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Prediction of captured solar energy for different orientations and tracking modes of a PTC system: Technical feasibility study (Case study: South eastern of MOROCCO)

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ABSTRACT

In this paper, a technical feasibility study on a parabolic trough concentrator (PTC) system for predicting the captured energy in different orientations and tracking modes has been investigated. Thus, the potential of captured solar radiation by a PTC has been estimated by combining simulations and different mathematical models, atmospheric parameters and optical as well as geometric characteristics of the PTC under climate conditions of Errachidia region in south eastern of Morocco (latitude 31.93° N, longitude −4.53° E, altitude 1039 m). Moreover, simulations study for an annual period was carried out using Matlab and TRNSYS for different orientations and tracking modes for the investigated PTC system. From the simulations result we noticed a higher mean daily PTC thermal efficiency of about 28.2% during summer solstice for a full tracking. However, the thermal efficiency of the PTC remains about 27.5% during spring equinox for full tracking and inclined N-S axis (E-W tracking), while it is around 24.2% for full tracking and polar axis (E-W tracking) and about 22.5% for full tracking during autumn equinox and winter solstice, respectively. These first results may enable to forecast the region potential and the feasibility of the investigated system for various orientations and tracking modes for each annual period. In addition, the simulation results clearly show that the studied region remains a suitable location to install PTC systems.

1. Introduction

Solar power is undeniably one of the most important sources of renewable energy in Morocco. With well over 3000 h/year of sunshine, the equivalent of a radiance of about 55 kWh/ft^2/day, Morocco remains a solar power field of excellence [1]. This energy source represents an even greater potential in area not enough serviced by the energy grid [2]. Focus on the development of renewable energy and sustainable development, Morocco has launched a Moroccan Solar Plan in 2009, which is one of the ambitious and interesting projects parts of Morocco's energy strategy. Installed on an area of more than 3000 ha, Ouarzazate is considered one of the most powerful solar power plants in the world [3,4]. Moroccan Agency For Solar Energy (MASEN) leads development programs of installed projects that aim to create an additional 3000 MW of renewable power generation capacity by 2020 and a further 6000 MW by 2030, whose the goal is to secure 52% of the country's energy demand from renewable energy sources [3,4].

The solar radiation measurements have only been available in a limited number of sites around the world, and the solar radiation data are not always available. The use of models and simulations is virtually the only way to solve this problem [5]. Thus, in order to predict the solar radiation data from various geographical sites, different models have been reported based on meteorological and climatologic variables such as sunshine duration, cloud cover, humidity, temperature, pressure, altitude… [2,6]. However, for an appropriate model to estimate the incident irradiation, the integration of experimental and theoretical results is required for portions estimation of solar radiation on horizontal or tilted surface. Indeed, El Mghouchi et al. [7] have used two developed empirical models to predict direct, diffuse and global solar radiation flux by day of the year in twenty-four cities of Morocco to evaluate the performances of these models using several statistical analysis. While, El Mghouchi et al. [8] have used acquired data from Meteonorm, where five best models have been investigated in order to predict the received daily global solar radiation intensity (DGSRI) on an inclined surface to the south, and to evaluate the day by day performance of these models using a statistical analysis performed with

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Nomenclature

J	day number of the year
D_{hg}	the time difference (advance of 4 min per degree)
T_1	local time (hours)
DT_1	difference between local and standard time (hours)
h	height of the sun
Φ	rim angle (°)
C	geometric concentration ratio of the aperture area to that of the receiver
Z	altitude at local studied (m)
I_n	solar irradiance on collector aperture (W/m^2)
I_b	solar irradiance incident on aperture and accepted by absorber (W/m^2)
I_0	solar constant = 1373 W/m^2
C_t	correction of the earth-sun distance (dimensionless)
φ	latitude (degrees)
β	tilt angle (degrees)
T_0	turbidity factor of the gaseous absorption (dimensionless)
I_h	direct flux on horizontal surface (W/m^2)
D_h	diffuse flux on horizontal surface (W/m^2)
G_h	global flux on horizontal surface (W/m^2)
γ	intercept factor
A	aperture area
G_e	daily absorbed solar flux (W)
G_m	mean daily absorbed solar flux (W/m^2)
$G_{est,i}$	predicted values of hourly global horizontal solar radiation (W/m^2)
$G_{mes,i}$	measured values of hourly global horizontal solar radiation (W/m^2)
ρ	reflected surface reflectivity
k	incidence angle modifier
I_D	the direct solar radiation
θ	incidence angle (degrees)
Ly	measurement units of solar energy (1 langley [Ly] = 41,840 J/m^2)
α	absorptance factor
σ_{Tot}	standard deviation of the total errors
$\sigma_{Displacement}$	standard deviation of receiver displacement errors (mrad)
$\sigma_{Contour}$	contour error (mrad)
$\sigma_{Tracking}$	tracking error (mrad)
σ_{Opt}	total optical error (mrad)
σ_{Sun}	rims angular width of sun (mrad)

