Optimum Tilt Angle of Photovoltaic Panels for Some Iraq Cities

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Abstract:

The operation of a photovoltaic (PV) panels are influenced by its inclination angle with the horizontal surface. Thus, it must be inclined at a proper angle to raise the effectiveness of these panels. This research focuses on the computation of optimum slope angle of the PV panels in order to get the maximum incident solar radiation. Therefore, it is recommended to set the PV panels at fixed slope angle throughout the year to avoid the cost of sun tracking systems. In this research, an optimum slope angle of PV panels is investigated to get a maximum incident solar irradiance value using Bernard-Menguy-Schwartz model for some Iraq cities: Baghdad city (latitude of 33°22'N), Mosul city (latitude of 36°15'N), Zakho city (latitude of 37°10'N), and Samawah city (latitude of 31°15'N). The results showed that the optimum slope angle for these panels seems to be close to latitude of these cities.

Keywords: PV Panels, Optimum Slope Angle, Solar irradiance, Bernard-Menguy-Schwartz model.

الخلاصة:

يتأثر أداء الألواح الكهروضوئية بزاوية الميل مع المستوي الأفقي. وهكذا، يجب أن تميل الالواح الكهروضوئية بزاوية ميل مناسبة لرفع فعالية هذه الالواح. ويركز هذا البحث على حساب زاوية الميل المثالية للالواح الكهروضوئية من أجل الحصول أقصى قدر من الإشعاع الشمسي الساقط على ذلك اللوح. ولذا ينصح بتعيين زاوية ميل ثابتة للالواح الكهروضوئية خلال فترة السنة لتجنب كلفة أنظمة تعقب الشمس. في هذا البحث تم دراسة زاوية الميل المثلى للالواح الكهروضوئية للحصول على القيمة القصوى للإشعاع الشمسي الساقط باستخدام نموذج برنار- منغوي- شوارتز لبعض مدن العراق: مدينة بغداد (خط العرض 33°22'N)، مدينة الموصل (خط العرض 36°15'N) ، مدينة زاخو (خط عرض 37°10'N)، ومدينة السماوة (خط عرض 31°15'N). أظهرت النتائج أن زاوية الميل المثلى لتلك الالواح تقترب من قيمة زاوية خط العرض لتلك المدن.

الكلمات المفتاحية: الالواح الكهروضوئية، زاوية الميل المثلى، الاشعاع الشمسي، نموذج برنارد- منغوي- شوارتز.

Introduction:

The main applications of renewable energy systems are involving the photovoltaic panels, solar thermal energy, wind energy, biomass energy, hydro-electric power plants, and geothermal energy. The photovoltaic solar cell are the main elements of energy conversion PV systems. Solar panels use sun light energy to produce electricity using semiconductor materials, and the amount of electrical power generated by photovoltaic systems depends on the incident solar radiation falling on the panels surface.

Thus, to obtain the highest electrical energy, the PV solar cell surface must be made perpendicular to the incoming solar radiation, which means constantly changing the PV panel slope angle using solar tracking systems.

The collected amount of daily solar energy increased (from 19% upto 24%) using the single-axis solar-tracking system (East-West) than by using a stationary system (Vilela *et.al.*,2003). The use of solar tracking mechanisms have high operation and servicing costs and are not always usable, so it is often suitable to put the panel at a stationary angle which is considered an optimum slope angle (Elminir *et.al.*,2006).

The operation of a solar PV panels are affected by panel angle of inclination with respect to the horizontal plane. Thus, any change in PV panel slope angle leads to change in the solar radiation reaching the surface of the panel. The slope angle, which is considered as an important parameter affecting the collection of radiation value of a PV solar panel, can be defined as the angle inclination of PV panel with respect to horizontal surface. Many literature on the optimum slope angle determination have been reviewed (Manes *et.al.*,1983;Tiris *et.al.*,1998;Yakup *et.al.*,2001;Ibrahim,1995;Chinnery, 1981;Hottel, 1954;Lin,1989;Garg, 1982). Another inspectors have made different suggestions for the best tilt, based on the latitude of place and solar declination angle (Lunde,1980;Erbs *et.al.*,1982;Ibrahim,1995;Asl-Soleimani *et.al.*, 2001;Soulayman, 1991;KORAY, 2006;Ali *et.al.*, 2014).

