ΕΘΝΙΚΟ
ΜΕΤΣΟΒΙΟ
ΠΟΛΥΤΕΧΝΕΙΟ
ΣΧΟΛΗ ΜΗΧΑΝΟΛΟΓΩΝ ΜΗΧΑΝΙΚΩΝ

Α.Π. : 41649
Αθήνα, 15/9/2023

ΚΟΣΜΗΤΟΡΑΣ

**Προς τα Μέλη ΔΕΠ της
Σχολής Μηχ/γων
Μηχ/κών**

<u>ΠΡΟΣΚΛΗΣΗ</u>

Σας προσκαλούμε στην παρουσίαση της Διδακτορικής Διατριβής του Υ.Δ. **κ. Ανδρέου-Σεραφείμ Γιάννη,** διπλωματούχου **Μηχανολόγου Μηχανικού ΕΜΠ**, την οποία εκπόνησε στον Τομέα Ρευστών. Η παρουσίαση θα πραγματοποιηθεί τη *Πέμπτη 27/9/2023* ώρα 11:00π.μ στην αίθουσα διαλέξεων του κτιρίου ΑΝΥΜ της Σχολής Μηχανολόγων Μηχανικών ΕΜΠ, Πολυτεχνειούπολη και με δυνατότητα απομακρυσμένης παρακολούθησης στο κάτωθι link:

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Ο ελληνικός τίτλος της Διδακτορικής Διατριβής είναι ο εξής:

«*Πολυ-πεδιακή βελτιστοποίηση πτερυγίων ανεμογεννητριών με ενσωμάτωση τεχνικών παθητικού ελέγχου φορτίων*»

Και ο Αγγλικός ως εξής

«*Multi-disciplinary design optimization of wind turbine blades including passive load control techniques*»

Ο Κοσμήτορας της Σχολής

Ι. Αντωνιάδης
Καθηγητής ΕΜΠ

Summary

The main pursuit of both the scientific community and the wind energy industry in the last twenty-five years, is the compression of the cost of the energy (Levelized Cost of Electricity – LCoE) produced by wind at comparable or even lower levels than those by the conventional energy sources. The effort to reduce the cost of wind energy during the years of its explosive development was also accompanied by the continuous increase in the size of the wind turbines. Up-scaling their size from $500kW$ (rotors diameter of about $40m$) in the early of 1990s, to $5-15MW$ (rotors diameter $>150m$) today, had the consequence of facing various technical challenges, the overcoming of which became possible through the introduction of new innovative construction approaches, the use of modern materials and the application of active and/or passive load control techniques. Today's economic and geopolitical environment makes it imperative to further compress the cost of wind turbines, entailing the design and development of very large wind turbines ($>15MW$) and very large scale wind farms (of hundreds of MWs). The path of the continuous up-scaling of wind turbines has today become a one-way street and the installation of turbines of $10-15MW$ rating is common practice in offshore applications. In order to render their cost comparative to conventional energy sources, manufacturers have employed modern active load control techniques, targeting both to enhancing power production (at the wind farm scale) and reducing loads. However, standard active control techniques alone, usually based on pitch, are not sufficient to suppress cost at desirable levels. This is why recently, the wind energy community has also tackled passive load control methods based on "Aero-elastic Tailoring" (A/T).

The A/T is a design technique through which geometric or stiffness properties of a structure are matched with its aero-dynamic characteristics in such a way that overall structural loads are reduced. The subject of A/T and its application to the modern large-scale wind turbines in the context of a holistic blade design framework, is a very hot-field of the today's scientific research. In general, the A/T methods can be distinguished into two categories:

- Bend-Twist-Coupling (BCT): by this term the behavior of a structure that has been designed to undergo torsion deformation under the action of bending loads, is described. The resulting change in sectional angle will affect the aerodynamic loading through a change in the angle of attack. Its materialization can be achieved either through material (by offset ply angle on uni-directional material) or geometrical (so-called sweep) approaches.

- Flap-Edge-Coupling (FEC): is the design concept in which when the blade is excited and undergoes vibrations in one bending direction (e.g. edge-wise) it also vibrates in the other bending direction (flap-wise). As a result, a trading of aerodynamic damping from the highly damped flap-wise motion to the poorly damped edge-wise motion is established and thereby edge-wise vibrations can be reduced. This control method can be materialized either through the shift of the *'caps'* of the shear box of the blade internal structure (geometric approach) or by non-uniform change of the blades' walls thickness (material approach).

In the recent years, several EU collaborative projects such as the UpWind and the INNWIND.EU have dealt with the application of BTC control on $5-10MW$ wind turbines, concluding that the use of passive control can reduce the ultimate loads by about 15% in the occurrence of extreme turbulence conditions. In this work, the alleviation of the loads has been utilized, to saving in manufacturing material for the blades, resulting in the design of a rotor with 10% less mass. On the other hand, the FEC has proven to be an effective

approach for alleviating severe vibrations observed during the parked or idling state of the rotors, in storm conditions. In the current thesis it has been shown that a uniform shift of *'caps'* by 3% (throughout the length of the blade) is sufficient to significantly reduce the vibrations of the blade of a reference $10MW$ wind turbine.

An optimization framework has been established in the current thesis aiming to design a modified wind turbine rotor based on the Reference Wind Turbine (RWT) DTU-10MW, which can achieve a minimum Levelized Cost of Electricity (LCoE). Alleviation of loads using effective combinations of different passive load control techniques is integrated in the optimization loop. Two pathways for reducing LCOE are addressed in the work a) compressing CAPEX through reduced use of composite material and b) design of rotors with higher S/P (as Specific Power has been defined the ratio of power to area of the rotor disk, so increased S/P rotors implies larger rotor diameters for the same rated power) or increased annual energy production. The numerical tools included in the above framework are listed below:

- Servo-aero-elastic analysis tool: in-house, multibody FEM solver hGAST provides ultimate loads along the span of the blades through non-linear time domain aero-elastic simulations of the full wind turbine system.

- Cross-sectional analysis tool: in-house, cross-sectional analysis tool, based on thin lamination theory provides structural properties, stresses distributions and values of the Tsai-Hill failure criterion over the various cross-sections of the blade.

- Cost model: a cost model has been synthesized with the aim to determine the cost of the full wind turbine. It is based on actual cost data for modern wind turbines and existing in the literature simplified cost formulas.

- Optimization framework: an optimization framework has been established using ready-mades functions from the published available scipy library of Python.

Some of the above numerical tools (e.g. hGAST) have been developed, used and validated in the context of several research projects (EU and national), while others were either upgraded (e.g. cross-sectional tool) or developed exclusively (e.g. cost model) in the framework of the present thesis.

The main result from the aforementioned process is a hybrid blade design with $8-10\%$ less mass, which has shifted the *'caps'* by 3% (FEC 3%) and has introduced in one or better in two parts (starting from $20-30\%$ onwards) a moderate offset angle (about $5^o-7.5^o$) in the uni-directional material.

At the next level, a multi-disciplinary optimization procedure, has been adopted with the aim of LCoE minimization. In the above environment, in addition to the necessary materials mass and the parameters of the passive control, the distributions of chord and twist as well as the length of the blade have been considered as optimization parameters. The above approach results in a modified blade that is 1% heavier, and 3.7% longer. In the same context, a gradually developing hybrid configuration, which includes material BTC, material and geometric FEC and re-twist design, has been proposed. The result is a modified rotor with 19.5% and 1.36% less mass and LCoE respectively, evaluating it through full-time domain aero-elastic simulations of extreme turbulence (DLC-1.3) and parked or idling case (DLC-6.x).