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Experimental study on novel curved blade vertical axis wind turbines

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ABSTRACT

This paper presents the experimental study into the design and the electrical performance of a few novel curved blade vertical axis wind turbines. In the wind turbines, blade shape and quantity are crucial. In this study, curved wind blades are designed, fabricated, and used in developing the small-scale vertical axis wind turbines. Wind tunnel tests were carried out, and Results were presented for cases of vertical axis wind turbines with 2-blade, 3-blade, 4-blade configurations. Electrical parameters were monitored and compared for three different configurations. Results show that the curved blade wind turbine with a 3-blade configuration performs better when compared to the other two configurations.

1. Introduction

Climate change is a menace for the existence of life on this planet and the energy sector is the prime responsible, especially the thermal power plants [1]. To mitigate the climate change impacts due to the energy sector, the world is looking at the various alternative sources for power generation [2]. The most suggested alternatives are renewable energy sources as they are clean and sustainable [3]. Among these alternatives sources, the use of wind energy systems is becoming popular in modern-day power systems like hybrid microgrids and smart grids [4]. Wind turbines with a specific number of blades are generally used for harvesting the energy available in the wind. The most widely used wind turbine systems are horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). Among these two wind turbines, the research work carried out in VAWT is very little, and it is gaining much interest in recent years due to its advantages when compared to the HAWT. The VAWT does not need to have constant yaw control, and it can be operated even with lower wind speeds. Besides, they have benefits in terms of manufacturing and installation costs [5]. Although VAWTs have many advantages, the use is still limited. The most stressed issues in the literature are on the performance and design aspects. Several studies were available on the blade designs, but even the problems related to performance are prevailing [5–7]. To address such issues, researchers have opted for simulations and experimental studies [8].

In this paper, to add up to the literature on design aspects of VAWT wind turbines, new curved type wind blades were designed and fabricated. The fabricated blades were used to develop the prototypes of VAWT in three different configurations (2-blade, 3-blade, 4-blade), see in Fig. 1. The main objective of this study is to carry out the wind tunnel tests and to present the performance results. Also, a comparative study of performance results is done to select the best wind blade configuration.

2. Experimental

A wind blade is shown in Fig. 1 a) is designed. The designed curved wind blade is based on varying chord length and width, as shown in Fig. 1 b). Using the designed curved wind blades, the solid works models of 2-blade, 3-blade, and 4-blade VAWT systems were developed, as shown in Fig. 1c) and d), and e). The created models and various components, such as supporting structures and shafts, were then fabricated by using the computer numerical control (CNC) machine. Aluminum 7020 alloy is used for the fabrication of VAWT components, see in Fig. 2a) and b), c), and d).

A small-scale direct current (DC) generator and DC load are considered to understand the electrical parameters. The fabricated VAWT models were tested in the subsonic wind tunnel. For the experimental study, we used the wind tunnel facility that is available in the wind tunnels laboratory at the Karunya Institute of Technology and Sciences. The wind tunnel used for this study has a square test section of dimensions 600 × 600 × 4000 mm and has the bell mouth screened inlet for wind flow. In the test section, the VAWT models were placed and fixed, see in Figs. e), f), and g). Once the VAWT is placed in the test section, the wind tunnel is operated at different speeds. The wind velocity in the test section is controlled by varying the speed of the subsonic

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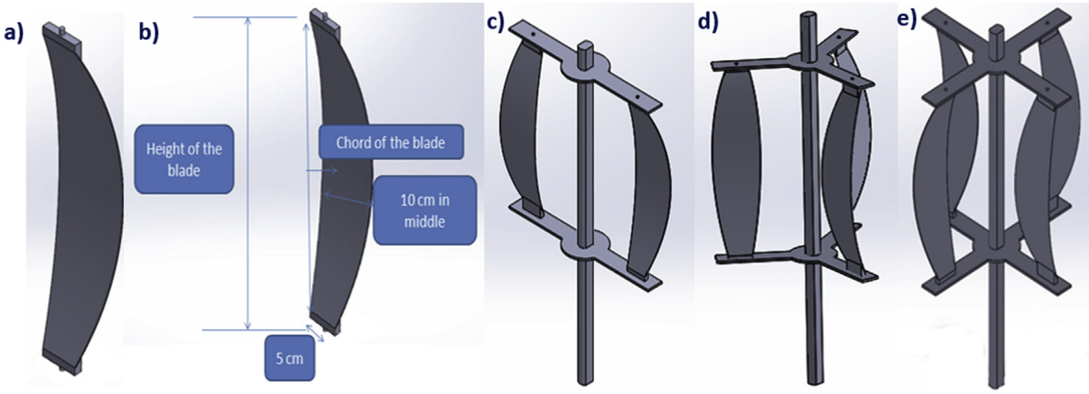

Fig. 1. a). Curved wind blade; **b).** Curved wind blade with labels; **c).** Solid works model of 2-blade vertical axis wind turbine; **d).** Solid works model of 3-blade vertical axis wind turbine model; **e).** Solid works model 4-blade vertical axis wind turbine model.