In this research, the optimum photovoltaic panel inclination angle is investigated for some Iraq cities (Zakho, Mosul, Baghdad, and Samawah), and the MATLAB software is used to compute the optimum panel slope angle which gives maximum incidence solar radiation on that panel surface.

Methodology:

The global solar radiation on a flat surface consists of two elements: Beam and Diffuse irradiations components, (John *et.al.*, 2013). In this research, the Bernard-Menguy-Schwartz model, is used to estimate the optimum inclination angle of PV panels for several Iraq cities (Zakho, Mosul, Baghdad, and Samawah).

In Bernard-Menguy-Schwartz model, the Beam radiation component can be estimated under three sky conditions as follows (Bernard *et.al.*, 1980):-

a. Clear sky

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

b. Very clear sky

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

c. Polluted sky

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

In this paper, a clear sky model is considered to determine the Beam radiation component, while diffuse radiation component can be presented for any sky type as follows (Bernard *et.al.*, 1980):-

$$D_H = 125[\sin(h_s)]^{0.4} \quad (4)$$

So, the total solar radiation (G_H) received on the horizontal surface with the use of the following equation (Bernard *et.al.*, 1980):-

$$G_H = D_H + I_D\sin(h_s) \quad (5)$$

The diffuse radiation component (D_i) received by the inclined PV surface can be calculated as follow (Bernard *et.al.*, 1980):-

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

Where α is the reflection factor of the ground (usually taken equal to 0.2) (Romdhane *et.al.*, 2009).

The total solar radiation (G_i) on inclined surface can be calculated from the following equation (Bernard *et.al.*, 1980):-

$$G_i = D_i + I_D\cos(\theta) \quad (7)$$

The incidence angle (θ) located between the normal of the PV panel surface and the solar rays at mid-day can be estimated as follows (Soteris, 2009):-

$$\theta = 90 - (\beta + h_s) \quad (8)$$

Where (h_s) is the solar altitude angle at mid-day and it is can be calculated as shown in following equation (Soteris, 2009):

$$h_s = 90 - \phi + \delta \quad (9)$$

The length of the day (*ΔD*) in hours can be written as clear in the following equation, (Soteris, 2009):-

$$\Delta D = \frac{2}{15}\cos^{-1}\left[-\tan(\delta)\tan(\phi)\right] \quad (10)$$

The solar declination angle (δ) in degrees can be computed as shown in the following equation (Soteris, 2009):-

$$\delta = 23.45\sin\left[360\frac{(284+N)}{365}\right] \quad (11)$$

The received solar energy can be computed for the date out of the date interval from March 21 to September 22 as shown in the following formula (John *et.al.*, 2013):-

$$E = \frac{2}{\pi}\times G_i \times \Delta D \quad (12)$$

While for a PV panels pointed towards the south, and for the date period located between the March 21 to the September 22, the length of the day ΔD is to be corrected to the following formula (John *et.al.*, 2013):-

$$\Delta D' = 12 + \frac{AD-12}{7} \quad (13)$$

Finally, the received solar energy can be computed for the above mentioned date intervals as follows (John *et.al.*, 2013):-

$$E = \frac{2}{\pi}\times G_i \times \Delta D' \quad (14)$$

Results And Discussion:

Figs. (1 through 4) show the effect of slope angle variation (0-90^o) of (PV) panel on the collected solar radiation located in (Zakho, Mosul, Baghdad, and Samawah) cities throughout the year. It is clear from these figures that every month has a peak value of collected solar radiation corresponding to a specific value of panel inclination angle, and this angle represents the optimum PV panel tilt angle at every month. Also, it is clear that the months (June and July) which represent the Summer months in most cities of Iraq give maximum collected incidence radiation on PV panel surface. This is happened due to inclination of earth rotation axis toward the sun in northern hemisphere of earth at Summer months which allows cities that are located in the northern hemisphere to collect more energy.

