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Energetic and economic investigation of the operation management of an Organic Rankine Cycle cogeneration plant

Anna Stoppato*

Department of Mechanical Engineering, University of Padova, 1, via Venezia-35131 Padova, Italy

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ABSTRACT

In the past few years a special attention has been paid to the use of renewable energy, but some negative features of these sources (low power density and unpredictable availability) bring about remarkable difficulties of economic payback. For this reason, in many countries incentives are provided to promote energy conversion plants fed by these sources. Such incentives can influence not only the design of new plants, but also their operation strategy. This paper describes the results of the energetic and economic analysis of a new plant sited in Asiago (Italy), for different operation strategies. The plant consists of 2 boilers fed by the wastes from a sawmill: one of them directly supplies hot water to a district heating grid, while the other provides heat for a cogeneration (ORC) Organic Rankine Cycle. The ORC plant has a nominal electric power of 1.25 MW and can produce 5.3 MW of heat. It is connected to the electric grid and to the local district heating grid. The emissions have been evaluated, too and compared with those of the pre-existing situation: domestic boilers fed by natural gas or diesel oil.

1. Introduction

The energetic question has more and more increasing political and economic implications. The awareness about the importance of environment defence and of a responsible use of fossil reserves has widely brought to a series of actions to save energy and reduce the impact of energy systems. This seems to be a winning strategy also from the economic point of view, especially for nations, as Italy, strongly dependent on imported fossil fuels. In addition, the development and improvement of a national productive sector related to the energetic efficiency can load to new energetic strategies.

In many countries, the promotion of the use of renewable resources is considered one of the main points to reach the target of reducing greenhouse emissions: among other goals, the 20–20–20 Climate action and renewable energy package by the European Union [1] aims at reaching a 20% of production by renewables by 2020. To get this target, many directives have been promulgated and incentives and facilitations introduced. The most important in Italy are:

- The Italian law 79/99 [2] and its modifications, following the European Directive 96/92/CE [3], which introduces the obligation for electric producers and importers of electricity from not renewable sources to put into the grid a quota of electricity by renewable sources. For 2010, this quota is 6.05% of their production or importation by fossil fuels. It is also possible to fulfil the renewable quota obligation by purchasing (GC) Green Certificates which have been issued in respect of certified renewable electricity (RES-E) generated by other parties. One Green Certificate is worth 1 MWh of electricity. The electricity generated by RES plants commissioned or repowered after 1 January 2008 is certified as RES-E for the first 15 years of operation of the plants.
- The law on the promotion of the electric energy produced by renewable sources, defining the characteristics, the benefits and the incentives for the plants using renewable energy sources [4].

In addition, both European and Italian laws promote high efficiency cogeneration (CHP) based on a useful heat demand [5,6], since it permits a better efficiency than the traditional production of heat and electricity by separate plants. The laws give the rules to qualify a plant as CHP plant and the benefits that can be applied to it.

Special attention is paid to small plants and distributed generation, whose promotion contributes to reduce the transmission losses on the grid and the grid congestion problems, permits the use of low density distributed renewable sources (biomass, wind, solar, minihydro) and/or can serve a cogeneration scheme thermal and electric loads located near the plants [7]:

* Tel.: +39 049 827 6780; fax: +39 049 827 6785.
E-mail address: anna.stoppato@unipd.it.

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- Simplified procedures for the connection to the grid are contemplated.
- Small plants ($P < 10$MVA) can opt for indirect sale through the Italian Energetic Services Manager (Gestore Servizi Energetici, GSE), instead of the direct sale in the market profit. For plants having $P > 1$ MW the sellback prices are the market ones, while smaller plants have minimum granted prices for the first 2 million kWh.
- Very small plants ($P < 1$ MW) fed by renewable sources can also choose the all-inclusive feed-in tariff, comprehensive of the Green Certificates, which gives granted sellback prices for the whole production.
- Finally, the net metering service is granted for electricity generated by RES plants of up to 200 kW.

These facilitations have promoted the growth in Italy of distributed ($P < 10$MVA) and small ($P < 1$ MW) generation. In 2008, 21.6TWh of electric energy (about 4.3% of the Italian production) were produced by distributed plants (1.9 TWh by small plants), with an increase of 1.3 TWh (+11.8%) with respect to 2007 and of 8.1 TWh (+60%) with respect to 2006. About 60% of this energy is produced by renewable sources, of which about 15% using biomass.

