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Effects of uncertainties on the stability of the results of an optimal sized modular cogeneration plant

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Abstract

In the last decades, the growing concerns about global warming and climate changes effects led to specific Directive, especially in Europe, promoting the use of primary energy saving techniques. In particular, a more widespread adoption of cogeneration systems has been obtained. However, distributed energy systems do not ensure the achievement of primary energy and cost savings without a proper sizing and operation of the plant. Therefore, vector optimization algorithms could play a key role to identify optimal solutions even when conflicting goals are pursued. The potential of the proposed methodology is demonstrated showing the results achieved from a specific application.

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Keywords: *Combined Heat and Power; Multi-Objective Optimization; Robust Design Optimization; Hospital Facility.*

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1. Introduction

The balance between energy supply and energy demand is a critical issue to address, especially in developed countries, as extensively discussed in [1]. Human activities have required 13699 Mtoe (≈159327 TWh) of primary energy worldwide in 2014 [2], which corresponds to an annual hourly average power supply of approximately 18 TW. Therefore, the development of innovative technologies in future [3]-[4] and traditional engines [5]-[6], the use of alternative and clean fuels [7]-[10], a more efficient use of energy [11]-[12] and an increasing use of renewable

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energy sources [13] are still mandatory to face the challenges imposed by the world energy balance and recognized by Paris Agreement on climate change. In this scenario, a key role for primary energy saving and greenhouse gas emission reduction could be played by cogeneration systems [14]-[17]. The strategic role of CHP plants to achieve the Paris Agreement goals is leading the transition from centralized energy generation to a mature distributed, small and medium scale energy generation. However, due to the decrease in thermal efficiency and the increase in specific investment costs with the reduction of the plant size, the study of an effective utilization of the recovered heat is a fundamental issue to identify solutions that maximize the relevant energetic and economic objectives (e.g., primary energy saving, simple payback period, CO_2 emission, etc.) through a suitable use of the recovered thermal power and generated electricity [1]. Moreover, the proposed methodology enables the design of a CHP plant when energetic, economic, regulatory or market scenarios change. In fact, many studies ignore uncertainties that could alter the outcome of the optimizations, as stated in [18]. For example, most of the researches considered fixed energy prices, electricity tariffs, grid carbon intensity, etc., while these and other quantities can vary through the plant life. Moreover, most of the proposed models do not provide real-life solutions because CHP units size obtained from the numerical solution of the optimization problem could not be available in the market, as stated in [19] and [20]. Therefore, objective of this research paper is to highlight, with reference to the load profiles of an Italian hospital facility, the key role that advanced mathematical methods have for the optimal design of CHP systems and the effects of uncertainties on the stability of the results of an optimal sized modular cogeneration plant.

Nomenclature

std dev	Standard deviation of the considered quantity
Abbreviations	
CHP	Combined heat and power
DII	Department of industrial engineering of the University of Naples Federico II
ICE	Internal combustion engine
h	Generic hour of the year [h]
MOGA	Multi-objective genetic algorithm
SPB	Simple payback period
TPES	Total (or technical) primary energy savings

2. Methodology

Starting from the load profiles of the reference hospital facility (Fig. 1), whose details are reported in [21], one of the goals of the proposed study was the calculation of the potential energetic and economic benefits achievable over the useful life of the CHP plant, which is estimated to be 10 years long. For this reason, with the goal of optimizing specific target quantities, a constrained optimization problem was solved to find optimal modular plant configurations (i.e., CHP engine size and number) adopting a multi-objective approach. Vector optimization [22]-[27] can be useful for deducing general results by conducting a predictive investigation on a large number of possible plant configurations, especially with regard to possible tradeoffs between energetic and economic objectives. In fact, most optimization problems are characterized by several objectives, which are usually conflicting real functions to be maximized or minimized. Generally, these problems, also called multi-objective optimization problems, can be formalized as follows [28]:

$$min\boldsymbol{F}(\boldsymbol{x}) = min(F_1(\boldsymbol{x}), F_2(\boldsymbol{x}), \dots, F_k(\boldsymbol{x})) \tag{1}$$

where: $\boldsymbol{x} \in X \qquad F_i: R^n \rightarrow R \qquad i = 1, \dots, k \qquad k \geq 2$

where R^k is called the objectives space, while R^n represents the decision variable space. Therefore, vector $x \in R^n$ is a vector decision variable, while $y = F(x) \in R^k$ is a vector of objectives. Obviously, it is assumed that the functions $F_1(x), F_2(x), \dots, F_k(x)$ are, at least partly, conflicting.