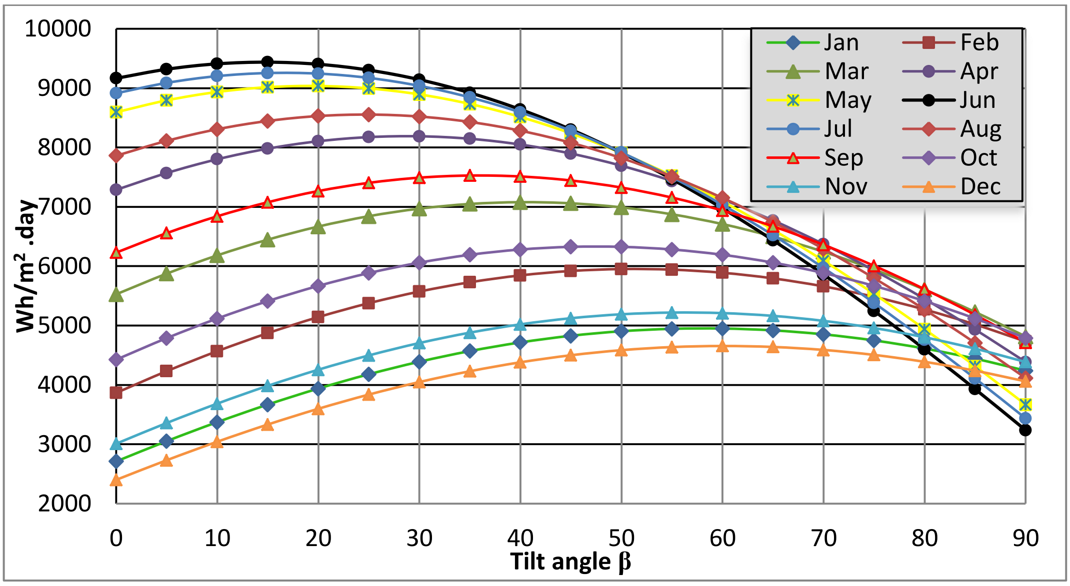

Fig. (1) Monthly total global solar radiation versus PV panel tilt angles over twelve months for Zakho city.

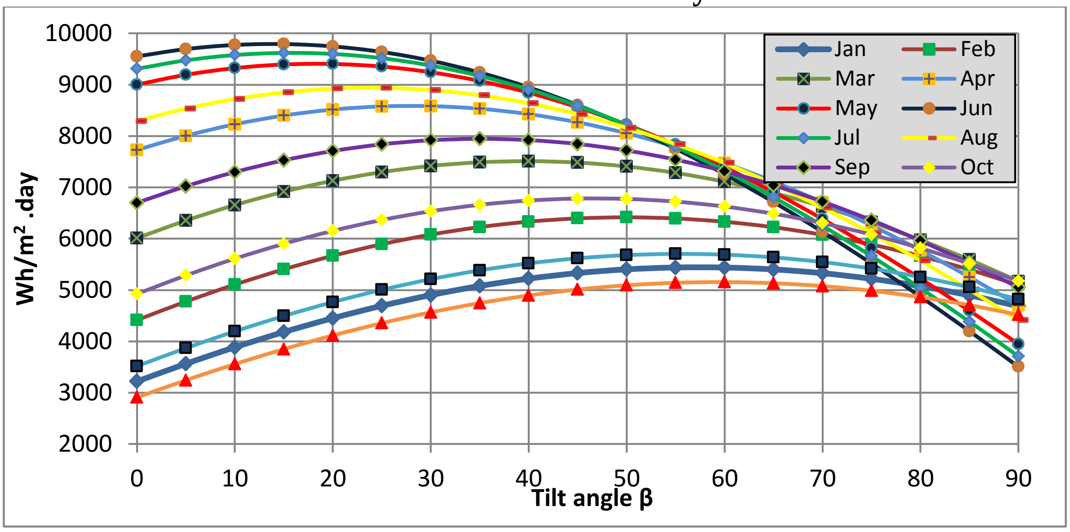

Fig. (2) Monthly total global solar radiation versus PV panel tilt angles over twelve months for Mosul city.

