Solar Panel Angle Orientation Influences Power Gain: A Case Study for KRG Location

Ronak Ahmad Saeed [1*], Pshtiwan M. Sharif [2], Rezan Ahmed Ali[3] and Abubaker Aziz Ahmed [4]

Authors affiliations:

1*) Department of Automotive Technology Engineering, Erbil Technology College, Erbil Polytechnic University, Erbil, Iraq.
ronak.saeed@epu.edu.iq

2) KRG- Ministry of Electricity, General Directorate of Power Generation, Erbil, Iraq.
pshtiwan.sharif@epu.edu.iq

3) Department of Automation Industrial Technology Engineering, Erbil Technology College, Erbil Polytechnic University, Erbil, Iraq.
rezan.ali@epu.edu.iq

4) Department of Automation Industrial Technology Engineering, Erbil Technology College, Erbil Polytechnic University, Erbil, Iraq.
Abubaker.ahmed@epu.edu.iq

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Abstract

Due to the Kurdistan regional government-KRG district mission potential towards huge solar energy power generation plant investments by global investors, a genuine study is required to explore the impact of PV-panels installation angles on power generation gain within all seasons duration as the KRG located in four season area which, affect the annual total power gain due to daylight duration effect in each season. The proposed study was conducted within a duration of "513" days utilizing three PV tilt installation angle tests of " 30^{o}, 35^{o}, and 40^{o} " with " 545 watts single side PV plates" selecting the Erbil district area gaining a crucial role in maximizing energy output for comparison, Results presented a significant variation in power gain due to deviations in annual effective daylight duration effectively mostly a reduction in cold seasons within 25%-37.7% drops compared to the hot season, while the sunset and sunrise duration presented a significant influence of 5%-10% drops in power generated. The season change shows a significant influence of weather variation in each calendar on power gain annually. The installation orientation angle impact presented divergence in production within the cold season only. Process output can potentially unlock a novelty awareness of the investors toward innovative yield project optimization in the area as it will affect the annual power purchasing influence and production divergence with interest.

Keywords: Solar Energy, Solar Panels, Tilt Angle, Power Gain, KRG

تاثير تنسيق اتجاه زاوية الألواح الشمسية على اكتساب الطاقة: دراسة حالة لموقع حكومة إقليم كردستان

روناك احمد، پشتيوان محمد ، ريزان احمد ، ابوبكر عزيز

الخلاصة:

نظرا لدعم حكومة إقليم كردستان نحو استدراج استثمارات ضخمة في مجال بناء محطات توليد الطاقة الشمسية ذو سعة عالية من قبل المستثمرين عالميين ، يستوجب إجراء دراسة حقيقية لاستكشاف تأثير تنسيق زوايا تركيب الألواح الكهروضوئية على زيادة توليد الطاقة خلال جميع الفصول كون إقليم كردستان تقع ضمن منطقة الفصول الأربعة والتي تؤثر على إجمالي توليد الطاقة السنوية المنتجة بسبب تأثيرها لمدة توفر ضوء النهار في كل موسم. أجريت الدراسة المقترحة خلال فترة "٥١٣" يوما باستخدام ثلاثة اختبارات لزاوية تركيب الميل الكهروضوئي لـ "٣٠° و ٣٥° و ٤٠°" مع "٥٤٥ واط لوحات كهروضوئية أحادية الجانب" و اختيار منطقة أربيل للمقارنة لدورها الحاسم في تعظيم إنتاج الطاقة في المنطقة. قدمت النتائج تباينا كبيرا في انتاج الطاقة بسبب الانحرافات في مدة تعرضها للاشعاع الضوئي اليومي و طاقة الفعالة المنتجة سنويا بشكل فاعل وفي الغالب هنالك انخفاض للطاقة المتولدة في المواسم الباردة بنسبة ٢٥ ٪ -٣٧,٧ ٪ مقارنة بالمواسم الحارة، في حين كانت للمدة الزمنية لغروب الشمس وشروقها تأثيرا كبيرا بانخفاض بنسبة ٥ ٪ -١٠ ٪ في توليد الطاقة الاجمالي. اظهرت تغيير المواسم في المنطقة تأثيرا كبيرا لتباين حالة الطقس لكل تقويم على زيادة نسبة الطاقة المتولدة سنويا. اظهرت تأثير تنسيق زاوية اتجاه التثبيت للخلايا تباعدا في الإنتاج خلال

موسم البرد فقط. مخرجات الدراسة تساعد في فتح وعي المستثمرين الجدد نحو تحسين مشروعهم لعائد انتاج طاقة افظل وتفادي الخسارة التي ستؤثر على معدل شراء الطاقة السنوي وتفاوت الإنتاج.

