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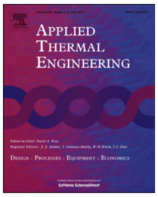

Technical and cost analyses of two different heat storage systems for residential micro-CHP plants

L. Mongibello [a],*, M. Capezzuto [b], G. Graditi [a]

[a] *ENEA – Italian National Agency for New Technologies, Energy and Sustainable Economic Development, CR Portici, P.le E. Fermi n.1, 80055 Portici, NA, Italy*
[b] *University of Naples Federico II, Faculty of Engineering, P.le V. Tecchio n.80, 80125 Naples, Italy*

HIGHLIGHTS

- Water and sodium acetate trihydrate have been considered as heat storage media.
- The storage tanks volumes with the PCM are about the 30% of the ones with water.
- With the PCM the heat exchangers are many times larger than with water.
- The components total cost is always lower for the storage systems with PCM.

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ABSTRACT

The heat storage system represents a key component for micro-cogeneration plants since it permits to store the unused thermal energy during electricity production for a later use. Nevertheless, it also represents a consistent additional cost that has to be taken into account in order to evaluate the profitability of the micro-CHP system with respect to the separate generation. In this paper the results of a technical and of a cost analysis of two different types of thermal energy storage systems for residential micro-CHP plants are presented. Indeed, in the present work hot water thermal energy storage systems and latent heat thermal energy storage systems have been dimensioned for different micro-CHP systems producing electrical and thermal energy for two different buildings situated in Italy. For each analysed micro-CHP system an adequate thermal energy storage capacity is estimated on the basis of the operational logic and of the electric and thermal loads, and the sizing of the cylindrical tank and of the coil heat exchanger relative to both types of thermal energy storage systems is performed. Comparisons in terms of components cost between hot water thermal energy storage systems and latent heat thermal energy storage systems are performed as well.

1. Introduction

It is well known that the combined production of electric and thermal energy (CHP) permits to obtain high overall conversion efficiencies of both conventional and renewable fuels. Moreover, distributed energy production systems, as the residential micro-CHP ones, allow to achieve further energy savings, as they permit to avoid energy losses due to electricity transmission and distribution. These aspects, together with the necessity to respect the Kyoto Protocol constraints relative to the primary energy savings and greenhouse gas emissions, and with the continuously increasing oil and natural gas costs, have led in recent years to a great interest of Governments, industries and researchers towards the identification of the most suitable technologies for micro-CHP systems. Nowadays, in Europe the growth of cogeneration is supported by the EU directive 2004/08/EC [1] requiring each Member State to assess the potential for cogeneration in their own country and to promote its exploitation. In the Italian context, there are essentially two main incentives for micro-cogeneration ($P_{el} < 50$ kW), namely a reduction of the excise duty on the fraction of the natural gas used for the electricity production by means of CHP systems [2], and advantages related to the possibility of releasing the electricity produced by the CHP system but not immediately consumed in the external grid for a later use on a yearly basis [3].

In general, the integration of a thermal energy storage system (TES system) into a CHP system allows to accumulate the heat recovered from the prime mover, when it is not needed by the

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* Corresponding author. Tel.: +39 081 7723584; fax: +39 081 7723344.
E-mail address: luigi.mongibello@enea.it (L. Mongibello).

