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Performance Analyses of 15 kW Grid-Tied Photo Voltaic Solar System Type under Baghdad city climate

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ABSTRACT

The performance analyses of 15 kWp (kW peak) Grid -Tied solar PV system (that considered first of its type) implemented at the Training and Energy Research Center Subsidiary of Iraqi Ministry of Electricity in Baghdad city has been achieved. The system consists of 72 modules arranged in 6 strings were each string contains 12 modules connected in series to increase the voltage output while these strings connected in parallel to increase the current output. According to the observed duration, the reference daily yields, array daily yields and final daily yields of this system were (5.9, 4.56, 4.4) kWh/kWp/day respectively. The energy yield was 1585 kWh/kWp/year while the annual total solar irradiation received by solar array system was 1986.4kWh/m^2. The average power losses per day of array, system losses and overall losses were (1.38, 0.15, 1.53) kWh/kWp/day respectively. The average capacity factor and performance ratio per year were 18.4% and 75.5% respectively. These results highlighted the performance analyses of this PV solar system located in Baghdad city. The performance can be considered as good and significant comparing with other world PV solar stations.

Keywords: Baghdad, Performance, Grid- Tied, PV solar System, energy

تحليل اداء لمنظومة شمسية كهروضوئية بقدرة 15 كيلو واط مربوطة مع الشبكة الوطنية في ظل مناخ مدينة بغداد

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الخلاصة

تم تحليل اداء اول محطة شمسية سعة 15 كيلو واط المنفذة في دائرة التدريب والتطوير التابعة لوزارة الكهرباء العراقية في مدينة بغداد. النظام يحتوي على 72 لوح مقسم الى 6 مصفوفات وكل مصفوفة تحتوي على 12 لوح مربوطة على التوالي لزيادة الفولتية بينما تربط هذه المصفوفات على التوازي لزيادة التيار. بموجب المدة المرصودة بلغ العائد المرجعي اليومي و عائد المصفوفة

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اليومي والعائد النهائي اليومي لهذا النظام (5.9، 4.56، 4.4) كيلوواط. ساعة/ كيلو واط / يوم على التوالي. كان العائد من الطاقة 1585 كيلو واط ساعة / كيلوواط في السنة في حين أن إجمالي الإشعاع الشمسي السنوي الذي تلقاه نظام المحطة الشمسية 1986.4 كيلوواط. ساعة/ المتر مربع. وبلغ متوسط خسائر الطاقة في اليوم للمصفوفات ، وخسائر النظام والخسائر الكلية (1.38 ، 0.15 ، 1.53) كيلوواط. ساعة / كيلوواط / يوم على التوالي. وكان متوسط معامل القدرة ونسبة الأداء السنوي 18.4 ٪ و75.5 ٪ على التوالي. سلطت هذه النتائج الضوء على تحليل أداء النظام الشمسي الكهروضوئي الذي يقع في مدينة بغداد وهو أداء جيد للغاية مقارنة بمحطات الطاقة الشمسية الكهروضوئية في العالم.

الكلمات الرئيسية: بغداد، اداء ، منظومة شمسية مربوطة على الشبكة ، طاقة

1. INTRODUCTION

Recently, photo voltaic (PV) technology is gathering momentum around the world. Global PV energy generation severely increased since 2010 while the total energy consumption of the world reached 19,710 billion kWh/year in 2016 **(Haibaoui, et al., 2017).** The merits of using PV technology are: low cost of electricity generation, simple installation and green energy production. In case of PV usage, the solar power plant is a non-polluted source of energy in contrast with traditional ones that produces environment pollution like greenhouse gases **(Micheli, et al.,2014)** Iraq is one of countries that severs environment pollution due to the use of conventional power plants as well as it possesses reduction in electricity generating especially in peak time demand during afternoon. Photo voltaic solar Grid –Tied power plant is an important application of electricity generation that can be used to reduce this problem and need no batteries to store energy making it very suitable to use.