1.Introduction

The Iraqi-KRG electricity demand increases proportionally with development and population increases in the area leading to an increase in Electricity production demands residentially and commercially [1]. The country's power production sources in generally dependable on fossil fuels [2]. The power generation exhaust causes an increase in environmental pollution [3]. In addition, fuel price purchasing increases which causes increases in the electricity commercial price furthermore there is a fear of fuel resources depletion threat [4]. Alternative energy sources become a global concern [5], The greatest alternative un depletion energy source that provides light and energy is the sun [6], and now using solar technologies as a sustainable clean energy source has been conferred by the government policy as an effective solution power source [7],[8]. Photovoltaic-PV technology produces electricity by using semiconductors after being exposed to solar irradiation [9]. However, factors such as temperature, dust, boundary conditions of humidity, and air circulation play an affective impact on PV power gain efficiency [10]. Previous studies on new and renewable sustainable energy sources introduced a significant improvement in PV technology by manufacturing quality and commercial which opened a huge opportunity for clean sustainable power generation [11]. The optimum tilt angle is generally gained by searching for the best values of the maximum total Incident radiation on the PV collector surface during a particular day or a specific duration period [12]. The amount of gained energy generated through converting solar thermal energy by PV collectors is influenced highly by tilt installation orientation and angle [13], the energy gained by PV modules is affected by several dependable variables, such as the solar irradiance intensity, environment temperature, wind speed, instillation orientation, dust and pollution particles, and shading [14], The design considerations of collector installation angle require calculations of the solar intensity and absorbed energy direction by the PV surface along with facing the equator with azimuth. Furthermore, for optimum tilt collector orientation located in the selected study area which is located in the Northern Hemisphere, the tilt installation angle orientation faced south depending on latitude [15]. A local survey for the fixed tallit installation angle was conducted to understand the orientation technique in the area, it was found that local technicians installed the angle depending on the area's GPS latitude with (-5o) reduction of five degrees. This technique is conducted due to yearly optimum tilt angles average degree of (30^o to 36^o). Such an install technique was found to be effective for small domestic systems during the summer compared to winter time which was less efficient as the solar angle changed while no tilt orientation changed. While for commercial PV station installation, the technician adopts application program tolls for yearly solar angle identification, most adopted applications are (Google Earth, NASA [16], PV Watts, solar panel tilt angle calculator, and SunCalc [17], the SunCalc offers better handling for the user for its easy handling of use [18]. Several studies conducted on the optimal tilt angle for solar panels conducted for most Iraq areas [19]. However, the KRG location required accurate studies to be carried out in it providing solar power technology information that can be adopted by investors in the area. In this study, objectives and methodologies adopted for the PV optimum tilt angle were by selecting variable angles for validation in controlled angle ranges. This study was supported by using previous experimental data gained by the (Iraqi and KRG Meteorological Organization and Seismology [20] for yearly solar irradiance over the years (2022-2023).

The obtained results were collected based on two years of solar radiation experimental data recording for the PV modules installed in Erbil city, KRG-Iraq. However, as the Kurdistan region is located in the Northern Hemisphere, the optimum collector orientation is south-facing, and the optimum tilt depends upon the latitude and the day of the year, in this study the seasonal weather was found to be an effective influence on generated power efficiency in the area. During the study duration, there was a decrease in solar radiation due to clouds and storms in cold seasons which continued for days influencing the solar radiation's direct contact intensity on the PV surface. The sunrise was shorter within 2-3 hours compared to the summer sunrise depending on the weather. In the summertime, the reduction of PV power gain was affected by environmental elements such as dust and birds. Sandstorms occurred during Jun and Juley's, with direction from the West-south desert. The dust covers the PV surface causing a decrease in solar radiation intensity and an increase in the PV temperature due to surface absorption, The thermometer reading reached 60^o-63^o which influenced the thermal efficiency of the PV systems. Solar Data Collector is an intelligent metering device for advanced forecasting and proactive management of the output of photovoltaic systems. The solution measures irradiation, temperature, and humidity in a more precise manner and uses specific algorithms and historical data for prediction modeling. The experimental data results showed diversion and converging within the selected three tilt angles especially in cold seasons due to solar radiation reflection in clouds [21] which equalized the solar intensity on the PV. While, during the hot season mostly summer, the gain power showed equalized, especially afternoon duration time. However, the critical diversion showed effects at both time sunrise and sunset. Thus, results showed effective tilt angle installed was 40^0 compared to the test angles. The sun path in a fixed-tilt PV system is inconsiderate which influences annual power gain due to solar angle change with the sun path position during the year [22], Fig. 1 shows the sun path of the tested selected area (latitude 36.114° N, longitude 44.018° E) illustrating the sun path position information in month, day and time of the year designed by (Dr. Andrew Marsh) there will be variations in sun direction angle with day in year.

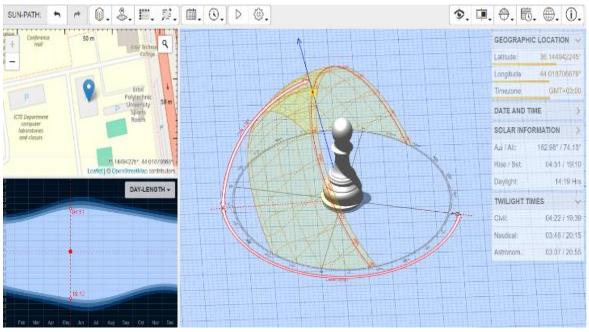


Figure (1) : Dr. Andrew Marsh the sunpath3d experimental location GIS and solar data information [23]

Therefore, in most countries to obtain the optimum solar energy, the tilt orientation angle configuration changes twice a year [24]. Thus, to obtain a maximum tilt angle for annual optimum power gain, the tilt angle should be changed proportionally to the sun location path using mechanical or automation techniques [25]. In this study, key contributions presented both validations of a novel understanding of qualified tilt angle in the KRG area and the consideration of the weather influence on huge PV power plant energy output power production. However, the monthly sun diffuse radiation availability varies with locations in KRG depending on selecting a geographical location within the plane area, hills, or mountains. The case search objective of this study was to validate the effective tilt angle of the PV system used in KRG with selective angles for optimum energy gain and obtaining optimum orientation correlation convenience angle in the area.

