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Optimisation of tilted angles of a photovoltaic cell to determine the maximum generated electric power: A case study of some Iraqi cities

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ABSTRACT

This work was carried out to predict both the monthly and yearly optimum tilt angle for the photovoltaic cells that are located in Baghdad (latitude 33°20′), Diyala (33°14′), and Tikrit (34°35′). These Iraqi cities were selected based on their geographical location. Mathematical models were used and programmed by engineering equation solver, EES, to find the optimum tilt angle, depending on the maximum solar power intensity obtained; the tilt angle varied within a range from 0° to 90°. The results show that the optimum tilt angle for all these cities is the same for 31°. The monthly tilt angle was different from one month to another.

1. Introduction

In Iraq, most electric power is generated by using thermal power plants that use fossil fuel to generate steam, which is required for its permanency to generate electric power, since more carbon dioxide emissions come from burning fossil fuel. The electric power generated by these plants is insufficient for population requirements, therefore, an alternative electric source that is environmentally friendly must be found. Over the past decade, there has been an increasing awareness of climate change hazards and energy security considerations that have forced the global community to focus on renewable energy sources.

The green house effect produces rapid and alarming warming of the lower level of the atmosphere. It is caused by the presence of greenhouse gases (GHG), which trap heat that would otherwise escape into space. The most significant cause of the increased greenhouse effect and global warming is the 30% increase in atmospheric carbon dioxide since 1750 [12]. According to the World Health Organization, global warming killed 150,000 people in the year 2000 and this number could double in the next decade. [1]

The use of solar energy technologies can help our environment by decreasing CO_2 emissions and reducing pollution from fossil fuel power plants.

Photovoltaic cells are a common form of solar energy technology used to convert solar radiation into electricity. The performance of photovoltaic cells is highly dependent on its orientation, cell tilt angle, optical and geometric properties, macro- and micro-climatic conditions, geographical position, and the period of use [2]. The tilt angle, defined as the angle of PV arrays with respect to the horizontal, is a dominant parameter affecting the collectable radiation of a fixed PV array.

Many studies focus on the effect of photovoltaic cell orientation and tilt on its performance; Soulayman et al. [3] showed that optimum tilt angle is almost equal to the latitude. Vilela et al. [4] showed the daily solar energy collected was reported to be 19–24%

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Nomenclature

D_H	Diffused solar radiation received by the horizontal plane [W/m^2]
D_i	Diffused solar radiation received by the titled photovoltaic cell [W/m^2]
E	Energy theoretically received per m^2 and per day [kWh/m^2/day]
G_i	Global solar radiation received by the collector [W/m^2]
G_H	Global solar radiation received by the horizontal plane [W/m^2]
h_s	The height of the sun at true solar midday [°]
N	Number of the solar days [dimensionless]
I_D	Direct solar flux [W/m^2]
θ	The angle formed by the normal to the collector and the solar rays incident to the collector [°]
θ_z	Azimuth angle [°]
α	Albedo [dimensionless]
β	Photovoltaic cell tilted angle [°]
φ	Latitude of the city [°]
δ	Declination angle of the sun [°]
ΔD	Duration of the day [dimensionless]

higher from a solar PV panel with one axis east-west tracking system than by a fixed system. Elminir [5] showed that yearly optimum tilt angle for Helwan, Egypt is about latitude ± 15°where +refers to summer and –refers to winter. Koray [6] reported that the optimum orientation of the PV array should be directed towards the equator, facing south in the northern hemisphere, and the optimum tilt angle depends only on the latitude. Skeiker [7] showed that the changing of the tilt angle of the PV cell located in Syria 12 times in a year achieves a solar radiation of approximately 30% more than a solar collector fixed on a horizontal surface. Kumar et al. [2] found the optimum tilted angle of the PV cell array in Punjab, India changes between 60.5° (January) and 62.5°(December) throughout the year. Moghadam et al. [8] found the optimum tilt angle for two different Iranian cities, Zahedan (Lat. = 29.49°) and Bandar Abbass (Lat. = 27.18°). The results are in the same time step so the increase of latitude led to the increase of the optimum tilt angle. Al-Sayyab et al. [9] found the optimum tilt angle for the photovoltaic cell located in northern Iraq for Arbil, Dahuk, Sulaymaniyah, and Kirkuk; the tilt angle varied in the range from 0°to 90°. The results show the optimum tilt angle for Arbil is 34°, Dahuk is 34°, Sulaymaniyah is 33°, and Kirkuk is 33°. And these cities are nearly at an optimum tilt angle due to nearly in latitude. Arbil (latitude 36°15′), Sulaymaniyah(35°35′), Dahuk (36°50′), and Kirkuk (35°30′). Al-Sayyab et al. [10] found the optimum tilt angle of the photovoltaic cell located in the southern Iraq cities of Basra (latitude 30°.30), Amara (31°.55), and Nasiriya (31°). by using a mathematical model that was programmed into the engineering equation solver (EES) programme to find the optimum tilt angle depending on the maximum solar radiation; the tilt angles varied within a range from 0° to 90°. The results show the optimum tilt angle of Basra is equal to its latitude –2.33°. The optimum tilt angle in Amarah is equal to its latitude –1.55°, and in Nasiriyah, the optimum tilt angle is equal to its latitude –2°. In this study, we present a simulation study to predict the optimum tilted angle for the photovoltaic cells that are located in Baghdad (latitude 33°20′), Diyala (33°14′), and Tikrit (34°35′).

2. Mathematical modelling for the optimum tilt angle

The total daily irradiation on a horizontal plane is the combination of two components, the direct irradiation and the diffuse irradiation from the sky. [2]

In this study, the Bernard-Menguy-Schwartz model is used to find the optimum tilt angle (β) of the photovoltaic cell solar collector because it is a simpler correlation than that of other authors and predicts the northern hemisphere more accurately. [9,10]

In the Bernard-Menguy-Schwartz model, the direct radiation under three conditions of the sky are given below.

Clear Sky:

$$I_D = 1230e^{\left(\frac{-1}{3.8\quad \sin(h_s+1.6)}\right)} \tag{1}$$

Very Clear Sky:

$$I_D = 1210e^{\left(\frac{-1}{6\quad \sin(h_s+1)}\right)} \tag{2}$$

Polluted Sky:

$$I_D = 1260e^{\left(\frac{-1}{2.3\quad \sin(h_s+3)}\right)} \tag{3}$$

The diffused radiation for any sky conditions: -

$$D_H = 125(\sin(h_s))^{0.4} \tag{4}$$

The total radiation received by the horizontal plane: -

$$G_H = D_H + I_D \sin(h_s) \tag{5}$$

Diffuse and total radiations receipts by the inclined collector plane:

$$D_i = \frac{1+\cos(\beta)}{2}D_H + \frac{1-\cos(\beta)}{2}G_H\alpha \tag{6}$$