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Performance enhancement of wind turbine systems with vibration control: A review

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ABSTRACT

Renewable energy becomes an asset to the world's energy resource for its eco-friendly and low cost energy production feature. As an important renewable energy source, wind turbine technology has become a significant contributor to the world energy production because of its feasible production cost, reliability and efficiency. Researchers are very active to optimize the effectiveness of wind turbines which may lead to increase the productivity of this source of energy. Vibration in the wind turbine system affects the productivity and thus reduces efficiency. Vibration of a system cannot be destroyed but can be reduced or converted to energy using appropriate strategies. Vibration control system improves structural response of wind turbines and reliability which has impact on lifetime of the components. Lowering the vibration amplitude of a system will provide a lesser amount of noise, assure user and operating comport, maintain the high performance and production efficiency. These will assist the system to prolong the lifetime of an industrial structure or machinery. Also vibration control enhances the performance of wind turbines providing suitable work environment without external disturbance. This paper presents an ample review on performance enhancement of the wind turbines by vibration mitigation. The aim of this review is to provide a concise point for researchers to assess the current trend to control vibration of wind turbines technology. This paper will focus on main vibration control techniques of wind turbine structures. It provides the applications of passive, active and semi-active and vibration control strategies for structures, especially for wind turbines. Besides, this paper reviews on damping devices needed for vibration mitigation of structures. These damping devices have been implemented extensively in wind turbines for increasing their efficiency by mitigating vibration. This paper also reviews and assesses the performance of different control policies to control the system input and power input of damping devices.

Contents

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Nomenclature

Abrreviations

HAWT	horizontal axis wind turbine
VAWT	vertical axis wind turbine
TMD	tuned mass damper
STMD	semi-active tuned mass damper
TLCD	tuned liquid column damper
MTMD	multiple tuned mass damper
TLD	tuned liquid damper
ER	electrorheological
MR	magnetorheological
BVA	ball vibration absorber
LQR	linear quadratic regulator
LQG	linear quadratic Gaussian
MPC	model predictive control

Symbols

U	actuating force
k	spring co-efficients
c	damping co-efficients

1. Introduction

Power generation using wind turbines is an effective and potential source to meet the electricity requirement all over the world nowadays. Wind energy is utilized for different purposes such as rural electrification, at street lamp post, to charge electric vehicles and even to operate wind turbines to generate electricity. Wind energy is widely used in rural electrification mainly in less developed country and low-income households. Several studies presented utilizations of wind energy as renewable energy source for rural electrification [1–4]. Wind energy is also suggested to be used to charge electric vehicles in Netherlands in 2020 [5]. Wind energy is also used for outdoor/street lighting system [6]. There are many different types of wind turbines which were proposed and developed in the past depending on the orientations of the blade and configurations. But they can be grouped into two namely: horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) based on the orientation of their axis of blade rotation. HAWTs have been the most implemented wind turbines technology since few decades; however, VAWTs have also become very prominent in this technology in the recent decades. The initial development of HAWTs and VAWTs is studied in [7]. The blades of the HAWTs rotate horizontally and perpendicular to the wind. Researchers proposed different types of HAWTs based on different methods and configurations to enhance their efficiency [8–14]. HAWTs are typically tall which assists the system to face much higher and stronger winds to generate power effectively. However, installation and maintenance cost of HAWTs is relatively high because the installation kits are placed on the top of the tower inside the nacelle. So it becomes difficult and costly when it needs to be repaired. On the other hand, VAWTs consist of blades with the vertical axis of rotation and they do not have to be arranged to any specific direction to face the wind. Another advantage of the VAWTs is that the installation box which includes generator, gearbox, etc. can be placed at the basement of the tower. It makes the maintenance and repair work easy and simple. The advantages, different designs and optimizations of VAWT are presented in several research papers [15–18]. Different designs and configurations of VAWTs are also reviewed in [19,20]. Darrieus type wind turbine has the highest value of efficiency although problems of low starting torque and poor building integration are the major drawbacks of the system. This type of wind turbine is called as ‘lift type’ wind turbine where lift forces on the blades result the rotor to rotate and produce electricity. Savonius rotor type wind turbine is another type of VAWT which has less efficiency value than Darrieus type and not used for high power applications. However, self-starting capability is the important advantage of savonius type wind turbine compared to lift type wind turbines. Four aerodynamic models for VAWT have been analysed in Ref. [20] to highlight the performances as well as advantages and disadvantages. The blade element momentum and cascade models have good power predictions capability and fast computational times but may fail to predict instantaneous blade forces. However, vortex and panel models can simulate the wake of the VAWT and have capability to model a rotor which consists of multiple rotating bodies. The rotation axis for horizontal wind turbine is horizontal or parallel to the ground. For big wind areas, HAWTs are very popular and produce more energy. However, HAWTs need big space and are generally heavier which are not efficient enough in turbulent winds. HAWTs are generally installed in high wind areas, especially in sea areas. The rotation axis of vertical wind turbine is perpendicular to the ground and mostly used in residential applications. VAWTs work well under turbulent wind conditions, thus VAWTs are efficient where wind is not consistent. VAWTs are capable of generating power from low wind and they are generally positioned in the low wind urban environment. Unlike HAWT, VAWT does not have a tower and is situated at the ground where the wind is low and turbulent. Also the direction of blade rotation encourages the structure to be at low wind environment for better performance. There are several other factors that affect the efficiency of HAWTs and VAWTs. Few factors and possible solutions for them are presented in [21]. Several challenges have been highlighted for performance degradation of wind turbine technology which are maintaining performance efficiency, intermittent nature of wind supply, global industrialization, fossil fuel energy market, social acceptability of on-shore wind power, cost, technical and climate change of off-shore wind power, competition from other clean energy competitors, policy instability, etc. The possible solutions are suggested in the study to enhance the performance of wind turbines and some of the important solutions are proper maintenance of different machining parts such as blades, gearbox, bearing, etc. to ensure good performance, ensuring adequate nature wind supply, reducing noise of heavy weight wind turbines, reducing cost and solve technical issues such as place of installation, designs, etc. Furthermore, the HAWTs need higher wind speeds for generating a smaller amount of electricity and thus they become less important in the urban environment. HAWTs and VAWTs have different efficiency levels based on their direction of rotation, configurations and they are compared in [22–24]. Table 1 shows the comparison