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RESEARCH ARTICLE

Performance Analysis and Comparison of Performance Ratio of Solar Power Plant

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ABSTRACT

Significant advancements have been made in the field of renewable energy worldwide. In light of these improvements, renewable energy will meet a substantial part of Türkiye's energy needs in the future. Solar energy is abundantly present in many parts of the country, and grid-connected solar photovoltaic (SPV) power plants are gaining increasing importance. In the present study, the performance analysis of a 250 kWp solar power plant built at the Dicle University was performed in accordance with the performance criteria in the standard IEC 61724. Final yield, reference yield, and performance ratio were detected to vary from 1.94 to 5.98 kWh/kWp-day, 2.1 to 8.88 kWh/kWp-day, and 58 to 99%, respectively. The average annual performance ratio, capacity factor, and system efficiency were observed to be 83%, 1.23%, and 97.6%, respectively. This study also presents the calculated performance parameters along with such values as energy generation, global radiation, temperature, wind, and sunshine duration of the period concerned. The results presented provide insight into the long-term performance of the solar power plant under actual working conditions in Türkiye. The obtained results were also compared with the performance ratios of solar power plants (SPP) in other countries as reported in the literature. Thus, the performance ratios of SPP in different countries were comparatively assessed.

Index Terms—IEC 61724, performance analysis, solar energy.

I. INTRODUCTION

While the world was trying to reduce the harmful effects of COVID-19, a global energy crisis began to be experienced in the world with the invasion of Ukraine by Russia [1, 2]. This war caused a shortage of fossil fuels and an increase in fossil fuel prices. As a result of this adverse impact, investments in solar PV and wind generation have increased worldwide. It is predicted that the installed power capacity of solar PV will increase by approximately 1500 GW in 2027, exceeding the energy capacity of coal. According to the IEA Renewables 2022 report, it is predicted that annual solar energy capacity will continue to increase every year [3]. Considering this foresight, the data obtained from solar power plants (SPP) that are installed and in operation are of great importance in order to make maximum use of solar energy. By analyzing the data obtained from plants installed and operating under real atmospheric conditions, it will be possible to have information about the energy to be obtained and plant performance. In light of these data, it will be possible to obtain the region-specific design criteria for SPP to be established and maximum benefit will be provided.

In this context, many scientific studies are conducted regarding the performance analysis of SPP. Performance analyses of many SPP with various capacities built particularly in different parts of India in recent years were performed according to the standard IEC 61724 [4–8]. Performance analyses of SPP with various capacities in different countries of Europe were also performed [9–13]. Performance analyses of SPP with various capacities in the USA, New Zealand, South Korea, and Brazil were also conducted [14–17]. Furthermore, performance analyses of SPP in Africa were performed [18]. In addition, various solar cell technology (polycrystalline (Pc-Si)), monocrystalline (mc-Si), Copper Indium Disulphide (CIS) thin film, Amorphous Silicon photovoltaic (PV) systems were assessed by using performance parameters based on the standard IEC 61724 in various countries, and results were compared [19–22].

Nevertheless, there is no study in the literature regarding the performance analysis of power plants built in Türkiye according to the standard IEC 61724. Türkiye has a highly significant potential in terms of solar energy. Therefore, a performance analysis to be conducted

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will have a great importance. The southeastern Anatolian Region of Türkiye was chosen for the analysis as it is one of the regions with the most solar energy potential in Türkiye [23]. In this study, a 1-year performance analysis of the 250 kWp solar power plant built in the Engineering Faculty of Dicle University was conducted. Data required for the analysis were obtained from the power plant and the meteorological measuring station installed in the region. Global solar radiations and sunshine durations for the period studied were compared with the electrical energy generation values of the power plant. Thus, it was possible to examine the degree to which the current potential was used. Performance parameters identified in the standard IEC 61724 were also calculated. In light of all these data, the performance of Dicle University Solar Power Plant was assessed.

II. TECHNICAL DESCRIPTION OF THE SYSTEM

Dicle University Solar Power Plant is installed at the geographical coordinates of 40.016′E longitude and 37.054′N latitude. Its plant power is 250 kWp. The ambient air temperature of the solar power plant varies between 31.1°C– and 1.7°C throughout the year [24]. In this system, 1000 modules with 250 Wp power were placed at a 30-degree tilt angle facing south. Moreover, 60 solar cells are present in each module. Characteristics of the panel used are given in Table I [25].

In the power plant, one 10 kW and eight 30 kW outdoor-type inverters were used for the strings. The inverters have two MPPT inputs each. The plant is made of eight 30 kW and one 10 kW strings. Each of the 30 kW strings has six arrays. Every three arrays are connected to one MPPT input of the inverter. Each of the 10 kW strings has two arrays. Each of these arrays is connected to a separate MPPT input. In each array, 20 modules are serially connected. Catalog information of the inverters is given in Table II [26], [27].

Dicle University Solar Power Plant is connected to the network via a 34.5 kV line. Network contact is provided by the conversion of low voltage at the inverter outputs to high voltage by a three-phase 0.4/34.5 kV 50 Hz, 630 KVA dry-type transformer. The general wiring configuration of Dicle University Solar Power Plant is shown in Fig. 1 [28].

Main Points

- The article notes significant advancements in renewable energy globally, emphasizing the potential for renewable sources to meet a substantial part of Türkiye's energy needs in the future. This context sets the stage for understanding the importance of solar energy and its role in Türkiye's energy strategy.
- The article compares the performance of the Dicle University solar power plant with various international studies. This comparative approach helps to contextualize the performance of the Turkish plant within a global framework, highlighting both similarities and differences. Such comparisons include studies from India, Europe, the USA, New Zealand, South Korea, Brazil, and Africa, among others
- One-year production data of the solar power plant established at Dicle University was examined. Thus, it provides important information in terms of evaluating and optimizing solar energy potential.