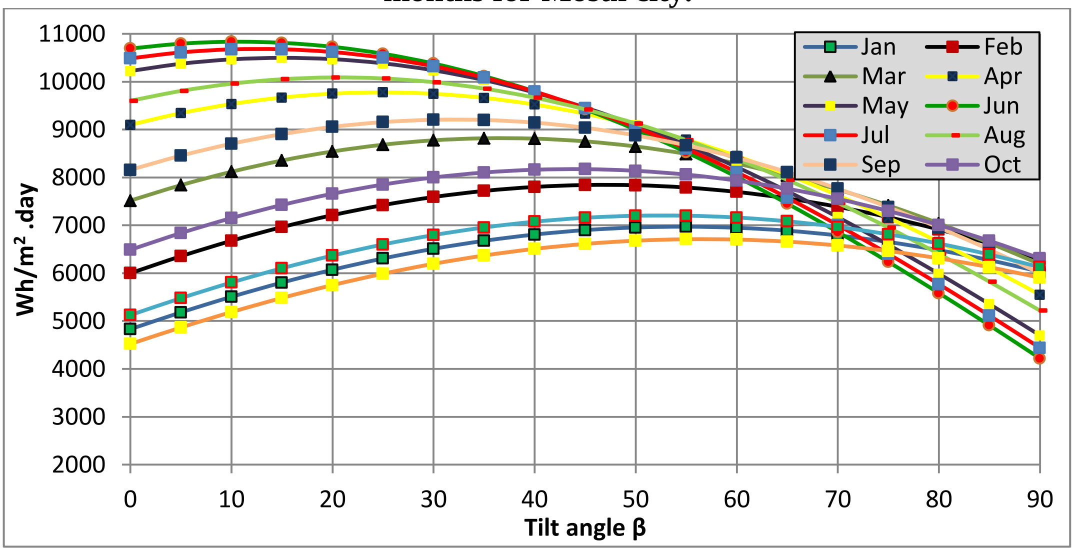

Fig. (3) Monthly total global solar radiation versus PV panel tilt angles over twelve months for Baghdad city.

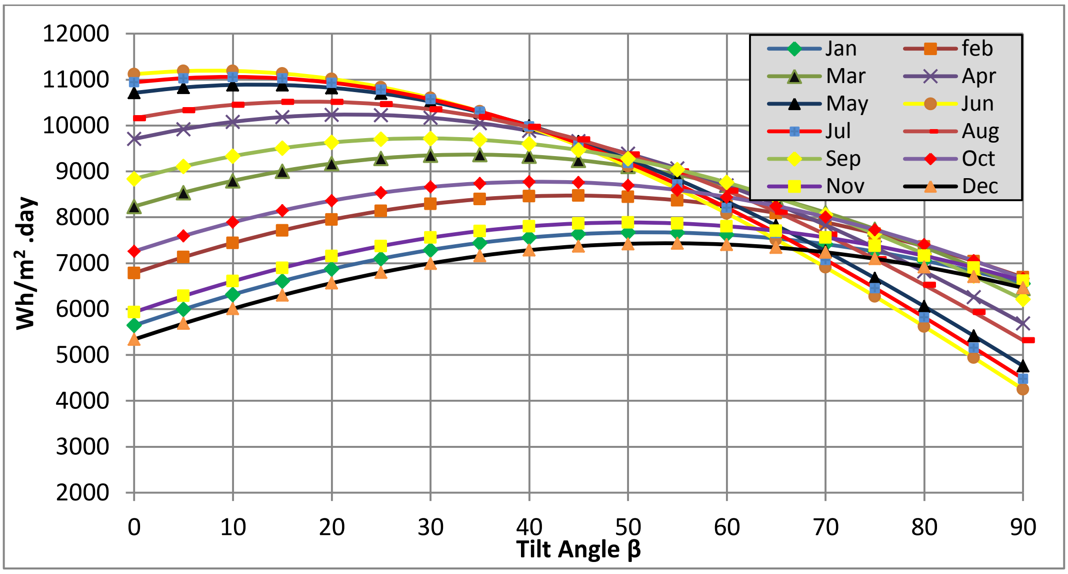

Fig. (4) Monthly total global solar radiation versus PV panel tilt angles over twelve months for Samawah city.

