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Performance Analysis of 15kW Solar PV System

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ABSTRACT

In recent years, Iraq has suffered from a severe shortage of electricity supply to the government and domestic sectors, whose production depends on fossil fuels, which requires the investment of another energy source to make up for this shortage. The sun is one of the giant energy sources friendly to the environment and renewable and Iraq is one of the rich countries of this kind of energy source. In the present work a 15 kW of PV solar system type HIP-205BA19 was installed Baghdad's Training and Energy Research Center, which is part of the Iraqi Ministry of Electricity. The performance of a Grid-Tied plant with a capacity of 15kW in the Baghdad environment was evaluated. The solar systems were synced with a 0.4kV low voltage distribution sector and their annual performance was monitored. During the time period studied, yearly energy production was 23669.22 kWh. The daily average of array, final, and reference yields were 3.15kWh/kWp, 3.03kWh/kWp and 3.86kWh/kWp, respectively. The result, also, indicated that the yearly daily-average of overall, array and system losses were 1.62kWh/kWp/day, 1.45kWh/kWp and 0.17kWh/kWp, respectively, Inverter, system, and array efficiencies were 96.2 percent, 13.16 percent, and 13.68 percent, respectively, on an annual basis. The capacity factor and performance ratio for were 18.01 percent and 72.5 percent, respectively, on an annual basis. These findings revealed that the systems performed admirably under Baghdad's climatic conditions.

Keywords: *Solar system, performance ratio, Array yield, reference yield solar system losses*

1. Introduction

Human civilisation and survival are inextricably linked to energy. The demand for energy is directly proportional to the rate of human progress. The amount of energy utilized per capita can indicate a country's technological progress. Because energy is derived from both natural and abnormal sources, it is classified into two categories: renewable and non-renewable. Renewable energy is derived from natural sources, while non-renewable energy is derived from non-natural sources..

Solar energy is one of the most important renewable energy sources responsible for the most of the others. One of the most important investments of solar energy is that convert it into electric power by photovoltaic solar cell technology. Iraq is a solar-rich country with rates of more than 2000kWh/m^2 per year [1]. This reality encouraging Iraqi researchers to invest this type of energy.

Several studies in the field of solar energy were conducted in Iraq through which the levels of solar energy reaching the Earth's surface were measured during year days [2], the performance of various types of commercial solar panels was assessed [3] and the impact of both environment temperature and dust accumulation on the performance of these panels respectively [4,5] as well as work to development the performance of these panels through the use of tracking systems [6], solar concentrates [7], and cooling [8]. The results of these studies can be invested in building solar energy systems in different locations of the country and comparing the performance of these systems through performance assessment tools. The present work aims to assess the performance of a 15 kW solar system works in Iraqi environment.

2. Experimental part

The performance analysis of solar PV systems, 15kW (see Figure ures 1) installed at Training and Energy Research Office in Ministry of Electricity, Baghdad, Iraq at (longitude 44.4°E, latitude 33.3°N and 41m above the sea level) was carried out. The characteristics of the solar PV modules of this system is listed in tables 1

. Figure . 1. 15kW solar PV system.

Table 1. Characterization of HIT Solar Module are in SIT Condition "irradiance of 1000 W/m2, air mass (AM)=1.5, cell temperature =25 oC"

Model	HIT power 205	Maximum System Voltage	600V
Rated Capacity (Pmax)	250W	Cell efficiency	20.2%
Pmax voltage voltage (Vmp)	65.7V	Module efficiency	17.7%
At Pmax, current (Imp)	3.62A	Internal by pass diodes	4 by pass diodes
Voltage in an open circuit (Voc)	68.8 V	Module area	1.16m^2
Current in a Short Circuit (Isc)	4.84A	Weight	15kg
Coefficient of temperature (Pmax)	-0.29% / ^{o}C	Dimensions L×W×H	1319x88x46mm
Coefficient of temperature (Voc)	-0.172 V / ^{o}C	Cable length – Male/+Femail	780/630mm
Coefficient of temperature (Isc)	0.88 mA / ^{o}C		

The PV solar system major components are the PV array; the inverter and utility grid (see Figure .2).

