YEARLY IMPROVEMENT OF GRID-CONNECTED SOLAR PV SYSTEM PARAMETERS BY PLANAR CONCENTRATORS

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Abstract: Planar concentrators are used in the current manuscript to improve the solar PV system parameters (electrical energy, array yield, and solar irradiation). Additionally, study the temperature (both the ambient temperature and the temperature of the PV modules), performance ratio, and efficiency. The current PV system is situated at Al-Taji town in Baghdad. These improvements are achieved by using planar concentrators to increase solar radiation (made of aluminium metal). The results demonstrated a 21% increase in the yearly average energy output for improved solar PV modules. The improved solar PV modules' average yearly array yield increased by 20.6%. Compared to the reference PV modules, the improved solar PV modules received 24% more solar irradiation yearly on average. The monthly average of the performance ratio (PR) and efficiency to the improved solar PV modules and reference solar PV modules are 89.3% & 13.61%, and 91.2% & 13.89%, respectively. The yearly average temperatures of the reference PV solar modules and improved PV solar modules are 48.8^{O}C and 46.0^{O}C, respectively, at an average ambient temperature of 29.2^{O}C. The originality of this work is the successful improvement of the electrical energy of the grid-tied PV system, in addition to studying the performance of the second generation of photovoltaic solar modules (CIGS), where CIGS is the PV module technology that is used in this manuscript.

Keywords: Planar concentrators; Performance; Efficiency; PV modules; Grid-Connected.

التحسن السنوي لمعاملات نظام الطاقة الشمسية الكهروضوئية المتصلة بالشبكة العامة بواسطة المركزات المستوية

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الملخص: تُستخدم المركزات المستوية في البحث الحالي لتحسين معلمات نظام الطاقة الشمسية الكهروضوئية (الطاقة الكهربائية، وعائد المصفوفة، والإشعاع الشمسي). بالإضافة إلى دراسة درجة الحرارة (درجة الحرارة المحيطة ودرجة حرارة الالواح الكهروضوئية) ونسبة الأداء والكفاءة. يقع النظام الكهروضوئي الحالي في بلدة التاجي ببغداد. يتم تحقيق هذه التحسينات باستخدام المركزات المستوية لزيادة الإشعاع الشمسي (المصنوع من معدن الألمنيوم). أظهرت النتائج زيادة بنسبة 21٪ كمتوسط سنوي من إنتاج الطاقة للألواح الشمسية الكهروضوئية المحسنة. زاد متوسط عائد المصفوفة السنوي للألواح الكهروضوئية الشمسية المحسنة بنسبة 20.6٪. مقارنةً بالألواح الكهروضوئية المرجعية، تلقت الوحدات الشمسية الكهروضوئية المحسّنة إشعاعًا شمسيًا أكثر بنسبة 24٪ كمتوسط سنوي. المتوسط الشهري لنسبة الأداء (PR) والكفاءة لألواح الطاقة الشمسية الكهروضوئية المحسنة والالواح الكهروضوئية المرجعية عند 89.3٪ & 13.61٪ و 91.2٪ & 13.89٪ على التوالي. يبلغ متوسط درجات الحرارة السنوية للألواح الشمسية الكهروضوئية المرجعية والمُحسَّنة 48.8 درجة مئوية و46.0 درجة مئوية على التوالي، عند متوسط درجة حرارة محيطة يبلغ 29.2 درجة مئوية. أصالة هذا العمل هو التحسين الناجح للطاقة الكهربائية لنظام الكهروضوئية المرتبطة بالشبكة. بالإضافة إلى دراسة أداء الجيل الثاني من الالواح الشمسية الكهروضوئية (CIGS). حيث أن CIGS هي تقنية الوحدة الكهروضوئية المستخدمة في هذا البحث.

الكلمات المفتاحية: المركزات المستوية؛ الأداء؛ الكفاءة؛ الألواح الكهروضوئية؛ المنظومة المتصلة بالشبكة.

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NOMENCLATURES

AC: Alternating Current.
A_m: Array area.
CIGS: Copper Indium Gallium Selenide (solar module).
DC: Direct Current.
E_{AC}: Alternating energy production.
EINCP: Energy Increment Percentage.
H_R: Reference Solar Irradiance.
H_T: in-plane solar irradiation.
MPPT: Maximum Power Point Tracking.
PR: Performance Ratio.
PV: Photovoltaic.
S.IRR: Solar Irradiation.
T_m: PV module actual temperature.
T_{ref} : PV module reference temperature.
β: Temperature coefficient.
H_{ref} : rated (nominal) efficiency of PV modules
POTA : planar concentrators optimum tilt angles.
MOTA : modules optimum tilt angles.
PV/T: Photovoltaic/Thermal systems

1. INTRODUCTION

It is necessary to develop and employ renewable energy sources in view of the global warming issues facing the globe in general and Iraq in particular, as well as the severe imbalance between the supply and demand for energy. Solar photovoltaic technology is mainly used to reduce the demand for fossil fuels used in the production of electric power and to reduce the gap between consumption and production to achieve a stable state in the electric grid. Employing renewable energy sources reduces the large number of local diesel generators that are used to produce electricity when the grid shuts down, which has a negative impact on both human health and the environment. Solar energy resources are a clean energy source that can be exploited to meet global energy demands (Abedin and Rosen, (2011). The introduction of clean, renewable energy technology is a great achievement because Iraq suffers from a shortage in the supply of electrical energy to institutions and homes and also suffers from an increase in pollutants as a result of the widespread use of local diesel generators to make up the shortfall in electrical power outages (Alaa, 2020).

Employing solar power reduces emissions because it doesn't produce any greenhouse gases like CO_2 (Al-Shamani et al.,2016). In contrast to conventional power systems like diesel generators, solar technology like photovoltaic solar modules is used even on rooftops. It can be directly harnessed at the place of generation without specifically requiring a transmission grid (Naveen et al., 2017). From sunrise to night, solar energy is abundant everywhere, giving us enough time to harness it. There are no negative effects of solar energy on the environment. In contrast to traditional energy sources like gas and oil, which are concentrated in a certain region of the world, clean energy sources are present everywhere. The rapid adoption of green energy and energy efficiency is reducing climate change, providing significant energy security, and having an economic benefit. (Seitel, 1975).

