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A mixed-integer linear programming (MILP) model for the evaluation of CHP system in the context of hospital structures

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HIGHLIGHTS

- An optimal method is proposed for sizing a CHP to be installed within a micro-grid.
- The optimization tool is based on a mixed integer linear programming model.
- Two different scenarios of micro-grid hospital structure have been investigated.
- The method produces an increase of energy performance and a notable cost saving.

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ABSTRACT

In this paper an optimal planning method is proposed for sizing a cogeneration plant to be installed within a public/commercial micro-grid. The optimization tool is based on a mixed integer linear programming model which uses a set of experimental input data in terms of both thermal and electric power consumption for determining the annual operational strategy, able to reach a twofold objective: minimizing the total operational cost of the micro-grid and finding the optimal size of the CHP to be installed. A numerical example arisen from a case study is proposed with the aim of investigating the economic advantages coming from the adoption of an optimal cogeneration operation strategy. Two different scenario problems exploiting a set of experimental data have been investigated. The former focuses on the comparison between a micro-grid wherein the cooling energy demand coming from final users is neglected and a micro-grid wherein the cooling energy demand is taken into account. The latter assesses the effect of a heat storage properly introduced into the micro-grid, once the cooling energy demand is taken into account.

1. Introduction

Depletion of fossil energy resources as well as environmental pollution has justified the increasing interest in developing high efficiency energy generation techniques. Cogeneration, which consists of the simultaneous production of electricity and heat, yields a high energy-saving effect, especially if compared to the traditional energy supply configuration that separately produces heat and electricity. This leads to lower fuel consumption, the energy is generated at a lower cost and in a more environmentally friendly way [1–4]. In order to take advantage from the high economical and energy saving potential, the energy capacity of the prime movers needs to be properly exploited by an effective planning and design analysis. Indeed, whenever the capacities of the prime movers are under estimated, the effect of introducing cogeneration plants becomes relatively small. On the other hand, if they are overestimated, plant installation may become a pure cost. Selecting the optimal size of a cogeneration plant to be located into a commercial or into a public building is a really hard task. In fact, it is well known as both electric and thermal demand characterizing residential buildings fluctuate seasonally and hourly, thus introducing a concrete need of an annual operating strategy for the CHP system. In addition, the operation of residential CHP system should be subject not only to the variations of load demands, but also to the fuel prices and local energy policies as well. According to the aforementioned remarks, it is necessary to develop a rational method for determining both the CHP system size and the operational strategy through the annual time horizon. A large amount of literature addressed the proposed problem in hand. Beihong and Weiding [5] used mixed integer non-linear programming (MINLP)

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for deciding the optimal size of cogeneration system in consideration of the plant's annual operational strategy. In a similar research, Ren et al. [6] used a MINLP approach to minimize the annual cost of the energy system for a given residential customer equipped with a CHP plant, combined with a storage tank and a back-up boiler. The optimal sizing of a cogeneration plant through an optimal operation planning of the same prime mover plays a key role in several researches. Wakui and Yokoyama [7] developed a mixed integer linear programming (MILP) model for optimizing the size of a residential gas engine cogeneration system named R-GCGS under an energy-saving viewpoint, by means of an optimal operation planning. Several research contributions concerning the planning issue involved micro combined heat and power generation technologies. Bosman et al. [8] used an integer linear programming-based tool for tackling the planning of the production which is run by several micro CHP appliances installed in houses, cooperating in a fleet. Kopanos et al. [9] developed a mathematical programming framework for the operational planning of an energy supply chain based on a domestic micro-grid. Minimization of the total costs (including start-up and operating cost as well as electricity production revenue, sales and purchases), with the aim of satisfying the full heat demand, constitutes the objective function of their study. Shaneb et al. [10] developed an online linear programming optimizer model to determine the optimal operation of a CHP system. To evaluate the proposed model the authors investigated three tariff schemes. In another paper [11] the same authors deal with both complexity and uncertainty connected to the operation of CHP system, by proposing a real time fuzzy logic operation strategy. In Ref. [12] a generic mixed integer linear programming model to minimize the operating cost of a residential microgrid, properly connected with a CHP unit, is proposed. In particular, the microgrid under investigation involved: solar energy, distributed generators and energy storages. The paper shows that the minimum operational cost can produce significantly savings, however, they are rather small compared to the investments for the automated control.

