Performance Assessment of First Grid –tied PV Solar System under Baghdad City Climate Condition

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Abstract

The performance assessment of 15 kWp PV solar system installed at Baghdad/Iraq was achieved. The yields (final, reference) and performance ratio where changeable from (3.5-4.8) kWh/kWp-day, (4.3-7) kWh/kWp-day and (66-83) %respectively. The average yearly capacity factor was 18.4%, annual average performance ratio was75.55% with system efficiency of 13.27%, the yearly energy yield was 1585.16 kWh/kWp of year 2018. By using PVsyst software, it was found that the yearly predicted energy yield 1631 kWh/kWp with uncertainty of 2.8% from real value, this was because of differences between real metrological date of rainy and cloudy days in winter season and hot weather in summer season and estimated data in PVsyst software. The overall predict system losses due to module temperature rise, radiation reflection losses from the collector, system losses of inverter and DC, AC wiring were 16.7 %. The present study showed the generated energy was at a high value in August and lowest in December. The system performance was compared with other Grid-Tied PV solar systems in various countries around the world and found comparable. itis proved the very good long-term performance of this solar system in real operation conditions in Baghdad city climate in spite of high temperature in summer days and cloudy and rainy days during winter in Baghdad city.

Key Words: Baghdad, Performance, Grid- Tied, PV Solar System and Energy.

تقييم اداء اول منظومة شمسية كهروضوئية مربوطة على الشبكة الوطنية في ظل الظروف المناخية لمدينة بغداد

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الخلاصة

تم تقيم الاداء لأول منضومة شمسية في مدينة بغداد بسعة 15 كيلوواط حيث بلغ العائد النهائي والعائد المرجعي ونسبة الاداء(3.5–4.8) كيلو واط.ساعة/كيو واط و(4.3–7) كيلو واط. ساعة/ كيلوواط و(66–83)% على التوالي، وبلغ متوسط معامل القدرة 18.4% والمعدل السنوي للاداء 75.55% حيث كانت تبلغ كفاية النظام الكلية13.27% ووجد ان العائد السنوي للطاقة 1585.16 في 2018 . باستخدام برنامج PVsyst ، وجد ان العائد السنوي للطاقة يبلغ1631وكانت نسبة عدم الدقة 2.8% وذلك بسبب الفرق بين الطقس الحقيقي من الايام الممطرة في الشتاء ودرجات الحرارة المرتفعة صيفاً والبيانات المستخدمة في البرنامج.

بلغ إجمالي خسائر المنظومة في برنامج PVsyst الناتجة عن خسائر الخلايا الشمسية مثل ارتفاع درجة الحرارة وانعكاس الإشعاع من سطح الخلايا و العاكس الكهربائي و أسلاك التيار المتردد و المستمر 16.7 ٪ . أظهرت الدراسة الحالية أن الطاقة المولدة كانت عالية ذات قيمة في شهر اب وأدناها في شهر ايلول، و وجد أداء النظام مقارنا بعد ان تم مقارنته مع أنظمة الطاقة الشمسية الكهروضوئية في مختلف بلدان مختلفة من جميع أنحاء العالم. لقد أثبت هذا اداء جيد للغاية في ظروف التشغيل الحقيقية في مناخ مدينة بغداد على الرغم من ارتفاع درجة الحرارة في أيام الصيف والأيام الملبدة بالغيوم خلال فصل الشتاء في مدينة بغداد.

الكلمات المفتاحية : بغداد ، اداء ،منظومة شمسية مربوطة على الشبكة و طاقة.

