OPTIMUM YEARLY TILTED ANGLE OF PHOTOVOLTAIC CELL TO RECEIVE MAXIMUM SOLAR RADIATION IN SOUTHERN IRAQ CITIES

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Abstract:

The performance of photovoltaic cell is affected by the value of its tilt angle with respect to horizontal plane, where the variation of tilt angle changes the amount of solar radiation permit to the photovoltaic cell surface. So that, the using of solar tracking system for photovoltaic cell will get the maximum solar radiation that permit to the surface of the cell at any time and day of the year, but the solar tracking systems have high operation and maintenance costs and are not always applicable. It is often convenient to set the solar collector at an optimum fixed tilt angle over a time of the year with less reduction in solar radiation received in the cell surface.

This work is to find an optimum tilt angle of photovoltaic cell located in southern Iraqi cities Basrah city (latitude 30.30°), Amarah city (31.55°) and Nasiriyah (31°). A mathematical models was used and programed by engineering equation solver EES to find an optimum tilt angle depending on the maximum solar radiation, the tilted angle varied with range from 0° to 90°. The results showed that the optimum tilt angle for Basrah is 28°, where for Amarah is 30° and for Nasiriyah is 29°.

الخلاصة:

يتأثر اداء الخلية الشمسية بزاوية الميل عن المستوى الافقي، حيث ان تغيير زاوية الميل تغير كمية الاشعاع الشمسي الواصل لسطح الخلية الشمسية. لذلك فان استخدام منظومة التتبع الشمسية سيمكن من الحصول على اقصى كمية من الاشعاع الساقط والواصل لسطح الخلية في أي وقت من اليوم وفي أي يوم من ايام السنة . هذه المنظومة تمتاز بكلفة عمل وصيانة عالية ولا يمكن تطبيقها دائما. في الغالب يكون من المناسب ضبط المجمع الشمسي على زاوية ميل مثلى ثابتة على مدار السنة بأقل نقص في كمية الاشعاع الاشعاع الواصل والساقط على سطح الخلية.

تم في هذا البحث ايجاد زاوية الميل المثلى للخلية الشمسية عن المستوى الافقي في المنطقة الجنوبية من العراق والتي هي مدينة البصرة (على خط عرض°30.30) وفي مدينة العمارة (على خط عرض °31.55) وفي مدينة الناصرية (على خط عرض °31). تم استخدام موديل رياضي لإيجاد زاوية الميلان المثلى من خلال برمجته وتحليله باستخدام برنامج EES بالاعتماد عل اقصى كمية للإشعاع الشمسي الساقط، حيث ان زاوية الميلان تتغير من 0^0 لغاية 90^0.

اظهرت النتائج بان زاوية الميلان المثلى لمدينة البصرة هي (°28) و لمدينة العمارة (°30) و لمدينة الناصرية (°29).

1- **Introduction**:

The ozone layer, which considered the "protective shield against ultraviolet radiation" ,regulates the amount of radiation that reaches Earth's surface. The ultraviolet radiation can cause non-melanoma and malignant melanoma skin cancer. It can also have negative effects on plant growth, marine animals, and normal ecological cycles in nature. Yet in the 1977s it was discovered that Because of the actions of humans, the ozone layer is deteriorating by emissions into the atmosphere from industrial [1]

The Greenhouse Effect produces rapid and alarming warming of the lower level atmosphere. It is caused by the presence of greenhouse gases (GHG) which trap heat that would otherwise escape into space. The most significant cause of the increased greenhouse effect and global warming is the 30% increase in atmospheric carbon dioxide (a well-known GHG) since 1950. Present carbon dioxide concentrations have not been seen in 20 million years. It is estimated that ¾ of the GHG emissions in the last 20 years. According to the World Health Organization (WHO), global warming killed 150,000 people in the year 2000 and this number could double in the next decade [1].

At 1997, in Kyoto a protocol was written, which an effort to work toward sustainable development. The Kyoto Protocol was signed by more than 55% of the countries worldwide. The goal of the Kyoto Protocol is to reduce the emissions levels of 6 major greenhouse gases in 1990 by 5.2% between the years 2008 and 2012[2]. Only developed countries have been able to quantify their commitment to emissions reduction.There for the use of energy source with no emission of Co2 is a good choice for reducing the effect of global warming

Renewable energy technologies are those that provide energy from a source considered inexhaustible (i.e. the sun, wind, biomass, river water, etc.). Within renewable, the potential of

solar technologies has recently caused a large increase in its development, the use of renewable energy technologies is an effective way to reduce emissions.

