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Original article

Optimized fixed tilt for incident solar energy maximization on flat surfaces located in the Algerian Big South

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ABSTRACT

Maximization of the incident energy at surfaces of the photovoltaic modules is among the key factors of energy extraction maximization. In this paper, fixed tilt solar-PV systems are considered. The incident solar energy maximization problem is formulated as the maximization of the solar energy incident on the flat surfaces of the traditional flat solar-PV modules. Therefore, the presented study is not applicable to the curved solar-PV modules. The monthly, seasonally, semi-annually, and annually fixed tilt alternatives have been tested, then the optimal alternative has been selected. The Sahara middle (Adrar) district is considered as a representative site at the Algerian Big South as the long-term meteorological data are available from the ground meteorological station there. In comparison with the horizontally placed solar-PV modules, it is found that the incident solar energy increased by 20.61% for monthly, 19.58% for seasonal, 19.24% for semi-annual, and 13.78% for yearly adjustments. The results obtained with the ground measurements are compared with satellite measurements. It is found that the semi-annual adjustments in the tilt, which is estimated at 3.50° for the warm period (April – September) and 49.20° for the cold period (October – March) is the optimal compromise choice for the selected region.

Introduction

Algeria has high amounts of different renewable energy potentials from sources like wind, tidal, geothermal and solar. Currently, there are favorable conditions for exploitation of renewable energies at various locations in the country, especially the Big South area. It should be noted that Algeria has an exceptional solar potential in the Mediterranean basin. It is estimated that the region is capable of providing 4 times the total global energy demand, and 60 times that of the European countries needed for electricity [1]. This situation gives Algeria an excellent opportunity for the energy production through exploitation of solar energy. Although numerous efforts are being taken to assess the potential of solar energy in many regions, however the data obtained is not extensive and doesn't suffice the requirements, which makes it difficult for practitioner and scientists to explore possibility of solar energy utilization. It is evident that in order to receive the maximum energy from the sun using solar panels, we must place the panels in the direction that captures the most incident solar radiation. There are a few variables in calculating the best direction which is called the tilt angle of the surface [2].

In the estimation of the solar radiation on an inclined surface, the knowledge of solar radiation components is imperative. Among these, the diffuse solar radiation is an important component that is usually used to define the quality of incoming solar radiation. Several empirical models have been developed for estimation of diffuse solar radiation [3]. Liu and Jordan [4] developed the first approach for the assessment of diffuse component which was developed on input predictor as global solar radiation on horizontal surfaces (normalized as clearness index, K_t), and following this pioneering work, numerous researchers have concentrated on calibration of this model with different data, regions and time scales, like, but are not limited to, Jiang [5], Orgill and Hollands [6], Karakoti et al. [7]. Some additional factors have been taken into consideration such as ambient temperature, cloudiness, relative humidity and other meteorological factors.

Liu and Jordan [8] developed an isotropic model for estimating the distribution of diffuse solar radiation that is independent of azimuth

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Nomenclature

H_{opt}	total tilted solar radiation (MJ/m^2.day)
D_{opt}	diffuse component of solar radiation on an inclined surface (MJ/m^2.day)
B_{opt}	beam component of solar radiation on an inclined surface (MJ/m^2.day)
R_{opt}	reflected component of solar radiation on an inclined surface
K_t	global clearness index
H	global solar radiation on a horizontal surface(MJ/m^2.day)
D	diffuse solar radiation on a horizontal surface(MJ/m^2.day)
B	direct solar beam on a horizontal surface(MJ/m^2.day)
R_b	ratio of beam tilted radiation to horizontal radiation
R_d	diffuse radiation conversion factor
S	monthly mean daily sunshine hours (h)
S_0	maximum possible sunshine hours (h)
n_d	day number
MBE	mean bias error
RMSE	root mean square error
RRMSE	relative root mean square error
R	coefficient of correlation

