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Biomass-fired CHP and heat storage system simulations in existing district heating systems

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HIGHLIGHTS

- Analysis of a wood-biomass ORC unit in an existing DH system.
- Parametric study with optimization on ORC size and heat storage system size.
- Simulation of heat demand from a dataset of a similar DH system in operation.
- Different optimal configurations when considering energetic or economic criteria.
- The Italian incentive still not encourages system layouts with higher efficiency.

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ABSTRACT

The installation of a biomass-fired Organic Rankine Cycle (ORC) unit coupled to a heat storage system (HSS) in an existing district heating (DH) system is proposed and analyzed from both energetic and economic point of view. A real DH system is considered as case study, and the optimal layout configuration is investigated varying the size of the components. The analysis is carried out tuning the heat demand dataset obtained from real data of a different existing DH system with a 6-min time step and ten years of operation. The heat demand is used to match the production from different generation units. The overall efficiency of the system, the primary energy savings related to CHP production, as well as the pay back time of the investment are evaluated. Calculations show that for the considered case study the maximum size of the HSS that gives noticeable advantages is 150 m^3/MW_{th}. The optimal configuration is different when considering energetic or economic criteria. Moreover, the current Italian incentive tariff on electricity production from renewable sources appears to promote the choice of low efficiency layouts for the case study under consideration.

1. Introduction

Energy production from renewable sources, together with energy efficiency and energy saving measures, is a key question in the limitation of greenhouse gases emissions (GHG) and in the diversification of energy resources.

The European Union in its Climate Package has set a target of 20% of energy production from renewable sources by 2020, with further objectives for 2050 [1,2].

Energy production from renewable sources has increased in recent years up to 1660 Mtoe in 2010 [3]. Biomass is currently the most diffused and exploited renewable source all over the world. In 2010 about 75% of primary energy production from renewable sources was produced from biomass and renewable wastes [3].

However, research and planning activities are still required in order to improve overall sustainability and energy conversion efficiency of biomass to energy pathways.

The use of wood-fired combined heat and power (CHP) and district heating (DH) systems can play an important role in improving a rational use of bioenergy [4–6], when an accurate analysis of both availability of local biomass and thermal demand is performed.

CHP plants can reach higher overall efficiencies due to the recovery of the waste heat resulting from electricity generation, even though wood-fired plants often work at lower performances than expected due to not optimal design and operational strategies. For these reasons, a careful design and operation of the plant based on

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integrated analysis of both thermal demand side evaluation and CHP unit, boilers and HSS performance can allow to enhance the overall efficiency of the system. Furthermore, reduced emissions of pollutants typical from a wood-fired combustion plant (above all particulate matter and nitrogen dioxide) can be obtained limiting part load operation of the plant and with proper operational and control strategies that are beyond the scope of the study performed so far.

Several simulation codes have been developed in recent years to support DH planning [7], both in the short-term [8] and the mid-term [9] perspective. Furthermore, some studies have investigated CHP systems coupled with DH [10] as well as CHP performances at partial load [11]. However, there is often a lack of information about the data measured from DH systems during operation and consequently the real behavior can differ from the design hypothesis.

This work represents the first stage of a study aiming to simulate the behavior of DH systems and to analyze energetic, economic and environmental aspects with a multi-criteria approach. The model proposed is based on the integration of computed and measured datasets.

2. Methodology

2.1. Methodology summary

This paper aims to describe the analysis of configuration and operational criteria of a DH system through simulations with respect to multiple parameters. The study is performed by means of a simulation tool capable of analyzing the operation of multiple generation units in matching the heat demand load and of evaluating/assessing energetic, economic and environmental aspects. The model proposed is based on the integration of computed and measured datasets in order to analyze energetic, economic and environmental aspects with a multi-criteria approach.

In this paper the installation of a CHP unit coupled to a HSS in an existing DH network is considered. The heat load profile has been simulated by means of real data that has been recorded over several years of operation of an existing DH system with similar characteristics.

