Doctoral Dissertation

Doctoral Program in Mechanical Engineering (37^{th}cycle)

Numerical modeling of floating vertical axis wind turbines for offshore renewable energy generation

By

Alberto Ghigo

Supervisors:
Prof. Giovanni Bracco,
Prof. Giuliana Mattiazzo

Doctoral Examination Committee:
Dr. Michael Borg, Referee, Stiesdal (Denmark)
Dr. Anna Garcia-Teruel, Referee, RWE (Germany)

Politecnico di Torino

ABSTRACT

Offshore wind power is expected to play a leading role to achieve decarbonization goals and implement an energy transition toward clean energy sources in the coming years. The development of floating offshore wind technologies, despite challenges to be addressed, like high investment costs due to the lack of a mature supply chain and the need for frequent maintenance, represents a key enabler for the exploitation of wind resources in deep waters, where traditional bottom-fixed turbines are not technically and economically feasible. While the offshore wind sector has been largely dominated by Horizontal Axis Wind Turbines (HAWTs), *Vertical Axis Wind Turbines* (VAWTs) have attracted increasing interest due to their potentialities, including their ability to exploit multi-directional winds, the more cost-effective maintenance, the increased stability and the reduced aerodynamic losses.

This dissertation investigates the feasibility, performance, and competitiveness of floating VAWTs through a comprehensive numerical, technical, and economic analysis. The work begins with a literature review of the state-of-the-art in floating wind technologies, with a particular focus on the typologies and design characteristics of VAWTs and their floating substructures. Three main research areas are identified, with the aim of analyzing the dynamic response of a floating VAWT system, estimating aerodynamic losses within a wind farm, and conducting techno-economic assessments to evaluate the sustainability and feasibility of the technology.

To capture the dynamics of floating VAWT systems, a novel coupled numerical model that integrates aerodynamics, hydrodynamics, and mooring dynamics is developed. The model is applied to the design and simulation of a multi-megawatt Darrieus H-rotor VAWT for offshore deployment. The turbine's performance is assessed under both static and dynamic conditions, and results are compared with the tool QBlade. A comprehensive parametric study is then performed to explore the influence of key design parameters on turbine performance under wind and waves.

Beyond single turbine analysis, the thesis addresses the modeling of wake interactions within VAWT wind farms. Several wake loss models, including the Jensen, Top-Hat, and Gaussian approaches, are reviewed and adapted to the specific characteristics of vertical rotors. A novel methodology is proposed for evaluating velocity deficit and wake expansion, allowing for the estimation of the Annual Energy Production and the wind farm layout optimization. Comparative analysis reveal that VAWTs exhibit faster wake recovery than HAWTs, which enables reduced spacing between turbines and higher spatial power density.

Finally, a techno-economic methodology is developed, introducing a case-study in the Mediterranean Sea, next to the island of Pantelleria. The analysis encompasses resource assessment, siting constraints, and cost modeling, in-

cluding Capital Expenditure, Operational Expenditure, and expected revenues. Levelized Cost of Energy, Net Present Value, and other key financial indicators are evaluated and compared with a reference HAWT wind farm. The results indicate that floating VAWTs can achieve cost competitiveness and offer advantages under certain conditions, including the development of economies of scale, the reduction of investment costs, and lower financial interest charges.

In conclusion, this research demonstrates that floating VAWTs, despite their current lower technology readiness level compared to HAWTs, represent a significant opportunity for future offshore wind deployment, especially in deep seas basins like the Mediterranean Sea, lacking infrastructure, logistics, and an existing supply chain. The thesis contributes to the existing literature by introducing a novel numerical model of floating VAWTs to quantify the dynamic response; a methodology to assess wake losses in a VAWTs wind farm, and a techno-economic model to evaluate the feasibility and cost competitiveness of the technology.