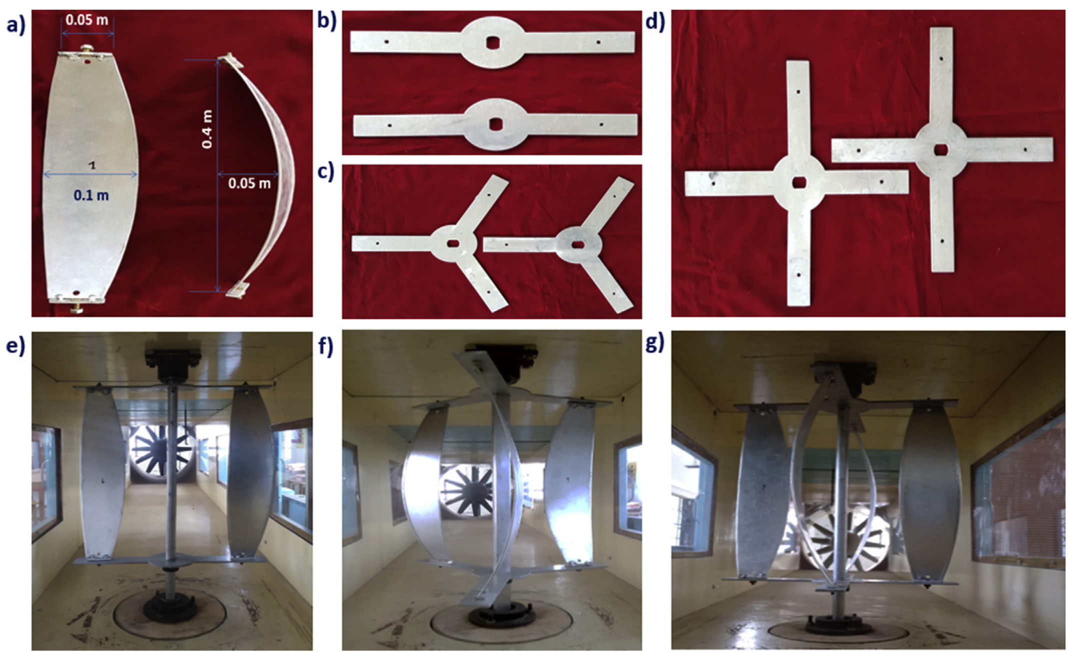

Fig. 2. a). Fabricated model of a curved wind blade; **b).** Supporting structures for 2-blade vertical axis wind turbine; **c).** Supporting structures for 3-blade vertical axis wind turbine; **d).** Supporting structures for 4-blade vertical axis wind turbine; **e).** Wind tunnel testing of a fabricated model of 2-blade vertical axis wind turbine; **f).** Wind tunnel testing of a fabricated model of 3-blade vertical axis wind turbine**;** **g).** Wind tunnel testing of a fabricated model of 4-blade vertical axis wind turbine.

wind tunnel motor. The wind velocity experienced by the VAWT is calculated based on manometers height difference (h_1 and h_2) using Equation (1) [9].

$$Wind\ Velocity = \sqrt{\frac{Manometer\ fluid\ density}{Air\ density} \times 2 \times gravitational\ force \times (h_2 - h_1)} \quad (1)$$

3. Results and discussion

This section presents the results obtained from the experimental study of VAWTs in the wind tunnel. The results showed in this section include the wind velocities and the electrical parameters of the VAWT for 2-blade, 3-blade, 4-blade configurations, see in Fig. 3.

In Fig. 3 a), the 2-blade, 3-blade, and 4-blade VAWTs shaft rotation are presented concerning the experienced wind velocities. From Fig. 3 a), it is observed that the shaft rotation of the 3-bladed VAWT is higher than the other two (2-bladed, and 4-bladed VAWT) up to 10.32 m/s wind velocities. With velocities higher than 10.32 m/s, the shaft rotation of the 2-bladed VAWT has increased drastically. In Fig. 3 b), the voltage generated in the VAWTs with 2-blade, 3-blade, 4-blade configuration is given. The voltage produced by the 4-bladed VAWT is more up to 4.47 m/s wind velocity, but later, with an increase in wind velocity, the voltage produced has drastically fallen. Whereas 2- bladed VAWT produced less voltage up to 4.47 m/s wind velocity, and for wind speeds higher than 4.47 m/s, the voltage produced has increased drastically. The current produced in the VAWTs with 2-blade, 3-blade, 4-blade configurations are presented in Fig. 3 c). From Fig. 3 c), it is understood that 2-bladed VAWT produced more current up to 3.7 m/s and reduced with an increase in wind velocity. Whereas the 4-bladed VAWT produced less current up to 3.7 m/s wind velocity, and after 3.7 m/s, the amount of current produced increased than the other two rotors. Based on the obtained voltage and current data, the power outputs were evaluated and showed in Fig. 3 d). The overall power generated is high for a 4-bladed rotor up to 13.16 m/s. But with wind speeds higher than 13.16 m/s, the amount of electricity generated by 4-bladed VAWT is less than that of 2-bladed and 3-bladed VAWT.

