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BIFACIAL AND MONOFACIAL PHOTOVOLTAIC MODULE WITH TRACKER SYSTEM ANALYSIS

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ABSTRACT

Solar energy is preferred today because it is environmentally friendly and clean energy. In order to get the best production from solar power plants, it is necessary to make maximum use of the sun. In this context, the installation of solar panels with a single-axis monitoring system in the designed system is a cost-effective distribution strategy. On the other hand, the bifacial or monofacial of the panels used directly affects the gain. Bifacial modules increase energy efficiency of 4% - 15% depending on module type and ground albedo. In this study, the performance of 1123.2 kWp PV plants connected to the network planned to be established in Karaman was evaluated by the PVSYST analysis program by selecting both monofacial and bifacial panels. Energy production, specific efficiency, performance ratio values of this study were calculated. It was found that the system carried out with the working bifacial panel produced 170 MWh more per year, resulting in a 7% gain.

Keywords: Solar power plant; solar power; bifacial; monofacial; tracker system.

ÖZET

Güneş enerjisinin çevre dostu ve temiz enerji olmasından dolayı günümüzde tercih edilmektedir. Güneş enerji santrallerinden en iyi şekilde üretim alabilmek için güneşten maksimum faydalanmak gerekmektedir. Bu bağlamda tasarlanan sistemde güneş panellerinin tek eksenli izleme sistemi ile kurulması uygun maliyetli bir dağıtım stratejisi konumundadır. Öte yandan kullanılan panellerin çift yüzlü yada tek yüzlü olması elde edilecek kazancı direk olarak etkilemektedir. Bifacial modüller, modül tipi ve zemin albedo bağlı %4 - %15 enerji verimini artırmaktadır. Bu çalışmada Karaman ili, kurulması planlanan şebekeye bağlı, 1123,2 kWp PV santrallerinin hem monofacial hemde bifacial panel seçilerek performansları PVsyst analiz programı tarafından değerlendirilmiştir. Bu çalışmanın enerji üretimi, spesifik verim, performans oranı değerleri hesaplanmıştır. Çalışma bifacial panel ile gerçekleştirilen sistemin yılda 170 MWh daha fazla üretim yaparak %7 lik bir kazanç sağladığı sonucuna varılmıştır.

Anahtar Kelimeler: Güneş enerji santrali; güneş enerjisi; çift yüzeyli panel; tek yüzeyli panel, takip sistemi.

1. INTRODUCTION

Solar power plants have become the fastest developing edible energy source since the costs of solar panels in the world and Turkey have decreased greatly in recent years. The current leveled electricity cost of large-scale photovoltaic (PV) panels is in some cases lower than that of fossil fuel (Lazard's, 2017).

Developing technology replaces traditional photovoltaic modules with bifacial panels. Unlike PV modules (monofacial), which convert only the light entering the module through the front side into electricity, two-sided (bifacial) PV modules can convert the light entering the module from both sides. This means that bifacial modules can perform better than one-sided modules when used under the same conditions. In the literature, it has been reported that bifacial modules for specific installation conditions have a 50% increase in power compared to monocrystal modules (Cuevas, 1982).

According to the International Technology Roadmap for Photovoltaic (ITR PV) 2019 report, the increasing market share of bifacial cell structure in the world is indicated in Figure 1.

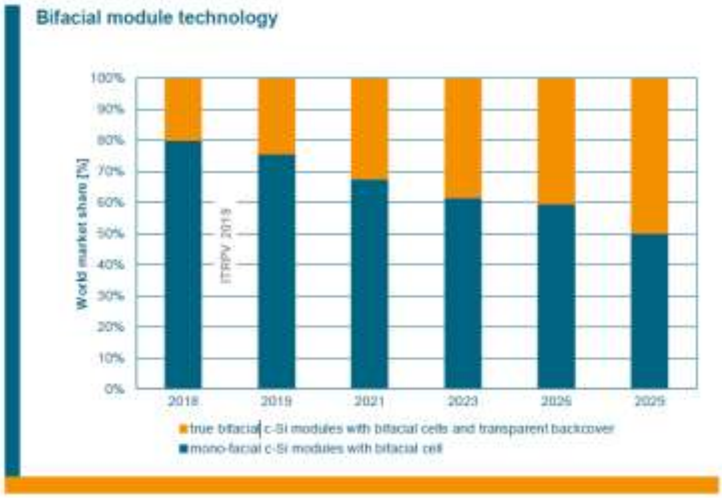

Figure 1. Bifacial modules market share (ITRPV 2019)