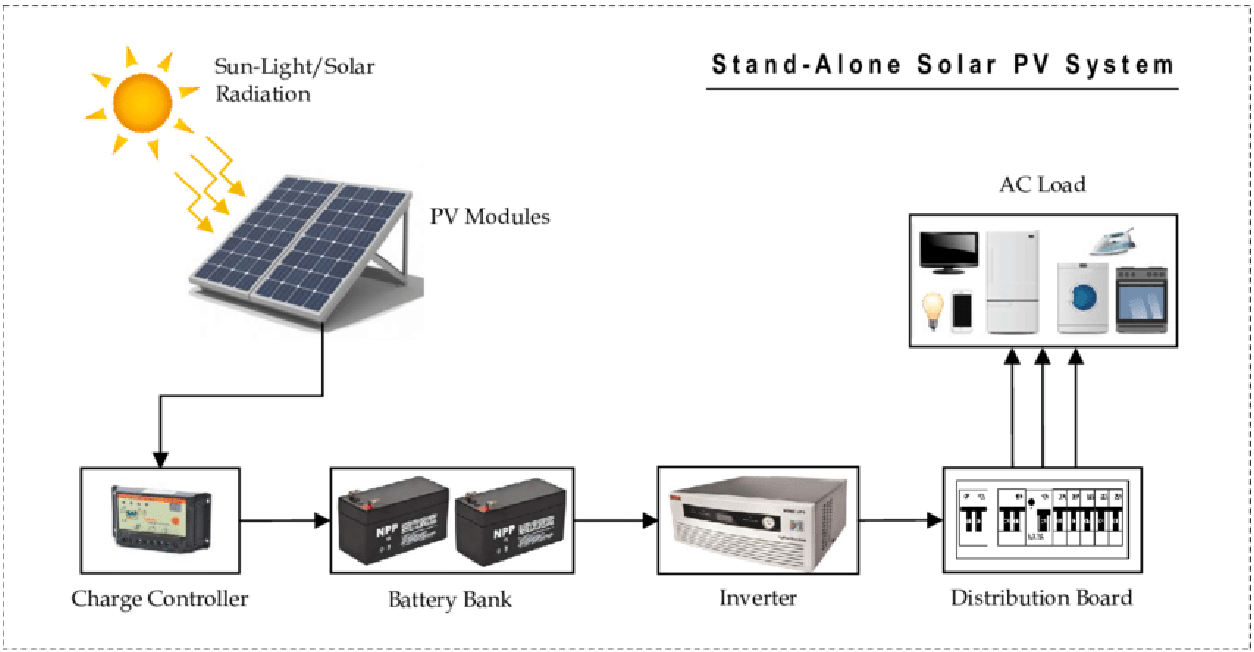

Figure . 2. ConFigure uration of Stand-Alone solar PV system [9]

The solar PV system consists of 72 modules of HIT (Hetero junction with Intrinsic Thin-layer) technology type. However, to increase the voltage, each string of 12 modules connected in series consequently. The system has six strings with parallel connection accordingly output current will be increased. The conversion of DC current is taken place to AC current using the inverter. It contains MPPT (maximum power point tracking) device which is built inside the inverter and have ability to rise the voltage when it drops down in hot days till reaching the maximum power point.

PV solar system was monitored by Sunny Portal monitoring system which is the biggest PV monitoring system that used to monitor 20 GW in over 160 countries with about 330,000 worldwide registering systems. The Sunny Portal system has the efficient use merits so the operators and installers can access the system anywhere at any time. Sunny Portal system can analyze the measured values as well as imagine and compare yields. The program holds the possibility of providing information of weather, system location, capacity and reimbursement. This program offers professional views of the energy yields (daily, monthly, yearly system energy). As well as, it provides the descriptions maximum opportunities for assessment the measured values and visualizing yields, whether a data table or diagram.

3. Performance Parameters of PV systems

The total energy provided by the PV system; Final Yield (YF); Reference Yield (YR); Performance Ratio (PR); Capacity Factor (CF); and system efficiency are the primary components of the performance metrics of PV systems, according to the International Energy Agency (IEA) [10].

• Energy Produced

The quantity of alternating current (AC) power generated by the system during a specific length of time is referred to as total energy. The total energy produced on an hourly, daily, and monthly basis can be calculated as follows:

$$E_{AC;h} = \sum_{t=1}^{60} E_{AC,\ t} \quad (1)$$

$$E_{AC;d} = \sum_{h=1}^{24} E_{AC,\ h} \quad (2)$$

$$E_{AC;m} = \sum_{d=1}^{N} E_{AC,\ d} \quad (3)$$

where E_{AC},t represents AC energy output at time t (in minutes), $E_{AC,h}$ represents AC energy output at hour h, and E_{AC},d represents daily AC energy output The monthly AC energy output is E_{AC},m, and the number of days in a month is N.