Solar energy technology is one of the best solutions for future energy production. It is clean which produces no fossil fuel emissions. Combustion does not occur within a solar energy system, storable and will eventually be less expensive than fossil fuel.

The characteristics of solar energy make it well suited to supply peak electricity demands. In the southern Iraq cities which receive high solar radiation, in these cities the summer peak demands have become overwhelming give strong pressure to the installation of solar plants is ideal in this cities as the "solar belt"

Photovoltaic cells are the one of common type of the form of solar energy collector it convert solar radiation into electricity. The performance of the Photovoltaic cells is highly dependent on its orientation, cell tilted angle, optical and geometric properties, macro and microclimatic conditions, geographical position, and the period of use (Ashok Kumar,2011). The tilt angle, defined as the angle of PV arrays with respect to horizontal.It is a dominant parameter affecting the collectible radiation of a fixed PV array.

Many studies show that the optimum tilt angle depends on latitude angle (λ), solar declination angle or days of the year [6]. Soulayman et al showed the optimum tilt angle is almost equal to the latitude [3].Where other show the daily solar energy collected was reported to be 19 to 24% higher by a solar PV panel with one axis east-west tracking system than by a fixed system [4] **.**Hamdy K.Elminir et al showed the yearly optimum tilted angle for Helwan Egypt is about (latitude ± 15°) where (+)refer to summer and(–)refer to winter [5].Koray reported that the optimum orientation of the PV array should be directly towards the equator, facing south in the northern hemisphere and the optimum tilt angle depends only on the latitude [6]**.** Kamal Skeiker (2009)show that the changing of the tilt angle of PV cell located in Syria by 12 times in a year achieves a solar radiation of approximately 30% more than the case of a solar collector fixed on a horizontal surface[9]. Ashok Kumar et al. found the optimum tilted angle for PV cell array in Punjab India changes between 60.5° (January) and 62.5° (December) throughout the year [11].

2- Mathematical Method for Finding the Optimum Tilted Angle:-

The total daily irradiation on a horizontal plane is the combination of two components, the direct irradiation and the diffuse irradiation from the sky [11]

In this study the Bernard-Menguy-Schwartz model is used to find the optimum tilt angle (β) of photovoltaic cell solar collector in southern Iraq cities because it's more simple correlation than other authors and predicted to northern hemisphere [10].

In Bernard-Menguy-Schwartz model the direct radiation under three conditions of sky,they are :

a- Clear Sky:

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

b- Very Clear Sky:

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

c- Polluted Sky:

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

The diffused radiation (D_H) for any sky conditions:-

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

The total radiation received(G_H) by the horizontal plane is:-

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

The Diffuse (D_i) and the total radiations (G_i) receipts by the inclined collector plane are :

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

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

Where the factor α is the coefficient of reflection of the ground located in front of the collector (usually taken equal to 0.2)[10]. The angle θ formed between the normal of the collector and the solar rays at solar midday that shown fig(1) is define by:

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

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

The duration of the day (ΔD) is given by:-

$$\Delta D = \frac{2}{15} arccosh(-tan(\varphi) . \tan(\delta)) \quad (10)$$

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

The received energy is given by:

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

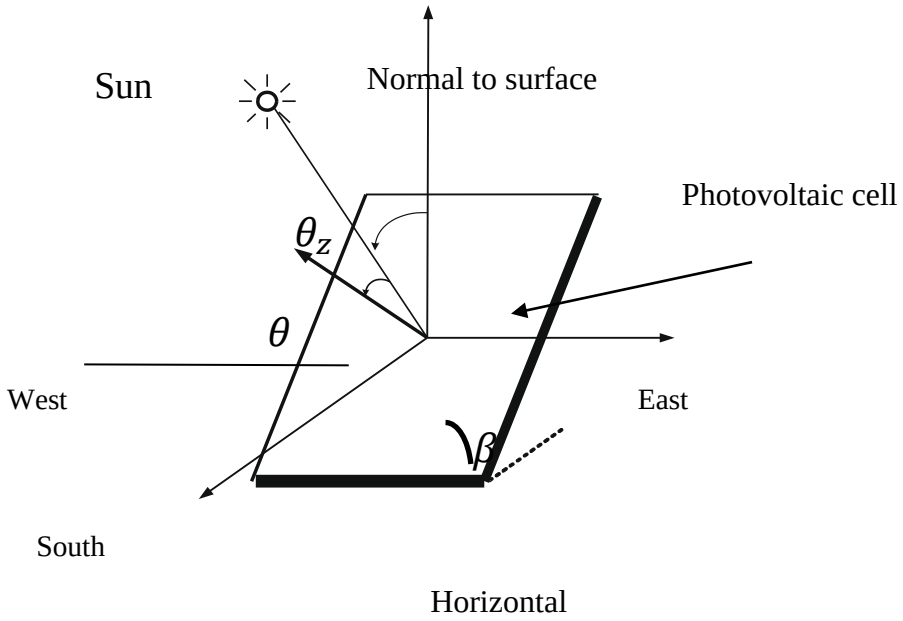
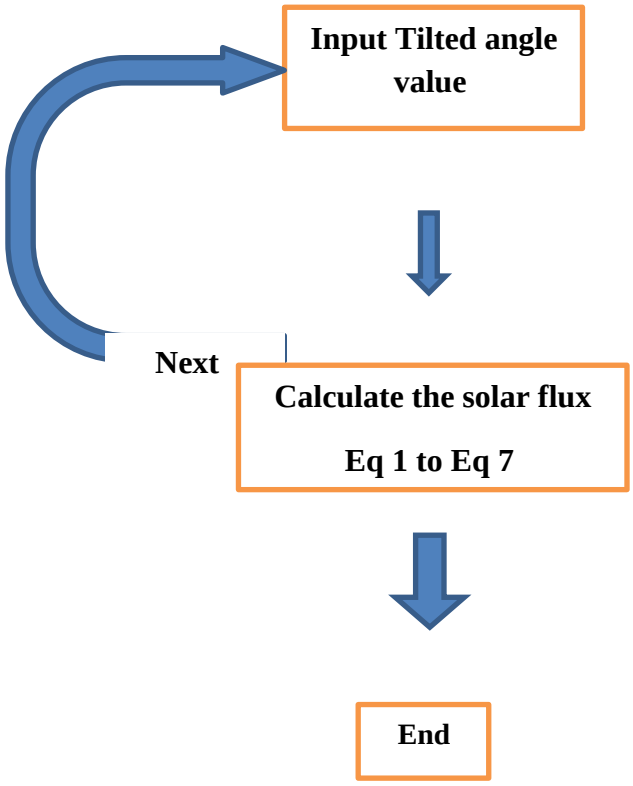


Fig (1) Common Angles in solar application [6]

3-System modeling:

The tilted angle model is programmed using Engineering Equation Solver (EES); all governing equations are performed on EES. EES incorporates the programming structures of C and FORTRAN with a built-in iterates, thermodynamic and transport property relations, graphical capabilities, numerical integration, and many other useful mathematical functions. By grouping equations that are to be solved simultaneously, EES is able to rapidly solve large numbers of transcendental equations. In this study an exact solution is used as a way to solving the module, The Flow chart of the present program is shown below.



Fig(2) System modeling Flow chart

4- Results and Discussion:

4-1 Monthly Optimum Tilted Angle:-

Fig (3) shows the effect of tilted angle variation of photovoltaic (PV) cell on the collected solar energy located in Basrah city for all months of the year. From this figure, as the tilted angle increases the collected solar energy flux will increase until reach to maximum value due to the increasing in the amount of the solar radiation normal component that incident to the cell surface .After this value of tilted angle the collected solar energy flux will decrease, therefore the optimum monthly tilted angles can be indicated. Each month has its optimum tilted angle due to the difference in solar characteristics of these months (solar day number that affect the declination angle).

