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Multidisciplinary Design Analysis and Optimization of Small Wind Turbines. A VAWT case

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Summary

Small wind turbines (SWTs) are an essential component of decentralized renewable energy systems, providing sustainable power for residential, agricultural, and remote applications.

For decades, the development of tools to support analysis and design in the wind energy community has primarily focused on very large machines due to the complexity and critical nature of these massive structures.

However, SWT design presents several unique challenges, such as noise emissions—given their proximity to populated areas—and the high Cost of Energy, which remains significantly higher than that of comparable systems like photovoltaics.

This work attempts to apply the same Multidisciplinary Design, Analysis, and Optimization (MDAO) approach—commonly used for multi-megawatt wind turbines—to SWT design, with the primary goal of supporting SMEs in the design phase." (corrects awkward phrasing and missing plural form of SME).

The paper presents one result applied to a Small Vertical Axis Wind Turbine.

1. Introduction

Small wind turbines (SWTs) are an essential component of decentralized renewable energy systems, providing sustainable power for residential, agricultural, and remote applications. The design and analysis of these turbines involve optimizing aerodynamic efficiency, structural integrity, noise emission reduction, and power generation capacity while ensuring cost-effectiveness and durability. Key aspects of SWT design include blade aerodynamics, generator selection, tower configuration, and control mechanisms to enhance performance in varying wind conditions. A thorough analysis involves computational simulations, wind resource assessment, and mechanical stress testing to maximize efficiency and reliability. This field continues to evolve with advancements in materials, smart controls, and hybrid energy integration, making small wind turbines a viable solution for clean energy generation.

While rapid technological advancements have been observed in the design and manufacture of large wind power plants over the past decades, small wind turbines have only recently begun to receive similar interest, as these machines can contribute to the further expansion of electricity generation from renewable sources by complementing large-scale wind farms in certain applications.

Despite their smaller size, SWTs exhibit a complexity that is not significantly lower than that of multi-megawatt wind turbines. Recently, a study on the current status and major challenges of small wind technologies was published [1]. This study highlights critical issues related to the aerodynamic, noise, structural, and aeroelastic modeling of these systems, as well as the growing interest in Vertical Axis Wind Turbines (VAWTs) [1].

Typically, the manufacture of SWTs is carried out by small or medium-sized companies, which often enter this emerging field by transitioning from related but distinct industries. As a result, there is not only a theoretical knowledge gap but also a lack of modeling and design tools specifically suited for this type of machine.

2. Methodology

This paper presents the ongoing activity over the past year aimed at supporting industries in the design and certification of wind turbines.

As widely explored for large Horizontal Axis Wind Turbines (HAWTs) [3], the design process is formulated as a constrained optimization problem, where the objective function is the Cost of Energy (CoE) (or other key performance indicators), and the constraints reflect technological limitations, geometric boundaries, structural requirements, and more. Fig. 1 ([3]) schematically illustrates the nested optimization problems developed in recent years for the design of a land-based wind turbine.

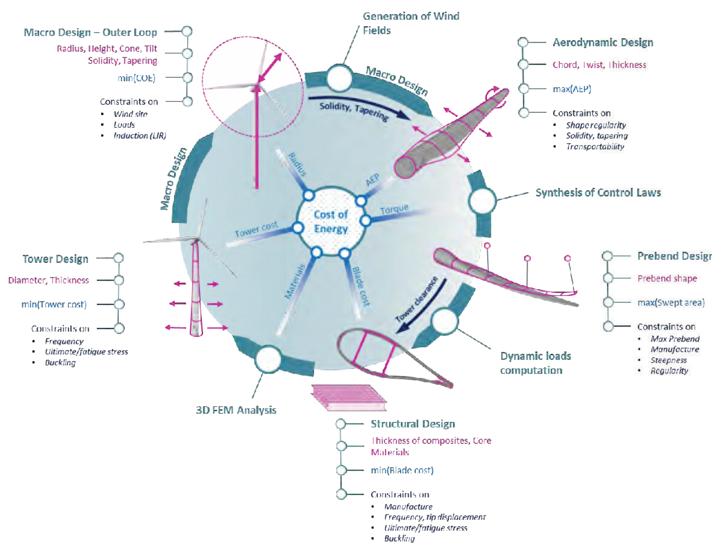

Figure 1: The multidisciplinary design tool Cp-Max architecture [3].