Furthermore, the KRG government Ministry of Electricity adopted the Power Purchase Agreement (PPA) contract type which is a power offtake contract agreement between involved parties the clean green electricity producers and the power buyer as the KRG Ministry of Electricity or trader [26][27]. The per (Kw/h) power price purchased by the Ministry till 2024 is (5.3 # per Kw/h). The offered price is critically compared with other countries thus, producer companies are concerned about power losses or a drop in power plant production, a good planning assessment is required with caution and precision to prevent interest clash [28].

2. Experimental Methodology

2.1. Experimental setup

The study case was conducted with consideration of various effective installation parameters such as the tilt orientation of installation angle, geographical information, pitch, radiation gain factor, and environmental ambient conditions. The external climate conditions observation presented the most influential factor affecting the power gain of the PVs, climate influence during the study introduced a significant diverge in power gain beyond designing expectations.

Such influence requires to be considered by power plant designers as a risk, visualizing the loss of power generation reduction due to season change in the area.

Three solar tilt PV modules were proposed with variable selective angles for comparison, studying the affected parameters involved in the case study. Modules are similar in detail and exposed to the same environmental conditions, **Error! Reference source not found.** illustrates the test system component installation, three independent PV tilt components separately were installed. The independence of the system helps to increase the data accuracy gained recorded by the data logger application.

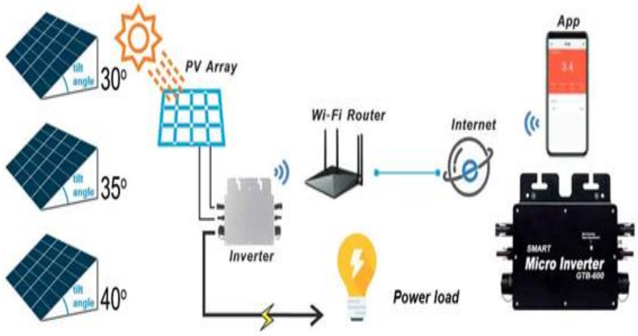


Figure (2): Experimental test components for each module installation angle

The tested PV module commercially adopted by the region is (HI-MO by LONGi) with details shown in Table 1.

Table (1): PV module Electrical characteristics data at ($800W/m^2$), cell temperature 25 °C

Module Type	LR5-72HPH-545M		Operation T.	-40°C ~+85°C
Testing Condition	STC	NOCT	Output cable	$4mm^2$, +400, -200mm/±1400 mm
Maximum Power (Pmax/W)	545	407	Voc and Isc Tolerance	± 3%
Open Circuit Voltage (Voc/V)	49.65	46.55	Max. System voltage	DC1500V (IEC/UL)
Short Circuit Current (Isc/A)	13.92	11.25	Max. Serris fuse rating	25A
Voltage at Maximum Power (Vmp/V)	41.8	38.92	Power output Tolerance	0~ +5 W
Current at Maximum Power (Imp/A)	13.04	10.46	Glass	Single glass, 3.2 mm coated temper glass
Module Efficiency (%)	21.3		Dimension	2256*1133*33mm

The smart micro inverter "GTB-600" with the specification details shown in in Table 2, is used for output AC power connected to the external power consumer load. Power consumption Data monitoring using the "Data logger" device-supported application (kaideng-app) [29] or (Smart Life app) supported by Google [30].

Table (2): PV module commercial information

Model	GTB-600	Rated output power	600 Watt
Maximum input power	600 Watt	Rated output current	5 A
Peak power tracking voltage	22-50 V	Rated voltage range	80 -160 VAC
Min/Max starting voltage	22-55 V	Power factor	41-51/ 58-61 Hz
Maximum DC short-circuit	30 A	Static MPPT η	99.5 %
Minimum input operating current	27.2 A	Max output η	95 %
Output data	@120/230 V	Ambient T. range	-40 °C - 60°C
Peake power output	600 Watt	Weight	1.6 Kg
Communication mode	WIFI	Monitoring system	App/ PC browser

Primary experimental tests were conducted for performance evaluation of the PV system before operating the system duration validating calibration and data accuracy [31]. The power consumer test was conducted directly without the use of battery power storage (off-grid), the aim was to measure the generated power during the availability of daylight [32]. Data monitoring was collected by the data-logger platform application.

