Doctoral Dissertation

Doctoral Program in Mechanical Engineering (35^{th}cycle)

Modelling, survivability, assessment, and control of moored wave energy conversion systems

By

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Ad ogni donna che si trova a combattere ogni giorno in questa società patriarcale.
Alla sottile differenza tra l'avere lo stesso trattamento e le stesse opportunità,
che un giorno possano essere la stessa cosa.

A mia madre, alle mie sorelle, ad Alessia.

Giornalista: Cosa si prova ad essere sposati ad un genio?
Marie Curie: Lo chieda a mio marito.

Maria Salomea Skłodowska, durante un intervista

To every woman who fights every day in this patriarchal society.
To the difference between receiving equal treatment and having equal opportunities,
may they become one and the same someday.

To my mother, to my sisters, to Alessia.

Interviewer: How does it feels to marry a genius?
Marie Curie: Go ask my husband.

Maria Salomea Skłodowska, during an interview

Gaetano: Cioè, chello che è stato è stato, basta! Ricomincio da tre!
Lello: Da zero!
Gaetano: Eh?
Lello: Ricomincio da zero!
Gaetano: Nossignore, ricomincio da... cioè, tre cose me so' riuscite dint' 'a vita, pecché aggia perdere pure chelle? Che aggia rimincia' da zero?! Da tre!

Massimo Troisi, Ricomincio da tre

ABSTRACT

In the current energy landscape, with a rising demand for energy, there is an increasing concern about the extensive use of fossil fuels. Consequently, governments and institutions are increasingly promoting the adoption of renewable energy sources, including *wave energy*, which has the potential to make a substantial contribution to the overall energy supply.

However, wave energy systems are still in early stages of commercialisation. These technologies typically consist of a hull for wave interaction, a mechanism and controller for energy harvesting and optimisation, and a mooring system for station-keeping.

Despite the significant influence of moorings on device dynamics, these are often overlooked in productivity-focused device modelling. This thesis aims to provide insights into the mooring problem and thoroughly analyse its impact on overall device dynamics. Through a combination of experimental and numerical investigations, the thesis demonstrates the significant influence of moorings on device dynamics and harvested energy.

Consequently, it is essential to synthesise a controller that effectively maximises energy harvest by incorporating relevant mooring dynamics. To address this, a framework is proposed, that integrates mooring knowledge into controller synthesis using the impedance-matching principle in a straightforward manner. The approach is tested in detail using the PeWEC case study, revealing that neglecting mooring dynamics in controller synthesis can result in a performance reduction of up to 18%.

While the proposed straightforward approach is effective, it has limitations when different control strategies are required. To overcome this, a data-based parametric model is employed to include the mooring system in a control co-design optimisation. The results demonstrate the significant impact of the mooring system on harvested energy, with the optimisation of the mooring layout increasing the productivity of a heaving point absorber by up to 14%.

Furthermore, experimental investigations highlight that moorings not only have a significant influence in extreme conditions but also require a higher-fidelity model for analysing wave-hull interaction. Consequently, existing standards are examined, and a simulation framework is proposed to evaluate the design state of a device under extreme and operational conditions.