For applications using biomass the employment of Organic Rankine Cycles (ORC) is a good solution [8–12]. Among other technologies, they present high efficiency for low temperature applications, high availability and simple management. The combustion takes place in boilers of proven and simple operation, where diathermic oil is heated and so the operation problems related to the use of superheated steam are avoided. Then, this oil provides heat to the organic fluid, which evaporates and expands in a turbine. ORC plants seem to be particularly interesting for low temperature cogeneration applications.

Since the end of 2009, an ORC plant has been working in Asiago, Italy, using the wastes of a sawmill. It produces electricity, sold to the grid, and heat for the local district heating grid.

In this paper, different operation modes for this plant will be analyzed from both energetic and economic viewpoints. Special attention will be paid to the influence of the incentives on the results of the analysis. This aspect is particularly interesting for this plant whose size, 1255 kW_{el}, gives the possibility to choose among different options of incentives. The paper will also present the analysis of the emissions of the plant, comparing them with the pre-existing conditions, when domestic boilers fed by natural gas or diesel oil were used.

2. Description of the plant

The CHP plant under analysis is fed by the wastes (wood shavings, barks, sawing, chips) of a big sawmill, which are directly sent to the bunker of the plant by a conveyor belt.

Its thermal section consists of two moving grate furnace boilers fed by biomass:

- The first produces hot water directly for the local district heating grid and is sized 3.5 MW.
- The second heats diathermic oil up to 310 °C for the ORC plant and is sized 6.8 MW.

Both of them have a design efficiency of about 85%.

A supplementary boiler (5.8 MW sized) fed by rape seed oil is available for integrative purposes.

The cogeneration section of the plant is an ORC unit T1100 by Turboden s.r.l. [13].

Its main design characteristics are summarized in Table 1: nameplate electric output is 1.255 MW, thermal power 5.35 MW.

Table 1
Main characteristics of T1100 unit [13].

Diathermic Oil	
Temperature (in/out) high temperature loop	310/250 °C
Thermal power high temperature loop	6130 kW
Temperature (in/out) low temperature loop	250/130 °C
Thermal power low temperature loop	585 kW
Total thermal power	6715 kW
Water (for thermal use)	
Temperature (in/out)	60/80 °C
Thermal power to water	5350 kW
Performances	
Gross active electric power	1317 kW
Gross electric efficiency	0.196
Captive Power Consumption	62 kW
Net active electric power	1255 kW
Net electric efficiency	0.186
Total efficiency	0.98
Electrical generator	asynchronous triphase L.V. 400 V

Note that the efficiencies are calculated with respect to the thermal power supplied by the diathermic oil to the organic fluid, which is a siliconic oil of siloxanes class, and do not consider the boiler efficiency.

T1100 is a cogeneration unit with **split**: as can be seen in Fig. 1, after the feed pump (point 2) the fluid is split into two streams: the first goes, as in standard ORC cycles, to a regenerative exchanger, while the other is heated by the diathermic oil in a supplementary preheater (called "low temperature loop" in Table 1). Then the two streams are remixed together before the evaporator. Note also that there are two economizers between exhaust gases and oil and a further economizer between flue gases and hot water. These devices permit a very efficient recovery of heat from diathermic oil and from flue gases and so the increase of the electric power and of the net electric efficiency of the group up to 18.6%. In the condenser the organic fluid warms up the water of the heating grid from 60° to 80 °C. Two heat wasters can be used when the thermal requirement by the users is lower (down to 0) than the heat supplied by the organic fluid in the condenser.

Globally, the plant can supply 8850 kW (14200 kW considering the supplementary boiler) of heat to the local heating grid.

2.1. The users

The plant is located in Asiago, Italy, a town of about 6500 residents at 1000 m over s.l. Asiago is a winter and summer holiday site, and so many hotels, holiday buildings, health resorts, recreational facilities can be found in its area.

At present (2010), 43 thermal users are connected to the local district heating grid, among them a hospital, some schools and hotels. Globally, their installed thermal power is 9234 kW, while the peak load is 2550 kW. The annual requirement by users is 8237 MWh: considering about 10% of energy losses in the grid, the plant must supply 9061 MWh per year. Note that at present the users' requirement is much lower than the plant potentiality: the connection to the grid of new users, which will double the thermal requirement, is expected by 2–3 years. Table 2 and Fig. 2 summarize the load trends of typical winter and summer days and the average request month by month. They have been obtained combining data registered in the first months of operation of the grid and data from literature [14], considering the annual temperature trend of Asiago [15]. It can be noted, that, as usual for civil utilities, the load is very variable from month to month, and from hour to hour. Also the distribution of loads during the day hours varies from summer to winter.