Different system configurations have been investigated by varying the CHP nominal power, the HSS size and the operation mode of the system (e.g. full year or heating season only operation). In this case study the CHP unit is an organic Rankine cycle (ORC) system.

An economic analysis has been carried out, focusing on the current Italian incentive tariff on electricity production from renewable sources and its effect on the pay back time, with the aim of evaluating the incentive attitude.

2.2. Description of the heat demand dataset

The heat demand model used for the simulations was developed by processing operational data collected over ten years of operation from the Turin DH system, which has similar characteristics regarding users typology and climate conditions [12]. The heat supplied to the thermal grid from each generation unit has been recorded every 6 min, as well as the water temperatures and flow rates, from 2002 to 2010. This large amount of data was processed taking into account also the expansions of the network that have occurred over the years. Considering the specific thermal power demand a comparison between data of different years has been performed.

The Turin DH system currently supplies about 50 million cubic meters of buildings, which represent more than 40% of the city. The overall thermal peak power increased during last years to almost 2 GW, with an annual heat requirement of 1800 GWh. The heat is mainly provided by three gas turbine combined cycles, whereas backup boilers and heat storage systems provide the remaining part of the load. Over the next years several projects aim to increase the generation capacity in order to connect new areas of the city to the grid and reach 73 million cubic meters of connected buildings.

Through the evaluation of cumulative specific power it has been possible to compare the network behavior for different years. The result is showed in Fig. 1, considering hourly heat demand. The slight differences among the years are related to climate conditions, as well as some anomalies due to the connection of new generation units or significant amount of buildings.

The calculation of specific heat power allows the analysis of the data for different years and also the comparison with other DH systems. The comparison with data of various systems is essential in order to create a wider database, which can track the relations between different parameters (e.g. volume of the buildings, degree-days, length of the grid, users typology, etc.).

Furthermore, the data related to heat production from each generation unit have been analyzed to outline some considerations about unit operation behavior. The profiles of heat storage systems have been analyzed in more detail, in order to assess the operational criteria.

2.3. Description of the case study

This paper presents the results obtained from the application of the simulation model mentioned above to a small DH system already in operation, in order to analyze some possible improvements to the system concerning both design and operational criteria. Particular attention has been paid to the evaluation of the best configurations and operational criteria of a biomass-fired CHP system coupled with a heat storage system.

The DH system under examination is located in Leini, a little town of about 15,000 inhabitants in the outskirts of Turin. About 500,000 cubic meters of buildings (mostly residential structures) are supplied by a 12-km DH system powered by two biomass boilers (5 MW each) and a natural gas backup boiler (3.5 MW). The annual thermal energy supplied by the system is about 17 GWh, with a consumption of more than 9500 tons of chipped wood. In the current configuration the system produces only heat (no CHP), without any HSS coupled to the boilers.

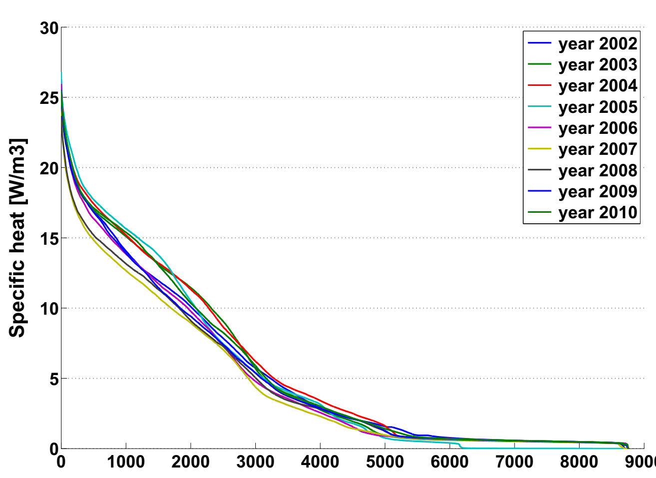

Fig. 1. Cumulative specific power profiles for different heating seasons.