2.2. Study area

Erbil city called by the local "Hawler", is the capital city in the (Kurdistan Region of Iraq)-KRG located in the north of Iraq at latitude 36.2°N and longitude 44.0°E, at a 420m altitude above sea level. It is the largest and most crowded densely populated city in KRG. The climate characterization of the city is Mediterranean climate cold and wet with snow in the mountains in winter and dray hot in summer with almost the highest summer temperature record in Iraq due to climate change impact [33]. The average temperature from May till September reaches 42℃-45℃. In winter, the weather is influenced by the sky status to be clear or cloudy, the average day temperature is 5℃ - 12℃ and the rainy season starts in October with snow in December on the mountains [34]. An open area was selected in the University location for component installation. Table , shows the selected test area geo-information with the support of the Suncalc platform.

Table (3): Selected test area geo data information at time zone 01. Jul.2022, 12:00 UTC+3

Down	04:20:05	Hight	413m
Sunrise	04:49:58	Latitude:	N 36°8'41.87" 36.14496
Sun peak level	12:07:47	Longitude:	E 44°1'7.16" 44.01866
Sunset	19:25:27	Time zone:	Asia/Baghdad +03
Dusk	19:55:18	Altitude:	76.85°
Duration:	14h35m29s	Azimut:	172.10°

3. Formula Analysis

3.1. Fixed Flat Surface Global Solar Radiation Maximizing

The general mathematical method used to evaluate the optimum tilt angle for maximizing the solar radiation in fixed PV modules applied within two cases (Isotopically and non-isotopically) depending on boundary conditions.

3.1.1. The Case of Ideal (Isotropic) Diffusion:

For a knowing month daily solar radiation exposure by tilt estimated by Tilted surface global solar radiation"I_T", daily direct exposure to solar radiation "I_b" and solar radiation diffused "I_d", reflected ground radiation "I_r" [9 algorithm].

$$I_T = I_b + I_d + I_r \qquad (1)$$

The daily-direct-radiation "I_b" on a tilted PV surface obtained by the means of the average daily direct radiation ratio in the horizontal surface on a horizontally tilted plane "R_b" [37 algorithm]:

$$I_b = {\cos\theta}/{\cos\theta_z} = H_b R_b \qquad (1)$$

Where: $R_b = \cos\beta - \sin\beta(\sin\delta\ \cos\varphi\ \cos\gamma - \cos\delta\ \sin\varphi\ \ cos\ \omega\ cos\ \gamma - cos\ \delta\ sin\ \gamma\ sin\ \omega) \times (sin\ \delta\ sin\ \varphi + cos\ \delta\ cos\ \varphi\ cos\ \omega)^{-1}$

Where: θ and θz are the solar incidence and the solar zenith angle, respectively, β is the tilt angle as to the horizontal plane, φ is the latitude, γ is the azimuth, and ω is the solar hour angle.

For a clear sky hemisphere considering uniform ideal diffuse distribution then:

$$I_{d\ ideal} = {H_d(1 + cos\ \beta)}/{2} \qquad (2)$$

Ground-reflected diffuse radiation is dependent on "I_r"

$$I_r = {H_g\ \rho\ (1 - cos\ \beta)}/{2} \qquad (3)$$

Where: ρ represents (ground albedo) ground diffuse reflectance

The incident global solar radiation on the sloped fixed surface is dependable on the sun's position along the daily trajectory (solar angle ω) and (β) with (γ).

Based on the assumption of maximum daily solar irradiation impinging PV surface related to the angles β, γ, and ω, the: maximization of the solar radiation acquired by PV panel mathematical can be expressed as [8 algorithm]:

$$\partial I_T/\partial\beta = 0,\quad \partial I_T/\partial\gamma = 0,\quad \partial I_T/\partial\omega = 0, \qquad (4)$$

In the ideal (isotropic) status application both model's expressions:

$$\partial I_T/_{\partial\beta} = \sin\beta\left[H_o + \frac{H_d}{2} - \frac{H_g\rho}{2}\right] - \cos\beta\, H_o \times [\cos\delta\sin\varphi\cos\omega\cos\gamma - \sin\delta\cos\varphi\cos\gamma + \cos\delta\sin\gamma\sin\omega] \times [\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega]^{-1} = 0 \tag{5}$$

$$\partial I_T/_{\partial\gamma} = \sin\gamma\,[\cos\delta\sin\varphi\cos\omega - \sin\delta\cos\varphi] - \cos\gamma\cos\delta\sin\omega = 0 \tag{6}$$

$$\partial I_T/_{\partial\omega} = \sin\gamma\,[\cos\gamma\sin\omega\sin\delta - \cos\delta\cos\varphi\sin\gamma] - \cos\omega\sin\delta\sin\gamma = 0 \tag{7}$$

The set of angles β, γ, and ω equations with respect to [8] solved as:

$$\beta = \tan^{-1}\left[H_o \times [\cos\delta\sin\varphi\cos\omega\cos\gamma - \sin\delta\cos\varphi\cos\gamma + \cos\delta\sin\gamma\sin\omega] \times \left[\left(H_o + \frac{H_d}{2} - \frac{H_g\rho}{2}\right) \times \sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega\right]^{-1}\right] \tag{8}$$

$$\gamma = \tan^{-1}\left[\frac{\cos\delta\sin\varphi}{\cos\delta\sin\varphi\cos\omega - \sin\delta\cos\varphi_o}\right] \tag{9}$$

$$\omega = \sin^{-1}[[\sin\delta\cos\delta\ \ \sin\gamma\cos\gamma\cos\varphi \pm [\sin^4\delta\,(\sin^2\varphi\sin^2\gamma\cos^2\gamma + \sin^4\varphi\sin^4\gamma)\sin^2\delta\cos^2\delta\sin^2\varphi\cos^2\varphi\sin^4\gamma]^{0.5}] \times [\sin^2\delta\cos^2\gamma + \sin^2\delta\sin^2\varphi\sin^2\gamma]^{-1}] \tag{10}$$

Solving equations (9), (10), and (11) requires an iteration method dependent on each provided angle with the solar angular position and tilt installation orientation for maximized radiation exposed by the PV.

