An aerodynamic study of a micro scale vertical axis wind turbine

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Abstract

The utilization of wind to generate power provides an alternative and renewable energy source compared to current fossil fuels based power generation. The world’s fossil fuel energy is finite and is depleting at a faster rate. Moreover, the fossil fuel is directly related to air pollution, land and water degradation. Despite significant progresses have been made in power generation using large scale wind turbines recently, domestic scale wind turbines especially vertical scale wind turbines have been received less attention which have immense potentials for standalone power generation. This paper examines the aerodynamic advantages of a novel prototype vertical axis wind turbine that can be used for power generation in built up areas.

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Keywords: Wind turbine; aerodynamics; efficiency; power generation; wind characteristics.

1. Introduction

The rising greenhouse gas emission from fossil fuel energy resources and the uncertainty of energy supplies have forced to explore alternative renewable energy sources for power generation. Most developed including Australia and emerging economies adopted a renewable energy target. Power extraction from wind has achieved significant improvement over the decade, making it more economically competitive over other renewable energy sources for power generation.

The wind power is abundant, renewable, widely distributed, clean, produces no greenhouse gas emissions during operation and uses little precious land [3, 4, 9, 10]. Any effects on the environment are generally less problematic than those from other energy sources. As of 2010, wind energy production was over 2.5% of worldwide power, growing at more than 25% per annum. Thanks to the technological advances and better understanding of wind characteristics, the overall generation cost per unit of energy has come down to the cost of power generated by using high grade coals and/or natural gas [2, 5, 6, 7].

In 2010 and 2011, more than half of all new power generation from the wind was added for the first time outside of Europe and North America. China and India lead the construction of wind turbines for power generation, accounting over half of the world’s total new wind turbine installations [7]. Over the past five years the average growth of new wind turbine installations is estimated to be over 27.6% each year. The world’s top eleven countries that generated power from the wind in 2011 are shown in Fig. 1.

Currently two types of wind turbines: a) horizontal axis wind turbines (HAWTs) and b) vertical axis wind turbines (VAWTs) are widely used to generate electricity. Both types of turbine have been tested and optimized in smooth flows –
usually in wind tunnels or in computations fluid dynamic domains. However, their performances can significantly differ in situ from the predicted performances.

China has become world’s largest manufacturer of wind turbines ranging from large scale to domestic scale. The power output of a domestic scale or micro scale wind turbine is generally less than 10 kW. One of the difficulties for the application of domestic scale wind turbines in urban environment is the complex wind characteristics due to the presence of buildings and structures. In urban areas close to the ground the atmospheric wind is highly turbulent and this is particularly strong in close proximity of buildings. Turbulence exhibits significant fluctuations in magnitude and high directional variability. Under such conditions the VAWT is a more effective power generator than the HAWT. Generally, VAWTs possess fewer moving parts and a lower tip speed ratio than HAWTs making VAWTs significantly quieter and thus well-suited for urban applications. Unlike HAWTs, which have to continuously ‘yaw’ (rotate about the vertical axis) into the ever-changing wind direction, VAWTs are less sensitive to changing wind directions and therefore to turbulence. This is an important advantage for the effective use of VAWTs in urban and built environments [1]. However, most domestic scale VAWTs and HAWTs are not efficient and do not perform well as they are being developed by wind energy enthusiasts and small companies who generally do not have adequate technological and financial resources to refine their initial designs to perform better by increasing efficiency [1]. A few savonius type VAWT require a motor to get them up to operating speed. Some ornamental domestic scale wind turbines are shown in Fig. 2. Apart from aesthetic, these turbines hardly produce any measurable power.
In this paper, we propose a new concept of a vertical axis wind turbine which is capable to operate at a wider range of wind speeds with much higher efficiency. The concept of this turbine has been developed by Wind Energy Technologies Pty Ltd Australia. It has overcome one of the major limitations of current VAWTs. As the airflow moves through the rotor of VAWT, it has to negotiate the rotating vanes at the rear. In so doing it imparts a negative torque on the rotor. The domestic scale vertical axis wind turbine developed by the Wind Energy Technologies Pty Ltd Australia used a shroud which diverts the wind from the rear of the vanes of the rotor. The device simultaneously shields parts of the rotor from the wind, whilst directing it to those parts where it can more efficiently impart momentum to the rotor. The prototype model is shown in Fig. 3. The device has been patented in Australia by the Wind Energy Technologies Pty Ltd Australia. The primary objective of this paper is to undertake experimental investigations in the wind tunnel environment as part of a large scale research project of domestic scale wind turbines in the School of Aerospace, Mechanical and Manufacturing Engineering in partnership with the Wind Energy Technologies Pty Ltd. The dimensions of the developed prototype turbine are not given here due to confidentiality.