From Fig(3) , the maximum solar flux occurs at Jun ,that is due to high angle of declination .the higher angle of declination leads to reduce the path of the sun ray, so it reduces

the solar beam absorbing and scattering and increased the flux of solar energy that reaches to earth surface see Fig(4) and Fig(5)

Fig (6) show the effect of tilted angle of PV cell variation on the collected energy located in Amarah city, where Fig(7) show the effect of tilted angle of PV cell variation on the collected energy located in Nasiriyah city for all months of the year . From these figures, these cities (Basra ,Amarah and Nasiriyah) have different in

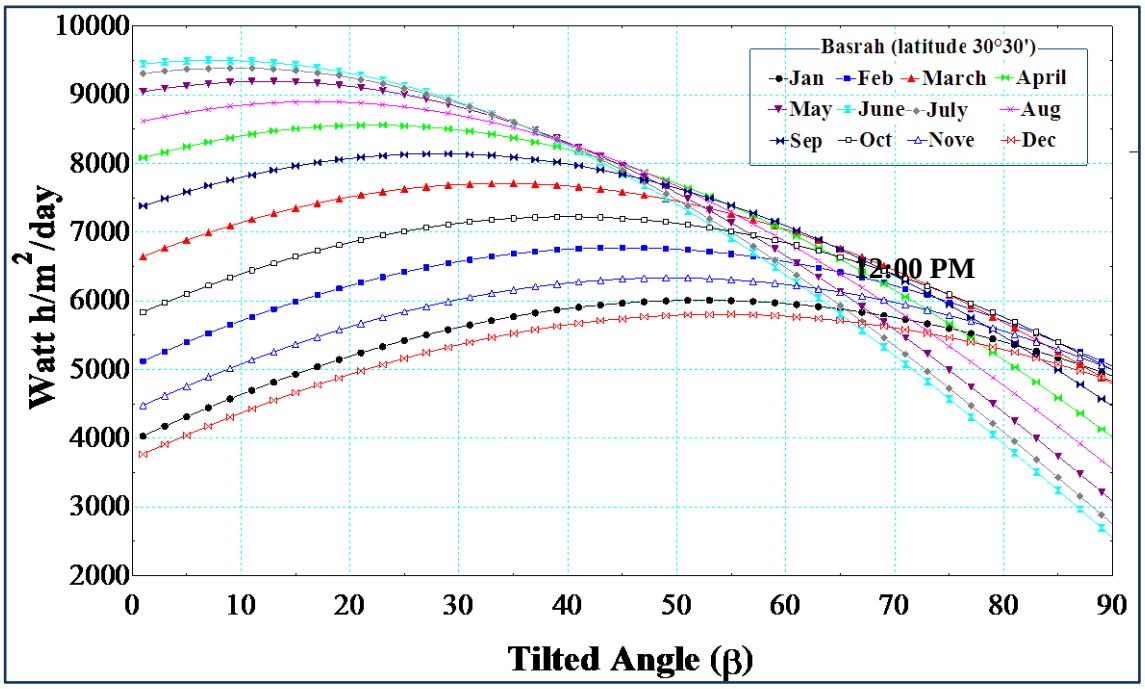


Fig (3) Effect of PV Cell Tilted Angle Variation on Collected Solar Flux located at Basrah city around months of the year

longitude and latitude therefore for this reason the optimum monthly tilted angle of these cities will different from one to other. And The total solar radiation was the highest in Basrah city because it has the nearest latitude angle from equator as compared with other cities (Amarah and Nasiriyah) .

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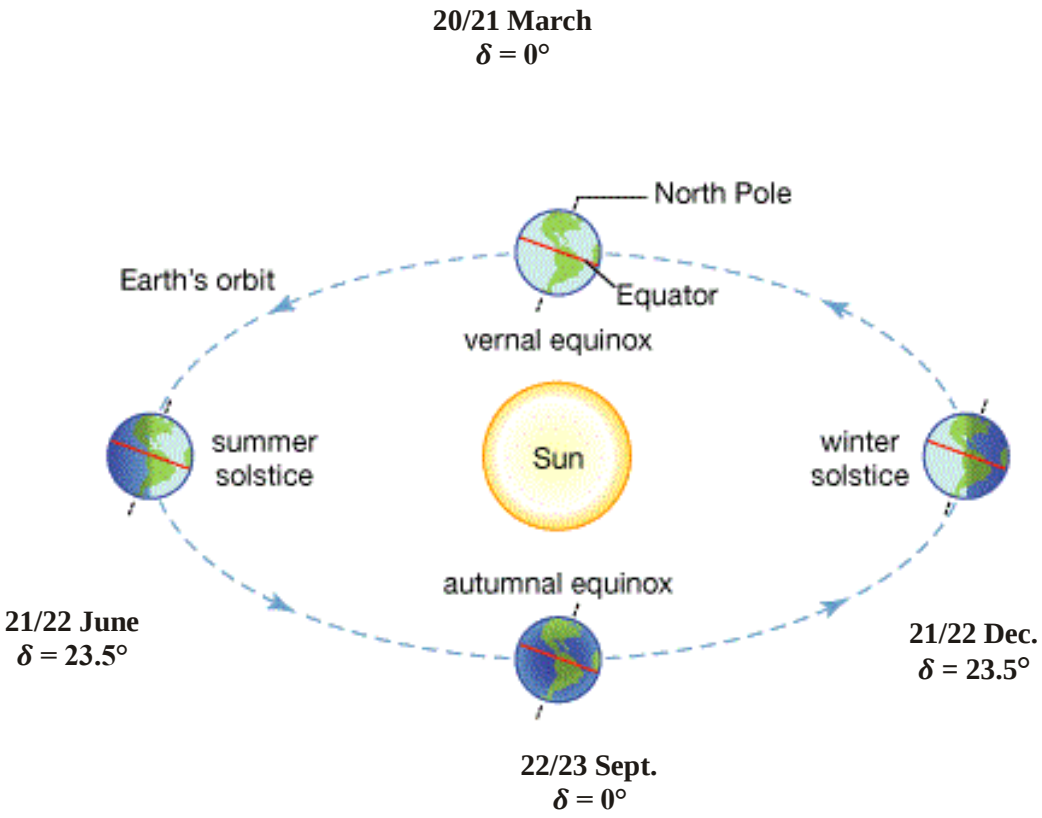