TABLE I
MODULE CHARACTERISTICS

	Measured Values	Reference Values
Nominal power	253.1438 W	250 W
Maximum power voltage	30.3639 V	30.38 V
Maximum current	8.337 A	8.29 A
Open circuit voltage	37.1664 V	37.12 V
Short circuit current	8.796 A	8.76 A
Maximum system voltage		1000 V

Meteorological station data used in this study were taken from the solar measuring station placed on the roof of Dicle University DÜBTAM (Science and Technology Research and Application Center) building [29]. The solar measuring station is able to measure and record eight different data: global radiation, sunshine radiation, temperature, humidity, wind speed, wind direction, maximum wind speed, and maximum wind direction. For this purpose, a pyranometer and related sensors and data loggers for wind and temperature measurements are used in the solar measuring station. Total radiation data were measured in W/m^2 in 10-minute intervals, sunshine duration was measured in minutes and temperature was measured in centigrade degrees. LoggerNet program was used to record these data in the computer and to analyze them. Total global radiation in W/m^2 was multiplied with time data and converted into energy data in kWh/m^2. Average annual temperature, total sunshine duration, average global radiation, and average wind speed values for the winter period attained from the measuring station are given in Table III. Since total sunshine duration and global radiation are the highest in July, the energy generated is the highest during this month with 46.38 MWh. Average annual temperature, total sunshine duration, average wind speed, and global radiation values are 17.30°C, 240 hours, 1.52 m/s and 5.1 kWh/m^2-day respectively.

TABLE II
INVERTER INFORMATION

		30 kW Inverter	10 kW Inverter
Maximum input power	–	28 600 W	12 800 W
Maximum input voltage	$U_{INV\text{-}Max.Input}$	1000 V	900 V
Minimum input voltage	$U_{INV\text{-}Min.Input}$	500 V	360V
Maximum input current	$I_{MPPT\text{-}1}$	64 A	18 A
Maximum output current	–	46 A	22 A
Maximum output power	–	27 600 W	12 500 W
Maximum yield	η_{max}	98.2%	97.8%

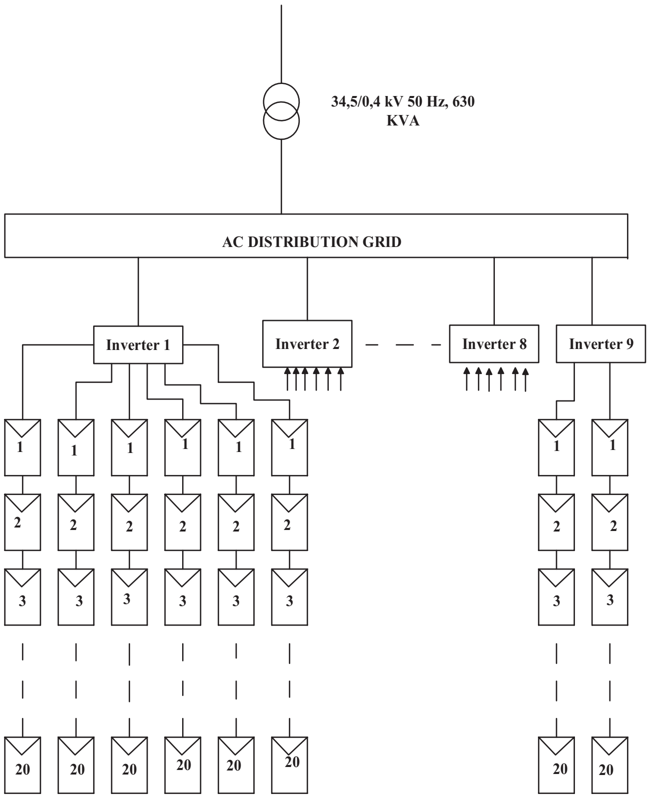

Fig. 1. Configuration of the Dicle University Solar Power Plant.

In this PV plant system, 10 different parameters including immediate PV power, PV energy, generated power, generated energy, DC power, DC voltage, current, voltage, frequency, and inverter temperature of the 250 kWp power plant can be measured and recorded by using a data ogger. Immediate data were recorded in the data logger at 5-minute intervals. The data logger has 12 digital inputs-outputs, 6 analogue inputs, and 2 RS-485 serial communication ports. Recorded data can be remotely accessed and monitored by using the Aurora Vision program.

III. PERFORMANCE CRITERIA OF PHOTOVOLTAIC POWER PLANTS

The standard IEC 61724 is a standard used to examine the performance of SPP. Performance analysis of Dicle University solar power plant was conducted in accordance with IEC 61724 standard parameters [4], [30–32]. According to this standard, the energy and performance values of the system are monitored within a certain period (τ). The analysis of data obtained can be assessed in terms of days, months, and years by using the following definitions and formulas [4], [5], [13]. The first performance parameter reference yield (Y_R) is the ratio of total solar radiation received by a particular platform (H_t) to the reference radiation G (1 kW/m^2) and is expressed with the following equation:

$$Y_R = \frac{H_t(\mathrm{kWh/m^2})}{G(\mathrm{kW/m^2})} \tag{1}$$

Another performance parameter is the array yield (Y_A). Array yield is the ratio of energy generated from the PV arrays in the system within a certain time period (day/month/year) to the installed power and is expressed with the following equation:

$$Y_A = \frac{E_{A,d}(\mathrm{kWh})}{P_0(\mathrm{kW})} \tag{2}$$

In this equation, $E_{A,d}$ refers to the energy generated by the system and P_0 refers to the installed power. Another performance parameter

TABLE III
MONTHLY AVERAGE VALUES OF MEASURED METEOROLOGICAL DATA

Date	Average Temperature °C	Total Sunshine Duration	Average Wind Speed (m/s)	Global Radiation (kWh/m^2-day)
January	1.69	119.74	1.22	2.16
February	8.68	170.56	1.06	3.7
March	10.43	215.59	1.39	4.36
April	16.72	279.93	1.21	6.25
May	20.44	29.84	1.75	6.9
June	27.26	337.98	2	7.65
July	31.89	401.59	2.51	8
August	32.68	350.95	1.6	6.67
September	24.89	325.48	2.1	5.82
October	19.94	283.5	1.024	4.16
November	9.81	233.67	0.91	2.97
December	2.96	128.06	1.425	1.79

used is the final yield (Y_F). Final yield is the ratio of energy transferred to the system within a certain time period (day/month/year) to the installed power and is expressed with the following equation:

$$Y_F = \frac{E_{Use,PV}}{P_0} \quad (3)$$

In this equation, $E_{Use,PV}$ indicates the energy transferred to the system and P_0 indicates the installed power. Performance ratio (PR), one of the performance criteria identified in the standard IEC 61724, is defined as the ratio of the final yield to the reference yield [12].

