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The ecological and energetic transition is driving a deep transformation of the energy and utility industry, promoting a shift from centralized to distributed generation systems. This transformation is supported by advanced digital technologies and requires the introduction of new paradigms for energy management and control, including a radical change in the user role, advancing the definition of the control problems from the device level to a system level, and by the integration of different energy vectors.

This requires to extend the idea of smart grids to Smart Thermal Energy Grid (Smart-TEG): the generation nodes are composed of multiple integrated units that require coordination and control to fulfill the demand of the various consumers, which in turn may vary (in part) their demand based on optimization criteria.

The thermal and electricity demand defined by the production scheduling must be fulfilled at any time, however the mix between on-site generated energy and net exchange with the main grid must be optimized, as well as the commitment of the GUs and their operating point. The control of the integrated generation units become a necessary element to operate them safely and efficiently.

Most of the ideas and approaches discussed in this work can be extended to a broader class of problems of industrial and scientific interest e.g., multi-line (parallel) plants with raw material or energy/power constraints; water/steam supplier (consumer) networks.

Despite the relevance of these problems, many issues are still present regarding coordination and control of these systems. Classical centralized solutions are limited by computational issues, lack of scalability and privacy concerns. The industrial need for an extension of dynamic optimal management strategies, from subsystem to plant-wide level, is well known: new strategies and methods must be put in place to approach plant-wide optimal management.

Model-based optimization and control is assumed as a common framework for the development of the solution strategies at the different layers: model predictive control (MPC) and, in general, receding horizon formulations are used.

The architecture for the smart-TEG management considers a multi-layer approach. In the top layer, the UC problem and the economic dispatch optimization is dynamically solved, considering networked systems sharing a set of common resources. The optimization at this level can benefit from decomposition and parallelization strategies, based on distributed and decentralized approaches, see Sect. 3.3.

At the lower layers, hierarchical and distributed control levels based on MPC are defined: advanced control solutions for single generation units are developed to enable the integration with the upper layers, and a control scheme for the coordination of homogeneous ensemble of subsystems is also proposed. The latter exploits subsystem configuration to reach a top-down integration, from scheduling to dynamical control, which is scalable and flexible.

At any level, the proper modeling of the systems becomes a fundamental and critical task: an extensive discussion is carried out in [3] [Part II], whereas a brief digression on hybrid models for UC optimization is given in the following section.

The coordination of the generation units in a node of the smart-TEG, i.e., inside a company, is itself a local problem of UC and control for the set of interacting sub-systems. A two-level hierarchical scheme is here proposed. The hierarchical control structure, see Fig. 1, includes a high layer that aims to optimize the performance of the integrated plant on a day-ahead basis with a longer sampling time (typically 15 min.) and a low-level regulator to track the set-points. The model used at the high level is sketched in Fig. 2.

The high-level optimizer determines the future modes of operation of the systems, as well as the optimal production profile for the whole future optimization. The receding horizon optimization is formulated as a mixed-integer linear program (MILP), due to the presence of both continuous and discrete decision variables, a linear objective function defining the operating cost, and linear inequalities enforcing demand satisfaction.

Energy plants are typically characterized by a number of similar subsystems operating in parallel: this ensures reliability, continuity of service in case of unexpected breakdowns or planned maintenance, and modularity of operation. In particular, when the demand fluctuation range is wide, a unique GU is forced to operate far from its most efficient working conditions: so, instead of operating at inefficient low regimes at low demand, a set of cooperative units can be opportunely committed to run in the most efficient configuration.