For this project, starting with the development of a parametric analysis tool based on engineering models, such as the Double Multiple Stream Tube model [2] coupled with rigid blades, the idea is to build up a tool for the multidisciplinary analysis and design of VAWTs.

As shown in Fig.2, global design parameters, such as rotor radius, blade chord and blade length, are used in a combined aero-structural optimization problem to estimate a preliminary design. Then, an aero-servo-hydro-elastic model is used to extract load conditions (ultimate and fatigue loads) as commonly done for multi-megawatt wind turbine. For this step, the in-house aero-elastic multibody solver *Cp-Lambda* (*C*ode for *P*erformance, *L*oads, *A*eroelasticity by *M*ulti-*B*ody *D*ynamics *A*nalysis), which has been widely used for other applications (such as HAWT and helicopters) is employed [4].

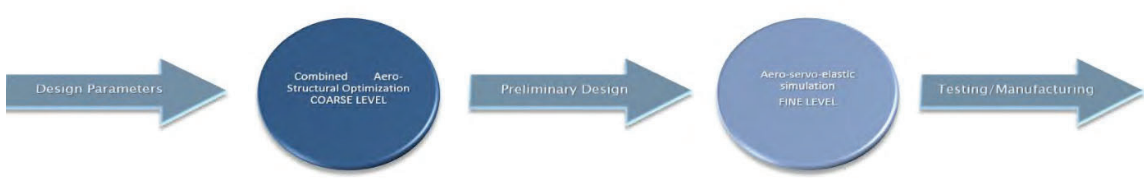

Figure 2: The multi-level design approach architecture.

2. Results

Preliminary results refer to an Italian industrial case involving a 20kW VAWT, which builds upon the current 10kW prototype. Due to industrial restrictions, only qualitative results can be presented in this paper.

Fig. 4 (left) briefly illustrates the first step of this multi-level approach: the optimization problem seeks the best combination of global parameters (blade chord, rotor diameter, etc.) based on a simplified DMST model with rigid blades, implemented in MATLAB®. Centrifugal and inertial loads are also correctly accounted for in the preliminary structural sizing. These optimized parameters are then used to develop the *Cp-Lambda* aeroelastic model (Fig. 4, right), which is employed to extract maximum and fatigue loads on the subcomponents in accordance with IEC 61400 standards for conventional (i.e., non-small) wind turbines.

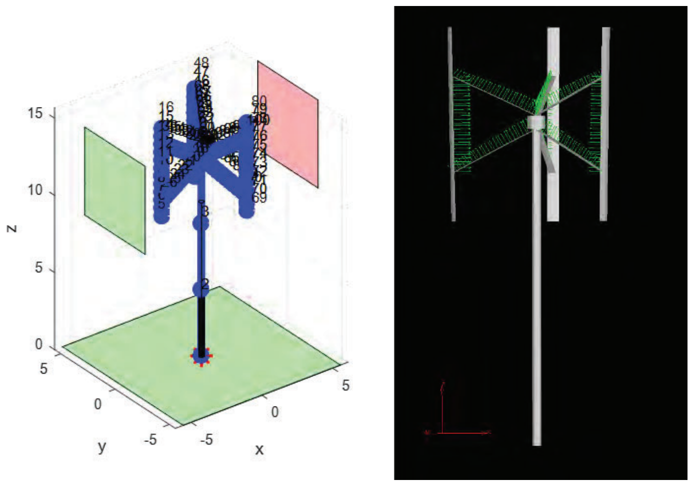

Figure 3: The multi-level design approach: left the simplified model for the optimization phase, right the aero-servo-elastic model for the load analysis.

4. Conclusions

This paper briefly presents an in-house multi-level design approach for vertical axis wind turbines. The presentation will provide more details on the tool and will include the ongoing work aimed at developing sound emission models to be included in the design phase of these VAWT.

Acknowledgements

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