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Solar tracker for enhancement of the thermal efficiency of solar water heating system

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ABSTRACT

This paper deals with thermal efficiency enhancement analysis of a solar water heating system with a solar tracker. Made at laboratory-scale, an automated mechanical system enables solar panel rotation and inclination. The control system is programmed to place the solar panels facing the sun throughout the day. Its coordinates by means of the solar height and the azimuthal angle will determine the sun position on the celestial sphere. The thermal behaviour of the solar water heating system is developed with energy balance on solar panels, heat exchanger and storage system. The solar irradiation intensity is measured by a pyranometer placed in the plan of the solar panels. Comparison between experimental results obtained for fixed inclinations of solar panels and those obtained with the solar tracker shows a 40% gain of overall stored thermal energy. The energy gain depends on the season. The low inclinations are still favourable in summer while in winter they are higher inclinations are needed.

1. Introduction

Since Kyoto's protocol has been ratified, environmental preservation is an essential priority in the field of energy production improvement and the development of clean renewable energies has become a major technical and scientific challenge.

Development of solar energy is an alternative to limit the exploitation of fossil fuels that leads to massive gas emissions and climate changes. Solar energy presents interesting assets because it is a clean and almost unlimited resource and as it is uniformly distributed all over the area of sunny countries, its supply does not require sophisticated transports facilities. Therefore, the development of this resource could contribute to the energy mix.

The amount of absorbed solar energy by a given surface is directly dependent on its orientation with respect to the solar position. To maximise the absorbed energy, it is necessary to face the receiver towards the sun. However, the panel positioning compared to the direction of the solar irradiation is not throughout the day in an optimal orientation. The usual recommendations for the integration to the construction roofing lead to an optimal fixed position determined in regard with the average stored energy along the day. The solar tracker is a possible solution to enhance the solar energy by approximately 33% [1]. An increasing of solar still productivity around 22% was obtained by using sun-tracking system [2]. According to freedom degrees, solar trackers can provide a movement to the panels along a single [3] or double axis - [4,5]. A comprehensive comparison of different maximum power point tracking techniques for photovoltaic systems has been presented in Ref. [6].

In Ref. [7], the authors presented a software solution implemented on hardware system to manage and drive multiple bi-axial solar trackers by personal computer (PC) in photovoltaic solar plants. Several methods of sun pursuing have been investigated and evaluated to keep the solar panels, solar concentrators, telescopes or other solar systems perpendicular to the sunbeam [8–10]. To extract the maximum output power from a PV module or solar concentrator, a solar tracker can be used to track the sun direction

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Nomenclature

A	area [m^2]
a	solar azimuth [°]
a*	albedo of sol
C_P	specific heat capacity [J $kg^{-1}K^{-1}$]
D.C.	Direct Current
E	energy [J]
h	heat transfer coefficient [W $m^{-2}K^{-1}$]
h	sun height [°]
i	inclination angle [°]
K	heat transfer coefficient [W $m^{-2}K^{-1}$]
$\vec{k}$	unit vector
$\dot{m}$	mass flow rate [kg s^{-1}]
n	numbers of days
$\vec{n}$	unit vector
P	thermal power [W]
PV	Photovoltaic
PC	personal computer
Q	flow rate [m^3 s^{-1}]
t	time [s]
T	temperature[K]
TSV	true solar time[h]
U_l	heat transfer coefficient of solar panel [W.m^{-2}.K^{-1}]
V	volume [m^3]

Greek symbols

α_1	static gain [K W^{-1} m^2]
α_2, α_3	static gain
β_1, β_2	static gain
δ_1, δ_2, δ_3	static gain
τ	time constant [s]
Φ	solar radiation intensity [W m^{-2}]
Φ_{Dh}	diffuse total radiation by the ground [W m^{-2}]
Φ_{solarD}	solar flux direct [W m^{-2}]
Φ_{solarG}	global solar flux [W m^{-2}]
φ	geographic latitude [°]
θ	orientation [°]
ω	hour angle [°]
δ	declination angle [°]
$\dot{\theta}$	speed of rotation of the earth[°/h]
γ	angle to the south[°]
Δ	variation
λ	thermal conductivity [W m^{-1} K^{-1}]
ρ	density [kg m^{-3}]
η_0	yield of panel [%]

Subscripts

c	calorific liquid
c1	calorific liquid in the collector
c2	calorific liquid in serpentine heat exchanger
D	diffuse
ext	external
G	global
I	direct light
in	inlet
loc	local
max	maximum
out	outlet
p	panel
sp	solar panel
ss	storage system
th	thermal
w	domestic water

where sunbeam is perpendicular to the face of the PV module or solar concentrator, and the maximum value of solar energy is captured [11]. A review of different types of sun tracking systems and methods of maximizing solar systems were presented in Ref. [12]. An ideal tracker enable the PV cell to point accurately at the sun with compensation changes in the altitude angle of the sun throughout the day, in the latitudinal shift of the sun during the season and in the azimuth angle [12]. The sun tracking systems are classified into two categories corresponding to passive and active trackers [12,13].

A passive solar tracker activated by aluminum/steel bimetallic strips and controlled by a viscous damper presents an increase in efficiency of up to 23% over fixed solar panels [13].

The active trackers were also the subjects of research of several authors. Active trackers are based on the use of a motor and a controlled system. The active trackers of solar photovoltaic cells were presented in several researches [14–17]. A self-powered solar tracker for low concentration PV systems has been recently designed and presented in Ref. [18].

The works of literature cited previously deal with solar trackers applied to PV panels. This paper focuses on the study of a thermal domestic solar water heating system with a solar tracker based on calculation of the solar position. The performance enhancement is assessed from the stored thermal energy. The purpose of the automatic solar tracker is to make it possible for the solar panels to follow solar positioning during the day with two degrees. In order to implement this study, the experimental set-up presented in Ref. [19] was improved by the installation of equipment that makes it possible to track the sun during all the day. The thermal model presented in this reference can easily be adapted to any configuration of the solar panels orientation.

This tracker takes into account the terrestrial position of the installation, its altitude, latitude as well as the sun elevation. These parameters are assessed according to the relations proposed in Ref. [20–22] and are implemented into a control system to set the solar panels at the front of the sun. The experimental results will be compared to the theoretical results, obtained from the solar water-heating model described in Ref. [19], taking into account the progress of the solar panels in the sun direction and the solar irradiation intensity. The gain in term of thermal energy with solar tracker is presented in comparison with the configuration, in which the solar collectors are fixed at different inclinations.

2. Experimental set-up description

Fig. 1 shows the different elements of the experimental pilot. The solar electromagnetic radiation energy is converted into calorific energy at the plane solar collector shown by the picture (A) of Fig. 1. A pump brings into circulation the fluid in the primary circuit to transport this energy from the collector to the heat exchanger located in the storage system shown on picture (B) of Fig. 1. The last one transfers heat energy to the secondary circuit through the heat transfer area.

As presented on depiction (C) of Fig. 1, a pyranometer was installed for the measurement of the solar radiation intensity. It is placed in the same plan as the collector with respect to the solar