Moehlecke et al. analyzed with a white reflective reflector for 18 months to improve solar radiation reaching the back surface of double-sided solar cells. They observed that the output power of the modules increased by 29% thanks to the white reflector (Moehlecke et al., 2003)

Kaddoura and his friends indicated that the angles of inclination of the photovoltaic panels affected the amount of radiation falling on the panel surface. For this purpose, they performed panel optimum angle of inclination simulations in various cities in Saudi Arabia and calculated the optimized angle of inclination by maximized the sun's rays in Matlab software. In the studies carried out by changing the panel angle 6 times a year, they stated that they profited from 99.5% solar radiation (Kaddoura et al.,2016)

Ihaddadene and his friends analyzed seasonally, monthly and yearly to find the best angle of inclination in the M'sila region. They used lui & jordan model, Hay model, Reindl model and Circumsolar models. They've found that the Reindl model is suitable for that area. They indicated that changing the angles of the panels monthly or seasonally would result in more energy (Ihaddadene et al.,2017)

In their study, Lanjewar and his colleagues stated that the horizontal (according to the ground) angle of the solar energy system affects the amount of solar radiation received. For this, they propose a simple and universal method for the angle of inclination, predicting solar radiation monthly, seasonally. In addition, they have produced general correlations to estimate the optimum angle of inclination of solar collectors at six typical climate stations in China. They compared the performance of the proposed models using statistical error tests such as average absolute bias error (MABE), root average Square error (rmse), and correlation coefficients (r) (Lanjewar et al.,2016). Kaçan E. and Ülgen K. in their study for İzmir city; By measuring the daily total and spreading sun radiation values coming on the horizontal surface, they calculated that the optimum angle of inclination for solar energy is between 0° and 61° depending on the time. They revealed that the optimum angle in winter was 55.7°, in spring and autumn it was 18.3°-43°, and in summer it was 4.3° (Kaçan E. and Ülgen K.,2012).

Arslanoğlu N. in its study, it calculated optimum solar angles in Bursa province. The optimum annual slope was in the range of 0° for July and 59° for December. In winter, 55°, spring 19°, Autumn 44.3° stated that it was 5.6° for summer. Predicted an average fixed optimum angle of 31.1° per year (Arslanoğlu N.,2016).

Despotovic M. and Nedic V. have indicated that the amount of energy converted in the solar collector depends on the horizontal plane and the angle of inclination according to the direction of the collector. They set the optimum tilt angle for solar collectors for Belgrade. The optimum angle of inclination was found by searching for values where solar radiation on the collector's surface is maximum for a certain day or a certain period of time. In this way, optimum slope angles are determined yearly, every two years, seasonal, monthly, every two weeks and daily. The energy collected per square meter of the sloping surface is compared for ten different scenarios. In addition, these optimum angles of inclination were used to calculate the amount of energy on the surface of PV panels, which can be mounted on the roof of the building. As a result, for the case study, where it was observed that the panels were placed at the annual, seasonal and monthly optimum slope angles, they showed that by placing the panels at the surface angles of the existing roofs, the energy that can be collected would increase by 5.98%, 13.55% and 15.42%, respectively (Despotovic M. and Nedic V.,2015).

Solar tracking systems are preferred to obtain energy from solar energy in the most efficient way. In this study, analysis of the plant with bifacial panel solar tracking system and monofacial panel solar tracking system was carried out to obtain the best efficiency from solar energy. As a result of the study, the efficiency of the system under the same conditions of bifacial and monofacial panels was evaluated by the analysis program Pvsyst.

