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Development of a floating Vertical Axis Wind Turbine for the Mediterranean Sea / Ghigo, Alberto; Petracca, Ermando; Mangia, Gabriele; Giorgi, Giuseppe; Bracco, Giovanni. - In: JOURNAL OF PHYSICS. CONFERENCE SERIES. - ISSN 1742-6588. - 2745:(2024). (Intervento presentato al convegno WindEurope Annual Event Bilbao tenutosi a Bilbao (ESP) nel 20/03/2024 - 22/03/2024) [10.1088/1742-6596/2745/1/012008].

Availability:
This version is available at: 11583/2989681 since: 2024-06-19T07:46:00Z

Publisher:
IOP Science

Published
DOI:10.1088/1742-6596/2745/1/012008

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21 December 2024

Journal of Physics: Conference Series

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To cite this article: Alberto Ghigo *et al* 2024 *J. Phys.: Conf. Ser.* **2745** 012008

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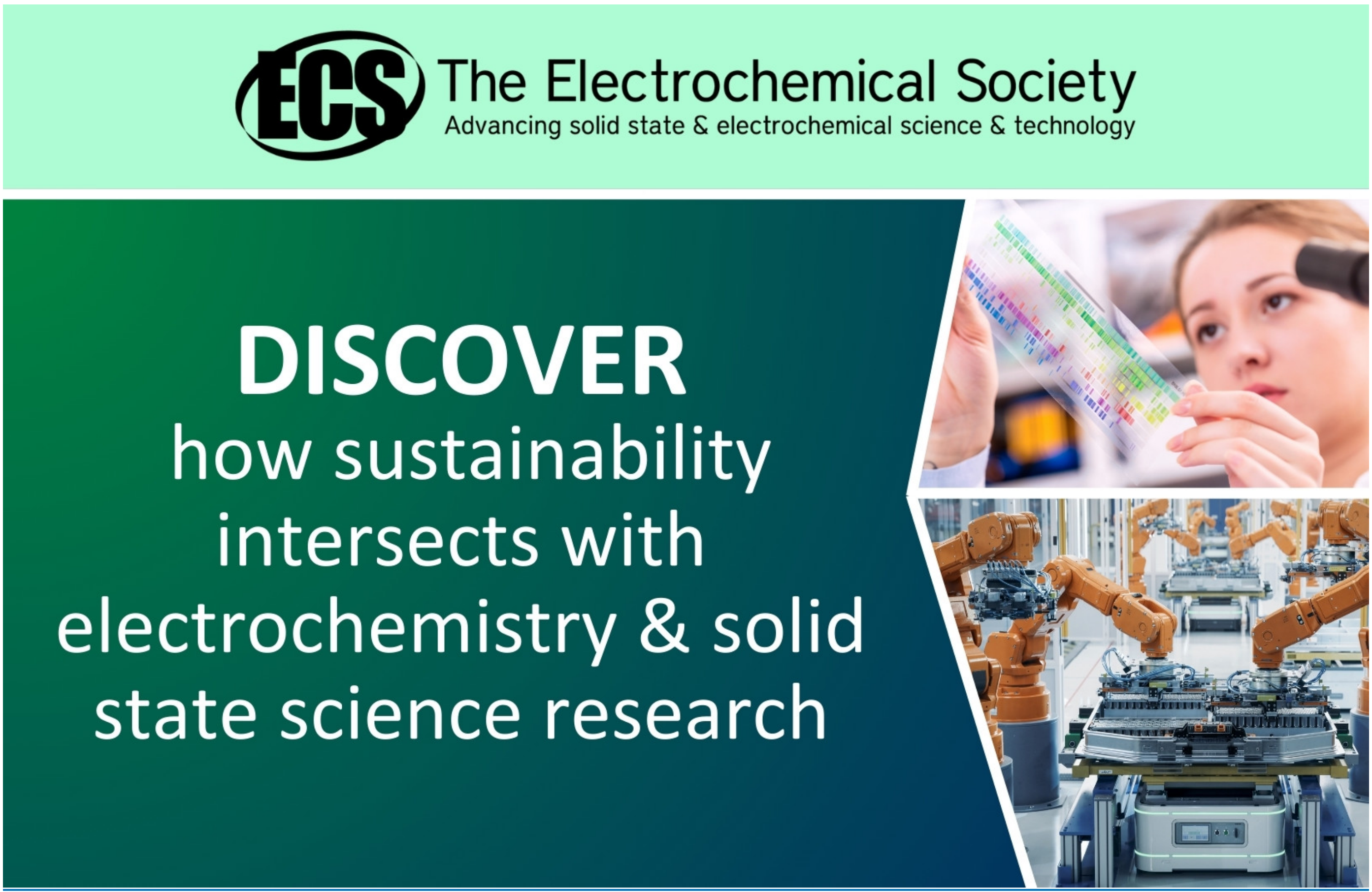

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Development of a floating Vertical Axis Wind Turbine for the Mediterranean Sea

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Abstract. Differently from Horizontal Axis Wind Turbines (HAWTs), which are the reference technologies in the wind market for their reliability and maturity, Vertical Axis Wind Turbine (VAWT) applications are related to small-scale contexts, such as providing electricity in isolated areas or urban settings. Consequently, the capacity of VAWTs results significantly lower than the order of megawatts and does not exceed a few tens of kilowatts. A promising field of application for VAWTs is the floating offshore: among the main advantages there are an increased static stability, by placing the rotor-nacelle assembly (RNA) at the base of the VAWT and reduced operational and maintenance (O&M) costs. Moreover, the different wake dynamics allows to reduce the aerodynamic losses, allowing closer turbine installations. However, to be competitive with floating HAWTs, it is necessary to have numerical models for the analysis and simulation of multi-megawatt VAWTs. This paper aims to introduce a time domain model of a floating vertical axis wind turbine, developed within the Matlab-Simscape environment. The model comprises an aerodynamics module, based on Double Multiple Stream Tube theory while hydrodynamics is modelled using WEC-Sim. A case study, involving a Darrieus H-rotor VAWT tested in the Mediterranean Sea and supported by a semi-sub foundation, the OC4-DeepCwind, is introduced. The results obtained are compared with those from QBlade, an software developed by TU Berlin, demonstrating a good agreement between the two codes.