• The Final PV System Yield

Final PV System Yield (YF) (also known as the yield factor) is defined as the daily, monthly or annually alternating current (AC) energy produced by the PV system (E_{AC}), divided by the rated output power of the used PV system ($P_{PV,\ rated}$) [11]. It is given by:

$$YF = E_{AC} / P_{PV,\ rated} \quad (4)$$

The maximum capacity of a PV array is calculated by multiplying the PV panel maximum output in kW by the number of panels in the array field. The system yield is a useful approach to compare the energy produced by different brands of PV systems in various latitudes.

• Reference yield

The ratio of total solar irradiation (Ht) in (kWh/m^2) to the reference irradiation G (1 kW/m^2) is known as reference yield (YR) [11]. It is given by:

$$YR = (Ht)\ (kWh/m^2) / G\ (1\ kW/\ m^2) \quad (5)$$

• Performance ratio

Performance ratio (PR) is the ratio between the final yields to the reference yield. Any PV solar system Performance ratio (PR) shows how the system approaches to the perfect performance through real action. These parameters allow the comparisons of PV systems in depending on different variables; tilt angle, installed location, orientation and their rated power capacity [12]. It is given as:

$$PR = YF / YR \qquad (6)$$

• Capacity factor

The capacity factor (CF) is the ratio between actual yearly output energy from PV system to the energy can be produced in case of operation at full rated power for year, and is given as [13]:

$$CF = EAC / (P_{PV,\ rated} \times 8760) \qquad (7)$$

• Efficiency of the system

PV system efficiency is divided into three categories: PV array efficiency, system efficiency, and inverter efficiency. These efficiencies can be calculated on an instantaneous, hourly, daily, monthly, and annual basis, depending on the available data and desired level of detail. The array efficiency is determined by DC power output, but the system efficiency is determined by AC power output. PV reflects the PV array's mean energy conversion efficiency, which is defined as the ratio of daily array energy output (DC) to the product of total daily in-plane irradiation and PV array area. [14]. The PV module efficiency is calculated by the following equation:

$$\eta_{PV} = \frac{100 \times E_{DC}}{H_t \times A_m} \% \qquad (8)$$

Where: Am = area of the array (m^2)

The efficiency of system demonstrated the performance of the entire PV system installed, represent as:

$$\eta_{SYS} = \frac{100 \times E_{AC}}{H_t \times A_m} \% \qquad (9)$$

The inverter efficiency is given as:

$$\eta_{INV} = \frac{100 \times E_{AC}}{E_{DC}} \% \qquad (10)$$

4. Losses in array and system energy

The array capture losses LA denote the losses incurred as a result of array operation, highlighting the array's inability to completely utilize the available irradiance [14]. The difference between the reference yield and the array yield is the array capture losses. It is written as follows:

$$L_A = Y_R - Y_A \quad (kWh/kWp) \tag{11}$$

The system losses LS are caused by the inverter's losses in converting the DC power output from the PV to AC power. It's written as the difference between the reference and array yields. It is written as follows:

$$L_S = Y_A - Y_F \quad (kWh/kWp) \tag{12}$$

5. Results and discussion

There are several key factors that determine the solar panel's production of electric power, including the specifications of the panel and the other related to the circumstances surrounding such as the amount of incident solar energy on the solar panel, ambient temperature and local wind activity. The last three variables were measured in Baghdad’s environment during the days of 2021. The results are shown in Figure ures 3, 4 and 5. Figure ure 5 shows promising values solar fuel for investment in solar energy applications, especially in the summer when the demand for electricity energy at its peak. According to the solar radiation levels, temperature rates, and wind speed rates and for a specific type of solar panel (HIP-250BA19) in the 15 kW solar system, the monthly production of output power ranged between minimum (1410.6kWh) and maximum (2419.8 kWh), as shown in Figure ure 6.