In Ref. [13] the importance of the thermal heat-storage on the operational behavior of CHP facilities in both single and multiple units is investigated. The authors state as it is impossible to draw any conclusion either about the amount of heat to be stored or about the time when this stored heat is used. Furthermore, they verified as a single large fictitious cogeneration unit could approximate the overall behavior of multiple small-scale CHP facilities. In Ref. [14] the benefits arising from an additional energy thermal storage to a CHP system for eight different commercial buildings is analyzed. In particular, for hospitals and small hotel buildings the thermal storage does not significantly affect the costa savings generated by the single CHP system. Another eminent paper to be mentioned about the optimization of a CHP system within a hospital structure is [15]. In this paper the authors report the study of a cogeneration plant integrated with compression and absorption heat-pumps to satisfy the demand of the hospital. In this case, it has been demonstrated how such a technology, along with an optimized management strategy, may significantly yield cost savings.

As confirmed by the aforementioned literature contributions, there are several papers focusing on the optimization of the CHP systems installed in residential structures, while the cost-effectiveness of the CHP systems into complex structures like hospitals and schools has been overlooked. The aim of this paper is proposing an optimized design tool, which computes the optimal size of a cogeneration plant to be employed within a complex public/residential micro-grid characterized by both an electric grid and a local thermal network. In particular, a proper linear programming model aiming at finding the optimal operational strategy for a given CHP system embedded within a specific micro-grid has been developed. Due to the linearity of the mathematical programming-based design strategy, the nominal power of the CHP plant is a parameter of the proposed model and, as a result, the decision maker should evaluate the most effective micro-grid configuration at varying CHP capacity values. Indeed, once several planning scenarios have been generated according to different CHP capacities, the energy designer can identify the optimal sizing, which produces the maximum cost saving. In order to test the proposed optimization approach, a numerical analysis has been performed on the basis of a real dataset concerning an Italian Hospital structure. Basically, both electricity and heat loads generated by the micro-grid Hospital day by day for an entire year have been used for assessing the economic advantage arising from the use of the CHP technology. The proposed optimized design model is able to minimize the overall operational cost of the micro-grid, once the capacity of the CHP system is a-priori determined and, as a consequence, the CHP hourly working schedule may be drawn. In order to assess the effectiveness of the proposed design tool, a comprehensive numerical analysis has been carried out as energy demand, cooling demand, and thermal storage related conditions change.

2. Problem statement

The aim of this paper consists of developing an energy planning tool able to generate the optimal schedule for the operation of a CHP plant installed within a public/commercial micro-grid in which the electric grid and a local thermal network has been considered.

Once the optimal schedule is obtained, a proper tuning analysis on the CHP capacity may be performed to individuate the optimal CHP sizing under an economic viewpoint. Two different scenario problems have been developed to evaluate the performance of the proposed approach; the former is based on a micro-grid wherein two different kinds of load demands (either cooling-not-included or cooling-included) have been considered, the latter is concerned with a micro-grid wherein the load demand is fixed (cooling-included) and a heat storage equipment is involved.

Figs. 1 and 2 refer to the first scenario problem where a plant equipped with a CHP and a boiler properly connected to both gas and electric energy services are provided. In Fig. 1 the final users' energy demand consists of thermal energy for heating, hot water

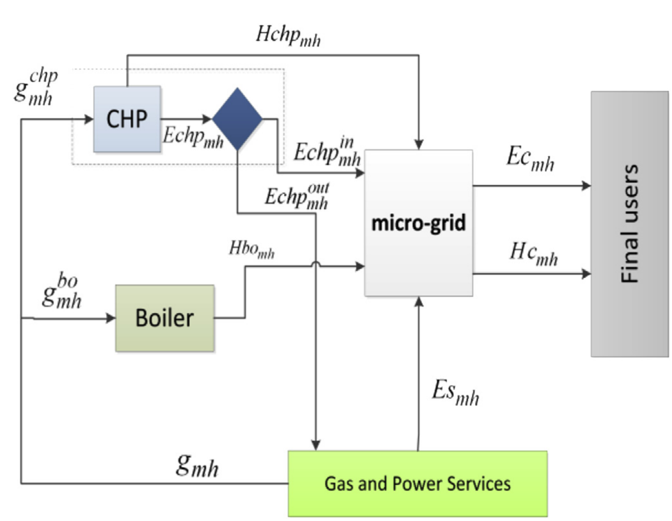

Fig. 1. Energy flows for the micro-grid regardless of cooling energy demand.