Many tapes of PV modules technology can be used in solar systems. The main types are crystalline silicon, thin film and novel technologies. The crystalline silicon has good efficiency with low degradation but it possesses high temperature loss coefficient compared with thin film technology **(Raut, et al., 2017).** Heterojunction with Intrinsic Thin-layer technology (HIT) solar module classified within novel technologies combines between the significant properties of crystalline silicon and thin film types. It has a good property of these two technologies of low degradation, high efficiency up to 21% with low temperature losses coefficient of 0.3%/°C **(De Wolf, et al., 2012).**

Several papers were published worldwide investigating the performance analysis of On-grid Type systems. **(Necaibia, et al.,2017)** investigated the performance of 2.5 kWp PV solar implemented south of Algeria, they found that totally generated energy was in the spring season of 399.05 kWh, while the minimum generated energy was at autumn season with value of 328.23 kWh. The average yearly, performance ratio (PR) of the system was 73.82% while the annual average final yield of this system was (1737.28kWh/kWp/year). In the other hand, **(Dobaria, et al., 2016)** studied the performance analysis of Grid- Tied photo voltaic system with power of 5.05 kWp for three years. The system installed on the roof of Darshan Institute of Engineering and Technology building, Rajkot, India. They observed that the final yield, reference yield and performance ratio were (2.96 h/d -5.43 h/d), (4.22 h/d - 7.29 h/d) and (68%–83%) respectively. The global horizontal solar radiation was 2212 kWh/m^2/year. The energy yield was found to be 1636 kWh/kWp while the total estimated system losses were found 26%.

Besides that, **(Canete et al., 2014**) studied four different panel technologies: Cadmium telluride (CdTe), micro crystalline silicon (μc-Si), poly crystalline silicon (pc-Si) and amorphous silicon (a-Si), with quantity of incident solar radiation for a 12 month in Spain. They found from the performance comparisons that the performance of thin film technology modules was better than that of pc- Si technology modules. However, CdTe and pc-Si modules achived the best

performances during winter months with low total losses with high daily yield values. **Kumar et al. (2019)** studied the performance analysis of integrated building PV solar system. Thin-film cadmium telluride (CdTe) technology was used at their study. The Average yearly performance ratio was (7 kW flat roof, 2.3 kW facade in east and west, 5.5 kW facade in the north) are (76.26%, 71%, 70.53%) respectively and losses of energy were (−23.6%, −28.8%, −29.4%). The lowest performance in the system was recorded when it oriented northward.
The key target of the current research is to analysis the performance of PV solar system with 15kWp of power for a one-year period time under Baghdad climate conditions.

2.PV SOLAR SYSTEM DETAILS

The Grid- Tied PV solar system that used in the current study is installed at Training and Energy Research Center of Ministry of Electricity in Bagdad city at longitude 44.4°E, latitude 33.3°S and 41m above the sea level. The system first operating was in March 2016 and contains 72 HIT modules with total area of 83.52 m^2 as shown in **Fig 1.** The power of single solar module is 205 Wp and tilted at a fixed optimized angle of 30° and zero azimuth angle. Inverter of SMA Sunny Tri-power with type of 15000TL-10 was used. The inverter had a maximum rated efficiency of 97% with size of 15 kW. Fig (2) presents schematic diagram of 15 kWp PV solar system.

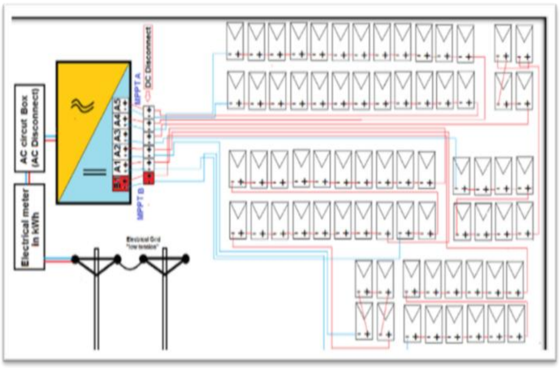

Figure 1. 15kWp PV solar system grid-tied type

Figure 2. Single line diagram of PV solar HIT grid- tied system

The experimental part was done by collecting the real data from sunny portal program which is the best PV monitoring system worldwide. The data had been recorded hourly, daily, monthly and even yearly in terms of AC and DC power and energy. For example**, Fig.3** represents daily power output for the current PV system in 3/2/2017. The program belongs to SMA Company that manufactured the inverter system as shown figure.4. The inverter system is located indoor to avoid high temperature losses.