2. MATERIAL AND METHODS

The energy gain of a bifacial module on a monofacial module depends on many factors, including assembly parameters and properties of event radiation. Because these factors affect the amount of light that can enter through the back of the module.

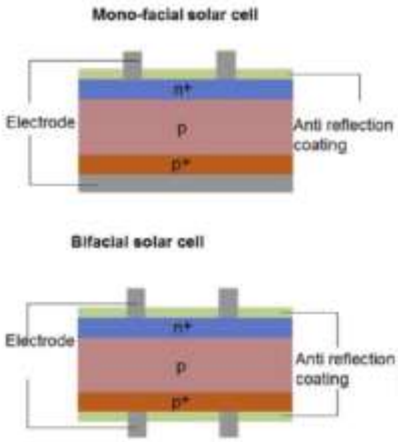

Figure 2. Monofacial and bifacial cell structure

Bifacial modules have a transparent substrate that allows reflected light to be absorbed by cells. In addition, the cells in each module have a symmetrical structure designed to capture both the front and rear radiation. The front surface of bifacial solar panels is usually the same as the monofacial surface structure. However, the rear side structure is different. The main difference is surface, rear contact. In monofacial solar cell, as shown in Figure 2, aluminum rear contact covers the entire rear of the module (Shishavan Amir A., 2019).

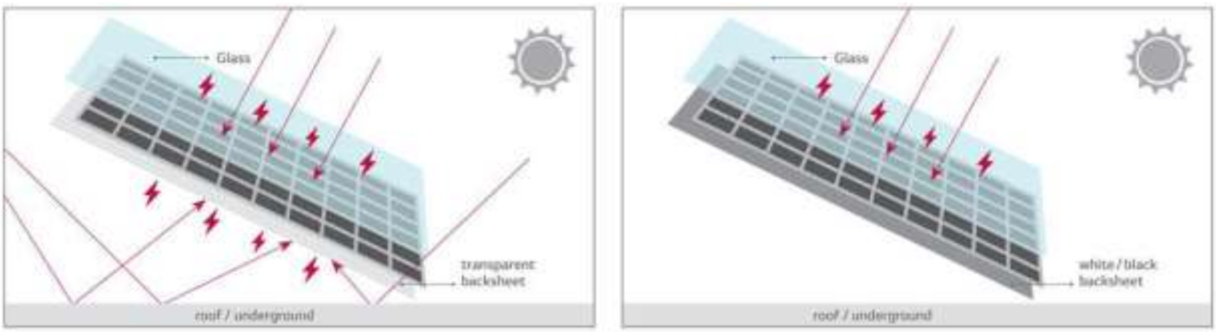

Figure 3. Monofacial and bifacial cell structure (gtm.com.mt)

However, as Figure 3 states, bifacial solar cells use a finger grid to allow light to pass to the back of the cell's surface.

Even if bifacial PV modules receive light from both sides, the efficiency of the front and rear is not the same. Back-side efficiency is generally lower than front-side efficiency. The bifaciality factor is calculated as the ratio of the rear power measured in standard test conditions (STC) (1000 W/m2 and 25° C) to the front (Shishavan Amir A., 2019). Bifaciality factors normally vary between 70% and 95%. For example, a 95% bifaciality factor means that under the same conditions, the rear will produce only 95% of the energy generated from the front (Rogoll M., 2019).

$$bifaciality\ factor = Rearside\ Power\ at\ STC\ /Frontside\ Power\ at\ STC \qquad \textbf{(1.1)}$$

According to the International Solar Energy Research Center (ISC) Constanz research group, bifacial gain is calculated using the following equation (Borrull Míriam G., 2019).

$$gbifacial\ [\%] = ((ebifacial - emonofacial)/emonofacial) x\ 100 \qquad \textbf{(1.2)}$$

- $gbifacial$: Bifacial gain
- $ebifacial$: Specific energy efficiency of two-surface modules (kWh / kWp)
- $emonofacial$: Specific energy efficiency of single-surface modules (kWh / kWp)

In order to increase the efficiency obtained from bifacial panels, the most important effect is albedo with factors such as the height of the panel and tilt angle. Albedo is a measure of how well a surface reflects light and is defined as the ratio between the power of reflected light and the power of total incoming light (Thomas C. R. et al., 2017). The surface of an object with high albedo reflects 80% of the incoming radiation. The surface of an object with low albedo reflects only 10% of the incoming radiation. The Albedo coefficient is the ratio of the spherical incident radiation reflected by the ground in front of an inclined plane. The albedo "seen" in the plane indicated in Figure 4 is of course empty for a horizontal plane and increases with the slope. Albedo depends on surface properties.