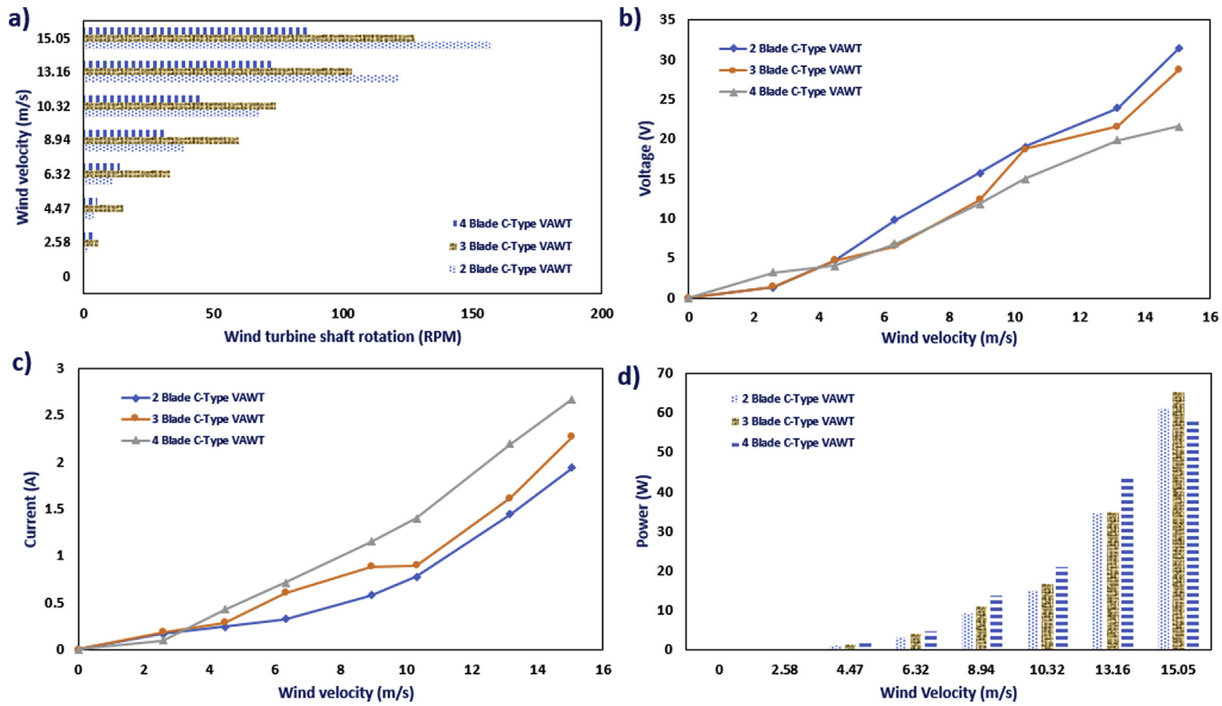

Fig. 3. a). Wind turbine shaft rotation vs. wind velocity; **b).** Output voltage; **c).** Output current; **d).** The power produced by the vertical axis wind turbine.

4. Conclusions

A small model of curved blade vertical axis wind turbines has been designed, manufactured, and tested in the subsonic wind tunnel, and Results were presented for 2-blade, 3-blade, and 4-blade configurations. The experimental study was carried out to select the suitable blade configuration over a range of operating wind conditions. From the preliminary research, the following conclusions were made:

- With an increase in the number of blades, the total amount of power generated is increased only up to 13.16 m/s and later is reduced.
- For wind velocities, less than 13.16 m/s, 4-bladed vertical axis wind turbine rotors are more suitable.
- With wind speeds higher than 13.16 m/s, the 3-bladed vertical axis wind turbine rotor gives the optimal result.

Overall, from this experimental investigation on the curved wind blade-based vertical axis wind turbine, it is suggested to use a 3-blade configuration for higher wind speeds for desired electrical outputs.

Declaration of competing interest

We declare that this manuscript is not under consideration for publication anywhere else and its communication is approved by all the authors.

To the best of our knowledge no conflict of interest (financial or otherwise) exists.

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