Applied Thermal Engineering 48 (2012) 402–413

Contents lists available at SciVerse ScienceDirect

Applied Thermal Engineering

journal homepage: www.elsevier.com/locate/apthermeng

Techno-economic evaluation of commercial cogeneration plants for small and medium size companies in the Italian industrial and service sector

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HIGHLIGHTS

► The best technologies for 1 ÷ 10 MW distributed generation plant are gas turbine and ORC.
► A variety of commercial cogeneration plants is available to meet user needs.
► Cogeneration is a technical and economical advantage for industrial sector companies.

ARTICLE INFO

Article history:
Received 1 September 2011
Accepted 20 April 2012
Available online 28 April 2012

Keywords:
Cogeneration
Distributed generation
Techno-economic analysis
Industrial sector

ABSTRACT

The liberalization of the electricity market and the concern for energy efficiency have resulted in a surge of interest in cogeneration and distributed power generation. In this regard, companies are encouraged to evaluate the opportunity to build their own cogeneration plant. In Italy, the majority of such companies belong to the industrial or service sector; it is small or medium in size and the electric power ranges between 1 ÷ 10 MW. Commercially available gas turbines are the less expensive option for cogeneration. Particular attention has been given to the possibility of combining an organic Rankine cycle (ORC) with gas turbine, to improve the conversion efficiency. Companies have to account for both technical and economical aspects to assess viability of cogeneration. A techno-economic analysis was performed to identify, in the Italian energy market, which users can take advantage of a cogeneration plant aimed to cover at least part of their energy demand. Since electricity and thermal needs change considerably in the same sector, single product categories have been considered in the analysis. Our work shows that in the industrial sector, independent of the product category, cogeneration is a viable option form a techno-economic perspective.

1. Introduction

The term “distributed generation” refers to a power generation scheme where an isolated plant provides energy only to a limited region around the production/conversion site. As reported by Pepermans et al., it entered recently in the vocabulary of scientific literature related to the electric market [1] even though it was the first method used for electricity distribution. Hence, a precise definition of distributed generation is still missing and the meaning changes very much from author to author in terms of maximum electric power of the plant, application, technology and so on [2,3]. The IEA [2] highlighted five main topics that brought new interest on distributed generation: they are mainly concerned with liberalization of the electricity market, increase of conversion efficiency (loss reduction, combined generation of electric and thermal power), environmental issues (biomass utilization, Kyoto protocol). Many works dealing with distributed generation analyze the feasibility of small self-sufficient plants (up to a few hundred kiloWatts electric power) designed for the exploitation of energy resources placed in isolated locations (such as biomass, geothermal sources, and so on) for onsite production and utilization of electric and thermal power [4–13]. Among the main issues of distributed generation there are lower electric efficiency if compared with large power plants and high initial cost. It follows that the possibility to use distributed generation is related to a more efficient use of the fuel and to a net positive economic income at the end of the plant's lifetime.

The easiest way for a better exploitation of the primary energy is the combined production of electric and thermal power, which is commonly called cogeneration. This technology is very promising because it allows to get higher overall efficiency, and greater energy

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1359-4311/$ – see front matter © 2012 Elsevier Ltd. All rights reserved.
doi:10.1016/j.applthermaleng.2012.04.048

saving, than the equivalent separated production does. Cogeneration is also acknowledged as an important tool to meet the requirements of the Kyoto protocol. For this reason the European Parliament defined the constraints to determine if a technology can be classified as “high-efficiency cogeneration plant” [14] and left to the single states the decision to support cogeneration plants with incentives. The Italian Parliament decided to introduce economical support to cogeneration plants and enacted a law [15] to regulate the accessibility to the incentives. The well-known methods of investment evaluation are commonly used [16–21] in economic analyses.

