Sarah Ali Al-shammari
Phd Student
Mechanical enginering department
University of technology, Baghdad
Iraq

AbdulHassan A. Karamallah
Professor
Mechanical Engineering Department
University of Technology, Baghdad
Iraq

Sattar Aljabair
Assistant Professor
Mechanical Engineering Department
University of Technology, Baghdad
Iraq

Optimization of Tilt Angle and Experimental Study of Standalone PV System for Clean Energy Home Supply in Baghdad

The performance of the system of the solar radiation conversion is influenced via the angle of tilt with a horizontal plane; therefore, the photovoltaic array requires to be tilted at the right angle for maximizing the system conversion efficiency. The present paper has been carried out monthly at the optimum tilt angle numerically with an experimental system set up for home supply in Baghdad city (latitude 33°20'). Mathematical models were programmed by MATLAB to predict the solar energy incident on the surface all day of the year at angles from (0-90^0). Experimental results manifested the performance of photovoltaic panel (PV) to provide a home with a light energy use in the shortcut electricity. The solar power system output is a function of the solar radiation. The high output of power was between (11.00 am) and (1.00 pm), which matches the high-power output time. The monthly optimum tilt angle can vary significantly during the year between 18^o in summer to 65^o in winter season.

Keywords: Solar energy, Photovoltaic cell, Optimization, Tilt angle

1. INTRODUCTION

By slow growing of the solar energy demand in the world, the solar energy conversion common. For removing the dependence upon the fossil fuel, fresh choices are studied for developing the hygienic and maintainable energy for the universe[1]. The solar energy is hygienic ordinary supply utilized straight via photovoltaic module and thermal collector everywhere in the universe. The photovoltaic module or the thermal collector performance depends upon the solar radiation quantity that attains to it. Solar radiation relies on the period, site and location of the panel with regard to the sun [2,3].

One third of the world population of (6) billion is in the evolving states. Numerous of such people are lacking the admittance to the contemporary energy facilities for the social and the economic evolution, and certain of their current systems of energy are unmaintainable. The appearance of the regular crisis of fuel in the majority of the evolving states has taken the consideration to the requirement for the energy specialists for more concentrating upon creating the feasible substitute [4].

The (PV) panels resulted energy is influenced via various variables, such as the temperature of environmental, irradiation, and the (PV) set point control with its voltage-current feature. Recently investigators have made great efforts for getting the ultimate energy creation of the (PV) panels that are classified into two groups. The 1st group included an investigation conducted upon the ultimate power point tracking of the (PV) panels having various electrical controllers. The 2nd group involved an investigation mainly considered the features of solar system, like the angle of tilt upon the attained solar radiation impact upon the (PV) panel surface.

The (PV) arrays angle with regard to horizontal is a prevailing variable influencing the collected radiation of a fixed (PV) array. Generally, the optimum angle of the tilt of a fixed (PV) array is connected to the local climatic state, the geographical latitude, and its usage time. Therefore, various positions will possess the optimum angles of tilt for an annually-utilized solar (PV) array. Until now, several investigations upon the optimum angle of the tilt of (PV) arrays have been carried out and many experimental correlations to estimate the optimum tilt angle are accessible in the literature[5,6].

Due to the goals of the present research, the optimum angle of the tilt of PV panels, is computed and headed to the stated 2nd group. When the rays of the sun are normal to the absorbing surface, the density of energy upon the surface equals the density of incident energy. Nevertheless, as the tilt angle between the absorbing surface and the sun varies, the intensity upon the surface is decreased. If the module being parallel to the sun's rays, i.e., the angle of the module is perpendicular (90°), the light intensity fundamentally reaches approximately zero. Thus, at any specified instant, an array is going to create an ultimate result if focused straight at sun [7,8].

All techniques used in the past for optimizing the angle of tilt for various locations around the globe upon the foundation of monthly, seasonally, bi-yearly and annually were covered via [2]. Such review would be advantageous for more investigation in the solar energy

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Correspondence to: Sarah Ali Al-shammari, PhD student, Mechanical enginering department, University of technology, Baghdad, Iraq
E-mail: 21552@student.uotechnology.edu.iq
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for identifying the optimum angle of tilt and the radiation gathering for various sites in the world.

The algorithm used for improving the photovoltaic performance and optimizing the solar tilt angle to maximize the PV generation for three sites (Najaf, New Delhi, California) was solved by MATLAB. The output depicted an improvement of 18% in the power output in winter for al-Najaf city [9]. A mathematical procedure comprising the equation of Cooper and the progra–mming of the Visual Basic Application (VBA) in Mic–rosoft Excel was used for determining the optimal angles of tilt for solar collectors set up in Kuala Lumpur in Malaysia. The result indicates that the worst inf–luences of shading occurred in December, and the optimal flat distance between the rows of solar collector for a flat area was (2.66 m) for a collector of (2 m) height, in the meantime, for an area having steps and an inclined field, the solar panel preparation is relied upon to the tilt angle *(ß)* introduced in the pertinent graphs [10].