Introduction

One of the main drawbacks of using conventional energy sources is the disadvantages of generating gases as CO_2 and cases environment pollution, in addition that it is Nonrenewable energy sources. Photovoltaic PV systems are one of the methods to eliminate of its difficulties and meet the growing demand for electricity worldwide Cañete C *et al.,* (2014). Iraq electricity generation based largely on exhaustible fossil fuels that cause clear environment pollution and facing reduction in electricity Generation especially during peak demands. Photovoltaic systems have the possibility to play a considerable function in obviate CO2 emissions and reduce the gap between power generation and consumer demands. Several studies were taken place in world as Mensah *et al.,* (2019) presented a study of a Grid-Tied of PV solar system in the northern part of Ghana at Navrongo. They found that performance ratio was 70.4% and the mean annually generated energy was 3547.8 MWh and payback period time is found to be 14.95 years. Also, this PV solar plant reduced over 3852 metric tons of CO2 annually since its implementation. While Kumar *et al.*, (2019), studied the performance of 200 kW grid connected PV System on rooftop in northern India. They found the system estimation of Yearly operation capacity factor, performance ratio, and energy losses as (16.72%, 77.27%, −26.5%) respectively. Another study of 3MW performance assessment in Karnataka State, India was conducted by Padmavathi and Daniel (2013), they compared the performance parameters for the station with the same parameters of other stations worldwide. Yearly average generation energy was 1372 kWh / kWp of the installed solar station and Performance of the plant was satisfy in comparison with reported station from other countries. Quansah *et al.*, (2017), studied the performance analyses for five PV solar systems of various technologies, they early exported energy to the grid by overall systems was 20.62 MWh, The performance ratio varies from 48.84% (CIS) to 71.26% (for p-Si) and yearly energy exported to the grid varies between 3133.2 kWh for CIS and 4572.1 kWh for pc-Si . The major objective of the present work is to evaluate the performance of 15 kWp system constituted with of HIT technology for 12 months period of year 2018 under Baghdad climate conditions and compare it with simulated program of PVsyst software. The performance of this system has been compared with other systems installed around the world.

PV Solar System Details

The solar system applied in the current study is installed in Training and Research Center subsidiary to Iraqi Ministry of Electricity, Bagdad, Iraq at longitude 44.4°E, latitude 33.3°S and 41m above the sea level), the system was connected to the feeder that provided contentious electricity to the main building, and starts operate since march 2016, the System area is 83.57 m^2 of 72 HIT modules with a capacity of 15kWp as shown in Fig (1).The power of single solar panel is 205W. The optimum tilt angle of the current system is 30° and zero azimuth angle. Inverter of SMA Sunny Tripower, 15000TL-10 type was used. Maximum efficiency of the inverter is 97% with size of 15 kW and provided by mentoring system connected to sunny portal program which give daily, monthly and yearly information of power production. Fig (2) presents schematic diagram of 15 kW solar.

system.

Fig. (1) 15kWp HIT Solar System Grid- tied

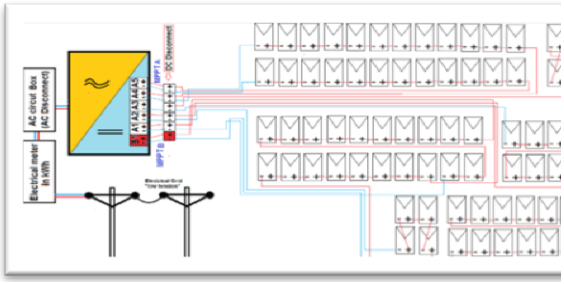

Fig. (2) Single Line Diagram of 15 PV Solar HIT Grid -tied System

Performance Analyses

The performance analyses parameters of Grid-Tied PV system are AC energy output, reference yield, array yield, and final yield, PV system efficiencies (array, system, and inverter), performance ratio and capacity factor Adaramola, and Vågnes, (2015)

A. Energy Output

It is the measurement of the generated (AC) energy by the system in a specific time as total monthly, daily and hourly energy production respectively, it can be calculated by the equations below:

$$EAC_m = \sum_{d=1}^{N} EAC_d \quad (1)$$

$$EAC_d = \sum_{h=1}^{24} EAC_h \quad (2)$$

$$EAC_h = \sum_{t=1}^{60} EAC_t \quad (3)$$

Where: EAC, t is energy production (in minute); (EAC, h) is energy production (in hour); EAC, d is the energy production in (day); EAC, m is the production of energy (in month) and N represent days number in a month. While AC symbol represent alternating current, for example EAC, t is AC energy product in minutes and so on.

