The Optimum PV Panels Slope Angle for Standalone System: Case Study in Duhok, Iraq

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Abstract. Due to the high operation and maintenance charges of the photovoltaic (PV) tracking systems, it is better to install the PV panels at a stationary angle which is considered as an optimum slope angle. Usually, the optimum annually slop angle equals to latitude. However, Duhok site (latitude 36°50'40.6" N, longitude 43°01'05.3" E) has a special case because it’s located in valley between two mountains where the eastern sides of these mountains block the sunlight at the early morning. This paper aims at finding the optimum annually slop angle that makes the solar panels in this site generate the highest possible amount of electrical energy by capturing largest amount of solar radiation at this period when the sun appears from behind the mountain. HOMER software is used to simulate the suggested standalone PV system at the study site. The optimization outcomes present that the optimum annually slope angle for the PV panels should be equal to 25 °.

1. Introduction
With the increasing requirement of inexpensively achievable, unpolluted and renewable energy, the utilization of solar photovoltaic (PV) systems is growing [1,2,3]. The main elements of energy conversion PV systems are the solar panels which are builds from a semiconductor material in order convert the sun light energy into electrical energy. The quantity of this electrical energy depends on the value of solar radiation falling on the panel’s surfaces [4]. The operation of any photovoltaic system is directly affected by the panel’s slope and azimuth angles as shown in figure 1. This is because any change in these angles affects the solar radiation amount that falling on the panels surfaces [5].
Figure 1. Illustration of the solar panel orientation

The PV slope angle can be defined as the angle at which the panels are mounted as compared with the horizontal. An angle of 0° relates to horizontal, and an angle 90° relates to vertical, the PV azimuth angle is the direction to which the PV panels face. Due south is 0°, due east is -90°, due west is +90°, and due north is 180° [6]. Thus, in order to obtain the highest electrical production, the solar panels surface must be made vertically to the incoming solar radiation. This means using a solar radiation tracking mechanism for constantly changing the PV panel angles [7]. However, the solar tracking systems are not always usable and have high operation and maintenance costs. Therefore, it is better to install the panels at stationary angles which is considered as an optimum azimuth & slope angles [8,9]. The optimum fixed-azimuth systems, the panels are practically adjusted towards the equator (0° azimuth in the northern hemisphere, 180° azimuth in the southern hemisphere).[6]
Figure 2. Satellite image of the study site (Duhok City) latitude 36°50'40.6" N, longitude 43°01'05.3" E

There are many researches that emphasis on the consequence of PV panels alignment upon the PV production. Soulayman et al. report that the optimal slope angle to get highest energy production is approximately equal to the latitude [10]. Vilela et al. report that the collected solar energy in one axis east to west tracking system is 19% to 24% higher than in fixed mounting. [11]. Elminir et al. report that optimum slope angle for the PV panels throughout the year in Helwan/Egypt is about ±15° around the Latitude where the positive degrees refer to summer while the negative degrees concern winter [12]. koray proves that the optimal alignment of PV panels at northern hemisphere must be facing to the South and the optimum orientation of PV panels at southern hemisphere must be facing to the North, while the optimum slope angle only depends on the latitude [13]. Skeiker reported that the PV panels production in Syria has increased by 30% when he changed the slope angle of the PV panels 12 times a year compared with fixed installation on a horizontal surface. [14]. Ashok Kumar reported that in Punjab-India the optimum PV panels slope angle is approximately about 60.5° through all the year [15]. Moghadam et al. presented a simulation study about two cities in Iran which both have a different latitude, Zahedan city at 29.49° and Bandar Abbass city at 27.18°. The consequences showed that the optimum slope angle increased when the latitude increase [16]. Al-Sayyab et al. used a mathematical model to find the optimum slope angle for photovoltaic panels in four cities in northern Iraq (Duhok, Sulaymaniyah, Kirkuk, Arbil ), the result shows that the optimum slope angles are (34°, 33°, 33°, 34°) respectively [17].
All previous studies of the PV panels slope angle rely on mathematical models without taking into account the effect of terrain. For example, Duhok (study site) located in valley between two mountains as shown in figure 2, where the eastern sides of these mountains block the sunlight in the early morning, particularly the southern mountain in the winter season when the solar elevation decreases as shown in figure 3 [18]. that leads to search for the optimum tilt angle (slope) that makes the solar panels capture largest amount of solar radiation at this period when the sun appears from behind the mountain as illustrated in in figure 4. This paper presents a simulation study using HOMER software’s optimization technics for a fixed-tilt standalone photovoltaic system supplying residential load during 5 years (project life time) in order to find the optimum annually slop angle that gives a lowest Net Present Cost (NPS) throughout the project life time.