Engineering equation solver (EES) utilized for predicting the monthly and annually optimal angle of tilt for the photovoltaic cells situated in more than sites in Iraq are relying upon the ultimate intensity of the resulted solar power, the angle of tilt changed over a range (0° - 90°). The outputs manifested that the optimal angle of tilt for the whole cities is similar for (31°), and the monthly angle of tilt was dissimilar from any month to other [11]. In China cites, researchers determined the optimum angle for PV panel by Harmony Search (HS) Meta Heuristic Algorithm and utilized the ergodic technique performed for obtaining the optimal angle of tilt as well as the optimal azimuth angle depending upon the Julian dating model. The presentation of the Harmony Search technique was compared with that for the ergodic technique and the other optimization algorithms. The outputs exhibited that the angle of tilt has to be varied once per month, and the best orientation is typically toward the south in the chosen cities. Additionally, the Harmony Search algorithm is an applicable and dependable substitute to estimate the optimal angle of tilt in addition to the optimal azimuth angle of the (PV) panels [12]. In Jourdan, the use of a confirmed model to calculate the solar irradiation upon the south facing tilted surfaces in Ma’an area was evaluated, also the optimum angles of tilt to maximize the gathered radiation were studied in Jeddah in Saudi Arabia for analysing the optimum orientation and the tilt angle effects on the photovoltaic module performance (PV) [13,14] .

Experimentally, many researchers who studied the optimization of tilt angle, improved the performance of the (PV) system and maximized the power output of solar cell in more sites by using a tracking system. The investigation suggests a technique to harness the ultimate output from the (PV) panels through the year via obtaining the optimum angle of tilt. A study was conducted upon the real-time solar (PV) panels having a rated capacity of (5 kW) and set at an angle of (10°), (20°), (25°), (30°), and (40°) upon the roof of an Engineering Institute located at Chandigarh in India [15], while[16] studied four different models of PV and changed the orientation and analysed the relation between the power and incident radiation value by the real data of measurement for Kitakyushu city. Then, a procedure of computation for the optimum angle of tilt was introduced utilizing horizontal and diffuse radia–tion. This procedure was confirmed throughout a com–parison with the data of experiments. Additionally, the sensitivity of the optimum angle of tilt to the rate of radiation, rate of reflection solar declination and latitude were studied throughout parameter analysis. The maxi–mum generation of solar power with the angle of tilt optimization was obtained utilizing the technology of advanced mirror because the extremely polished mirror enhanced the reflected solar radiation efficiency via raising the incoming solar radiation intensity upon the (PV) panel [17].

The aim of present research is to provide a confirmed simple model to predict the solar radiation upon the tilted surfaces having various orientations. A model will be presented and utilized for generating the optimum circumstances at which the received solar power can be at an optimized angle for the home energy supply in Baghdad city to provide clean energy.

2. THE METHODOLOGY

The article's structure is drawn to concisely describe the models to estimate the solar radiation and the expe–rimental work for the (PV) prototype system, as shown in figure [1].

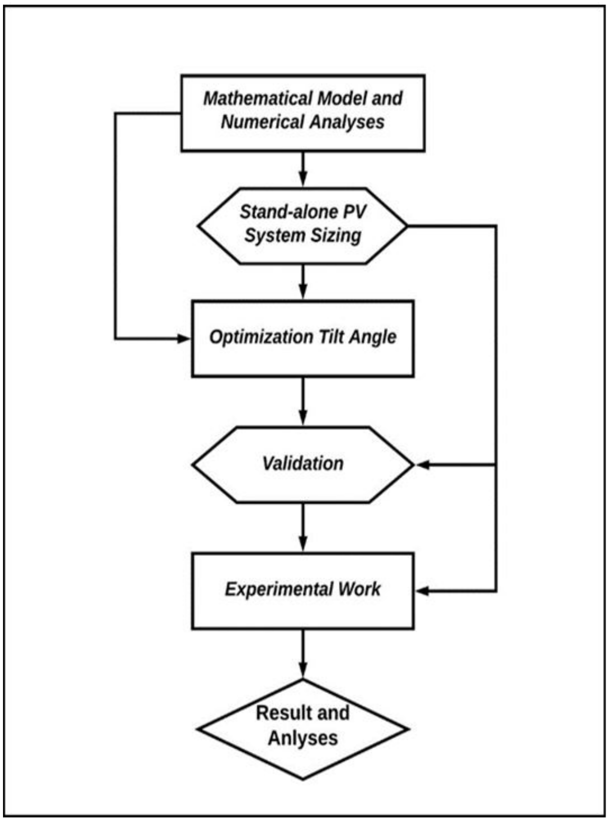


Figure 1. Flow chart of work

3. System Modeling

The tilt angle model is programmed, and the results of numerical simulation are obtained by MATLAB R2014a.

