Ocean Engineering 57 (2013) 248–255

Contents lists available at SciVerse ScienceDirect

Ocean Engineering

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

Design and analysis of a straight bladed vertical axis wind turbine blade using analytical and numerical techniques

M. Saqib Hameed [a,*], S. Kamran Afaq [b]

[a] Department of Mechanical Engineering, COMSATS Institute of Information Technology, Sahiwal, Pakistan
[b] Department of Mechanical Engineering, HITEC University, Taxila, Pakistan

A R T I C L E I N F O

Article history:
Received 19 November 2011
Accepted 13 September 2012
Available online 6 November 2012

Keywords:
VAWT
Centrifugal forces
Wall thickness
Darrieus
H-rotor
Blade design

A B S T R A C T

Wind as a source of energy is being used from very long time. It has gained more significance in the current age of energy crisis. Lots of efforts have been made to develop the horizontal axis wind turbines but vertical axis wind turbines did not get much attention over the past couple of decades. Blade is the most important component of a wind turbine which controls the performance of a wind turbine and design of other components attached to it. A concept for the design of a straight symmetrical blade for a small scale vertical axis wind turbine using beam theories for analytical modeling and a commercial software ANSYS 11.0 for numerical modeling is presented in current research. Design parameters of the blade like solidity, aspect ratio, pressure coefficient etc are determined aiming the 1 kW power output and the blade design was analyzed at extreme wind conditions where maximum values of deflection and bending stresses were determined at peak values of aerodynamic and centrifugal forces. The design was optimized to attain the structural strength i.e. reduction in deflections and bending stresses. This blade design has high strength and lower material consumption to achieve the low cost of complete rotor assembly of the wind turbine which actually covers more than 50% of the overall wind turbine cost.

1. Introduction

The attempts have been made to explore and analyze the aerodynamic models utilized for the high performance and strong design of straight bladed darrieus VAWTs. The major advantage of VAWTs is that it can be used at any location and it is a standalone system where you can place the generator at the ground level (Islam et al., 2008b) The principle advantages of VAWTs are that they accept the wind from any direction without yawing. Straight, untwisted and uniform section blades of VAWTs are easy to fabricate and give the performance which is comparable with HAWT, with almost 40% extraction of wind energy (Habtamu and Yingxue, 2011). The long blades of darrieus vertical axis wind turbine with high aspect ratios subjected to a large value of bending moments due to centrifugal forces which may result into the failure of the blades (Kragten, 2004). Even the small scale vertical axis wind turbine is potentially dangerous because when it is allowed to spin freely it accelerates rapidly due to the absence of stall; it creates explosive centrifugal forces within few moments, so as the aerodynamics forces over the blade increase the effect of centrifugal forces increases too (Sharp). Therefore, high rotational speeds leads to high centrifugal forces and pulsating torque which actually supports the blades but probability of structural failures increases at the same time (Jain, 2011). The blade centrifugal stresses are maximum at the location where the connection with the tower is made which is actually the location of strut attachments in case of darrieus vertical axis wind turbines (Blackwell, et al. 1977). So without compromising on the performance of darrieus rotor, three blades model is recommended to use in order to reduce the structural loads on the blades. Struts were made with NACA 0025 to withstand the extreme values of centrifugal and aerodynamics loads (Wahl, 2007). The design mechanism, selections of design variables with theoretical modeling and aerodynamics modeling is discussed and compared briefly for different wind turbine blades (Eriksson et al., 2008).

This research aims to design and optimize the blade of darrieus VAWT using analytical and numerical techniques. The blade design parameters and its dimensions are calculated analytically. The aerodynamics forces acting on a blade are determined during its complete 360° rotation. The blade is designed on the basis of maximum values of deflection and bending stresses at extreme loading condition i.e. maximum sum of aerodynamic and centrifugal forces during one complete rotation of blade. These values are determined analytically and validated numerically and

* Corresponding author. Tel.: +92 3349607734.
E-mail addresses: saqibhameed@ciitsahiwal.edu.pk, saqib.hameed@hotmail.com (M.S. Hameed), kamran.afaq@hitecuni.edu.pk (S.K. Afaq).

0029-8018/$ - see front matter © 2012 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.oceaneng.2012.09.007

an optimized value of wall thickness is chosen keeping in view the maximum deflections and bending stresses.

2. Design parameters

In this section a complete methodology for the selection of blade geometry, profiles and dimensions are described when designing it for required power output.

2.1. Design velocity, V

The designed wind velocity is chosen as 8 m/s which is an average wind speed in areas where this wind turbine will be operational.