Abbreviations

E-W	east west
N-S	north south
H N.S	east-west horizontal axis (north-south tracking)
H E.W	north-south horizontal axis (east-west tracking)
I E.W	inclined N-S axis (E-W tracking)
WS	winter solstice
SS	summer solstice
ES	equinox of spring
EA	equinox of autumn

several statistical indicators. Besides, Ouammi et al. [2] have reported an artificial neural network (ANN) model to forecast the annual and monthly solar irradiation in Morocco. The learning set consists of the normalized longitude, latitude, elevation and the normalized mean annual and monthly solar irradiation of 41 Moroccan sites. The new climatic zoning of Morocco realized by the Moroccan Agency for Energy Efficiency (AMEE) in collaboration with the National Center of Meteorology [9,10], divided the climate of Morocco into six climate zones; the Errachidia region is classified into the sixth zone. Recently, Bouhal et al. [11] have investigated the PTC technology thermal performance as well as Moroccan Solar Plan potential projects, where several annual simulations for six climatic regions in Morocco have been carried out to determine flow parameters and heat transfer applied to PTC technology. Thus, it was noticed that the maximal efficiency values were reached (i.e. approximately 70%) under the climate of zone 6. This result can be explained by the huge solar irradiation and the ideal climatic conditions of this region.

The parabolic trough collectors are one the most mature solar technology that is able to generate heat at temperatures up to 400 °C for electricity generation or process heat applications [12,13]. Generally, the PTC is made by bending a sheet of reflective material into a parabolic shape. A black metal tube, covered with a glass tube to reduce heat losses, is placed along the focal line of the receiver. When the parabola is pointed toward the sun, parallel rays incident on the reflector are reflected onto the receiver tube [14]; therefore, it is necessary to investigate the dynamic characteristics of the concentrating solar system, by considering the effect of the climatic conditions, impact of the optical and geometric characteristics, orientation system and tracking mode. Indeed, an experimental study on a parabolic trough collector with U shaped exchanger has been already investigated in our previous work [15], where the concentrated solar flux distribution on the circumferential absorber was reported for different rim angles and diameters, and its relation with the position of U-pipe under the climatic conditions of Errachidia region. In the other hand, Patil et al. [16] have reported a CFD technique based on a numerical study concerning the effects of different parameters like non-uniform flux distribution, hour angle and the annulus distance between absorber pipe and glass envelope on the heat loss from receivers.

In addition, for a PTC system, the incident rays are concentrated at its tracked appropriately focal line. However, diver types of tracking mechanisms, varying from complex to very simple, can be divided into two main categories, namely electronic and mechanical systems [17–19]. The PTC tracking system can be used according to two tracking methods; single and dual tracking axis systems. The full tracking system follows the sun by changing altitude and azimuth, in order to place the system toward a normal incidence of solar rays. While for a single axis tracking system, the collector can be orientated in an east-west direction, tracking the sun from north to south, or orientated in a north-south direction, tracking the sun from east to west [20]. Thus, the PTC can be tilted at an angle equal to the installation site's latitude facing directly the sun, following the sun from east to west, which is called the polar (E-W) tracking system [14]. In this way, an estimated study to evaluate the potential of direct solar irradiance and the performance of the PTC under Algerian climate have been presented by Ouagued et al. [21]; different thermal oils have been investigated for various considered tilted and tracking collectors in order to determine the most efficient PTC system. Moreover, the monthly mean daily direct solar radiation have been estimated and compared for different locations corresponding to different climatic regions; it was reported that the most important direct solar radiation potential was found for the Sahara regions. Thus, a numerical simulation study for the solar parabolic trough collector performance in Algeria Saharan region was presented by Marif et al. [22], it was reported that the polar axis (E-W tracking) and horizontal East–West tracking systems are more desirable for the parabolic trough collector throughout the whole year.

As the prediction of captured solar energy and the selection of the appropriate tracking mode are a key role to implement any solar project and to make it more profitable, in particular CSP systems based project,