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Editorial

Advancements in Offshore Vertical Axis Wind Turbines

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In the past few years, the journal *Energies* received various original research manuscripts on offshore vertical axis wind turbines (VAWTs). These articles highlight the heightened interest (see also Hand and Cashman [1]) in expanding the penetration of VAWTs beyond the small to medium-scale units found, for instance, in the built environment. This editorial aims to highlight various articles received by *Energies* that may be relevant to floating offshore VAWTs. The general landscape of the state-of-the-art progress in this area is also provided, but this article is *not* meant to be a literature review. This editorial is also intended to entice the growth of this field of wind energy science.

In a recent review, Arredondo-Galeana and Brennan [2] highlight major advantages of floating offshore VAWTs that contribute towards improved stability due to their generally low center of gravity (CoG), as well as the lower over-turning moment (OTM). This corroborates with other literature, such as that by Borg et al. [3] and Borg and Collu [4]. The severity of generator or gearbox failures is also reduced due to easier accessibility, while wind-farm power density is improved given the possibility to reduce turbine spacings as opposed to the HAWT alternative. Other risks predominant in HAWTs, such as yawing system failures, are eliminated in the case of VAWTs. On the other hand, it is well known that the power coefficient of VAWTs can be in the order of 20% less than HAWTs, a fact that has led to HAWTs leading the way in both industry and research. Nevertheless, this ball-park figure refers to the ideal condition when the HAWT rotor is perpendicular to the wind direction. In practice, floating offshore turbines can exhibit 6-degrees of freedom (DOF) motions due to the wave motion that can degrade performance substantially unless extensive control engineering is implemented. Figure 1 (source: Arredondo-Galeana and Brennan [2]) shows that current VAWT offshore design initiatives have mostly focused on buoyancy and ballast foundation types, highlighting the lack of penetration of other technologies at the pilot scale level.

Senga et al. [5] showed, using a lifting line numerical solution, that a tilted VAWT provides an improved wake recovery effect compared to an upright VAWT, thus allowing to improve further the power density of a wind farm. VAWTs tend to employ simpler airfoil profiles than HAWTs, but the flow unsteadiness in the floating case highlights the need for improved airfoil data. Models that require airfoil data as an input, such as lifting line and double multiple streamtube models, remain reliant on accurate data, which can also model correctly dynamic stall conditions (see, for example, Dyachuk and Goude [6]). The use of tailor-made airfoils for floating applications have also started to emerge, as in the study by Pan et al. [7]. Unsteady effects and structural dynamics have been studied by Ishie et al. [8]. These lead to structural fatigue damage exacerbated by the dynamic conditions in the floating case. Such fatigue effects have been reported in a case study for onshore VAWTs. Borg and Collu [9] also provide a frequency domain analysis of the loads experienced by floating VAWTs. The authors report a noticeable increase in aerodynamic loads which directly impact the fatigue of mooring lines and other VAWT components. Similarly, Liu et al. [10] emphasise the importance of aerodynamic loads on the structural strength of floating VAWTs. It remains clear that further insight into floating offshore VAWT fatigue phenomena is needed.

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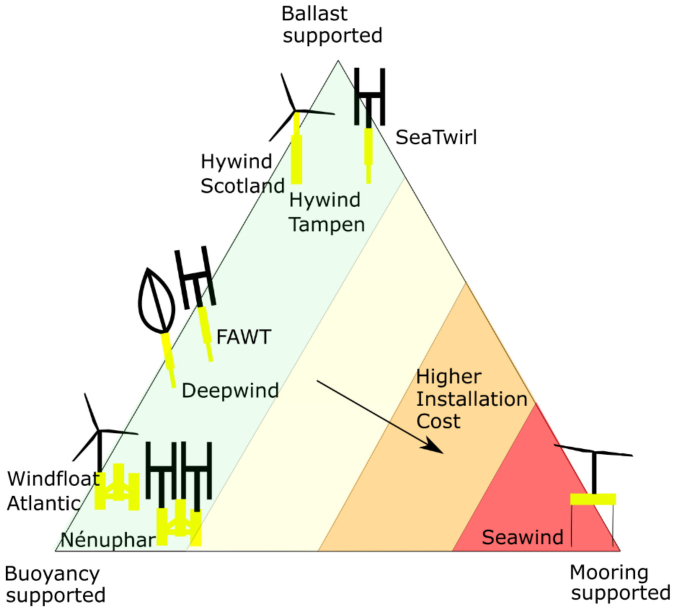

Figure 1. Stability triangle showing various foundation types (vertices) and comparing between VAWT and HAWT offshore concepts. Source: Arredondo-Galeana and Brennan [2].

The complex 6-DOF motions for floating offshore VAWTs, combined with the varying azimuthal loads experienced during blade rotation, resulted in an overall degradation of the aerodynamic performance of the turbine. However, appropriate control can be adopted to mitigate these effects. For instance, Li et al. [11] showed that speed control could be used based on efficiency and load considerations to match the rotational speed with wind speed. Furthermore, past articles in *Energies* have shown how Circulation Control (CC) using active jets can provide lift augmentation and load control (Shires and Kourkoulis [12]). Such technologies have already been extensively researched in HAWTs but can be transferred to VAWTs if further research is conducted.

Authors such as Buranarote et al. [13] have created 2D wake models that can provide quick insight into rotor-to-rotor interactions. More elaborate 3D CFD approaches, such as that by Brownstein et al. [14], have been used to show the enhanced performance of both the downstream and upstream turbines. In addition, the authors show, using a surrogate model, that turbine spacings can be optimised based on the resulting wake dynamics. Another study by Furukawa et al. [15] proposes a model for quantifying the interacting torques as a result of the VAWT rotor phase synchronisation. More advanced studies on floating VAWT wake interactions, taking into account pitching motions, can be found in Kuang et al. [16]. The authors again highlight the positive effects on wake recovery due to these pitching motions. These studies underpin the fundamental need to study VAWTs at the wind farm scale, which would help further support the research drive towards floating offshore VAWT wind farms.

The review by Arredondo-Galeana and Brennan [2] highlights various possibilities for increasing the technology readiness level of future offshore VAWTs. These include: (i) a better understanding of the rotor aerodynamics as a result of 6-DOF motions, (ii) improvement of mechanical design to mitigate cyclic loading, and (iii) control using techniques, such as morphing blades.

Conflicts of Interest: The authors declare no conflict of interest.

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