Techno-Economic Analysis of 4MW Utility Scale Solar Photovoltaic Power Plant at AL-Mahmudiyah/Iraq

*Samah Shyaa Oudah, **Mohammed A. Salah.

Iraqi Creativity Centre for Sustainable Energy.*

Ministry of Electricity/Iraq.**

jnbjnb29@gmail.com

Abstract:

The aim of this work is to analyze the solar radiation aspects, the performance and the cost-effectiveness of designing a proposed utility scale, grid-connected PV Power Plant of 4 MW capacity to enhance the energy demand at AL- Mahmudiyah region and encourage investment in solar PV systems. The data of Monthly averaged daily insolation incident on a Horizontal Surface (kWh/m2/day) was obtained from NASA-SSE over the 22-year period (Jul 1983 - Jun 2005) satellite measurements. Two methods were adopted (Mathematical modeling and PVsys6.43 software package) in calculation and evaluation of the proposed project.

The average of in-plane global solar radiation of (2130.8) kWh/sq.mt/day. The PV Plant supplied the grid with an average of 6767 MWh/year at an annual performance ratio (PR) 79.2%. The final yield (Yf) ranged from 3.53 to 5.45 kWh/kWp/day with an annual capacity factor 19.4%. The array yield (Yr) with an average value of 4.7 kWh/kWp/day. The AC output power 3.162 MW at an average system efficiency of 15.5%. The power losses were calculated and displayed in a diagram loss.

The total investment cost was $3600000 and the internal rate of return (IRR) is 10.0%. The net present value (NPV) is 5.027 million $ with a discounted payback period 11 years. The benefit cost ratio (B/C) was found 1.4, the overall CO2 reduction of Emissions 122821.435 tons. The Levelized Cost of Electricity (LCOE was found 0.05 $/kWh which exported to electric grid at selling price (Feed-in Tariff) of 0.08 $/kWh. The results of the present study illustrate that it is possible to construct utility-scale, grid-connected PV Power Plant for generation electricity because it is a cost-effective project and could be generalized to other governorates at Iraq and encourage governments to impose the basic investment legislations of renewable energy. Sensitivity analysis was done to check the uncertainty of assumed financial input parameters.

Keywords: *Solar energy; Optimization; Tilt angle; Photovoltaic System, Net Present Value, Levelized cost of energy, Payback period.*

الخلاصة:

يهدف البحث إلى اجراء تحليل الإشعاع الشمسي وبيان مدى امكانية تصميم محطة طاقة كهروضوئية افتراضية ذات طاقة تصميمية ٤ ميكاواط تربط على الشبكة الكهربائية وبيان كفائتها وانتاجيتها وجدواها الاقتصادية لتعزيز الطلب المتزايد على الطاقة في منطقة المحمودية ولتكون حافزا تشجيعيا للاستثمار في مجال الطاقة الشمسية الكهروضوئية للمباني الحكومية والتجارية والمنشات. تم الحصول على بيانات الاشعاع الشمسي (المتوسطات الشهرية) على السطح الأفقي (كيلوواط ساعة / م ٢ / يوم) المستخدمة في التحليل من وكالة الفضاء الامريكية ناسا (برنامج الأرصاد الجوية السطحية والطاقة الشمسية) على مدى ٢٢ عاما (يوليو ١٩٨٣ - يونيو ٢٠٠٥). تم اجراء الحسابات التصميمية وتقييم المشروع فنيا واقتصاديا بطريقتين وهما استخدام برنامج المحاكاة (PVsys6.43) والثانية بطريقة النمذجة الرياضية.

بلغ متوسط الإشعاع الشمسي الكلي على السطوح المائلة للالواح الشمسية (٢١٣٠,٨) كيلوواط ساعة / متر مربع / يوم. تنتج المحطة الكهروضوئية وتضخ الى الشبكة الكهربائية متوسط قدره ٦٧٦٧ ميجاواط ساعة / سنة وبمعدل أداء متوسط قيمته ٧٩,٢٪. وتراوح العائد النهائي من ٣,٥٣ إلى ٥,٤٥ كيلوواط ساعة / كيلوواط ذروه / يوم، وعامل القدرة السنوي هو ١٩,٤٪. يتراوح معدل إنتاج المصفوفة بمتوسط قيمة ٤,٧ كيلوواط ساعة / كيلوواط ذروه/ يوم. وتبلغ طاقة انتاج (AC) السنوي ٣,١٦٢ ميغاواط بمتوسط كفاءة سنوية بنسبة ١٥,٥٪ للمشروع.

إجمالي تكلفة الاستثمار ٣٦٠٠٠٠٠ $ بمعدل عائد داخلي (IRR) هو ١٠,٠٪، ,والقيمة الصافية الحالية (NPV) هي ٥,٠٢٧ مليون دولار، وفترة الاسترداد المخصومة هي ١١ عاما، وجد ان نسبة العائد الى التكلفة (B / C) هي ١,٤، والمشروع يحد من انبعاثات الغازات الملوثة للغلاف الغازي بما يكافيء ١٢٢٨٢١,٤٣٥ طن من CO2. تم احتساب (LCOE) ٠,٠٥ $ / كيلوواط ساعة وان الطاقة الكهربائية التي يتم تصديرها إلى الشبكة الكهربائية بسعر البيع (حسب تعريفة التغذية) ٠,٠٨ $ / كيلوواط ساعة. ان نتائج هذه الدراسة اثبتت أنه من الممكن بناء محطة توليد الطاقة الكهروضوئية المتصلة بالشبكة على نطاق واسع لغرض توليد الكهرباء كمشروع فعال من حيث التكلفة ويمكن تعميمها على المحافظات الأخرى في العراق وتشجيع الحكومات على فرض التشريعات الاستثمارية الأساسية للطاقة المتجددة. تم إجراء تحليل الحساسية للتحقق من عدم التيقن من معلمات المدخلات المالية المفترضة وبيان ايها اكثر تاثيرا على المؤشرات الاقتصادية للمشروع.

1. Introduction

The forecasts demand of electricity which was made by the Ministry of Electricity of Iraq and Parsons Brinckerhoff, expected to reach to about 32.5 GW by 2030[1]. A significant increasing interest in solar energy all over the world to reduce the emission of greenhouse gases, increasing energy demand. The investing in solar energy field that are targeted at household supply needs to be considered to reduce the reliance on fossil fuels. Therefore, the performance of PV Power and profitability of the investment give assessment its economic viability.

The total estimated solar photovoltaic installation in Iraq till 2016 is 17 MW [2]. The average annual value of global solar radiation in Iraq varies from (1700 to 2150) kWh/m2/year [3], which is of great importance in order to support the investor’s expectations for system performance and the associate economic return. It is clear that PV solar energy will become one of the major future sources of electricity generation.

A comprehensive study for various sites in Iraq adopting measured values of solar radiation (1961–1992), were showed the net annual solar radiation in southern 2017.77 kWh/m2/year and central regions 1755.23 kWh/m2/year and higher than in the north. The annual net annual solar radiation was found 1800.3 kWh/m2/year [4]. In Morocco, an evaluation of a roof grid-connected photovoltaic (PV) system of 5 kW was conducted. The PV Park supplied the grid with 6411.3 kWh during the year 2015. The performance ratio (PR was found from 58% to 98% and the annual capacity factor was found to be 14.84% while the power losses was 45.6% [٥].

A Design Study of 20MW, 50MW and 100MW PV systems by using PVsys6.43. Software package in Saudi Arabia. For the solar system 20MW it was assumed that the operation cost and maintenance of 5% of the total cost. The annual energy was found 33.039GWh. The calculated tariff of the solar station varies from 0.216 to 0.24 $/kW/h in comparing with the applied (Feed in tariff) with 0.013$/kW/h in Saudi Arabia , and this tariff is responsible [٦, ٧].

The present study proposes utility scale photovoltaic solar plant of 4MW capacity will be constructing in land by two methods: Mathematical modeling and PVsys6.43 software package simulation. The arising question of how much this proposed project will be acceptable from view point of technical and economical for both of the investors and Iraqi government? The answer will be in related to following steps of analysis and evaluation to achieve the targets of the study to asses and evaluate the following technical and economic output parameters: -

-Evaluation of PV Power Plant performance parameters, monthly and annual production of electricity injected into the grid.

-Assessment of the selected site for construction the proposed PV Power Plant.

-Economic analysis and evaluation to show how the Profitability and suitability to invest in such project.

-studying the effects of technical and financial parameters on the main results of productivity, performance, viability of the project by doing sensitivity analysis.

-The establishment of the basic outline of the plant will help to carry out a more detailed simulation of future work.

2. The Potential of Solar Radiation at selected site

The proposed Solar PV Power Plant to construct on the land at Al-Khidr district, AL- Mahmudiyah region of Iraq as seen in the Figure (1). It is located in (40) kilometers in the southern Baghdad. The geographical location of the selected site at 32.57 N (Latitude), 44.18E (Longitude). The land is free of plantations and it is suitable for the construction of residential, educational, health or economic utilities. It's located near the highway between Baghdad and the southern provinces of Iraq. The national grid is located near to the suggested site, which makes the cost of connection to the grid as low. The cost of the land is free of any, which encourages investing there.

The monthly averaged solar Insolation Incident on a Horizontal Surface (kWh/m2/day) of the selected site was obtained from Surface meteorology and Solar Energy of atmospheric science data center of NASA, over 22 years which is an excellent web resource of data [٨] as seen in the Figure (2). The annual average of solar radiation 5.16 kWh/m^2 /day.

Fig. (1): Geographic location of proposed Utility Scale Solar PV Power Plant at AL- Mahmudiyah region, 32.958672N (Latitude), 44.300993E (Longitude).

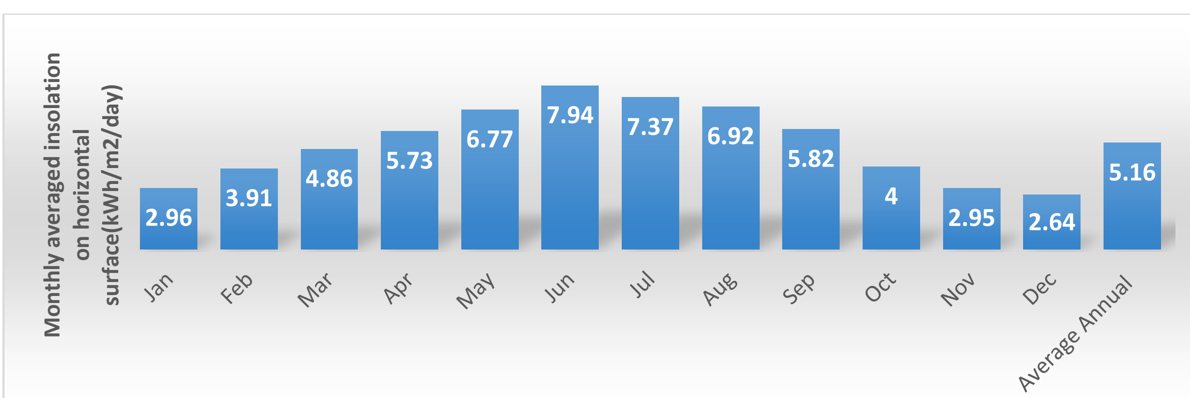


Fig. (2): Monthly Averaged Insolation Incident on a Horizontal Surface (kWh/m2/day) in Al-Khidr district at AL-Mahmudiyah

3. Mathematical Modeling of the Utility Scale Photovoltaic Power Plant

3.1. Sizing of Solar Power Plant

A grid-connected Utility–scale photovoltaic solar power plant with a capacity of ٤.0 MW consists from polycrystalline silicon solar modules type Panasonic, HIT, VBHN240SJ25, N 240 Wp. Each panel consists of 72 solar cells with, 19.0% module efficiency. The manufacturer's technical specifications of both the modules and inverters are shown in Table (١).

