Abstract

Decarbonization of District Heating is one of the main challenges facing this technology in the coming years. This goal is fundamental to achieve a future sustainable energy system relying on non-fossil resources. For this reason, new concepts and operational modes are being introduced: among the most relevant characteristics, future District Heating will be based on lower operating temperatures, significant use of low-temperature and renewable heat sources, and smart integration to other energy grids in a Multi-Energy System perspective. These new characteristics have led to the conceptualization of new generations of District Heating: fourth- and fifth-generation systems represent the future evolution of this technology. However, the transition to next-generation systems cannot be only limited to the construction of new District Heating infrastructures specifically designed to operate with these new conditions. To reach a cost-effective decarbonization, the transition needs to be focused to a large extent to the transformation of existing systems. Indeed, many large-scale existing systems are currently in operation and cannot be entirely replaced, but they must be adapted to different operating conditions than those for which they were designed. In this context, the main goal of this dissertation is to propose suitable simulation and optimization models to support and unlock the transformation of existing District Heating towards next-generation systems.

In the introduction (Chapter 1), the main critical issues that may arise in the transformation of existing systems to fourth- and fifth- generation systems are identified. These may be associated with the presence of thermal peaks, the difficulties of interconnecting different energy grids and exploiting the various synergies of the systems, the limitations on the reduction of operating temperatures due to the possible presence of fluid-dynamic bottlenecks and/or not suitable sizing of existing devices. To overcome these problems, tailored strategies are proposed in this dissertation.

An ad hoc model for the simulation of thermo-fluid dynamic problems in District Heating networks is introduced to replicate the operation of the networks and also to optimize its operation by taking into account all the complex dynamics (Chapter 2).

Then, appropriate strategies are discussed to address the problem of thermal peak shaving: in particular, there is a focus on the development of an optimization approach for thermal Demand-Side Management and on the introduction of an innovative strategy for peak shaving based on the usage of the network as a thermal storage (Chapter 3).

Integrated optimization tools are developed to simultaneously address the problem of demand optimization and production optimization in the framework of Multi-Energy Systems, by exploiting all the different sources of flexibility given by the production, the energy storages, and the demand (Chapter 4).

Finally, the potential for supply temperature reduction given by existing District Heating substations and distribution infrastructures is analyzed by developing a model of the building thermal substations and an optimization approach for the temperature minimization in the distribution infrastructures by acting on the pumping system (Chapter 5).

Throughout the thesis, different applications to large-scale systems are proposed to test the various models and quantify the expected benefits introduced. These achievements, summarized in the conclusions (Chapter 6), allow taking some step forwards in the transformation of current District Heating systems towards next-generation energy systems and also broaden the horizon for promising future research.