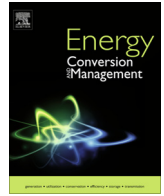




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Optimal operating strategies of combined cooling, heating and power systems: A case study for an engine manufacturing facility

Francesco Calise*, Massimo Dentice d'Accadia, Luigi Libertini, Edoardo Quiriti, Raffaele Vanoli, Maria Vicidomini

Department of Industrial Engineering, University of Naples Federico II, P.le Tecchio, 80, 80125 Naples, Italy

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ABSTRACT

In this paper, a detailed numerical analysis of a Combined Cooling, Heating and Power system is presented, aiming at determining its optimal operating strategy in a real industrial application. The system layout includes a reciprocating engine, fuelled by natural gas, heat exchangers for waste-heat recovery, pumps, storage tanks, a single-effect water lithium bromide absorption chiller, a cooling tower, a backup vapour-compression electric chiller, mixers and valves. A dynamic simulation model of the whole system was developed in TRNSYS. A case study was analysed, referred to a real industrial application, where the system under evaluation should be installed in the near future, providing electricity, mainly used for the production process, and space cooling. Real measured data were used to estimate the electric energy demand of the factory. A detailed building simulation model was used to calculate heating and cooling demands. A detailed economic analysis was carried out, aiming at evaluating: (i) the optimal size of the Combined Cooling, Heating and Power system; (ii) the optimum control strategy, from a thermo-economic point of view, comparing three different cases: Base-Load operation, electric load tracking and a new hybrid strategy based on the simultaneous tracking of electric and thermal-loads. The results showed that the optimal capacity of the system was lower than that selected by the designers of the real unit to be installed. The hybrid control strategy obtained the best profitability, achieving a simple pay-back period equal to 3.8 years, compared to 4.1 years achieved in case of electric-load tracking.

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1. Introduction: cogeneration and trigeneration systems

Cogeneration and trigeneration represent a well-known and mature technology able to ensure significant economic and energy savings, due to the simultaneous production of electric, cooling and thermal energy, using a single primary energy input [1]. In a trigeneration system (Combined Cooling, Heat and Power, CCHP), all these three energy outputs can be produced [2]. Conversely, cogeneration systems (Combined Heat and Power, CHP) only produce heat and electricity [3]. Finally, a polygeneration system is a special case of CCHP, where useful by-products (e.g. alcohols, hydrogen, glycerine, etc.) are also provided [2]. The basic principle of CHP and CCHP systems lies in the possibility of recovering the exhaust heat rejected by a Prime Mover (PM) in order to provide thermal energy for heating or cooling (by means of a thermally-driven chiller [4]). Obviously, such thermal and cooling energy does not require any additional amount of fuel with respect to

the one used to produce electricity [5], leading to a potential reduction of fuel consumption and greenhouse gas emissions with respect to the conventional separate production, where electricity is provided by a public grid, heat by boilers and cooling energy by electric vapour-compression chillers [3]. Further potential advantages are reduction of fuel and operating costs, increased energy reliability, easier energy capacity expansion, higher flexibility in distribution [3]. CHP and CCHP systems showed good energy, environmental and economic performance for large number of applications, such as: chemical industries [6], other large-sized industries (steel and iron factories, pharmaceutical, textile, glass and plastic, etc. [7]), hospitals [8], paper mills [9] and food industries [10]. In addition, in some rare cases, cogeneration is also exploited for other specific applications, such as: sludge treatment [11], minutes reserve markets [12], heat source for natural gas expansion systems [13], residential applications [14], salt production [15].

As mentioned before, CCHP and CHP systems are based on the recovery of thermal energy normally rejected by a prime mover used to convert a fuel into electric energy [2]. The most common technologies are the following:

* Corresponding author.

E-mail address: frcalise@unina.it (F. Calise).

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