Table (١): The manufacturer's technical specifications of both the modules and inverters.

Panasonic, Photovoltaic module HIT/VBHN240SJ25		Inverter ABB PVS800-57-0500kW-A	
Electrical data (at STC)		Recommended max input power (PPV) 1	٦٠٠kWp
Max. power (Pmax) [W]	240	DC voltage range, mpp (UDC)	٤٥٠to 750 V (825 V)
Max. power current (Imp) [A]	٥,٥١	Maximum DC voltage (Umax (DC))	900-1000V
Open circuit voltage (Voc) [V]	٥٢,٤	Maximum DC current (Imax (DC))	1145A
Max. power current (Vmp) [V]	43.6		
Short circuit current (Isc) [A]	٥,٨٥	Nominal AC output power (PN (AC))	٥٠٠kW
Power tolerance [%] *	+10/-0	Nominal AC current	965A
Max. system voltage [V]	١٠٠٠	Efficiency	98.6%
Solar panel efficiency [%]	١٩,٠	Nominal output voltage (AC)	300 V
Temperature (NOCT) [°C]	٤٤,٠		
Temp. coefficient of Pmax [%/°C]	-0.285		
Temp. coefficient of Voc [V/°C]	-0.123		
Temp. coefficient of lsc [mA/°C]	٣,٢٢		
Module dimensions (mm)	1580x798		

www.eu-solar.panasonic.net, 05/2017. Source: www.abb.com/solar. Source:

- Based on the desired size of the PV plant in Wp the number of PV modules needed is found by dividing the desired size with the nominal effect of a single module. [٩]: -

No, of modules= size of the total PV plant [Pnom] ÷ Nominal power [Wp]/module .... (1)

No modules / array = Nominal power of the array÷ Nominal power [Wp]/module .... (2)

3.2. Determining the Maximum Open-Circuit Voltage

The solar modules output power decreases with temperature above 25C˚ and increases with temperatures below 25C˚.The adjusted maximum open-circuit voltage for coldest design temperature (-10C˚) in the winter, by using [1٠]:-

Voc max, =Voc {1+ (Tc min-25) x (ΔVoc/ΔC/100) ……………(3)

3.3. Determining the Minimum MPP Voltage

The minimum PV module voltage Vmp value for hottest solar cell temperature 60 C˚ in the summer calculated from: -

Vmpp,min = Vmpp {1+ (Tc max-25) x (ΔVoc/ΔC/100) ……………. (4)

3.4. Determining the Maximum PV Module Current

The maximum current of PV module is the same as the string current and can be calculated from the equation [1١]: -

I_{string} = Isc {1+ (Tc max-25) x (mA/°C/100) ……………. (5)

3.5. Determining the Number of PV Modules per String

The number of PV modules in string much ensures that the string voltage is always above the minimum MPP voltage of the inverter. [1١].

Maximum modules per series string= Inverter max MPP,DC voltage / Voc,Max ……………. (6)

Minimum modules per series string= Inverter min. MPP,DC voltage / Vmp,Mi ……….…. (7)

3.6. Determining the String Number

The minimum number of strings can be calculated from the ratio of the total PV array power and the power of all the PV modules of a string [1١].

$$N_{\min.STR} = \frac{P_{DC,Array}}{P_{\max,\text{module}} \times n_{\text{module}/string}} \qquad \text{……………………..(8)}$$

3.7. Determining the Inverter Efficiency

The rated efficiency η_{inv} of the inverter is the ratio of the full-load AC nameplate rating $P_{inv,ac}$ divided by, the effective inverter DC rating $P_{inv,dc}$ can be calculated from the following equation[1٢]:-

$$\eta_{inv} = \frac{P_{inv,ac}}{P_{inv,dc}} \qquad \text{…………………….. (9)}$$

3.8. Determining the Output Energy

The total energy is defined as the amount of alternating current (AC) power generated by the system over a given period of time. The total hourly, daily and monthly energy produced can be determined respectively as [1٢- 1٤]:

$$E_{AC,d} = \sum_{h=1}^{24} E_{AC,h} \qquad \text{…………..… (10)}$$

$$E_{AC,m} = \sum_{d=1}^{N} E_{AC,d} \qquad \text{…………. (11)}$$

Where; $E_{AC,d}$ is the daily AC energy output; $E_{AC,m}$ is the monthly AC energy output and N is the number of days in a month.

The average of monthly and annual electrical energy production of the PV Solar system will depend upon the location and the orientation of the array. After subtracting the

overall derating losses of the array, average yearly energy yield can be determined as follows [1٥]:-

$$E_{SYS,annual} = \sum_{m=1}^{m=N} P_{array,STC} \times H_t \times (L_{temp} \times L_{man} \times L_{dirt}) \times \eta_{inv} \times \eta_{pv\_inv} \times \eta_{inv-sub.arry} \qquad \text{………(12)}$$

Parray-stc= rated output power of the array under standard test conditions, in watts, L_{temp} = temperature de-rating factor, L_{man} = de-rating factor for manufacturing tolerance,

L_{dirt} = de-rating factor for dirt, H_t = peak Sun Hours (PSH). η_{inv} = efficiency of the inverter. η_{pv_inv} = losses of the (cables) between the PV array and the inverter $\eta_{inv-sub.arry}$ = losses of subsystem (cables) between the inverter and the switchboard.

3.9. PV Solar Power Plant Losses

The difference between the array output energy and the PV modules nominal power over a period of working time represents the array losses of the Solar system. These losses are the losses in AC and DC cables and connectors, mismatch losses, inverter loss, soiling due to dirt (sometimes snow) on the modules, ambient temperature, varying insolation levels, shading loss, and degradation of photovoltaic cells. All these losseswere adopted as 16.8% [٦, ١٦-١٧].

3.10. Performance Analysis of Solar PV Power Plant

The performance of the 4 MW grid-connected system is analyzed using the performance parameters final yield (Y_F), array yield (Y_A),, performance ratio (P_R) and capacity factor (CF). Energy output, array and system energy losses, system efficiencies (array efficiency, system efficiency and inverter efficiency), performance ratio and capacity factor [18-27].

3.10.1. Array yield Y_A

The array yield (Y_A) is defined as (DC) energy output from the PV array over a given period of time normalized by the PV rated power. [28, 29].

$$Y_A = \frac{E_{DC}}{P_{PV,rated}}\left(kWh / kW_P\right) \quad \text{.......... (13)}$$

Where E_{DC} is the DC energy output (kWh) from the PV array.

3.10.2. Final System Yield (Y_F)

The Final yield (Y_F) of PV solar power plant is the ratio of the total annual, monthly or daily net AC energy output (E) divided by the peak power of the installed PV array at the standard test conditions 1000 W/m2 irradiance, 25˚C ambient temperature and A.M 1.5) [30-31]. It is given by the expression: -

$$Y_{F,a} = \frac{E_{AC,a}}{P_{PV,rated}}\left(kWh / kW_P\right) \quad \text{.......... (14)}$$

Where E_{AC} is the (total) net energy output of the system kWh AC, $P_{PV,rated}$ is the peak power of the installed PV array kW DC.

3.10.3. Performance Ratio P_R

Performance ratio (P_R) is the ratio of the energy fed to the grid (final yield, Y_F) to the reference yield (Y_R). It can be expressed as [21]: -

$$P_R = \frac{Y_F}{Y_R} \quad \text{.......... (15)}$$

3.10.4. Capacity Factor *(CF)*

The annual capacity factor (*CF*) is defined as the ratio of the actual annual energy output of the PV system over a given period of time (usually one year) to the energy output that would have been generated if the system were operated at full capacity for the entire period. It can expressed as [29, 31- 32]:-

$$C_F = \frac{E_{AC,a}}{P_{PV,rated} \times 8760} = \frac{Y_{F,a}}{8760} = \frac{P_R \times Y_R}{8760} \quad \text{.......... (16)}$$

3.10.5. The array efficiency η_P

The array efficiency is the ratio of daily array energy output (DC) to the product of total daily in-plane irradiation and area of the PV array. It is calculated by the following equation [34]: -

$$\eta_{pv} = \frac{100 \times E_{DC,day}}{H_t \times A_m} (\%) \qquad \text{.......... (17)}$$

Where A*m* = array area (m2). H_t total daily in-plane irradiation.

3.10.6. System efficiency η_{SYS}

The overall system efficiency represents the performance of the entire PV system installed and it is given as [35, 36]:-

$$\eta_{SYS} = \frac{100 \times E_{AC}}{H_t \times A_m} (\%) \qquad \text{.......... (18)}$$

٣.11. Modelling of solar radiation

The ratio of normal beam radiation on tilted surface (H_{Bt}) to radiation on horizontal surface (H_B) is given in terms of θ_z and ϑ as shown in the Figure (3)[37].

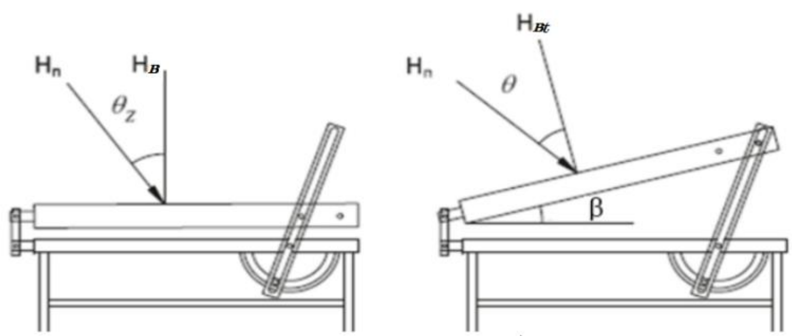


Fig. (3): Beam radiation on horizontal surface and tilted surface.

$$H_{Bt} / H_B = H_n \cos\theta / H_n \cos\theta_Z = \cos\theta / \cos\theta_Z = R_B \qquad \text{.......... (19)}$$

Where R_B is called the beam radiation tilt factor, θ_Z the zenith angle, θ the incident angle.