Figure 3. The sun path illustration for different seasons in the study site (Duhok)

Figure 4. Illustration the effect of a mountain in blocking solar radiation at the early morning hours
2. Methods

2.1. HOMER Simulation

HOMER software is used to connect and simulate the standalone photovoltaic system as shown in figure 5, the azimuth angle defined as 0° because the study site located in northern hemisphere, the slope angle defined as a sensitivity variable at range of (0°, 5°, 10°, 15° ... until 90°). HOMER will simulate the strategy of a system by creation energy balance computations in every time step of the year (which is by default 60 minute time step), then evaluates the electric demand in that time step to the energy that the system can provide in that time step, and computes the flow of energy to and from every component of the system, also resolves in each time step whether to charge or discharge the batteries. HOMER performs these energy balance computations for each system configuration. It then clarifies whether that configuration is feasible, (i.e., whether it can converge the electric demand), and estimates the operating and installing cost of a system over project lifetime. Then HOMER will apply optimization process using a proprietary derivative-free algorithm to search for the optimum solution among all these feasible system configurations by chose the least NPC system, also repeats these optimization procedure for each sensitivity variable (each slope angle), This criteria (NPC) is an abbreviation for (Net Present Cost) its represents the present value of all the costs the system incurs over its lifetime including the capital (C), operation and maintenance (OM) and replacement costs (R) (sometimes NPC called life-cycle cost) [6].

\[ NPC = C + OM + R \] (1)

All previous cases studies using HOMER, based on the NPC criteria, showed that this criteria has high sensitivity analysis of outputs in relation to changes in inputs [19].

![Figure 5. HOMER schematic of the standalone PV system](image-url)
2.2 Study Site Data:
The study site (Duhok city) located at (latitude 36°50'40.6" N), longitude (43°01'05.3" E) in valley between two mountains at north of Iraq, Duhok site receives a large quantity of solar energy, where the annual average solar radiation (4.9 kw/m²/day).

![Figure 6](image)

**Figure 6.** The daily average solar radiation for each month in the study site

The daily average solar radiation in the study site are shown in figure 6, and the average ambient temperature are shown in figure 7, [20]. It clearly showing that the maximum daily radiation is in the month of June (7.68 kWh/m²/day) while the minimum in month of December (2.21 kWh/m²/day). and the maximum daily ambient temperature is in the month of July (32.4 °C) while the minimum in month of January (4.8 °C).

2.3 PV Panels Data:
The rated power of photovoltaic panel is 260W and the capital cost is 140$ per panel. this photovoltaic panels are oriented to the south (0° azimuth) with a fixed slope angle during the entire project lifetime (5 years). The photovoltaic panels have a lifetime 10 years, a derating factor of 80%, ground reflectance approximately of 20%, and the effect of temperature is also considered.

2.4 Electrical Load Data:
The electrical load is a residential load for small apartment. The daily load profile shown in figure 8, the daily power usage for the apartment is 11.1 kWh per day in average. The annually load profiles are shown in figure 9 with peak load 2.34 kW.
Figure 7. The average ambient temperature for the study site

Figure 8. The electrical daily load profiles
2.5 Batteries Data:
The system batteries are 12 volts, 245Ah, connected as one battery per string such that the system bus voltage was 12 volts, round trip efficiency 85%, the capital and replacement costs per battery is 460$ and 400$ respectively as shown in figure 10, with 5 years battery lifetime.

2.6 Converter Data:
A 3kW converter is used with capital cost 600$ as shown in figure 11, with a 10 years lifetime. The inverting and rectifying efficiency are 90% and 85% respectively.
3. Results and Discussion
The net present cost NPC and the cost of energy COE obtained from HOMER analysis results are shown in figure 12, & figure 13, respectively. These results are for Duhok site which is located at latitude 36°50'40.6" N during 5 years period. The result clearly shows that the optimum annually slope angle is 25° because the standalone PV system at this slope has the lowest NPC and lowest COE throughout the project life time. This angle is a little far from the latitude angle because Duhok located in valley between two mountains which blocks the early morning hours of solar radiation. Therefore the optimum annually slope angle needs to be less than latitude to make the solar panels more perpendicularly to the incoming solar radiation to capture more solar energy at that time when the sun becomes high and appears from behind the mountaintop as illustrated in figure 4. This study contradicts the Al-Sayyab study [17], which reported that the optimum angle in Duhok equals to 34° because the latter study depends on the mathematical model without taking into account the effect of terrain which HOMER simulation environment can deal with more accurately.

Figure 11. Converter capital cost curve

Figure 12. The Net Present Cost (NPC) of the standalone photovoltaic system for each tilt angle(slope)
4. Conclusion
This article investigates the optimal selection of the annually slope angle for the solar panels to be proficient to save a maximum quantity of energy. The impact of the slope angle on the obtained solar energy and the delivered energy of photovoltaic system according to their cost was analyzed using HOMER software. Drawings the graphs of deviation of the system cost consistent with the slope angle provided more knowledge approaching accessible energy by HOMER software. The results validated that the optimal annually slope angle in Duhok city/Iraq is 25°.

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