3.1.2. Anisotropic Diffusion Case :

In reality, ideal status wouldn't be accurate to measure the solar diffusion intensity [35]. Direct solar radiation diffused redirected due to the scattering atmospheric effect [36]. Thus, PV systems exposed to both diffused and direct solar radiation, the system generate energy using exposure to concentrated direct radiation [37]. However, global radiation and diffused radiation empirical correlations used in hemispherical radiation computing error reduction of diffused and direct estimating radiation in case condition of the nuclear sky.

The diffuse radiation from the solar beam relation is:

$$I_{d\ sun} = \frac{H_d\cos\theta}{\cos\theta_z} \tag{11}$$

The above equation modeling is opposite to the ideal status, proposing the diffused solar radiation as two vector components [38][39].

$$I_d = F * I_d(\text{ ideal }) + (1-F) * I_d(\text{ sun }), \tag{12}$$

Where: $(1-F)$ presents the anisotropy degree. The F = 0.8 [40].

Factors that represent "circumsolar & horizon" brightening:

$$I_d = I_{d\ ideal}\left(1 + K\sin^3\left(\frac{\beta}{2}\right)\right)(1 + K\cos^2\theta\sin^3\theta_z), \tag{13}$$

Where: K parameter is the degree of anisotropy, $K = 1 - Hd/Hg$ ratio of diffuse to global radiation

The conditions of equation (11) applied to anisotropic condition solutions

$$\beta = \tan^{-1}\{[(H_o + (1-F)H_d) \times (\cos\delta\sin\varphi\cos\omega\cos\gamma - \sin\delta\cos\varphi\cos\gamma + \cos\delta\sin\gamma\sin\omega)] \times \left[\left(H_o + \frac{FH_d}{2} + (1-F)H_d - \frac{H_g\rho}{2}\right) \times (\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos(\omega)\right]^{-1}\}, \tag{15}$$

$$\gamma = \tan^{-1}\{[(H_o + (1-F)H_d)\cos\delta\sin\omega] \times [(H_o + (1-F)H_d) \times (\cos\delta\sin\varphi\cos\omega - \sin\delta\cos \tag{14}$$

$$\omega = \sin^{-1}\{[(H_o + (1-F)H_d)\sin\delta\cos\delta\sin \pm[[(H_o + (1-F)H_d)\sin\delta]^4 * (\sin^2\varphi\sin^2\gamma\cos^2\gamma + \sin^4\varphi\sin^4\gamma) - [(H_o + (1-F)H_d)\sin\delta\cos\delta]^2 \times \sin^2\varphi\cos^2\varphi\sin^4\gamma]^{1/2}] \times [[(H_o + (1-F)H_d)\sin\delta]^2 \times (\cos^2\gamma + \sin^2\varphi\sin^2\gamma)]^{-1}\}. \tag{17}$$

Equations (15), (16), and (17) iteratively solved in relationship to the angles (β, γ, and ω) expressed

$$\frac{\partial I_T}{\partial\beta} = -H_o\sin\beta - H_o\cos\beta[(\sin\delta\cos\varphi\cos\gamma - \cos\delta\sin\varphi\cos - \cos\delta\sin\gamma\sin\omega) \times (\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega)^{-1}] - H_d\sin\beta\frac{(1 + F\sin^3(\beta/2))}{2} + 3\sin^2\left(\frac{\beta}{2}\right)H_dF\frac{(1+\cos\beta)}{2} - \frac{H_dF\sin\beta q_1q_2}{2} + 3F\sin^2\left(\frac{\beta}{2}\right)q_1q_2H_dF\frac{(1+\cos\beta)}{2} + \frac{H_g\rho\sin\beta}{2} + H_dF(1+\cos\beta)(\sqrt{q_1}) * [\cos\beta(\cos\delta\sin\varphi\cos\omega\cos\gamma + \cos\delta\sin\gamma - \sin\delta\cos\varphi\cos\gamma) - \sin\beta(\sin\delta\sin\varphi + \cos\delta\cos\varphi\cos\omega)]q_2q_3 \tag{15}$$