Fig (5) shows the monthly maximum incidence solar radiation at PV panel surface for the four Iraq cities mentioned above corresponding to optimal PV panel inclination angle. As seen, Samawah city has maximum solar radiation received on PV panel surface (especially in June) because it has the lowest latitude than other cities, which means it is the closest city to the equator of other cities. It is known, as the city approaches to equator plane, the incoming solar radiation takes less time and way to reach the earth surface, and it becomes near from orthogonal to that surface which means araise in the collected solar radiation on that surface.

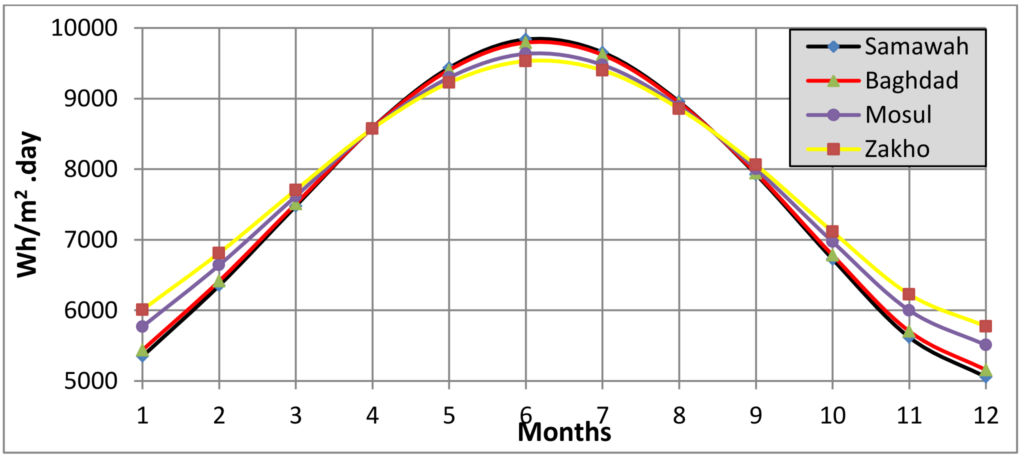

Fig. (5) Monthly total global solar radiation corresponding to PV panel optimum tilt angle over twelve months for (Zakho, Mosul, Baghdad, Samawah) cities.

Fig. (6) shows the optimum inclination angle for the cities mentioned above along the months of the year. As seen, Samawah city (which is located at southern of Iraq) has the lowest tilt angle (less than 10^{o} at Summer months) than the other cities. This fact is due to, as the PV panel approaches to the equator its tilt angle becomes more flatten and approaches to zero (especially in Summer months).

The use of movable PV panel (daily or monthly tracking sun system) is very complex and needs high cost mechanisms. So with optimum yearly tilted angle for the cities mentioned above is more efficient for getting maximum incidence solar energy at panel surface. Thus, the use of stationary PV panel system is more efficient from using tracking system with daily or monthly slope angle variations.

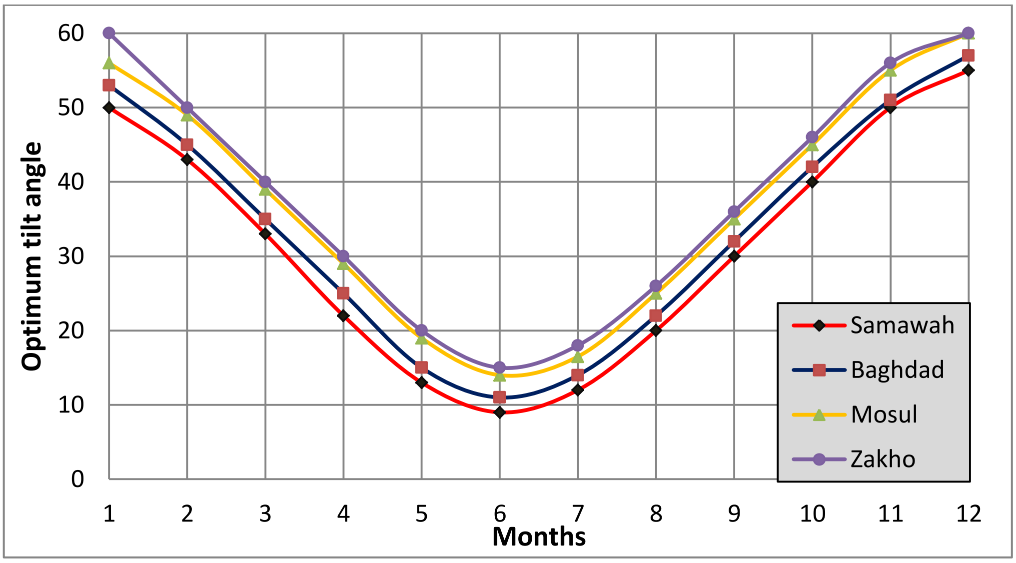

Fig. (6) PV panel optimum tilt angle over twelve months of the year for (Zakho, Mosul, Baghdad, Samawah) cities.

