Optimization of seasonal tilt adjustment photovoltaic system in Karbala, Iraq, by using the albedo benefit

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ABSTRACT

This study aims to identify a cost-effective method for enhancing incident irradiation on the collector plane. Two different orientations for photovoltaic (PV) systems have been considered. The PV system is installed with albedo (0.25) on a concrete surface. The system is an off-grid with 690 Wp power, used for office applications with a yearly energy (1,068) Khp/yr, located at Karbala Governorate/Iraq. The first orientation has an optimal seasonal tilt angle of 13º and 53º for summer and winter, respectively. In contrast, the second orientation is one-axis tracking, horizontal E-W axis, which produces more output power. To avoid the cost of using a tracking system and improve the amount of the output power of the first system, the old concrete surface of this system was treated with white Portland cement with a higher albedo value of 0.87 and then compared to the parameters (incident irradiation in the collector plane, transposition factor and the product available energy) with a second system. It was using Perez transposition model in PV system software in this study. The results showed a higher value of comparing parameters when using inexpensive materials like white Portland cement, which improved the output PV system power than the tracking system.

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1. INTRODUCTION

Photovoltaic (PV) systems present a multitude of benefits compared to traditional energy sources. Not only are they a clean and renewable source, but they also don't produce any detrimental emissions that could heighten the impacts of climate change. They require minimal maintenance and last a long time; PV modules can operate for up to 30 years. PV modules have an energy payback time of less than 4 years, meaning that in their life span, they can generate more energy than what was used to manufacture them. Different types of PV systems exist, such as on-grid and off-grid. On-grid systems are linked to the utility grid and can provide energy to it when there's a surplus, while off-grid require batteries for energy storage as they are not connected to a power grid [1], [2].

When designing a PV system, it's essential to consider location, orientation, tilt angle, solar tracking, shading, as well as the size of the system [3], [4]. Plenty of design tools are available to help you with this process, such as PV system software [5], [6]. The main thing that keeps solar PV systems from being widely used is their high cost. So, the research and improvement in photovoltaic technology is driven by the goal of making solar power cheap. To make photovoltaics less expensive, research is being done in different areas, such as the materials used and the way they are made. At the same time, it is interesting to study how to improve the total amount of sun radiation that hits the photovoltaic panel, since the power output of the PV module is directly linked to the amount of radiation that hits it [7]. By increasing the amount of radiation that hits the photovoltaic cell, the output can be increased by a lot [8]–[10]. Solar tracking PV systems and focused systems are two traditional ways to do this [11].

In a solar tracking system, a PV panel is placed on a device that uses either a single-axis or a double-axis solar tracking gear to follow the sun. This idea works well for a single or a small number of PV panels, but it gets expensive as the number of panels increases. As the number of screens goes up, so does the total load, which means that the motors and other parts of the tracking device will need to be bigger. This limits how much sun tracking can be used with a PV grid [12]. Putting a spotlight on a PV panel is another way to make the sun's rays hit it more strongly. This will make the PV panel work better or lower the amount of expensive active material needed. At the same time, there are other things to think about when directing the sun's rays on the screen. First, this focus of the sun's rays makes more heat, which makes the PV module hotter. The efficiency of a typical PV cell goes down as the temperature goes up [13]. Therefore, the PV cell usually needs active or passive cooling to keep its temperature low [14], [15]. This makes the solar setup more expensive. Second, concentrating lenses cost more than a simple PV system with a flat plate. Third, most focus devices need to be able to track the sun in order to work. Therefore, the concentrate system is costly and not good at making power continuously.

Taking into account the advantages and disadvantages of the mentioned above systems for increasing the power of solar energy, a new idea has been put forward to make PV systems more cost-effective. The idea is to use albedo to increase the amount of radiation that hits a stationary PV panel or put the mirrors on the solar panel to get the most concentrated solar rays and, as a result, more electricity [16]. Since the total output of the PV panel will go up as a result, raising the albedo value of the reflective surface is a good way to take advantage of this.