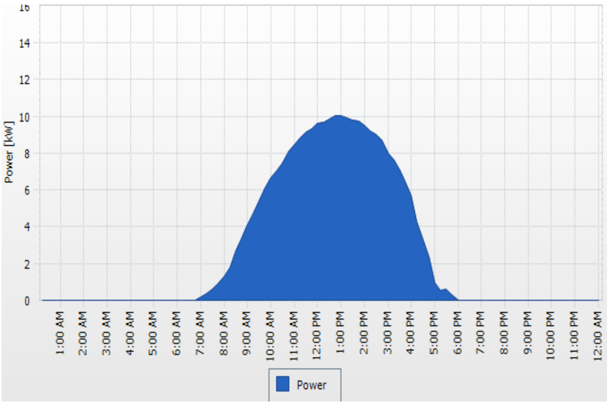

Figure 3. Daily Power output in 3/2/2017

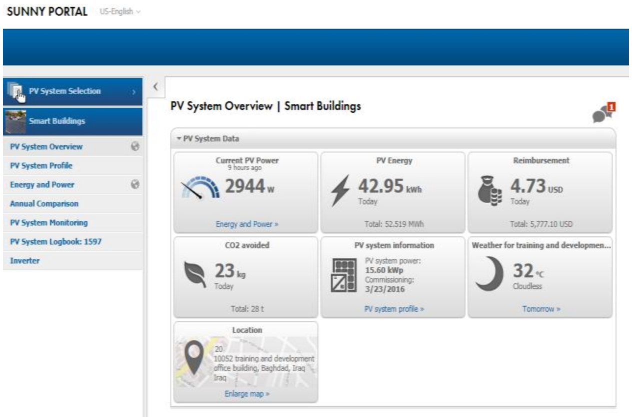

Figure 4. SUNNY PORTAL Mounting System

3. PERFORMANCE ANALYSIS

System parameters assessment includes the following items: yields (array, final and reference yield),energy output ,losses (system and array energy losses), inverter, total system and array efficiencies , capacity factor and performance ratio.

3.1 Energy Output

The full energy output (product) is the magnitude of AC energy generated via solar system per specific duration **(Adaramola et al., 2015)**.

The total monthly, daily and hourly power output can be calculated respectively as follows:

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

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

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

Where: EAC_m is the monthly energy , EAC_d is the output daily energy , EAC_h is the hourly energy , EAC_t is the energy in minute and N represents number of days in a month. While AC symbol represents alternating current, for example *EAC,t* is AC energy product in minutes and so on.

3.2 System Yields

System yields include the array, final and reference yields. The PV solar array yield (YA) is the DC power output for an assumed duration per PV nominal power of the system, it denotes to the time measured in kWh/kW_p (kilowatt hour/kilowatt peak) unit (**Sidy et al.,2016)**, Array yield is given as follows:

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

Where: E_{DC} is DC (direct current) power produced by the PV modules of the system in kWh.

The final yield (Y_F) is the (AC) power output of the PV solar system in kWh/kWp for an assumed period of time per system nominal (rated) power that cab be calculated by Equation 5 **(Sharma et al.,2013)**

$$Y_F = \frac{E_{AC}}{P_{PVrated}} (kWh/kW_P) \qquad (5)$$

Where, E_{AC} is the altering current (AC) energy output in kWh

The reference yield (Y_R) is the global solar irradiation in collimated surface over the reference irradiance. The reference irradiance is calculated at standard conditions and its value 1kWp/m^2. The reference yield can be given by Equation 6:

$$Y_R = \frac{H_T}{H_R} (\frac{kWh}{kW_p}) \qquad (6)$$

Where, H_R is the reference solar irradiance in kW/m^2 and H_T is the in collimated solar irradiance in kWh/m^2.