1. Introduction

One of the primary applications of Vertical Axis Wind Turbines (VAWTs) is in small-scale energy production, with installations in both urban and remote areas. In urban settings, these turbines can be placed on building rooftops, while in remote areas without access to the electricity grid, they can satisfying the energy needs of small-scale users, such as water pumping and desalination. In recent years, the application of VAWTs for offshore wind generation has been explored. The **DeepWind** technology, introduced in 2012, featuring a 5 MW ϕ-Darrieus turbine supported by a spar-buoy foundation, was one of the most studied concepts. The floating system incorporates a generator located at the bottom of the structure. Experimental verification was conducted in both a test tank and a wind tunnel, and a 1 kW prototype tested at sea in Roskilde Fjord near Risø campus (Denmark).

Another attempt at a pre-commercial scale involved the Savonius Keel and Wind Turbine Darrieus (**Skwid**), developed by Modec. This hybrid wind-currents platform comprised a 500 kW H-Darrieus

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turbine supported by a floater, with a 60 kW Savonius turbine arranged on top to harness currents. However, in 2014 the installation of the demonstrator encountered difficulties due to buoyancy issues with the structure and the technology has been abandoned after huge financial investments.

Among the more recent technologies is **SeaTwirl**, featuring a Darrieus H-shape turbine supported by a spar-buoy foundation. The floater, rotating along with the turbine, is anchored to the seabed with multiple catenary moorings, while a static, non-rotating generator is enclosed just above sea level on the substructure. This device offers scalability for higher powers and reduced maintenance. A 30 kW prototype was installed in Norway in 2015, and a 1 MW device is scheduled for installation in Norway by the end of 2023.

Compared to floating HAWTs, VAWTs boast some interesting advantages [1]. By placing the rotor-nacelle assembly (RNA) at the base of the VAWT, the system gains increased static stability, thanks to a lower moment of inertia. Moreover, this allows greater accessibility to the RNA, especially in more intense metocean conditions, and reduces operational and maintenance (O&M) costs. Furthermore, the different wake dynamics, which dissipates in a more confined space compared to HAWTs, allows for reducing aerodynamic losses, increasing Annual Energy Production (AEP), and placing the VAWTs closer.

To evaluate the performances and to quantify the advantages previously introduced, it is essential to use numerical models with different levels of accuracy and computational time required. Several review works on numerical models are available in the literature [2], [3]. However, many state-of-the-art software, only allow to simulate HAWTs due to greater diffusion and technological maturity. The main ones are listed below.

FloVAWT (Floating Vertical Axis Wind Turbine), developed by Cranfield and Strathclyde Universities, is an aero-hydro-servo-elastic coupled model based on Paraschivoiu's Double-Multiple Streamtube model for aerodynamics and a time-domain model for hydrodynamics [4],[5].

HAWC2, created by DTU, is a versatile multibody time-domain program suitable for both floating and bottom-fixed offshore wind turbines, incorporating blade element momentum theory for aerodynamics and Morrison's equation for hydrodynamic loads [6].

QBlade, an open-source code from TU Berlin, allows the design and simulation of wind turbines, with the latest version, QBlade Ocean, enabling the simulation of complete systems of floating offshore wind turbines, both horizontal and vertical axis [7]. Qblade utilizes a multi-body formulation for structural dynamics and employs the Lifting Line Free Vortex Wake method for aerodynamics.

OpenFast, is a state-of-the-art software for simulating floating offshore wind turbines, primarily designed for HAWTs. Despite this limitation, there have been attempts to incorporate VAWTs by coupling OpenFast with the Offshore Wind ENergy Simulator (OWENS) [8], [9].

Simo-Riflex-DMS is a aero-hydro-servo-elastic simulator operating in the time domain that couples three codes [10], [11]. Simo computes hydrodynamic loads based on the actual displacement of the floater, while the DMS code calculates aerodynamic loads on the blades. Riflex conducts full equilibrium iterations at each time step.

Another obstacle is the lack of publicly available turbines, whose data can be accessed for analysis and simulations, such as the NREL 5 MW or the IEA 15 MW for HAWTs. Among the most studied, there is the DeepWind concept: it entails a two-bladed Darrieus-Φ rotor with a modified Troposkien shape to accommodate the substantial blade weight [12], [13]. Designed for a nominal power of 5 MW, the turbine had a diameter of 60.5 m, a height of 130 m and a chord of 5 m. Different upscales were made, up to a nominal power of 20 MW.

The objective of this study is to present a numerical model of a floating vertical axis wind turbine. The model, created in Matlab-Simscape, includes a floating platform, a wind turbine and a mooring system. Aerodynamics is simulated using the Double Multiple Stream Tube method, while hydrodynamics is modeled using WEC-Sim. The VAWT used for the simulations was designed starting from a Darrieus H-rotor VAWT: the chord length and type of airfoil were analyzed, and then the power and thrust were compared with QBlade. Finally, a case study of the floating VAWT, with a semi-sub foundation, the OC4-DeepCwind, under operative and extreme conditions is presented.

2. Material and methods

The numerical model introduced in this work is based on Most (Matlab for OFWT Simulations Tools), developed by MOREnergy Lab of Politecnico di Torino [14]. Most main application regards the design and analysis of a FOWT: due to its flexibility it is possible to simulate different floating foundations, wind turbines and mooring layouts. The use of look-up tables for the aerodynamics also allow a remarkable time reduction while the accuracy has been compared with OpenFast in [15].