The absence of precise geographical and temporal solar resource assessment, which has an influence on the capacity for power generation, is one of the major issues that developers must deal with throughout the planning and design of solar PV projects. The output of PV systems is influenced by a number of variables, including the kind of PV modules, ground albedo (ground reflectance), and building orientation [17], [18]. The term "albedo" refers to the ratio of the amount of sunlight reflected by the ground to the total amount of sunlight that strikes a certain area from all directions. A dark surface has an albedo of zero because it completely absorbs all light that hits it. The albedo of a perfectly reflective white surface is 1. Grass, bare soil, a paved road, or even snow cover are all suitable locations for installing a solar PV system. For snow-covered terrain, albedo values are typically in the range of 0.2 to 0.8 [19]. Common ground surfaces, together with their albedo factors, are asphalt (0.15), grass (0.25), concrete (0.35), and aluminum (0.85). The PV system software can model a solar PV installation at a given location. Albedo is measur with two pyrometers, one towards the sun and the other toward the ground [20].

2. THEORETICAL CALCULATION OF SOLAR RADIATION

The amount of solar radiation received by an on-earth surface at a specific geographical point and time is contingent upon the orientation and tilt of the indicated surface [21], [22]. At the flat surface the solar radiation is the sum of absorbed beam radiation (G_{Bt}), diffuse radiation (G_{Dt}) and ground-reflected radiation (G_{Gt}) as shown in Figure 1.

$$G_t = G_{Bt} + G_{Dt} + G_{Gt} \tag{1}$$

As shown in Figure 1, the beam radiation on the horizontal surface is (G_B) and for a tilted surface is (G_{B_t}), then, the tilt factor beam radiation (R_B) is equal to:

$$\mathrm{R_B} = \frac{\mathrm{G_{B_t}}}{\mathrm{G_B}} = \frac{\cos\theta}{\cos\Phi} \tag{2}$$

then, for any surface, G_{B_t} is equal to:

$$G_{B_t} = R_B G_B \tag{3}$$

the standard representation of incidence angle (θ):

$$\cos\theta = \sin L \sin\delta \cos\beta - \cos L \sin\delta \sin\beta \cos Z_s$$

$$+\cos L\cos\delta\cos h\cos\beta+\sin L\cos\delta\cos h\sin\beta\cos Z_s$$

$$+cos\ \delta\ sin\ h\ sin\ \beta\ sin\ Z_s \quad (4)$$

for the case of horizontal surfaces, θ = ϕ , $\beta = 0$ as shown in (4).

$$\cos(\phi) = \sin L\sin\delta+\cos L cos\ \delta\cos h \quad (5)$$

Many models show how solar energy affects a surface that is tilted. The first is the isotropic sky model, which was first made by [23] and then improved by [24]. Based on this model, here is how to figure out how much radiation there is. At a horizontal surface, diffuse radiation is,

$$G_D = 2\int_2^{\frac{\pi}{2}} G_R cos\ \phi\ d\phi = 2G_R$$

$$G_R = \frac{G_D}{2} \quad (7)$$

G_R stands for "diffuse sky radiance." A tilted surface diffuse radiation is,

$$G_{D_t} = 2\int_2^{2\pi-\beta} G_R cos\ \phi\ d\phi + 2\int_2^{\frac{\pi}{2}} G_R cos\ \phi\ d\phi \quad (8)$$

substitute (7) in (8).

$$G_{Dt} = \frac{G_D}{2}\int_2^{2\pi-\beta} G_R cos\ \phi\ d\phi + \frac{G_D}{2}\left[sin\ \left(\frac{\pi}{2}-\beta\right)\right] + \frac{G_D}{2} = G_D\left[\frac{1+cos\ (\beta)}{2}\right] \quad (9)$$

Also, in the same way, ground-reflected radiation G_{Gt} is $\rho_G(G_B + G_D)$.where ρ_G is the ground albedo, therefore the ground reflector concerning isotropic ground reflected (Gr)will be:

$$\rho_G(G_B+G_D) = 2\int_0^{\frac{\pi}{2}} G_r\cos(\Phi)\,d\Phi = 2G_r \quad (10)$$

tilted ground-reflected radiation is:

$$G_{G_t} = \int_{\frac{\pi}{2}-\beta}^{\frac{\pi}{2}} G_r\cos(\Phi)\,d\Phi \quad (11)$$