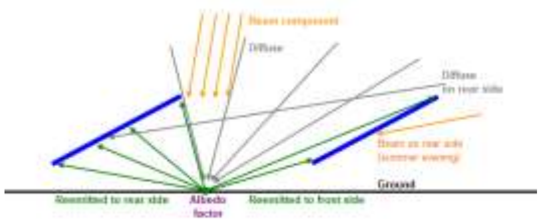

Figure 4. Albedo Factor Radiation Reflection (Pvsyst)

The Albedo component is calculated using the following equation 1.3 (Pvsyst,2019).

$$AlbInc = \rho * GlobHor * (1 - \cos i) / 2 \tag{1.3}$$

i = Plane tilt

ρ = Albedo coefficient (usual value 0.2)

Table 1 also has albedo values accepted by the Pvsyst program. Snow is considered the highest value because of its high surface reflectiveness. (Pvsyst,2019)

Table 1. Albedo values

Surface	Albedo
Urban Environment	0.14-0.22
Grass	0.15-.025
Fresh Grass	0.26
Fresh Snow	0.82
Wet Snow	0.55-0.75
Dry Asphalt	0.09-0.15
Wet Asphalt	0.18
Concrete	0.25-0.35
Red Tiles	0.33
Aluminum	0.85
Copper	0.74
New Galvanized Steel	0.35
Very Dirty Galvanized	0.08

Various simulation and experimental methods have been proposed in the literature to estimate the gain from bifacial modules (Chieng Y.K. et al,1993; Jaeger K. et al,1993). When the potential atlas of solar energy (Gepa) solar radiations was examined on the map in Figure 5, it was appropriate to perform bifacial and monofacial analyses in Karaman province.

Figure 5. Turkey solar radiation (Gepa, 2019)

For the planned solar power plant, 2 different types of panels have been selected with solar tracking system. Bifacial Phono Solar PS400M9GFH 400Wp panel and Phono Solar PS400M1FH 400Wp Monofacial panels selected. Table 2 also has the properties of the panels.

Table 2. Modules electrical values

PS400M1H-24/TH MODULE	
Power Pmpp	400 W
Voltage at Maximum Power Umpp	40.7 V
Current at Maximum Power Impp	9.83 A
Open Circuit Voltage Uoc	49.21 V
Short Circuit Current Isc	10.19 A

PS400MGFH-24/TH MODULE	
Power Pmpp	400 W
Voltage at Maximum Power Umpp	40.82 V
Current at Maximum Power Impp	9.80 A
Open Circuit Voltage Uoc	49.92 V
Short Circuit Current Isc	10.16 A

Solar monitoring systems are used to increase solar radiation to solar panels (Karki P. et al.,2012) A single-axis solar tracking system was also applied at the planned solar plant. The solar tracking system specified in Figure 6 has a rotation angle of +55°, -55° in the north south direction.

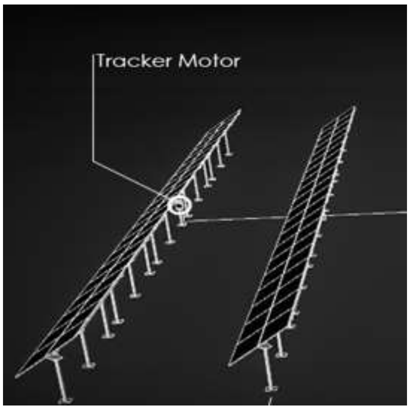

Figure 6. Tracking system

The inverter used is a series produced by Huawei with a nominal DC power of 185kW and running in the range of 500 -1500Vdc, and is limited to 999 kW using 6 pieces. Within both projects, 2808 panels were obtained with 27 series 104 strings. The property's nominal power output is 1123.2kWp.