Greek letters

β	tilt angle (degrees)
β_{opt}	optimum tilt angle (degrees)
ρ	ground reflectivity
φ	latitude of the location (degrees)
δ	declination angle
ω	sunrise hour angle for tilted surface

and zenith angles. Other researchers have estimated total solar radiation on inclined surfaces using isotropic and anisotropic models [9,10]. Sabbagh et al. [11] determined daily global radiation for numerous Arabian locations. The monthly average global and diffuse radiations in Madina, Saudi Arabia was estimated by Benghanem [12]. It is important to mention that all proposed models consist of empirical constants which are dependent on the investigated location, climate, season and geographical conditions. The literature shows many studies on solar panels and collectors' optimum tilt angle [13]. For major Syrian zones, Skeiker [14] computed optimum tilt angle of the solar collector using a mathematical model. The outcomes reported that changing tilt angle 12 times in a year, the solar radiation roughly is close to maximum. Elminir et al. [15] presented a study to receive maximum solar radiation based on optimum slope angle of the solar collector in Helwan, Egypt. Obtained tilt angle values were compared with the obtained results utilizing several other models (which were functions of the clearness index of the day, declination and ground reflectivity). Hussein et al. [16] investigated the performance of PV modules for Cairo, Egypt based on orientation and tilt angle. They concluded that yearly performance of PV is maximum with tilt angles between 20° and 30° and the surface adjusted towards south direction. Techno-economic analysis of solar photovoltaic (solar-PV) energy projects in Egypt considering many factors including various sun tracking methods has been reported by various researchers. It is generally found that the one-axis or two-axis automatic sun trackers provide higher energy production gains in comparison with the annually fixed solar-PV modules tilted at the latitude of the site. On the other hand, the techno-economic gain of the use of automatic sun trackers is highly dependent on the location of the site. Within Egypt, it is found that the single-axis trackers are more techno-economically feasible in comparison with annually fixed systems and systems equipped with two-axis trackers [17,18]. It is worthy to be mentioned that the energy production gain

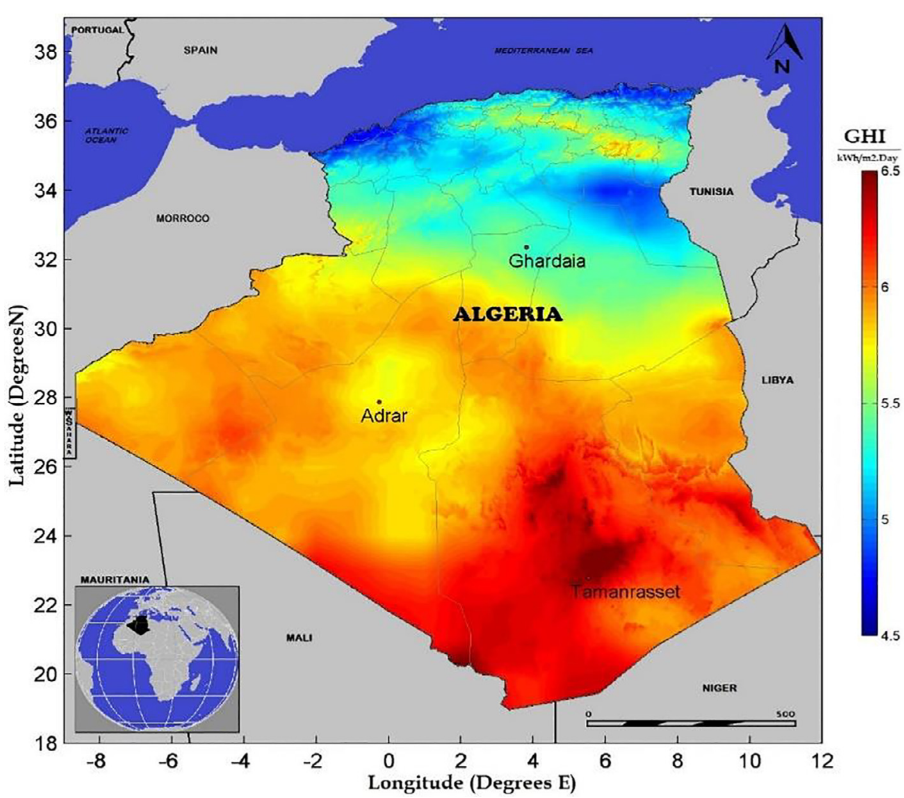

Fig. 1. Mean annual sum of global horizontal irradiation in Algeria (kWh/m^2/year).