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Nomenclature

$A_{\text{HE,HW}}$	total heat transfer area of the heat exchanger relative to the hot water thermal energy storage systems (m^2)
$A_{\text{HE,PCM}}$	total heat transfer area of the heat exchanger relative to the latent heat thermal energy storage systems (m^2)
A_{i}	coil internal heat transfer area (m^2)
$c_{\text{p,HTF}}$	specific heat at constant pressure of the HTF (J/(kg K))
$c_{\text{p,w}}$	specific heat at constant pressure of water (J/(kg K))
C	parameter relative to the thermal conduction between the coils external surfaces and the phase change front (m)
d_{e}	external diameter of heat exchangers coils (m)
d_{i}	inner diameter of heat exchangers coils (m)
h_{e}	external free convention heat transfer (W/(m^2 K))
h_{i}	internal forced convection heat transfer coefficient (W/(m^2 K))
k_{PCM}	PCM thermal conductivity (W/(m K))
k_{wall}	coils walls material thermal conductivity (W/(m K))
L	coil length (m)
LH_{PCM}	PCM latent heat (J/kg)
$\dot{m}$	mass flow rate (kg/s)
N	number of coils
NTU	number of transfer units
P_{el}	electric power (kW)
$P_{\text{el,PM}}$	electric power generated by the prime movers (kW)
$P_{\text{th,Peak}}$	thermal peak demand (kW)
$P_{\text{th,PM}}$	thermal power produced by the prime movers (kW)
$\dot{Q}$	thermal power (kW)
R_{e}	thermal resistance relative to free convection on the external surface of coil
R_{HTF}	thermal resistance due to the internal forced convection of prime mover HTF (K/W)
R_{PCM}	thermal resistance due to thermal conduction inside PCM (K/W)
R_{tot}	overall thermal resistance (K/W)
R_{wall}	thermal resistance relative to the thermal conduction in the coils wall (K/W)
SC_{TES}	capacity of thermal energy storage systems (kWh)
S	building surface (m^2)
$T_{\text{in,TES}}$	the temperature of water entering the storage tank (°C)
$T_{\text{h,TES}}$	hot water temperature after the storage system has been fully charged (°C)
$T_{\text{in,PM}}$	HTF temperature at the inlet section of the prime mover (°C)
$T_{\text{out,PM}}$	HTF temperature at the outlet section of the prime mover (°C)
V	building volume (m^3)
V_{PCM}	total volume of PCM inside the thermal energy storage tank (m^3)
V_{HW}	total volume of the hot water inside the thermal energy storage tank (m^3)
ΔT	temperature difference (°C)

Greek letters

δ	ratio between the liquefied portion of the PCM total volume and the PCM total volume
ε	efficiency of the heat exchangers relative to the latent heat thermal energy storage systems
$\bar{\varepsilon}$	average efficiency of the heat exchangers relative to the latent heat thermal energy storage systems
ρ_{PCM}	density del PCM (kg/m^3)
ρ_{w}	water density (kg/m^3)

Acronyms

CHP	combined heat and power
HW	hot water
HE	heat exchanger
HTF	heat transfer fluid
ICE	internal combustion engine
LHTES	latent heat thermal energy storage
MGT	micro gas turbine
MRC	micro Rankine cycle
PCM	phase change material
PM	prime mover
SE	Stirling engine
TES	thermal energy storage

thermal utilities, for a later use. Thus, allowing the prime mover to produce electricity when it is possible or more convenient without any heavy heat loss. Therefore, it is straightforward that a suitable sizing of the thermal energy storage system for a CHP system has to take into account the prime mover size, the electric and thermal demand of the utilities, the electricity and fuel costs, and the incentives delivered by the country in which the system is installed.

The research of cost-effective solutions for thermal energy storage systems integrated into CHP systems has been conducted in many recent papers, as those of Fragaki et al. [4,5] focused on the profitability of CHP systems in UK, those of Ren et al. [6,7] in which the optimal sizing of the residential micro-CHP systems in Japan is performed by means of a home-made numerical model, and that of Bogdan and Kopjar [8] in which the improvements to the EL-TO Zagreb CHP plant in Croatia due to the thermal energy storage are evaluated. The most recent Italian studies about the above subject are those of Bianchi et al. [9] and Barbieri et al. [10]. In the first one guidelines are provided for the evaluation of the optimal thermal energy storage capacity in residential micro-CHP systems, while in the other one the authors perform a numerical analysis in order to assess the influence of the thermal energy storage on the profitability of micro-CHP systems for a residential building.

As far as the thermal energy storage materials are concerned, water is used in almost the totality of the storage systems for residential micro-CHP plants producing electricity and thermal energy for hot water utilities and ambient heating. This is because water can be directly used in hot water utilities, it has practically no cost, a high specific heat, a relatively high boiling temperature compared to the working temperatures of hot water utilities, and it is not toxic. Nevertheless, in the last years latent heat thermal energy storage (LHTES), that typically relies on the latent heat relative to the isothermal solid–liquid phase transition of phase change materials (PCM) like paraffins, fatty acids and salt hydrates, has gained great attention from researchers and industries as it can provide much higher energy storage density than the sensible thermal energy storage method, and as a consequence it can lead to a consistent reduction of weight and volume of thermal energy storage systems [11,12]. To date, among the commercially available PCM for thermal energy storage applications, one of the most promising for residential thermal energy storage systems is the sodium acetate trihydrate [13], due to its very high latent heat of fusion and to its melting temperature of about 58 °C, suitable for the above application.

In the following, the results of a technical analysis and of a cost analysis of two different types of thermal energy storage systems

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