3.1 Solar Radiation Calculations

The solar radiation incident on a surface consists of beam as well as diffuse radiation. The beam radiation is defined as the solar radiation taken from the sun without being scattered via the atmosphere, while the diffuse radiation is the solar radiation taken from the sun beyond its direction being varied via scattering through the atmosphere. Deficient these or the data from adja–cent sites of alike climate, it's likely to utilize experi–mental relations for estimate radiation from the cloudi–ness or sunshine hours. The solar radiation attaining the surface of earth relies upon the state of climatic of the particular site position, also this's necessary for the precise prediction and the solar energy system design [18]. In this section of work, the model of Liu and Jordan is considered for predict both the monthly and daily optimum tilt angle for the PV cells. The benefit of such model compared with the others being that it's capable to create the solar flux taken at the level of ground for various sky circumstances and various tilts of surfaces from (1^o – 90^o). The direct irradiation upon an inclined plane at an angle of (β) is

$$I = I_h \times R_b \quad (1)$$

where, (R_b) represents the factor of inclination given via

$$R_b = \frac{\cos(\varphi-\beta)\cos\delta\cos\omega + \sin(\varphi-\beta)\sin\delta}{\cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta} \quad (2)$$

For a horizontal surface, (β) is (0) and then (Rb) is equal to (1), the expression of direct irradiation becomes

$$I = I_h = A\sin(\alpha)\exp\left(\frac{-1}{c\sin(\alpha+2)}\right) \quad (3)$$

The overall equation of diffuse radiation for the tilted surfaces is

$$D = D_h\left(\frac{1+\cos\beta}{2}\right) \quad (4)$$

For a horizontal surface, $D=D_h$, and

$$D_h = B(\sin(\alpha))^{0.4} \quad (5)$$

For the tilted surface, the reflected radiation equa–tion is

$$R = (I_h + D_h)\left(\frac{1-\cos\beta}{2}\right)\times\rho \quad (6)$$

For the horizontal surfaces, the reflected solar constituent is (0).

A, B, and C are constants that consider the nature of sky, and vigorously rely upon the considered site's microclimate, as depicted in the Table (1).

Table (1): The values of the coefficients (A, B, and C)

Sky's nature	A	B	C
Clear sky	1300	87	6
Average sky	1230	125	4
Polluted sky	1200	187	5

The universal irradiation is the summation of the direct, diffused, and reflected solar constituents

$$G = I + D + R \quad (7)$$

$$G = I_h \times R_b + D_h\left(\frac{1+\cos\beta}{2}\right) + (I_h + D_h)\left(\frac{1-\cos\beta}{2}\right)\times\rho \quad (8)$$

For the horizontal surfaces,

$$G = I + D$$

The solar altitude angle *(α)* is given as

$$\sin\alpha = \cos\delta\cos\varphi\cos\omega + \sin\varphi\sin\delta \quad (9)$$

The latitude angle (φ) is the angular position north or south of the equator, and for the city of Baghdad, it is equal to (33.3^o). The angle between the sun-earth center line and this line projection upon the equatorial plane is changed from (23.45°) to (23.45°). The declination can be computed from the expression [18].

$$\delta = 23.45\times\sin\left[360/365(284+n)\right] \quad (10)$$

4. EXPERIMENT SETUP

The stand-alone photovoltaic system is a group of the interconnected electrical constituents, which are able to produce the electricity from the light of sun and meet the daily needs of energy without upsetting about every interval if the light of the sun mayn't be accessible. Such system kind is significant merely if there's a load requirement for running during time of night or if the light of sun isn't accessible for certain time. The time of photovoltaic comprises the array of solar (PV), the devices of protection, the controller of charge, battery, cables, and inverter, [19,20] as shown in the figure [2].

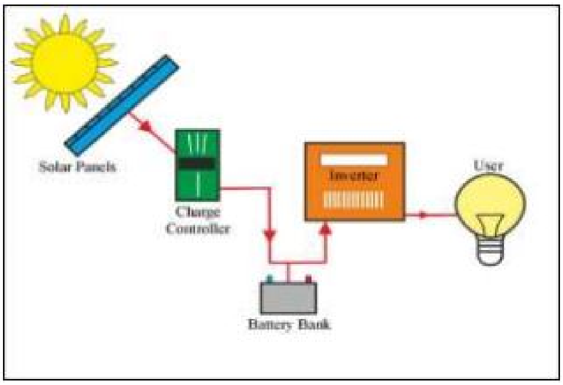


Figure 2. The schematic of (PV) system for electrification

4.1 Installation of the system

The installation of system was upon a home building's rooftop in Baghdad city. The tests were conducted prior to the last system installation for the easy availability of system and instruments of measurements. The system of solar power was located outside in open area, where radiation could be attained without obstruction.

4.2 Experimental Testing

The ambient temperature was measured using elect–ronics thermometer beneath the shade for avoiding the straight solar radiation influence. The straight radiation was measured by digital soler meter, and the perfor–mance of (PV) panel was collected by solar analyzer to record the P-V and I-V curve at each hour of working day, figure [3]. The frame of (PV) design has to be movable to provide the required tilt angle, as displayed in the figure [4].

