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# An aerodynamic analysis of a novel small wind turbine based on impulse turbine principles

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The paper presents both a numerical and an experimental approach to study the air flow characteristics of a novel small wind turbine and to predict its performance. The turbine model was generated based on impulse turbine principles in order to be employed in an omni-flow wind energy system in urban areas. The results have shown that the maximum flow velocity behind the stator can be increased by 20% because of a nozzle cascade from the stator geometry. It was also observed that a wind turbine with a 0.3 m rotor diameter achieved the maximum power coefficient of 0.17 at the tip speed ratio of 0.6 under the wind velocity of 8.2 m/s. It was also found that the power coefficient was linked to the hub-to-tip ratio and reached its maximum value when the hub-to-tip ratio was 0.45. It is evident that this new wind turbine has the potential for low working noise and good starting feature compared with a conventional horizontal axis wind turbine.



## 1. Introduction

Due to the limitation of fossil fuels and concerns over global warming, the wind energy technology has been developed greatly and become one of the mature technologies in the renewable energy field. Wind turbines as wind energy conversion devices can be divided into four categories by the rotor diameter [1]: i) micro-scale (rotor diameter < 0.1 m); ii) small-scale (0.1 m < rotor diameter < 1 m); iii) middle-scale (1 m < rotor diameter < 5 m) and iv) large-scale (rotor diameter > 5 m). Small scale wind turbines have recently become attractive satisfying on-grid and off-grid applications [2]. In an urban area small scale wind turbines can be suitably constructed on the top of a building and could provide electricity directly to the building [3]. In urban areas, the wind velocity on the top of a building is higher than that near the ground. Rich wind energy can compensate electricity consumption of high buildings with wind turbines for both economic and environmental protection purposes. Limited by the rotor diameter, the power coefficient ($C_P$) of a small scale horizontal axis wind turbine (HAWT) is normally about 0.25 which is lower than that of a large-scale HAWT of over 0.45 [4]. Kishore [5] compared fourteen small-to-middle scale HAWTs with the rotor diameter range from 0.234 m to 2 m and found that the minimum and maximum values of overall efficiency were about 12% and 26%. It appears that this range also applies to vertical axis wind turbines (VAWTs). Pope [6] gave a prediction about power coefficients of Savonius and Zephyr VAWTs and reported that a Savonius turbine with 2 m rotor diameter had the maximum $C_P$ of 0.18 and another one with 1.524 m rotor diameter only managed the maximum $C_P$ of 0.11. Howell [7] studied power performances of a Darrieus VAWT with a straight blade of 0.6 m diameter and reported that the maximum $C_P$ was about 0.2.

An omni-flow wind energy system for urban areas has been developed [8,9]. The shrouds and chambers of this wind energy system can take the entrance wind from different directions and convert the flow to a vertical exit where the turbine is located. The flow velocity at the outlet is increased during this process. However, due to structure features, the flow velocity distribution in front of a turbine blade is not uniform and the blade will experience four to five different flow velocities and the aerodynamic loads during one cycle of revolution [8]. Therefore a wind turbine with the conventional thin blades has difficulty to accommodate the flow conditions in the omni-flow wind energy system. A new type of wind turbine blade is needed.

It has been reported that an impulse turbine has a potential to operate well under the variable air flow velocities in the marine energy field [10,11]. Impulse turbines have been applied in an oscillating water column (OWC) for wave energy conversion [12,13]. In wave energy, the impulse turbine has been proven as the best one in power generation, starting capability and so on [14]. Considering these features, the impulse turbine principles appear

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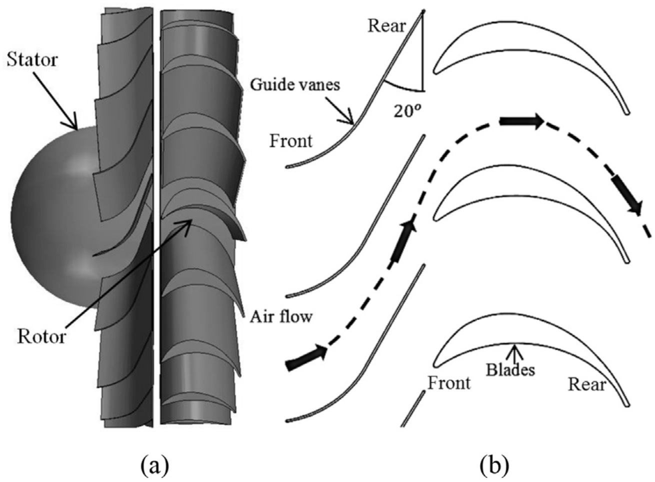


**Fig. 1.** (a) 3D view of the turbine model and (b) schematic view of guide vanes and blades.

attractive for an omni-flow wind energy system. However, there is little information on impulse turbine principles applied to a wind turbine.