Ronald et al.(2000) tested the effect of a PV solar module with a V-trough and a fixed tilt angle in a Swedish climate. They demonstrated that the flat-plate fixed reflector increases the PV module's annual power production by 20% to 25%. According to a study by Pavlov et al. (2015), using planar concentrators increased daily power by 35% during specified times of the year when there were no clouds. For poly-Si and amorphous-Si modules, the monthly power increases are calculated at 18% and 26%, respectively.

Tabaei and Ameri. (2015) found that the use of booster reflectors made of aluminium foil increased the power output of polycrystalline silicon by 14%. The maximum power output when using aluminium foil reflectors with water film is 50.4%. In 2009, planar concentrators made of various materials were attached to the high and low sides of the solar PV module to examine its performance. In order to determine the most effective type of material for planar concentrators that harvests the most electrical energy with the fewest extra heat, experiments are conducted with stainless, aluminium, chrome, and steel planar concentrators. It has been found that planar concentrators made of chrome material provide 27.65% greater energy output than planer concentrators made of aluminium foil and 34.1% more energy output than planer concentrators made of stainless steel (Rizk and Nagarial, 2009). According to some studies, horizontal planar concentrators with vertical modules are better situated at high latitudes (Duffie et al ., 2020).

Under the climatic circumstances of Al-Dhahran (KSA), Bahaidarah et al. (2013) developed a solar system that is cooled by the flow of water on the backside of the PV module. The outcomes showed that the operating temperature of the PV solar modules decreased to about 20%, and the electrical efficiency increased to 9%. The PV/T system has planar concentrators that boost solar radiation to $950 W/m^2$ and a water mass flow rate of 0.042kg/sec.

Figure 1. Present PV solar system.

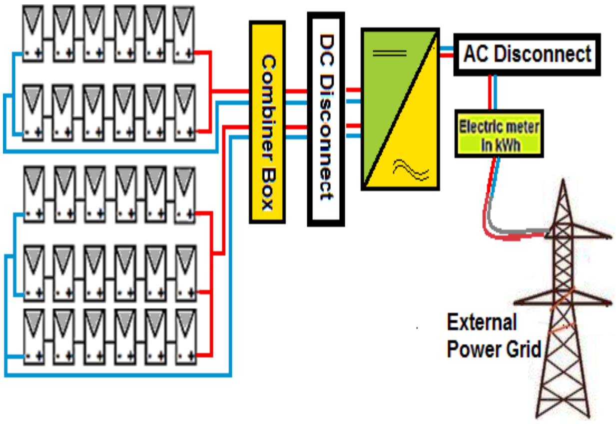

Figure 2. Diagram of PV system block circuit.

Table 1. Specifications of the solar PV system and solar PV module.

Module Features	Value	System Features	Value
Module model	TS-165C2 CIGS	Inverter model	SMA SB-5000T-21
Max Power (Pmax)	165 W	Number of modules	30
Open-Circuit Voltage (V_{oc})	88.7 V	Inverter size	5.30 kWp
Short-Circuit Current (I_{sc})	2.66 A	Inverter efficiency	97%
Max Power Voltage (V_{mpp})	68.5 V	System size	5 kWp
Max Power Current (I_{mpp})	2.41 A	PV modules tilt Angle	30^o
Max Reverse Current (I_R)	6.5 A	Planar concentrators tilt angle	
Operating Temperature	-40°C to 85°C	Temperature coefficient of Pmax	-0.30% /^{O}C

The results of the combined electrical and thermal efficiencies are reported at 71.40, where the PV electrical efficiency is 12.40% and the thermal efficiency is 59% (Palaskar et al., 2015).

This study aims to raise energy output because doing so will increase revenue, which will lead to good economic feasibility.

2. PV SYSTEM DESCRIPTION

The present PV system has been mounted in Baghdad at latitude 33.3^{O}N and longitude 44.4^{O}E, as exposed in figure 1. The present solar PV system includes 30 modules, which are designed in 5 strings with six series-connected modules, as exposed in figure 2. The specifications of solar PV systems and solar PV modules are shown in Table 1.

3. SOLAR PV MODULES AND PLANAR CONCENTRATORS

The current solar PV system in this work is divided into two groups: the first group, which is classified as an improved group that contains 12 PV modules, and the second group, which is classified as a reference group that contains 18 PV modules. The increment percentage (gain) in the performance characteristics of the solar PV system is then calculated by comparing the improved group to the reference group. The improved group receives solar radiation of a higher intensity than the reference group (one of which is from the planar concentrators and the other from the sun). In contrast to the second group (18 modules), the improved group's planar concentrators are attached in front of it, as indicated in fig. 3 (added to 12 modules). The inverter in the present solar PV system has two inputs: the improved group input, which contains 12 PV modules (1980 W), and the reference group input, which has 18 PV modules (2970 W). The data is gained by connecting an inverter to a computer with a speed wire. As seen in fig. 4, an inverter exhibits data in two clusters (A and B). The reference group data are represented by cluster (B), while the improved group data are represented by cluster (A). The inverter in the current system involves two inverters with the maximum point tracker (MPPT) technology (Yilmaz et al., 2019).

Since the reference group contains 18 PV modules and the improved group contains 12 PV modules, before all the calculations, the power of the reference group is divided by 18 and multiplied by 12 to accomplish an equalization in power (number of PV modules) between the improved and reference groups so that each group contains 12 PV modules.

The planar concentrators are manually attached to the solar modules and oriented to reflect the sun's radiation directly onto the solar modules in order to attain the optimum angle. Then it is monitored since the sun's path varies throughout the months and prevents planar concentrators from reflecting all of the solar radiation that reaches them. As a consequence, the concentrators' angle must be adjusted to coincide with the sun's elevation angle for each month. Six of the optimum angles throughout the course of a year are determined after all these observations and adjustments, and they are shown in table 2. Throughout the year, the PV solar system modules' tilt angles are fixed at 30° in accordance with Baghdad's latitude.