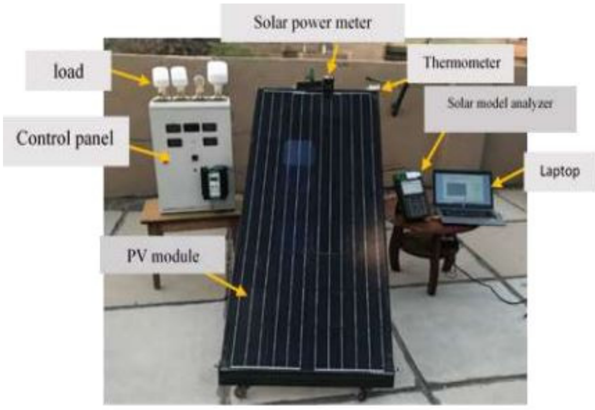


Figure 3. Experimental setup system with measuring device

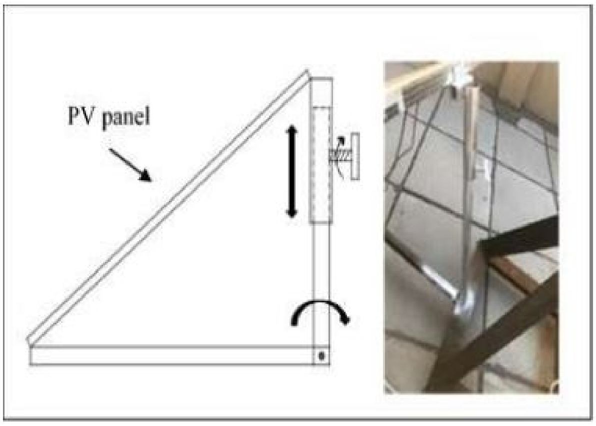


Figure 4. PV panel supported frame

5. RESULT AND DISCUSSION

5.1 Validation test

The MATLAB code was tested for a selected day in the year to calculate the solar radiation along the day time. At the same date, the solar radiation was measured experimentally by using a small pyranometer model pyrometer, (TES-1333/1333R) solar power meter, ha–ving a range varied from (0 to ~2000 W/m^2). It was fixed into the upper comer of the insulation attached to the collector, parallel to the face of the collector, as revealed in the figure [3]. Therefore, the reading of the pyranometer is the actual solar intensity incident on the face of the collector. The solar radiation intensity with the time of day was recorded and compered with the result from the numerical model as shown in the figures [5] and [6] for day (15 September) at tilt angle (33°) according to location of Baghdad city with the latitude (33°20′). The rig must be directed facing the south, and the error is approximate (3%) at midday.

5.2 Optimization

a. Monthly optimum tilt angle

The power intensity estimation obtained from solar radiation related to the monthly tilted angle for Baghdad (latitude 33°20′), for 12 months can be seen in figure [7]. It's shown that each angle of tilt provides more intensity of solar power through the season of summer than that for the other seasons at the similar angle of tilt, that's owing to the high declination angle that will decrease the sunray path, thus it decreases the flux of solar energy that attains the surface of earth. The months of summer in relation to the weather of Iraq are April, May, June, July and Aug. If the monthly angle of tilt is ranging from (0°) to (90°), the maximum values of the intensity of solar power is obtained from the photovoltaic cell in every month of year. When the angle of tilt of angle raises, the intensity of solar power will rise till it attains the ultimate value owing to the rise in the usual constituent ratio of the solar radiation, which being at the surface of the cell. The monthly optimal angle of tilt depicted for the favored cities is briefed in figure [7] appearing that the monthly optimal angle of tilt can change considerably through the year between (18°) and (65°).

The intercept radiation on the surface with different tilt angle is shown in figure [8] and [9]. The monthly daily average radiation result shown in figure [8] a and b for all year months, its clearly nots a unique optimum tilt angle for every month with which maximum solar radiation is achieved. Figure [9] evinces the contour chart of the catching radiation upon the surfaces having diverse angles of tilt all through the year. It's apparent that the greatest catching radiation happens through the days of summer upon the surfaces having little slants as stamped via the dark red color. Also, figure [8] gives more data on the optimal angles of tilt that can be utilized for guaranteeing the ultimate intercepted radiation all through the year. From such figure, the monthly daily normal radiation can be computed as well as the optimal angle of tilt for every month can furthermore be evaluated.

b. Experimental Test

The solar module analyzer of elucidated in the figure [3] was employed to introduce: the current-Volte (I-V) and power-volte (P-V) curves for solar module; compute the ultimate solar power (Pmax), specify the ultimate voltage (Vmax), the ultimate current (Imax), the voltage at open-circuit (Vopen), the current at short-circuit (Ishort); and forecast the electrical effectiveness it can be seen this characteristic of the performance of PV panel shown in figure [10]. The highest intensity of solar radiation was recorded at the hours 11:00, 12:00, and 13:00. The experimentally tested angles were 10°, 15°, 20°, 25°, and 30°. The maximum power for the selected time was recorded at tilt angle (30°) as Pmax (78.7 W, 75.7 W, and 77.57 W) for the time (11:00, 12:00 and 13:00), respectively, as illustrated in figure [11].

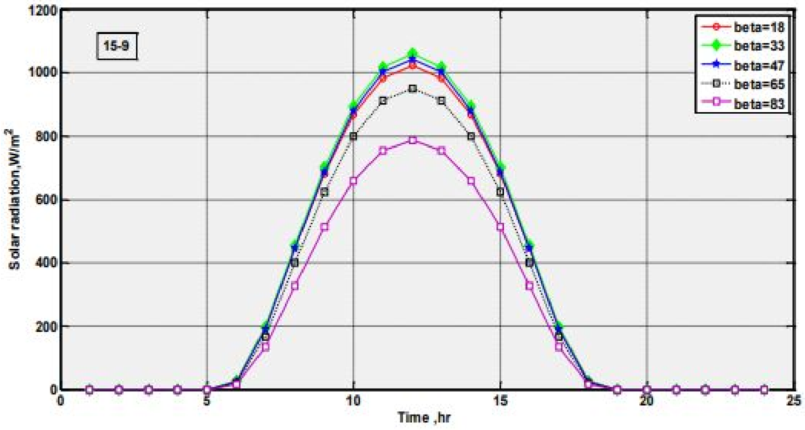


Figure 5. Numerical variation of solar radiation during specific day, site of Baghdad