$$\frac{\partial I_T}{\partial \gamma} = \sin\,\beta(H_o \sin\,\delta \cos\,\varphi \sin\,\gamma - H_o \cos\,\delta \sin$$
$$+H_o \cos\,\delta \cos\,\gamma \sin\,\omega)$$
$$\times (\sin\,\delta \sin\,\varphi + \cos\,\delta \cos\,\varphi \cos\,\omega)^{-1}$$
$$+\left(1 + F\sin^3\left(\frac{\beta}{2}\right)\right) H_d F(1 + \cos\,\beta) q_2(\qquad \textbf{16}$$
$$\times [\sin\,\beta(\sin\,\delta \cos\,\varphi \sin\,\gamma + \cos\,\delta \cos\,\gamma$$
$$-\cos\,\delta \sin\,\varphi \cos\,\omega \sin\,\gamma)] = 0$$

$$\frac{\partial I_T}{\partial \omega} = \frac{H_o \sin\,\beta(\cos\,\delta \cos\,\omega \sin\,\gamma - \cos\,\delta \sin}{\sin\,\delta \sin\,\varphi + \cos\,\delta \cos\,\varphi \cos}$$
$$+\left(1 + F\sin^3\left(\frac{\beta}{2}\right)\right) H_d F(1 + \cos\,\beta) q_2$$
$$\times [\sin\,\beta(\cos\,\omega \cos\,\delta \sin\,\gamma - \sin\,\omega \cos \qquad \textbf{17}$$
$$-\cos\,\beta \cos\,\delta \cos\,\varphi \sin\,\omega]$$
$$+\left(1 + F\sin^3\left(\frac{\beta}{2}\right)\right) H_d F(1 + \cos\,\beta)\left(\frac{3}{4}\right.$$
$$\times [1 - (\sin\,\delta \sin\,\varphi + \cos\,\delta \cos\,\varphi \cos\,\omega$$
$$\times (\sin\,\omega \cos\,\delta \cos\,\varphi) = 0,$$

Evaluating the accurate values requires iterative methods due to high-order complicity equations.

3.2. Uncertainty Analysis

Validating data results compared to the mathematical case study introduced a significant understanding of the error that occurred in the mathematical case compared to experimental data gained presenting a fact of environmental climate change influence. However, a clear view was introduced for solar power plant investors regarding financial interest to be aware of Kurdistan's environmental status to be considered in their investing plan and study.

Furthermore, the experimental data gained accuracy with minimum error accuracy is dependent on gadget accuracy and calibration before use. The error analysis of the PV electrical efficiency module approach was evaluated as a function of the results [41].

$$\eta = \eta\,(I, V, G) \qquad (18)$$

$$U_\eta = \left[\left(\frac{\partial \eta}{\partial I} U_I\right)^2 + \left(\frac{\partial \eta}{\partial V} U_V\right)^2 + \left(\frac{\partial \eta}{\partial G} U_{I_T}\right)^2\right]^{1/2} \qquad (19)$$

Where: $\mathbf{U}_\eta$ is the efficacy result uncertainty, $\mathbf{U}_I$, $\mathbf{U}_V$, and $\mathbf{U}_{I_T}$ are the uncertainty in load current, PV voltage, and solar radiation. The case experiment's overall uncertainty accuracy for the PV component system is 0.873% presenting acceptable data analysis results.

4. Results and Discussion

For the selected area of Erbil city, available historical data information used in this study supported by the Meteorological Center till 2022, which provided a life data database. In this case study, results were focused on the study area Erbil location analyzing selected angles for the PV modules for maximum power gain for maximum solar radiation.

•The PV tilt Orientation

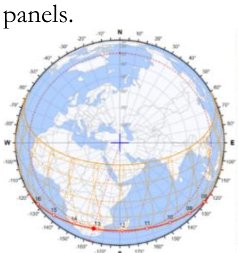
Theoretical calculations were conducted for both case statuses of ideal isotropic and anisotropic which are shown in

Table , where the tilt installation angle is proportional to the (θ and θz) angles, the results show significant power gain within hot seasons compared to cold seasons and each colander month tilt angle varies.

Table (4): The optimum PV tilt angle values (degrees) obtained by both theoretical models

Month	β optimum		H_o		H_d		K_t		I_T	
	Iso	Aniso	Iso	Aniso	Iso	Aniso	Iso	Aniso	Iso	Aniso
Jan	58.7	60.2	4.32	4.9	1.72	1.88	0.51	0.75	4.18	4.52
Feb	50.4	52.7	5.04	6.32	1.48	1.54	0.54	0.45	4.78	5.01
Mar	36.4	38.3	7.89	8	1.47	1.52	0.61	0.31	5.12	5.61
Apr	19.9	21.6	8.76	9.91	1.41	1.49	0.58	0.26	5.31	5.92
May	6.3	7.3	10.2	10.99	1.57	1.64	0.60	0.25	6.51	6.89
Jun	1.6	1.9	11	11.6	0.98	1	0.68	0.13	6.65	6.75
Jul	2.4	3.5	11.4	11.6	0.9	0.92	0.68	0.12	7.32	7.46
Aug	13.1	14.4	9.87	10.32	0.87	0.9	0.66	0.13	7.17	7.23
Sep	28.8	20.1	7.89	8.71	0.96	1.01	0.52	0.22	6.46	6.54
Oct	45.2	46.3	6.39	6.78	1.23	1.3	0.55	0.35	5.3	5.43
Nov	55.7	57.7	4.95	5.24	1.54	1.66	0.55	0.57	4.56	4.85
Dec	61.4	62.4	4	4.7	1.68	1.9	0.61	0.66	4.12	4.23

The installation PV tilt angle varies with the sun's path direction with monthly change due to the earth's rotation, Maximize power gain potentially depends on the optimal installation tilt angle [42], the varies angles limitation illustrated in **Error! Reference source not found.** which is proportional to the sun path in the subjected study area. Therefore, the optimum PV performance characterized by angle control which is varies with calendar day and season changes to ensure capture of the maximum sunlight by oriented properly panels.



