Politecnico di Torino

ENERGETICS

DENERG - Enhancing Sector Coupling through Thermal Prosumer Integration in District Heating Systems

Funded By	Dipartimento DENERG

Supervisor	VERDA VITTORIO - vittorio.verda@polito.it

Contact	CAPONE MARTINA - Gianluca Serale GUELPA ELISA - elisa.guelpa@polito.it

Context of the research activity	The present PhD research is focused on the integration of bidirectional thermal prosumers in district heating networks (i.e. building substations which can both take thermal energy from district heating networks and inject it) through the development of bidirectional substations equipped with heat pumps. The project investigates how distributed thermal generation and sector coupling between thermal and electrical networks can enhance system flexibility, efficiency, and decarbonization, enabling end-users to actively participate in energy markets and ancillary service provision. The activity is primarily based on system modelling and optimization, taking advantage of experimental analyses conducted in laboratory and in field.

	District heating and cooling networks are expected to play a central role in the decarbonization of the energy system, not only through the integration of renewable energy and waste heat sources, but also by providing flexibility to electrical grids via power-to-heat technologies, particularly heat pumps. In this framework, sector coupling enables the conversion of electrical energy into thermal energy that can be stored and dispatched by exploiting the inherent thermal inertia of buildings and district heating networks. Decarbonization and sector coupling should rely on both centralized and distributed installations of renewable technologies. This research addresses these challenges by analyzing the concept of the thermal prosumer enabled through bidirectional thermal exchange substations (BTESs), which are crucial for distributed installations. In fact, these substations transform buildings from passive heat consumers into active energy nodes capable of both consuming and producing thermal energy, dynamically interacting with district heating networks (DHNs) and electrical grids. This PhD research investigates the impact of decentralized and distributed thermal generation integrated into existing DHNs as a source of flexibility within multi-energy systems. The research focuses on the design, modeling, and optimization of BTES

Objectives	architectures integrating high-temperature heat pumps supplied by different heat sources (e.g. air, geothermal), coupled with renewable energy technologies such as photovoltaics systems and thermal storage units. Particular attention is devoted to the evolution of DHN thermohydraulic parameters under bidirectional operating conditions and to the optimization of system performance in terms of efficiency, reliability, and coefficient of performance. A key objective of the PhD is the development of advanced control and optimization strategies that combine physics-based models with data-driven approaches, aimed at supporting the integration of thermal prosumers into district heating networks and enabling the real-time operation of distributed heat pumps in response to system constraints. The research extends the analysis from the building level to the district heating network and multi-energy system levels, through a multi-level approach that enables the assessment of aggregated flexibility and coordinated control of thermal and electrical interactions. The project is developed in close collaboration with industrial partners, ensuring a strong link between theoretical research and real-world applications. The availability of real operational data and pilot installations allows the validation of proposed models and control strategies through realistic case studies on existing district heating networks. This approach enhances the practical relevance, transferability, and industrial applicability of the research outcomes, supporting the transition from research concepts to deployable solutions. In addition, a laboratory test rig able to simulate possible configurations of bidirectional substations is currently under installation. This installation is expected to provide the research with experimental data for the validation of the models that will be developed and it will also provide the opportunity to test designs and operational strategies that will be applied in real cases.

Skills and competencies for the development of the activity	The candidate should have a strong background in energy engineering, thermal systems, or related fields. Experience with programming tools (Matlab, Julia) is required. Desirable skills include modelling and simulation of energy systems, heat pumps, and district heating networks, as well as knowledge of optimization and control techniques.