, for three values of the setting blade pitch angle.

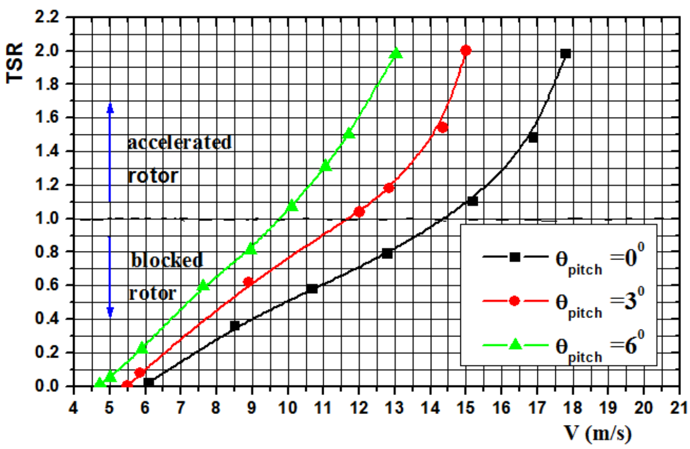

Fig. 4. Measured tip speed ratio versus wind speed for three values of blade pitch angle.

According to Fig. 4, the two stages Darrieus rotor has self-starting capabilities both at low Reynolds numbers and to moderate values of the solidity. Also, it can conclude from these curves that the blade pitch angle has a great influence on the self-starting behaviour of the turbine: higher values of the blade pitch angle are favourable for a low speed wind starting.

B. Setting angle influences

Three different turbine rotor configurations which comprise two stages, each with three blades, arranged at 0 and 3 setting (pitch) angle degree and one stage with six blades arranged at 3 setting (pitch) angle degree were considered. The results of the experimental studies are shown in figure 5, 6, 7, and 8.

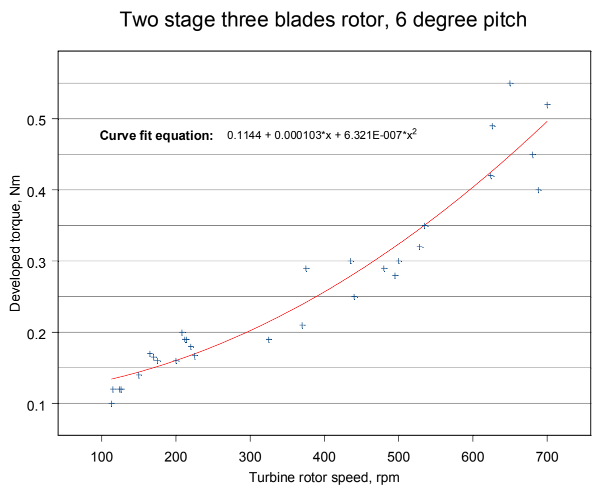

Fig. 5. Torque – rotational speed diagram for two stage three blades rotor with 6 degree pitch

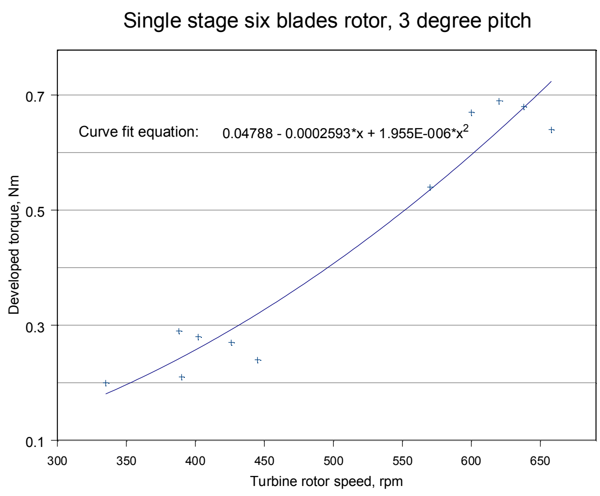

Fig. 6. Torque – rotational speed diagram for single stage six blades rotor with 3 degree pitch

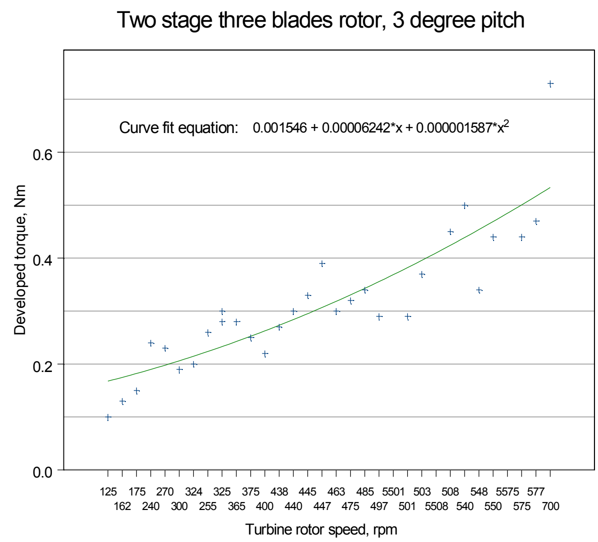

Fig. 7. Torque – rotational speed diagram for two stage three blades rotor with 3 degree pitch

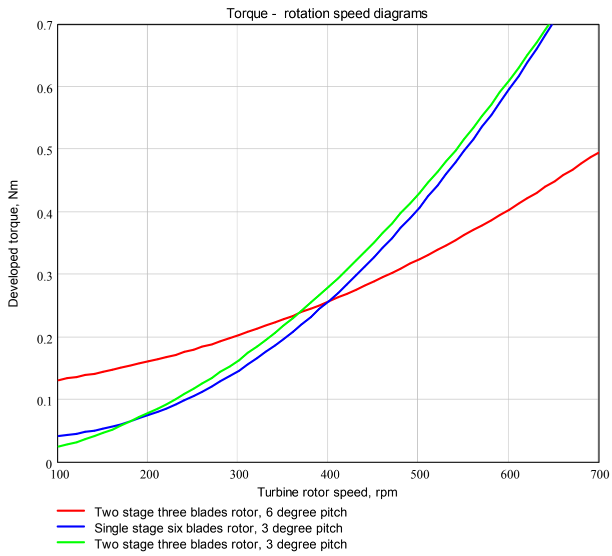

Fig. 8. Comparative torque – rotational speed diagrams based on curve fit equations for the analysed rotor configurations.

4. Conclusion

The straight blades Darrieus turbine has self-starting capabilities both at low Reynolds numbers and to moderate values of the solidity. The blade pitch angle has a great influence on the self-starting behaviour of the turbine: higher values of the blade pitch angle are favourable for a low speed wind starting.

According to the results showed in Fig. 8, the VAWT developed torque at low speeds is greater when the setting angle of blades is greater but the VAWT developed torque at higher speeds is greater when the setting angles of blades is less.

Acknowledgement

This work was realized through the Partnership program in priority domains - PN II, developed with support from ANCS CNDI - UEFISCDI, project no. PN-II-PT-PCCA-2011-3.2-1670.

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