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A novel polygeneration system integrating photovoltaic/thermal collectors, solar assisted heat pump, adsorption chiller and electrical energy storage: Dynamic and energy-economic analysis

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ABSTRACT

In this paper a dynamic simulation model and a thermo-economic analysis of a novel polygeneration system are presented. The system includes photovoltaic/thermal collectors coupled with a solar-assisted heat pump, an adsorption chiller and an electrical energy storage. The modelled plant supplies electrical energy, space heating and cooling and domestic hot water. The produced solar thermal energy is used during the winter to supply the heat pump evaporator, providing the required space heating. In summer, solar thermal energy is used to drive an adsorption chiller providing the required space cooling. All year long, solar thermal energy in excess, with respect to the space heating and cooling demand, is used to produce domestic hot water. The produced electrical energy is self-consumed by both user and system auxiliary equipment and/or supplied to the grid.

The system model includes a detailed electrical energy model for user storage and exchange with the grid along with a detailed building model. This study is a continuation of previous works recently presented by the authors. In particular, the present paper focuses on the real electrical demands of several types of users and on the analysis of the comfort of building users. Differently from the works previously published by the authors, the present work bases the calculations on measured electrical demands of real users (fitness center and offices). The system performance is analyzed with two different electricity supply contracts: net metering and simplified purchase/resale arrangement. Daily, weekly and yearly results are presented. Finally, a sensitivity analysis is performed in order to determine the system performance as a function of the system main design/control parameters and to evaluate the minimum Simple Pay-Back period. The results outlined a share of the electrical energy storage system on the self-consumed electrical energy of about 20%. The economic profitability is better in case of net metering contract compared to the simplified purchase/resale arrangement one. Moreover, a Simple Pay-Back of about 15 years is achieved for the best configuration, decreasing to 5.6 years in case of capital investment incentive of 65%. The best system configuration, in terms of solar field area, for the fitness center user ranges from 250 to 300 m^2.

1. Introduction

This paper deals with the coupled use of solar heating/cooling and electrical energy storage technologies, presenting a transient simulation of a novel polygenerative system. The modelled system is dynamically simulated and an energy-economic analysis is performed. The technologies included in the proposed system are: PhotoVoltaic/Thermal (PVT) collectors, solar assisted heat pump, adsorption chiller and electrical energy storage technologies. The model is developed by the commercial tool TRansient SYstem Simulation (TRNSYS) [1], considering both physical components (pumps, solar collectors, valves, etc.) and controlling devices (sensors, controllers, schedules, etc.). Moreover, the simulation tool also includes a number of additional components required to run the simulations and to process the results, such as: calculators, weather data readers, integrators, and plotters. The proposed system is a development of a previous layout, recently presented by the authors [2]. In fact, the layout investigated in this paper includes several major improvements with respect to the

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Nomenclature

A	area, m^2
C	cost, € or €/year
CE	savings, €/year
COP	coefficient of performance, –
e	open circuit voltages, V
E	energy, kW h
F	battery fractional state of charge, –
f	utilization factor, –
g	coefficients of H in voltage-current-state of charge formulas, V
H	complement to 1 of fractional state of charge, –
I	solar irradiance or electric current, kW/m^2 or A
j	specific cost-price, €/kW h
L	thermal load, W
LHV	low heating value, kW h/m^3
M	metabolic rate, MET
m	cell-type parameter for shapes of the battery I-V-Q characteristics, –
P	electrical power, kW
PE	primary energy, kW h
PMV	predicted mean vote, –
PPD	percentage of dissatisfied, –
Q	battery electrical charge or thermal power, A h or kW
r	internal resistance, Ω
SPB	simple pay-back, years
t	time, h
T	temperature, °C or K
U	heat transfer coefficient, kW/(m^2 °C)
V	voltage, V

Greek symbols

Δ	difference, –
η	efficiency, –

Subscripts and superscripts

adjust	referred to the adjustment of the contract tariff
aux	auxiliary
auto	self-consumed
batt	battery
build	buildings
buy	purchased
c	charging
C	fully charged
cap	capacity
CS	capital investment subsidy
chill	chill
cons	consumed
cool	cooling
d	discharge
D	when battery discharging
el	electrical
excess	in excess
f	fluid
g	glass
heat	heating
in	input
loss	losses
n	number
net	net
NG	natural gas
nom	nominal power or capacity
m	maximum capacity of the battery
out	output
pump	referred to pump
qc	full charge when charging
qd	full charge when discharging
ref	reference condition
req	requested/demanded
sell	selling
tariff	referred to the tariff
th	thermal
tot	total
user	referred to user

Abbreviations and acronyms

AC	alternating current
ADS	adsorption chiller
BATT	electrical energy storage
CHW	chilled water
CW	cooling water
D	diverter
DC	direct current
DHW	domestic hot water
EU	European Union
FC	heating/cooling device system
FPC	flat plate collectors
GB	auxiliary boiler
HE	solar loop heat exchanger
HEW	heated water
HET	excess heat use scenario
HF	hot fluid
HP	heat pump/chiller
IEA	International Energy Agency
ISO	International Standard Organization
M	mixer
NM	net-metering contract
P	pump
PR	purchase/resale arrangement contract
PS	proposed system
PV	photovoltaic
PVT	photovoltaic/thermal
R/I	electrical energy control device
RS	reference system
SAHP	solar assisted heat pump
SCF	solar collector fluid
TC	thermal energy incentives scenario
TK	thermal storage system
TRNSYS	TRansient SYstem Simulation tool
WE	well

previously investigated system, mainly due to the utilization of an electrical storage system. Moreover, differently from Ref. [2], the present work bases the calculations on the measured electrical demands of real users, namely: a fitness center and offices. In addition, the present paper also includes a detailed evaluation of buildings occupants comfort, performed by a detailed methodology for the assessments of dynamic thermal loads of buildings. Finally, this work also introduces a novel comprehensive model, developed in order to manage the electric flows of the system. In particular, in such model two different modes for the electrical energy exchange with the grid are taken into account: net metering and simplified purchase/resale arrangement contracts. The system energy and

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