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Energy production for dwellings by using hybrid systems based on heat pump variable input power

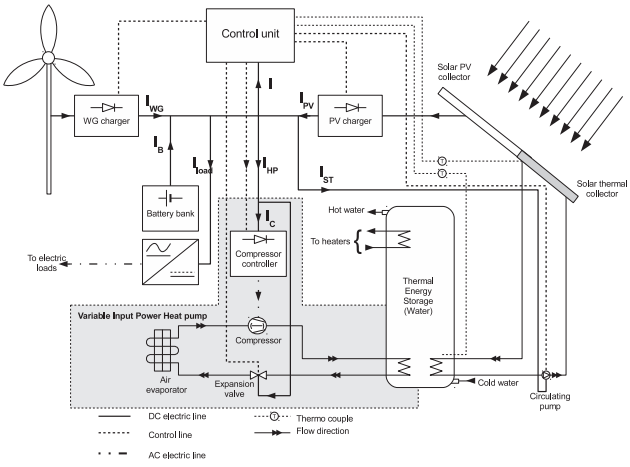
P. Poulet *, R. Outbib

LSIS, Aix-Marseille University, Domaine Universitaire de Saint-Jérôme, Av. Escadrille Normandie-Niemen, 13397 Marseille Cedex 20, France

HIGHLIGHTS

- Control methodology for air/water heat pump variable input power.
- Comparative study showing the interest of using energy conversion depending on the type of climate.
- Energy management of a hybrid system composed of solar panels, a wind generator and a heat pump.
- Analysis of the potential of energy production for dwellings in France.

GRAPHICAL ABSTRACT



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ABSTRACT

This study is a contribution to the analysis of energy production by hybrid systems using renewable energy sources. It is realized within the framework of an isolated site, i.e., without any connection to an electrical network. Generally, with the conventional solutions for energy production, the needs in terms of electrical energy and thermal energy are met separately.

In this paper, we explore an alternative approach based on a strategy of hybridization which uses energy conversion to meet the energy needs. In this alternative approach, a large part of the directly produced thermal energy is replaced by electrical energy and an air/water heat pump variable input power is introduced to ensure a crossover between the thermal energy flow and the electrical energy flow.

The contributions of this work can be summarized as follows. Firstly, we propose a methodology to control the functioning of the air/water heat pump variable input power. Secondly, we compare the potential of thermal energy production of two subsystems and we show the interest of using energy conversion according to the type of climate. Thirdly, we present a case study. More precisely, the study is realized for representative locations in France. The objective is twofold. First, an analysis of the energy potential at the representative sites is given. Second, it is established that the energy produced is increased by using the hybridization strategy based on energy conversion, especially in winter which is the critical period in terms of both electrical and thermal needs.

Simulation and experimental results are presented and analyzed to show the interest of introducing a pump heat in the hybrid system, mainly when using the technology with variable input power.

* Corresponding author. Tel.: +33 491056030.
E-mail addresses: philippe.poulet@lsis.org (P. Poulet), rachid.outbib@lsis.org (R. Outbib).

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Nomenclature

Variable

η	efficiency
ρ	density (kg m^{-3})
α	rate
A	surface (m^2)
C	mass-heat capacity (J kg^{-1} K^{-1})
G	coefficient of heat exchange (W m^{-2})
I	current (A)
N	speed (Rad s^{-1})
P	power (W)
R	solar radiation (W m^{-2})
T	temperature (°C)
U	voltage (V)
V	volume (m^3)
W	energy (kW h)

Superscript and subscript

c	consumed
ch	battery charge
dis	battery discharge
e	electrical
gs	glass
j	joule
l	losses
max	maximum value
min	minimum value
n	nominal value
os	outside
p	produced
r	regulator
sm	square meter
t	thermal
v	vertical
A	air
B	batteries
C	compressor
E	electrical devices
H	house
HP	heat pump
PV	photovoltaic panels
R	roof
S	storage
ST	thermal panels
W	water
WG	wind generator

1. Introduction

The main energy sources used in the world for more than one century have major drawbacks. Most of them are fossil [1], and they are also considered as the cause of global warming, due to the release of carbon dioxide in the atmosphere. Moreover, the production sites are far away from the places of use because of their geographical distribution.

The use of energy depends on the sector of activity, mainly transportation, industry and dwellings. Generally, for dwellings, the energetic needs are of two types (namely, thermal or electrical) and depend on the geographical area considered. For instance, in France, which is the case study considered in this work, the thermal needs are the greatest [2].

Among the possible solutions to solve the energetic problem, one is a better use of the energy sources available locally. For instance, over the world, these energy sources available locally can be based on solar energy and its derivatives such as wind energy. Moreover, and due to the variability of these local energy sources, hybridization in sources and storage systems is to be considered in order to get new solutions for energy production and hence meet the needs (see for instance Fig. 1). Also, note that the expected new configurations of the hybrid systems will necessarily depend on geographical and socio-economic considerations. Thus, studies have been realized on the energetic potential for several countries (see for instance [3–17]).

In western Europe it is well known that there are no significant reserves of oil, gas or uranium, which are the main primary energy sources used [1]. As for France, nuclear energy represents 40% of the primary energy consumption and provides 80% of the electricity. This was and is still seen as a guarantee of energetic autonomy. France is less oil dependent than other western countries, however its economic needs are also dependent on uranium. Hence, France faces a quite similar problem as the countries that are dependent only on oil. Moreover, despite the excellent control of nuclear technology, the probability of a nuclear catastrophe is not null. This fact has to be seriously considered.

Finally, in order to face the energy problem, new concepts for energy production have to be developed, and mainly hybrid systems based on renewable sources.

Generally speaking, conventional hybrid systems based on renewable energy sources for dwellings are composed of two independent systems, each system meeting specific (i.e., thermal or electrical) needs separately. For instance, the system composed of solar thermal ($\mathcal{ST}$) panels together with water tanks is the most common solution to provide heat from solar radiation. To provide electricity, photovoltaic ($\mathcal{PV}$) panels and/or a wind generator ($\mathcal{WG}$) are the most common solutions, when storage is ensured by chemical batteries.

An alternative strategy for energy production within the framework of dwellings consists in introducing a crossover between the thermal energy flow and the electrical energy flow using a heat pump ($\mathcal{HP}$). This means that the electricity provided by the photovoltaic panels and/or wind generator can also be converted into thermal energy by using the heat pump. Thus, in this alternative solution the energy management is improved, since a global system manages the energy production for all needs (i.e. thermal and electrical).

Thus, the heat pump becomes a key component in a renewable energy system with great potential for energy production and storage (see [18] for a state of the art on the subject). For instance, in the context of a local energy production with partial use of the electrical network, the interest of using a heat pump for thermal energy production is illustrated by considering some hybrid systems (see for instance [19,20]). Besides, improving heat pump performance and reliability has also been an ongoing issue. Thus, recent studies on heat pump systems have explored several approaches. Among these approaches, one can cite the analysis of the refrigerants used [21], the use of blended refrigerants [22], compressor input pressure control [23] or the use of a compressor with a variable frequency [24].

This work is a contribution to the analysis of energy production by hybrid systems using renewable energy sources. It is realized within the framework of an isolated site, i.e., without any