3. RESULTS AND DISCUSSION

Developed by Swiss physicist Andre Mermoud and electrical engineer Michel Villoz, Pvsyst software is considered a standard for PV system design and simulation worldwide. PVsyst applies the Perez model to predict radiation that occurs on an oblique plane. As a result of these calculations, monthly radiation values are assigned to the PVsyst program (Kılcı O. And Koklu M.,2019).

3.1. Tracker system analysis with monofacial panel

Three main parameters were evaluated from the main simulation results. The first parameter is the total amount of energy generated from the 1123.2 kWp Si-Mono photovoltaic system as energy produced on an annual period, that is, 2315.9 MWh / year. The second parameter is specific production on an annual basis per installed kWp and is 2062 kWh/kWp/year. The third parameter is the average annual performance rate (PR) of 87.13%.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	59.5	27.75	1.30	74.5	69.4	79.6	77.7	0.928
February	80.4	36.38	2.90	101.8	95.2	108.4	106.0	0.927
March	138.3	59.84	6.40	177.8	166.9	185.9	182.2	0.912
April	163.2	65.36	11.30	206.7	194.9	210.1	205.6	0.886
May	212.7	69.33	16.60	276.7	262.2	274.6	268.8	0.865
June	236.7	62.23	20.60	308.2	293.2	300.1	293.6	0.848
July	251.7	47.57	24.70	333.1	318.3	320.3	313.1	0.837
August	228.5	45.71	24.50	304.4	290.8	293.7	287.2	0.840
September	175.8	42.33	20.20	237.2	225.9	234.6	229.5	0.862
October	125.6	39.57	12.80	166.3	157.0	170.2	166.7	0.892
November	80.1	30.77	7.00	106.9	99.9	112.3	110.0	0.916
December	57.0	28.72	2.30	72.8	67.3	77.5	75.6	0.924
Year	1809.4	555.56	12.60	2366.4	2241.0	2367.2	2315.9	0.871

Figure 7. Balance and main results

The balances and main results are shown in Figure 7 include variables such as spheric radiation on the horizontal plane, ambient average temperature, spheric radiation on the collector plane without an optical plane, effective spheric radiation that take into account pollution losses and shading losses. In addition to these variables, the energy injected into the grid is calculated taking into account the losses in DC energy, electrical components, photovoltaic sequence, and system efficiency produced by twinplus monoperc photovoltaic sequence. The calculated values and main results of each variable specified in the results were obtained in monthly and annual values. Annual values of variables are possible as an average of the total for temperature, efficiency and radiation and energy (Kılcı O. And Koklu M.,2019).

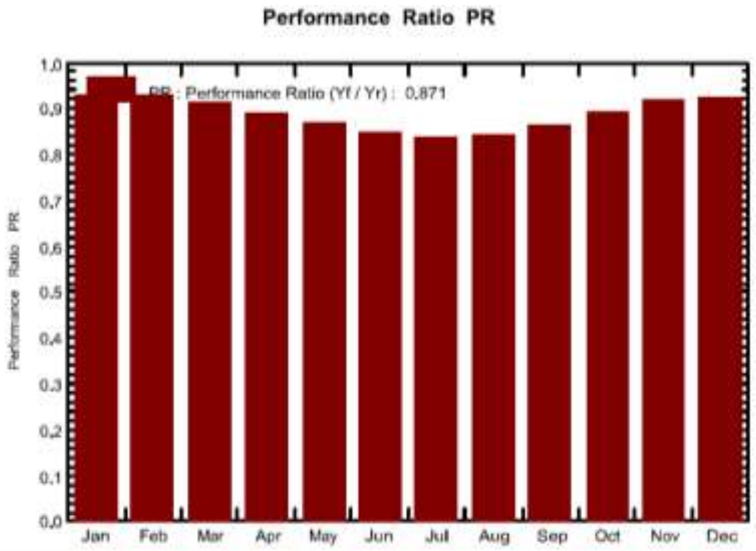

Figure 8. Performance ratio (%)

The performance ratio (PR) for the simulated 1148 kWp Si-poly photovoltaic system is 87.13% with an average annual PR value of 3.2% Figure 8.