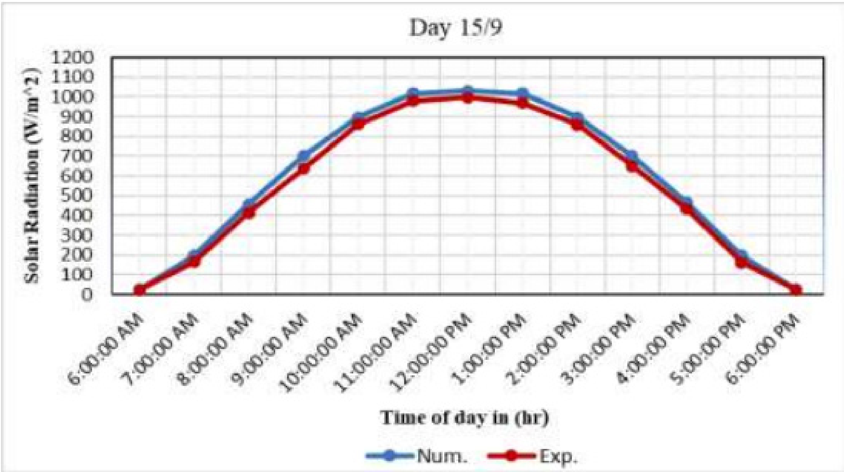
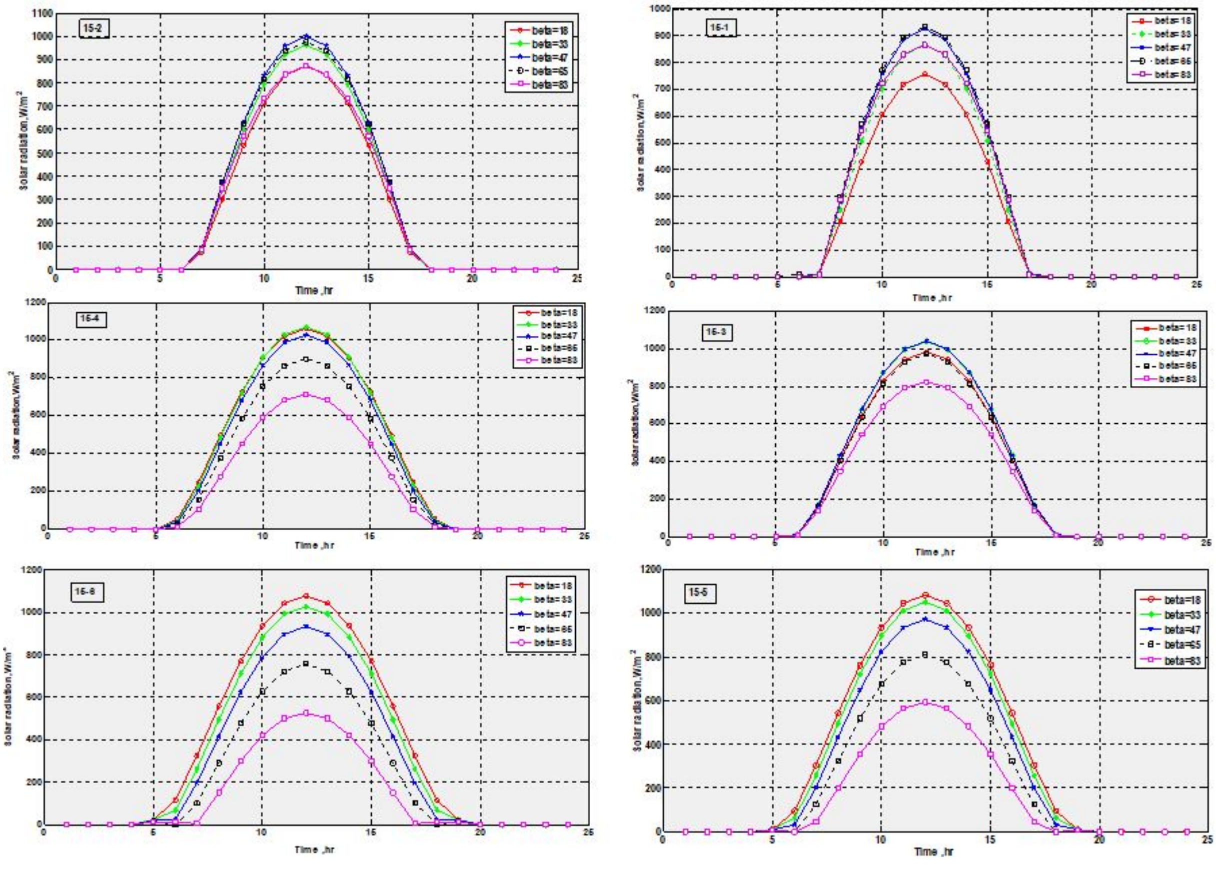


Figure 6. Comparison between numerical and experimental results of the estimated solar radiation



