Abstract

Cross-flow tidal turbines (CFTTs) are a promising technology for the exploitation of tidal energy due to their omnidirectional operation and their higher area-based power density compared to axial-flow turbines. However, as the turbine blades rotate around their axis, perpendicular to the incoming flow, they experience continuously varying angles of attack. This results in complex rotor hydrodynamics, which result in reduced efficiency and strong alternating loads that increase the risk of fatigue failure. One effective approach to mitigate these limitations is active blade pitching, where the blade angle of attack is controlled throughout the rotation.

For this reason, the interdisciplinary OPTIDE (experimental and numerical OPtimization of a cross-flow TIDal turbinE) project aims at investigating the potential of blade-embedded pitching actuation to simultaneously improve turbine performance and reduce fatigue-relevant structural loading through combined numerical and experimental approaches. Within this framework, the present thesis makes a contribution by developing and applying an optimization methodology that comprises numerical blade-shape optimization and experimental optimization of active blade pitching for CFTTs.

On the numerical side, 2D unsteady Reynolds-Averaged Navier–Stokes simulations are used to characterize a fixed-pitch turbine. This numerical framework is coupled with a genetic algorithm to conduct a fully automated blade shape optimization based on computational fluid dynamics. The optimization explicitly accounts for geometric constraints imposed by blade-embedded actuation and introduces a novel, comparative indicator for fatigue-relevant cyclic loading. The results allow the identification of optimal blade geometries that fit the pitching actuator, while reducing structural loading and increasing the power coefficient compared to a reference turbine.

Experimentally, a fully instrumented CFTT flume model with blade-embedded pitching actuators is developed and investigated in a laboratory flume. First, the fixed-pitch reference configuration is characterized, allowing the validation of the experimental setup. This setup is then coupled with an optimizer to perform an experimental optimization of the blade pitching law, with the aim of increasing turbine torque. The results show significant performance improvements of nearly 100% compared to the fixed-pitch reference case and reveal favorable trade-offs between performance, actuation effort, pitching range and a blade stress indicator, that motivate future investigations.