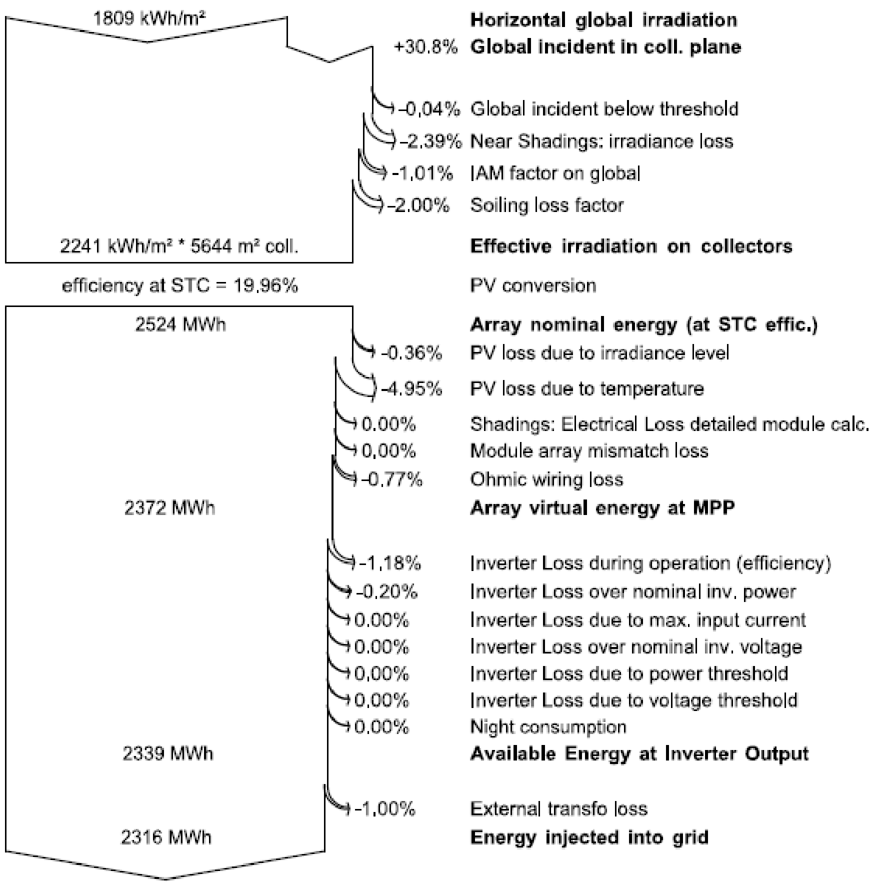

Figure 9. Arrow loss diagram representing various losses in the system

Various losses to be encountered when establishing a PV plant were obtained as a diagram of system loss as a result of the analysis. The system loss diagram is seen in Figure 9. Represents various losses in the system. Sphering irradiating on the horizontal plane is 1809 kWh / m². But the effective radiation on the collector is 2241 kWh / m². This causes energy loss, that is, 0.30%, depending on the level of teleportation. When this effective irradiating falls on the surface of a photovoltaic module or directory, electrical or electrical energy is generated. After PV conversion, the nominal energy in standard test conditions (STC) is 2524 MWh. The efficiency of the PV sequence in STC is 19.96%. The annual array of virtual energy in MPP is 2372 MWh. The various losses that occur at this stage are 4.95% due to temperature and Ohmic losses are 0.77%. The energy available year-on-year in the inverter output plant is 2339 MWh and injected into the same grid. Here two losses have been possible, one is the loss of inverter during inverter operation i.e. 1.18% and the inverter value is nominal inv. power is 0.20%. Transformer loss is 1%.