The geographical latitudes and longitudes for (Zakho, Mosul, Baghdad, Samawah) cities are presented in table (1), and the values of monthly, seasonally, and yearly optimal PV panel inclination angle is shown in table (2). The seasonally tilt angle was calculated corresponding to the four climate seasons (Winter, Spring, Summer, and Autumn) in Iraq.

Table (1) Geographical Latitude and Longitude for Iraq cities.

City	Latitude (Deg.)	Longitude (Deg.)	Elevation (m)
Zakho	$37^o10'$ N	42^o 50' E	439
Mosul	$36^o15'$ N	43^o 05' E	230
Baghdad	$33^o20'$ N	44^o 30' E	41
Samawah	$31^o15'$ N	45^o 15' E	15

These seasons can be represented as follows: Summer season (June to August months), Autumn season (September to November months), Winter season (December to February months), and Spring season (March to May months). Thus the seasonally PV panel inclination angles are calculated by taking the mathematical mean for twelve months. Finally, the yearly PV panel optimal slope angle is estimated by taking the mathematical mean for the four seasons to get yearly setting angle for every city.

Table (2) Monthly, Seasonally, and Yearly optimal PV panel tilt angles for (Zakho, Mosul, Baghdad, Samawah) cities.

City	Period	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Zakho	monthly	60	50	40	30	20	15	18	25	36	46	56	60
	seasonal	56.6	56.6	30	30	30	19.3	19.3	19.3	46	46	46	56.6
	yearly	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97	37.97
Mosul	monthly	56	49	39	29	20	14	16.5	25	35	45	55	60
	seasonal	55	55	29.3	29.3	29.3	18.5	18.5	18.5	45	45	45	55
	yearly	36.95	36.95	36.95	36.95	36.95	36.95	36.95	36.95	36.95	36.95	36.95	36.95
Baghdad	monthly	53	45	35	25	15	10	14	22	32	42	51	57
	seasonal	53.6	53.6	25	25	25	15.3	15.3	15.3	41.6	41.6	41.6	53.6
	yearly	33.87	33.87	33.87	33.87	33.87	33.87	33.87	33.87	33.87	33.87	33.87	33.87

Samawah	monthly	50	43	33	22	13	9	11	19	29	40	49	55
	seasonal	49.3	49.3	22.6	22.6	22.6	13	13	13	39.3	39.3	39.3	49.3
	yearly	31.06	31.06	31.06	31.06	31.06	31.06	31.06	31.06	31.06	31.06	31.06	31.06

Furthermore, a correlation equation (liner and quadratic) for the best slope angle based on the declination angle are applied and inspected for the four cities mentioned above to validate the Bernard-Menguy-Schwartz model. The linear and quadratic correlation equations can be presented as follows:-

$$\beta_{opt} = a - b \times (\delta) \qquad (15)$$

$$\beta_{opt} = a - b \times (\delta) - c \times (\delta)^2 \qquad (16)$$

The optimal PV panel inclination angles for (Zakho, Mosul, Baghdad, and Samawah) cities in the twelve months using Bernard-Menguy-Schwartz model, linear, and quadratic equations are indicated in table (3).

Table (3) Bernard *et. al*., Linear, and quadratic equations to compute optimal PV panel tilt angles for (Zakho, Mosul, Baghdad, Samawah) cities.