by incorporating (10) and (11) in a similar manner as previously done,

$$G_{G_t} = \rho_G(G_B+G_D)\left[\frac{1-\cos(\beta)}{2}\right] \quad (12)$$

consequently, by substituting in (9) and (12) into (1), we obtain:

$$G_t = R_B G_B + G_D\left[\frac{1+cos\ (\beta)}{2}\right] + (G_B+G_D)\rho_G\left[\frac{1-cos\ (\beta)}{2}\right] \quad (13)$$

on a horizontal surface, G is,

$$G = G_B + G_D \quad (14)$$

as a result, as (13) may alternatively be written as:

$$R = \frac{G_t}{G} = \frac{G_B}{G}R_B + \frac{G_D}{G}\left[\frac{1+cos\ (\beta)}{2}\right] + \rho_G\left[\frac{1-cos\ (\beta)}{2}\right] \quad (15)$$

where R is commonly referred to as the total radiation of tilt factor from (13), from (16) the ground-reflected tilt factor shown in (17) and the diffuse radiation tilted factor shown in (18).

$$G_t = R_B G_B + G_D R_D + \mathrm{G}R_r = (G-G_D)R_B + DR_D + R_{Gt}G \quad (16)$$

$$R_{Gt} = \rho_G \left[\frac{1-cos\,(\beta)}{2}\right] \quad (17)$$

$$R_D = \left[\frac{1+cos\,(\beta)}{2}\right] \quad (18)$$

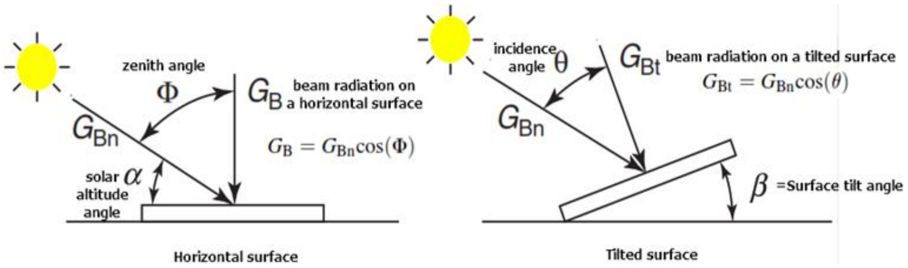

Figure 1. Beam radiation on the horizontal and tilted surface

3. SIMULATION CALCULATION OF SOLAR RADIATION

Depending on the above theory, PV system offers two transposition models (Hay model, Perez model) to calculate the incident irradiance on a tilted plane from the horizontal irradiance data. The Hay model is widely recognized and proven to yield accurate outcomes, even in cases where the knowledge of diffuse irradiation is incomplete. On the other hand, the Perez model is a more advanced model that necessitates precise and well-documented horizontal data, transposition is separately calculat for each irradiance component.

In this study Perez model used in the simulation PV system according to [25] show that the results from Perez's method had been more accurate than those from the Hay model, which makes sense since Perez's method takes into account more variables. Since the Hay model is thought to be reliable and is used in several simulation programs for PV systems, it doesn't take into account the horizon, which is a factor that adds to the amount that is diffuse radiation upon a tilted surface. So, Perez's model took into account how this factor affected things.

Also, the models that had been made up to that point didn't take into account some possible situations, like how the circumsolar component could get stronger in atmospheres with a lot of scattered radiation and a lot of light. Perez suggested a model that could be use for a wider range of celestial setups than the methods that were available at the time. The circumsolar and horizon components that cover the isotropic dome are weighted by two factors, $A_1^{'}$ and $A_2^{'}$, respectively. Perez *et al*. [26] found that these coefficients change based on their clarity and brightness score in addition to empirical coefficients. the case of 1987, the author came up with a new version of the model that was easier to understand. In this version, the coefficients $A_1^{'}$ and $A_2^{'}$ were changed. Then, $A_2^{'}$ can have negative numbers; this refers to the exchange of horizon luminosity for zenithal brightness. On days with a clear sky, the brightness of the horizon is typical, and the brightness of the zenith is checked on days with clouds [27]. Perez *et al*. [28] made changes to the model that made the clear score independent of the angle of the zenith. The scattered radiation that hits the tilted surface can be shown in (19), which is the final form of the model of diffuse radiation tilt factor:

$$R_d = \frac{1}{2}(1+\cos\beta)\left(1-A_1^{'}\right) + A_1^{'}(a/b) + A_2^{'}\sin\beta \quad (19)$$

where a and b are a=max (0, cos θ), b=max (0.087, cos Φ), $A_1^{'}$and $A_2^{'}$ are coefficients denoting the degree of horizon/zenith anisotropy and circumsolar anisotropy, respectively. Then,

$$G_t = R_B G_B + G_D R_d + \mathrm{G}R_{Gt} = (G - G_D)R_B + DR_d + R_{Gt}G \quad (20)$$

the formula on a tilted surface the tilt factor global radiation, denoted as R, is be (21).

$$\mathrm{R} = \frac{\mathrm{G_{B_t}}}{\mathrm{G_B}} = (1 - G_D/G\,)R_B + (G_D/G)R_d + R_{Gt} \quad (21)$$

In PV system software for tracking systems, the geometry changes each time the tracker moves, and the diffuse radiation distribution has to be recalculated at every simulated step [29]. Define the simulation method in PV system software focused on calculated transposition factor (TF) using Perez model, which is, as the ratio of the incident irradiation (GlobInc) on a given plane and the horizontal irradiation (GlobHor). In addition, the effect of albedo on TF by comparing the results of GlobInc and incident albedo irradiation in the collector plane AlbInc to get maximum available solar energy E_Avail.

4. SIMULATION METHOD

4.1. Step 1. Get geographical sites parameters

Using PV system software version 7.2.2. The system is located in Karbala Governorate, Iraq, which is located at latitude of 32°37'18.7"N and Longitude of 43°58'46.9"E at an altitude of 28 M above sea level. The software is used to obtain the geographical sites parameters and the solar paths at this location, as shown in Figure 2 and download the monthly global horizontal irradiation (GHI or GlobHor) and monthly diffuse horizontal irradiation (DiffHor) shown in Table 1.

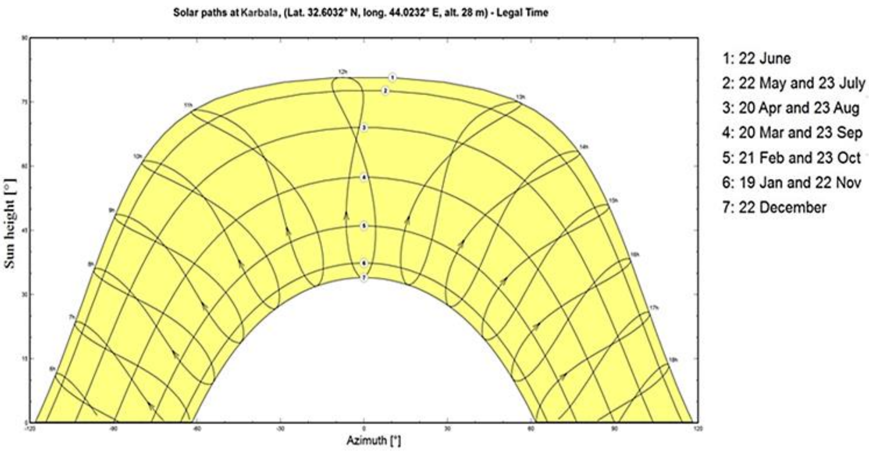

Figure 2. Solar paths in Karbala governorate-Iraq

Table 1. Monthly global horizontal and diffuse irradiation

Values Month	GlobH kWh/m²	DiffH kWh/m²	Values Month	GlobH kWh/m²	DiffH kWh/m²
January	91.8	30.7	July	228.5	59.8
February	109.5	33.6	August	214.5	52.1
March	150.7	49	September	174.6	43.8
April	171.9	58.8	October	124	42.5
May	209.9	64.2	November	88.5	33
June	238.2	53.7	December	81.8	28.5
Year				1883.9	549.7

4.2. Step 2. Set the seasonal tilt angle with albedo 0.25

Various seasonal tilt angles were tested for the PV system installed on a concrete surface, to find optimum seasonal tilt angle, which means harvesting maximum product available energy and maximum GlobInc. As shown in Figure 3. It is found that the optimum seasonal tilt angle was 13° and 53° for summer and winter, respectively. The albedo value for concrete is 0.25 [30], [31].

