Flexibility of multi-energy systems: the role of Power-to-Gas and Power-to-Heat at the district level

Doctoral Dissertation
Doctoral Program in Energy Engineering (34th Cycle)

Flexibility of multi-energy systems: the role of Power-to-Gas and Power-to-Heat at the district level

By

Gabriele Fambri
* * * * * *

Supervisor
Prof. Marco Badami

Doctoral Examination Committee:
Prof. Carlo Carcasci, Referee, Università degli Studi di Firenze.
Prof. Michela Vellini, Referee, Università degli Studi di Roma Tor Vergata.

Politecnico di Torino
June 28, 2022

Summary

The European Union established the goal of carbon neutrality by mid-century. The utilization of renewable energy sources will be pivotal for such a decarbonization process. However, renewable generation is not dispatchable, and an increasing share of these sources may lead to problems for the electricity system. This brings about the need to invest in flexible resources capable of handling the generation of renewable sources, so that the delicate balance between electricity generation and demand could be maintained. Flexibility may be defined as the capacity of a system to modify its energy generation/consumption profile. The quest for new forms of flexibility is a paramount challenge for the next decades of research. Such new sources of flexibility may be found, if researchers consider the energy system from a holistic point of view, rather than as a system that only includes the electricity sector. In these scenarios, energy conversion technologies may be used to connect different energy sectors, therefore increasing the flexibility of the whole system.

The study of multi-energy systems requires a number of different competences from different backgrounds. The use of conversion devices that exploit different commodities calls for the modeling of several different energy conversion technologies and different network infrastructures. The current thesis aimed to investigate the extent to which multi-energy systems could be efficient flexibility sources. In the research to be presented in this thesis, a co-simulation platform was developed in order to facilitate the simulation of such complex scenarios. In the co-simulation architecture, each component of the multi-energy system was simulated in a different module. This allowed the research groups involved to develop the different models separately. Some of these modules were developed within the work of this thesis, whereas some others were developed through the collaboration with other research groups. Importantly though, the various models were connected to the co-simulation platform and were made to communicate with each other through the mutual exchange of input and output data.

The co-simulation tool was used within the work of this thesis for the realization of four different multi-energy system case studies.

The first case study was developed to analyze the flexibility resulting from the coupling of the electricity sector to the gas sector. Power-to-Gas technology allowed electricity to be converted into synthetic natural gas, which could be directly injected into the gas network. Results showed the effectiveness of the flexibility enabled by the Power-to-Gas technology to mitigate the problems of over-generation of renewable sources. However, this solution turned out to be not convenient from an economic point of view, due to high investment costs.

In the second case study, the same multi-energy system scenario was used for another type of analysis. The impact of different simulation approaches was analyzed thanks to the property of the co-simulation platform to plug and play

different modules. The results obtained with the use of more simplified models (for the simulation of the electricity and gas networks, and the Power-to-Gas system) were compared with the results obtained with the detailed models of these components. The analysis showed that in some circumstances, the use of simplified models could lead to an underestimation of the flexibility that could be obtained with the Power-to-Gas technology.

The third multi-energy system case study investigated the utilization of large-scale heat pumps for the connection of the electricity sector and the district heating sector. The heat pumps were used to provide heat to district heating and, at the same time, flexibility to the electricity sector. Results showed that, thanks to their high heat production efficiency, the utilization of heat pumps was advantageous, even when their flexibility was not exploited. The flexible utilization of these plants could bring significant benefits from both an energy and economic point of view.

The fourth case study analyzed the flexibility enabled by heat pumps directly installed in buildings. The mass and thermal inertia of buildings could be exploited to flexibly modulate the use of heating systems. The heat pump technology allowed the flexibility of the building's thermal sector to be used within the electricity sector. This flexibility was used to optimize the energy and economic flows of an energy community. Results demonstrated that the exploitation of this kind of flexibility did indeed allow the self-consumption of the energy community to be increased significantly, also leading to a benefit from an economic point of view.