٣.11.1. Incident angle; the amount of angle between the light coming directly to a surface, and the normal to that surface. It represents the sun's angle of incidence. For a surface in northern hemisphere facing south direction (i.e. the azimuth angle γ=0) with latitude (φ), the angle of incidence (θ) for a tilted surface at tilt angle (β) at an a hour angle (ω) can be mathematically expressed by following relation [38]:

$$Cos\theta = \sin(\Phi - \beta)\sin\delta + \cos(\Phi - \beta)\cos\delta\cos\omega \qquad \text{.......... (20)}$$

٣.11. ٢.Hour Angle, ω

The hour angle, ω, is the angular distance between the meridian of the observer and the meridian whose plane contains the sun. The hour angles at sunrise and sunset (ω_S) have the same value and at solar noon equals zero, however, the sunrise angle is negative and the sunset angle is positive. Both can be calculated for horizontal surface from:

$$\cos\omega_S = -\tan\Phi\tan\delta \quad \text{.......... (21)}$$

The sunrise and sunset angles for a titled surface (ω_S') facing the equator (in the northern hemisphere) is given by:-

$$\cos\omega'_S = -\tan(\Phi-\beta)\tan\delta \quad \text{.......... (22)}$$

A check must be made to find the actual sunrise angle over the tilted plane since ωst cannot have values greater than ωs, the complete equation for ωst is given by [38]:-

$$\omega'_{St} = \min\left\{\omega_S, ar\cos^{-1}\left[-\tan(\Phi-\beta)\tan\delta\right]\right\} \quad \text{.......... (23)}$$

٣.11. 3. Sun declination angle

, δ, is defined to be that angle made between a ray of the Sun, when extended to the center of the earth and the equatorial plane.

The declination angle (δ) varies from a maximum value of +23°.45 on June 21st–22nd to a minimum value 23°.45 in December 20th –21st. Its value is zero on March 22nd and September 22nd of the year. Declination angle is calculated using the following relation [39-41]:-

$$\delta = 23.45°\sin\left[\frac{360}{365}(284+d)\right] \quad \text{.......... (24)}$$

Where d is the day of the year.

3.11.4. Azimuth Angle γ

The solar azimuth angle is the angle of the sun's rays measured in the horizontal plane from due south (true south); westward is designated as positive for the northern hemisphere. It is depending on the same three angles as the solar altitude angle. Following equation can be used to calculate the solar azimuth angle [42, 43]:-

$$\gamma = \sin^{-1}\left[\frac{\cos\delta * \sin\omega}{\cos\alpha}\right] \quad \text{........(25)}$$

The azimuth angle for the morning hours is -π+| γ | and for the afternoon hours is π- γ .

٣.11. 5. Solar Elevation (Altitude) Angle α

The angle of solar elevation, **α**, is defined the angular measure of the Sun's rays above the horizon. For noon altitude α_n for points in the Northern hemisphere, the angle is given by [42, 43]: -

$$\alpha = 90^{\circ} - \theta_z \qquad \text{.......... (26)}$$

The angle of solar elevation for times of day other than local noon can be expressed as: -

$$\alpha = \cos\theta_z = \sin^{-1}(\sin\delta.\sin\varphi + \cos\delta.\cos\omega.\cos\varphi) \text{ .... (27)}$$

.11. 6. Inclination angle (β) ٣

The amount of angle created by the panel surface plane given horizontally.. Inclination angle varies between 0º≤ **β**≤180º. The angle value can be calculated by the relation in equation 5 [42, 43].

Tanβ = |tanθz| cos γs .... (28)

٣.11. 7. Zenith angle (θz) is the angle between the line to the sun and the vertical axis. Zenith angle is 90º during sunrise and sunset whereas it is 0º at noon or midday (12:00, it is given by [44,45] : -

$$\theta_z = \cos^{-1}(\sin\delta.\sin\varphi + \cos\delta.\cos\omega.\cos\varphi) \text{ .... (29)}$$

Or from

θ_Z = 90° - altitude angle (α) .... (30)

3.11.8. Modelling of solar irradiation on inclined surfaces

The total of average global radiation solar radiation on horizontal surface represents the summation of horizontal beam and diffuse radiation as below[46-50]: -

$$\overline{H}_g = \overline{H}_B + \overline{H}_d \qquad \text{.......... (31)}$$

The total of solar radiation received on an inclined surface ($\overline{H}_t$) is the sum of the monthly average daily of (beam radiation $\overline{H}_B$, diffuse radiation directly incident on a surface $\overline{H}_D$, and reflected by the surroundings radiations $\overline{H}_R$). Thus, the monthly average total solar radiation in $(kWh/m^2/day)$ on an inclined surface is expressed as [51]:-

$$\overline{H}_t = \overline{H}_B + \overline{H}_D + \overline{H}_R \text{ .....(32)}$$

The monthly average daily of beam radiation, $\overline{H}_B$, falling on a tilted surface is given as [51]:-

$$\overline{H}_B = \left(\overline{H}_g - \overline{H}_d\right)\overline{R}_b \qquad \text{.......... (33)}$$

Where, $\overline{H}_g$ and $\overline{H}_d$ are the monthly average daily global and diffuse radiation on a horizontal surface.

The mean beam radiation tilt factor can be written in the form of: -

$$\overline{R}_b = \frac{\cos(\phi-\beta)\cos\delta\sin\omega_s + \left(\frac{\pi}{180}\right)\omega_s\sin(\phi-\beta)\sin\delta}{\cos\phi\cos\delta\sin\omega_s + \left(\frac{\pi}{180}\right)\omega_s\sin(\phi)\sin\delta} \qquad \text{.......... (34)}$$

The monthly average daily reflected radiation $\overline{H}_R$ reflected by the surrounding falling on tilted surface is given by:-

$$\overline{H}_R = \overline{H}_g\overline{R}_r \qquad \text{.......... (35)}$$

Where, ρ_g is ground reflectivity assumed as 0.2 for hot and humid tropical location as suggested by [52] and ($\overline{R}_r$) the mean reflected conversion factor

$$\overline{R}_r = \rho_g\left(\frac{1-\cos\beta}{2}\right) \qquad \text{.......... (36)}$$

The monthly average daily diffuse radiation falling on a tilted surface is given by [52]: -

$$\overline{H}_D = \overline{H}_d\overline{R}_d = \overline{H}_d\left(\frac{1+\cos\beta}{2}\right) \qquad \text{.......... (37)}$$

3.12. Determining Inter-Row Shading and Array Spacing by two methods

The calculation of the inter-row spacing for tilted ground mounted PV systems to avoid potential shading issues and have the ability to increase the system size was calculated by two methods.

3.12. 1. Landscape and portrait orientation

Shading of any single cell of PV module will drastically reduce the output of the entire PV module. To calculate shading distance (D) and therefore row space for both portrait and landscape orientations as displayed as in Figure (4) using the following equations [53]: -

$$D_{Portrait} = \sin(\alpha+\beta).\left(\frac{L}{\sin\alpha}\right) \qquad \text{.......... (38)}$$

$$D_{Landscape} = \sin(\alpha+\beta).\left(\frac{W}{\sin\alpha}\right) \qquad \text{.......... (39)}$$

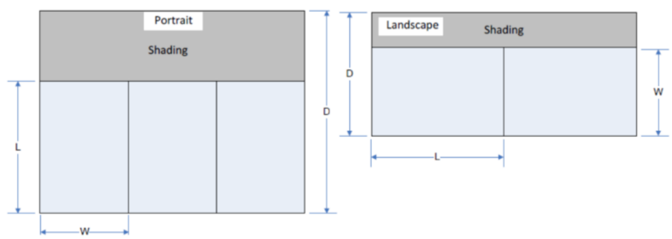


Fig.(4): shading distance (D) and row spacing

3.12. 2. Determining Module Inter-Row Spacing using the sun path chart

The average daily solar insolation (kWh/m2 / day) is referred to as "peak sun hours" which describes how much solar energy is available during a day. The path sun chart was used for determining the Module Row Spacing and minimum Module Row Spacing. The height difference (h) from the edge top of back of the module to the surface in the Figure (5) is [53, 54]:-

The inter-row spacing between the back edge of the first row of modules and the front edge of the next row which represent the shadow length can be expressed as[53, 54]:-

Height Difference (h) = Sin (Tilt Angle) x Module Width (w) …….(40)

Module Row Spacing = Height Difference (h) / tan elevation angle (α) ………. (41)

Determine the azimuth angle correction from the sun path chart, by drawing two vertical reference lines down from each time reference. The difference between South going in either direction turns out to be 31º and we will use this in the following formula to determine the Minimum Module Row Spacing as below [53, 54]:-

Minimum Module Row Spacing = Module Row Spacing x Cos (Azimuth Correction Angle) ………. (42)

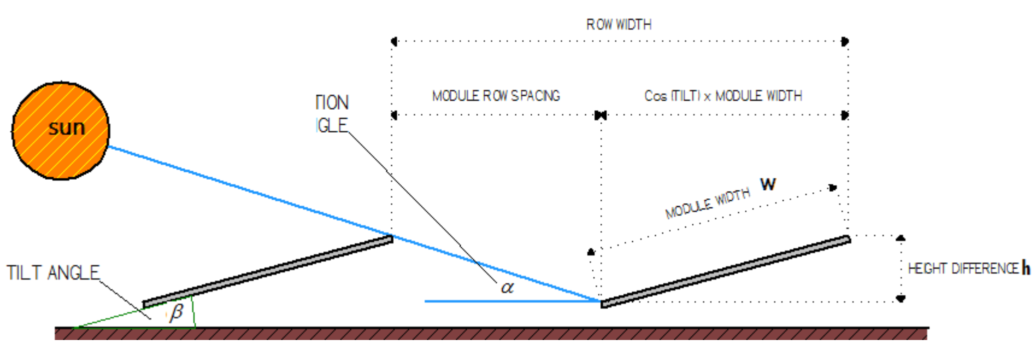


Fig. (5): Determination of module row spacing.

3.13. Economic Calculation

The total Equipment cost components, balance of system (development, electrical infrastructure, assembly and installation), Total Direct and Indirect Labor Costs, and Supply chain costs and fees. The cost of these components was considered according Modeling Inputs and Assumptions of Utility-Scale PV

Utility-Scale PV (Fixed-Tilt) of calculation of LCOE which was presented by NREL for utility-scale systems built in the first quarter of 2017 (Q1 2017) and the expected rapidly annual declining in solar PV costs . Total Capital Cost (I) was found $ 3600000 for 4MW Project[55].

For calculation of LCOE, the following were taken into consideration in evaluating the costs of kW h of energy produced:-

١.The discount rate was taken as 5%

2. The inflation rate was taken as 3% [60].

3. Module life time 25 years.

4. The capital cost was taken as according to NERL repot of 2017 [61].

5. PV O&M cost estimates was considered according to NREL, as 0.5% of system initial cost per year for large systems [62].

6. Annual degradation 0.75%

7. Debt interest rate 2%& Annuity Factor (Fraction of Capital) =6.12.

3.13.1. Levelized Cost of Energy (LCOE) method

The LCOE equation applied in this paper is includes capital expenditures (I), operational expenditures (O&M), annual energy production (Yo). Levelized Cost of Energy (LCOE), is the net present value of the unit-cost of electricity over the lifetime of the solar system in cents / kWh or $/MWh. It is a first-order economic assessment of the cost competitiveness of an electricity-generating system is given by [56, 57]: -

$$LCOE = \frac{I + \sum_{n=1}^{N} \frac{O\&M - RV}{(1+R)^n}}{\sum_{n=1}^{N} \frac{Y_o (1-D)^n}{(1+R)^n}} \qquad \text{.......... (43)}$$

Where: N = PV system life [years], I = total initial investment [$/kWp], O&M= annual operation and maintenance expenditures (OPEX) [$/kWp], RV = residual value [$/kWp], r = discount rate [%], Y0 = initial yield [kWh], D = system degradation rate [%].