Table 2. Planer concentrators and PV solar modules have optimum tilt angles.

POTA	MOTA	Month
17^{O}	30^{O}	December
20^{O}	30^{O}	November and January
25^{O}	30^{O}	October and February
30^{O}	30^{O}	March and September
35^{O}	30^{O}	April, May and August
37^{O}	30^{O}	June and July

Where: POTA and MOTA are abbreviations of planar concentrators' optimum tilt angles and modules' optimum tilt angles, respectively.

Figure 3. Reference and improved solar PV modules (groups).

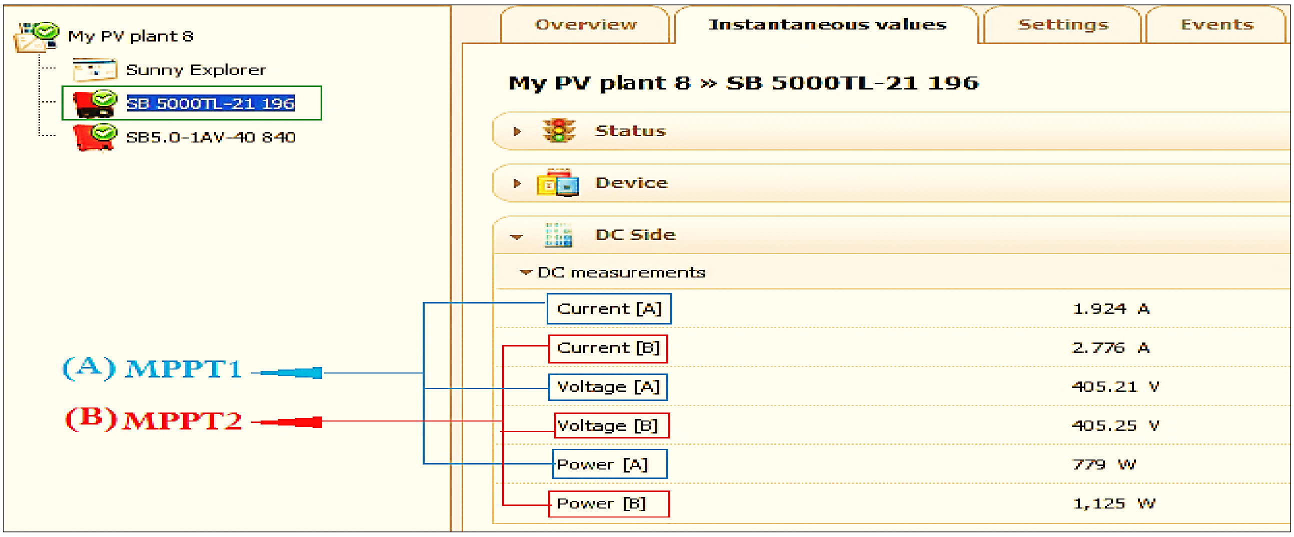

Figure 4. Screen capture of inverter data presentation in the laptop.

4. PREPARING THE STUDY

The current experiment is carried out at the Al-Mansour Company in Baghdad (longitude 44.4 degrees east and latitude 33.3 degrees north). Performance parameters that have been improved include electrical energy, array yield and solar radiation. The temperature of the improved PV modules, reference PV modules and ambient air are all measured. All of the parameters above-mentioned are recorded for both the reference and improved groups. Each group's data is collected from the inverter, which exhibits the solar PV system data in the individual (A and B) manner as described above. The study is conducted from 7:30 am to 6:00 am on each day. This work is a sample study, so the days in the middle of the month (13th, 14th, 15th, 17th) or even 19 in the case of cloudy months are those in which performance improvement is being studied because it is impossible to calculate electrical energy improvement on cloudy days. The purpose of doing this study in the middle of the month is that this is because solar radiation and ambient temperature are on average for each month. The current study was carried out in 2020 for a whole 12 months.

5. PERFORMANCE PARAMETERS

The performance parameters (electrical energy, performance ratio (PR), efficiency, and array yield in addition to solar irradiation, PV modules, and ambient temperatures) for the reference and improved (modules) groups are studied. Speedwire directly obtains energy and power from an inverter, whereas the following equations are used to calculate efficiency, PR, and solar irradiance. A digital thermometer is used to measure both the temperature of the solar PV modules and the surrounding environment.

5.1. Efficiency

Efficiency is classified into an array, system, and inverter efficiencies. The array efficiency (η_{PV}) is based on the DC power output, while the system efficiency (η_{SYS}) is based on the AC energy output (de Lima et al.,17; Abed et al.,2020). The array efficiency is the ratio of the DC energy output to the in-plane solar irradiation multiplied by the area of PV modules (PV array) (Kumar et al., 2017; Attari and Asselman, 2016). The array efficiency is calculated as follows:

$$\eta_{PV} = \frac{100 * E_{DC}}{H_T * A_m}\% \quad (1)$$

The system efficiency is given in equation 2:

$$\eta_{SYS} = \frac{100 * E_{AC}}{H_t * A_m}\% \quad (2)$$

where H_t is the in-plane solar insolation, A_m is the solar PV array area, and E_{DC} is the DC energy. Inverter efficiency is given in equation 3:

$$\eta_{INV} = \frac{100 * E_{AC}}{E_{DC}}\% \quad (3)$$

An inverter's efficiency ranges from 97% to 96% because it is indoors (Kasim et al., 2020).

5.2. Performance Ratio (PR)

PR is an essential indicator since it reveals all the negative impacts of the solar photovoltaic system. The PR allows for the comparison of PV solar systems regardless of solar radiation resources, tilt angle, orientation angle, their nominal, and power capacity. It shows how near the actual PV system is to reaching ideal performance during actual working time. (Ozden et al., 2017; Obaid et al 2020). PR is given in equation 4.

$$PR = \frac{Y_F}{Y_R}\% \quad (4)$$

where: Y_F is the final yield estimated by equation (5), (Y_R) is the reference yield estimated by equation (6).