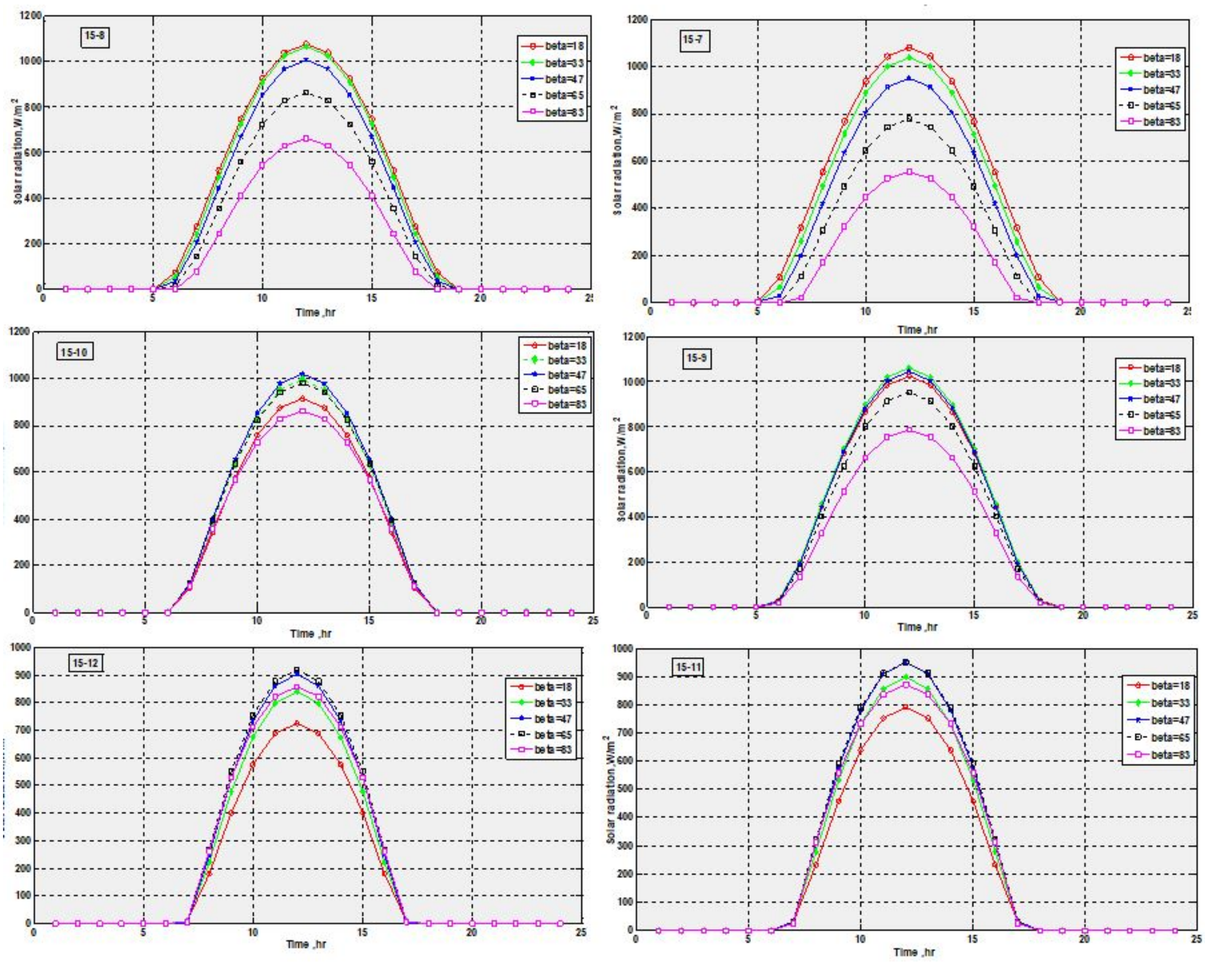


Figure 7. Variation of tilt angle through the months of year

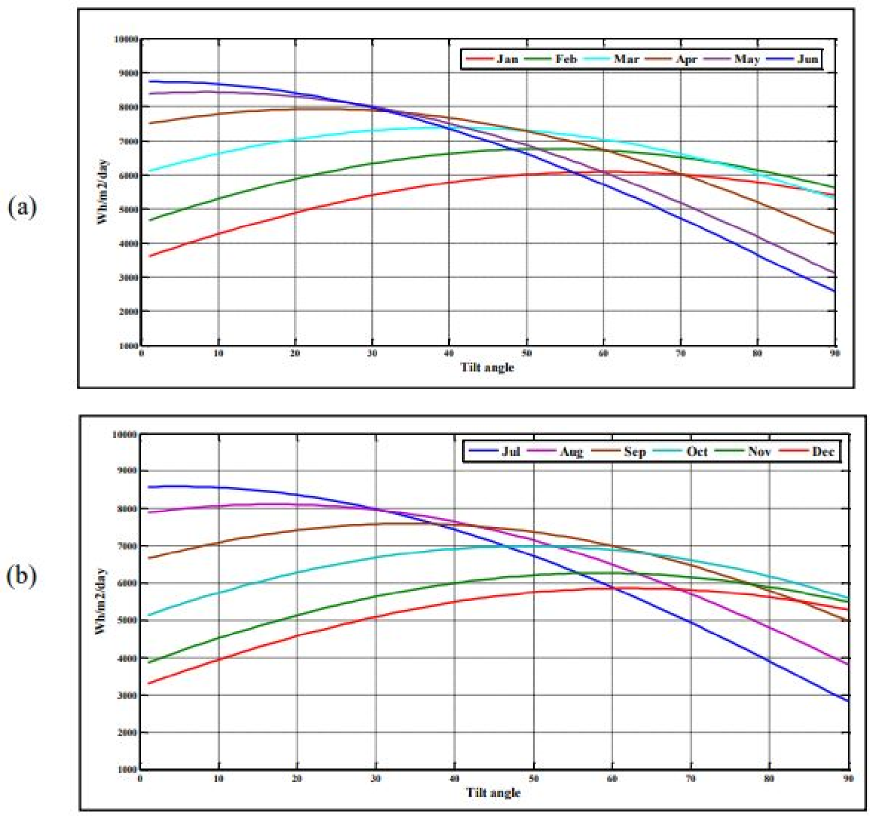


Figure [8]. Monthly average daily total solar radiation on a south facing