3.13.2. Net Present Value (NPV) Method

The net present value (NPV) is the difference between the value of all benefits (cash inflows) and costs (cash outflows) of the project, discounted back to the beginning of the investment and were calculated from [58, 59]:-

$$NPV = -C_o + \sum_{i=1}^{n} \frac{C_n}{(1+R)^n} \qquad \text{.......... (44)}$$

Where, C0 = Initial Investment Amount, Ci = Cash Flow, n = No. of Years and Nominal Discount Rate(R).

The real rate of discount (r) adjusted for inflation rate (i) to obtain Nominal Discount Rate (R) from the expression [63,64] as:-

Nominal Discount Rate= (1+Real Discount Rate) (1 + Inflation Rate) – 1 ………. (45)

3.13.3. Discounted Payback Period

Discounted payback period is used to evaluate the time period needed for a project to bring in enough profits to recoup the initial investment which accounts for time value of money by discounting the cash inflows of the project by the following equation[65]:-

. Discounted Payback Period = A + (B÷ C) ………. (46)

Where, A = Last period with a negative discounted cumulative cash flow; B = Absolute value of discounted cumulative cash flow at the end of the period A; C = Discounted cash flow during the period after A.

3.13.4. Internal Rate of Return (IRR)

The internal rate of return (IRR) is defined as the discount rate which sets the (NPV) of a series of cash flows over the project life equal to zero, the rate which is produced by the solution is the project's (IRR).It computed by either trial and error in excel or by using formula. It can be computed from the following expression [66]:-

$$C_n\left[\frac{(1+IRR)^n-1}{IRR\,(1+IRR)^n}\right]=C_o\left[1+m\left(\frac{(1+IRR)^n-1}{IRR\,(1+IRR)^n}\right)\right] \quad .... (47)$$

3.13.5. Benefit-Cost Ratio (BCR)

The benefit-cost ratio (BCR) is the ratio between discounted total benefits and costs and computed from the following equation [65, 66]:-

$$BCR=\frac{C_n\left[\frac{(1+R)^n-1}{R\,(1+R)^n}\right]}{C_o\left[1+m\left(\frac{(1+R)^n-1}{R\,(1+R)^n}\right)\right]} \quad ………. (48)$$

3.13.6. Simple payback period (SPB)

It represents the period to recoup the investment cost of the project. Tax and insurance related issues are not included in order to make the analysis less complicated. Simple payback is the number of years necessary to recover the project cost of a Payback period (PBP) is the year in which the net present value of all costs equals with the net present value of all benefits, i.e .NPV=0, it is computed from [65]:-

$$n=-\frac{\ln\left(1-\frac{RC_o}{C_n-mC_o}\right)}{\ln(1+R)} \quad ………. (49)$$

4. Results and Discussion

4.1. Results of Solar PV Power Plant design

1. The plant consists from 16688 polycrystalline silicon solar modules type Panasonic, covering a total surface area of (21041) m2 and inclined at 31°toward the south. The PV modules are arranged into 8 arrays and 8 inverters, each array with a nominal PV Power of 500 kWp consist of (2086 modules) forming149 strings in parallel, each string consists of 14 modules in series were connected to ABB central inverter, PVS800 –57-500 kW-A. The maximum open circuit voltage of the each array , Voc, (791V) and Vmpp (546V) which both of them are more than minimum Vmmp (450V) of each of the eight inverters and less than the maximum voltage limit of each inverter, Vmpp (825V), and this will insure that each inverter will operate at safe case of voltage levels. The voltage at AC inverter side will export to grid via feeders and medium voltage transformer, this part was not taken into consideration at this study, so it will be for future study.

4.2. Results of solar radiation on optimal tilts plane angle

A-The optimal tilt angles were found as: 56˚ for Winter, 34˚ for Spring, 8˚ for Summer, 29˚ for Autumn and 32˚ for annual installation of the modules. The results were compared with the results of the software simulation (PVsys6) as shown in Table 2. The seasonal and yearly optimal tilt module angles which were calculated in (PVsys6) software simulation were found as following: -

B-PVsys6.43 software suggest that the year is dividing into 2 parts, each of (6 months), i.e. the summer months include (April to September) and Winter months include (October to March) for the field type of (fixed tilted plane), and this scenario is not acceptable 100% within the weather environment of Iraq. The optimum tilt plane angles in PVsys6.43 were found as 53˚ for Winter,12˚ for Summer and 31˚ for annual. The differences between these two procedures due to mentioned suggestions of PVsys6.43 and the deference's of the applied algorithms.

Table 2: Monthly, seasonally and annually optimum tilt angles of 4.0MW PV Power Plant Al-Khidr district.

Month	Monthly(β˚opt) Math. Model	Season	Seasonal (β˚opt)		Annually(β˚opt)	
			Math. Model	PVsys6.43.	Math. Model	PVsys6.43.
Jan.	56	Winter	56	53	32	31
Feb.	51	Spring	34			
Mar.	34					
Apr.	18			12		
May	8	Summer	8			
June	8					
July	8					
Aug.	12	Autumn	29			

Sept.	29					
Oct.	45			53		
Nov.	56	Winter	56			
Dec.	56					

C-The total monthly average daily insolation on the tilted modules $\overline{H}t$ were calculated by using both of mathematical modeling and PVsys6.43 software simulation. The Figure (6) represents the variation of the total monthly average daily solar energy incident on the titled modules at the optimum tilt angles as following:-

-The system will harvest 5.16 kWh/m2/day at Winter months with tilt angle of 56˚ in mathematical modeling and 5.46 kWh/m2/day in PVsys 6.43 simulation.

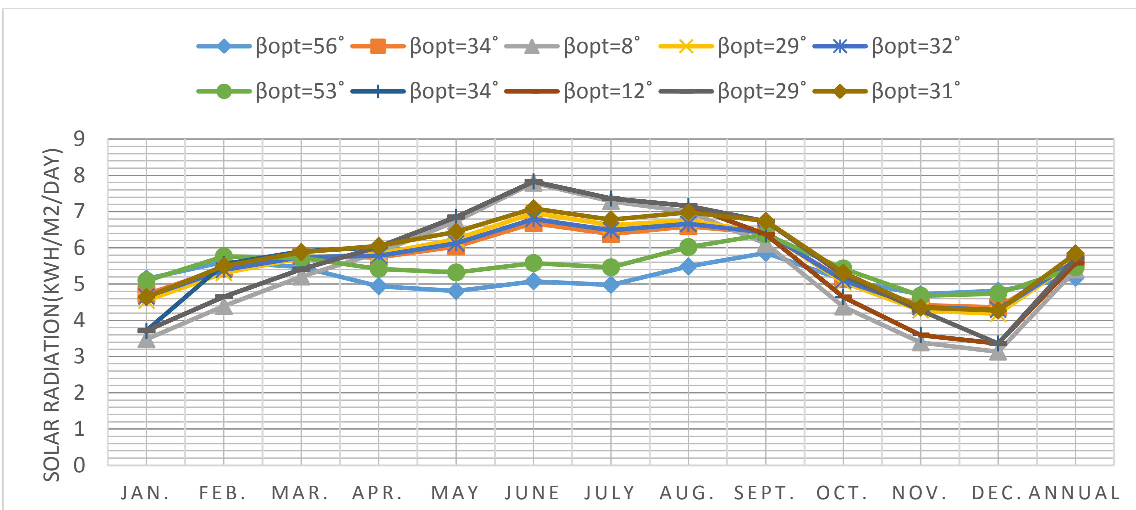


Fig (6): Variation of the total monthly average daily solar radiation on different tilt plane angles at **Al-Khidr** PV Power Plant.

- the average value of total solar energy in Summer months is 5.39 kWh/m2/day at tilt angle 8˚ from mathematical modeling, while it was found 5.58 kWh/m2/day at a tilt angle 12˚ in PVsys6.43 simulations.

-An average value of 5.63 kWh/m2/day and 5.65 kWh/m2/day at tilt angles of 34˚ and 29˚ in mathematical modeling, while the values were found 5.69 kWh/m2/day and 5.72kWh/m2/day at the same tilt angles during spring and Autumn in PVsys6.43 simulations respectively.

-The annual value of the total monthly average daily solar energy 5.6 kWh/m2/day incident on the tilted angle 32˚ of the modules in mathematical modeling, while this value was found as 5.84 kWh/m2/day in PVsys6.43 simulations at a tilt angle 31˚. It considers as good primary indicator of solar energy availability in this selected site.

The variations rate of the results from PVsys6.43 were 2.8% to 6.3% more than the same results of math. Modeling. The differences caused by Liu and Jordan model (1963) assumption which applied in PVsys6.43, that the diffuse radiation is isotropic only; whereas, circumsolar and horizon brightening were taken as zero [16, 20].

-The global (total) of the annual solar radiation on the inclined plane variation from 2130.8 kWh/m² to 2062.468 kWh/m² at mathematical modeling while its variation were 1980 kWh/m² and 1938 kWh/m² in PVsys6.43, which gives an excellent density of solar radiation for installing solar PV system.

4.3. Results of DC Output Energy analysis

1-The monthly generated DC energy of the PV Power Plant varies from minimum values 442.61MWh to 432.4MWh at November to a maximum value 660.77MWh and 671.5MWh at August in mathematical and PVsys6.43 respectively.

2- The annual DC output energy of the PV arrays of suggested Power Plant was found 6814.9277 MWh/year (math. Modeling) and 6885.9 MWh/year (PVsys6.43simultion). The differences between the results of the two methods are not big (1.6% for DC energy).

3-The effect of maximum and minimum temperatures on the average monthly DC output energy were analyzed by the mathematical method at a tilt modules angle of 32˚ and by PVsys6.43 simulations at a tilt angle 31˚ are shown in the Figure (7). The increase/decrease of the solar cells temperature determination with respect to the given external condition from NASA SEE, mainly affects the I/V curve voltage, and effective losses are strongly dependent on the array overvoltage with respect to the operating voltage.

4.4. Results of AC Output Energy analysis

1-At optimal annual tilt angles 32˚ and 31˚, the solar electric energy that feeds to grid from AC inverters sides varies from month to month. The maximum value occurs during the Summer season (as example, 651.52MWh and 671.5MWh at August) and minimum value occurs at November month (442.61MWh and 432.4 MWh) at both of mathematical modeling and PVsys6.43 software methods respectively.

2- From the Figure (10), were found as following: -

- The maximum, minimum and annual AC solar energy delivered to the grid at optimal annual tilt angle of the modules 32˚ were found 6903.354MWh/year, 6470.835MWh/year and 6719.519 at mathematical modeling respectively, while the annual delivered energy was found 6766.2MWh/year by PVsys6.43 simulations at a tilt angle of 31˚.

- The percentage difference of the average annual generated energy between the mathematical modeling and PVsys6.43 software was found very small (0.69%) which could be neglected and give the advantage of the high accuracy of the applied mathematical modeling.