To assess VAWT performances, the following implementations have been made:

- *Aerodynamics*: The simulation of aerodynamics utilizes the Double Multiple Stream Tube (DMST) method, which is based on the blade element momentum (BEM) theory. Aerodynamic forces are computed using pre-calculated look-up tables.
- *Hydrodynamics*: The hydrodynamics of the floating foundation is calculated using WEC-Sim, employing a time-domain approach to solve the dynamics of floating bodies based on a frequency-domain boundary element method. Hydrodynamic characteristics, including linear hydrostatics, added mass, radiation damping, and wave excitation coefficients, can be assessed using external software tools such as Wamit, Ansys Aqwa, Nemoh, or Capytaine.
- *Moorings*: Two options have been incorporated: quasi-static mooring lookup tables, obtained by solving catenary equations, or Moordyn,

Figure 1 shows a representation of the model.

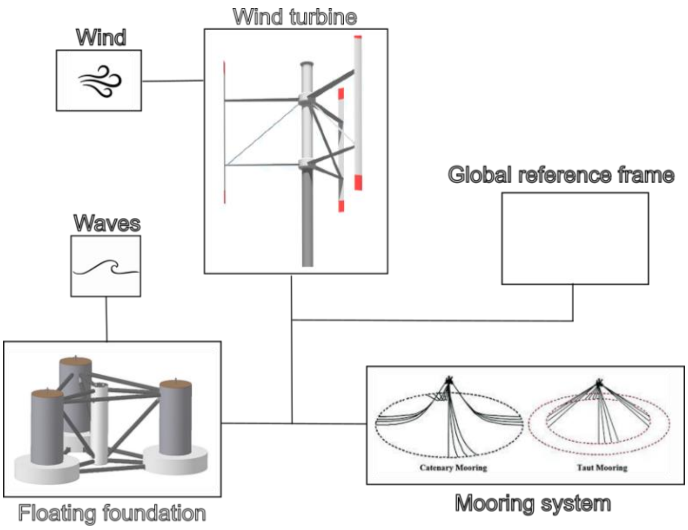

Figure 1. The numerical model representation.

2.1. Aerodynamics

The approach used in this work for the estimation of aerodynamic forces acting on the wind turbine is based on the Double Multiple Stream Tube (DMST) theory, developed by Parashivoiu [16]. In this model, several aerodynamically independent streamtubes are employed, wherein the upwind and downwind sections of the rotor are substituted by distinct actuator disks with equivalent loading.

This methodology enables the model to calculate different induction factors for each streamtube and separately for the upwind and downwind components. Similar to the actuator disk model utilized for Horizontal Axis Wind Turbines (HAWTs), the solution is attained through an iterative process. The induction factor from the momentum model serves as input for the blade element model, and conversely, the load from the blade element model is incorporated into the momentum model.

After dividing the rotor into N streamtubes, the induction factor is assumed to be zero. For each streamtube, assuming a specific airfoil type and obtaining tabulated values of the lift and drag coefficients as functions of the angle of attack, the calculation proceeds for main aerodynamic parameters such as lift, drag, relative velocity, angle of attack, and normal and tangential coefficients. To determine the induction factor value, the convergence criterion is set as the thrust coefficient, calculated using both the momentum theory and the blade-element equation. In the model, for each streamtube the cycle is iterated up to 500 iterations, allowing for an error in the thrust coefficient of up to 1%. The loop is iterated for all streamtubes, both upwind and downwind. Finally, by summing the upstream and downstream contributions, it is possible to determine the value of the torque, power and thrust. The methodology used is summarised in Figure 2.

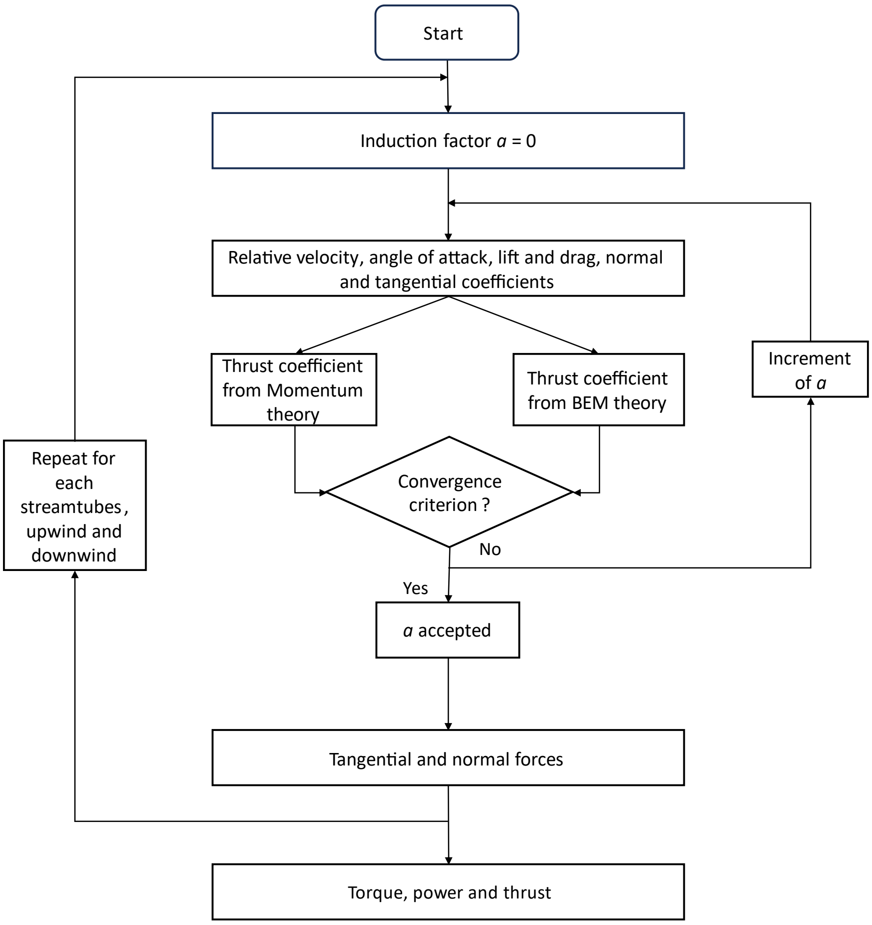

Figure 2. The DMST methodology used for the calculation of torque, power and thrust.