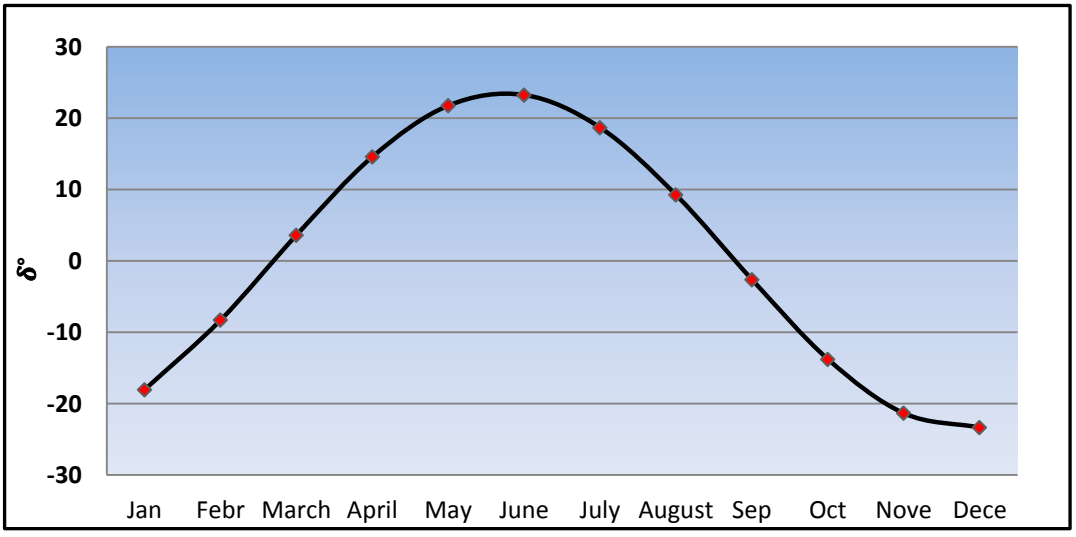

Fig (4) Ecliptic plane and position of the earth at the winter and summer solstices, and also at the spring and autumn equinoxes[12]

