Applied Thermal Engineering 75 (2015) 896–907

Contents lists available at ScienceDirect

Applied Thermal Engineering

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

Optimal sizing of hybrid solar micro-CHP systems for the household sector

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HIGHLIGHTS

- The importance of optimal sizing of renewable microgeneration systems is addressed.
- A hybrid system made up of solar and micro-CHP devices is considered.
- Both Photovoltaic and high concentration PV technologies are analysed.
- Optimal sizing enhances savings in dwelling sector applications.
- Electricity grid constraints can have the potential CO_2 emissions reduction.

ARTICLE INFO

Article history:
Received 7 July 2014
Accepted 9 October 2014
Available online 17 October 2014

Keywords:
Micro-generation
Optimal sizing
Micro-CHP
PV
CPV
Energy savings

ABSTRACT

The present paper addresses the importance of optimal sizing hybrid microgeneration systems for dwelling applications. Indeed, the parameters, the constraints and the criteria which must be considered in the sizing phase are several: i) energy prices, ii) ambient conditions, iii) energy demand, iv) units' characteristics, v) electricity grid constraints. The hybrid renewable system under analysis is made up of an electrical solar device and a micro-Combined Heat and Power, micro-CHP unit coupled to a cooling device. In addition to traditional PhotoVoltaic, PV, technology the work considers a High Concentration PhotoVoltaic, HCPV, device, with the aim of understanding its potential application in the countries of the Mediterranean. Results point out the importance of optimal sizing hybrid renewable energy systems, in particular the micro-CHP unit, in order to maximize the economic and the energy savings with respect to conventional generation. Furthermore results point out the critical nature of electricity grid constraints, which can halve the achievable energy savings.

1. Introduction

The building sector is a high energy-demanding sector in both developed and new developing countries. Due to the increasing urbanization, the number of people living in cities is expected to increase by up to 70% compared to the rural population [1]. In most IEA countries the building sector accounts for the 32% of the final demand for energy [2], of which an important share comes from dwellings. In EU-27, residential energy accounts for about 26% of the total consumption, second only to the transport sector in terms of usage [3].

Buildings offer great potential for savings in energy usage as revealed by an IEA study [4] according to which the 25% of the reduction in emissions of CO_2 will come from buildings by 2030. The measures identified to reach this challenging target are: (i) minimum energy performance standards, (ii) construction of new buildings with net-zero energy consumption, (iii) improvement of energy efficiency in existing buildings, (iv) building certificates and (v) improvement of energy performance of building envelope.

The introduction of decentralised energy generation is a further measure to meet this goal [5], necessarily required by recent building regulations which asks for "near-zero" energy buildings in the coming years [6].

Distributed generation devices can be fed by renewable or fossil fuels, and can also be operated in combined heat and power production [7], providing important results in terms of energy savings and emission reduction [8].

Among renewable generation, PhotoVoltaic, PV, systems are particularly suitable for building applications, due to: i) worldwide availability and potentiality of solar sources of energy iii) their easy

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http://dx.doi.org/10.1016/j.applthermaleng.2014.10.023
1359-4311/

Nomenclature

A	area [m^2]
c	cost [€]
e	electric energy [kWh]
f	fuel consumption [kWh]
G	solar radiation [W/m^2]
h	hours
I	current [Amp]
P	power [W]
r	interest rate
T	temperature [°C]
V	voltage [V]

Greek symbols

α	absorptivity
β	PV panel efficiency loss coefficient [1/°C]
η	efficiency
τ	transmissivity

Abbreviations

AC	alternating current
AS	alternative system
BOS	balance of system
CHP	combined heat and power system
COP	coefficient of performance
CO_2	carbon dioxide
CO_2ER	carbon dioxide emission reduction
DC	direct current
DNI	direct normal radiation
EF	emission factor [gCO_2eq/kWh]
EU	europe
FC	fuel cell
fiT	feed in tariff
GTI	global irradiation over a surface tilted at 30°
HCPV	high concentration photovoltaic
ICE	internal combustion engine
IEA	international energy agency
LP	linear programming
MGT	microturbine
MJ	multi junction
MOLP	multi objective linear optimization
NOCT	nominal operating cell temperature [°C]
NCV	net calorific value [kJ/kg]
O & M	operation and maintenance
PE	primary usage factor [kWhPE/kWh]
PES	primary energy savings [%]
PV	photovoltaic
SP	separate production
SPB	simple pay back
STC	standard test condition
TES	thermal energy storage
TMY	typical meteorological year
VER	variable energy resources

Subscripts

a	ambient
AC	annualized cost
c	cell
cool	cooling
el	electric
fiT	feed in tariff
h	hour
k	day
µCHP	micro-combined heat and power
op	operating
p	peak
n	nominal
sell	sell
th	thermal

Adscripts

A	annualized

integration into new and existing buildings, iv) the high temporal correlation of solar irradiation with electricity demand.

Over the last few years, thanks to Government funding and supporting schemes, the PV market has experienced a rapid expansion, with a consequently remarkable reduction in the capital cost of technology. For instance, the cost of a 3–10 kW$_p$ PV system, thanks to both improvements in research and economies of scale, has decreased from 14,000 €/kW$_p$ in 1990 down to 1800 €/kW$_p$ in 2014 [9]. In addition to traditional PV technologies, High Concentration PhotoVoltaic (HCPV) systems are attracting an increasing interest by industry, researchers and policy-maker [10], although the reduction in PV capital cost is threatening their competitiveness.

The main characteristic of this technology is that the amount of photosensitive material is reduced and it is replaced with a cheaper optical system [11]; this means that an HCPV module is able to capture only the direct normal rays but with a higher efficiency and a lower area occupancy than traditional silicon systems [12].

Consequently HCPV systems are really effective only in those countries where the solar radiation is more intense and constant [13].

The main problem related to the integration of solar electrical systems into the national electricity grid comes from its intermittency and unpredictable nature [14], which it shares with wind generation [15]. Although variability and uncertainties are familiar features of all power systems, in order to achieve a greater impact from these sources an additional introduction of load will be required, following and ramping reserves in a time frame ranging from minutes to hours. In particular, this aspect is of great concern for the integration of these sources (solar and wind power) into the existing low voltage grid (as required by solar systems for building sector applications); in fact, in most cases they are not equipped with sophisticated protective relaying and control schemes such as a utility scale transmission line [16].

A mid to long-term solution, widely studied in literature [17,18], is the introduction of micro-grids, but currently they are at an early stage in development and most of them are pilot projects. The main problem is related to their higher initial cost, since they require power electronics and sophisticated coordination among consumers or areas.

A promising opportunity in the short-term proposed by some of the authors in a previous paper [19] and studied further in the present work, is the introduction of hybrid systems, consisting of coupling solar systems with micro-CHP units fuelled by natural gas. Indeed developing hybrid PV systems with CHP devices enables additional PV deployment above what is possible with a conventional centralized electric generation system [20].

The high cost in terms of investment in the technologies involved requires the optimization of the system size in order to be competitive with conventional generation. When dealing with