Some corrections in particular have been applied to the proposed methodology, including Glauert correction and the dynamic stall, as well as the blade pitch mechanism to allow the blades to rotate along the pitch angle to reduce the thrust force and to keep a constant power.

3. VAWT design

The wind turbine considered in this study is a Darrieus H-rotor VAWT with straight blades. The adoption of this type of turbine lies in the simplicity of the system, where the blades are easily manufacturable compared to the curved blades of the Darrieus-Φ turbine. For the input data, turbines developed for two European projects were considered: the H2OCEAN (2012) [17] and S4VAWT (2016) [18] projects. The final VAWT design is the result of several analysis, in which the influence of the chord size and the type of airfoil are investigated, as detailed in the following sections.

3.1. Blade chord influence

In this section, the influence of the chord is investigated by considering five different values of chord lengths, from 2 up to 10 m. In Figure 3 the power and thrust coefficient are reported by considering the different chord lengths, while in Figure 4 the torque coefficient is shown.

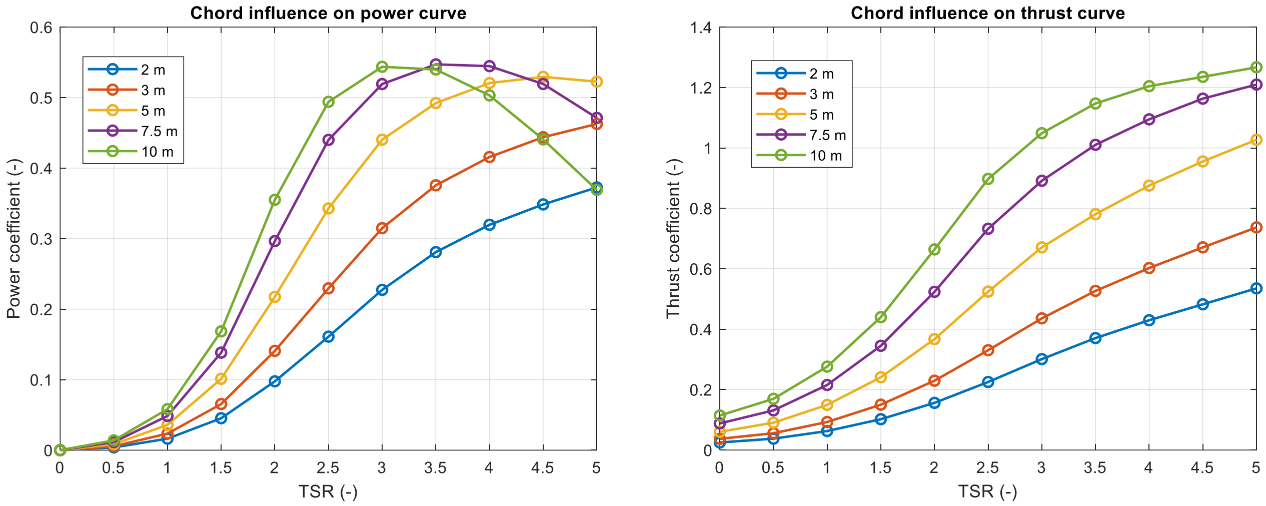

Figure 3. Power and thrust coefficient for different chord lengths.

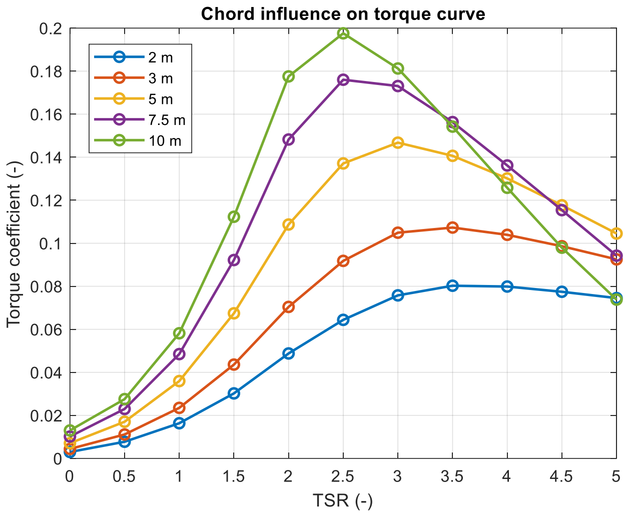

Figure 4. Torque coefficient for different chord lengths.

From the previous figures, it is observed that as the chord length increases, there is an increase in the thrust force acting on the blade. Regarding the power curve, for longer chords, the peak of the curve is reached earlier, to decrease rapidly for higher TSR values. Consequently, for the subsequent analyses, the intermediate chord value of 5 m is chosen as it is a good compromise in terms of power extracted and thrust force acting on the blades.

3.2. Airfoil influence

In this section, the influence of the airfoil is investigated by considering five types of airfoil profiles: NACA 0012, NACA 0015, NACA 0018, NACA 0024 and NACA 0027. The choice to consider NACA airfoils, in addition to data availability, is linked to their adoption in other studies about multi-megawatt VAWTs for offshore applications.