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

This parameter is used to assess the performance and the long-term changes. Capacity factor (CF) refers to the ratio of total energy generated all year round to the annual potential energy of the PV panel [33].

$$CF = \frac{E_{AC,a}}{8760 \times P_{PV,rated}} \quad (5)$$

In this equation, $E_{AC,a}$ is the value of total energy generated all year round in kWh, $P_{PV,rated}$ is the installed PV power and 8760 is the number of hours in a year. The yield of the system is expressed with the following equation:

$$\eta_{sys,m} = \frac{E_{AC}}{H_t \times A_a} \quad (6)$$

In the equation, E_{AC} refers to the AC power generated by the system, H_t refers to the radiation received by the system and A_a refers to the surface area of the system. Energy losses occurring in the system can also be calculated. During the operation of the system under actual conditions, losses occur due to various components of the power plant [5]. These losses can be described as. Array loss (L_C): the difference between the reference yield and array yield of the system [34].

$$L_C = Y_R - Y_A \quad (7)$$

System loss (L_S): the difference between the array yield and final yield.

$$L_S = Y_A - Y_F \quad (8)$$

IV. FINDINGS

The installation of Dicle University solar power plant was initiated in August 2015 and completed in November 2015. It started energy generation by December 2015. Thereafter, data from the plant were recorded with a data logger and then, by means of a program used for remote monitoring of SPP, data were monitored and recorded. 12-month data received from the data logger were subjected to a performance analysis according to the standard IEC 61724 by using this program and results were obtained. System performance was calculated with the help of measured values. Table IV demonstrates the actual performance parameters calculated from the measured values.

When Table V is carefully examined, it is observed that the final yield varies between 1.94 kWh/kWp-day and 5.98 kWh/kWp-day. The final yield reached its lowest value in January and its highest value in July. Reference yield was found to vary between 2.1 kWh/kWp-day and 8.88 kWh/kWp-day. Reference yield reached its lowest value in January and its highest value in July. The performance ratio varied between 58% and 99%. The performance ratio reached its highest value in December and February and its lowest value in May when energy generation was interrupted for 4 days due to a system failure.

TABLE IV
CHANGE OF PERFORMANCE PARAMETERS BY MONTH

	Y_R (kWh/kW)	Y_F (kWh/kWp)	PR	CF	η
January	2.12	1.94	0.915	0.007	0.973
February	3.47	3.45	0.99	0.012	0.97
March	4.36	4.2	0.96	0.015	0.979
April	6.88	4.86	0.71	0.017	0.98
May	7.65	4.44	0.58	0.016	0.981
June	8.49	5.37	0.64	0.018	0.98
July	8.88	5.98	0.68	0.021	0.98
August	7.4	5.3	0.71	0.019	0.98
September	6.43	5.18	0.81	0.018	0.982
October	4.61	4.21	0.91	0.0149	0.981
November	3.6	3.56	0.98	0.0122	0.978
December	2.1	2.08	0.99	0.0073	0.976

TABLE V
COMPARISON OF SOLAR POWER PLANT PERFORMANCE RATIOS FOR DIFFERENT COUNTRIES

Country	**Authors**	**Plant Power kWp**	**Annual Average PR**	**January**	**February**	**March**	**April**	**May**	**June**	**July**	**August**	**September**	**October**	**November**	**December**
India	Sharma et al. [7]	190	0.74	0.64	0.72	0.81	**0.82**	0.77	0.75	0.79	0.65	0.8	0.75	**0.55**	0.71
India	Sukumaran et al. [7]	12000	0.8656	**0.8**	0.83	0.8	0.87	0.88	**0.974**	0.91	0.86	0.86	0.85	0.86	0.83
India	Satsangi et al. [8]	40	0.7	0.8	0.72	**0.59**	0.7	0.78	0.73	0.74	0.69	0.64	0.71	0.7	**0.81**
India	Kumar et al. [35]	10 000	0.8612	0.96	0.88	0.82	**0.739**	0.77	0.79	0.81	0.83	0.83	0.88	0.93	**0.975**
India	Ark Kumar et al. [36]	20	0.82	0.92	0.77	**0.7**	0.76	0.78	0.79	0.8	0.88	0.85	**0.99**	0.83	0.84
Pakistan	Bukhari et al. [37]	178.08	0.63	0.69	**0.71**	0.65	0.59	0.59	**0.45**	0.6	**0.71**	0.68	0.62	0.67	0.64
Canada	Panchula et al. [38]	20 000	0.8	0.87	0.82	0.86	0.85	0.845	0.84	0.82	0.74	0.83	0.84	0.86	0.48
New Zealand	Emmanuel et al. [18]	10	0.78	**0.762**	0.763	0.773	0.776	0.78	**0.79**	0.792	0.791	0.787	0.78	0.776	0.767
South Korea	H. Mun Lee et al. [16]	10.6	0.69	0.7	0.75	0.73	0.66	**0.58**	0.6	0.62	0.7	0.74	**0.77**	0.73	0.72
China	Wu et al. [39]	2.99	0.8066	0.805	0.795	0.82	0.81	0.79	0.81	**0.78**	0.79	0.792	0.794	**0.825**	0.8
Singapore	Wittkopf et al. [40]	142.5	0.81	0.802	0.79	0.803	0.798	**0.75**	0.81	0.83	0.83	0.82	**0.84**	0.82	0.82
Brazil	Lima et al. [15]	2.2	0.829	0.78	0.83	**0.919**	0.8	0.75	0.89	0.85	0.87	0.89	0.85	**0.729**	0.75
Iran	Edalati et al. [41]	5.52	0.829	**0.712**	0.72	0.792	0.841	0.86	**0.94**	0.924	0.891	0.853	0.865	0.812	0.829
Northern Ireland	Mondol et al. [42]	13	0.61	0.63	**0.54**	0.59	**0.67**	0.65	0.66	0.62	0.61	0.6	0.63	0.59	0.58
Ireland	Ayompe et al. [43]	1.72	0.815	0.9	0.723	0.81	**0.77**	0.8	0.8	0.78	0.78	0.78	0.77	0.888	**0.916**
Italy	Congedo et al. [44]	960	0.82	–	–	**0.865**	0.859	0.83	**0.79**	0.788	0.796	0.844	0.845	–	–
South Africa	Okello et al. [45]	3.22	0.843	0.825	**0.81**	0.82	0.835	0.86	0.856	0.86	**0.86**	0.857	0.84	0.835	0.825
Algeria	Cherfa et al. [46]	9.54	0.7	0.66	0.71	**0.82**	0.63	0.67	0.64	0.63	0.74	0.62	0.79	0.71	0.78
Algeria	Chikh et al. [18]	2.3	0.41			0.41	0.38	0.48	0.4	0.38	0.35	**0.3**	**0.56**		
Türkiye	Present study	250	0.823	0.92	0.99	0.96	0.71	**0.58**	0.64	0.68	0.71	0.81	0.91	0.98	**0.99**

