Energy 61 (2013) 72–86

Contents lists available at ScienceDirect

Energy

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

Dynamic simulation of a novel high-temperature solar trigeneration system based on concentrating photovoltaic/thermal collectors

Francesco Calise [a,*], Massimo Dentice d'Accadia [a], Adolfo Palombo [a], Laura Vanoli [b]

[a] DETEC – Univ. of Naples Federico II, P.le Tecchio 80, 80125 Naples, Italy
[b] DIT – Univ. of Naples "Parthenope", Centro Direzionale, IS.C4, 80143 Naples, Italy

ARTICLE INFO

Article history:
Received 28 July 2012
Received in revised form
4 October 2012
Accepted 5 October 2012
Available online 1 November 2012

Keywords:
PVT
Solar heating and cooling
Solar energy
TRNSYS

ABSTRACT

The paper is focused on the dynamic simulation of a Photovoltaic/Thermal collector (PVT) integrated in a high-temperature Solar Heating and Cooling (SHC) system. The system is based on the following main components: concentrating parabolic PVT (photovoltaic thermal) collectors, a double-stage LiBr-H2O absorption chiller, storage tanks, auxiliary heaters, balance of plant devices. The PVT is made-up by a parabolic dish concentrator and a triple-junction receiver. The polygeneration system provides electricity, space heating and cooling and domestic hot water for a given building, whose simulation is also included in the model. In particular, PVT produces electric energy, which is in part consumed by the building loads (lights and equipments), in part by the system parasitic loads, whereas the eventual excess is sold to the public grid. Simultaneously, the PVT provides the heat required to drive the absorption chiller. The system was simulated by means of a zero-dimensional transient model, that allows the evaluation of temperature profiles and also heat/electrical energy flows for whatever period of the year. It is also possible to evaluate the overall energetic and economic performance on whatever time basis (day, week, month, year, etc.). The economic results show that the system under investigation can be profitable, if a proper funding policy is available. The paper also includes an extensive parametric analysis aiming at evaluating the set of design and operating parameters (solar field area, tank volumes, set point temperatures, etc.) that maximize the energetic and/or economic performance of the system.

1. Introduction

Solar energy is probably one of the most promising renewable energy sources, due to its large availability in several regions of the world. Several possible technologies are under investigation for the utilization of solar energy for the production of electrical, thermal and/or cooling energy [1]. For example, solar energy can be used for the production of electricity by photovoltaic collectors [2,3] or solar power plant [4]. This kind of renewable energy source can be also employed for producing thermal energy for different applications (residential [5], industry [6], etc) and cooling energy for space cooling [7] or refrigerating processes [8].

Solar Heating and Cooling (SHC) is one of the most promising solar technologies, providing heating and cooling by converting the solar irradiation incident on a solar collector field. SHC systems are particularly promising for their summer operation, when the cooling energy demand is often simultaneous to the availability of solar radiation [9]. Although SHC systems have been investigated since 1970, this technology is still far from a mature commercialization, due to their high initial costs [10]. However the recent impulse for renewable energy technology also promoted SHC systems (e.g.: the "Solar Heating and Cooling Programme, SHC" launched by IEA [11]). Nowadays, the market potential of SHC systems is very promising, also as a consequence of the dramatic growth in the energy demand for cooling, especially in residential, commercial and office buildings [12]. The most common configuration of Solar Heating and Cooling systems is based on the combination of low-temperature solar collectors (e.g. evacuated tubes) and single-stage absorption chillers [9,13–20]. However, a possible attractive layout may be based on the use of concentrating solar collectors driving a Double Effect Absorption CHiller (DEACH). Such configuration may be attractive due to the higher chiller Coefficient of Performance (COP (Coeffiicient of Perfomance)) [21]. Such configuration (Concentrating Solar Heating and Cooling Systems, CSHC) is competitive in climates where the direct to total radiation ratio is high. Parabolic Trough Collectors (PTC) is probably the most promising technology of solar collector for CSHC applications [10,21–26]. Concentrating Solar Heating and Cooling Systems

* Corresponding author. Tel.: +39 (0)817682301; fax: +39 (0)812390364.
E-mail address: frcalise@unina.it (F. Calise).