3.2. Tracker system analysis with bifacial monoperc module

Three main parameters were evaluated from the main simulation results. The first parameter is the total amount of energy generated from the 1123.2 kWp Si-Mono photovoltaic system as energy produced on an annual period, that is, 2540.6 MWh / year. The second parameter is specific production on an annual basis per installed kWp and is 2213 kWh/kWp/year. The third parameter is the average annual performance rate (PR) of 91.33%.

	GlobHor kWh/m²	DiffHor kWh/m²	T_Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	59.5	27.75	1.30	76.2	71.6	85.3	83.2	0.973
February	80.4	36.38	2.90	104.5	98.8	117.2	114.7	0.978
March	138.3	59.84	6.40	181.9	172.9	202.0	197.9	0.969
April	163.2	65.36	11.30	211.4	201.6	226.5	221.7	0.934
May	212.7	69.33	16.60	282.9	270.8	294.3	288.1	0.907
June	236.7	62.23	20.60	314.6	302.2	318.7	311.9	0.883
July	251.7	47.57	24.70	341.1	329.0	341.5	334.0	0.872
August	228.5	45.71	24.50	310.7	299.5	314.6	307.6	0.881
September	175.8	42.33	20.20	243.8	234.4	253.6	248.1	0.906
October	125.6	39.57	12.80	171.4	163.5	183.9	180.0	0.935
November	80.1	30.77	7.00	110.1	103.9	120.3	117.7	0.951
December	57.0	28.72	2.30	74.7	69.8	82.9	81.0	0.965
Year	1809.4	555.56	12.60	2423.3	2318.0	2540.6	2485.9	0.913

Figure 10. Balance and main results

The balances and main results are shown in Figure 10 are 1809.4 kWh / m² of annual sphery radiation on the horizontal plane for the workplace. Effective global radiation after global event energy and optical losses on an annual basis in the collector without optical corrections is 2423.3

kWh / m² and 2318 kWh / m². With this effective beam, the annual DC energy generated from the PV sequence and the annual AC energy injected into the grid are 2540.6 MWh and 2485.9 MWh, respectively.

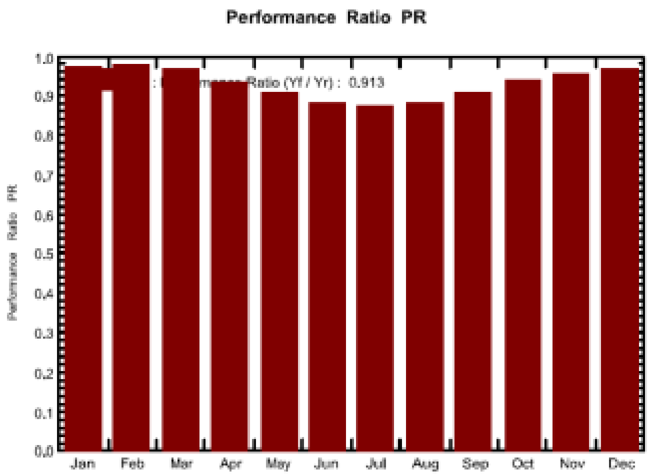

Figure 11. Performance ratio (%)

The performance ratio (PR) for the simulated 1123.2 kWp photovoltaic system is 91.33%, the average annual PR value. There are small differences in PR value on a monthly basis and these are given in Figure 11.

The arrow loss diagram representing various losses in the system is given in Figure 12. Sphering irradiating on the horizontal plane is 1809 kWh / m². But the effective radiation on the collector is 2318 kWh / m². This causes energy loss, that is, 0.34%, depending on the level of teleportation. When this effective irradiating falls on the surface of a photovoltaic module or directory, electrical or electrical energy is generated. After PV conversion, the nominal energy in standard test conditions (STC) is 2815 MWh. The efficiency of the PV sequence in STC is 19.68%. The annual array of virtual energy in MPP is 2572 MWh. The various losses that occur at this stage are 5.06% due to temperature, 0% due to module array incompatibility, and Ohmic losses are 0.84%. The energy available year-on-year in the inverter output plant is 2511 MWh and is injected into the same network. Here two losses have been possible, one of which is inverter loss during inverter operation i.e. 1.14%, and inverter value nominal inv. power is 1.25%. Transformer loss is 1.01%. Since 40% of albedo value was taken on the back surface, 60% ground albedo loss occurred. Gains were made on the rear surface diffusion of 16.54. 5% shading and 0.87% rear surface mismatch loss occurred.

