Available online at www.sciencedirect.com

ScienceDirect

Energy Procedia 126 (201709) 597–604

Energy Procedia

www.elsevier.com/locate/procedia

72nd Conference of the Italian Thermal Machines Engineering Association, ATI2017, 6-8 September 2017, Lecce, Italy

Integration of an Organic Rankine Cycle and a Photovoltaic Unit for Micro-Scale CHP Applications in the Residential Sector

J. Settino[a], P. Morrone[b]*, A. Algieri[b], T. Sant[a], C. Micallef[a], M. Farrugia[a], C. Spitieri-Staines[a], J. Licari[a], A. Micallef[a]

[a]*University of Malta, Msida MSD 2080, Malta*
[b]*University of Calabria, Via P. Bucci, 87036 Arcavacata di Rende (CS), Italy*

Abstract

The purpose of this work is to analyse the performance of a novel system for combined heat and power (CHP) generation in small-scale applications. The system is based on an Organic Rankine Cycle (ORC) fed with biomass and a photovoltaic (PV) unit. The ORC and PV sub-systems operate in parallel to produce the required electrical energy. A preliminary investigation is performed to define the proper size of the photovoltaic unit. Afterwards, the analysis is focused on the hybrid system and a comparison between the two configurations is carried out.
This work demonstrates the potential for integrating biomass and solar energy resources: during daylight, solar radiation is significant and the ORC system can be switched off or operated at partial load. Furthermore, the adoption of biomass makes it possible to overcome the intermittency of solar resource, increase the self-consumed electrical energy, and produce thermal energy, thereby saving natural gas for heating purposes.

Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association

Keywords: Photovoltaic, Organic Rankine Cycle, Combined Heat and Power, Hybridisation

1. Introduction

Nowadays, the combined heat and power (CHP) production is considered an efficient alternative to conventional

* Corresponding author. Tel.: +39 0984 494162; fax: +0-000-000-0000
E-mail address: pietropaolo.morrone@unical.it

1876-6102
Peer-review under responsibility of the scientific committee of the 72nd Conference of the Italian Thermal Machines Engineering Association
10.1016/j.egypro.2017.08.223

Nomenclature

A	area (m^2)
G	solar irradiance (W/m^2)
I	current (A)
P_{el}	electric power (W)
$\dot{Q}_{th}$	thermal power (W)
V	voltage (V)
η	efficiency

systems with separate electric and thermal generation owing to the higher energy efficiency and saving capability and to the lower pollutant emissions [1]-[2]. In this context, the integration of biomass-fired Organic Rankine Cycles (ORCs) and photovoltaic systems (PVs) represent an interesting solution for small-scale CHP applications, capable to overcome the stochastic nature of the solar source. Specifically, ORC systems present different advantages compared to conventional installations due to their lower maintenance requirements, better partial load performance, faster start-up and stop procedures, higher flexibility and safety [3]-[4]. In this framework, energy systems hybridisation appears to be a very innovative and efficient solution, able to assess larger operation flexibility and lower costs [5]-[7]. In particular, there is significant potential for integrating solar and biomass resources: during daylight the solar radiation is high and the ORC system can be fuelled with a low amount of biomass. Furthermore, the adoption of biomass satisfies the energy demand also when the solar radiation is absent or insufficient.

Nevertheless, few investigations on this topic have been documented in literature and further studies are necessary [8]. The present work aims at analysing the energy performance of a hybrid ORC/PV system for domestic applications. The two sub-systems operate in parallel to produce electrical and thermal energy. The investigated concept may offer interesting opportunities to achieve the Nearly Zero Energy House (NZEH) target in the residential sector and to overcome the energy "trilemma" of affordability, supply security, and environmental protection.

2. Methodology

The work aims at analysing the performance of an innovative hybrid energy system for domestic micro-scale combined heat and power (CHP) generation. Figure 1 shows the simplified scheme of the proposed system that consists of a biomass-fired Organic Rankine Cycle (ORC) and a photovoltaic (PV) unit. Solar PV is the primary energy source while the ORC works when the solar radiation is not sufficient to satisfy the electric demand of domestic users. Furthermore, electrical energy can be exchanged with the grid and an auxiliary boiler is used to cover the thermal demand if the CHP output is low.

2.1. Biomass-fired ORC model

The Organic Rankine Cycle consists primarily of a pump system, an evaporator, an expander, and a condenser. The pump supplies the organic fluid to the evaporator, where the fluid is preheated and vaporised. The vapour flows into the expander where it is expanded to the condensing pressure and then, it is condensed to saturated liquid. A biomass boiler provides the energy input to the evaporator through a thermal oil circuit in order to avoid local overheating and to prevent organic fluids from becoming chemically unstable.

A thermodynamic model has been developed to characterise the performance of the biomass ORC section. More details can be found in literature [9]-[11]. The REFPROP database [12] has been integrated with the energy model to define the thermodynamic properties of the organic fluid. For the analysis, a steady state condition has been assumed, while pressure drops and heat losses in the system components have been neglected.