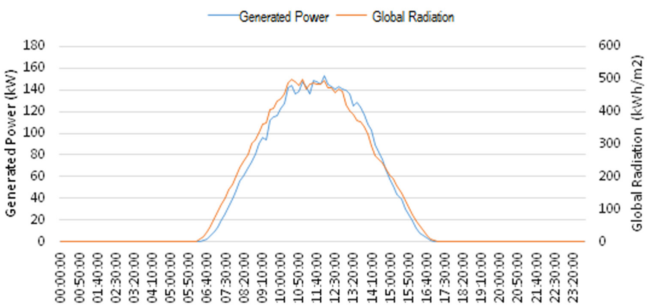

Fig. 2. Change of global radiation and power generation for February.

Average annual system ratio, capacity factor, and system efficiency were detected to be 83%, 1.23%, and 97.6% respectively.

This study also included a detailed assessment of a month chosen from each season. February for winter, April for spring, July for summer, and October for autumn were chosen for this purpose. In the analysis performed, radiation values and generation values were compared and the impact of temperature and wind on energy generation was studied. Fig. 2 shows the change in the average total radiation and generated power hour by hour during the day for February 2016. February was sunny in general. Maximum values of the average total radiation for February were measured around 550 kWh/m^2. The maximum value of the generated power was close to 150 kW.

Fig. 3 presents the daily change of generated energy, temperature, and wind speed for February. This graph shows that generated energy varies depending on temperature and wind changes on days with the same global radiation values. It was measured that the maximum energy generated in February reached 1471.7 kWh. On February 3, 2016, the energy was 1269 kWh under the conditions of 356.7 W/m^2 global radiation, 3.9°°C temperature, and 1.6 m/s average wind speed, while the energy generated on February 4, 2016, was 1248 kWh under the conditions of 356 W/m^2 global radiation, 4.4°C temperature and 0.5 m/s average wind speed. Although average temperature and global radiation values were so close to each other on both days, the 1.1 m/s difference between the wind speeds caused a 20.1 kWh more energy generation. In addition, the desired level of energy could not be generated on some days due to the cloudiness although the weather was generally clear in February.

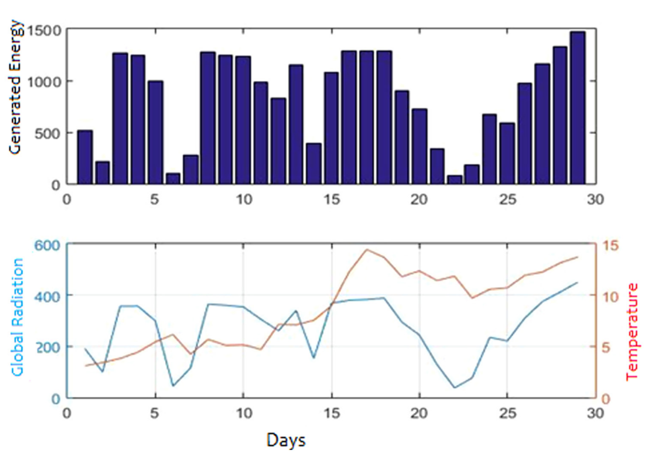

Fig. 3. Change of energy generated in February depending on global radiation and temperature.

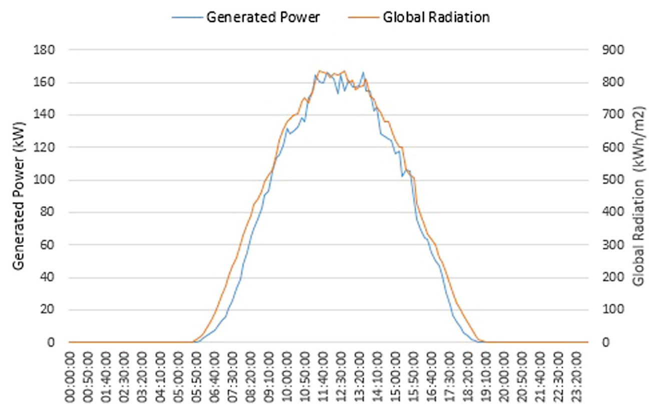

Fig. 4. Change of global radiation and power generation for April.

Fig. 4 shows the change in the average total radiation and generated power hour by hour during the day for April 2016. Maximum values of total radiation in April exceeded 800 kWh/m^2. On the other hand, the maximum value of generated power was around 170 kW. Furthermore, the generated power surpassed the installed power for an instant on April 1 with 251 kWp.

