Politecnico di Torino

MECHANICAL ENGINEERING

DIMEAS - Modular modelling and optimal management of small coastal communities as linked energy hubs

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Context of the research activity	The project develops modular models simulating the full energy flow from renewable sources through converters to storage and end-use. Focus is placed on accurately modeling converter dynamics (e.g., wind, wave, PV, hydrogen conversion systems) and their integration with storage systems and utilities. The modular approach enables flexible coupling of components, supporting the analysis, control, and design optimization of energy hubs in small and medium-sized coastal communities.
	The global transition towards sustainable energy sources demands innovative methods for managing decentralized energy systems. Small and medium-sized communities, such as islands, represent unique cases as integrated energy hubs. These systems must efficiently coordinate multiple, often intermittent, generation technologies—such as offshore/onshore wind, wave energy, photovoltaic (PV) systems, and fuel or hydrogen-based plants—alongside energy reserves like batteries and hydrogen storage. Moreover, the energy systems of these communities must address diverse consumption needs, ranging from household electricity demand to water resource management and utility operation, including harbour equipment, desalination plants, and electric vehicles. Balancing these diverse demands with fluctuating energy supply requires advanced modelling and control strategies tailored to the local context. This research aims to develop modular, flexible models that can describe and simulate the entire energy conversion and consumption chain, from the energy source to the final users and utilities. A bottom-up approach will be employed to ensure scalability and adaptability, allowing each module (generation, storage, or utility) to be accurately represented and integrated within a broader energy hub framework. The project will also develop optimization and control strategies to manage these systems autonomously, ensuring reliable power supply, grid stability, and minimal environmental impact. These strategies will consider not only operational efficiency and cost minimization but also the interaction among different stakeholders, each with unique goals and constraints.

Objectives	The primary objective of this PhD project is to create modular, integrable models capable of simulating and optimizing energy conversion and consumption processes within small/medium communities. The work will be structured around the following pillars: 1. Modeling of Energy Systems and Energy Conversion Chain • Develop modular models for various energy generation systems (offshore/onshore wind, PV, hydrogen/fuel-based plants), storage systems (batteries, hydrogen), and community-specific utilities (e.g., harbour machinery, desalination plants, EVs), focusing on electricity and other demands. • Calibrate the fidelity of each module according to operational optimization needs, ensuring computational efficiency without compromising decision-making accuracy. • Assemble a comprehensive global model for a selected case study community, using real-world data for validation (e.g., energy production, storage levels, demand profiles). 2. Optimal Management and Control Strategies • Implement optimization-based control strategies to operate the energy hub, aiming to minimize costs, improve system efficiency, and reduce emissions. • Develop optimal scheduling methods for the operation of energy converters and reserves, accounting for seasonal and demand variability, as well as weather and economic factors. • Use game-theoretic models to capture the interactions among key actors (consumers, grid operators, plant developers, environmental bodies), enabling the reformulation of the management problem to reflect competing objectives and shared benefits. • Investigate how operational insights can inform and influence the design of energy converters, suggesting improvements to enhance their integration within decentralized energy hubs (e.g., increased adaptability, improved reliability, and better storage compatibility). This research will provide a holistic framework for the design and management of resilient, low-emission energy hubs. The modular approach ensures adaptability to a wide range of community sizes and energy configurations, while the optimization framework supports autonomous and intelligent operation. Moreover, by considering the perspective of technology developers, the project aims to bridge the gap between energy converter design and community needs, enhancing alignment between supply and demand.

Skills and competencies for the development of the activity	The candidate should have a background in energy conversion modelling, together with the following knowledge and skills: • Knowledge of MATLAB programming, together with Simulink environment • Previous experience in modelling of wind and wave (as well as other renewable) energy systems and related conversion chain • Previous experience in modelling of basic principles of mechanical and electrical power conditioning • Knowledge of optimisation principles is a plus • Knowledge on renewable energy resources analysis and assessment is a plus