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Analysis and evaluation of various aspects of solar radiation in the Palestinian territories

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ABSTRACT

This paper aims to evaluate the different models used to analyze different aspects of solar radiation in the Palestinian territories. Calculations of the optimized tilt and surface azimuth angles on monthly, seasonal and yearly basis were conducted, with the genetic algorithm being used for this purpose. Different PV tracking methods were also evaluated, taking into account the annual energy production. The different models used to calculate hourly global solar radiation from the daily data were tested in order to facilitate the selection of the most suitable model in the context of Palestine. The calibration of coefficients for the different regression models that were used for estimating the global solar radiation based on sunshine hours was also performed during the course of this work. These coefficients were calculated using both MATLAB's fitting tool and genetic algorithm. Linear, quadratic and linear–algorithmic regression models displayed almost identical results. Each has a distinctive predominant feature, especially in the context of statistical indicators. They were calculated using both the monthly average daily data and the daily data sets. With regards to the PV panel angles' optimization, it was found that the yearly optimum tilt angle (32.8°) is adjacent to the latitude of the location (31.8°), while the surface azimuth angle is 16°. It was also found that changing the tilt angle of the PV panels quarterly (optimized on seasonally basis) increases energy yield by 3.4% when compared with fixing this tilt angle at yearly optimized value. It was also discovered that changing the surface azimuth angle is more effective during winters than summers.

1. Introduction

Nowadays, rural and urban areas utilize different types of renewable energy sources, with the photovoltaic (PV) system proving the most popular [1–4]. This technology offers clean, environmentally friendly and secure energy source [5–9]. Another important advantage of this technology is both its low maintenance and operating costs, due to its lack of moving components [10–14]. However, the total cost of PV panels and its corresponding technology is still overly expensive, especially when larger power generation is concerned [15–17]. These drawbacks resulted in many studies that try to optimize the PV systems by focusing on maximizing energy production and minimizing cost. Power generation of PV panels is location dependent, and different pre-studies should be conducted for the analysis of solar radiation data.

Palestine is blessed with high sunshine hours throughout the year. In the Palestinian territories, the yearly average daily solar radiation on horizontal surface ranges from about 5.5 kW h/m^2 to about 6 kW h/m^2, while the total annual sunshine hours exceeds 3000 h [5]. These values are relatively high, and especially advantageous in terms of solar water heating and other photovoltaic (PV) applications.

Single axis or double axis tracking systems can be used to maximize the energy production of the PV panels. The idea behind the tracker is to keep following the sun's movement across the sky. However, tracking systems are expensive, requires specialized installation and energy source to operate. Therefore, in many applications, fixed mountings or manually adjusted mountings are used. For such cases, the maximization of energy can be realized via the determination of the optimal values for both the tilt and azimuth angles of the solar panels on annual, seasonal or monthly basis.

To obtain values of the optimum tilt angles of the PV panels, the value of the solar radiation on the tilted surface from global radiation on horizontal surface needs to be calculated. Different models have been suggested and used by many authors for this purpose [10,18–21]. In these studies, the same approach was used to calculate the direct (beam) and the ground reflected solar radiation, while different approaches were used to calculate the diffuse

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Nomenclature

G	global solar radiation (W/m^2)	SS_0	day length (h)
G_H	global solar radiation on horizontal surface (W/m^2)	SSR	sunshine ratio
G_{Hd}	daily global insolation on horizontal surface (kW h/m^2/day)	T_{amb}	ambient temperature (°C)
G_{ref}	solar radiation at reference conditions (G_{ref} = 1000 W/m^2)	T_c	PV cell temperature (°C)
I_{ei}	estimated value of a certain quantity	TC_F	temperature coefficient of the PV panel ($TC_F = -3.7 \times 10^{-3}$ (1/°C) for mono and poly crystalline Si)
I_i	measured value of a certain quantity	T_{ref}	PV cell temperature at reference conditions (°C)
MAPE	mean absolute percentage error	ts	true solar time (h)
MBE	mean bias error	α	solar altitude angle (°)
N	day number	β	tilt angle (°)
$NOCT$	normal operating cell temperature	γ	surface azimuth angle (°)
RMSE	root mean square error	γ_s	sun azimuth angle (°)
$P_{PV\text{-}out}$	output power from the PV panel (W)	δ_s	declination angle (°)
$P_{R\text{-}PV}$	nominal power of the PV panel at reference conditions (W)	θ	incidence angle (°)
r_g	hourly solar insolation to daily solar insolation ratio	φ	location latitude (°)
R_r	view factor of the tilted surface	ρ_g	reflectance factor
SS	day sunshine hours (h)	ω	solar hour angle (°)
		ω_s	sun set hour angle (°)

radiation. Taking into account the diffuse radiation, whether isotropic or anisotropic, instigated the presence of these different approaches. Treating the diffuse radiation as anisotropic-distributed results in values that are closer to the measured values [22].