In this paper, a model of a new wind turbine based on impulse turbine principles was presented. Both the experimental and computational investigations were carried out for the aerodynamic properties of a wind turbine under steady velocity wind. The effects of different parameters on the power coefficients and the other properties of this wind turbine were investigated.

## 2. The turbine model

As shown in Fig. 1, a newly designed wind turbine consists of two parts: a stator with guide vanes and a rotor with blades. This wind turbine was located inside an exit chamber of an omni-flow wind energy system [8]. Fig. 1(a) shows the 3-D model of the turbine generated with CATIA, a Computer Aided Design (CAD) software package. Fig. 1(b) is a schematic view of guide vanes and blades. The guide vanes on the stator led wind to the rotor. Their setting angle was 20°. These guide vanes had thin plate geometry and were fixed on the surrounded wall of the exit chamber. The front part of the guide vane took the shape of an arc and the rear part was straight.

A type of the aerofoil from a unidirectional impulse turbine was employed for the blades on the rotor since this type of blade aerofoil had the best power performance compared with the other blade aerofoils in wave energy [15]. Based upon the sketch from Maeda et al. [16], a further change of the blade aerofoil has been made. The amount of this aerofoil camber takes a 36% of the chord length and it is greater than 4–6% of NACA aerofoils which have been widely used on the wind turbine blades.

## 3. Experimental apparatus

All lab tests were carried out in a closed return wind tunnel in the School of Engineering and Technology at the University of Hertfordshire. The tunnel had a test section of 1.14 m (width) × 0.84 m (height), with a maximum wind velocity of 25 m/s. A wind turbine test rig was located at the centre of the test section within the tunnel. Fig. 2(a) shows the photograph of the stator with 20 guide vanes inside a cylindrical flow chamber. This wind turbine was produced by rapid manufacturing technology with ABS plastics. As shown in Fig. 2(b), it had 20 blades with a rotor diameter of 300 mm. The hub diameter of this turbine was 135 mm. Both stator and rotor had an identical hub diameter. The hub-tip-speed ratio was 0.45 which was defined as the ratio between the hub diameter and rotor diameter. In this study the dimensionless hub-to-tip ratio was used to represent the hub diameter for a wind turbine. This wind turbine was installed inside a 200 mm long cylinder chamber and the thickness of this chamber was 12 mm. The guide vanes were fixed on the chamber wall. There was a clearance of 2 mm between the blade tip and wall.

Fig. 3 shows the wind turbine test rig together with its primary measurement system utilised in this study. A torque transducer was employed to measure the shaft torque from 0 to 10 Nm with an accuracy of 0.1% and its maximum rotational speed was 5000 rpm. A DC motor was connected to the other end of this torque transducer through a pair of gears to apply a load. The applied load was adjusted by changing the current in the motor. In all tests, an energy loss caused by the bearing and gears was considered. Both Pitot-tube and pressure meter were used to measure both flow pressure and velocity at the selected positions in the wind tunnel test section.

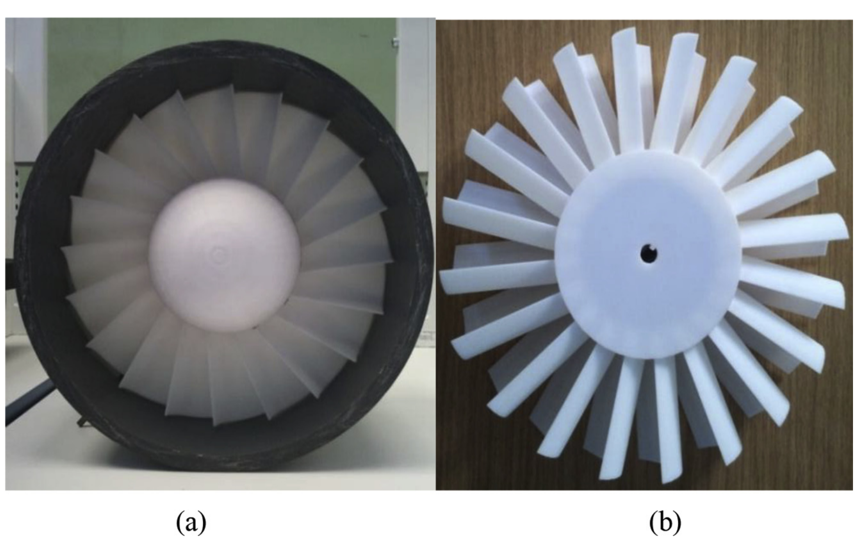


**Fig. 2.** The wind turbine prototype produced by rapid manufacturing technology: (a) the stator with 20 guide vanes inside a cylinder flow chamber; (b) the rotor with 20 blades.