- The analysis of the studied project gives an indication that the harvested solar energy delivered to the grid more than 500 MWh/month from February to October, which means about 0.75 of the year days, the proposed PV Power Plant will be able to supply a variable solar energy from 500MWh/month to a maximum value of 674.29MW h/month.

- The high increase in an ambient temperature throughout the Summer months (especially through July month) with 2% and 2.9% decreasing in delivered solar energy with respect to June month and August months respectively.

- The output energy through the Winter months will be in the range of 450 - 500 MW h/month as shown in the Figure (8).

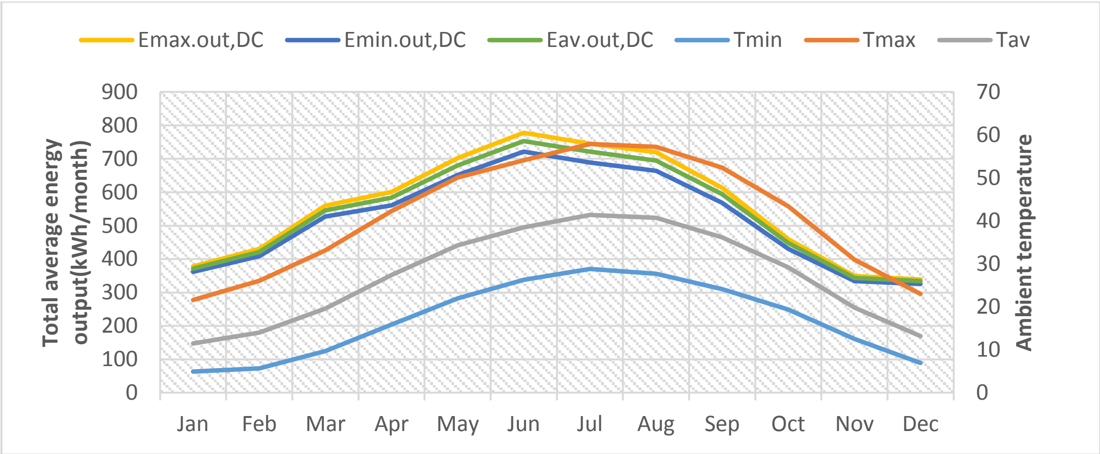


Fig. (7): The effect of maximum and minimum temperatures on the DC output energy (math. Modeling).

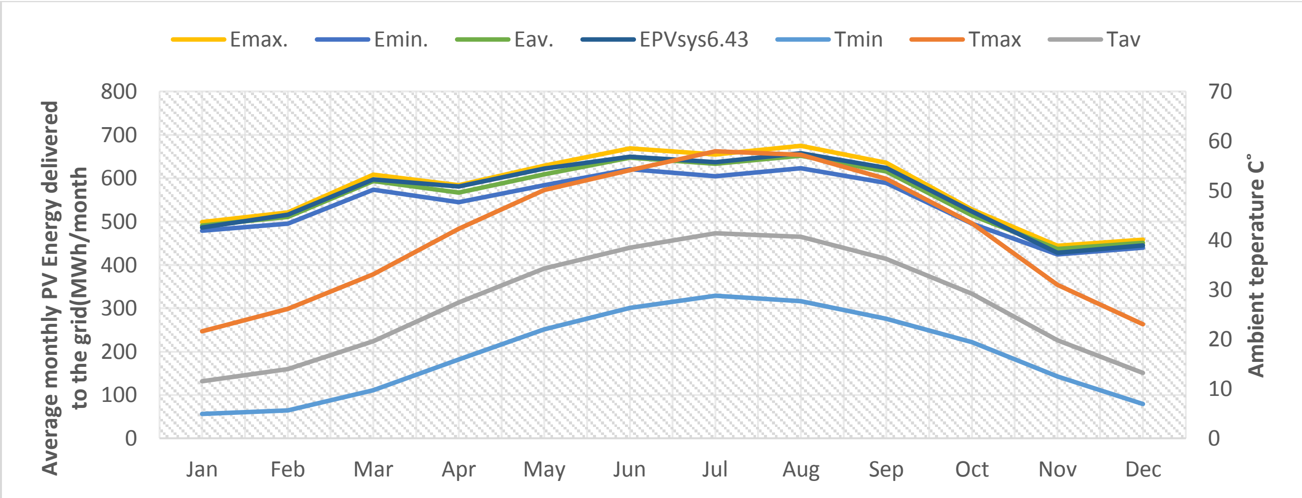


Fig. (8): The effect of maximum and minimum temperatures on the AC output energy (PVsys6.43 simulation).

4.5. Performance Analysis of PV Power Plant

4.5.1. Final System yields Y_F

The Final System yield is an ideal indicator of the energy produced in accordance with the system size and represents the daily useful energy, referred to the nominal power [kWh / KWp / day].

1- The maximum values of the average of operation is 6.37 hours / day at a tilt angle β=8˚, during June month, 5.7 hours/day during August month with β=29˚, 5.46 hours during the June at β=34˚, and 4.83 hours / day during September with a tilt panels angle of 56˚.

2- The maximum of average daily of operation hours on an annual tilt angle β˚=32˚ and β˚=31˚ of modules, was found 5.38 hours/day and 5.45 hours/day at June month in both of the mathematical and PVsys6.43 simulation calculation methods respectively.

3- The average monthly of daily values of (Y_F) increase from 3.95 hours/day at January to 5.38 hours/day at June and decrease to 3.62 hours/day at December month at an optimum annual tilt panel angle of β= 32˚ in mathematical modeling. At a tilt angle β= 31˚ in PVsys6.43 simulations, the minimum value of 3.53 h/d at November.

5-The average value of annually of (Y_F) was found 4.59 hours/day and 4.62 hours/day at in both of the mathematical and PVsys6.43 simulation calculation methods respectively as in Figure (9).

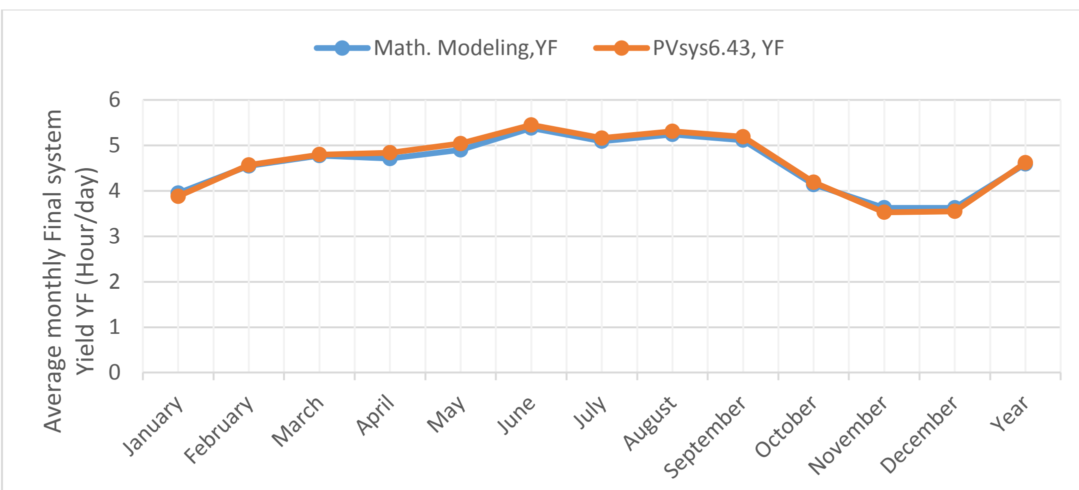


Fig.(9): Final System Yield (Y_F) of PV Power Plant in Al-Khidr district.

4.5.2. Array yield *(Y_A)*

The array yield YA results which represents the time, measured in kWh/kWp or (h/d), that the PV arrays at the proposed plant must be operating with its nominal power given in the Figure (10) as: -

1-The monthly averaged array yield ranged from minimum value 3.678 h/d and 3.60 h/d (December) to a maximum value of 5.46 h/d and 5.55 h/d (June), while the annual average values were found 4.65 h/d and 4.71 h/d in both of mathematical and PVsys6.43 simulations respectively.

2-The Figure (10) show the compatibility of Yield Array values in both of mathematical and PVsys6.43 simulations, which give an indication of good accuracy of the mathematical modeling procedure.

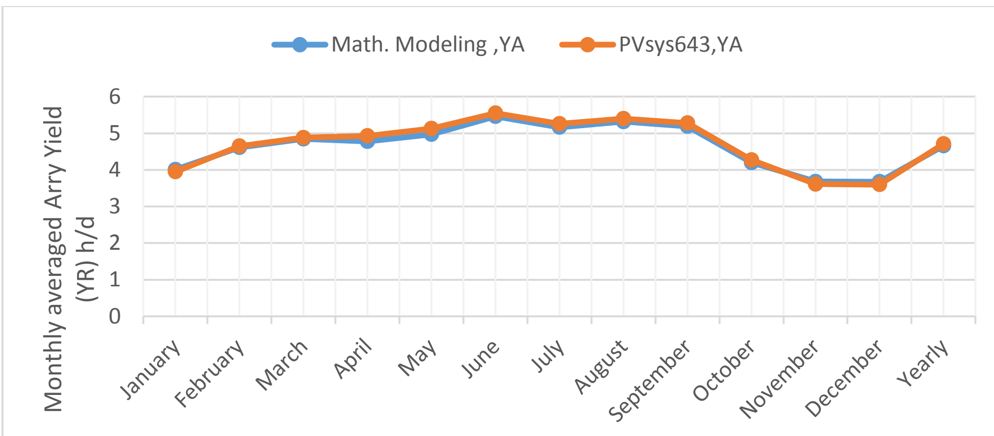


Fig. (10): Array yields of the PV Power Plant at Kidhr site.

4.5.3. Performance Ratio P_R

Performance ratio (PR) which is the ratio of the final yield (Y_F) to the reference yield (Y_R), shows the overall effect of PV Power Plant losses as in Figure (11).

1. In mathematical modeling, it was found that PR variation from minimum value of 78.5% due to high losses of temperature rising at June month to maximum value of 84.89% at January month due to the decrease in temperature as in the Figure (16).

2. In the analysis of PVsys6.43, it was found that PR values changing from minimum value of 75.7% at June month to a maximum value of 84.3% at January month. The average yearly value of 81.2% and 79.2% which were calculated in mathematical and PVsys6.43 respectively. This parameter was used for evaluation of the long term changes in the performance of PV Power Plant and gives the indication of the loss in the performance of the system.

4.5.4. The array efficiency η_{PV}

The array efficiency represents the mean energy conversion efficiency of the DC power output of PV arrays w.r.to the product of total daily in-plane irradiation and area of the PV array. The average of annual value of the array efficiency were 15.35% and 15.7% at mathematical and PVsys6.43 simulations. Its represent an excellent conversion efficiency of the DC output power of studied PV project as shown in the Figure (12).