2. Methods

The experimental investigation was undertaken in RMIT Industrial Wind Tunnel under a range of wind speeds. The wind tunnel is a closed return circuit with a rectangular test section (3 m width, 2 m height and 9 m length). The maximum air speed of the tunnel is approximately 150 km/h. More details about the tunnel can be found in [11]. The experimental set up in RMIT Industrial Wind Tunnel is shown in Fig. 3. Prior to wind tunnel testing, some preliminary CFD investigations were also undertaken to understand the basic concept of the design. However, the CFD results were not included here. The rotational speed of the turbine was initially tested using a free standing pedal fan. This finding was later verified with the wind tunnel data.

![Prototype VAWT](image)

Fig. 3. A prototype developed by Wind Energy Technologies is in the test section of RMIT Industrial Wind Tunnel.

3. Results

The prototype was tested with two configurations. The first configuration was the bare rotor without the shroud (cowl) and the 2nd configuration was the bare rotor shrouded with a cowl. Both configurations were investigated at wind speeds ranging from 5 km/h (1.4 m/s) to 30 km/h (8.33 m/s). Due to fragility, the higher wind speed was not attempted. However, a new model has been under construction which will allow the prototype to be tested at a much higher speed (~100 km/h).

The rotational speed of the rotor was measured as a function of wind speeds which are shown in Figs. 4 and 5. Fig. 4 shows the variation of spinning rate (rotational speed) with the wind speed of the turbine with and without the cowl. The figure clearly indicates that the cowling has increased the spin rate of the turbine more than double at all wind speeds tested.
The spin rate of the turbine with and without cowl achieved using a free standing pedal fan is shown in Fig. 5. Although the flow condition is significantly inferior compared to the wind tunnel environment, it is clearly shows the trend that the cowling has notable impact as it reduces the resistance on the rare blade. The wind speed range achieved by the pedal fan was from 10 km/h to 20 km/h. The figure visibly demonstrates that the cowl has increased the spinning rate over two compared to the bare rotor.

**4. Discussion**

The performance of a wind turbine is measured by its power curve. The work is currently underway to develop the power curve of the prototype over a range of wind speeds. The spinning rate is indicative only. A thorough and in-depth study is needed to establish the full potential of the prototype. A wind turbine that shows good performance in a controlled environment such as wind tunnel does not necessarily performs well in situ as the wind characteristics in urban (built up) areas significantly vary compared to rural and unobstructed areas. At present, there is no prediction model for wind characteristics of built up areas that can be used with confidence to estimate the wind profile (wind velocity, wind direction,
wind gustiness & turbulence intensities, etc.) as the urban areas are very diverse and substantially dynamic. Most currently available wind data lacks the required resolution and practically invalid for heights less than 10 m. For example, the wind data determined through modeling for the city of Melbourne, Australia is available at an elevation of 25 m which is an impractical height for most urban dwellings as a mast that high would make it difficult to get planning permission. Additionally, most Australian metropolitan cities except the city centre are being developed where the heights of dwellings are less than 10 m. In order to maximize the use of wind resources for power generation using a wind turbine in urban areas, the wind flow around a typical house/building, both in isolation and within an array of houses with different configurations needs to be understood. Once the wind behavior is understood, the potential site and a guide or a recommendation for installing wind turbines can be determined. It should be stressed that the complexity of modeling the urban environment using computational models has severe limitations and results can only be considered over simplified but nonetheless, gives an indication of expected yields within the built environment [3, 4, 10]. The understanding of micro wind environments is required for the appropriate site selection.

To investigate the real performance in situ, the prototype turbine needs to be monitored over a long period and refine the performance by undertaking further design change. The turbine’s fatigue life, payback period and noise level are also required to be assessed as the service life and wider acceptability largely depend on their important criteria.

5. Concluding remarks

The domestic scale wind turbines have immense potential for wind power generation in built up areas. With current commercial domestic scale wind turbines, it is difficult to generate any appreciable power due to their poor performance in situ. However, the prototype developed by Wind Energy Technologies has shown to be promising. In order understand its overall performance and economic viability, a comprehensive study is required. The in situ performance data needs to be reconciled with the wind tunnel data along with the appropriate mounting site selection. The site selection cannot be relied on simulated data only. Government policies and regulations are required to be enacted for better utilization of domestic scale/micro wind turbines. Significant research and development are required for improving the efficiency and power generation capacity of domestic scale wind turbines. As majority small wind turbine manufacturers are small companies and/or wind turbine enthusiasts, public and large companies’ financial investments in this important sector are essential.

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