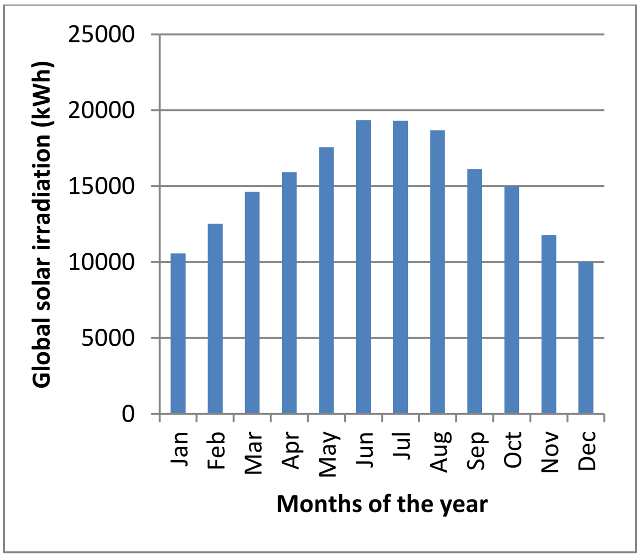

Figure . 3. Incident solar radiation on the tilted panel.

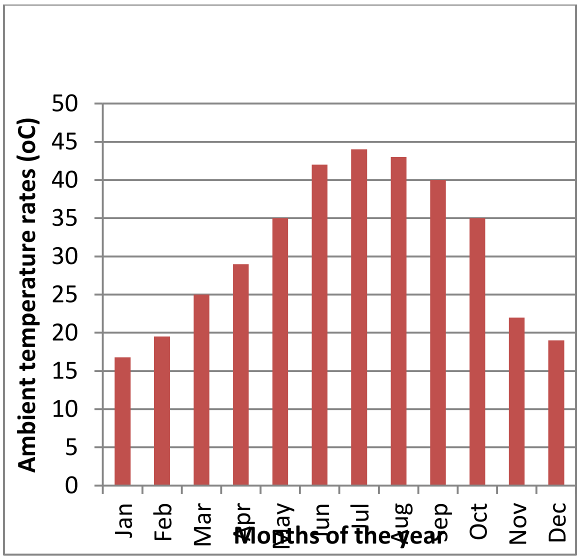

Figure . 4. Ambient temperature rates during the year.

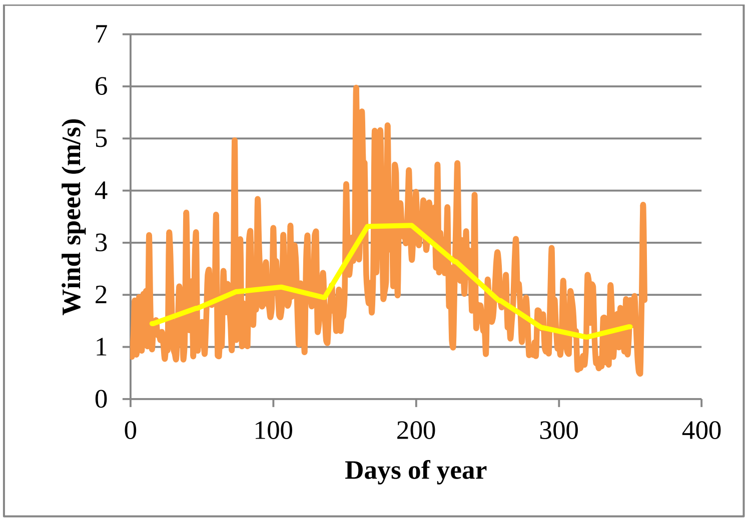

Figure . 5. Wind speed rates during the year.

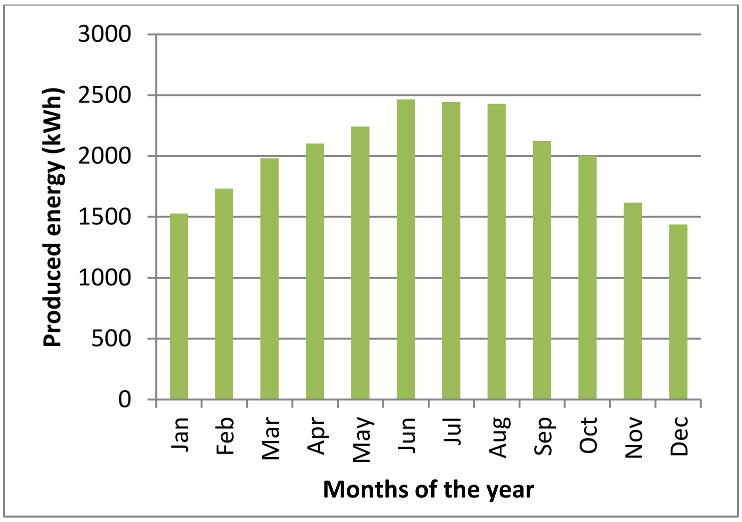

Figure . 6. Electrical energy production during the year.