B. System Yields

System yields classified to array, final and reference yields. The array yield (YA) is the DC energy product of PV solar array for an assumed duration per PV nominal power of the system. It refers to the measured time in kWh/kWp unit Sidi, *et al.*, (2016) - Vignola, *et al.*, (2008**)** Array yield is given by Eq. (4):

$$Y_A = \frac{E_{DC}}{P_{PV.rated}} \ (kWh/kW_P) \quad (4)$$

E_{DC} is (DC) energy product by PV system in unit of (kWh).

The Final yield (YF) is alternating energy (AC) energy product of the PV solar system for a specific time per system nominal power Sharma, *et al.*, (2013) It denotes in kWh/kWp and it is given in Eq. (5):

$$Y_F = \frac{E_{AC}}{P_{PV,rated}} (kWh/kW_P) \quad (5)$$

Where: E_{AC} = AC energy output in unit of (kWh).

While the reference yield (Y_R) is the global solar irradiation in-collimated plane over the reference irradiance. The reference irradiance is calculated under standard conditions and its value of 1kWp/m^2. The reference yield can be given by Eq. (6):

$$Y_R = \frac{H_T}{H_R} \left(\frac{kWh}{kW_p}\right) \quad (6)$$

Where: HR represents the reference irradiance and HT is the in-collimated solar irradiation.

C. Array and System Energy losses

Itis represent the losses in modules due to temperature rise, shading, dust

accumulation, snow and internal problem in the module as depletion losses Wittkopf, *et al.*, (2012)The array capture losses**(**L_A**)** are given by Eq. (7):

$$L_A = Y_R - Y_A(kWh/kW_P) \quad (7)$$

A system losses (L_S) , itis the losses of DC to AC power conversion by the inverter in PV solar system. It is given in Eq. (8):

$$L_S = Y_A - Y_F(kWh/kW_P) \quad (8)$$

D. System efficiencies

It is PV solar system is classified as three types: system, array and inverter efficiency. These efficiencies are calculated on basic of annually, monthly, daily, hourly and instantaneous. the system efficiency depends on AC power product, while the array efficiency depends on DC power product Abbas, *et al.,(*2010), an Array efficiency is given in Eq. (9):

$$\eta_{PV} = \frac{100*E_{DC}}{H_t*A_m}\ \% \quad (9)$$

Where: Am = array area (m^2), Ht =in-collimated plane solar irradiation.

The system efficiency of PV solar system given Eq. (10):

$$\eta_{SYS} = \frac{100*E_{AC}}{H_t*A_m}\ \% \quad (10)$$

The inverter efficiency is given in Eq. (11):

$$\eta_{INV} = \frac{100*E_{AC}}{E_{DC}}\ \% \quad (11)$$

E. Performance ratio

It is the final yield divided by reference yield Wittkopf, *et al.*, (2012) The PR value shows how PV solar system approaches to perfect performance through actual act and it gives a comparison of PV systems with each other without consideration to the rated power capacity of a system, tilted angle, location, orientation (Azimuth angle), shown in Eq. (12):

$$P_R = \frac{Y_F}{Y_R}\% \quad (12)$$

F. Capacity factor (CF)

It used to quntify energy generated by an electric power generation AlSudany *et al.*,(2009).The ratio of energy generated by the solar system is to the generation power system plant at whole capacity (nominated value) for the same period of time. The yearly CF of the PV system is given in Eq. (13):

$$C_F = \frac{E_{AC}}{P_{pv,rated}*8760} \quad (13)$$

Simulation Software and Data Input

Various simulation software programs were used to estimate the performance of a solar power plant to assist the system designers and installers Ozden, *et al.,(*2017). To quantifying the performance of PV solar systems .In this work, PVsyst software was used to forecast the monthly and yearly energy output of 15 kW solar system On- Grid tied . This program is used in many issues as studying , sizing and performance assessment of photovoltaic Grid -Tied , pumping of water systems and stand alone PV systems. To take advantage fome PVsyst program , firstly it is need for meteorological data as the temperature of ambient and the global radiation .The specifications of mechanical and electrical of the module HIT, Power 205 or HIP-205BA19 and inverter SMA Sunny Tripower,15000TL-10 are used in estimation of the specified sytem .