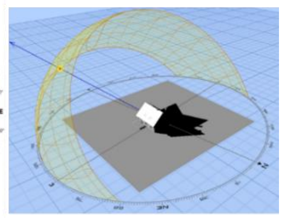


Figure (3): Sun Path for the geographical location.

The experimental process indicates the tilt angle (40°) as the optimum angle with higher performance power generated. The power gained by the PV shows a variation in response depending on calendar duration

Figure illustrates the average gained power within the (24) month test duration in the area location, a huge power gain disparity introduced compared to each month, the high power generation were indicated within the hot seasons with full generation capacity while at cols seasons there is divergent and converging depending on day weather status in return there is less power generation indicated per month compared. The lower power gained carve indicates the power drops due to climate and daytime duration compared to the hot season where power is at maximum.

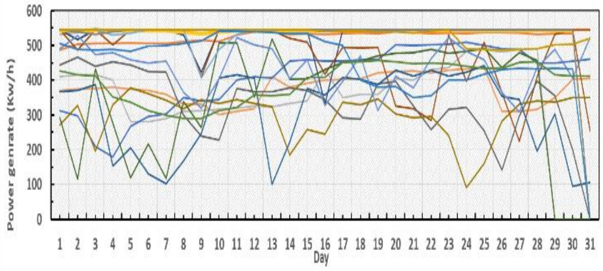


Figure (4): Power generation variation within the 24 months for selected tilt angle 40°

The effective parameter that influenced the power gain indicated was the PV daytime duration exposed during both sunrise and sunset, Figure illustrates the variation duration of exposed radiation at sunrise, day, and sunset. In the cold season, the sunrise is delayed a few hours compared to the hot season while subsite earlier compared to the hot season. In addition, the radiation exposed amount depends on the daylight range.

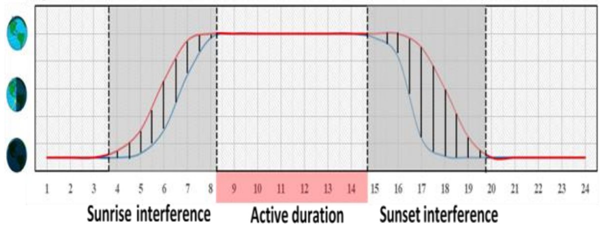


Figure (5): Daily sunrise and sunset transition interference of cold and hot seasons

- **Climate impact**

The KRG area presents a significant unstable weather condition which need to be indicated by the solar power investors at the time they plan to invest in the selected area.

Figure shows the monthly average power generated by the PV for the tilt angle (40°), deviation variation can be visualized as the power gain performance within each testing month. Standard deviation indicates the monthly variation gap of power gain shown in the cold season deviation increase while in the hot season, it indicates a high-performance power generation.

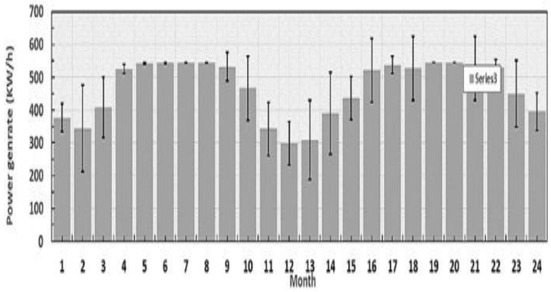


Figure (6): Average monthly power generation variation within the 24 months for selected tilt angle 40°

The comparison of selected proposed tilt angle results of each system within (24) months summarized as annual gained energy by solar radiation, which found the impact of fixed tiled is affected by the installation angle,

Figure illustrates the three tilt power gains within tested two years (2022-2023) showing a diverging in each month, the climate impacts introduced a significant impact on power gain which can be noted within cold seasons, for tilt (40°)a 23% total average power drop was noted.