Figure ures 7 show the monthly-daily average of reference, array, and final yields. It's worth noting that the lowest levels are found during the winter months of December and January. The monthly averages of reference, array, and final yields in December 2021 are 3.86kWh/kWp/day, 3.15kWh/kWp/day, and 3.03kWh/kWp/day, respectively. While The monthly average daily yields of reference, array, and final yields in June 2021 are 7.72kWh/kWp/day, 5.59kWh/kWp/day, and 5.37kWh/kWp/day, respectively. There is a continual change in the average of system and array yields during the course of the measurement period. This variance is caused by the inverter's DC to AC conversion losses, which mean that regardless of the weather, the inverter consumes about the same amount of monthly energy for the conversion process (indoor installation). It can be also that the difference between the reference yield and the others was increased toward the summer due to thermal factor.

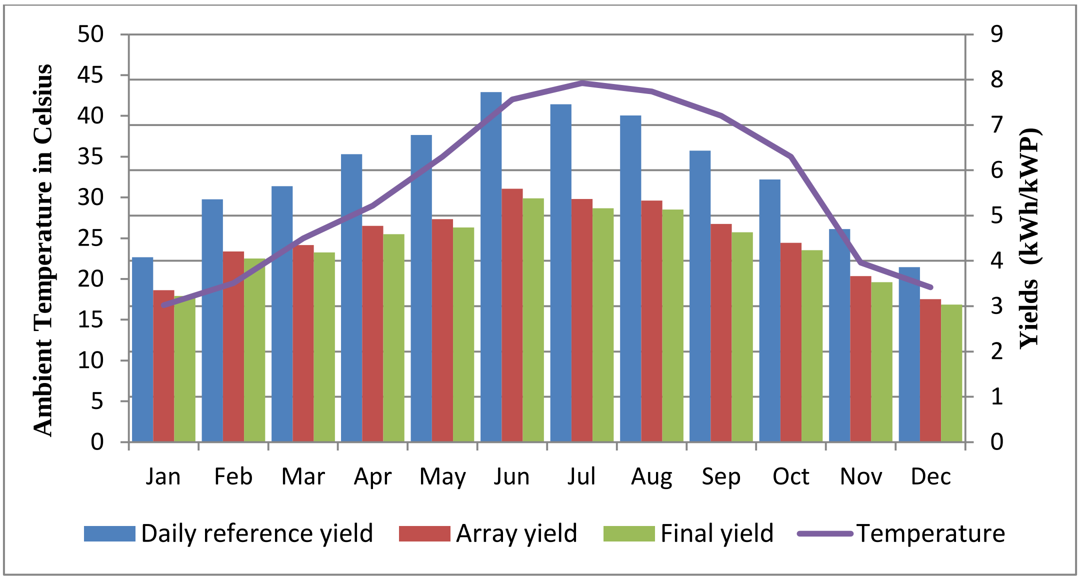

Figure ure (7): Monthly daily average of yields.

Figure ures 8 and 9 illustrate the monthly daily average of array, system, and total losses in comparison to the average daily reference yield.The largest value of monthly daily array losses was 2.1 kWh/kWp/day, which was recorded in June due to high ambient temperature, while the smallest value was 0.72 kWh/kWp/day, which was observed in January and December. The maximum value of overall losses was recorded in June (2.35kWh/kWp/day) and the minimum value was recorded in January and December in (0.84kWh/kWp/day). The yearly daily averages of array, system and overall losses are 1.62kWh/kWp/day, 1.45kWh/kWp/day and 0.17kWh/kWp/day, respectively. Overall losses equal to summation of array losses and system losses.

