POLITECNICO DI MILANO

PhD in SCIENZE E TECNOLOGIE ENERGETICHE E NUCLEARI / ENERGY AND NUCLEAR SCIENCE AND TECHNOLOGY - 41st cycle

THEMATIC Research Field: HYBRID COMBUSTION-ASSISTED COMPRESSED AIR STORAGE SYSTEM

Monthly net income of PhDscholarship (max 36 months)
1600.0 In case of a change of the welfare rates during the three-year period, the amount could be modified.

Context of the research activity	
Motivation and objectives of the research in this field	The PhD research program is focused on the **development of a hybrid energy storage system**. Indeed, the rapid increase in renewable energy penetration poses structural challenges to both electrical grids and industrial energy users, particularly in terms of flexibility, reliability, and material sustainability. Current grid balancing strategies rely heavily on fuel-based gas turbines, which limit the effective utilization of renewable energy and perpetuate dependence on combustible fuels and critical raw materials. In this context, hybrid energy storage systems emerge as a promising alternative, especially if designed to avoid the use of critical materials while enabling the coupling of renewable generation with industrial demand. A **central motivation** of this research is to assess whether such hybrid solutions can offer tangible advantages in terms of efficiency, scalability, and resource availability. In parallel, the need for long duration energy storage, exceeding eight hours, remains an open question as renewable penetration increases and temporal mismatches between supply and demand become more pronounced. Clarifying the role of long duration storage for grid balancing is essential to guide future infrastructure investments. The **primary objective** of the proposed research is to investigate hybrid energy storage systems that combine

	energy storage and power production functionalities, with particular emphasis on gaseous fuels and thermodynamic conversion processes. The work aims to determine how renewable electricity can be maximally utilized to assist fuel conversion, thereby reducing primary fuel consumption while maintaining grid stability. A key focus will be the **numerical and experimental analysis of internal combustion expanders** operating with gaseous fuels, evaluating their achievable performance, efficiency, and operational flexibility within hybrid configurations. Furthermore, the research seeks to explore how energy storage and power generation tasks can be coherently coupled with system development, ensuring that hybrid solutions are not only technically viable but also economically and environmentally meaningful. Through this integrated approach, the research intends to contribute to the design of sustainable energy systems capable of supporting both grids and industrial users in a high-renewable energy scenario.
Methods and techniques that will be developed and used to carry out the research	The research will rely on a **structured modelling approach** to identify when and how hybrid energy storage systems are advantageous. Different scenarios will be analyzed by considering fuel availability, emission constraints, and temporal mismatches between energy production and demand. Weekly and seasonal cycles will be explicitly addressed. A focused review of the literature will be carried out on air-based energy storage technologies, including compressed and liquid air systems, with particular attention to thermally integrated configurations. At system level, the complete energy storage assembly will be modelled to compare **alternative layouts** and to evaluate their technical and economic competitiveness. In parallel, detailed models will be developed for an **internal combustion expander** operating with gaseous fuels. The modelling activity will focus on prechamber-assisted combustion to achieve high efficiency and stable operation with different fuels, such as natural gas and hydrogen. Additional numerical models will be developed

	for innovative valve systems, aiming at improved control and performance under variable operating conditions. The modelling work will be supported by targeted **experimental activities**. A prototype internal combustion expander will be designed and built, including a prechamber and variable intake air temperature control. The combustion chamber will be equipped with optical access to enable direct observation of the combustion process. This setup will allow the evaluation of combustion stability, efficiency, and emissions, and will provide data for model validation. The experimental results will be used to assess the achievable performance of the expander with different gaseous fuels. At system level, a **hybrid energy storage prototype** at the 10-kW scale will be developed. The system will combine air-based energy storage with an internal combustion expander assisted by natural gas. This prototype will enable the integrated operation of energy storage and power production to be tested under realistic conditions. The system-level experiments will validate the proposed concept as a whole and will support the assessment of its potential for further development beyond the laboratory scale.
Educational objectives	At the end of this PhD program, the candidate will be able to: •build a python code on an energy system and calibrate it against literature data; •improve an in-house model on prechamber-assisted combustion in an internal combustion engine; •design and realize an apparatus for the characterization of an energy conversion system; •critically analyze data related to a energy conversion system or a subcomponent of such a system; •teach and supervise younger students; •manage a research project.
Job opportunities	The PhD research will qualify the candidate with skills in

	applied research and technology transfer in the field of process technologies, low-carbon technologies and in the sector of energy storage systems.
Composition of the research group	5 Full Professors 6 Associated Professors 10 Assistant Professors 30 PhD Students
Name of the research directors	Gianluca Valenti

Contacts
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Additional support - Financial aid per PhD student per year (gross amount)	
Housing - Foreign Students	--
Housing - Out-of-town residents	--

Scholarship Increase for a period abroad	
Amount monthly	800.0 €
By number of months	6

Additional information: educational activity, teaching assistantship, computer availability, desk availability, any other information

Teaching assistantship

Availability of funding in recognition of supporting teaching activities by the PhD student. There are various forms of financial aid for activities of support to the teaching practice. The PhD student is encouraged to take part in these activities, within the limits allowed by the regulations.

Awards

Economic awards, in gross amount up to Euro 1500 for first year, 2500 second year, and 5000 third year, will be recognized to the PhD candidate in case of significant contributions in the research project, subject to the evaluation of the research director.