Renewable Energy 94 (2016) 547–557

Contents lists available at ScienceDirect

Renewable Energy

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

Design and kinetic analysis of wind turbine blade-hub-tower coupled system

Wenyi Liu

School of Mechanical and Electrical Engineering, Jiangsu Normal University, Xuzhou, 221116, PR China

ARTICLE INFO

Article history:
Received 24 July 2015
Received in revised form
25 February 2016
Accepted 21 March 2016

Keywords:
Wind turbine
Blade-hub-tower
Kinetic analysis
Force analysis
Modal analysis

ABSTRACT

A typical 1.5 MW wind turbine suitable for Xuzhou City is designed and simulated in this paper. The wind turbine blade-hub-tower coupling system and most of the parameters are designed and calculated in the design process. In the kinetic analysis process, the force analysis under 4 different situations are taken to verify the structure design, which are under quiescent condition, under random angle and random wind turbine, under maximal wind speed and over maximal wind speed. At last, the modal analysis selected the turbine hub and tower to solve the inherent frequencies and vibration modes. The first 5 order inherent frequencies and vibration modes of the hub and tower are solved to verify the design rationality.

1. Introduction

In recent years, as one of the non-pollution and renewable clean energy, wind energy has obtained more and more attentions form the world [1–5]. The economy and technique input on wind energy and additional techniques about wind turbine has been improved in many wind turbine countries [6–10]. With the fund and manpower increased, wind turbine techniques have been more and more advanced. Wind turbine is the main equipment to transform wind energy into power energy. Many wind turbine researchers have done lots of relative research works in the last few years [11–16]. Some corresponding new research areas are excavated by many wind turbine researchers, such as wind turbine design [17–19], blade kinetic analysis [20–22], tower design and force analysis [23–28], turbine fault diagnosis [29–31], turbine healthy condition monitoring [1], etc.

If we want to obtain a good wind turbine, we have to design the wind turbine structure theoretically firstly. Then we can use some kinetic analysis and other modal analysis methods to verify the turbine design results [32–35]. It is necessary to analyze the vibration characteristic of wind turbine structure, especially the blade-hub-tower system [36,37]. Some researchers have done some designing work on wind turbine blades, hub, tower, cabin, etc [38–42], separately.

However, the main problem is lacking of kinetic analysis about the whole blade-hub-tower coupled system, with the immature theoretical system. Actually, when the wind turbine is running in the wild, the blade, hub, cabin and tower coupled together, which makes the kinetic analysis complex. Therefore, the single force analysis on blade or tower is not all-inclusive. Researchers should consider the blade, hub and tower together to do the force analysis and model analysis.

This paper deals with the typical 1.5 MW wind turbine design work, and at the same time do some research on blade-hub-tower coupled system, at last doing some theoretical verification on the design results.

2. Wind turbine structure design

Wind turbines can be divided into two types, named horizontal axis wind turbines and vertical axis wind turbines. On the other hand, they can also be divided into offshore wind turbine and land wind turbines. Nowadays, typical horizontal axis wind turbines have gained more attentions from the world.

The basic wind turbine structure we designed in this paper is shown in Fig. 1. There are mainly 4 parts in the large wind turbine, named wind wheel, tower, base and cabin, in which the wind wheel can be divided into blade and hub.

E-mail addresses: liuwenyi1984@126.com, wyliu1984@gmail.com.