The final yield (Y_F) is the yearly, monthly, or even daily output AC energy of the PV system divided by the rated power of the PV system at standard test conditions (1 kW/m2 and 25°C cell temperature) (Sharma et al.,2013; Obaid et al., 2019). The Y_F denotes the number of hours per day that the solar PV system is working at its rated capacity. Equation 5 calculates Y_F.

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

where E_{AC} represents AC energy production (kWh), the reference yield (Y_R) is calculated by dividing the reference irradiance, which is equal to 1 kW/m^2, by the in-plane global insolation. Y_R is given by equation 6 (Adaramola et al., 2015; Rezk et al., 2019).

$$Y_R = \frac{H_T}{H_R} \ (kWh/kW_P) \quad (6)$$

where H_R and H_T are the reference irradiance and in-plane global insolation (irradiation), respectively.
When the Equations. (5) and (6) are substituted into Equation (4), and Equation (7) is gotten (Kasim et al., 2019).

$$PR = \frac{E_{AC} * H_R}{P_{PV,rated} * H_T}\% \quad (7)$$

The performance ratio (PR) can also be estimated by equation 8:

$$PR = \frac{\eta_{Actual}}{\eta_{ref}} \quad (8)$$

Equation 8 is utilized to calculate the (PR).

The array yield (Y_A) is the DC energy output for a specific period of time divided by the nominal power of the PV solar system. The Y_A represents the number of hours per day that the solar PV system is operating at its nominal power (Abed et al., 2020). The array yield is given in equation 9:

$$Y_A = \frac{E_{DC}}{P_{PV.rated}} \ (kWh/kW_P) \quad (9)$$

where E_{DC} represents the direct energy output (DC) (kWh) of the PV solar array.

The actual (P_{AC}) and rated (P_{rated}) power are estimated as follows:

$$P_{AC} = H_R * \eta_{Actual} * A_m \quad (10)$$

$$P_{rated} = H_R * \eta_{ref} * A_m \quad (11)$$

The actual efficiency (η_{Actua}) is estimated via equation 12. It can also be estimated by equation 13.

$$\eta_{Actual} = \eta_{ref} [1-\beta(T_m-T_{ref})] \quad (12)$$

where η_{ref} is the rated efficiency (15.2%), A_m is the area of reference and improved PV modules (13.04 m^2 each), β is the temperature coefficient that equals -0.3%/°C, T_{ref} is the reference modules' temperature (25°C), and T_m is the actual PV modules' temperature (Kasim et al., 2019).

$$\eta_{Actual} = \frac{\text{Electrical Power}}{\text{Solar Irradiance} * \text{Area}} \quad (13)$$

From equation 10, equation 14 is obtained as follows:-

$$H_R = \frac{P_{AC}}{A_m * \eta_{Actual}} \quad (14)$$

where P_{AC}, A_m and η_{Actual} are the actual power, improved group area and actual efficiency, respectively.

Equations 14 and 8 are used to calculate solar irradiance (H_R) and actual efficiency (η_{Actual}), respectively.

The formula used to calculate energy increment percentage (EINCP) is given as follows:

$$EINCP = (E_{im}-E_{ref})/ E_{ref} * 100\% \quad (15)$$

where $E_{im,}$ and E_{ref} are the energy of the improved and reference groups, respectively. EINCP is an abbreviation of the energy increment percentage or the energy INCP (energy gain). Equation 14 is used to calculate the energy increment percentage.

6. RESULTS AND DISCUSSION

Figure 5 shows the energy INCP, improved, and reference PV modules (groups). The highest energy output values coincide with the peak solar radiation and the optimum tilt angle for solar PV modules. In May, the maximum monthly daily energy values of the reference and improved modules were 12.99 kWh and 16 kWh, respectively, whereas the energy INCP for this month was 23.3%. While the minimum values are 8, 28 kWh, and 10 kWh, respectively, in December, the energy INCP for this month is 18%. Utilizing planar concentrators results in a 21% monthly daily average increase in energy over the course of the year (34.0 kWh). The physical interpretation of May having the highest energy production is that it gets the most solar radiation and has the optimal tilt angle for PV solar modules, which is 30^O. Tests are conducted on one day of each month that lies in the middle of the month, and this day is considered the monthly daily average.

In Fig. 5, the energy INCP curve has two crests and three bottoms. The crests show up during the spring and autumn seasons as energy INCP increases. While the bottoms show up during the cold and hot seasons as energy INCP decreases.

The daily behaviour of the power produced by improved and reference PV modules is shown in Figure 6. The difference between the two groups is clearly shown in the figure. At 12:00 pm, the maximum power values for the reference and improved PV modules are 1.712 kW and 2.308 kW, respectively, with an INCP (the gain) of 34.4%. At 5:00 pm, INCP has the lowest value of 4.9%, while on average, throughout the day, it is 24.7%.

The data for all parameters studied in this research) electrical energy, array yield, solar radiation, efficiency, and PR) are included in the appendix.

Figure 7 shows the performance ratio of improved and reference PV modules. The maximum PR values of reference solar PV modules and improved solar PV modules are 94.5% and 95.5%, respectively, in December and January. In comparison, the minimum performance ratios were 84.3% and 88.1% in July, respectively. The performance ratio for the improved reference PV modules is 89.2% and 91.1%, respectively, on a monthly daily average over the course of the year.

Because the planar concentrators attached to the PV modules in the improved group increase the temperature of these PV modules, the PR of the improved PV modules is lower than the PR of the reference PV modules. As demonstrated in Fig 7, the PR of the improved PV modules and the PR reference PV modules converge in the cold and mild months while diverging in the hotter seasons. Despite the fact that planar concentrators increase solar radiation, which in turn raises the temperature of solar PV modules, the PR of the improved modules remains to be excellent throughout the winter.

