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Review

A review on computational fluid dynamic simulation techniques for Darrieus vertical axis wind turbines

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ABSTRACT

The global warming threats, the presence of policies on support of renewable energies, and the desire for clean smart cities are the major drives for most recent researches on developing small wind turbines in urban environments. VAWTs (vertical axis wind turbines) are most appealing for energy harvesting in the urban environment. This is attributed due to structural simplicity, wind direction independency, no yaw mechanism required, withstand high turbulence winds, cost effectiveness, easier maintenance, and lower noise emission of VAWTs. This paper reviews recent published works on CFD (computational fluid dynamic) simulations of Darrieus VAWTs. Recommendations and guidelines are presented for turbulence modeling, spatial and temporal discretization, numerical schemes and algorithms, and computational domain size. The operating and geometrical parameters such as tip speed ratio, wind speed, solidity, blade number and blade shapes are fully investigated. The purpose is to address different progresses in simulations areas such as blade profile modification and optimization, wind turbine performance augmentation using guide vanes, wind turbine wake interaction in wind farms, wind turbine aerodynamic noise reduction, dynamic stall control, self-starting characteristics, and effects of unsteady and skewed wind conditions.

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1. Introduction

In the last decade, utilization of renewable energy sources have been accelerated due to global warming threats, depletion of fossil fuel sources, and stricter environmental regulations in global energy market and society [1]. Among all renewable energies, wind energy is considered to be the most cost-effective source and it has experienced a rapid growth globally [2]. The global cumulative installed capacity of wind power rose from 24 GW in 2001 to 487 GW in 2016 and is expected to reach 817 GW by 2021 (see Fig. 1). In 2016, as shown in Fig. 2, the new installed capacity of the worldwide wind power constituted the total of 54.6 GW with three major contributors as China (42.8%), U.S. (15%) and Germany (10%) [3].

Wind turbines can be classified into horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs) based on the rotation axis [4]. Although HAWTs continue to be the commercially viable for large-scale power production, VAWTs operate under low wind speed conditions which are favorable for micro-generation. VAWTs have recently received growing interest for energy harvesting in the urban environment [5,6]. This growing interest is due to lower manufacturing costs, simple blade profile and shape, lower installation and maintenance costs, having the generator installed at the ground level, lower noise pollution, and lower operational tip speed ratio. Moreover, VAWTs are more appropriate for high turbulent regions where unsteady and skewed wind conditions are prevalent. Another advantageous for VAWTs, there is no need to a yawing mechanism to adjust the rotor direction to the changing wind direction.

Generally VAWTs can be categorized into two types: Savonius and Darrieus wind turbines [7]. The Savonius rotor is a vertical axis wind turbine that operates under a differential drag between its buckets. The Savonius rotor is promising solution for low wind speed conditions, but it's efficiency is low [8]. On the other hand, Darrieus type wind turbines are lift type machines which have higher power performance compared to the Savonius rotors. To acquire a better insight into different wind turbines concepts, the power performance and operating range for different types of wind turbines are shown in Fig. 3.

Increasing studies are made towards improving the efficiency and to extend the applicability of wind turbines to all suitable locations [11]. The wind turbine performance and flow characteristics were studied experimentally and numerically. A number of numerical simulation techniques were developed from which the Vortex model, Blade Element Momentum (BEM), Multiple Streamtube Model, and Computational Fluid Dynamics (CFD) are highly cited. Analytical models such as Vortex model [12] and Multiple Streamtube Model [13] are based on one dimensional simplified equations which requires some measured data on the employed airfoil sections in terms of lift and drag coefficients. In addition, these simplified models do not consider information on the wakes and merely employ semi empirical equations to consider the tip vortex and dynamic stall effects. Since these models use the statistically determined airfoil data will fail to determine accurately when the airfoil experiences dynamic stall [14]. On the other hand, Computational Fluid Dynamic (CFD) technique has become a routine practice to research in wind energy and helped to design more efficient and productive wind turbines. CFD can be employed as a powerful tool to analyze, design, and optimize wind turbine blades. CFD can provide more accurate data of flow characteristics around wind turbines compared to the other numerical models.

Many review papers highlighted different aspects of wind turbines such as aerodynamics model for Darrieus wind turbine [15], fluid dynamics aspect of Savonius wind turbine [16], VAWTs airfoil design [17], small scale wind turbines [18], Darrieus VAWTs [19], performance enhancements on vertical axis wind turbines using flow augmentation systems [20], wind turbine noise mechanisms [21], wind turbine wake aerodynamics [22], computer aided numerical simulation techniques in wind energy [23]. But, the lack of a detailed review paper that addresses the computational fluid dynamic simulations in Darrieus VAWTs field is felt.

The current paper provides an extensive literature review on the Computational Fluid Dynamic simulation of Darrieus VAWTs.

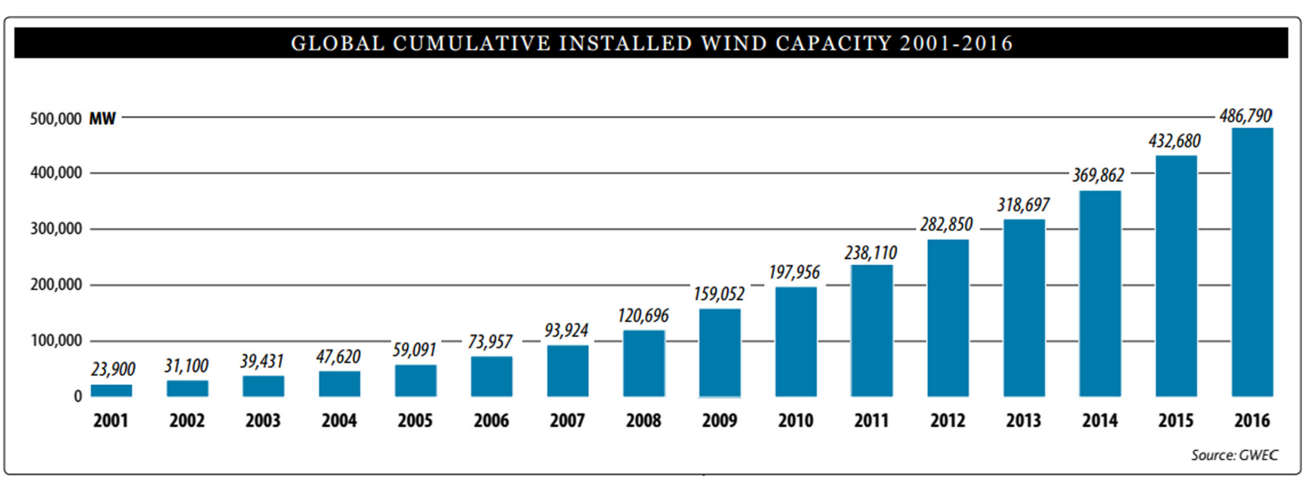

Fig. 1. Global cumulative installed wind capacity 2001–2016 [3].