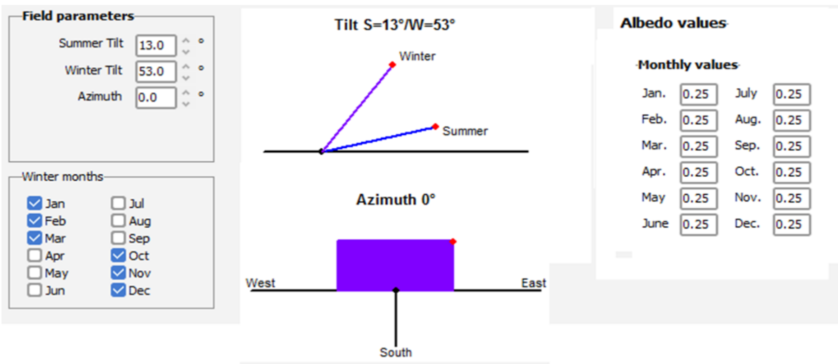

Figure 3. Seasonal tilt angles with albedo 0.25

4.3. Step 3. Sizing the PV system

The stand-alone PV system is designed for office with daily and yearly energy of 2.976 and 92.3 kWh, respectively. The module area 4.0 m², cell area 3.5 m². The energy needed by the user is 1086.24 kWh, and the system power 690 Wp. Other system parameters are show in Table 2.

Table 2. System description and parameters

PV array		Battery		Controller		Area		At operating cond. (50 °C)	
Unit Nom. power	230 Wp	Nb. of units	2 in parallel x 2 in series	Universal controller		Module area	4.0 m²	P Mpp	622 Wp
Number of PV modules	3 units	Voltage	24 V	Technology	MPPT converter	Cell area	3.5 m²	U Mpp	23 V
Nominal (STC)	690 Wp							I Mpp	27 A
Modules	3 Strings x 1 in series							Discharging min. SOC	20.0%
								Nominal capacity	310 Ah

4.4. Step 4. One-axis tracking horizontal E-W axis system with albedo 0.25

For one axis tracking horizontal E-W axis with albedo 0.2. To get maximum incident irradiation in the collector plane GlobInc, maximum output power. The axis and limiting angles are set at 0.0° for axis orientation, -90.0° for minimum tilt and 90.0° for maximum tilt as shown in Figure 4.

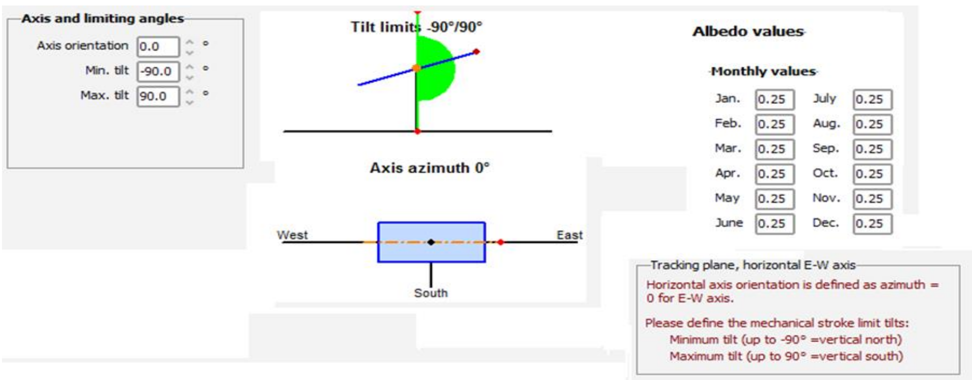

Figure 4. One axis tracking horizontal E-W axis orientation with albedo 0.25

4.5. Step 5. Seasonal tilt angle with albedo 0.85

As shown in the Figure 5, the same orientation as in step 1 has been considered, but the old concrete surface has been treated with white portland cement. The treated area is twice the area of PV modules [32]. The albedo value of white portland cement is 0.87 [32], [33].