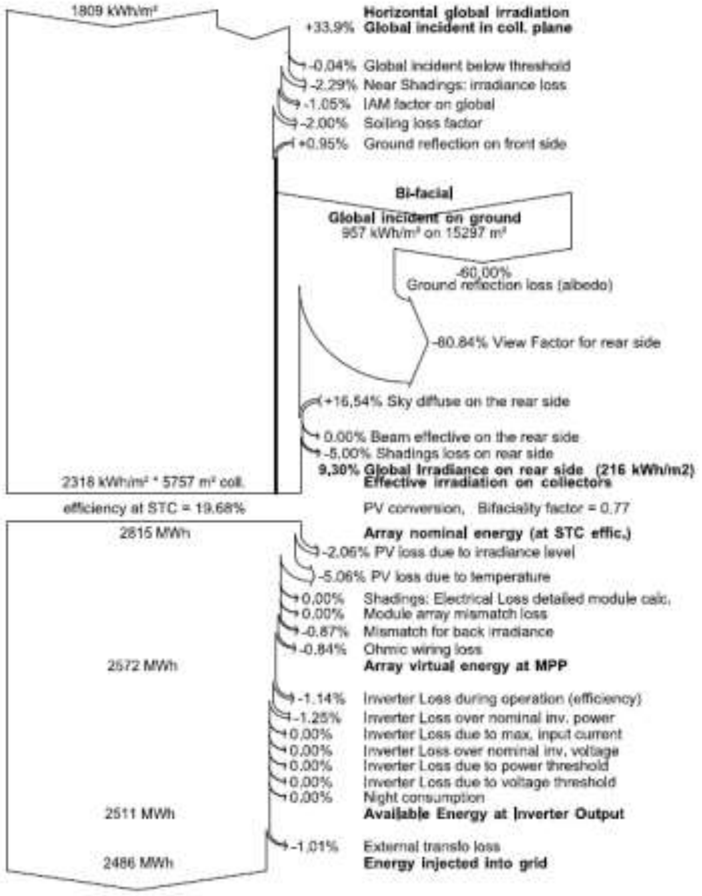

Figure 12. Arrow loss diagram representing various losses in the system

4. CONCLUSIONS

This study provides an evaluation of the performance of the tracker system bifacial and monofacial panels of 1123.2 kWp PV plant based on radiation values in Karaman. Energy production, specific efficiency, performance ratio (PR) values of 2 different systems were analyzed. The data measured from the established system were compared in Table 3 Both plants, which are intended to be established at the same power, were found to produce 170 MWh more per year than the bifacial panel system.

Using PVsyst, we did a comparative study between the two configurations, the two simulations were done under the same conditions and for the same geographic region. The tables show the energy generated by both systems, as also the losses. It is revealed that the bifacial system is more advantageous in production than monofacial system.

Table 3. Comparison of main results

	Bifacial	Monofacial
Global Horizontal Irradiation (kWh/m²)	1809	1809
Ambient Temperature (°C)	12.60	12.13
Global incident Irradiation (kWh/m²)	2423.3	2366.4
Effective Global, corr for IAM and shadings (kWh/m²)	2318	2241
Energy at the output of the array (MWh)	2540.6	2367.2
Energy injected into grid (MWh)	2485.9	2315.9
Specific energy yield (kWh/kWc/year)	2213	2062
Performance ratio (%)	0.9133	0.8713

Using PVsyst, we did a comparative study between the two configurations, the two simulations were done under the same conditions and for the same geographic region. The tables show the energy generated by both systems, as also the losses. It is revealed that the bifacial system is more advantageous in production than monofacial system.

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