http://dx.doi.org/10.1016/j.renene.2016.03.068
0960-1481/

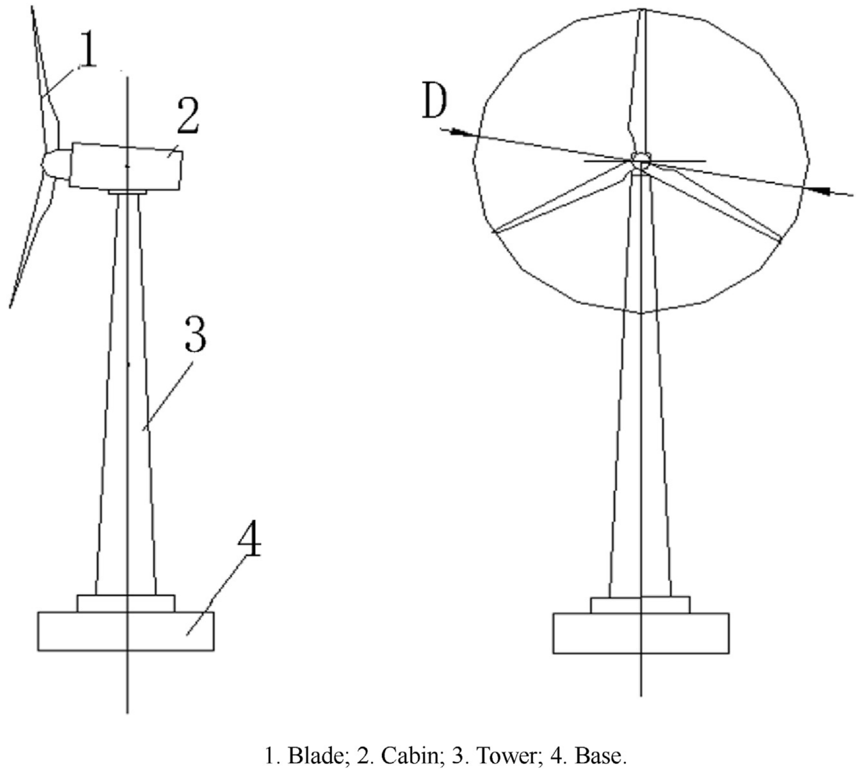

Fig. 1. Basic structure of large wind turbine.

As shown in Fig. 1, parameter D is the wind wheel diameter. Strictly speaking, D is the encircle diameter of wind wheel when wind turbine is running. The swept area of the wind wheel and the choice of blade length have some relationship with this parameter D. Therefore, the wind wheel diameter D is one of the main parameters in wind turbine design.

2.1. Blade parameters design

The wind turbine is designed to satisfy the demand in Xuzhou City, Jiangsu Province in PR China. The wind turbine is designed according to the annual mean wind speed data in Xuzhou City. According to the last 5 year statistics data in Xuzhou City, the annual mean wind speed is 5 m/s on the ground, 6.5 m/s in 60 m high altitude. Therefore, the wind turbine rated power is designed as 1.5 MW, the cut-in wind speed is 3 m/s, rated wind speed is 11 m/s, cut-out wind speed is 25 m/s, rated speed of the generator is 1880 r/min. According to the Batz theory, the power P of wind wheel can be calculated by

$$P = \frac{1}{2}\rho S C_P v^3 \tag{1}$$

$$S = \frac{\pi D^2}{4} \tag{2}$$

Where,

ρ is the air density, which has relationship with air temperature and altitude;
C_P is the power coefficient, which is determined by experience, as shown in Fig. 2;
S is the wind wheel swept area;
v is the wind speed.

Then we can obtain the diameter D:

$$D = \sqrt{\frac{8p}{\rho C_P \pi V_R^3}} \tag{3}$$

As shown in Fig. 2, the parameter C_P can be choose at the peak point of the curve

$$C_P \approx 0.43 \tag{4}$$

P is the generator rated power, which is designed as 1.5 MW in this paper.
ρ is the air density, which is designed as

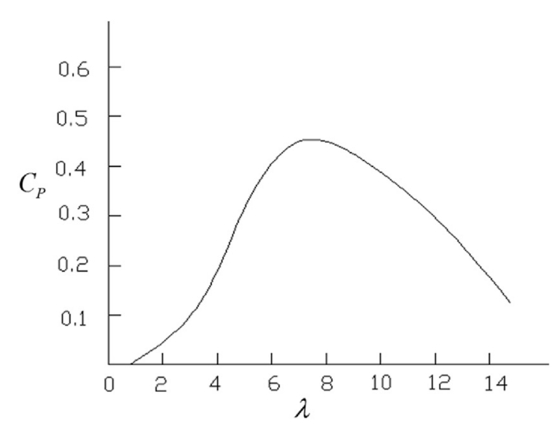

Fig. 2. Wind wheel power coefficient C_P