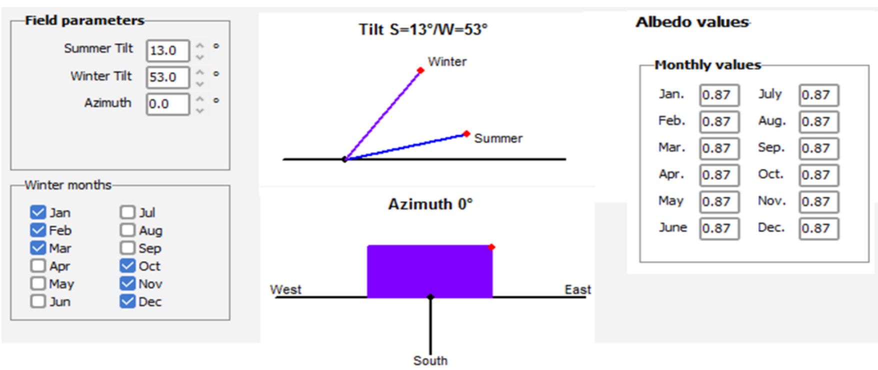

Figure 5. Seasonal tilt angles orientation with albedo 0.87

4.6. Step 5. Compute the results

The PV system software is use to compute the results for steps 2, 4, and 5; the important results of this study calculate the maximum global incident in the collector plane reached to PV panel, maximum TF, which means getting maximum available energy. TF equal to:

$$TF = \frac{Global\ irradiation\ on\ tilted\ plane}{global\ irradiation\ on\ horizontal\ plane} = \frac{G_t}{G} = \frac{GlobInc}{GlobHo} \quad (22)$$

in PV system software GlobInc = G_t and $GlobHor = G$.

5. RESULTS AND DISCUSSION

The Perez transposition model that is currently implemented in PV system has been selected for use in this study. The results of the three cases will be yearly and compared between each other based on the maximum global incident in the collector plane reached to PV panel, maximum TF, which means getting maximum product available energy. The compounds of global horizontal irradiation as read from PV system are shown in Table 3.

Table 3. Compounds of global horizontal irradiation

Horizontal diffuse irradiation	Horizontal beam irradiation	Global horizontal irradiation
kWh/m²	kWh/m²	kWh/m²
640.6	1,243	1,884

The three cases are as follows:

5.1. Case (1): Seasonal tilt angle with albedo 0.25

The optimum seasonal tilt angle equals 13° and 53° for summer and winter, respectively. The albedo value for concrete is 0.25. The results for this case, according to incident irradiations in the collector plane, as shown in Table 4. The system will produce available energy E_Avail 1141.4 kWh with missing energy 50.57 kWh. The solar fraction EUser/ELoad is 0.953. The optical and array losses diagram depicts in Figure 6.

Table 4. Results of seasonal tilt angle with albedo 0.25

Beam incident in coll. plane kWh/m²	Circumsolar incident in coll. plane kWh/m²	Sky diffuse incident in coll. plane kWh/m²	Albedo incident in coll. plane kWh/m²	Global incident threshold kWh/m²	Global incident in coll. plane kWh/m²	TF ratio
1,514	331.3	351.2	28.9	0.0795	2,166	1.15

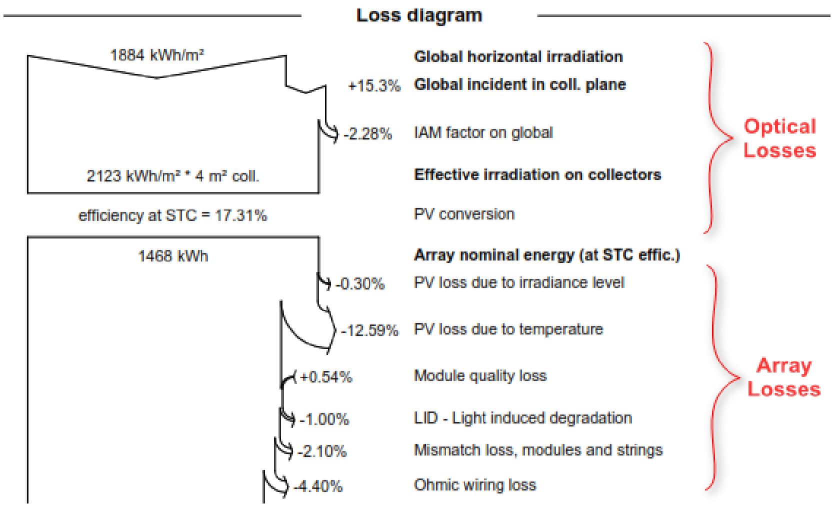

Figure 6. Optical and array losses diagram (case 1)