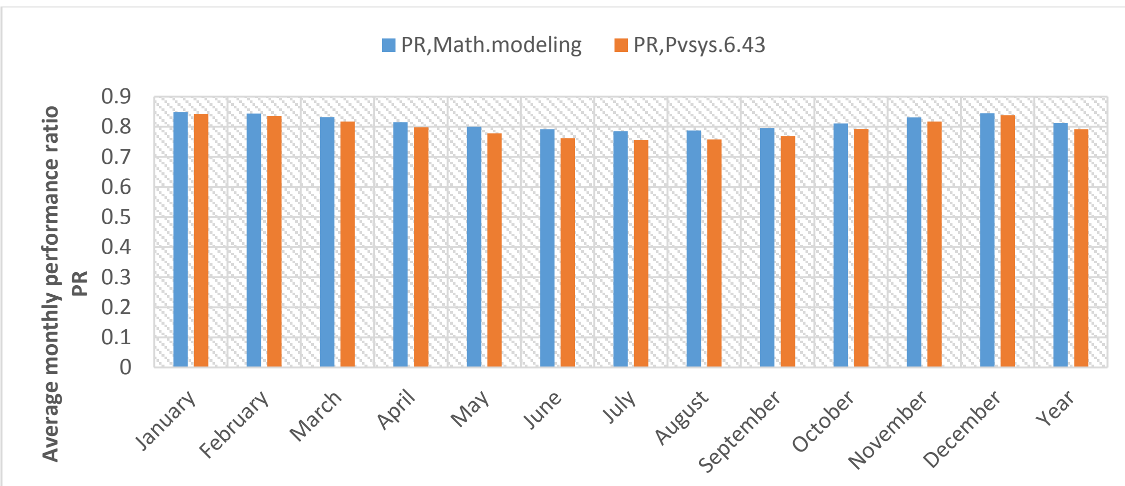


Fig.(11): Performance Ratio of PV Power Plant at at Kidhr site.

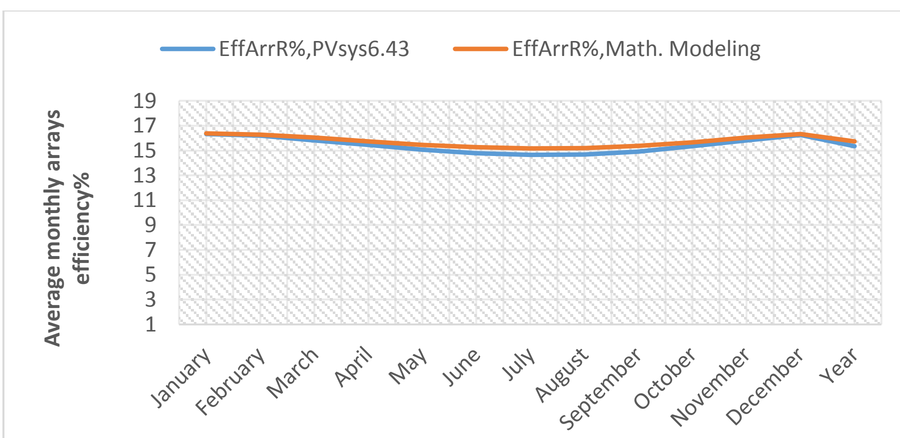


Fig.(12): Average monthly arrays efficiency of PV Power Plant at at Kidhr site.

4.5.5. System efficiency η_{SYS}

-The overall system efficiency variation from minimum value14.95% and 14.4% at June month due to high temperature of the environment, to a maximum value of 16.15% and 16.05% at the coldest month(January) in mathematical and PVsys6.43 modeling as shown in the Figure (13).

- The average annual efficiency of the PV Power Plant was found 15.5% and 15.0% in mathematical and investment of this proposed PVsys6.43 modeling respectively. This an excellent indicator for encourage of project at Al-Khidr district in AL- Mahmudiyah region.

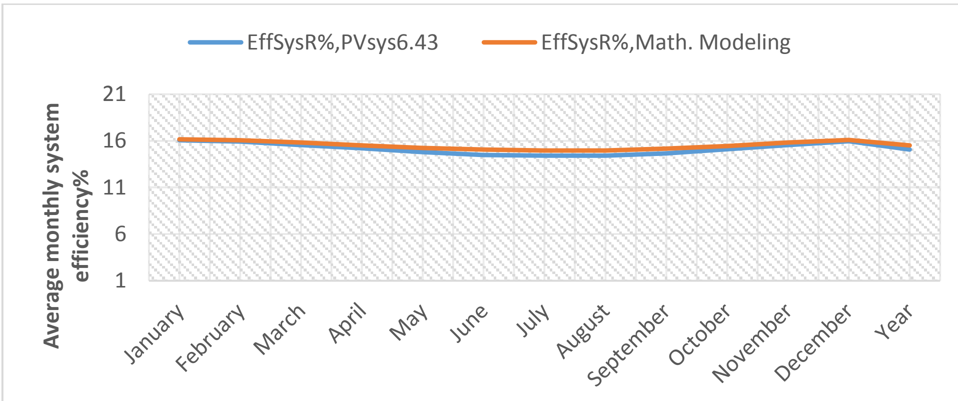


Fig.(13): Average monthly system efficiency of PV Power Plant at Kidhr site.

4.5.6. Capacity Factor (CF)

The average annual value of capacity factor CF of the proposed 4MW PV Power Plant was found 19.13% and 19.4% in both of mathematical and PVsys6.43 modeling which is considered good [26]. As shown in the Figure (14).

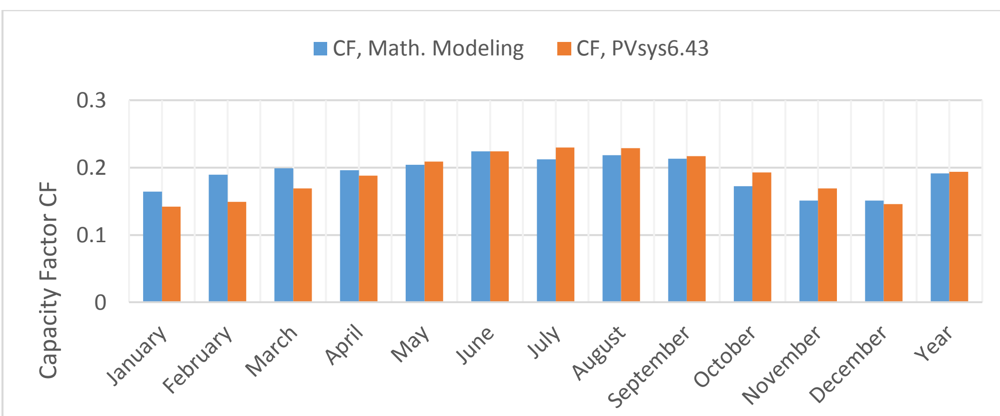


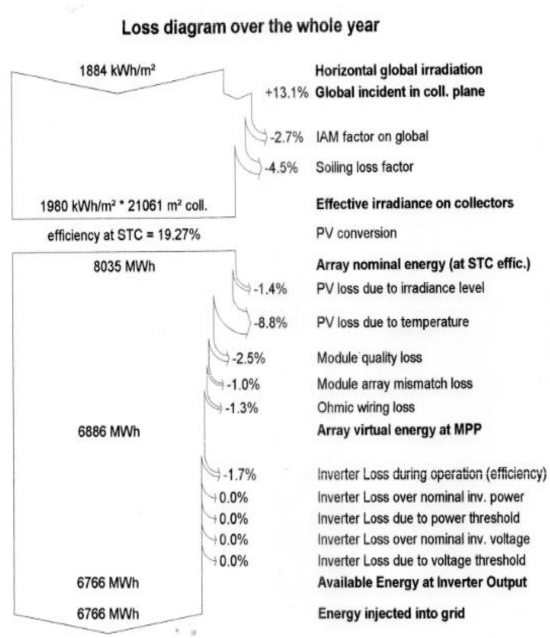
Fig. (14): Capacity Factor, CF, of PV Power Plant at Kidhr site.

4.5.7. Solar PV Power Plant Losses

In PVsyst6.43, The array loss parameters (Thermal losses- Ohmic wiring losses- Module quality losses- Mismatch losses –inverter loss during operation (efficiency) - Incidence angle (Incidence angle modifier (IAM), or the reflection loss corresponding to the weakening of the irradiation really reaching the PV cells surface soiling losses, losses was computed by the software which causing a decrease of the array output energy by 20.9% as shown in the Figure (15). Initially those losses are default set with a reasonable default values. The applied value of all losses in mathematical modeling was set as 16.8% according to the literatures and references.

4.6. Results of Inter-Row Shading and Array Spacing

The total of the average monthly solar radiation received on an inclined surface with optimum tilt angle (βopt=56˚) for the design month (21 December) was found (4.56 kWh/m2/day). The peak sun hours was found as PSH= 4 Hours/day for (December 21), the shortest day of the year (during the winter solstice for the worst case scenario).The results of Inter-Row Shading and Array Spacing as listed in the Table 3.



.Fig. (15): The yearly losses diagram of the proposed PV Power Plant in Al-Khidr district

Table 3: Module Row Spacing of the suggested Solar PV Power Plant.

	sun path chart	Landscape	portrait
Module Row Spacing	1.713m	1.237	1.868
Minimum Module Row Spacing	1.468	1.060	1.601

4.7. Results of Economic Calculation

A-The assumed cost of Utility-Scale PV Power Plant was done using the equations of economic analysis, excel worksheets, and PVsys6.43 were used in this calculations.

B-The Total Capital Cost of the project of $ 3,600,000.

C-The emission analysis worksheet gives the greatest amount of net annual GHG emission reduction (Saved CO2 Emissions=122821.435 tons).

D-The financial worksheet provides the following results: -

The total annual saving and income $ 541,360 which represent how much could the project save to recoup the initial cost to make the project profitable and viable by assuming the generated electricity will export to grid with Feed-in Tariff of 0.08$/kWh.

The Net Present Value NPV $5026283, this positive value indicates that the project is feasible at the nominal discount rate (2%).

IRR as the discounting rate was solved by trial and error method with Excel worksheet .The required minimum IRR 10% which represent the threshold value that the investor must compare with the Firm IRR. The higher value of IRR is recommended for feasible project.

The Discounted payback is found in 11 years. The repayment period is reasonable for the investor to recoup the investment cost of the proposed project.

The benefit –cost ratio was found 1.49 which mean the project is acceptable, i.e., is economically satisfactory.

Energy production cost 50. $/MWh with an electricity exported to grid 6767MWh per year at overall Solar PV Power Plant with a performance ratio 79.1% and capacity factor of 19%.

Annuity Factor (Fraction of Capital) =6.12% for debit payment and annual cost.

5. Sensitivity analysis

There is some uncertainty due to the assumption of key input economic parameters that impact on financial indicators and need to examine how is the profitability of the project affected by the errors in the values of input parameters.

Variation of the input parameters over a range (±10%) to indicate which parameters cause the most changeability of the financial indicators. In addition to identify the most sensitive inputs to investigate the effects of uncertainty of the input parameters such as (Annual Productivity Price, O&M, Initial Investment, Discount rate, Inflation Rate and Debit interest rate) on the financial indicators .