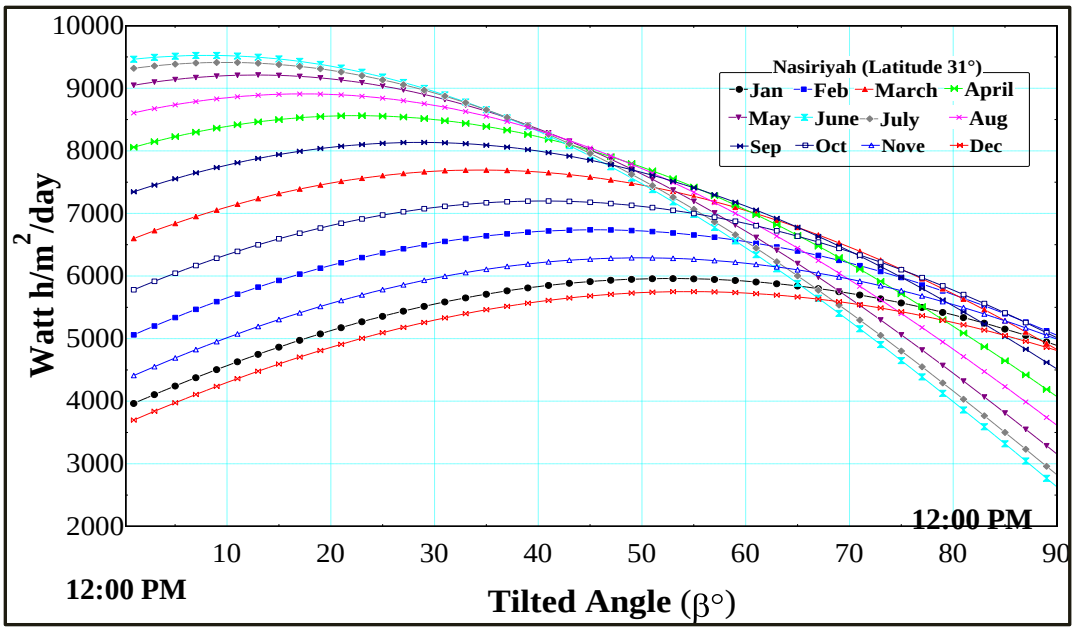

Fig (6) Effect of PV Cell Tilted Angle Variation on Collected Solar Flux located at Nasiriyah city around months of the year

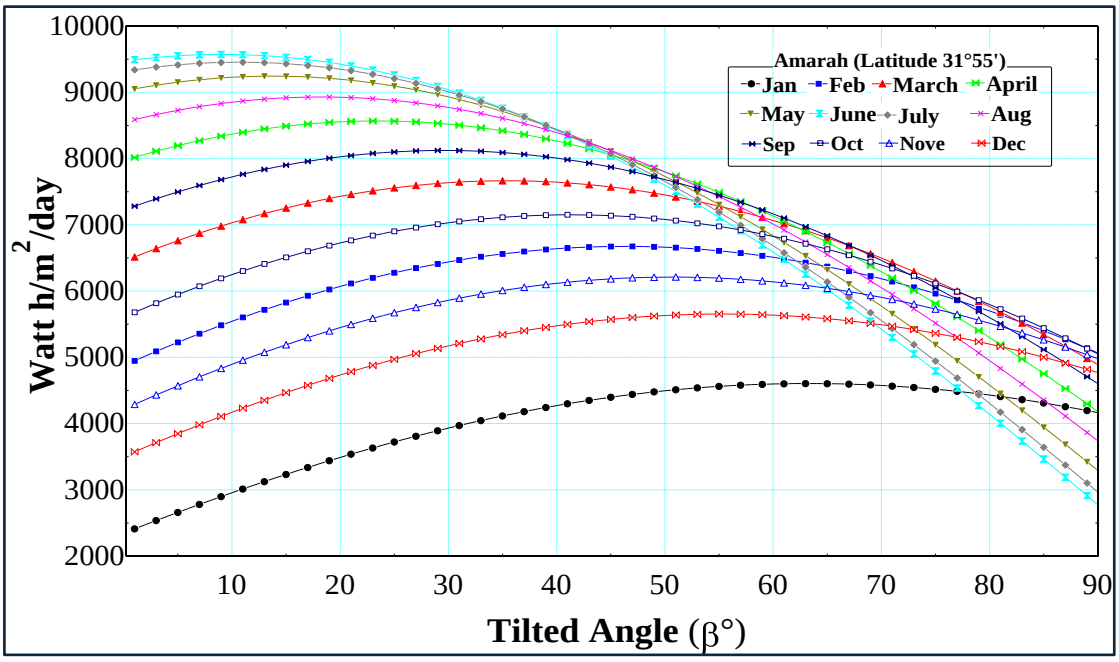

Fig (7) Effect of PV Cell Tilted Angle Variation on Collected Solar Flux located at Amarah city around months of the year

4-2 Yearly Optimum Tilted Angle:-

The using of stationary system with optimum yearly tilted angle is more efficient from using tracking system with daily or monthly tilt angle, because of tracking system maintenance cost and energy requirement to operate the system.

The tilted angle varies over range from 0° to 90°. The variation of tilted angle was adopted over the days of the year, and an average value of collected solar energy was taken as a method to find the collected energy by any tilted angle.

