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Performance enhancements on vertical axis wind turbines using flow augmentation systems: A review

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ABSTRACT

There are many advantages of vertical axis wind turbines (VAWTs) compared with horizontal axis wind turbines (HAWTs). Research has shown that VAWTs are more suitable for turbulent wind flow and urban applications. However, the efficiency and low self-start ability of VAWTs are always the main drawbacks especially for the lift-type VAWTs. Unlike HAWTs, the rotor blades for VAWTs do not always provide positive torque during operation. Many innovative designs have been implemented to improve the performance of VAWTs, and this includes different configurations and blade profiles. This paper extensively reviews various flow augmentation systems and attempts to provide information to researchers on current augmentation techniques and other relevant research. The flow augmentation system is able to increase the coefficient of power, C_P, hence improving the output power of different types of VAWTs. Some augmentation systems are able to increase the maximum power output by up to 910%. The methods and designs used to increase upwind velocity and to reduce negative torque created on the wind turbine have been discussed in detail. Additionally, the flow augmentation devices that are integrated with building structures are also reported in this paper.

1. Introduction

Since the last decade, the increase in the world's population has led to a dramatic increase in energy demand. With the depletion of fossil fuels and the rise in environmental problems such as global warming, unusual weather changes, and high emission rates of carbon dioxide (CO_2), the world has come to realize that alternative energy sources are needed to ensure sustainability and the conservation of the environment. These factors have popularized the use of different renewable energy types which include solar, wind, hydro, and biomass amongst others. Of these, wind energy is abundant, clean, cheap, and has been used by mankind for centuries in agriculture for water pumping, crop irrigation and grain grinding [1,2]. Nowadays, wind energy is established as a mainstream form of energy in electrical power generation, and has been an increasing trend. According to the global wind energy outlook, the global cumulative installed wind capacity has increased significantly since year 2000, and reached 432,419 MW in year 2015 as shown in Fig. 1 [3].

Generally, there are two categories of wind turbines: the horizontal axis wind turbines (HAWTs), and the vertical axis wind turbines (VAWTs). Both of these wind turbines have their respective advantages and drawbacks. Compared with the HAWTs, capturing the wind from any direction is the main advantage for VAWTs, where a yaw mechanism is not required [4,5]. With a simple structure, less noise, and small operation space, VAWTs are more suitable for urban areas where the wind flow is highly turbulent and inconsistent [6,7]. However, the main drawbacks of the VAWTs include having a low efficiency and difficulty in self-starting [6–8].

1.1. Types of vertical axis wind turbines

VAWTs can be classified into two types which are drag-type and lift-type VAWTs based on the rotor blade design. For drag-type VAWTs, they normally comprise of a plurality of straight or concave cup shaped blades which utilize the push force of the wind to rotate the turbine. The typical drag-type VAWTs are the Savonius rotor and the Sistan rotor. Compared to the lift-type VAWTs, the drag-type VAWTs have shown a better self-start ability, however, they are lower in efficiency [9–11].

The lift-type VAWTs that include the H-rotor and Darrieus rotor are constructed with airfoil shaped blades, and when the wind flow

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Nomenclature

VAWT	vertical axis wind turbine
HAWT	horizontal axis wind turbine
TSR	tip speed ratio
CFD	computational fluid dynamics
FVM	finite volume method
GBT	guide box tunnel
PAGV	power augmentation guide vane
VSA	vortical stator assembly
ODGV	Omni-direction-guide-vane
BIWT	building integrated wind turbine
C_P	coefficient of power
C_T	coefficient of torque

interacts with the blades, the aerodynamic lift forces created cause the turbine to rotate. The lift-type VAWTs perform efficiently but they face difficulty in self-starting [11]. Hence, some researchers and engineers have suggested a hybrid VAWT that combines both types of VAWTs to overcome their weaknesses [7,12].

Unlike the HAWTs, positive torque is not always created when the incoming wind stream interacts with the rotating blades of VAWTs. The negative torque that reacts in the counter direction reduces the overall performance of the VAWTs. Therefore, many innovative ideas have been suggested by researchers to improve the performance of VAWTs.