Fig. 5 presents the daily change of generated energy, temperature, and global radiation for April. It is observed that the maximum energy generated on April 24, 2016, reached 1799.9 kWh. The energy generated on April 4, 2016, was 1404.6 kWh under the conditions of 523.12 W/m^2 radiation, 14°C temperature, and 1.31 m/s average wind speed. The energy generated on April 5, 2016, was 1368.6 kWh under the conditions of 523 W/m^2 global radiation, 13.8°C temperature, and 0.6 m/s average wind speed. Although average temperature and global radiation values were so close to each other on both days, the 0.71 m/s difference between the wind speeds caused 35.8 kWh more energy generation. Moreover, despite the clear weather

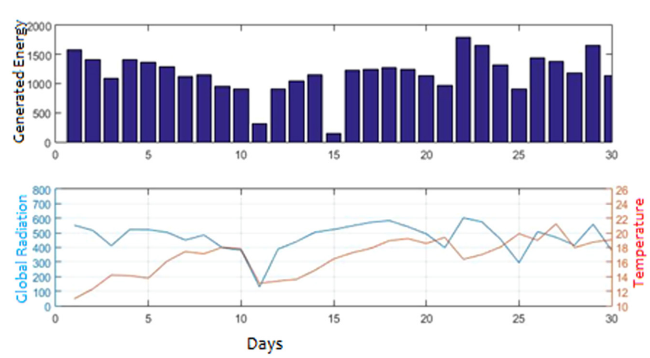

Fig. 5. Change of energy generated in April depending on global radiation and temperature.

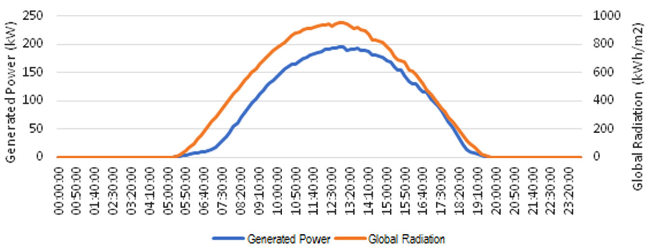

Fig. 6. Change of global radiation and power generation for July.

on April 15, 2016, with 523.21 W/m^2 global radiation, only 151.1 kWh of energy was generated due to a technical failure and an energy loss of approximately 1100 kWh occurred on this day.

Fig. 6 demonstrates the change in the average total radiation and generated power hour by hour during the day for July 2016. Maximum values of total radiation in July reached 800 kWh/m^2. On the other hand, the maximum value of generated power was around 200 kW.

Fig. 7 shows the daily change of generated energy, temperature, and global radiation for the month of July. It is observed that the maximum energy generation reached 1782.60 kWh on July 21, 2016. The energy generated on July 9, 2016, was 1512 kWh under the conditions of 555.2 W/m^2 radiation, 30°C temperature, and 2.4 m/s average wind speed. The energy generated onJuly 30, 2016, was 1479 kWh under the conditions of 555.1 W/m^2 global radiation, 31°C temperature, and 1.4 m/s average wind speed. Although average temperature and global radiation values were so close to each other on both days, the 1 m/s difference between the wind speeds caused a 33 kWh more energy generation.

Fig. 8 demonstrates the change in the average total radiation and generated power hour by hour during the day for October 2016. Maximum values of total radiation in October reached 600 kWh/m^2. On the other hand, the maximum value of generated power was around 170 kW.

Fig. 9 shows the daily change of generated energy, temperature, and global radiation for the month of October. It is observed that

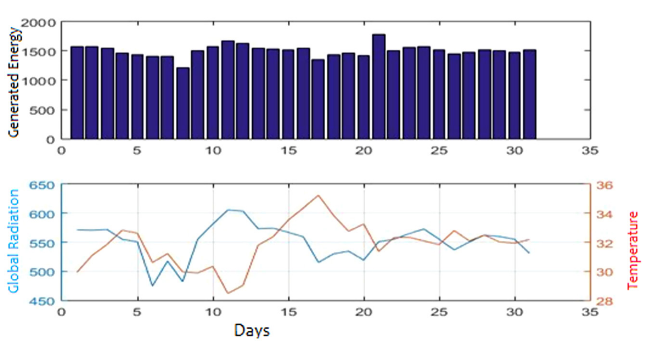

Fig. 7. Change of energy generated in July depending on global radiation and temperature.

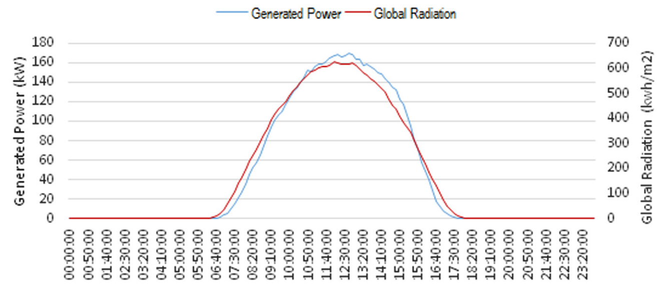

Fig. 8. Change of global radiation and power generation for October.

the maximum energy generation reached 1418.5 kWh on October 1, 2016. The energy generated on October 19, 2016, was 1134 kWh under the conditions of 394.5 W/m^2 radiation, 21°C temperature, and 0.9 m/s average wind speed. The energy generated on October 20, 2016, was 1164 kWh under the conditions of 394 W/m^2 global radiation, 18°C temperature, and 0.9 m/s average wind speed. Although average wind speed and global radiation values were so close to each other on both days, the 3°C difference between the temperatures caused a 30 kWh more energy generation. Furthermore, a full-scale energy generation could not be provided for 2 days on October 7–9, 2016, due to a technical failure. The energy loss resulting from the failure of energy generation on these 2 days is approximately 2300 kWh.

The monthly energy generation by the Dicle University solar power plant throughout 2016 is given in Fig. 10. A total of 385.86 MWh of energy was generated in 2016. The highest energy generation was in July with 46.38 MWh. The lowest energy generation was in January with 15 MWh. The power plant has been in operation since November 2015 and generated 702.17 MWh of energy by the end of October 2017.