tilted surface in Baghdad for tilt angles ranging from (0o to 90°)

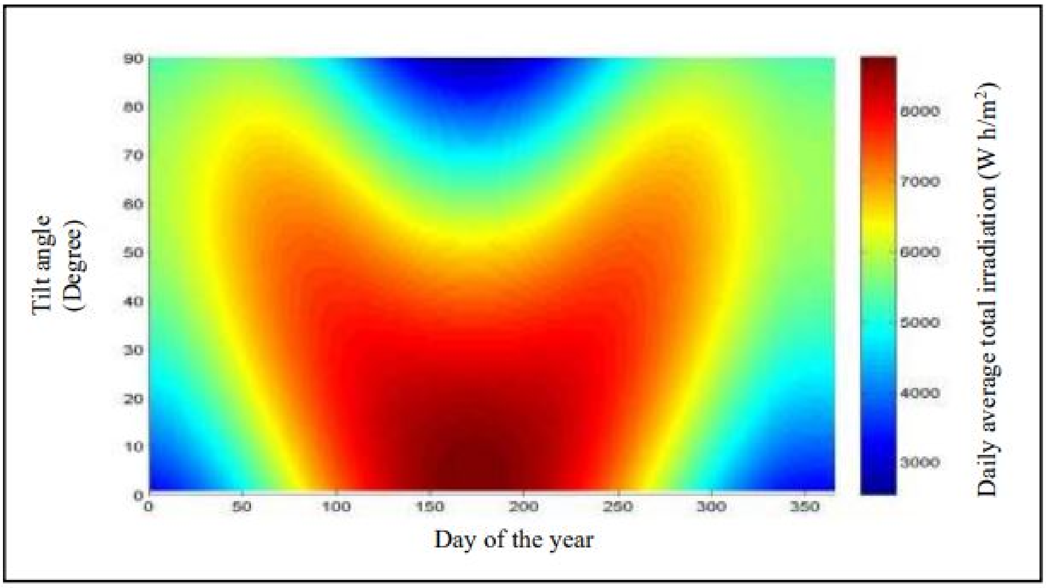


Figure 9. The daily average whole irradiation (W.h/m^2) intercepted via the surfaces having various angles of tilt