City	Model	Months											
		Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
Zakho	Bernard *et. al.*	60	50	40	30	20	15	18	25	36	46	56	60
	Linear	58.2	50.5	40.4	28.9	19.9	15.7	17.6	25.1	35.9	47.3	56.3	60.3
	Quadratic	58.3	50.5	40.2	28.8	19.9	15.9	17.7	25.2	35.7	47.2	56.3	60.4
Mosul	Bernard *et. al.*	56	49	39	29	20	14	16.5	25	35	45	55	60
	Linear	56.9	49.1	39.2	27.9	19.1	15.1	16.8	24.2	34.8	45.9	54.8	58.7
	Quadratic	56.7	49.2	39.3	28	19.1	15	16.8	24.2	34.9	46	54.8	58.7
Baghdad	Bernard *et. al.*	53	45	35	25	15	10	14	22	32	42	51	57
	Linear	53.3	45.7	35.8	24.6	15.7	11.6	13.4	20.7	31.4	42.6	51.4	55.3
	Quadratic	53.4	45.7	35.7	24.5	15.8	11.8	13.6	20.7	31.3	42.6	51.5	55.5
Samawah	Bernard *et. al.*	50	43	33	22	13	9	11	19	29	40	49	55
	Linear	51.1	43.5	33.4	22.1	13.1	9.1	10.9	18.2	28.9	40.3	49.1	53.1
	Quadratic	50.3	43.2	33.1	21.7	12.6	8.2	10.1	17.8	28.7	40	48.5	52.3

Finally, table (4) presents the correlation equations coefficients, (*a*, *b*, and *c*), the regression coefficients (*R*) and the root mean square error (*RMSE*) for (Zakho, Mosul, Baghdad, and Samawah) cities respectively.

Table (4) Regression coefficients and statistical errors (*RMSE*, *R*) using Eqs. (15) and (16) for (Zakho, Mosul, Baghdad, Samawah) cities.

City	Equation	*a*	*b*	*c*	*RMSE*	*R*
Zakho	Linear	38.0	-0.965	----	0.577	0.998
	Quadratic	37.8	-0.965	0.000584	0.577	0.998
Mosul	Linear	36.9	-0.946	----	0.241	0.998
	Quadratic	37.0	-0.946	-0.000212	0.213	0.998
Baghdad	Linear	33.4	-0.954	----	0.089	0.998
	Quadratic	33.4	-0.954	0.0000242	0.140	0.998
Samawah	Linear	31.1	-0.955	----	0.376	0.999

	Quadratic	30.8	-0.955	0.00103	0.418	0.999

The precision of the used model was investigated using the root mean square error (*RMSE*) and the correlation coefficient (*R*). The average value of the correlation coefficients for these cities was close to 0.998, and the general results showed that the best inclination angle for PV solar panels obtained from these correlation equations approach to Bernard-Menguy-Schwartz model.

The (*RMSE*) test provides information about the performance of the proposed model as it allows a comparison of the actual deviation between the used model results values and the correlated equations values. Many literatures like (Iqbal, 1983), and (Almorox *et.al.*, 2005) have recommended that a low *RMSE* value is desirable.

Conclusion:

The photovoltaic panels optimum inclination angle have been investigated in order to get maximum incident solar radiation value using Bernard-Menguy-Schwartz model for some Iraqi cities. Due to complexity of tracking mechanism, it is proper to put the PV panels at fixed tilt angle throughout the year. To validate this model, a linear and quadratic correlations equations are used depending upon sun declination angle for these cities to show the degree of agreement to that model. The results of correlations equations gave a good agreement with Bernard-Menguy-Schwartz model, so that the correlation coefficient (*R* close to 0.998) for all cities. The normal results showed that the PV panels optimum inclination angle seems to be close to latitude of these cities.

Nomenclature

Symbols	**Definition**	**Unit**
D_H	Diffused solar radiation received on the horizontal surface	W/m^2
D_i	Diffused solar radiation received on the titled surface	W/m^2
E	Energy theoretically received per square meter 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 surface	W/m^2
h_s	Solar altitude angle at solar noon	Degrees
N	Number of the day	
I_D	Beam solar radiation	W/m^2
θ	Angle established by the orthogonal to the panel and solar radiation incident to that panel	Degrees
α	Ground albedo	
β	Photovoltaic panel tilt angle	Degrees
β_{opt}	Panel optimum tilt angle	Degrees
δ	Sun declination angle	Degrees
ϕ	Latitude of the place	Degrees
ΔD	Number of the daylight hour	Hours

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