Table V shows the comparison of performance ratios of 20 SPP installed in different countries and subjected to performance analysis. According to the average annual performance ratios, the power

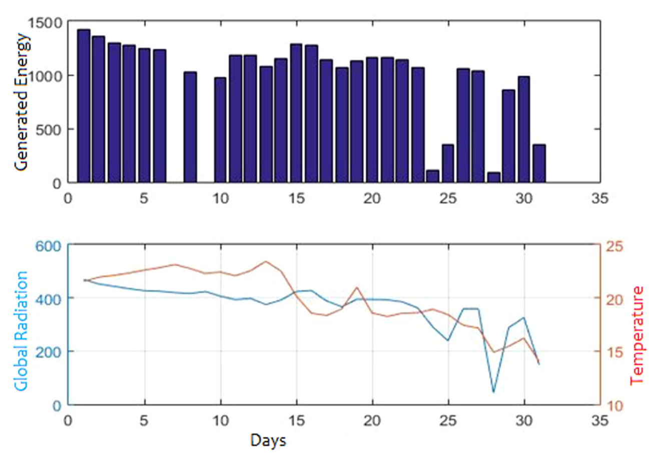

Fig. 9. Change of energy generated in October depending on global radiation and temperature.

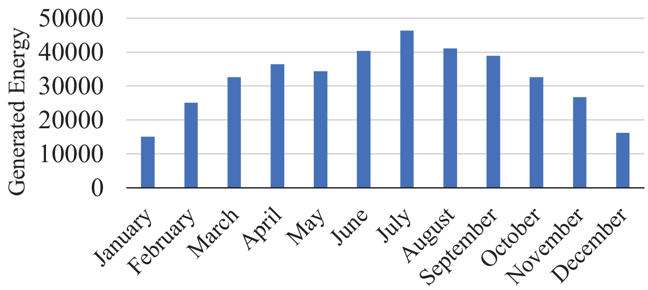

Fig. 10. Monthly change of energy generated.

plant installed in Algeria had the lowest performance with 2.3 kWp. However, due to the lack of a full-scale annual analysis and the low installed power of this power plant, its data is questionable. The highest performance ratio was 86.6% achieved by the 12 MWp power plant installed in India, followed by the 10 MWp power plant also in India. The present study yielded better results than 14 studies with a performance ratio of 82.3% and ranked fifth among the power plants with the best performance ratios. When the power plant performances are analyzed in general, 10 power plants have a performance ratio above 0.8%. While two of these power plants installed in India achieved a performance ratio of over 0.86%, another power plant installed in South Africa ranked third with a performance ratio of 0.84%. Subsequent power plants are those installed in Brazil, Iran, and Türkiye with performance ratios of about 0.82%. This also proves that the power plants in countries located in the tropical zone exhibited better performance compared to others. Table V also shows the periods with the highest and lowest performance ratios within the year. While the highest monthly performance ratio reached 0.99%, the lowest performance ratio was 0.35%. Dicle University Solar Power Plant which is addressed in this study reached a performance ratio of 0.99% in December and February. The lowest performance ratio, on the other hand, was in May with 0.58%. Energy generation was interrupted for four days in May due to a system failure, which led to a decreased performance ratio in this month. A similar situation happened in June as well.

V. CONCLUSION

In this study, a 250 kW solar power photovoltaic plant installed in the Southeastern Anatolian Region of Türkiye was analyzed in accordance with the standard IEC 61724. Meteorological data were also measured in the one-year period concerned. Obtained performance values were compared with the performance values in the literature. Data regarding the location of Dicle University Solar Power Plant installed in the southeast of Türkiye were assessed for the said 1-year period. According to this data, the highest radiation value was measured in June with 619.88 kWh/m^2. Average annual temperature, total sunshine duration, average wind speed, and global radiation values were 17.30°C, 240 hours, 1.52 m/s, and 5.1 kWh/m^2-day, respectively. The highest total annual sunshine duration was in July with 401.59 hours.

It is observed from the results of the performance analysis of Dicle University Solar Power Plant according to the standard IEC 61724 that the final yield varied between 1.94 and 5.98 kWh/kWp-day. The final yield reached its lowest value in January and its highest value in July. Reference yield was found to vary between 2.1 kWh/kWp-day and 8.88 kWh/kWp-day. Reference yield reached its lowest value in January and its highest value also in July. The performance ratio of the power plant was observed to vary between 58% and 99%. The performance ratio reached its highest value in December and February and its lowest value in May when energy generation was interrupted for 4 days due to a system failure. Average annual performance ratio, capacity factor, and system efficiency were detected as 82.3%, 1.23%, and 97.6% respectively. Final yield and reference yield were found to reach their highest values in July with 5.98 kWh/kW and 8.88 kWh/kWp, respectively. Reference yield was found high because the weather was generally sunny and sunshine duration was long in the month of July. However, the performance ratio in July was below average at 0.68. This is due to the fact that the temperature was too high and, as a result, reduced the panel efficiency although the radiation and sunshine duration had high values. In addition, since there was no rain in July, the panel surfaces got contaminated and thus decreased the panel efficiency. Therefore, panel surfaces have to be cleaned especially in the months of summer.

Energy generation data of the power plant shows that 385.86 MHw of energy was generated throughout 2016. The highest energy generation was in July with a value of 46.38 MWh. The lowest energy generation was in January with a value of 15 MWh. Due to the system failures and power outages in the network, approximately 13.922 kWh of electrical power that was supposed to be generated in 2016 could not be generated.

The comparison of the performance ratio of Dicle University Solar Power Plant with that of other power plants in the literature provides insight into the performance of polycrystalline PV technology under Türkiye's climatic conditions. The comparison revealed that the performance ratio of the solar photovoltaic system in Türkiye was higher than those in Canada, New Zealand, South Korea, China, Singapore, Pakistan, parts of India, Ireland, and Italy, but lower than those in Brazil, Iran, South Africa, and some parts of India. The average annual performance ratio of Dicle University Solar Power Plant PV system was 82.3. It can be deduced from these results that the performance ratios of potential SPP to be installed in the southeast of Türkiye would be over 0.80 and that this value would be close to the performance ratios of countries achieving the best results. An analysis of the performance ratios in the literature shows that the highest performances were achieved in some regions of India in the tropical zone with high altitudes. It was observed that the performance ratio in the southeast of Türkiye decreased during summer due to such reasons as high temperature and contamination. It is possible to increase the average performance ratio by taking the necessary precautions against this problem.