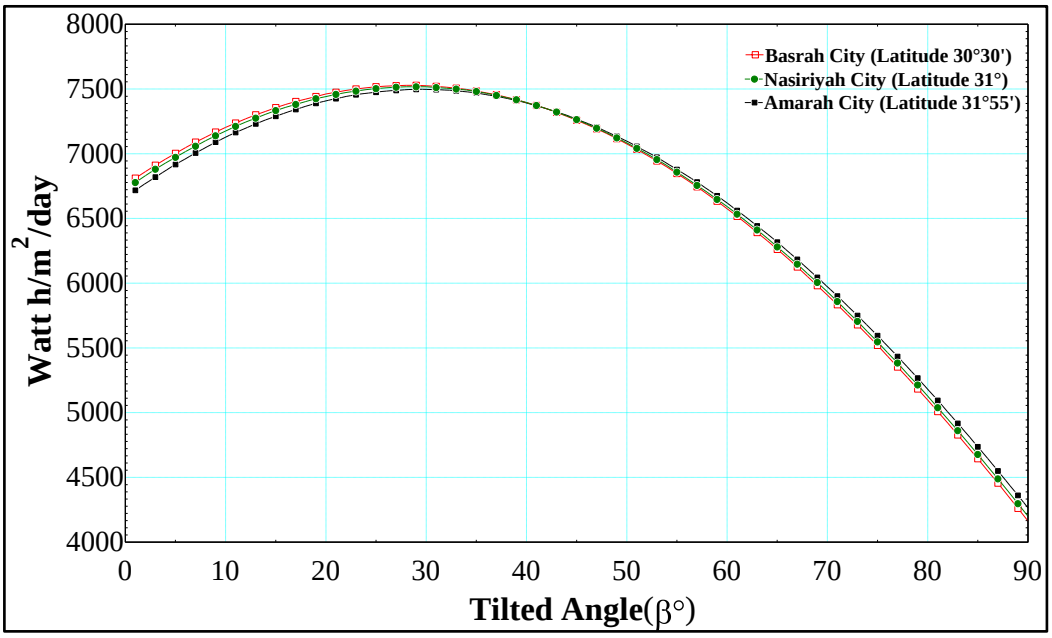

Fig (8) Effect of PV Cell Tilted Angle Variation on Collected Solar Flux located at Amarah city around months of the year

Fig (8) gives solar energy flux around the year for three cities Basrah, Nasiriyah, and Amarah, From this figure there is one angle that give overall maximum value of collected solar energy flux . This value of angle can be taken as optimum yearly tilted angle, so that this angle will deferent from monthly optimum tilted angle with less decrease in collected energy as compared with monthly optimum tilted angle that give the highest solar energy at the same day of the year (12% less from solar energy collected with optimum monthly tilted angle at April for Basrah city) .

CONCLUSION

Many recent studies shows that the optimum tilted angle of photovoltaic cell is approximately equal to the latitude at the given location, this study showed that the optimum tilted angle(monthly or yearly) is not equal to the latitude of the city.

From results the optimum monthly tilt angle of the given location is differs from month to other due to deferent in the declination angle , and the maximum solar flux occurs at Jun which have high declination angle.

Also showed that the optimum yearly tilt angle for Basrah city (latitude 30° 30")is 28°, where for Amarah city (latitude 31° 55") is 30° ,and for Nasiriyah city(latitude 31°) is 29°.From all these values the optimum tilted angle is not equal to latitude of the given location.

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Nomenclature

Symbols	Description	Unit
D_H	Diffused solar radiation received by the horizontal plane	W/m^2
D_i	Diffused solar radiation received by the titled photovoltaic cell	W/m^2
E	Energy theoretically received per $m^2$and per day	$kWh/m^2/day$
G_i	Global solar radiation received by the collector	W/m^2
G_H	Global solar radiation received by the horizontal plane	W/m^2
h_s	Height of the sun at true solar midday	(°)
N	Number of solar day	
I_D	Direct solar flux	W/m^2
θ	Angle formed by the normal to the collector and the solar rays incident to the collector	(°)
θ_z	Azimuth angle	(°)
α	Albedo	

β	Photovoltaic cell tilted angle	(°)
φ	Latitude of the city	(°)
δ	Declination angle of the sun	(°)
ΔD	Duration of the day	