The values of input economic parameters are considered “Base Case " and several variables are uncertain to determine which of them will significantly affects the results of NPV, LCOE, B/C ratio, IRR and discounted PBP. In the last seven columns, one variable at a time was varied by (±10%) in the direction that will decrease or increase (NPV, LCOE, B/C ratio, discounted PBP) as shown with yellow cells in the Table 4 and Table 5. Over these ranges, as illustrated below: -

1.The decrease in annual productivity (-10%) causing sensitive reduction of 40% in NPV,20.43% in LCOE, 44% in B/C ratio and increasing discounted PBP by15.38%. The increase of annual productivity caused an increasing of 23.45% for NPV, 7.40% for LCOE, 23.45% for B/C ratio and decreasing 22.2% for PBP. It is seen that the NPV is very sensitive to value of annual productivity of Solar PV Power Plant.

2. It was found sensitive effects of sell price of electricity on the financial parameters, hence it was found a reduction in NPV 44%, LCOE 20.43%, B/C 44% when FiT decrease by (-10%) ,while an increasing of sell price (+10%) was made a an increasing of 23.4% for NPV, 16.6% for LCOE, 23.46% for B/C ratio and decreasing PBP to 22.22%.

3. The effects of O&M were causing a small variation ±1% in NPV and null variations in LCOE and B/C ratio.

4. The interest rate is very sensitive for financial parameters, the decrease in discounted interest rate (-10%) was caused an increasing of 4. 4% for NPV, 3.448% for LCOE and 4.38% for B/C ratio, while the increase of interest rate (+10%) caused decreasing the values of NPV, LCOE, B/C with percentage decrease values of -4.67%, -2.0% and -4.96% respectively.

5. The decreasing in inflation rate of (-10%) causing a reduction in NPV, LCOE, B/C with percentages of -7.0%, -3.7%, -7.38% while the increase of (+10%) caused by increasing these parameters with percentage values of 6.46% , 5.66%,6.30% and decreasing PBP by 10%.

6. The decreasing of debit interest rate have positive effects on NPV while its increasing have negative effects on NPV.

Table 4: Variables input parameters Deterministic Sensitivity Analysis.

First Scenario of percentages variations with yellow cells corresponds to each of input parameters with (-10%)								
Parameters	Base Case	Annual Productivity Varied	Price Varied	O&M Varied	Initial Investment Varied	Discount rate varied	Inflation rate varied	Debit interest rate varied
Annual Productivity-KWh	6767000	6090300	6767000	6767000	6767000	6767000	6767000	6767000
FiT(Sell Price-$/KWh)	0.08	0.08	0.072	0.08	0.08	0.08	0.08	0.08
Annual O&M	١٨٠٠٠	١٨٠٠٠	١٨٠٠٠	١٦٢٠٠	١٨٠٠٠	١٨٠٠٠	١٨٠٠٠	١٨٠٠٠
Initial Investment	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٢٤٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠
Discounted rate	2%	2%	2%	2%	2%	1.8%	2%	2%
Inflation rate	3%	3%	3%	3%	3%	3%	2.7%	3%
Debit interest rate	2%	2%	2%	2%	2%	2%	2%	1.8%
NPV	5026282.9	٣٤٨٦٠٦٥,٣	٣٤٨٦٠٦٥,٣	٥٠٧٧٤٩٤,٦	٥٠٢٦٢٨٢,٩	٥٢٥٨٩٠٧,٧	٤٦٩٤٨٦٥,٦	5146516.478
LCOE	0.05	٠,٠٤٦٥	٠,٠٤١٨	٠,٠٥١٢	0.05	٠,٠٥٢٣	٠,٠٤٩	0.0517
D.PBP	11	١٣	١٣	١١	١٠	١١	١١	11
B/C	1.396	٠,٩٦٨	٠,٩٦٨	1.41	١,٣٩٦	١,٤٦	١,٣	1.429
Percentages variations each of output parameters with (-10%)								
NPV (variation %)	0%	-44%	-44%	+1.0%	0%	+4. 4%	-7.0%	2.33%
LCOE	0%	-20.43%	-20.43%	1.58%	0%	3.448%	-3.7%	2.33%
Discounted .PBP	0%	15.38%	15.38%	0%	-10%	0%	0%	0%
B/C	0%	-44%	-44%	0.99%	0%	4.38%	-7.38%	-4.96%

Table 5: Variables input parameters Deterministic Sensitivity Analysis.

Second Scenario of percentages variations with yellow cells corresponds to each of input parameters with (+10%)								
Parameters	Base Case (Most likely)	Annual Productivity Varied	Price Varied	O&M Varied	Initial Investment Varied	Discount rate varied	Inflation rate varied	Debit interest rate varied
Annual Productivity-KWh	6767000	7443700	6767000	6767000	6767000	6767000	6767000	6767000
FiT(Sell Price-$/KWh)	0.08	0.08	0.088	0.08	0.08	0.08	0.08	0.08
Annual O&M	١٨٠٠٠	١٨٠٠٠	١٨٠٠٠	١٩٨٠٠	١٨٠٠٠	١٨٠٠٠	١٨٠٠٠	١٨٠٠٠
Initial Investment	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٩٦٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠	٣٦٠٠٠٠٠
Discounted rate	2%	2%	2%	2%	2%	2.2%	2%	2%
Inflation rate	3%	3%	3%	3%	3%	3%	3.3%	3%
Debit interest rate	2%	2%	2%	2%	2%	2%	2%	2.2%
NPV	5026282.9	6566500.6	٦٥٦٦٥٠٠ ٦.	٤٩٧٥٠٧١ ٣.	٥٠٢٦٢٨٢ ٩.	٤٨٠١٨٧٧ ٤.	٥٣٧٣٨٥٩ ٩.	4904740.77
LCOE	0.05	٠,٠٥٤	٠,٠٦	٠,٠٥٠	٠,٠٥٠	٠,٠٤٩	٠,٠٥٣	0.05
D.PBP	11	٩	٩	١١	١٢	١١	١٠	11
B/C	1.396	١,٨٢٤	١,٨٢٤	١,٣٨	١,٢٧	١,٣٣	١,٤٩	1.36
Percentages variations each of output parameters with (+10%)								
NPV (variation %)	0%	23.45%	23.4%	-1.%	0%	-4.67%	6.46%	-2.47%
LCOE	0%	7.40%	16.6%	0%	0%	-2.0%	5.66%	0%
Discounted .PBP	0%	-22.2%	-22.22%	0%	8.33%3	0%	-10%	0%
B/C	0%	23.45%	23.46%	-1.159%	-9.92%	-4.96%	6.30%	-2.64%4

5.1. Sensitivity analysis to Internal Rate of Return (IRR)

The internal rate of return (IRR) on a project is the rate of return at which the projects NPV equals zero was found 10% as in Figure (16), by using excel worksheets. At this point, a project's cash flows are equal to the project's costs. Similar to how management must establish a maximum payback period, management must also set what is known as a "hurdle rate", the minimum rate of return a company will accept for a project. When a project is reviewed with a hurdle rate in mind, the greater the IRR is above the hurdle rate, the greater the NPV, and conversely, the further the IRR is below the hurdle rate, the lower the NPV.

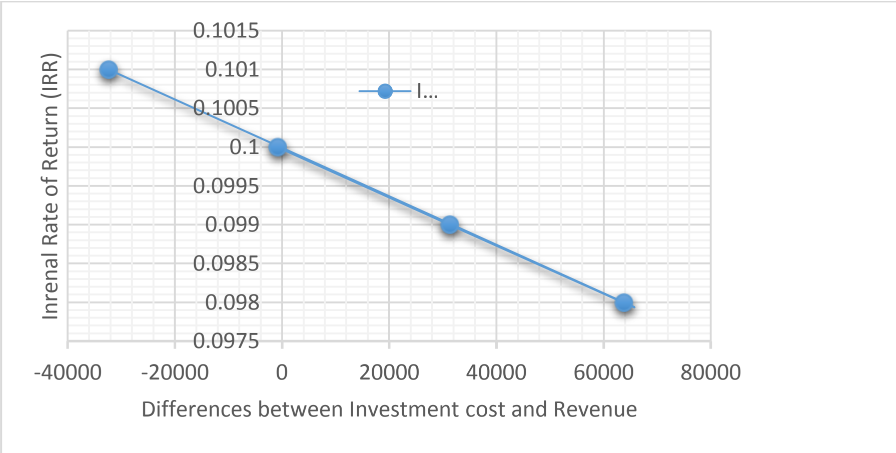


Fig. (16): Internal Rate of Return of Solar PV Power Plant.

6. Conclusions

1. The technical assessment of the proposed project stated the suitability of selected site for construction of 4MW Utility Scale Solar PV Power Plant at AL- Mahmudiyah region with an optimum annual tilt angle of module 31˚ which will inject 6767MW into the grid annually at performance ratio 79.2% and final yield (Yf) ranged from 3.53 to 5.45 kWh/kWp/day. 2-The Solar PV Plant at an annual capacity factor of 19.4% and average annual system efficiency of 15.5% consider active when producing annual AC output power of 3.162MW.The performance parameters of the studied project consider viable and attractive for investors to invest and construct such Solar PV Power Plant.

3. The economic evaluation proved that the project will be feasible and profitably after 11 years of running which maybe seems for investor as long for earning quick profits, but the potential investors should not expect that the project will generate profits during the first years as this kind of investments is profitable on the long run.

4.The economic evaluation of the project in related to sensitivity analysis, suggest that if the selling price (Feed in Tariff raised from 0.08 to 0.088 $/kWh) the project will earn NPV of 6.567 million dollars at discounted payback period of 9 years and LCOE 0.06 $/kWh (which is very accepted with the newest report of NREL which limits the LCOE of Utility Scale Solar PV Project at a range of 5.0-6.6 cents / kWh for utility-scale fixed-tilt systems) [85] and benefit cost ratio of 1.824.

5. The analysis was done for a specific investment strategy that consisted of constructing a 4 MW plant that could be extended to a larger system scale. A more in depth analysis would be to look at the different ways, the investment can be done and compare them. This project could be generalized to other Iraq districts for different load types (i.e., industrial, economic, etc.). The results of this work should encourage governments to impose new legislations related to renewable energy investments that limit all the financial parameters such as (FiT, taxes, interest rate, debit interest rate, subsidies, etc...).

7. References

[1]. Harry H. Istepanian* Luay J. Al-Khatteeb, Electricity Consumption and Economic in Iraq. Growth

[2]. International Renewable Energy Agency (IRENA), RENEWABLE CAPACITY STATISTICS 2017, (IRENA), Abu Dhabi,2017. www.irena.org/Publications. resourceirena.irena.org.

[4]. Y. Al-Douri and Fayadh M. Abed, Solar energy status in Iraq: Abundant or not—Steps forward, JOURNAL OF RENEWABLE AND SUSTAINABLE ENERGY , (2016).

[٥]. Kamal Attari, Ali Elyaakoubi, Adel Asselman, Performance analysis and investigation of a grid-connected photovoltaic installation in Morocco, journal homepage: www.elsevier.com/locate/egyr, Energy Reports 2 (2016) .

[٦]. S. Duggirala and Z. Li, “Case Studies on the Economic Viability of Renewable Energy” IEEE power engineering society, 2006.