3.3 Energy losses of Array and System

Array losses L_A are the losses happened due to array performance indicating the incapability of the array to entirely convert the solar irradiance to electricity. The array capture losses given as **(Wittkopf et al., 2013).** Array losses can be happened due to dust accumulation **(Hahsim and Hussien, 2016),** or solar over heating of the solar module. The general module losses are given as:

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

The system losses **(**L_S**)** are the losses happened during the conversion of DC power to AC power by the inverter in PV solar system. It is given as:

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

3.4 System Efficiencies

The efficiency of PV solar system is divided into three types system efficiency, array efficiency and inverter efficiency **(Vignola et al.,2008)**. These efficiencies are calculated on basis of annual, month, day, hour and instantaneous. The efficiency of system depends on AC energy output product, while the efficiency of array depends on the DC energy output product. While inverter efficiency depends on both DC and AC energy output. The array efficiency is given by Equation 9:

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

Where, Am is array area (m^2) and Ht is in collimated surface solar irradiation in W/m^2.

Equation 10 gives the system efficiency of PV solar system as:

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

While Equation 11 demonstrates the inverter efficiency as follows:

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

3. 5 Performance Ratio

Performance ratio (P_R) is the proportion between the final yield to the reference yield. The Performance ratio value of any system shows how the PV solar system approaches the perfect performance through actual act. These values permit comparisons of PV systems depending on different variables; angle, installed location, tilt angle, orientation and their rated power capacity **(Wittkopf et al., 2013**). Performance ratio can be defined as:

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

3.6 Capacity Factor

Capacity factor (C_F) is applied to assessing the energy output generated by an electric power generating system **(Adaramola et al.,2015).** It is the ratio of AC energy generated by PV solar system per a specified duration (usually one year) to the system energy when it works at whole capacity (rated value) for the given period of time. The yearly C_F of the PV solar system is represented by Equation 13:

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

The comparison between capacity factors of different countries worldwide can be seen in Table 1.

Table 1. Capacity factor of different countries.

Country	**C_F range**	**Ref.**
Ghana	18.2% (October) - 13.9% (August)	Mensah et al., 2019
India	16% - 20%	Padmavathi et al.,2013
Mauritania	11.7% (winter) - 20.5% (summer)	Elhadj et al., 2016
Lesotho	8.7% - 21%	Mpholo et al., 2015
Malaysia	10.47%	Khatib et al., 2013
Ireland	10.6%	Mondol et al., 2006

4. RESULTS AND DISCUSSION

The monthly real and predict production of energy and in collimated surface global radiation can be seen in Figure 5. The global irradiation differs from the highest value 18218KWh in August 2017 to the lowest value 11198.38 KWh in December 2017. The minimum values of global radiation are in the rainy, cloudy duration and the highest values are through the arid summer duration. A minimum value of monthly energy produced was 1640 kWh in December 2017 that caused by bad weather conditions like clouds, rain and low radiation intensity. The highest energy production in August was 2236 kWh due to clear sky and high solar radiation intensity. In the other hand, the tilt angle in August is more suitable for receiving solar irradiance rather than other months of the year, (The angle 30 deg was chosen in the installation of this system, which is an intermediate angle between summer and winter angles and closest to the ideal angle in August month). Total energy production by the solar PV system was 23777.43 kWh during the whole 12 months of 2017. The monthly average energy production was 1981 kWh. The outdoor average temperature varies from 16.8°C in January 2017 to 44 °C in July 2017. The uncertainty of PV solar system energy production was calculated using program of PVsyst **(Lalwani et. al 2010)**. The theoretical energy production was calculated as 24610 kWh per year and presented in figure 6

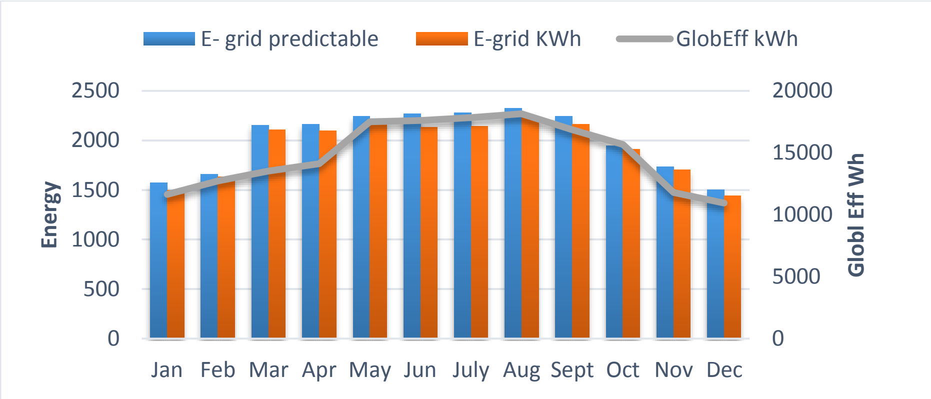

Figure 5. Monthly Real and Predict AC Energy and in collimated plane Global Iradiation.