1.2. Innovation on vertical axis wind turbine

Research has been conducted around the world to increase the performance of VAWTs. These designs include modifications on the blade or the configuration of the VAWTs. According to Elkhoury et al. [13], an H-rotor with variable pitch was developed where the vertical straight blades of the wind turbine can be slightly rotated to adjust the pitch angle, whereby the wind stream incidents occur at different angles of attack. The power coefficient, C_P at all TSR was found to be increased significantly. Similar studies were also conducted by Zeiner-Gundersen [14] on the passive pitching airfoil blade. Chougule [15] proposed a double-element airfoil for the blade design which consists of a main airfoil and a slat airfoil. The slat angle is able to change the lift coefficient of the blade, where the C_P was improved by approximately 43% compared with a typical airfoil [15]. A novel design on the Savonius rotor was suggested by Reupke and Probert [16] using a slatted blade where an array of hinged flaps is mounted onto the curve blades. The flaps will open passively when different pressures are created on both sides of the Savonius blade to let the flow pass through; reducing the negative torque of the returning blade. Also, an improved self-starting ability of the Darrieus turbine using an opening on the straight vertical blade was proposed by Chen et al. [17], however, it resulted in a decrease in the overall C_P. Rather than increasing the lift coefficient, another modification on the H-rotor blade was suggested by Ismail and Vijayaraghavan [18] which was to maximise the torque coefficient. The average tangential force was increased by up to 40% with the blade design consisting of an inward semi-circular dimple and a Gurney flap near the inner tailing edge surface of the airfoil. A double-bladed VAWT was introduced by Hara et al. [19] that comprises of two offset vertical blades attached to each rotor arm. The design is able to improve the self-starting behaviour which produces a larger starting torque compared to the typical H-rotor.

Besides modifications on the VAWTs, several researchers employ stators that can increase the efficiency of the wind turbines [20–29]. The present review aims to compile the flow augmentation techniques that are used to increase the in-coming wind speeds, hence increasing the power generated by the wind turbine.

2. Augmentation devices for VAWTs

Although the Betz limit shows that the maximum efficiency of a

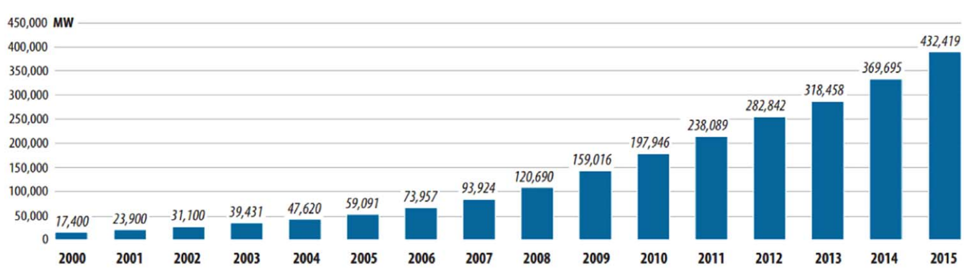

Fig. 1. Global cumulative installed wind capacity from 2000 to 2015 [3].

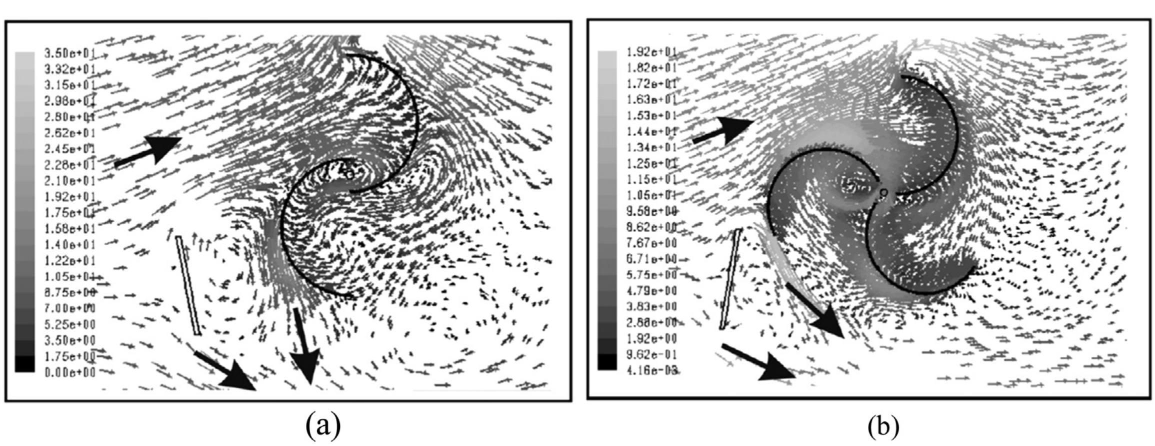

Fig. 2. Optimal orientation of the obstacle plate in front of the returning blade for (a) two-bladed (b) three-bladed Savonius turbine [21].