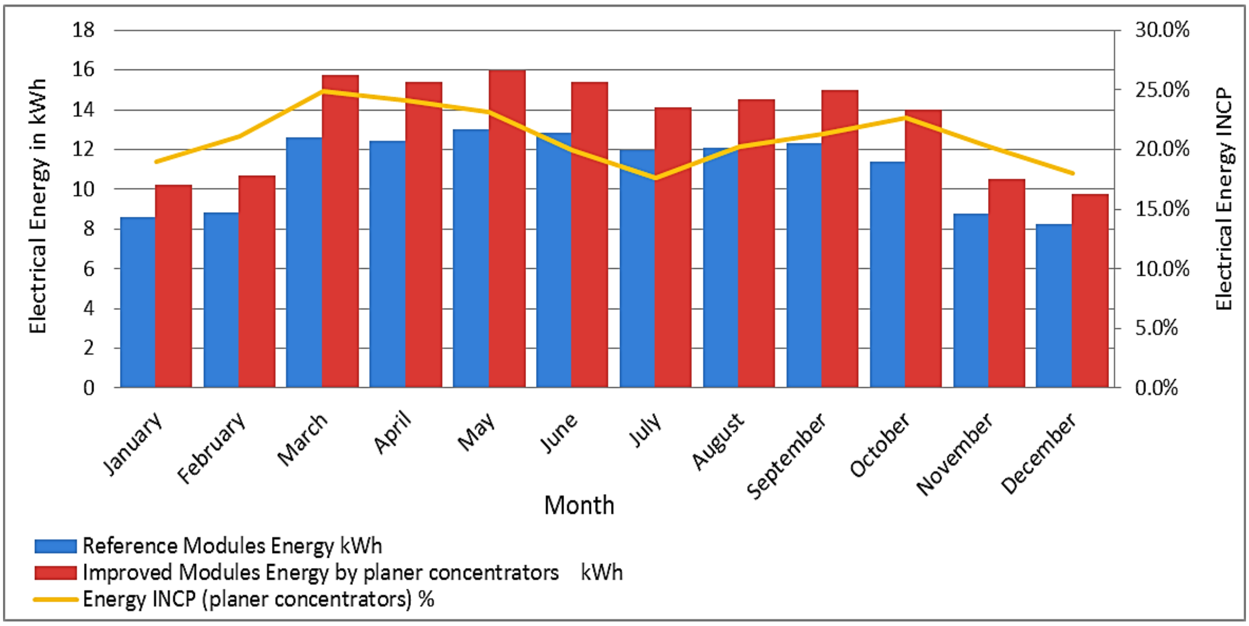

Figure 5. Energy INCP, improved and reference PV modules (groups) energy produced.

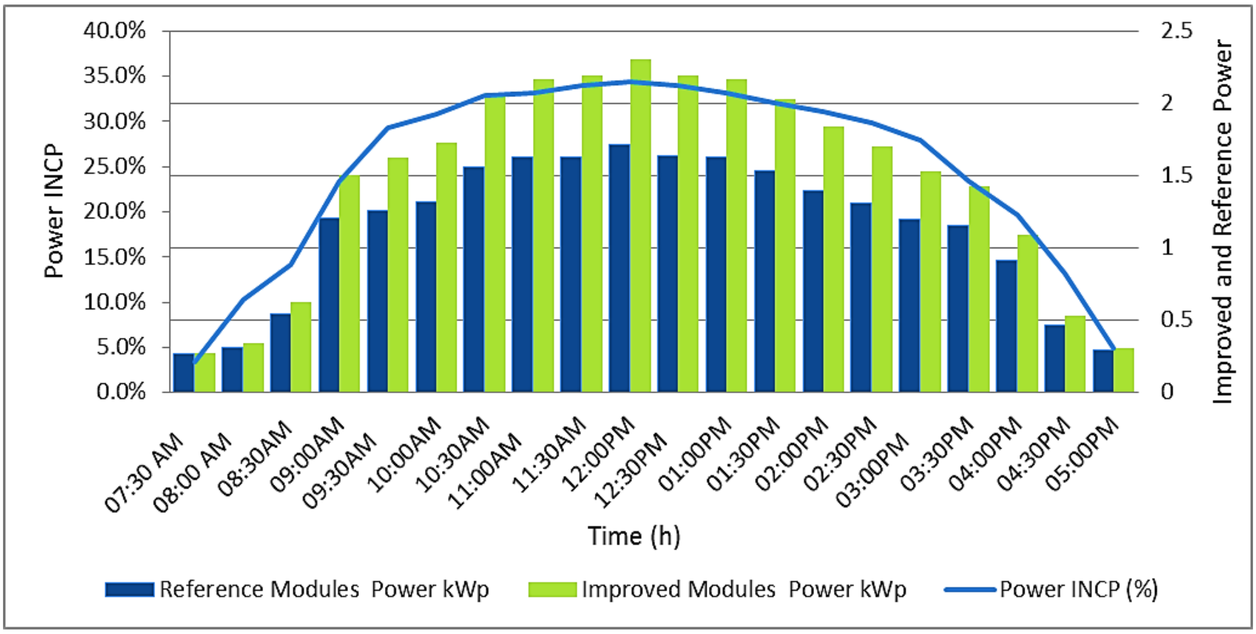

Figure 6. The power produced for improved and reference modules by using planar concentrators

