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Conceptual design of a large-scale floating offshore vertical axis wind turbine

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Abstract

Large-scale floating vertical axis wind turbines (VAWTs) are an attractive and economical solution to harness superior offshore wind resources in deep water locations. This paper presents the conceptual design of a VAWT for this application using a developed aerodynamic modelling strategy. A comprehensive examination of several critical VAWT design parameters was undertaken which included the turbine solidity, blade number, blade aspect ratio and non-prismatic strut design.

This study identified a low solidity turbine ($\sigma = 0.263$) gave the best aerodynamic performance, while a two-bladed VAWT design is recommended. The results also indicated a blade aspect ratio in the range $10 \geq H/c \geq 20$ gives favorable performance. Finally, the geometrical details and operating specifications for a 5 MW VAWT design are presented.

Keywords: Vertical axis wind turbine; offshore; aerodynamic design; blade; strut

1. Introduction

As a source of sustainable energy, offshore wind is indigenous, clean and inexhaustible. This industry has witnessed tremendous growth over the last two decades with wind farms being pushed further offshore to exploit superior wind resources [1]. In fact, offshore wind turbines experience average wind speeds 90% greater than land-based wind turbines [2]. However, current fixed-bottom turbine foundations are only economically viable to a limited range of sea depths (< 50 m) and in deeper waters floating platforms must be employed [1]. To improve the competitiveness of offshore wind energy generation in these regions, alternative wind turbine configurations to the

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conventional three-bladed horizontal axis wind turbine (HAWT) are now being considered. In particular, this has led to a renewed interest in the vertical axis wind turbine (VAWT) as a result of its distinct advantages over the HAWT for a floating dynamic system [3]. The VAWT is a promising solution due to its inherent scalability, robustness, reliability, simplicity of installation, low center of gravity and insensitivity to yaw and pitch [4]. Furthermore, studies have identified that VAWTs are more suitable for offshore wind farms as they are less effected by turbine wake effects [1] and platform hydrodynamic motions [5]. As a result, increasing attention has been concentrated on the development of floating VAWTs with several different concepts proposed and are discussed further by Tjiu et al. [3].

Despite these numerous works on different turbine design aspects, it is apparent that an optimal floating VAWT design is ambiguous when compared to their horizontal axis counterparts [6]. Therefore, this paper outlines the aerodynamic and structural design philosophy of a new offshore VAWT design. Several geometric parameters pertinent to the VAWT's design are examined with respect to the turbine's aerodynamic performance. In addition, this study presents an optimized support strut design to minimize parasitic torque losses while maintaining the VAWT's structural integrity.

2. Modelling strategy

The ability to simulate the aerodynamic performance of an offshore VAWT is imperative to assess the overall economic justification of its implementation. In previous work [6, 7], a low-order aerodynamic model for offshore VAWTs has been developed and will be utilized in this study. This model computes the aerodynamic forces created by the turbine's blades and incorporates a Beddoes-Leishman dynamic stall model to account for unsteady airfoil flow separation and vortex shedding. In addition, sub-models have been included to consider the effects of flow curvature, tower shadow and strut parasitic drag losses. A schematic of the model's operation is depicted in Fig. 1 where the VAWT's configuration and operating conditions are initially specified. The model's solution settings and defined constants are also prescribed. A number of inputs are dependent on the respective Reynolds number for the blade and tower and are therefore interpolated from stored experimental or generated computational fluid dynamics (CFD) datasets [8].

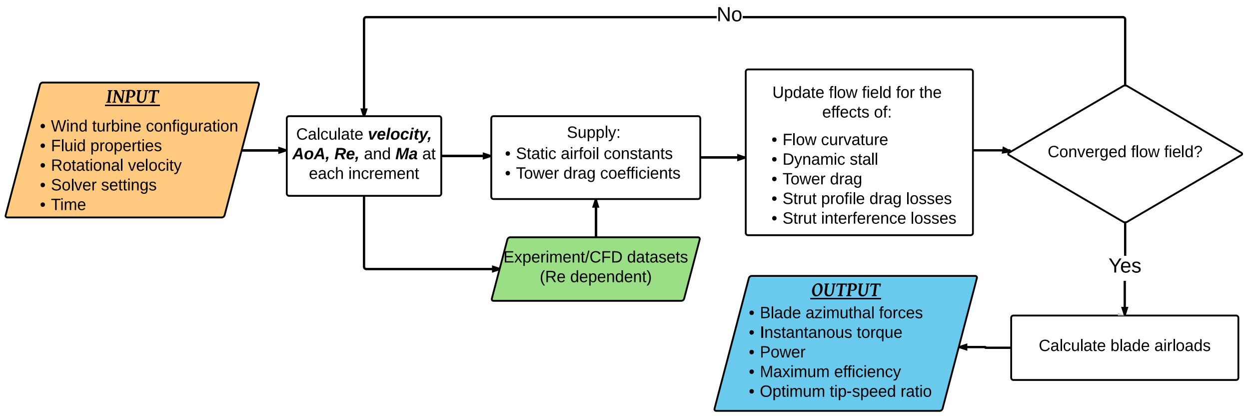

Fig. 1.Flowchart of the aerodynamic model.

3. Aerodynamic design

In this section, several design parameters are investigated to determine their influence on the aerodynamic performance of an offshore VAWT. The VAWT will have a straight-blade configuration, as it has been shown to possess a higher aerodynamic efficiency in comparison to other possible VAWT configurations [9]. Fig. 2 illustrates