[٧]. E. Al-Ammar and A. Al-Aotaibi, “Feasibility study of establishing a PV power plant to generate electricity in

Saudi Arabia, from technical, geographical, and economical viewpoints,” Technical report, July 2009.

[٨]. The NASA ATMOSPHERIC SCIENCE DATA CENTER, NASA SSE, http://thegrid.rexel.com/topics/energy_efficiency/w/solar_renewable_and_energy_efficiency/70.nasa-atmospheric-science-data-center-solar-power-potential-according-to-location.

[٩]. International Finance Corporation (IFC), Utility-Scale Solar Photovoltaic Power Plants, A Project Developer’s Guide, Washington, D.C. 20433,2015.

[1٠]. Stuart R. Wenham, Martin A. Green, Muriel E. Watt, Richard Corkish, 2006, Applied Photovoltaics Second Edition, Earthscan, p.33-83

[1١]. SMA Solar Technology AG, Central Inverter Planning of a PV Generator Planning Guidelines, DC-PL-en-11 | Version 1.1,2013.

[1٢] Systems, L.P., Industrial 10 to 100KW Grid-Connect Inverters, www.ltipowersystems.com, Editor 2014: www.ltipowersystems.com.

[1٣] .Choi Y, J. Rayl, C. Tammineedi, and J. Brownson. 2011. PV Analyst: Coupling ArcGIS

with TRNSYS to assess distributed photovoltaic potential in urban areas. Solar

Energy 85: 2924-293.

[1٤]. Adaramola, M., Vagnes, E., 2015. Preliminary assessment of a small-scale rooftop

PV grid tied in Norwegian climatic conditions. Energy Convers. Manage. 90,

458–465.

[1٥]. NORTHREP,NORTH PACIFIC ACP Renewable Energy and Energy Efficiency Project, Design of Grid Connect PV systems, SYSTEM DESIGN GUIDELINES.2015.

[١٦].Bruce Tsuchida, etl , Comparative Generation Costs of Utility Scale and Residential-Scale PV in Xcel Energy Colorado’s Service Area, July 2015.

[١٧]. Tutorial- PVSYS6.43 Help, iles.pvsyst.com/help/.

[١٨]. AdaramolaMS. Techno-economic analysis of a 2.1 kWrooftop photovoltaic-grid-tied system base on actual performance. Energy Convers Manag 2015;101:85–93.

[١٩]. Mediavilla M, Alonso-Tristán C, Rodríguez-Amigo MC, García-Calderón T, Dieste-

Velasco MI. Performance analysis of PV plants: optimization for improving profitability.

Energy Convers Manag 2012;54:17–23.

[2٠]. Ayompe LM, Duffy A, McCormack SJ, Conlon M. Measured performance of a 1.72kW rooftop

grid connected photovoltaic system in Ireland. Energy Convers Manag 2011;52:

816–25.

[2١]. IEC Standard 61724. Photovoltaic system performance monitoring-guidelines for measurement,

data exchange and analysis; 1998.

[2٢]. Ozden T, Akinoglu BG, Turan R. Long termoutdoor performance of three different on-grid

PV arrays in central Anatolia – an extended analysis. Renew Energy 2017;101:

182–95.

[2٣]. Dobaria B, Pandya M, Aware M. Analytical assessment of 5.05 kWp grid tied photovoltaic

plant performance on the system level in a composite climate of Western India.

Energy 2016;111:47–51.

[2٤]. Mpholo M, Nchaba T, Monese M. Yield and performance analysis of the first gridconnected solar farm at Moshoeshoe I International Airport, Lesotho. Renew Energy

2015;81:845–52.

[2٥]. Sundaram S, Babu JSC. Performance evaluation and validation of 5 MWp grid connected

solar photovoltaic plant in South India. Energy Convers Manag 2015;100:429–39.

[٢٦].Kumar KA, Sundareswaran K, Venkateswaram PR. Performance study on a grid connected

20 kWp solar photovoltaic installation in an industry in Tiruchirappalli (India). Energy

Sustain Dev 2014;23:294–304.

Marques RC, Krauter SCW, de Lima LC.

[27] .Padmavathi K, Daniel SA. Performance analysis of a 3 MWp grid connected solar photovoltaic

power plant in India. Energy Sustain Dev 2013;17:615–25.

Ruether R, Zilles R.Making the case for grid-connected photovoltaics in Brazil.

[28] . Adaramola MS, Vagnes EET. Preliminary assessment of a small-scale rooftop PV-grid tied

in Norwegian climatic conditions. Energy Convers Manag 20

[29].Ozden T, Akinoglu BG, Turan R. Long termoutdoor performance of three different on-grid

PV arrays in central Anatolia – an extended analysis. Renew Energy 2017;101:

182–95.

Padmavathi K,

[30] Hajiah, A., et al., Performance of grid-connected photovoltaic system in two sites in Kuwait. International Journal of Photoenergy, 2012. 2012.

[31] Kymakis, E., S. Kalykakis, and T.M. Papazoglou, Performance analysis of a grid connected photovoltaic park on the island of Crete. Energy Conversion and Management, 2009. 50(3): p. 433-438.

[32]. L.M. Ayompe, A. Duffy, S.J. McCormack, M. Conlon. Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland. Energy Conversion and Management 52 (2010) 816-825.

[33].Elhadj Sidi CEB, Ndiaye ML, Bah ME, Mbodji A, Ndiaye A, Ndiaye PA. Performance analysis of the first large-scale (15 MWp) grid-connected photovoltaic plant in Mauritania.Energy Convers Manag 2016;119:411–21.

[34]. Wittkopf S, Valliappan S, Liu L, Ang KS, Cheng SCJ. Analytical performancemonitoring of a142.5 kWp grid-connected rooftop BIPV system in Singapore. Renew Energy 2012.

[35]. A. Guenounou, A. Malek , M. Aillerie. Comparative performance of PV panels of different technologies over one year of exposure: Application to a coastal Mediterranean region of Algeria. Energy Conversion and Management 2016.

[36]. Adaramola, M., Vagnes, E., 2015. Preliminary assessment of a small-scale rooftop PV grid tied in Norwegian climatic conditions. Energy Convers. Manage. 90, 458–465.

Oyewola M Olarenwaju and Odesola I ,[37].Determination of optimum tilt angles for solar . collectors in low-latitude tropical region, . International Journal of Energy and Ifedayo Environmental Engineering, http://www.journal-ijeee.com/content///,2013.

[38].. Duffie, J.A., Beckman, W.A.: Solar engineering of thermal processes,3rd edn. John Wiley & Sons Inc, USA (2006)

[39]. Panchal, H., Shah, P.: Investigation on solar stills having floating plates. Intern. J. Ener. Environ. Eng. 3, 8 (2012).

[40]. (Petros Axaopoulos, Professor TEI of Athens Greece, Renewable Energy Technology, Basic principles of solar geometry.)

[41] P.I. Cooper, The absorption of radiation in solar stills, Sol. Energy, http://dx.doi.org/.

[42] Şenpınar, A. (2006). ‘’Bağımsız Güneş Pili Sistemlerinin Bilgisayar ile Kontrolü’’, Fırat Üniversitesi, Fen Bilimleri Enstitüsü, Doktora Tezi, Elazığ.

[43] Kattakayam T. A. & Srinivasan K., (1997). “Experimental Investigation on a Series-Parallel Cluster of Photovoltaic Panels”, Solar Energy, 61(4), 231-240

]. Jacobson, Mark Z. (2005). Fundamentals of Atmospheric Modeling (2nd ed.). ٤٤[Cambridge University Press. p. 317. ISBN 0521548659.

] . Jump up to: a b c Hartmann, Dennis L. (1994). Global Physical Climatology. Academic ٤٥[Press. p. 30. ISBN 0080571638.

[46] J. A. Duffie and W. A. Beckman, *Solar Engineering of Thermal Process*, JohnWiley & Sons, New York, NY, USA, 1991.

[47] Reindl DT, Beckman WA, Duffie JA (1990), Diffuse

fraction correlation. J. of Solar Energy 45:1-6.

[48]. Paulescu, M.; Schlett, Z. Performances assessment of global solar irradiation models under Romanian climate. *Renew. Energy* **2003**, *5*, 767–777.

[49] B. Y. H. Liu and R. C. Jordan, “The interrelationship and

characteristic distribution of direct, diffuse and total solar

radiation,” *Solar Energy*, vol. 4, no. 3, pp. 1–19, 1960.

[50]. Foster, R.,Ghassemi, M. & Cota, A. Solar Energy Renewable and the Environment. CRC Press. 2010.

[51] B. Liu, R. Jordan, Daily insolation on surfaces titled toward the equator, ASHRAE J. (1961) 10 (United States).

[52] T. Muneer, G.S. Saluja, A brief review of models for computing solar radiation on inclined surfaces, Energy Convers. Manage. 25 (4) (1985) .

[53] A Cooper B-Line, Solar Power Panel Orientation: Landscape vs. Portrait, Technical White Paper October 2010 .

[54]. pveducation.org, (http://www.pveducation.org/pvcdrom/average-solar-radiation

[55].NREL, U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017, https://www.nrel.gov/news/press/2017/nrel-report-utility-scale-solar-pv-system-cost-fell-last-year.html,Q1,2017.

[56].IEA, "Projected Costs of Generating Electricity" (2010);

[57]. US DOE, "2008 Solar Technologies Market Report" (2010).

[58].Prof. Beatriz de Blas, Net Present Value, Lesson 1.,April 2006

[59].John Richter, Financial Analysis of Residential PV and Solar Water Heating Systems, 2009.

[60] tradingeconomics.com/iraq/inflation-cpi/forecast and International Monetary Fund , Publication Services, International Monetary Fund, IMF Country Report No. 15/235 Washington, D.C.,2015. .http://www.vorpenergy.com/resources/calculators/Refrence

[61]. Ran Fu, David Feldman, Robert Margolis, Mike Woodhouse, and Kristen Ardani, NREL,U.S. Solar Photovoltaic System Cost Benchmark: Q1 2017

[62]. the National Renewable Energy Laboratory (NREL),The best-practices guide also reports PV O&M cost estimates from various organizations, which are generally around 0.5% of system initial cost per year for large systems, NREL/FS-7A40-68281 • May 2017

[63].Ali K. Resen, Dr. Firas H. Abdulrazzaq, Jawad S. Nmr,Suitable Wind Turbine Identification Using Capacity Factor and Economic Feasibility, International Journal of Science and Technology Volume 4 No. 8, August, 2015.

[64]. Short, W.; Packey, D.J.; Holt, T. (1995). A Manual for the Economic Evaluation of Energy Efficiency and Renewable Energy Technologies. Golden, CO, National Renewable Energy Laboratory. March 1995.

[65]. Mathew, S., "Wind Energy: Fundamentals. Resource Analysis And Economics", Springer, Heidelberg ISBN-10 3-540-30905-5 Springer Berlin Heidelberg New York; Printed in The Netherlands, 2006.

[66]. Samorani, M. Pardalos, P. M. et al. ,"Handbook of Wind Power Systems" , Energy Systems, Springer-Verlag Berlin Heidelberg , 2013.