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REFERENCES

1. International Energy Agency, "International Energy Agency (IEA) world energy outlook 2022," 2022, p. 524. Available: https://Www.Iea.Org/Reports/World-Energy-Outlook-2022/Executive-Summary.
2. IEA, *Electricity Market 2023*, vol. 2023, 2023. Available: https://www.iea.org/reports/electricity-market-report-2023.
3. IEA, *Renewables 2022: Analysis and Forecast to 2027*, vol. 2022, 2022. Available: https://www.iea.org/reports/renewables-2022.
4. K. Padmavathi, and S. A. Daniel, "Performance analysis of a 3MWp grid connected solar photovoltaic power plant in India," *Energy Sustain. Dev.*, vol. 17, no. 6, pp. 615–625, 2013. [CrossRef]
5. V. Sharma, and S. S. Chandel, "Performance analysis of a 190kWp grid interactive solar photovoltaic power plant in India," *Energy*, vol. 55, pp. 476–485, 2013. [CrossRef]
6. M. Kumar, and A. Kumar, "Performance assessment and degradation analysis of solar photovoltaic technologies: A review," *Renew. Sustain. Energy Rev.*, vol. 78, no. March, pp. 554–587, 2017. [CrossRef]
7. S. Sukumaran, and K. Sudhakar, "Fully solar powered airport: A case study of Cochin International airport," *J. Air Transp. Manag.*, vol. 62, pp. 176–188, 2017. [CrossRef]
8. K. P. Satsangi, D. B. Das, and A. K. Saxena, "Performance analysis of 40kWp solar photovoltaic plant," IEEE Region 10 Humanitarian Technology Conference 2016, R10-HTC 2016 - Proceedings, 2017, pp. 1–5. [CrossRef]
9. S. M. Pietruszko, B. Fetlinski, and M. Bialecki, "Analysis of the performance of grid connected photovoltaic system," in 2009 34th IEEE Photovoltaic Specialists Conference (PVSC), 2009, 2009, pp. 48–51. [CrossRef]
10. N. Aste, C. Del Pero, and F. Leonforte, "The first Italian BIPV project: Case study and long-term performance analysis," *Sol. Energy*, vol. 134, pp. 340–352, 2016. [CrossRef]
11. E. N. Une et al., "Performance ratio and yield analysis of grid connected clustered pv systems in Japan," *Sol. Energy* vol. 32, vol. 22, no. 3, pp. 2296–2299, 2014.
12. N. Aste, C. Del Pero, and F. Leonforte, "The first installation under the Italian PV rooftop programme: A performance analysis referred to 11 years of operation," 4th International Conference on Clean Electrical Power: Renewable Energy Resources Impact, ICCEP 2013, 2013, pp. 628–633. [CrossRef]
13. M. Bouzguenda, A. Al Omair, A. Al Naeem, M. Al-Muthaffar, and O. B. Wazir, "Design of an off-grid 2 kW solar PV system," 2014 9th International Conference on Ecological Vehicles and Renewable Energies, EVER 2014, vol. 2014, 2014, pp. 1–6. [CrossRef]
14. R. Lofaro, M. Villaran, and A. Colli, "Advancing the deployment of utility-scale photovoltaic plants in the northeast," Conference Record of the IEEE Photovoltaic Specialists Conference, pp. 608–612, 2012. [CrossRef]
15. L. C. de Lima, L. de Araújo Ferreira, and F. H. B. de Lima Morais, "Performance analysis of a grid connected photovoltaic system in northeastern Brazil," *Energy Sustain. Dev.*, vol. 37, pp. 79–85, 2017. [CrossRef]
16. H. M. Lee, J. H. Yoon, S. C. Kim, and U. C. Shin, "Operational power performance of south-facing vertical BIPV window system applied in office building," *Sol. Energy*, vol. 145, pp. 66–77, 2017. [CrossRef]
17. M. Emmanuel, D. Akinyele, and R. Rayudu, "Techno-economic analysis of a 10 kWp utility interactive photovoltaic system at Maungaraki school, Wellington, New Zealand," *Energy*, vol. 120, pp. 573–583, 2017. [CrossRef]
18. M. Chikh, S. Berkane, and A. Mahrane, "Performance analysis of a grid connected micromorphous silicon PV pilot plant after eight months monitoring," Proceedings of 2015 IEEE International Renewable and Sustainable Energy Conference, IRSEC 2015, 2016. [CrossRef]
19. M. E. Başoǃlu, A. Kazdaloǃlu, T. Erfidan, M. Z. Bilgin, and B. Cąkir, "Performance analyzes of different photovoltaic module technologies under ¯zmit, Kocaeli climatic conditions," *Renew. Sustain. Energy Rev.*, vol. 52, pp. 357–365, 2015. [CrossRef]
20. E. Elibol, Ö. T. Özmen, N. Tutkun, and O. Köysal, "Outdoor performance analysis of different PV panel types," *Renew. Sustain. Energy Rev.*, vol. 67, pp. 651–661, 2017. [CrossRef]
21. D. A. Quansah, M. S. Adaramola, G. K. Appiah, and I. A. Edwin, "Performance analysis of different grid-connected solar photovoltaic (PV) system technologies with combined capacity of 20 kW located in humid tropical climate," *Int. J. Hydrog. Energy*, vol. 42, no. 7, pp. 4626–4635, 2017. [CrossRef]
22. A. Balaska, A. Tahri, F. Tahri, and A. B. Stambouli, "Performance assessment of five different photovoltaic module technologies under outdoor conditions in Algeria," *Renew. Energy*, vol. 107, pp. 53–60, 2017. [CrossRef]
23. K. Akk, Y. S. Ocak, and Y. Musa, *Analysing Enhancement of Electricity Generating Capacity with Solar Tracking System of the Most Sunning Region of Turkey*, vol. 3, no. 4, 2015.
24. C. Haydaroğlu, and B. Gümüş, "Investigation of the effect of short term environmental contamination on energy production in photovoltaic panels: Dicle University solar power plant example," *Appl. Sol. Energy*, vol. 53, no. 1, pp. 31–34, 2017. [CrossRef]
25. C. Haydaroğlu, and B. Gümüş, "Dicle Üniversitesi Güneş Enerjisi Santralinin PVsyst ile Simülasyonu ve Performans Parametrelerinin Değerlendirilmesi," *DUJE*, vol. 7, no. 3, 2016, pp. 491–500.
26. C. Haydaroğlu, B. Gümüş, C. Kaçmaz, and E. Yıldız, "The simulation of photovoltaic solar power plants through the Bluesol Software and an investigation on the accuracy of simulation results," *International Engineering, Science and Education Conference, 01–03 December 2016*. Turkey: Diyarbakir.
27. C. Haydaroğlu, and B. Gümüş, *"Examination of PVGIS and Sunny Design Web Photovoltaic System Web-Based Simulation Programs and Evaluation of The Reliability of Results" International Engineering, Science and Education Conference 01–03 December 2016*. Turkey: Diyarbakir.
28. C. Haydaroğlu, B. Gümüş, and H. Kılıç, "Investigation and comparison of solar power plant simulation programs," The Fundamental and Applied Problems of Physics Conference, Taskent/Uzbekistan, 2017.
29. B. Gumus, and H. Kilic, "Time dependent prediction of monthly global solar radiation and sunshine duration using exponentially weighted moving average in southeastern of Turkey," *Therm. Sci.*, vol. 22, no. 2, pp. 943–951, 2018. [CrossRef]
30. M. Kisan, S. Sangathan, and J. Nehru, "Photovoltaic system performance Monitiring- guidelines for measurement, data exchange and analysis," *Indian Standard*, 1998.
31. C. P. Kandasamy, P. Prabu, and K. Niruba, "Solar potential assessment using PVSYST software," Proceedings of the 2013 International Conference on Green Computing, Communication and Conservation of Energy, ICGCE 2013, 2013, pp. 667–672. [CrossRef]
32. S. K. Kyprianou, N. G. Christofides, A. P. Papadakis, and A. Polycarpou, "Feasibility study of a 150kWp photovoltaic park in Cyprus," *Energy*, no. November, pp. 183–183, 2010. [CrossRef]
33. D. D. Milosavljević, T. M. Pavlović, and D. S. Piršl, "Performance analysis of a grid-connected solar PV plant in Niš, Republic of Serbia," *Renew. Sustain. Energy Rev.*, vol. 44, pp. 423–435, 2015. [CrossRef]