0360-5442/$ – see front matter
http://dx.doi.org/10.1016/j.energy.2012.10.008

Nomenclature

A	area (m^2)
c_p	specific heat (kJ/kg K)
C	cost (€)
$\dot{C}$	specific heat flow rate (kW/K)
C_{el}	cost of electricity (€)
C_{op}	operating cost (€)
C_{PVT}	concentration ratio (–)
COP	coefficient of performance (–)
E_{el}	electrical energy (kJ)
F_{sol}	thermal solar fraction (–)
$F_{sol,el}$	electrical solar fraction (–)
h	entalpy (kJ/kg)
h_c	convective heat transfer coefficient (W/m^2K)
I_b	beam radiation (W/m^2)
I_0	system capital cost (€)
J	component capital cost (€)
LHV	low heating value (kJ/m^3)
M	mass (kg)
$\dot{m}$	mass flow rate (kg/s)
NPV	net present value (€)
P	power (kW)
PE	primary energy (kJ)
PES	primary energy saving (–)
PI	Profit Index (–)
PLR	part load ratio (–)
Q_{heat}	heating energy (kJ)
Q_{cool}	cooling energy (kJ)
Q	thermal energy (kJ)
$\dot{Q}$	thermal energy flow rate (kJ/h)
r	thermal resistance (m^2 K/W)
SPB	Simple Pay-Back Period (years)
T	temperature (°C)
UA	heat transfer coefficient (W/K)
V	volume (m^3)
α	absorptance (–)
ε	emittance (–)
ε_{HE}	heat exchange effectiveness (–)
θ	time (s)
η_b	DHW boiler efficiency (–)
η_{inv}	inverter efficiency (–)
η_{mod}	module connection efficiency (–)
η_{opt}	PVT optical efficiency (–)
$\eta_{t,PVT}$	PVT thermal efficiency (–)
η_{PV}	PVT gross electrical efficiency (–)
$\eta_{el,PVT}$	PVT electrical efficiency (–)
η_t	thermal efficiency (–)
$\eta_{el,t}$	thermo-electric efficiency (–)

Subscripts

+	sold to the grid
–	bought from the grid
+/–	net between bought and sold from/to the grid
a	ambient
ap	aperture
aux	auxiliary
b	building
cool	cooling
c	concentrator
cc	capital cost contribution
DHW	Domestic Hot Water
el	electrical energy
ext	External
f	fluid
ft,ee	feed-in tariff (electricity)
ft,pe	feed-in tariff (primary energy)
H	Hot/heating
L	Load
in	Inlet
n	Nominal
NG	Natural Gas
out	Outlet
p	Primary
rec	Receiver
req	Requiredr
rej	Rejected
RS	Reference System
s	Summer
sub	CPVT receiver metallic substrate
top	CPVT top sourface
w	Winter

Abbreviations

ACH	absorption chiller
AH	Auxiliary Heater
BOP	Balance of Plant
CW	Cooling Water
CHW	Chilled or Hot Water
CPVT	Concentrating Photovoltaic Thermal
CSHC	Concentrating Solar Heating and Cooling
CT	cooling tower
DEACH	Double Effect Chiller
DHW	domestic hot water
HE	hot exchanger
HF	hot fluid
HS	hydraulic separator
HW	hot water
P	pump
PTC	Parabolic Trough Collector
PV	photovoltaic
PVT	photovoltaic thermal
SCF	solar collector fluid
SHC	solar heating and cooling
TK	tank

(CSHC) have been also recently analysed by the authors, presenting a numerical study of a CSHC based on small-sized PTC and a double-effect absorption chiller, for different Mediterranean climatic zones [27].

This paper is based on the work recently presented by the authors [27], in which the Parabolic Trough Collectors (PTC) collectors were replaced by a novel Concentrating Photovoltaic Thermal (CPVT) system presented in a recent work [28]. Replacing solar thermal collectors by CPVT collectors caused an additional production of electricity by the PVT. These results in a high-efficiency solar trigeneration system producing: heat, cool and electricity. Note also that the high-efficiency is due to the utilization of the high temperature CPVT allowing one to drive a double-effect absorption chiller versus the single-effect chiller typically installed in case of low-temperature solar collectors. It is well-known that the Coefficient of Performance (COP) of the double-effect absorption