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Offshore floating vertical axis wind turbines, dynamics modelling state of the art. part I: Aerodynamics

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A B S T R A C T

The need to further exploit offshore wind resources has pushed offshore wind farms into deeper waters, requiring the use of floating support structures to be economically sustainable. The use of conventional wind turbines may not continue to be the optimal design for floating applications. Therefore it is important to assess other alternative concepts in this context. Vertical axis wind turbines (VAWTs) are one promising concept, and it is important to first understand the coupled and relatively complex dynamics of floating VAWTs to assess their technical feasibility. A comprehensive review detailing the areas of engineering expertise utilised in developing an understanding of the coupled dynamics of floating VAWTs has been developed through a series of articles. This first article details the aerodynamic modelling of VAWTs, providing a review of available models, discussing their applicability to floating VAWTs and current implementations by researchers in this field. A concise comparison between conventional horizontal axis wind turbines and VAWTs is also presented, outlining the advantages and disadvantages of these technologies for the floating wind industry. This article has been written both for researchers new to this research area, outlining underlying theory whilst providing a comprehensive review of the latest work, and for experts in this area, providing a comprehensive list of the relevant references where the details of modelling approaches may be found.

Contents

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1. Introduction

With the need to increase renewable energy's share in global energy production and to exploit offshore wind resources, wind farms are moving further and further offshore into deeper waters. In water depths greater than 50 m, bottom-mounted (i.e. fixed) support structures for offshore wind turbines do not remain the most economically viable option [1]. A transition from fixed to floating support structures is essential for deep offshore wind farms to become economically viable in the near future.

The onshore wind industry has reached a relatively mature level, with the majority of large scale wind turbines sharing the same configuration: horizontal axis of rotation, three blades, upwind, variable-speed and variable blade pitch (with feathering capability). This has been the result of several decades of research and development, and originally several configurations had been considered, including horizontal axis wind turbines (HAWTs) with a different number of blades, but also vertical axis wind turbine (VAWT) configurations. The conventional design emerged as the optimum techno-economic trade-off for the onshore large scale wind market.

The same “evolutionary process” did not take place for the offshore wind market, substituted by a “marinisation” of the trusted configurations used for the onshore market. It has been implicitly assumed that, despite the very different environmental conditions of an offshore environment, the optimum configuration for the wind turbine is the same i.e. the conventional three bladed, upwind, horizontal axis wind turbine. This has been implicitly assumed not only for the bottom-mounted offshore wind turbine configurations, but also for proposed floating systems. In fact two prototype floating wind turbines, Hywind [2] and WindFloat [3], made use of 2–2.3 MW HAWT machines design for fixed on- and offshore foundations.

It is therefore important to assess the technical and economic feasibilities of alternative concepts for the offshore floating wind industry in order to ensure that the most suitable configurations are employed, with VAWTs being one promising concept that could complement HAWTs in offshore wind industry. The first step is to understand the complex dynamics of such a floating system subjected to the harsh offshore environment. As part of this task, a series of articles have been developed to present a comprehensive literature review covering the various areas of engineering expertise required to understand the coupled dynamics involved in floating VAWTs. This first article focuses on aerodynamic modelling of VAWTs and is organised as follows:

- Section 2 gives a brief history of the development of VAWTs
- Section 3 compares VAWTs to the more conventional HAWTs on a number of aspects highlighting their advantages and disadvantages
- Section 4 discusses and compares the different aerodynamic modelling techniques in depth
- Section 5 outlines current implementations by researchers
- Section 6 presents some conclusions.

2. A brief history of VAWT developments

As outlined by Shires [4], the modern onshore VAWT was developed in the years following the first oil crisis of 1973. These designs were based on a 1922 patent by the French engineer Georges Darrieus, with straight or curved blades rotating about a vertical shaft.

The 1970s and 1980s saw a substantial amount of research and development, particularly in the United States and Canada, that led to a number of curve bladed (or Φ-rotor) Darrieus turbines. The largest onshore VAWT, built in 1986 in Québec, Canada, was the Éole Darrieus Wind Turbine shown in Fig. 1, with a height of 96 m. With a rated maximum power of 3.8 MW, it produced 12 GWh of electric energy during the 5 years it operated but was shut down in 1993 due to a bearing failure.

Attempts to commercialise these VAWT developments were made in the United States during the 1980s by FloWind Ltd. A number of onshore wind farms were developed and worked efficiently, although they experienced fatigue problems with the blades [5].

The straight-bladed Darrieus turbine or H-rotor was largely developed in the UK by Peter Musgrove during the 1980s and 1990s. The concept of the H-rotor was to reduce blade manufacturing costs and simplify the support structure, relative to the Φ-rotor, with a shorter tower and eliminating the need for guy wires [6]. A number of onshore prototypes were constructed in the

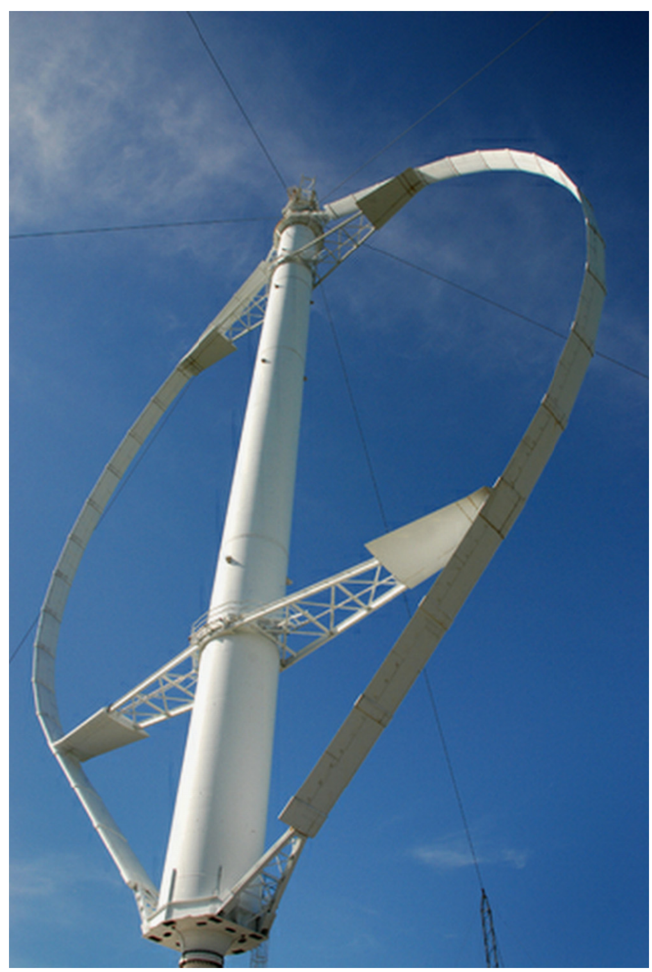

Fig. 1. 3.8 MW Éole VAWT Φ-rotor.

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