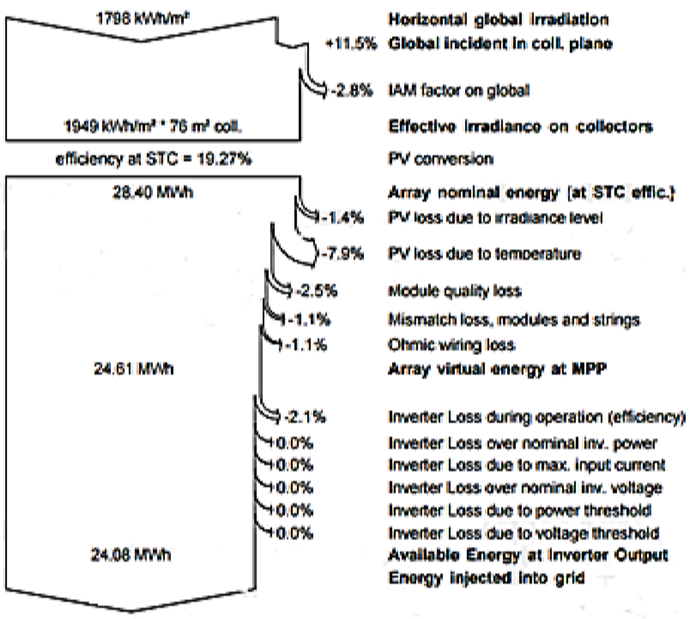

Figure 6. PVsyst Losses and Final Yearly Energy Production Diagram.

The monthly average of daily yields for final array and reference yields were displayed in Figure 7, It had been found that the highest values were reported in August 2017 with values of 5.06 kWh/kWp/day, 4.88kWh/kWp/day, 7.04kWh/kWp/day respectively. The lowest values were reported in December as 4.32kWh/kWp/day, 3.7kWh/kWp/day and 3.58kWh/kWp/day, respectively. The yearly average of daily yields for entire months of 2017 year were 5.9kWh/kWp/day, 4.5kWh/kWp/day and4.4kWh/kWp/day, respectively. During months of the measurements, the differences between average array yield and system yield were constant. These differences were ascribed for the DC to AC conversion losses caused by the inverter. That means regardless the atmospheric conditions, the inverter roughly consumed similar energy monthly to convert DC to AC power.

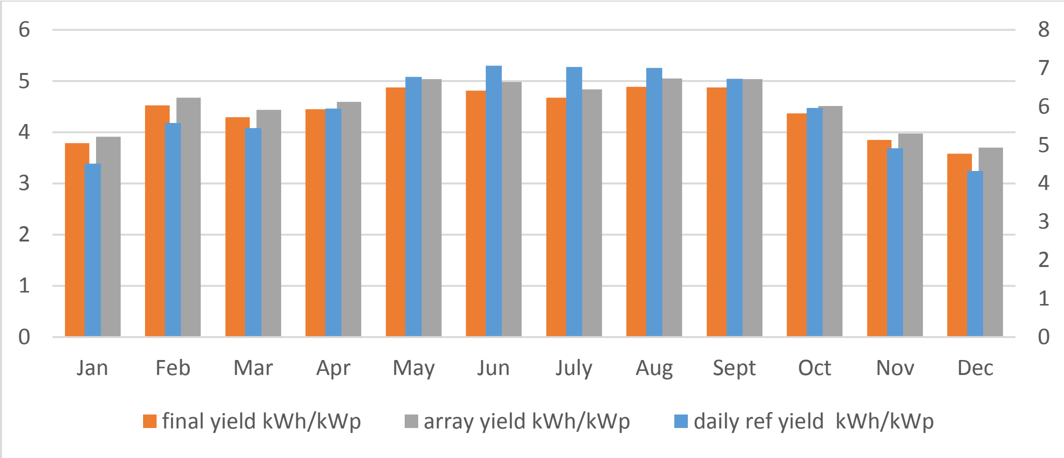

Figure 7. Monthly average of daily yields.