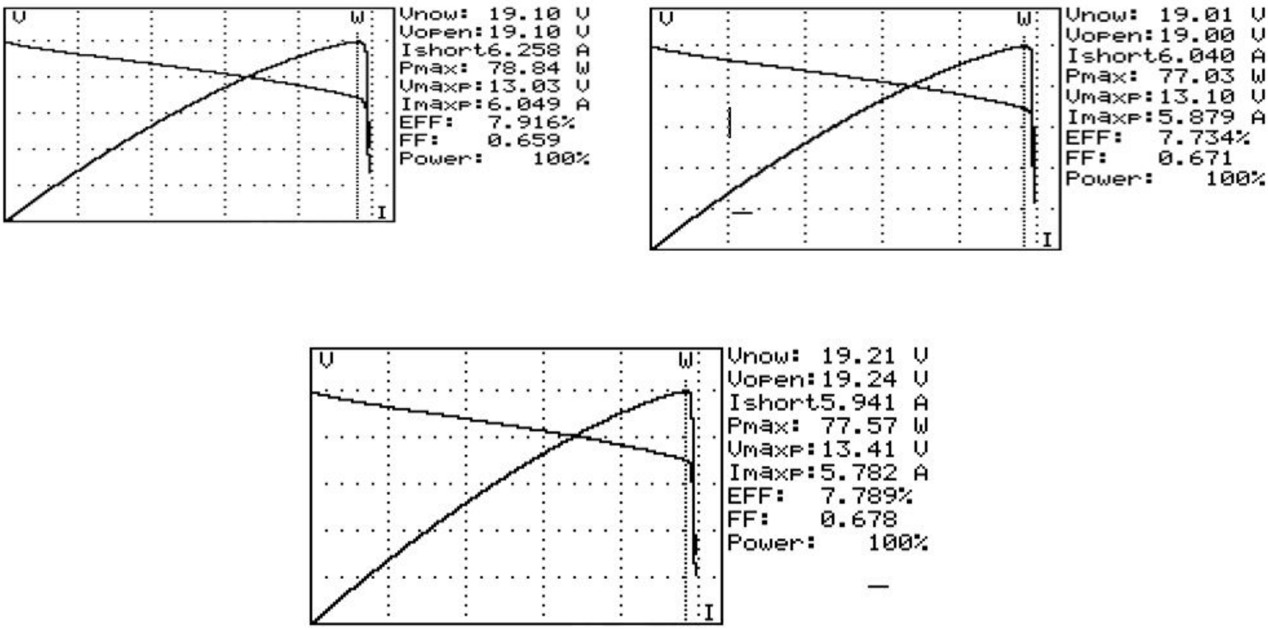


Figure [10]. Performance of PV panel for day (16 September) at tilt angle 30

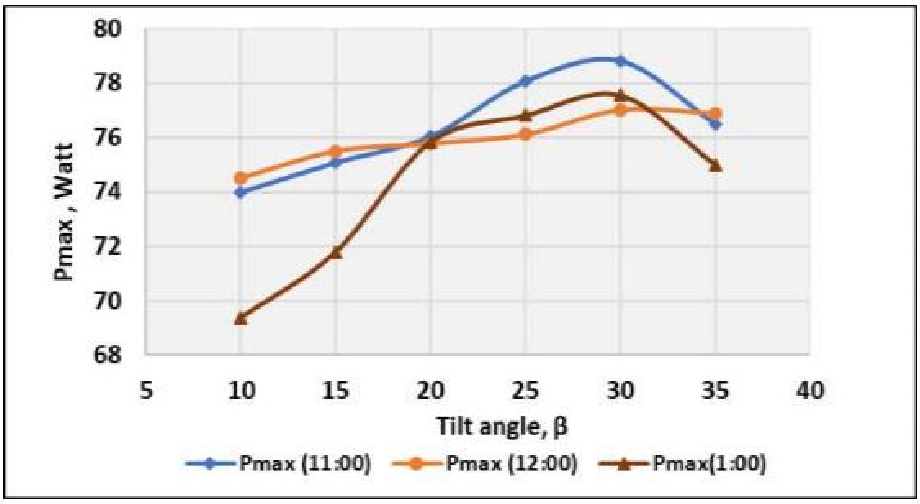


Figure [11]. Experimental comparison between the (PV) panel performance and the different tilt angles for day (16 Septembe

6. CONCLUSION

Owing to the various locations of earth and sun in various seasons and months, in addition to the location of site for the photovoltaic panel's installation, also the tilt angle and the sunlight absorption will be dissimilar. For rising the generation of energy, the optimal tilt angle for the solar panels has to be obtained so as to gather the biggest quantity of solar energy for maximizing the generation of electrical energy. The following conclusions can be drawn:

1. The relation between the optimal angles of tilt and the geographical latitude was verified. Also, the optimal values of the angle of tilt for the months of winter were obtained to be too dissimilar from those values' comparative to the months of summer.
2. The suitable angle for Baghdad city in each month was predicted.
3. The output power of the solar photovoltaic system is affected by the tilt angle value.
4. The numerical work was validated for more reliability.
5. The experimental results obtained by using a standalone (PV) solar system model were verified.
6. The monthly optimal angle of tilt can change considerably through the year between (18°) at summer and (65^o) at winter season.
7. The greatest catching radiation happens during summer days on the surfaces with little slants.

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Symbols and abbreviations

ß Tilt angle

φ	Latitude of site
Δ	Sun declination
A	Altitude angle
Ω	Hour angle
ρ	Ground albedo
n	Number of days in the year
I	Direct irradiation
D	Diffuse radiation
R	Reflected radiation
G	Universal irradiation
Rb	Inclination factor
Ih	Direct radiation at horizontal surface
Dh	Diffuse radiation on horizontal surface

ОПТИМИЗАЦИЈА НАГИБНОГ УГЛА И ЕКСПЕРИМЕНТАЛНО ИСТРАЖИВАЊЕ САМОСТАЛНОГ ПВ СИСТЕМА ЗА СНАБДЕВАЊЕ ЧИСТОМ ЕНЕРГИЈОМ ДОМАЋИНСТАВА У БАГДАДУ

С.А. Ал-шамари, А.А. Карамалах, С. Алџабаир

Перформансе система за конверзију сунчевог зрачења су под утицајем нагибног угла хоризонталне равни. Из тог разлога је потребно да ПВ низ буде нагнут под десним углом да би се постигла максимална ефикасност конверзије сунчевог зрачења. Истраживања су вршена сваког месеца са оптималним нагибним углом и експерименталним системом за снабдевање домаћинстава енергијом у Багдаду (геогр. шир. $33^0$20’). Математички модели су развијени коришћењем MATLAB-а за предвиђање инциденце сунчевог зрачења на површини, сваког дана у години, под углом од 0-90^0. Експериментални резултати су показали перформансе соларног панела за лако снабдевање електричном енергијом. Излазна снага соларног енергетског система је функција сунчевог зрачења. Највећа излазна снага се постиже између 11.00 и 13.00 часова што одговара времену остварења највеће излазне снаге. Месечни оптимални нагибни угао може значајно да варира у току године, од 18^0 лети до 65^0 зими.