34. R. Anto, and J. Jose, "Performance analysis of a 100kW solar photovoltaic power plant," Annual International Conference on Emerging Research Areas: Magnetics, Machines and Drives (AICERA/iCMMD), Kottayam, India, 2014, 2014, pp. 1–4. [CrossRef]
35. B. S. Kumar, and K. Sudhakar, "Performance evaluation of 10 MW grid connected solar photovoltaic power plant in India," *Energy Rep.*, vol. 1, pp. 184–192, 2015. [CrossRef]
36. K. A. Kumar, K. Sundareswaran, and P. R. Venkateswaran, "Performance study on a grid connected 20kWp solar photovoltaic installation in an industry in Tiruchirappalli (India)," *Energy Sustain. Dev.*, vol. 23, pp. 294–304, 2014. [CrossRef]
37. S. M. H. Bukhari, P. Akhter, and A. Mehmood, "Performance assessment of an on-grid 178.08kW Photovoltaic system Islamabad, Pakistan," International Conference on Emerging Technologies (ICET), Peshawar, Pakistan, 2015, 2015, pp. 1–5. [CrossRef]
38. A. F. Panchula, W. Hayes, and A. Kimber, "First-year performance of a 20-MW ac PV power plant," *IEEE J. Photovolt.*, vol. 2, no. 3, pp. 359–363, 2012. [CrossRef]
39. X. Wu et al., "Monitoring the performance of the building attached photovoltaic (BAPV) system in Shanghai," *Energy Build.*, vol. 88, pp. 174–182, 2015. [CrossRef]
40. S. Wittkopf, S. Valliappan, L. Liu, K. S. Ang, and S. C. J. Cheng, "Analytical performance monitoring of a 142.5kWp grid-connected rooftop BIPV system in Singapore," *Renew. Energy*, vol. 47, no. October 2009, pp. 9–20, 2012. [CrossRef]
41. S. Edalati, M. Ameri, and M. Iranmanesh, "Comparative performance investigation of mono- and poly-crystalline silicon photovoltaic modules for use in grid-connected photovoltaic systems in dry climates," *Appl. Energy*, vol. 160, pp. 255–265, 2015. [CrossRef]
42. J. D. Mondol, Y. Yohanis, M. Smyth, and B. Norton, "Long term performance analysis of a grid connected photovoltaic system in Northern Ireland," *Energy Convers. Manag.*, vol. 47, no. 18–19, pp. 2925–2947, 2006. [CrossRef]
43. L. M. Ayompe, A. Duffy, S. J. McCormack, and M. Conlon, "Measured performance of a 1.72 kW rooftop grid connected photovoltaic system in Ireland," *Energy Convers. Manag.*, vol. 52, no. 2, pp. 816–825, 2011. [CrossRef]
44. P. M. Congedo, M. Malvoni, M. Mele, and M. G. De Giorgi, "Performance measurements of monocrystalline silicon PV modules in South-Eastern Italy," *Energy Convers. Manag.*, vol. 68, pp. 1–10, 2013. [CrossRef]
45. D. Okello, E. E. Van Dyk, and F. J. Vorster, "Analysis of measured and simulated performance data of a 3.2 kWp grid-connected PV system in Port Elizabeth, South Africa," *Energy Convers. Manag.*, vol. 100, pp. 10–15, 2015.
46. F. Cherfa, A. H. Hadj Arab, R. Oussaid, K. Abdeladim, and S. Bouchakour, "Performance analysis of the mini-grid connected photovoltaic system at Algiers," *Energy Procedia*, vol. 83, pp. 226–236, 2015. [CrossRef]