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Modelling for the optimization of power plants and energy systems for combined production of energy vectors

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Umberto Tesio
2024

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Modelling for the optimization of power plants and energy systems for combined production of energy vectors

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The global increase in population and improved quality of life occurred in the last decades have led to a significant rise in the global energy demand, a trend expected to continue, particularly in developing countries. In the past, this demand has been met primarily through fossil fuels, resulting in widespread access to affordable energy. Concerns about the finite nature of fossil fuels and the global warming for which they are responsible have underscored the need for changing the approach used for the energy generation and achieve sustainable solutions. Four main strategies for achieving sustainability in the energy sector were identified: demand reduction, efficiency improvements, development of new technologies, and the transition to renewable energy sources.

A consistent implementation of these strategies is almost impossible without using optimization tools. In particular, the development of optimization models is very important for creating or improving energy technologies, since it allows to achieve the most convenient designs and operating conditions for a power plant or application. An extension of the operation problem of an energy plant is constituted by the operation of multiple power plants, energy networks and storage, which constitute Multi Energy Systems. The size and nature of these problems are significant and for these reasons their optimisation is a challenging task, but the benefits that can be achieved include reduced costs, energy savings and environmental impact.

The main aim of the works presented in this thesis is to provide a contribute to these topics by developing models for simulating and optimizing energy technologies and systems, addressing the integration challenges of renewable sources, and performing evaluations from energy and economic perspectives.

The global context and the energy optimization framework are discussed in order to provide an overview of the motivations that guided the works presented in the thesis and the perimeter of the research (Introduction, Chapter 1).

Successively, the methodology developed for optimizing an energy technology is presented and a model designed to optimize a novel CSP plant with thermochemical storage based on Calcium-Looping is introduced (Chapter 2). This complex case

study allows the model to address key features relevant to such optimization problems. Additionally, various integration alternatives for the CSP-CaL technology are explored and their results are discussed and compared.

The optimization of Multi Energy Systems is faced by starting with a detailed literature review to provide an overview of the current state of research, focusing on the development of practical optimization models and their impact on problem nature and mathematical formulation (Chapter 3). Literature gaps are identified, as well as future research directions.

Successively, two optimization models for the joint operation optimization of Multi Energy Systems and thermal networks are presented. The first one takes advantage of a simplifying assumption to include a small thermal network (considered as internal to the MES) in the operation optimization (Chapter 4).

A more realistic case study is considered in the second one, where a small District Heating Network is considered for the heat transportation (Chapter 5). The methodologies are developed on two different detail levels, consistently with the case studies under consideration and the measures adopted to increase the flexibility. The addressing of the mathematical formulation is carefully discussed, as well as the convergence to the solution and the obtained results.

The last part of the thesis summarises the research carried out and a comment on the most significant results obtained is provided (Chapter 6). Finally, the concluding interpretations and considerations are given, together with a suggestion for possible future developments in relation to this research topic.