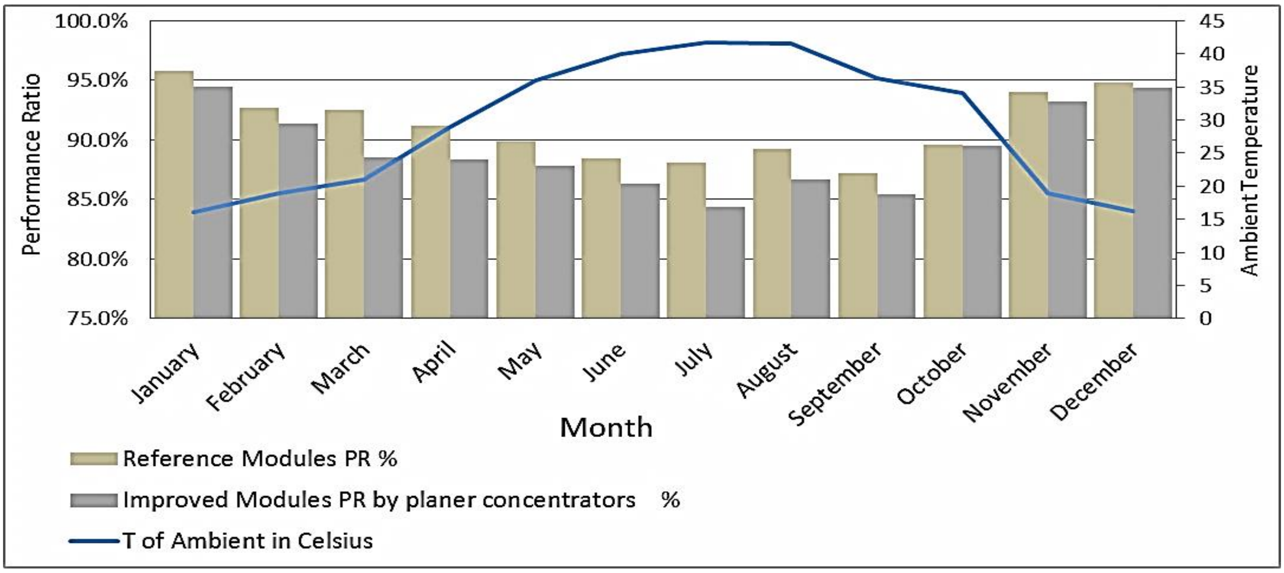

Figure 7. PR of the improved and reference groups.

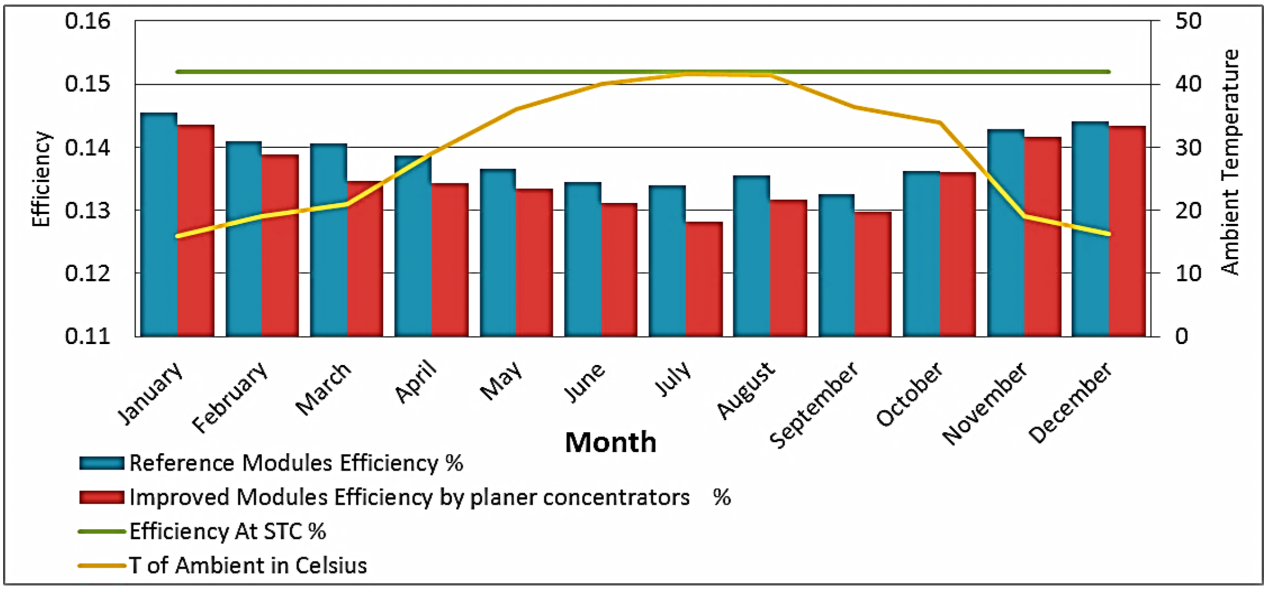

Figure 8. Efficiency of improved and reference PV modules (groups).

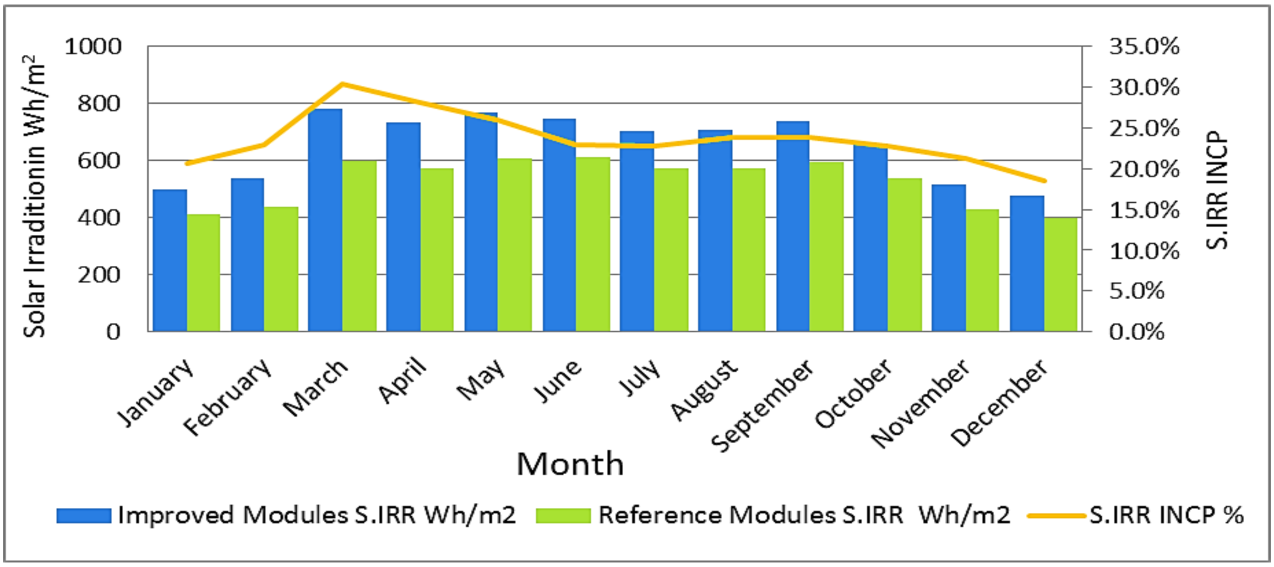

Figure 9. Solar irradiance of the S.IRR INCP, improved and reference PV modules (groups).