Fig.8 illustrates the monthly average of daily yields of overall array and system losses ratio. The highest losses values in the array were found in July with a value of 2.2kWh/kWp/day. That can be ascribed to high ambient temperature. While in December, the minimum value of 0.6 kWh/kWp/day was recorded. These values coincided with 7% and 4.5% of monthly average of daily reference yield. System losses (represent by inverter losses) varies from 0.17 kWh/kWp/day in July to the value of 0.11 KWh/kWp/day in December. These values coincided with 7% and 4.3% of the respective monthly average of daily reference yield. Yearly average overall system, inverter losses, array losses were found to be 1.53 kWh/kWp/day, 0.15 kWh/kWp/day and 1.38 kWh/kWp/day respectively.

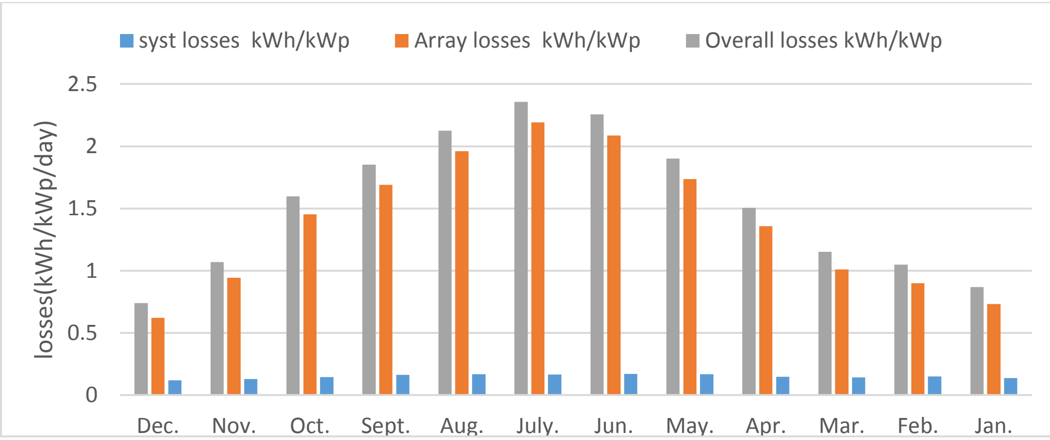

Figure 8. Monthly Average Daily of System, Array and overall Losses.

Fig.9 shows monthly average inverter ,system and array efficiencies during the observing duration. The annual average values were found to be 96.75% ,13.27% and 13.7 % respectively. In December, the maximum values of the inverter, system and array efficiencies were 96.80%, 14.8% and 15.2% respectively. In July, the minimum values were found to be 96.6%, 11.74% and 12.15% respectively.

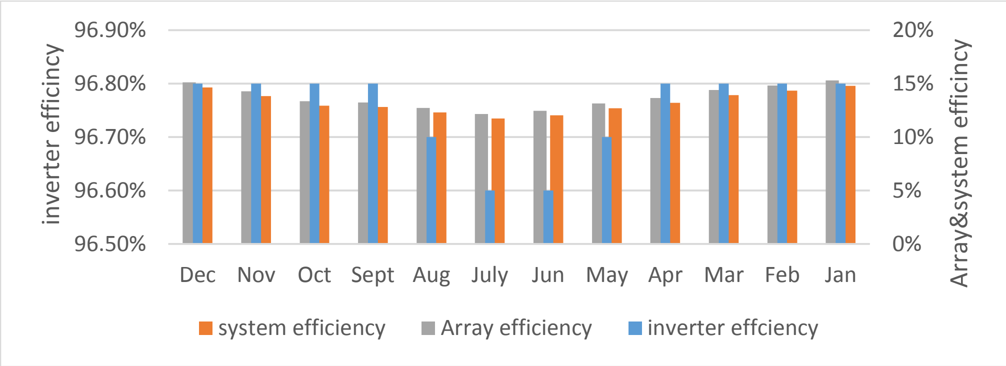

Figure 9. Monthly Average Inverter, System and Array Efficiencies.