The liberalization of the electricity market poses two further questions: which user can take advantage of its own cogeneration plant and how the plant should be designed to fulfill the whole or part of the electric and thermal needs. Some authors tried to give general answers. In particular, limited to the Italian market, Gullì [22] took into account the civil and service sector, Cardona and Piacentino [23] analyzed only the civil sector developing an algorithm for the optimal design of a trigeneration plant, Chinese and Meneghetti [24] presented a techno-economic model for the evaluation of a biomass-based industrial district. From these works it can be concluded that a cogeneration plant for distributed generation is a good option for the industrial sector while it is not convenient for the civil and service sectors without suitable incentives. It has to be pointed out that all these authors took into account only a specific case and they assumed that it was representative of all the companies of the sector. Other authors provided the cogeneration scenarios in different countries [17,25–29]. However, the majority of surveys dealt with plants of electric power size lower than 2 ÷ 3 MW. Moreover, there is limited information about two very important topics: the differences in energy needs of the various operators in the industrial sector and the technology commercially available to realize cogeneration plants able to fulfill the users' request (prices, performances and so on). A detailed ISTAT survey [30] highlighted that the majority of the Italian companies working in the industrial or service sector is small or medium in size and the required electric power lies in the range 1 ÷ 10 MW. For this size a widely used prime mover is the gas turbine, mainly because of its low specific cost [1]. Moreover, in the last few years particular attention was focused on the organic Rankine cycle engine (ORC) and on the possibility to couple it with a gas turbine in a combined cycle, in order to increase significantly the conversion efficiency. This advantage can overcome the two main drawbacks of small electric size ORC, i.e., low electric conversion efficiency and high investment cost [12].

Taking into account these considerations, this work is aimed to provide a techno-economic evaluation of commercially available cogeneration plants based on gas turbines or combined cycles (gas turbine plus ORC), suitable to fulfill at least partially the energy needs of companies working in the various product categories of the Italian industrial and service sectors.

2. Regulation

Since January 1st 2011 the “Directive 2004/8/CE of the European Parliament and of the Council”, dated February 11th 2004 [14], dealing with the promotion of the cogeneration, has become effective. The directive defines the criteria for high efficiency cogeneration. The III attachment defines a parameter, named “Primary Energy Saving Index” (*PES*), to quantify the energy saving. It is based on the comparison between:

- the electric efficiency of the plant (η_{ep}) and a reference electric efficiency (η_{er} = 52.2% corresponding to the best available technology and accounting for a grid loss correction term);
- the thermal efficiency of the plant (η_{tp}) and a reference thermal efficiency (η_{tr} = 90% corresponding to the best available technology).

The primary energy saving index is evaluated as:

$$\mathrm{PES} = \left[1-\left(\frac{\eta_{tp}}{\eta_{tr}}+\frac{\eta_{ep}}{\eta_{er}}\right)^{-1}\right]\cdot 100 \quad (1)$$

A cogeneration system is classified as a “high efficiency cogeneration plant” and therefore is eligible for incentives, if certain constraints on the *PES* value are met. In particular, for the electric power range taken into account (1 ÷ 10 MW) the requirement is $PES \geq 10\%$.

3. Methodology of analysis

An analytical procedure is defined for a technical and economic comparison of two alternative technologies that are able to meet both the electric and thermal needs of the user.

The technologies to be compared are:

- *separated generation*: the whole electric needs are purchased by the electric grid while the whole thermal demand is fulfilled with a conventional boiler (reference technology);
- *cogeneration plant*: the user is endowed with a cogeneration plant to meet, at least partly, both the electric and the thermal needs. The missing part of the electric need is purchased by the electric grid while the missing part of the thermal demand is produced by an auxiliary boiler with the same nominal power and characteristics of the one used for the separate generation (alternative technology).

The analysis takes into account only cogeneration plants with electric power in the range 1 ÷ 10 MW and deems if the replacement of the separated generation with a cogeneration plant could be an advantage for a company of the industrial sector or of the service sector. Data on the users were taken from a detailed survey performed by ISTAT [30], which, to get homogeneous information, divided each sector in product categories and each product category in five bands to group the companies of similar dimension, quantified by the number of employees.

3.1. Hypotheses

The analysis is based on the following assumptions:

1. the working period (expressed in terms of number of hours per year) for users of the same sector, product category and band is equal for both the reference technology and the alternative technology;
2. the electric energy provided by the cogeneration plant never exceeds the user demand, while the incidental missing part is purchased by the electric grid. Actually, the opportunity to overproduce electric energy to be sold has not been taken into account because electricity tariffs vary significantly over the national territory on an hourly basis. Hence, both the geographical distribution of the potential users and their electrical demand per hour should be needed for the analysis. Unfortunately, the ISTAT survey only reports the annual electrical demand, whereas no information is available on the users' location;
3. the heat provided by the cogeneration plant never exceeds the user demand, while the incidental missing part is supplied by a traditional boiler. As for the electric energy (item 2), the opportunity to overproduce thermal energy to be sold has not been considered, but for different reasons. Actually, in this case