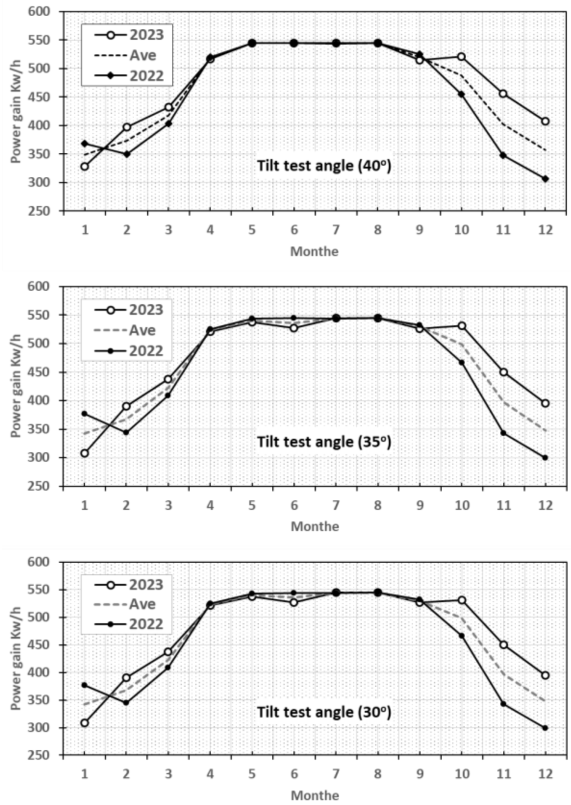


Figure (7): Average power gained in both years 2022-2024 for each Tallit test

In 2023 the rain season was delayed till the end of April compared to 2022 the rain season ended at the beginning of April. Such phenomena are expected to be coincidental, while in 2024 it was observed to be delayed till May and cloudy a few times in June. Such phenomena show an effective reduction in annual power production which has to be concentrated by investors due to power production reduction. Climate change played an important impact in solar project design, especially consecration to season change impact, rain and storm, sand storm, and tilt foundation land preparation as the area indicates soft sand land and soil erosion with floods which causes damage to the foundation leading to project financial loss.

- **Test events and observation**

During the experimental process, observation shows that the angle of incidence for the selected area did not have that much influence, especially in the summertime, where records indicate a high temperature increase which is a parameter considered crucial to substantially impact the PV power gain system performance. Environmental status indicated a significant influence on the PV system electrically and mechanically. The system platform frames and foundations are influenced by the weather conditions, especially on storm days, heavy rain, lightning, and sand storms. The surface area of the PV system indicates a dynamic impact by the wind motions causing vibrations in the frame and foundation leading to angular change or frame bending. Figure illustrates the daily record status of the power gained level and critical environmental impacts defined by colors for the total duration time:

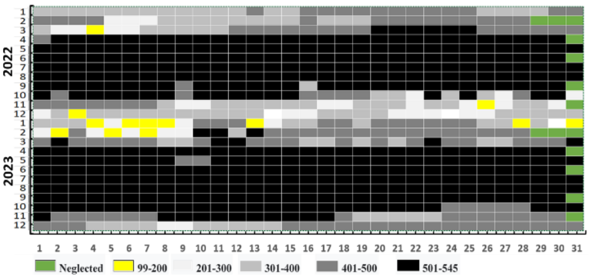


Figure (8): Daily observation status of 2022-2023, power generated in kW/h

The illustrate the non-data (neglected) blank cell

The illustrate the power generated by the PV system per day within a range of (501-600 Kw/h). However, the figure shows the best calendar duration where the PV performance reached maximum power production. Maximum power production illustrated in hot seasons starts from the end of March till the end of October 2022 while in 2023 there was a delay in season change which can be noted in the figure to start in April to end in mid-November indicating a season shifting duration.

The illustrate the power generated by the PV system per day within a range of (401-500 Kw/h) representing the medium range influenced by the Season's solstice. However, power gaining range is considered at a safe range in critical limit.

The illustrate the power generated by the PV system per day within a range of (301-400 Kw/h) representing the minimum range of power gaining within cold seasons. However, the above range is considered the maximum power generated in the season.

The illustrate the power generated by the PV system per day within a range of (201-300 Kw/h) representing the weather impact of rain and cloudy days which cause reflection and prevent the sun lights reaching the PV, the status indicated within the cold seasons and springs. However, power generated conflict with the investor's interests due to the power gain drop. However, power generation is defined as risky as the interest will drop.

The illustrate the power generated by the PV system per day within a range of (101-200 Kw/h) representing environmental conflict due to heavy rain, storms, wind, and dark clouds which cause the PV power to gain critical status reaching shutdown range. However, there is limited generated power such as status risk and full interest loss. Furthermore, such conditions are considered dangerous situations where the PV system is exposed to the risk of failure, frame fall, frame bending, frame foundation revealing, and PV surface misalignment. The generated power disqualifies to connect to the grid as the substation transformer will fail to synchronize and connect to the grid [43]. In addition, the power plant loss effect reduces benefits causing interest drop which is not desired by the power investors.

5. Conclusions

The present conclusion is based on the experimental sources studies, the comparison installation tilt angle orientation for the solar panel for the optimum angle obtaining the highest annual power gain yield. The comparison between tested installation angles was found especially during the hot seasons to be similar, the comparison can be indicated in cold seasons. Based on the test contribution observation of total annual power generated it was explored the climate conditions indicated an effective impact on the PV system in the multi-seasonal region which requires serious attention in design consideration. Solar power plant investors should be aware of the season variation and climate impact in the area. Lastly, to significantly maximize solar panels' power gaining for fixed tilt orientation should installed facing the south within a range of (35°-40°). For high-capacity efficient solar power plants with minimum power loss and financial interest drop recommended to adopt the tilt PV tracker system to track the solar radiation maximally which helps to prevent power losses and tilt frame misalignment resistance to climate environment excitation [44][45]. However, such a system causes project financial increases in reverse increases in power purchasing incomes with higher beneficial reword.

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