Figure ure 9 depicts the average monthly inverter, system, and array efficiencies during the course of the tests. Efficiencies were 96.2 percent, 13.16 percent, and 13.68 percent on an annual basis, respectively. In July, the inverter, system, and array efficiencies reached their lowest points, at 96.2 percent, 12.43 percent, and 12.92 percent, respectively. The minimum efficiency values are due to the high ambient temperature, while the maximum efficiency values are due to low ambient temperature.

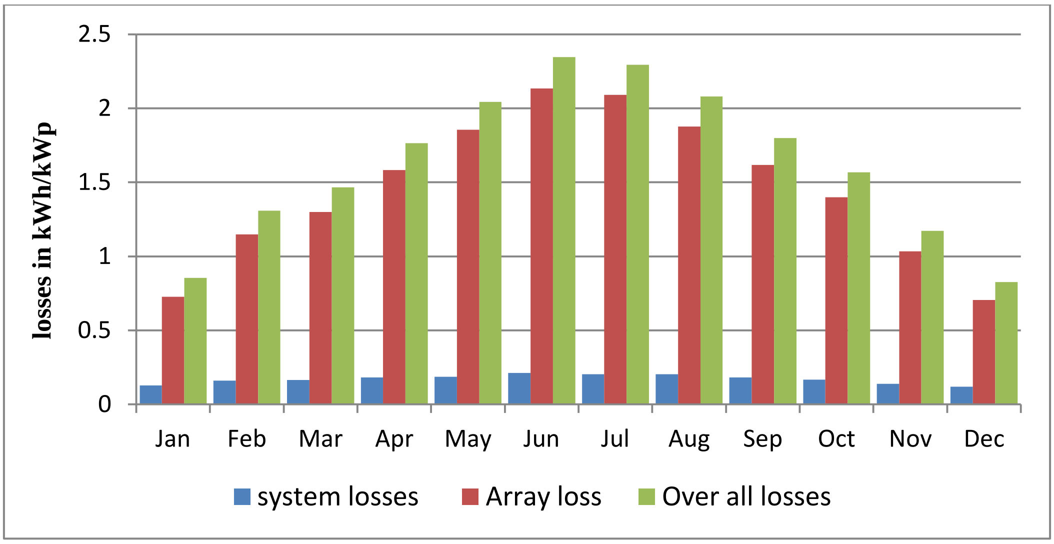

Figure . 8. The array, system, and total losses are averaged on a monthly basis.

Figure ure 9 shows that there are a wide difference in efficiency levels for inverter compare with system and array. The solar inverter was very efficient, approximately 96% depending on the make and model. Its efficiency will not equal to 100% because some of power was lost as heat, some power was used for powering the inverter. MOSFETs are employed as switches in power electronics, particularly in the design of electronic converters. This is because, in theory, a switch should have no losses because it has either zero voltage or zero current, hence power losses are always zero. By the way, even if employed as switches, these devices are not ideal switches, which means they generate power losses. These losses are unavoidable in both static and switching states, and there are also power losses due to the switching devices' drive. The level of this loss is, approximately, constant over time if the environment temperature is maintained. The efficiency of array related to the efficiency of solar panel, which is changed according to thermal factor. System efficiency reflects the total losses in output power caused by all components of the solar system.