The PR of a PV system indicates how close it approaches ideal performance during real operation and allows comparison of PV systems independent of location, tilt angle, orientation, and their nominal rated power capacity (Khalid et al.,2016; Kasim et al., 209). Figure 7 shows that the PR increases and decreases when the temperature of the PV modules decreases (during the cold months) and increases (during the hot months).

The improved and reference efficiency of PV modules is shown in Fig. 8. The two coldest months, January and December, had maximum efficiency values for the improved PV modules and reference PV modules of 14.4% and 14.56%, respectively. In contrast, efficiency drops to its lowest levels in July and September, at 12.8% and 13.3%, respectively. Fig 8 shows that the largest efficiency of PV modules does not exceed the efficiency at STC (15.2%) because the temperature of solar PV modules is greater than 25°C.

Planar concentrators slightly lower the efficiency of PV solar modules by increasing solar radiation, which raises the temperature of the PV solar modules. The improved and reference groups' monthly daily average efficiency is 13.6% and 13.85%, respectively. This shows a slight difference in efficiency between the improved PV modules and the reference PV modules.

Figure 9 displays the solar irradiation for the improved group and the control group. While the reference group solar irradiation reaches its maximum in May and June at 610 Wh/m^2, the improved group solar irradiation reaches a maximum in March at 780 Wh/m^2. The minimum solar irradiation for the improved and reference groups was 475.45 Wh/m^2 and 400.91 Wh/m^2, respectively, in December. This is due to the fact that both the tilt angles of solar PV modules and planar concentrators are optimum in March, but they are not optimal in June. Therefore, the solar irradiation (S.IRR) INCP reaches its highest in March (30%) and its minimum in December (18%). These INCP values correspond to 181 Wh/m^2 and 74.5 Wh/m^2, respectively.

The concept of array yield and its Equation are described above. The array yield is shown in Figure 10. In May, the array yield reaches its maximum value. The maximal array yields (monthly daily average) for the reference group and improved group are 6.56 kWh and 8.1 kWh, respectively. Where the array yield INCP is 23.2%, this value of energy INCP corresponds to 2.0 kWh. In December, because there is the lowest amount of solar energy, the array yield is at its lowest value. The minimum array yields for the reference group and improved group are 4.18 kWh and 4.94 kWh, respectively. The monthly daily average (over the course of the year) of the array yield INCP as a consequence of the usage of planar concentrators is 22.7%, and this value of energy INCP corresponds to 17.8 kWh.

Figure 11 illustrates the ambient air, improved, and reference PV module temperatures. Figure 10 shows that the maximum temperatures for the reference PV modules, improved PV modules, and ambient in July are 57.5°C, 61°C, and 41.7°C, respectively. The temperature of the improved PV modules is about 3.5°C higher than that of the reference PV modules. In January and December, the minimum temperatures for the reference PV modules, improved PV modules, and ambient air were 34.15 °C, 36.5 °C, and 16.3 °C, respectively. The average monthly daily temperatures of reference PV solar modules, improved PV solar modules, and ambient are 45.94 degrees Celsius, 48.8 ° C, and 29.15 ° C, respectively. In cold months, the temperature difference between reference and improved solar PV modules decreases because the temperature of the improved PV modules decreases. Figure 11 shows that the difference between improved and reference group temperatures is small, indicating that the planar concentrators add just a small amount of heat.

CONCLUSION

The current study reaches the following conclusions:

- The use of planar concentrators results in significant gains (INCP) for the PV solar system parameters (energy output, array yield and solar irradiation).
- The maximum energy increases in the summer months while it begins to decrease in the winter, based on the atmospheric elements, which include the ambient temperature and solar radiation. The energy enhancement varies throughout the year, dependent on these atmospheric elements.
- The improved PV modules get a small amount of heat from the planar concentrators.

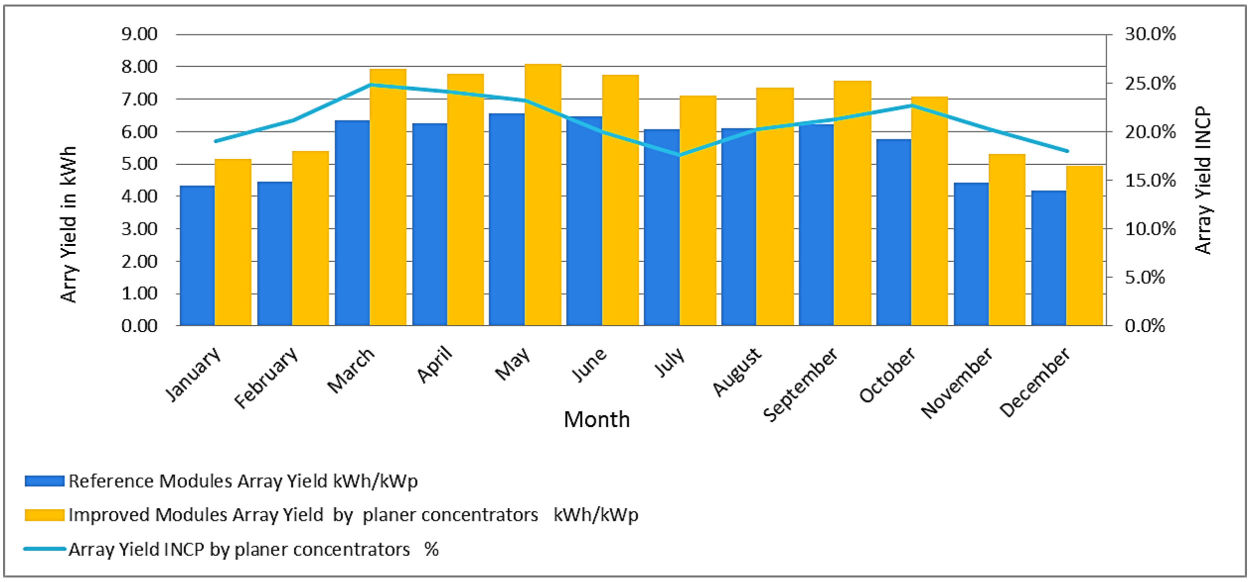

Figure 10. Array yields of improved reference groups.