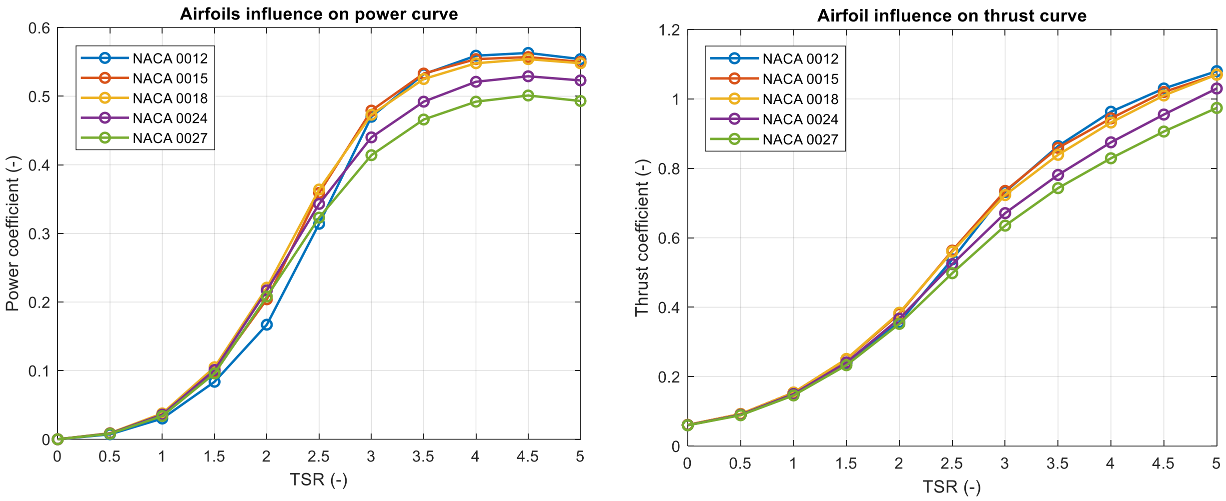

Figure 5. Power and thrust coefficient for different NACA airfoils.

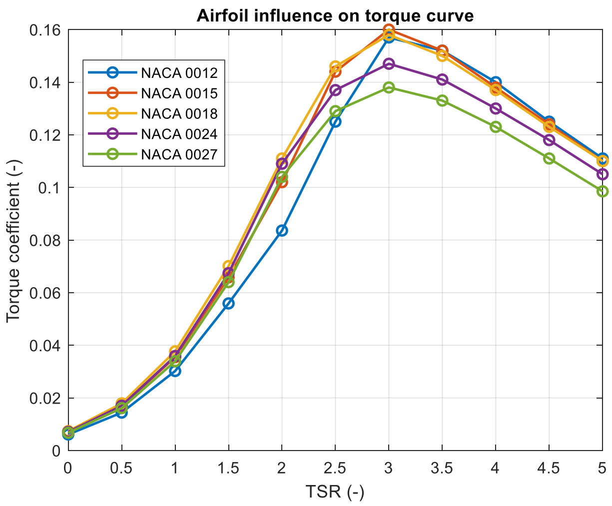

Figure 6. Torque coefficient for different NACA airfoils.

From Figures 5 and 6, it is evident that lower NACA airfoils exhibit higher maximum values for power and torque coefficients, as well as thrust. Conversely, larger NACA airfoils provide lower performance in terms of power and torque but result in lower thrust values acting on the blade. Consequently, since the blade height for a multi-MW VAWT is significant, the NACA 0024 has been chosen.

3.3. VAWT 6 MW final design

From the previous analyses, assumptions have been made about the characteristics of the turbine used in the study. The criteria used was to obtain a compromise in terms of productivity and reducing the thrust forces acting on the turbine. Table 1 shows the main VAWT data.

Table 1. Wind turbine data.

Wind turbine	*VAWT*
Nominal power	6 MW
V_cut_in, V_rated, V_cut_off	3, 10, 25 m/s
Ω_min, Ω_rated	2.1, 6.6 rpm
Wind turbine radius	63 m
Wind turbine height	140 m
Chord length	5 m
Airfoil	NACA 0024

In Figure 7, the power and torque curves are shown as a function of the rotor speed and the wind speed. The minimum rotor speed is 2.1 rpm, while over nominal conditions, i.e., for wind speeds exceeding 10 m/s, is constant and equal to 6.6 rpm.

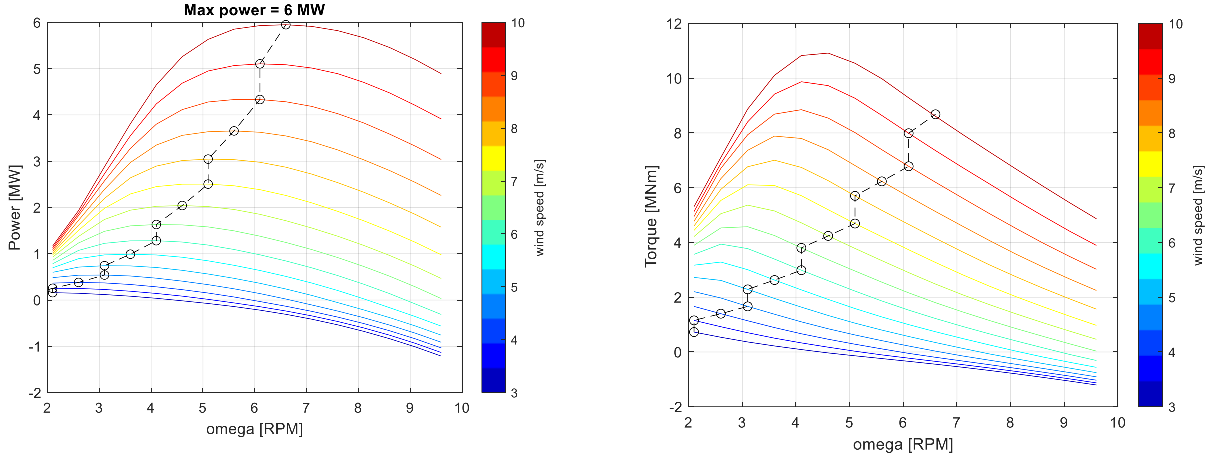

Figure 7. Power and torque curve.

In Figure 8, the thrust and power curves are presented. The blade pitch mechanism causes a decrease in the peak of the thrust curve once the nominal speed is reached, while the power curve follows a constant trend, equal to the nominal power. However, the power value is not instantaneous but is averaged over the entire rotation of the turbine.

