Applied Energy xxx (2017) xxx–xxx

Contents lists available at ScienceDirect

Applied Energy

journal homepage: www.elsevier.com/locate/apenergy

Cross axis wind turbine: Pushing the limit of wind turbine technology with complementary design

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HIGHLIGHTS

- A cross axis wind turbine (CAWT) is designed for testing in a lab environment.
- The CAWT combines the advantages of horizontal and vertical axis wind turbines.
- The CAWT captures energy from horizontal and vertical components of skewed airflow.
- The CAWT outperformed the conventional straight-bladed vertical axis wind turbine.
- The complementary design of CAWT presents a better outlook of wind energy industry.

ARTICLE INFO

Article history:
Received 15 January 2017
Received in revised form 20 June 2017
Accepted 28 June 2017
Available online xxxx

Keywords:
Wind energy
Cross axis wind turbine
Renewable energy
Urban energy system
Efficiency
Offshore wind turbine

ABSTRACT

In unfavourable wind conditions, factors such as low wind speed, high turbulence, and constant wind direction change can reduce the power production of a horizontal axis wind turbine. Certain vertical axis wind turbine design principles perform well under these harsh operating conditions; but, these wind rotors typically have low power coefficients. To overcome the problems above, a novel cross axis wind turbine has been conceptualised to maximise wind energy generation. This is achieved via harnessing the wind energy from both the horizontal and vertical components of the oncoming wind. The cross axis wind turbine comprises three vertical blades and six horizontal blades arranged in a cross axis orientation. Initial testing using deflectors to guide the oncoming airflow upward showed that the cross axis wind turbine produced significant improvements in power output and rotational speed performance compared to a conventional straight-bladed vertical axis wind turbine. In particular, it was found that the cross axis wind turbine integrated with a 45° deflector produced a power coefficient 2.8 times higher than the vertical axis wind turbine. The rotor rotational speed was increased by 70% with well-improved starting behaviour. Initial computational fluid dynamics analysis was done to illustrate the flow field of the deflected air stream by an omni-directional shroud. The simulation showed that the approaching air is deflected upwards by the guide-vane, which would interact with the horizontal blades and produce additional torque. The cross axis wind turbine is applicable in many locations, creating significant opportunities for wind energy devices and therefore reducing dependencies on fossil fuel.

1. Introduction

1.1. Research background

Harnessing wind energy provides a means to reducing dependencies on fossil fuel reserves. With the rapid growth of the global human population, the demand for energy also increases. Therefore, many countries around the world have adopted renewable energy technology to generate clean and inexhaustible energy to fulfill their ever-increasing electricity demands. In some places, 100% of their average yearly demand is provided by renewable energy resources [1–4]. As one of the fastest growing renewable energy resources in the world today [5], the global cumulative installed wind capacity has been increased significantly since 1996. The total wind power capacity at the end of the year 2015 was about 433 GW as reported in [6] (Fig. 1). It is projected to

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http://dx.doi.org/10.1016/j.apenergy.2017.06.099
0306-2619/© 2017 Published by Elsevier Ltd.

Nomenclature

A	swept area (m^2)
B	number of horizontal blades
c	chord length of vertical blade (cm)
c_b	chord length of horizontal blade (cm)
C_P	coefficient of power
CAWT	cross axis wind turbine
d	diameter of rotor (cm)
h	height of vertical blade (cm)
HAWT	horizontal axis wind turbine
l_b	length of horizontal blade (cm)
N	number of vertical blades
NACA	National Advisory Committee for Aeronautics
P	Wind turbine power (W)
R	radius of rotor (cm)
V_∞	wind speed (ms^{-1})
VAWT	vertical axis wind turbine

Greek symbols

β	vertical blade pitch angle (°)
β_b	horizontal blade pitch angle (°)
ρ	density ($kg\,m^{-3}$)
λ	tip speed ratio (TSR)
ω	angular velocity ($rad\,s^{-1}$)
σ	wind turbine solidity

reach 2000 GW [7] by the year 2030, supplying between 17 and 19% of global electricity demand.