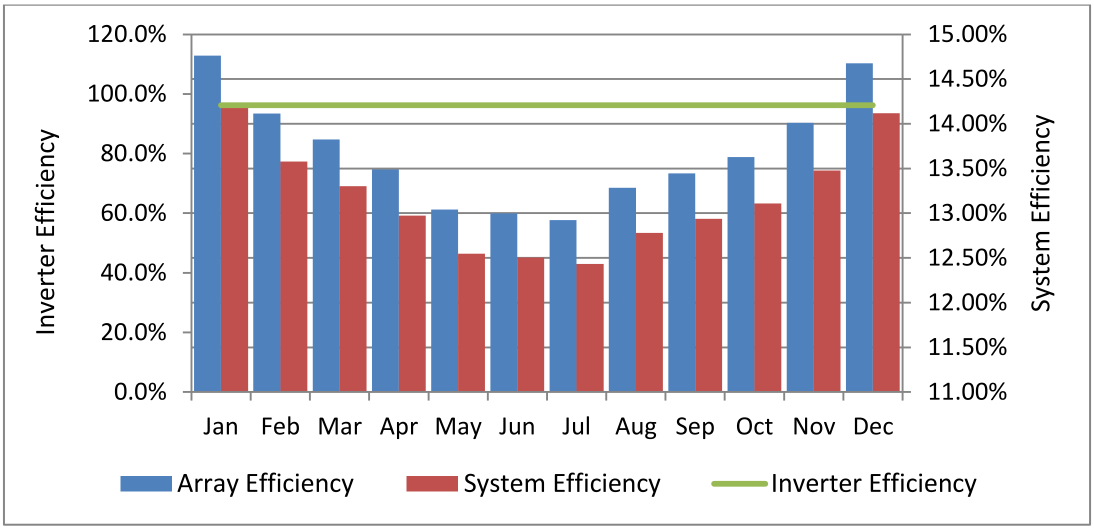

Figure . 9. Monthly average of inverter, system, and array efficiencies.

Figure ure 10 shows the monthly average of the capacity factor and the performance ratio. The yearly average of PR of the current system is 72.5%. Its maximum value was in January and December (79.1%), while the minimum value was 69.2% in July. The Figure ure shows the drop of PR during May, June, July and August due to arising in ambient temperature in these months. The average of annual capacity factor (CF) was 18.01%. Its value reached to 22.40% as a maximum in June and then decreased in cold months and reached to minimum value (12.64%) in December. CF is the indicator exhibits the time magnitude in percentage at which the PV solar system works in its maximum capacity, Consequently the PR and CF are a very significant parameters to assess On-grid PV solar system. This graph depicts how the performance ratio (PR) and capacity factor behave differently depending on the time of year. Because of this heterogeneous behavior, the performance ratio is a measure of a PV system's performance that takes into account environmental conditions such as temperature, wind speed, irradiance, and so on, whereas the capacity factor ignores all of these elements as well as module deterioration. The PR factor considers the grid's availability, the minimal amounts of solar irradiation required to generate power, and solar irradiation levels over time, whereas the capacity factor does not. PR can also be used to compare different PV solar systems against one another.

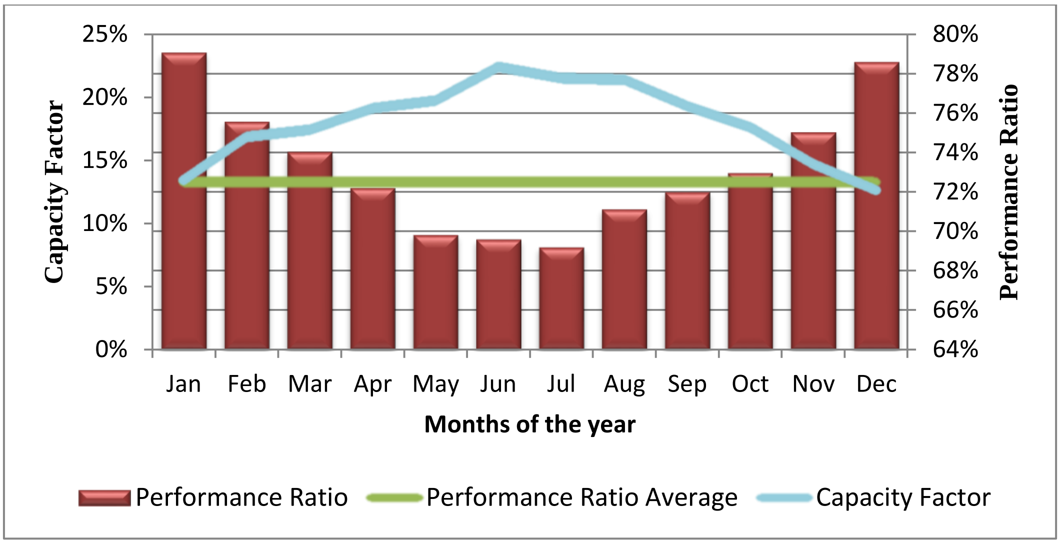

Figure . 10. Monthly average of capacity factor and performance ratio

6. Conclusions

From the results of the present work it can be concluded that in spite of high ambient temperature in summer, Baghdad governorate geographic area is promising for investment in the field of electrical energy production via On-Grid PV solar systems and investing the solar energy in Iraq supports the supplying of electricity, especially under the current conditions in which Iraq is suffering from a severe shortage of electrical energy supplying and reduces environment pollution outcome from conventional energy production power plants and factories.

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