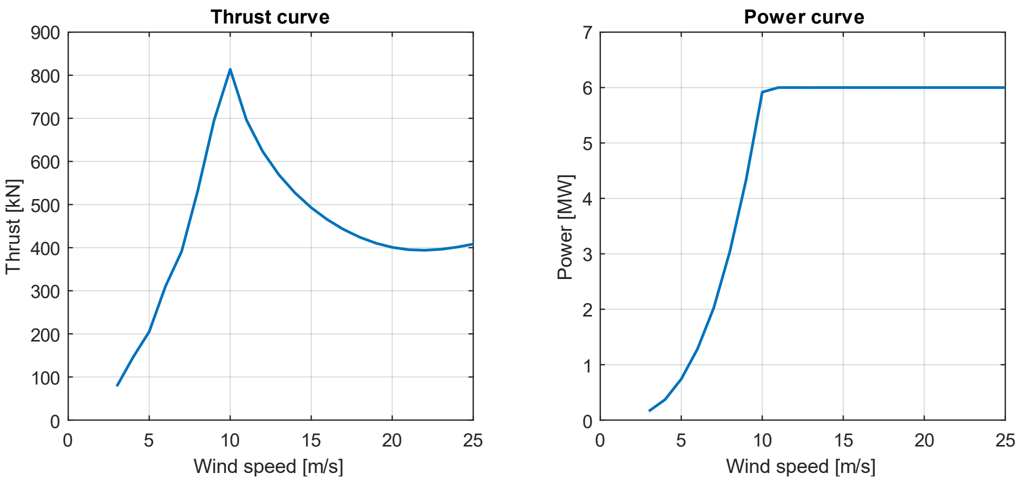

Figure 8. Power and thrust curve.

3.4. Comparison with QBlade

In this paragraph, a comparisons of the aerodynamic performances between the numerical model and QBlade is reported. In Figure 9, the power and thrust curved by varying the wind speed are shown.

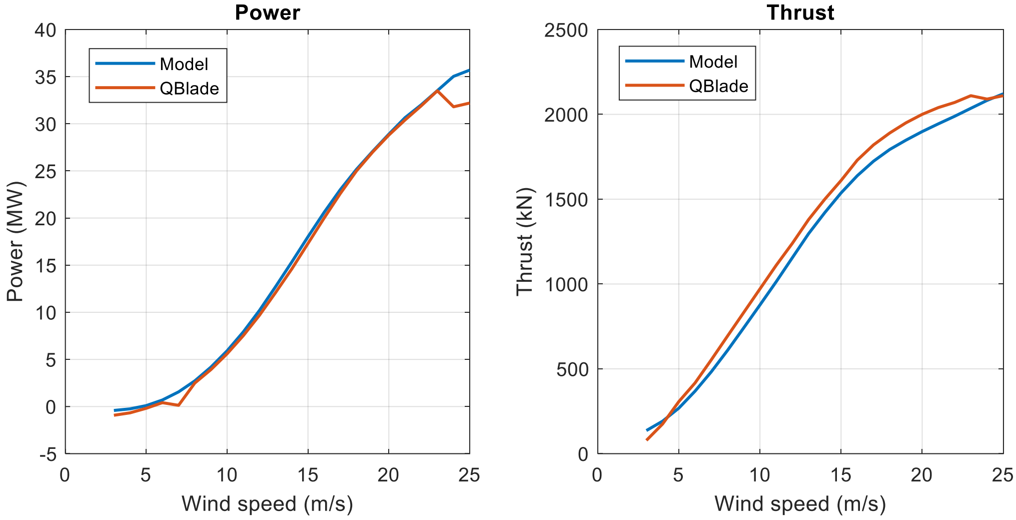

Figure 9. Power and thrust comparison between the numerical model and QBlade.

While QBlade slightly overestimate the thrust, there is a good agreement between the two codes for both the power and the thrust. In this simulation, to make the results comparable, the blade pitch mechanism for wind speed higher than the nominal speed was not implemented.

3.5. Floating VAWT simulations

The floating foundation selected for the case study is a semi-submersible platform, the OC4 [19]. This platform features a triangular shape with three columns positioned at its vertices, along with a central column that provides support for the wind turbine. The complete system, consisting of the 6 MW VAWT installed on the OC4 floating foundation, is simulated in an operational environment. The site is located in the Sicily Streat, next to the island of Pantelleria (Italy). In particular, two sea-states have been considered, one for operational and one for near cut-off wind speed condition, as reported in Table 2.

Table 2. the two sea states considered for the floating VAWT.

Sea states	***Operational***	***Near cut-off***
Average wind speed	7 m/s	21 m/s
Wave height	0.65 m	4.65 m
Wave period	3.65 s	8.13 s

The two sea-states have been considered from the MORE-RES platform, a web tool developed by Politecnico di Torino for the analysis of offshore wind and waves [20]. Wind and wave data are provided by ECMWF ERA5 database, from 2010 to 2019. In Figure 10, on the left the most occurrent triplets of wave height, wave period and wind speed are reported, while on the right there is the wave scatter for the site of Pantelleria.