Results and Discussions

The results of the comparison between the actual peformance assessment and the results obtained from the PVsyst software program were presented.for the solar radiation falling on the unit area in tilted surface , it is changed the in Iraq climate condition the highest value in August (217.4 kWh/m^2),and lowest in December (130 .8kWh/m^2) .The maximum ambient temperature in July was 34.26 °C and minimum value was 7.98 °C in January as can be seen in Fig. 3.

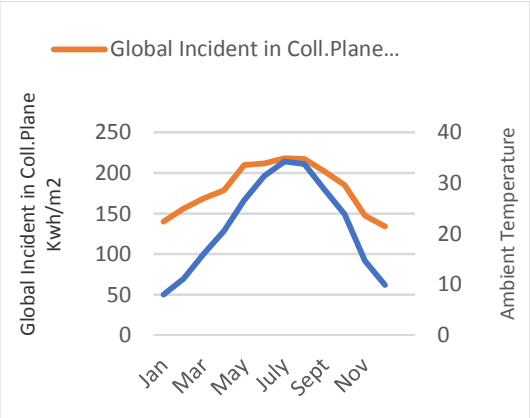

Fig. (3) Monthly Average Total In-plane Solar Radiation and Monthly Ambient Temperature.

The real reference yield varied between 4.3h/d (December) to 7 h/d (August). The real monthly final yield that measured varied from 3.58 h/d (December) to 4.8 h/d (August). This due to energy production rise in August that belong to high solar radiation intensity in this month (High Solar Fule) reverse to December month of low solar radiation intensity.The array yield varied from 3.7 h/d (December) to 5 h/d (August) as presented in fig.4.

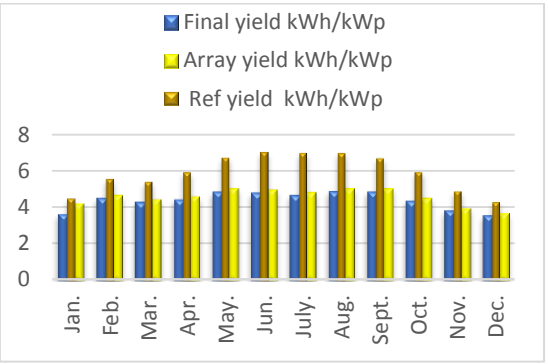

Fig. (4) Variation of Measured Monthly Final, Array and Reference Yields for the

The range of performance ratio (PR) vary between 66 % in July and 83% in December case of the temeperture rise in July, that case more temperature losses compared with Decamber of low temperature and the dust accumulation in Iraq environment increase in summer months like July,while dust accumulation in December was less because it is a rainy month, this explains the high value of (PR) in Decamber comparable with July month of 66% performance ratio, with an average yearly (PR) of 75.55% as in Fig 5.

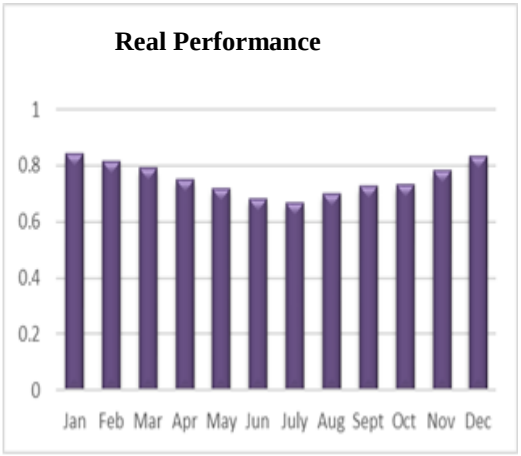

Fig. (5) The Measured Monthly and Yearly Performance Ratio for the Year 2018.

The average monthly yearly capacity factor was found to be 18% the high value of 20.36 % in August due to maximizing energy production in this month compared with other months .Less value in December month as less production of energy, was 14.93% as shown in figure. 6 .