Each location has its own PV panel optimum tilt and azimuth angles. These angles are affected by different factors, such as location latitude, clearness index and climate conditions. A correlation between the optimum tilt angle and the location latitude for different places around the world can be found in many studies [18–21,23–26]. Benghanem [18] found, in a study conducted for Madinah, Saudi Arabia, that the annual optimum tilt angle is approximately equal to the latitude of the location. His work depended on the daily global and diffuse solar radiation on a horizontal surface. He also found that the accumulated energy by the PV panels inclined by a tilt angle varied monthly is around 8% greater, compared with the case where the panels are inclined using the optimum annual fixed angle. Skeiker [23] determined in a study conducted for different zones in Syria that the maximization of the PV energy production is realized by varying the tilt angle of the PV panels on a monthly basis. He rightly concluded that this value is near the maximum value obtained by changing the tilt angle on a daily basis. He also found that the annual gain in solar energy of 30% can be achieved, compared to cases where the PV panels are fixed on a horizontal surface. Talebizadeh et al. [20] concluded that mounting the PV panels using the optimum tilt and azimuth angles that were calculated on the hourly basis significantly increases the generated energy, compared with mounting them on optimum angles calculated on a daily basis. Their study was conducted for Iranian sites, and genetic algorithm was used to optimize it. Furthermore, they concluded that the optimum tilt angles are mostly dependent on the direct solar radiation. Chen et al. [25] used genetic algorithm and stimulated-annealing method to calculate the optimum tilt angle for fixed PV panels in Taiwan. Their simulations results indicated that the optimum angles obtained by genetic algorithm and simulated annealing method are almost similar and agree with the experimental results.

The best method to maximize the PV energy production is by periodically changing the tilt and surface azimuth during the day, using single or double axis tracking fixtures. The evaluation of these two fixture types can be found in many studies [10,27–30]. Chang [10] found that a gain of 18.7% in PV energy production was obtained by using a single-axis tracking system in comparison with a fixed fixture, at an annual optimum tilt angle. The case study taken into account was Taiwan's. An experimental study was conducted by Abdallah [28], testing the effect of using different types of trackers on the PV energy production in Jordan. He found that a gain of 43.87% was obtained using double axis trackers, while a gain of 37.53% was obtained using a vertical single axis tracker.

Solar radiation data is very important for a variety of applications. Its availability is a prerequisite at any desired location for any studies regarding solar energy. Despite its significance, solar radiation is still not widely measured, due to high costs and the requirement for periodic maintenance and calibration. Developing methods to accurately estimate solar radiation utilizing other metrological measurements is imperative in solving the problem of unavailability [31–33].

Numerous methods have been suggested and used for the estimation of solar radiation based on different metrological variables, but the most common methods are based on sunshine hours. The Angstrom linear equation, the modified Angstrom linear equation (known as Angstrom–Prescott equation) and other developed equations are explicitly used for this purpose. Each of these equations relates in a particular form the clearness index (the ratio between global solar radiation and the extraterrestrial solar radiation) and the sunshine ratio (the ratio between the sunshine hours in a certain day to the day length in that day) [34–40]. Rahimi et al. [34] used Meta-Heuristic Harmony Search Algorithm to determine the Angstrom equation coefficients for Mashhad, located in the East of Iran. Daily data was used to calculate these coefficients, and different statistical parameters were used to validate the results. The values of statistical parameters indicated the effectiveness of their proposed approach for the estimation of the coefficients. Liu et al. [37] addressed the effect of considering the time variation of the regression coefficients. Using different performance indicators for the purpose of comparing the results, they concluded that the results of time-dependent coefficients were not superior than fixed ones.

There were no comprehensive or detailed study on the optimum tilt and surface azimuth angles that are needed to maximize the energy production of the PV panels conducted in the context of the Palestinian territories. Moreover, no detailed studies were performed to adopt an appropriate approach for the Palestinian