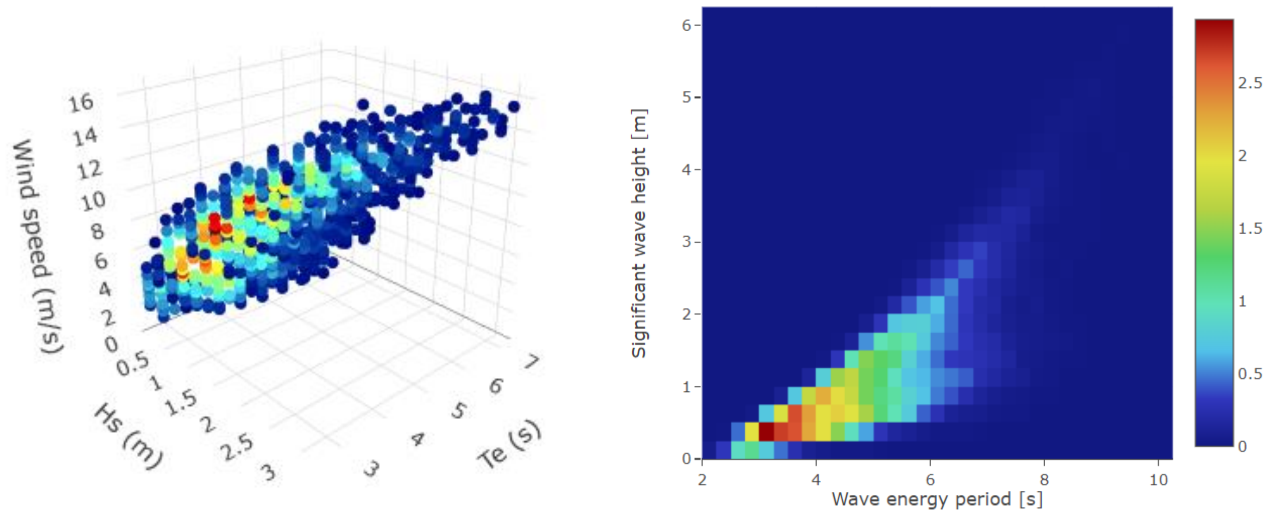

Figure 10. Wind speed, wave height and wave period triplets (on the left) and wave scatter (on the right) for the site near to Pantelleria, from MORE-EST platform.

The depth of the site is 200 m, while the mooring configuration includes three catenary lines arranged at 120° between them. The wind speed profile is generated by using the TurbSim software, developed by NREL. The turbulence model considered is a Kaimal, with a IEC turbulence characteristic B of 0.14. The power law exponent considered is equal to 0.11.

In Figure 11, on the left the VAWT performances are reported, while on the right the OC4 platform displacements.

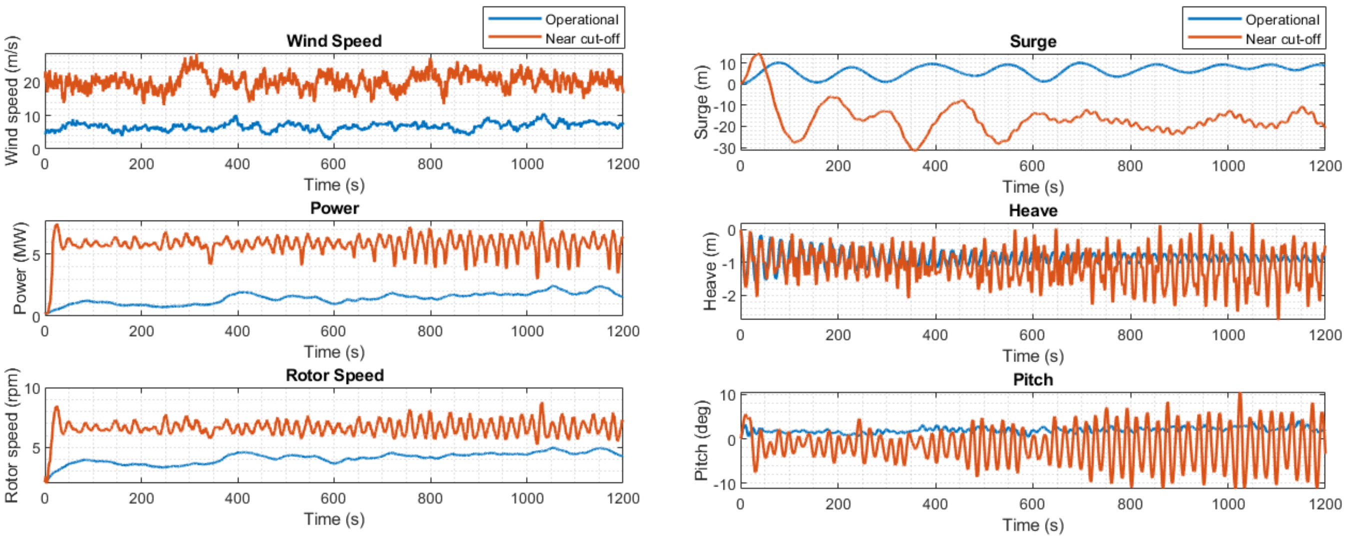

Figure 11. VAWT performances and displacements for the operational and extreme sea-states.

Regarding the operational conditions, with a wind speed of 7 m/s, lower than the nominal value, the turbine cannot achieve its nominal power and rotor speed. The initial transient appears slower, then settles at the value predicted by the power curve, with few oscillations. Conversely, in the extreme case, after a faster initial transient, the power and the rotor speed oscillate around the nominal values, with a greater amplitude than the operational case. As for displacements, there are significative differences between the two cases for the surge displacement. In the near cut-off conditions, the amplitude of surge is higher due to the significant wave height acting on the floating VAWT. Similarly, for the pitch, the system results more stressed, with oscillations up to 10°, while for operational conditions they are assessed to an average value of 3°.

Therefore, the design of an improved foundation and the study of an improved mooring configuration for the VAWT could help reduce these maximum values.

4. Results and discussion

The purpose of this work is twofold: firstly, to introduce the numerical model of a floating VAWT developed in the Matlab-Simscape environment; secondly, to exploit the model for the design of a multi-megawatt VAWT intended for the Mediterranean Sea. The numerical model, based on the Most tool, features aerodynamics grounded in the DMST model, with some corrections such as the Glauert correction and dynamic stall to improve the accuracy.

The VAWT design process has analyzed the airfoil type and the chord length, by considering the torque, power, and thrust as performance parameters. Once the VAWT design was completed, the power and thrust characteristics were compared with QBlade, demonstrating a good agreement. Finally, a case study near the island of Pantelleria (Italy) was presented, simulating a floating VAWT under both operational and extreme conditions.

