Abstract

The transition towards low-carbon energy systems is increasing, as the interest in renewable technologies able not only to reduce greenhouse-gas emissions, but also to complement more established resources such as wind and solar power. Within this context, ocean wave energy is widely recognized as a promising yet underexploited source. Devices that convert wave motion into electricity, namely wave energy converters (WECs), have attracted growing attention over the last decades, but the technology has not yet reached full commercial maturity. In the literature, there are several works that adopt optimization techniques during the preliminary design phase of a WEC system, with the aim to identify competitive design solutions and to quantify first-order trade-offs among WECs techno-economic performances. However, most optimization studies still rely on deterministic assumptions, while, in the real-world, WECs are inevitably exposed to multiple uncertainty sources, such as operating metocean conditions and key design parameters. As a result, deterministic procedures may conceal substantial sensitivity differences among devices that appear equivalent under nominal metrics.

Starting from these considerations, this thesis investigates robust optimization as an extension of conventional WECs design optimization, with the aim of identifying device configurations able to preserve satisfactory performance when uncertainty is explicitly accounted for. The study is developed around the Pendulum Wave Energy Converter (PeWEC), adopted as the reference case study. First, a nominal multi-objective benchmark framework is established, this benchmark is then used to demonstrate the sensitivity of nominally optimal solutions to uncertainty in key design parameters and in operating sea-state information, showing that highly productive nominal devices may also be among the most fragile ones.

On this basis, the thesis proposes a robust design optimization framework in which uncertainty is embedded directly within the design process through dedicated robustness metrics and uncertainty propagation procedures. The results show that robustly selected devices generally trade part of their nominal productivity for improved guaranteed performance, reduced sensitivity to adverse realizations, and, in several cases, more attractive techno-economic compromises. The analysis is then extended to the system scale through a robust energy-system co-design formulation, in which the PeWEC is optimized jointly with other renewable technologies, and battery storage, within an islanded case study. In

this setting, wave energy retains a stable role within diversified robust portfolios. Finally, a preliminary multi-site robust formulation is introduced to explore design transferability across heterogeneous wave climates, highlighting a trade-off between worst-site productivity and cross-site uniformity, while again suggesting that medium-to-lower cost devices can represent robustly attractive design choices. Overall, this thesis identifies robust optimization as a promising framework for supporting wave energy converter design in the presence of uncertainty.