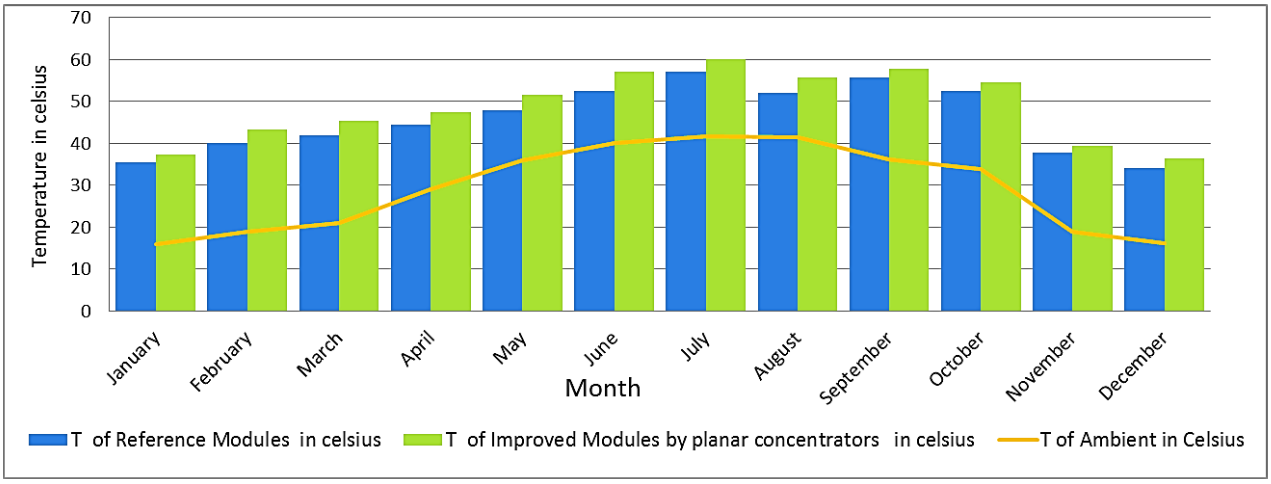

Figure 11. PV solar modules and ambient temperatures.

- Because the improved PV modules are becoming hotter than the reference PV modules, there Performance and efficiency are lower than those of the reference PV modules, but the difference between them is very small.
- The daily average monthly (throughout the year) energy gained (EINCP) is about 21%, which is equivalent to 34.0 kWh.
- The daily average monthly solar irradiation INCP (S.IIR INCP) is about 25%, which is equivalent to 127Wh/m^2.
- March and May have the highest INCP for all performance parameters due to the mild ambient temperature and sufficient solar radiation.
- Due to the highest solar radiation intensity and ambient temperature, solar PV modules reach their highest temperatures in July, August, and September

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CONFLICT OF INTEREST

The authors declare that there are no conflicts of interest regarding this article.

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APPENDIX

Table 3. Energy, array yield and S.IIR for improved and reference PV solar modules.

S.IRR INCP (%)	Reference PV Modules S.IRR Wh/m²	Improved PV Modules S.IRR Wh/m²	Reference Yield INCP (%)	Reference Modules array Yield kWh/kWp	Improved Modules array Yield kWh/kWp	Energy INCP (%)	Reference PV Modules energy kWh	Improved PV Modules energy kWh	Month
20.6%	411.8182	496.8182	19.0%	4.34	5.16	19.0%	8.59	10.22	January
22.9%	437.2727	536.3636	21.1%	4.45	5.39	21.1%	8.81	10.67	February
30.4%	598.0244	780	24.8%	6.36	7.94	24.8%	12.6	15.731	March
28.1%	573.0924	733.3333	24.1%	6.27	7.78	24.1%	12.41	15.4	April
26.0%	608.3333	766.6667	23.2%	6.56	8.08	23.2%	12.99	16	May
23.0%	610.8333	748.3333	20.0%	6.47	7.77	20.0%	12.82	15.38	June
22.8%	573.3333	704.1667	17.6%	6.06	7.13	17.6%	12	14.11	July
23.8%	570.8333	706.6667	20.2%	6.11	7.35	20.2%	12.1	14.55	August
23.8%	595.8333	737.5	21.3%	6.23	7.56	21.3%	12.34	14.965	September
22.8%	536	658.3333	22.7%	5.76	7.07	22.7%	11.41	14	October
21.3%	427.2727	518.1818	20.2%	4.42	5.31	20.2%	8.75	10.52	November
18.6%	400.9091	475.4545	18.0%	4.18	4.94	18.0%	8.28	9.772	December

Table 4. Efficiency and PR for improved and reference PV solar modules.

PR of reference PV modules	PR of improved PV modules	Efficiency of improved PV modules (%)	Efficiency of reference PV modules (%)	Month
95.8%	94.4%	0.143561877	0.145570495	January
92.7%	91.3%	0.138832392	0.140900673	February
92.5%	88.6%	0.134630136	0.140653298	March
91.2%	88.4%	0.134343434	0.138651433	April
89.9%	87.8%	0.133509003	0.1366044	May
88.5%	86.3%	0.131187576	0.134448308	June
88.1%	84.3%	0.128188393	0.133897111	July
89.2%	86.7%	0.131718125	0.135604217	August
87.2%	85.4%	0.129811105	0.132491347	September
89.6%	89.5%	0.136043984	0.136181466	October
94.0%	93.2%	0.141683502	0.142918547	November
94.8%	94.4%	0.143436661	0.1441352	December