The flexibility of the numerical model stands out as its primary advantage. Each Simulink block can be accessed and modified, including governing equations, wind turbine parameters, foundation configuration, and mooring layout. This flexibility ensures a balance between accuracy and computational efficiency, making the model an adaptable tool for preliminary assessments of floating VAWT projects.

References

[1] A. Ghigo, E. Faraggiana, G. Giorgi, G. Mattiazzo, and G. Bracco, “Floating Vertical Axis Wind Turbines for offshore applications among potentialities and challenges: A review,” *Renewable and Sustainable Energy Reviews*, vol. 193, p. 114302, Apr. 2024, doi: 10.1016/j.rser.2024.114302.

[2] E. Faraggiana, G. Giorgi, M. Sirigu, A. Ghigo, G. Bracco, and G. Mattiazzo, “A review of numerical modelling and optimisation of the floating support structure for offshore wind turbines,” *Journal of Ocean Engineering and Marine Energy*, vol. 8, no. 3. Springer Science and Business Media Deutschland GmbH, pp. 433–456, Aug. 01, 2022. doi: 10.1007/s40722-022-00241-2.

[3] A. Otter, J. Murphy, V. Pakrashi, A. Robertson, and C. Desmond, “A review of modelling techniques for floating offshore wind turbines,” *Wind Energy*, vol. 25, no. 5. John Wiley and Sons Ltd, pp. 831–857, May 01, 2022. doi: 10.1002/we.2701.

[4] M. Collu, M. Borg, A. Shires, F. Rizzo, and E. Lupi, “FLOVAWT: Further progresses on the development of a coupled model of dynamics for floating offshore VAWTS,” in *Proceedings of the International Conference on Offshore Mechanics and Arctic Engineering - OMAE*, 2013. doi: 10.1115/OMAE2013-10717.

[5] M. Collu, M. Borg, A. Shires, and F. P. Brennan, “FLOVAWT: Progress on the development of a coupled model of dynamics for floating offshore vertical axis wind turbines,” 2013. [Online]. Available: http://www.energytechnologies.co.uk

[6] F. Vorpahl, M. Strobel, J. M. Jonkman, T. J. Larsen, P. Passon, and J. Nichols, “Verification of aero-elastic offshore wind turbine design codes under IEA Wind Task XXIII,” *Wind Energy*, vol. 17, no. 4, pp. 519–547, 2014, doi: 10.1002/we.1588.

[7] D. Marten *et al.*, “QBLADE: An Open Source Tool for Design and Simulation of Horizontal and Vertical Axis Wind Turbines,” 2013. [Online]. Available: www.ijetae.com

[8] M. C. Devin, N. R. Mendoza, A. Platt, K. Moore, J. Jonkman, and B. L. Ennis, “Enabling Floating Offshore VAWT Design by Coupling OWENS and OpenFAST,” *Energies (Basel)*, vol. 16, no. 5, Mar. 2023, doi: 10.3390/en16052462.

[9] B. C. Owens, T. W. Strganac, and R. Talreja, “Theoretical Developments and Practical Aspects of Dynamic Systems in Wind Energy Applications A Dissertation,” 2013.

[10] K. Wang, N. / Cesos, N. Trondheim, M. Otto, and L. Hansen, “A method for modeling of floating vertical axis wind turbine,” *Proceedings of the ASME 2013 32nd International Conference on Ocean, Offshore and Arctic Engineering.* , vol. Volume 8, Nov. 2013, doi: https://doi.org/10.1115/OMAE2013-10289.

[11] K. Wang, T. Moan, and M. O. L. Hansen, “Stochastic dynamic response analysis of a floating vertical-axis wind turbine with a semi-submersible floater,” *Wind Energy*, vol. 19, no. 10, pp. 1853–1870, Oct. 2016, doi: 10.1002/we.1955.

[12] V. , Luca, *Offshore Vertical Axis Wind Turbine with Floating and Rotating Foundation*. APA, 2011. [Online]. Available: www.risoe.dtu.dk

[13] U. S. Paulsen *et al.*, “Outcomes of the DeepWind conceptual design,” in *Energy Procedia*, Elsevier Ltd, 2015, pp. 329–341. doi: 10.1016/j.egypro.2015.11.437.

[14] M. Sirigu, E. Faraggiana, A. Ghigo, and G. Bracco, “Development of MOST, a fast simulation model for optimisation of floating offshore wind turbines in Simscape Multibody,” in *Journal of Physics: Conference Series*, 2022. doi: 10.1088/1742-6596/2257/1/012003.

[15] L. Cottura, R. Caradonna, A. Ghigo, R. Novo, G. Bracco, and G. Mattiazzo, “Dynamic modeling of an offshore floating wind turbine for application in the mediterranean sea,” *Energies (Basel)*, vol. 14, no. 1, 2021, doi: 10.3390/en14010248.

[16] I. Paraschivoiu, “Double-Multiple Stream Tube for Darrieus Wind Turbines.”

[17] “H2OCEAN D4.2 Mechanical design of VAWT ad Power Take Off system FINAL”.

[18] F. Huijs *et al.*, “Integrated design of a semi-submersible floating vertical axis wind turbine (VAWT) with active blade pitch control,” in *Journal of Physics: Conference Series*, Institute of Physics Publishing, Nov. 2018. doi: 10.1088/1742-6596/1104/1/012022.

[19] A. Robertson *et al.*, “Definition of the Semisubmersible Floating System for Phase II of OC4,” 2014. [Online]. Available: www.nrel.gov/publications.

[20] G. Giorgi, R. Novo, G. Cervelli, and G. Bracco, “Wave energy converters technology database for a web-based platform for evaluating wave energy resource and productivity potential,” in *Trends in Renewable Energies Offshore - Proceedings of the 5th International Conference on Renewable Energies Offshore, RENEW 2022*, CRC Press/Balkema, 2023, pp. 33–41. doi: 10.1201/9781003360773-5.