5.2. Case (2): One-axis tracking horizontal E-W axis system with albedo 0.25

For one axis tracking horizontal E-W axis with azimuth 0°. The minimum and maximum tilt angles are-90° and 90° respectively. The results for this case, according to incident irradiations in collector plane as shown in Table 5. The system will product available energy E_Avail 1181.8 kWh with missing energy 49.54 kWh. The solar fraction EUser/ELoad is 0.954. The optical and array losses diagram depicts in Figure 7.

Table 5. Results one-axis tracking horizontal E-W axis system with albedo 0.25

Beam incident in coll. plane kWh/m²	Circumsolar incident in coll. plane kWh/m²	Sky diffuse incident in coll. plane kWh/m²	Albedo incident in coll. plane kWh/m²	Global incident below threshold kWh/m²	Global incident in coll. plane kWh/m²	TF ratio
1,514	344.8	349.7	28.76	0.1545	2,237	1.18

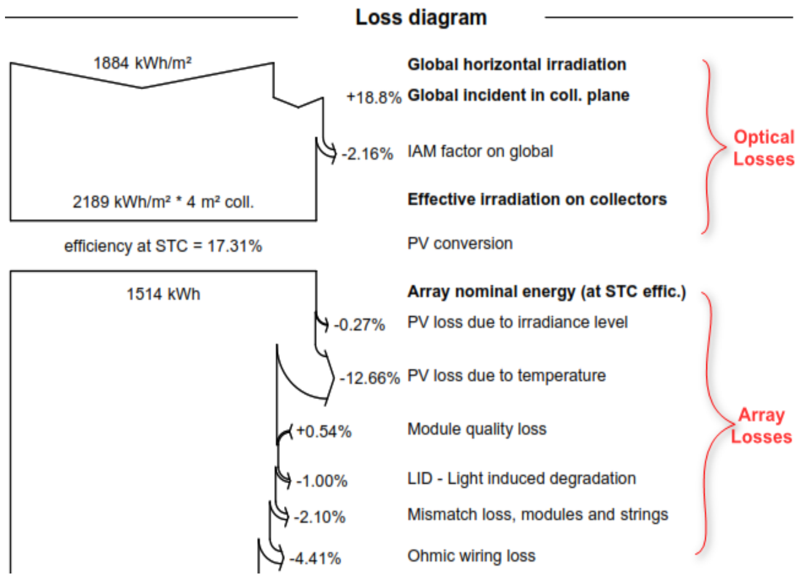

Figure 7. Optical and array losses diagram (case 2)

5.3. Case (3). Seasonal tilt angle orientation, with albedo 0.87

The concrete surface in case (1) will be treating with white portland cement with albedo 0.87. The results for this case, according to incident irradiations in collector plane as shown in Table 6. The system will product available energy E_Avail 1,187 kWh with missing energy 30.07 kWh. The solar fraction EUser/ELoad is 0.972. The optical and array losses diagram depicts in Figure 8.

Table 6. Results of seasonal tilt angle orientation with albedo 0.87

Beam incident in coll. plane kWh/m²	Circumsolar incident in coll. plane kWh/m²	Sky diffuse incident in coll. plane kWh/m²	Albedo incident in coll. plane kWh/m²	Global incident threshold kWh/m²	Global incident in coll. plane kWh/m²	TF ratio
1,454	331.3	351.2	125.7	0.0708	2,262	1.20

The summary of more important results for all cases is shown in Table 7. The results indicate that in case (3), where the concrete surface was treated with white Portland cement albedo 0.87, there was a significant increase in the global incident in the collector plane, global irradiation effectively reaching the PV-cell surface GlobEff and albedo incident irradiation in collector plane compared to other cases. The effective of albedo is clearly shown in increasing the amount of albedo incident irradiation in collector plane in case (3). This increase resulted in a higher transposition factor, leading to an increase in available energy at the output of the array and a decrease in missing energy supply to the user. Additionally, the solar fraction increased because of these changes.