2.2. No. of blades, n

The torque ripple can be reduced for the case of darrieus rotor by taking three or more number of blades. For small scale domestic use vertical axis wind turbines normally contain three blades which is an optimum number of blades.

2.3. Tip speed ratio, TSR

This is actually the ratio between rotational speed of the tip of a blade and the actual velocity of the wind. Relationship for calculating the TSR is given as

$$\lambda_{max} = \frac{4\pi}{n} = 4.1 = \mathrm{TSR} = Rw/V$$

where, n = no. of blades = 3

Value of TSR is observed to be a low in this case because the operating TSR range for darrieus rotor is 4–6 (Koksal and Hughes, 2005).

2.4. Solidity

The solidity is defined as the ratio of blade area with rotor area and represented as

$$\text{Solidity} = \frac{\text{Blade area}}{\text{Rotor area}} = \frac{ncD}{D^2} = \frac{nc}{D}$$

where, D is the diameter of the turbine and c is the chord length viz. unknown at this time.

For design velocity range of 7–11 m/s, the solidity values for darrieus VAWTs should be chosen in the range of 0.2–0.25 (Jain, 2011). Power production can be increased by increasing the value of solidity but at the same time production of torque on the blade increases too, more specifically, the value of solidity is within the range of 0.1–0.2 for straight bladed darrieus VAWT (Koksal et al., 2004). For three or more number of blades with small size of wind turbines and lower value of TSR, the value of solidity is preferred to be a high value (Islam et al., 2008a) within its given range in order to maximize the power production. Therefore, a high value of solidity was chosen as 0.24.

2.5. Power coefficient, C_p

For darrieus rotors and other rotary devices, the values of C_p are plotted against TSR for a range of solidity 0.05–0.40 (Koksal et al., 2004). For solidity 0.24, the value of C_p is approximately 0.43 at TSR 4.1.

2.6. Diameter of the turbine, D

The relationship between required power output and the design velocity was utilized to evaluate the diameter of the turbine, as (Blackwell et al., 1977)

$$P = 0.5 C_p \rho V^3 D^2$$

For 900 W output and density of air as 1.23 $\mathrm{Kg/m^3}$ the diameter D of the turbine was calculated as 2.578 m.

2.7. Span length of the blade, b

For the calculations of the blade span length, the complete rotor assembly was considered as a 3D cube for capture of same and maximum possible value of wind energy from any direction, as shown in the front view of designed turbine, Fig. 1.

On the right of the figure the front view of the designed wind turbine is shown diameter is already calculated as 2.58 m whereas, considering it a square from front span length is also taken as 2.578 m.

2.8. Aspect ratio, AR

Aspect ratio is the ratio of span length, b, with chord length, c, of the blade. Reducing the aspect ratio deteriorates the blade performance. Long slender blades with high value of aspect ratio are recommended for straight bladed VAWTs (Islam et al., 2008a). Therefore, a high value of aspect ratio as 12.5 is chosen for this design of straight bladed VAWT.

$$\text{Aspect ratio(AR)} = \frac{\text{Span length}}{\text{Chord length}} = \frac{b}{c}$$

2.9. Chord length of the blade, c

Using the above described relation of AR, the chord length of the wind turbine blade was calculated as 0.2062 m.

2.10. Selection of airfoil

For small scale vertical axis wind turbines, symmetric airfoils are utilized to have the same characteristics of lift and drag on upper and lower surfaces. The major advantage is that symmetric airfoils provide lift from both side of the airfoil therefore; it will provide lift during complete 360° rotation or the turbine. Plus, we will not need to readjust the blades in the direction of wind; the blade will provide lift when wind comes from any direction.

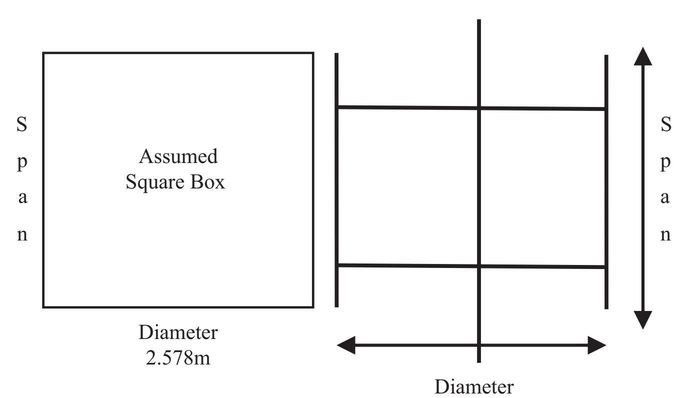

Fig. 1. Front view of darrieus VAWT design (left) with the front view of the assumed 3D cube for design calculations to extract energy from any wind direction.