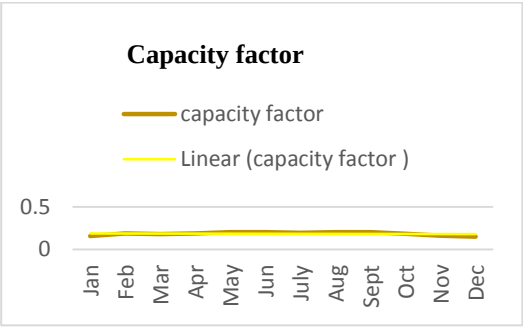

Fig. (6) Monthly and Annual Capacity Factor for the Year 2018

There are differences between solar radiation expected in the program and real solar radiation that affected by clouds, rain, temperature and dust, the predicted total solar radiation on tilt surface at 30° was 1728 kWh/m^2 while real radiation was 1698.3 kWh/m^2. The comparison of predicted global effective solar radiation and measured irradiance at 30° tilted surface, showed that both of

them was maximum during summer months (July, August) and minimum during the winter (December) as presented in Fig .7 .

In order to compare the energy yield of the solar system, real and expected yield was found,The average real energy yield for year 2018 was 1585.15 kWh/kWp while the average annual predicted energy out put was 1631 kWh/kWp with uncertinty of 2.8% (kWh/kWp). This was due to variances in metalogical input date and actual data that is influenced by cloud and rainy days along winter months and variance in ambient temperature(Hot Days in Summer Seson). Usually the maximum solar radiation on tited surface happened during August so ,the real monthly normalized energy yield was in highest value for the August (151.5 kWh/kWp),while the predicted normalized yield was (175kWh/kWp) for the same month as shown in Fig 8. This solar system supplied 23.77MWh / year, it is found that annual total energy yield forcasted by PVsyst software was 24.08 MWh/ year as shown in figure .8 .

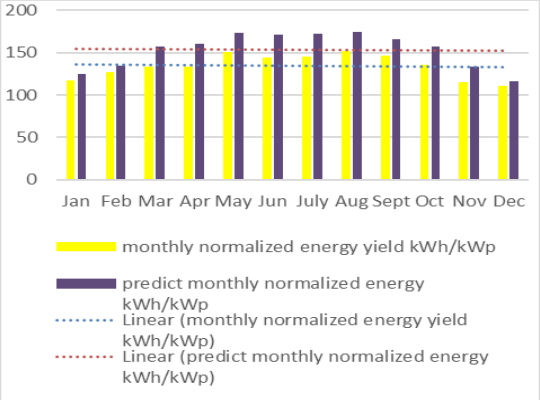

Fig. (8) Comparison of Measured, Predicte Normalized Monthly and Yearly Energy Yield

The average real annual PR was 75.55% while the PVsyst predicted PR had a value of 83.39% (Fig.9).

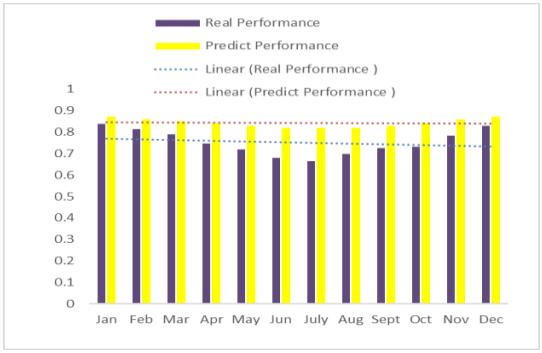

Fig. (9) Comparisons of Measured to Predicted Monthly and Yearly Performance Ratio.