In the wind energy industry, there are two major types of wind turbines; the horizontal axis wind turbine (HAWT) and the vertical axis wind turbine (VAWT). In general, the HAWTs are better at extracting wind energy than the VAWT. Therefore, most wind turbines in the commercial market today are dominated by the HAWT machines. However, new interests in the VAWT technology from researchers and manufacturers have reignited major development efforts for this wind turbine [8–10]. In some situations, the VAWT has superior advantages over the HAWT, including its ability to extract wind energy from almost every direction, easier to maintain, has less visual impact, produce low noise emissions and can work with improved performance in skewed wind flow conditions [11–14]. The complex characteristic of urban winds involves erratic, insubstantial and inconsistent wind flow due to the many obstacles (i.e. buildings). The distinctive characteristic of urban wind requires wind turbines that suit this phenomenon well. As such, the VAWT is deemed more suitable for the urban context compared to the large and more common HAWT.

The VAWT has two basic types according to the aerodynamic force characteristics that act upon their blades, i.e. drag-based and lift-based wind turbines [15]. The most common drag-based wind turbine is the Savonius wind turbine. It is a drag force driven wind turbine with two cups or half drums fixed to a central shaft in opposing directions. Meanwhile, the Darrieus wind turbine is a lift-based vertical axis wind turbine that uses lift forces generated by the wind hitting the airfoil to create rotation. A lift-type wind turbine has better performance output and efficiency compared to the Savonius turbine [16,17]. However, issues such as poor self-starting characteristic affect the overall performance of the turbine [18]. Nevertheless, new studies have shown that the modern Darrieus VAWT design can ensure self-starting by optimising the number of blades, exploiting new and improved airfoil shape, or by implementing minimum loading on the rotor [19–21].

As mentioned, the major disadvantage of the VAWT is in terms of its efficiency in extracting power from the wind. The lower efficiency of the VAWT is due to the unstable operating conditions of the turbine at all wind speeds, caused by the periodic variation of the rotor and the direction of the apparent wind velocity perceived by the blades [22]. Moreover, as the VAWT rotates, the interactions between wakes shed by the blades rotating in the upwind and downwind regions of the rotor causes dynamic and reliability issues in which the blades have to go through a dynamic stall in every revolution [23]. Intrinsically, the aerodynamic phenomena manifested in VAWTs present challenging tasks for researchers to understand the complex fluid mechanics of such devices to estimate their performances [24–26]. New concepts of vertical axis wind energy devices are being introduced to overcome the disadvantages of the conventional design of VAWTs. Some of these wind turbine concepts are being adopted in the design of the building [27–29], augmented with shrouds [30–35], or mounted on top of a building for maximum utilisation of wind energy [30,36]. The pertinent question then becomes; at the forefront of conventional wind turbine technology, particularly the VAWT–how do we innovate the conventional design to make it more efficient and also to

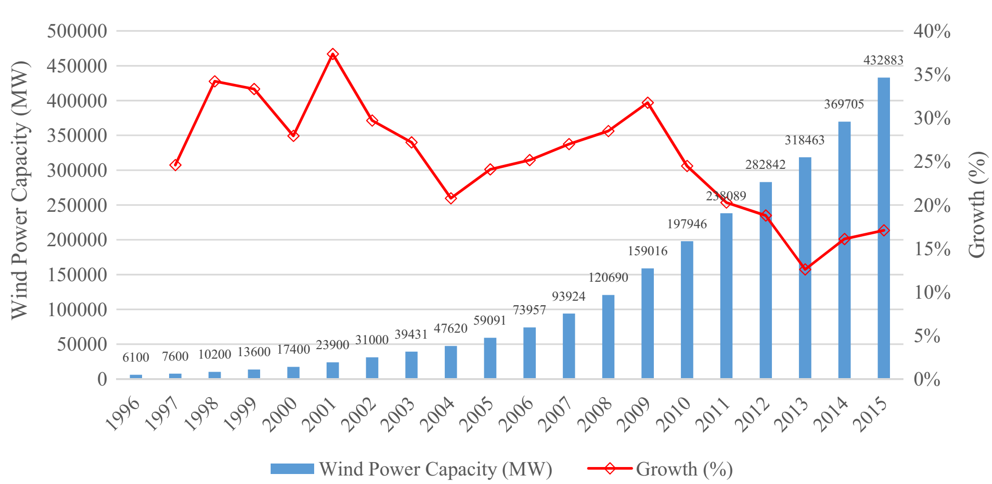

Fig. 1. Total installed wind power capacity (MW) and market growth rate (%) from the year 1996–2015 [6].

Please cite this article in press as: Chong W-T et al. Cross axis wind turbine: Pushing the limit of wind turbine technology with complementary design. Appl Energy (2017), http://dx.doi.org/10.1016/j.apenergy.2017.06.099