SUSTAINABLE MATERIALS, PROCESSES AND SYSTEMS FOR ENERGY TRANSITION

DIMEAS / Experimental methodologies for testing offshore energy conversion technologies

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Context of the research activity	This research aims to experimentally demonstrate the performance of various inertial mechanisms for converting wind and wave energy in offshore environments. The primary objective is to provide empirical evidence of the power conversion capabilities of these mechanisms, with a focus on wave energy extraction and stabilization of offshore wind turbines. The study involves testing three distinct energy conversion concepts—a gyroscope, a double pendulum, and a gyro-pendulum system—in controlled environments such as a wave tank and a steward platform.
	Offshore renewable energy from wind and waves offers immense potential for sustainable power generation, but effectively converting this energy into electricity remains a significant engineering challenge. A major challenge for wave energy technologies is the harsh marine environment, characterized by high corrosion from saltwater and extreme loads. Traditional approaches often involve generators fixed on the sea bottom with components exposed to these conditions, reducing system reliability. To address this, some Wave Energy Converter (WEC) concepts have been developed to protect sensitive equipment by enclosing it within the WEC, mitigating maintenance and accessibility issues. Solutions such as Self-Reacting WECs (SRWECs) transmit the motion of the floater to an internal translating or rotating mass, allowing energy harvesting through an inertial damper inside the hull. This research aims to advance these concepts by experimentally validating three distinct energy conversion mechanisms—a gyroscope, a double pendulum, and a gyro-pendulum system—in controlled environments like wave tanks and steward platforms. This involve several objectives: • Experimental Validation: To experimentally validate the power conversion capabilities of inertial mechanisms (gyroscope, pendulum, and gyro-pendulum systems) for wave energy extraction and offshore wind turbine stabilization. • Performance Assessment: To evaluate the performance of these mechanisms under controlled conditions using testing facilities such as wave tanks and steward platform.

Objectives	• Comparative Analysis: To perform a comparative analysis of the three energy conversion concepts in terms of efficiency, controllability, scalability and cost-effectiveness • Optimization and Design: To refine and optimize the design and operational parameters of the tested mechanisms for enhanced performance. • Industrial Application: To explore the potential industrial applications of the validated technologies and facilitate their integration into existing offshore energy systems. • Experimental and design practices: To define a standardized experimental framework, create an online repository with experimental data, and provide access to control algorithms and code. This aims to promote transparency, reproducibility, and collaboration in the offshore energy research field. These involve the following PhD program: 1. Design phase: In the design phase, three scaled prototypes of the mechanisms (gyroscope, double pendulum, and gyro-pendulum) will be evaluated with respect to a full-scale prototype intended for the Mediterranean Sea. This includes determining dimensions, performing structural verification, and drafting main performance metrics through numerical calculations. Additionally, sensors, control systems, electronics, and power conversion units will be considered. These analysis will be compared with existing available prototypes for the evaluation of marginal added value in constructing one or more new prototypes. 2. Construction phase: If needed, the construction phase involves procuring all necessary materials, sensors, and mechanical components to build the prototypes. The potential construction process should be managed to ensure proper electrical interfaces, quality checks, and installation on the experimental facility, resulting in fully constructed and operational prototypes. 3. Control development phase: advanced control algorithms and systems will be developed and integrated into the prototypes. This includes optimal feedback control (i.e. Impedance matching based controllers, MPC controllers) and optimal feedforward techniques (i.e. impedance matching based LiTeCon controllers). Programming the control units, tuning the control parameters, and ensuring the systems can adapt to varying conditions in the experimental setup. 4. Experimental tests phase: The experimental tests will involve testing the prototypes in controlled environments such as wave tanks and/or steward platforms. The performance of each mechanism will be evaluated under various conditions, including different wave and wind scenarios using HIL techniques. In particular, the wave and wind motion induced on the system will be simulated when the tests are performed on the stewart platform. On the other hand, realistic wind and wave condition would be used in wave tank experiments. Data will be collected to assess the efficiency, stability, and power output of each system. 5. Validation phase: In the validation phase, the experimental data collected will be thoroughly analyzed to assess the performance of each prototype. The results will be compared against numerical predictions and theoretical models to verify accuracy and reliability. The validated prototypes will be evaluated for their potential scalability and commercial viability. 6. Online repository: An online repository will be established to store experimental data and control algorithms developed in the program. Researchers and industry partners will be able to access detailed experimental results, control codes, and methodologies, ensuring reproducibility and enabling further advancements in offshore energy conversion technologies. The research aims to provide a significant contribution to the field of offshore renewable energy. The experimental validation of these mechanical concept

	applied to wave and wind energy conversion will provide: • Enhance the performance and safety of offshore energy systems based on inertial self-reacting systems. • Reduce the risks and uncertainties associated with the design and operation of these systems in real operating conditions (wind-waves reproduced in laboratory scale). • Advance in optimal control, stability and power production studies on wave and wind energy conversion systems. Moreover, the mechanism developed and validated in this research can be applied to other areas of ocean engineering, showcasing the broader impact and utility of the work beyond the immediate focus on renewable energy.

Skills and competencies for the development of the activity	The ideal candidate should have a background in renewable energy systems and experimental testing. Proficiency in experimental prototype, numerical modelling and data analysis is beneficial. Experience with modern control techniques applied to WEC and wind turbine desirable. The candidate should possess strong analytical skills, attention to detail, and the ability to work independently and collaboratively in an interdisciplinary and international research environment.