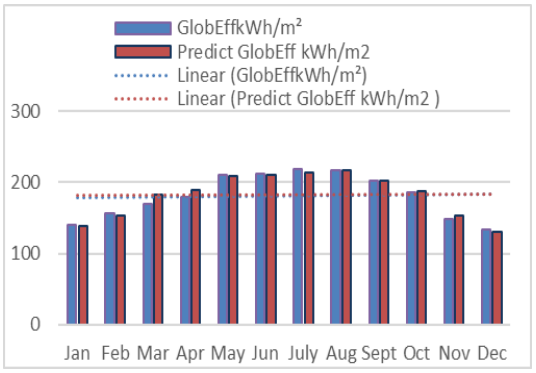

Fig. (7) Variation of Monthly, Yearly Global Horizontal, Predicted and Measured Solar Radiation

The over all predicted system losses using PVsyst are in Figure10 and outline losses in Table 1, this losses represent the solar radiation losses by reflction from module surface , ambient temperature, inputs of site parameters (Longitude and Altitude), inverer losses ,electrical and mechanical specifications of the modules.The system performance parametares was compered with other installed PV system world wide to have aclear idea of PV solar system performance in current study as in table

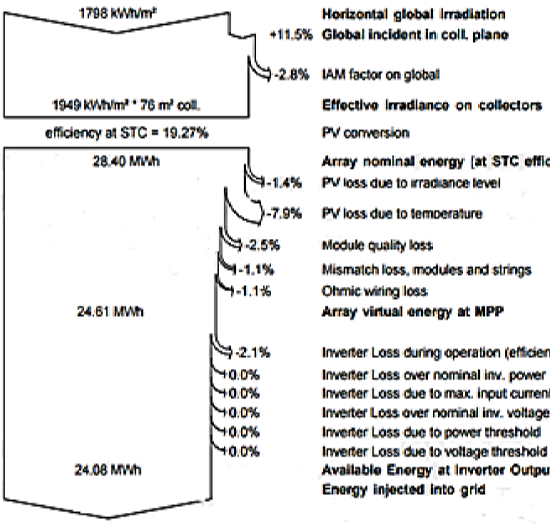

Fig. (10) PV Syst. Losses Diagram

The final yield of this system 4.3 kWh/kWp-day. This value was higher than other compared systems. The performance ratio of PV system was 75.55% higher than those in Germany and Poland but lower than and Ireland and slightly less then that in India. The system efficiency 13.27 % was higher than other comparable systems. The comparison study gave insight into the performance of HIT PV solar technology under Iraq climatic conditions as in table2.

Table (1) Predicted System Losses.

Losses	Range
Losses due to irradiancelevel	-1.4%
Loss due to temperature	-7.9%
Module quality loss	-2.5%
Array mismatch loss	-1.1%
Ohmic wiring loss	-1.1%
Inverter (DC to AC) conversion losses	-2.1%

Table(2) Performance Study Comparison of PV Systems in Different Countries

Location	Rated Power Wp)	Type of PV technology	Energy yield (kWh/k Wp)	Final yield (kWh/k Wp-day)	System efficiency (%)	PR (%)	Ref
Warsaw, Poland	1	Amorphous -Si	830	2.3	4.0-5.0	60.8	Pietruszko, S.M. and Gradzki, M.(2003)
Germany	-	Poly crystalline Si	680	1.9	-	66.5	Decker, B. and Jahn, U., (1997)
Baghdad, Iraq	15	HIT (Heterojun ction with Intrinsic Thin layer)	1585.16	4.3	13.27	75	Present study
Lucknow, India	5	Poly crystalline Si	1435.08	2.23	12.5	76.9	Yadav, S.K. and Bajpai, U. (2018)
Dublin, Ireland	1.72	Mono crystalline Si	885.1	2.4	12.6	81.5	Ayompe,L.M,et.al, (2011)

Conclusions

The study of performance analysis of a Grid- Tied 15 kWp solar photovoltaic system in Baghdad city was carried out. The main conclusions can be presented as follows:

- Measured average annual performance Ratio of 75 .55% of the Grid - Tied PV system indicated vast solar potential in Iraq. This
  required to utilize solar power generation systems in spite of hot climate condition in summer months and cloudy days in winter.
- Excellent performance comparable to the rest of the stations worldwide although of hot wither in summer and rainy days in winter.
- The average monthly real energy yield during the year 2018 was 1585.15kWh/kWp whereas the average monthly predicted output was 1631 kWh/kWp with uncertinty of 2.8% (kWh/kWp)and this is Reasonable values.

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