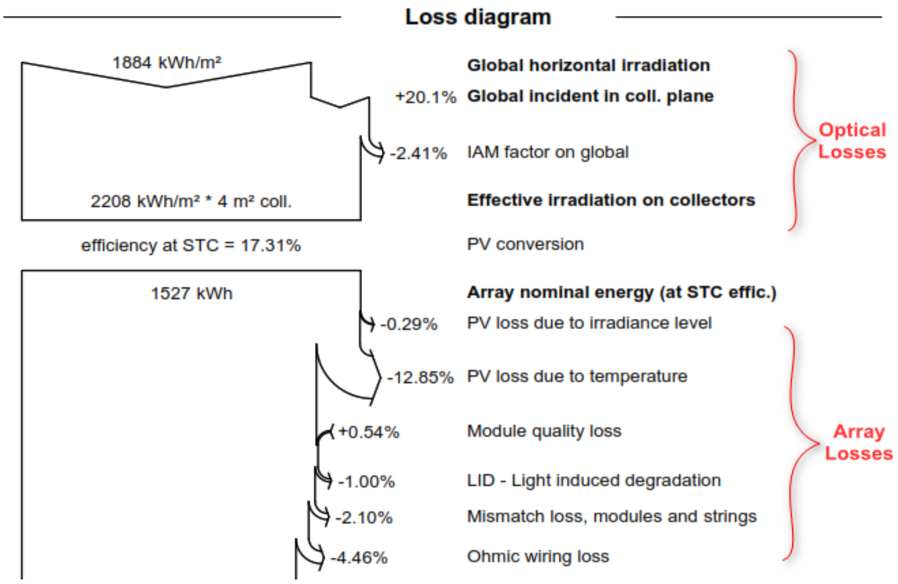

Figure 8. Optical and array losses diagram (case 3)

Table 7. The summary results of three cases

Case	AlbInc kWh/m²	GlobInc kWh/m²	GlobEff kWh/m²	TF ratio	E_Avail kWh	E_Miss kWh	SolFrac ratio
1	28.90	2,166	2116.3	1.12	1141.4	50.57	0.953
2	28.76	2,237	2188.8	1.18	1181.8	49.54	0.954
3	125.7	2,262	2207.9	1.20	1187.0	30.07	0.972

As shown in optical and array losses figures, the global horizontal irradiation is the same for all three cases due to the same location being used. For cases 3, 2, and 1, the global incident irradiation in the collector plane go up by 20 %, 18%, and 15%, respectively, from the global horizontal irradiation. The incidence angle modifier [34] causes the global incident irradiation to go down by 2.41%, 2.16%, and 2.28% respectively. More PV losses due to temperature in case (3) than in any other case.

6. CONCLUSIONS

In this study, a PV system of 690 kWp has been considered. The system is designed for office applications. The installation location was in Karbala governorate/Iraq. The ground of installation is concrete. Three cases have been investigated in this study. Case (1) seasonal tilt angle with albedo 0.25, case (2) one-axis tracking horizontal E-W axis system with albedo 0.25 and case (3) seasonal tilt angle with albedo 0.87. In case (3), white Portland cement was applied on the top of the concrete to change the albedo value from 0.25 to 0.87. This made the albedo incident in coll. plane is increased, then the incident global irradiation in the collection plane be higher, causing the transposition factor and available output energy to be higher than in cases 2 and 1. The results have shown that using cheap materials with higher albedo values, like white Portland cement improved the output of PV systems and made them more efficient than the same PV system in case (1) that had a lower albedo. Additionally, the output power for case (3) is more than the output power in case (2) means that costly one-axis tracking PV systems can be avoided. One of the drawbacks of raising the albedo is that it raises the PV loss due to temperature, although these losses may be neglected when compared to the increase in output power that results from increasing the albedo. For the future works, this study's primary focus is on a seasonal tilt angle PV system with a capacity of 690 kWp. It is essential to expand the study to include photovoltaic systems with higher system powers than this one and compare the results with either a photovoltaic system with one axis of tracking or two axes of tracking. Additionally, when sizing seasonal tilt angle PV systems with high albedo, there is a possibility that an increase in the number of photovoltaic panels that are used will be required. This is possible because increasing the number of PV panels is more cost-effective than tracking to attain the same or similar results.

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