Fig. 10 represents monthly average P_R and C_F. It can be seen from the figure that highest value of 83.81 % in December and the lowest value in July of 66.5% were observed. The yearly average C_F was with approximate value of 18.40% were it range was varied between maximum value of 20.3% in August and minimum value of 14.93% in December. C_F represents the time percentage which PV solar system works at its rated capacity. The system generation in its average capacity factor was 67.16 days or 1611.84 hr. Both P_R and C_F are very significant parameters that used for the assessment a Grid-Tied PV solar system.

HIT technology installed in Baghdad city at annual average air temperature equal to 30.3°C with performance of monocrystalline, amorphous and can be compared with poly crystalline technology installed in Morocco state with annual average air temperature equal to 20.76°C. The comparison showed that annual average performance of HIT technology was75.55% while performance of Monocrystalline(mc-Si), amorphous(a-Si) and poly crystalline (p-Si) technology were 76.7%, 73.1% and 75.6% respectively **(Haibaoui et al., 2017)**. This means that HIT performance is very good in Iraq climate condition in spite of high temperature that causes losses in system.

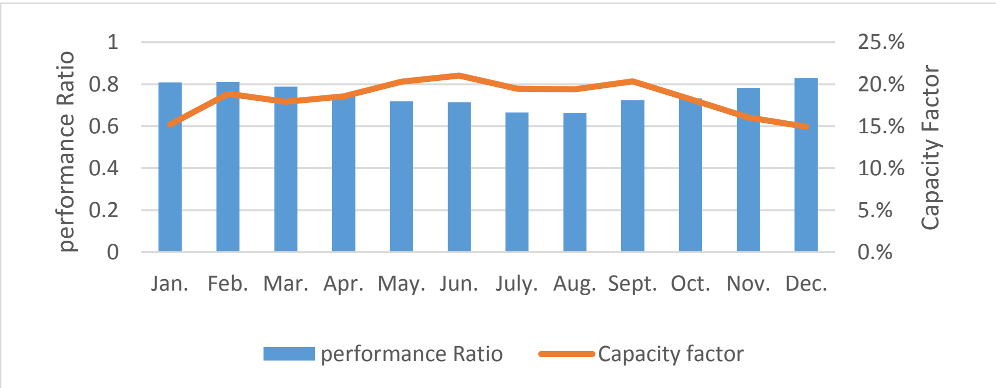

Figure 10. Performance Ratio and Capacity Factor.

5. CONCLUSIONS

In this study, the following conclusions had been concluded:

- Baghdad city environment is suitable to install PV solar On- Grid system as performance analyses results indicated good and promising performance in spite of high ambient temperature.

- Comparing with other recorded results of studies adopted Monocrystalline and poly crystalline technology worldwide, the recorded C_F in the current study can be considered as promising and significant.
- In terms of performance, the HIT technology was found to be effective and significant under hot climate in summer season.
- Comparing to other modules technologies, the current module technology (HIT) possesses an efficiency with a standard of 19.27% with temperature losses coefficient of 0.3/°C nominating it to work effectively and suitably in hot summer climate in Iraq.

Acknowledgment

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NOMENCLATATURE

kWp	Kilo Watt Peak
PV	Photo voltaic
HIT	Heterojunction with Intrinsic Thin-layer
C_F	Capacity Factor
P_R	Performance Ratio
EAC_d	Output power per day, kWh/day
EAC_m	Output power per month, kWh/Month
EAC_t	Output power per minute, kWh/ Minute
E_{AC}	Alternating current power of PV array, kWh
E_{DC}	Direct current power of PV array, kWh
H_R	Reference solar irradiance, W/m2
H_t	In collimated solar irradiance, W/m2
L_A	System losses, kWh
L_S	System losses, kWh
Y_A	Yield kWh/kW$_P$
Y_F	Final yield kWh/kW$_p$
η_{PV}	Array efficiency
η_{SYS}	System efficiency
η_{INV}	Inverter efficiency
$P_{pv,\ rated}$	Rated power of PV system kW

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