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Performance Investigation of On-Grid Solar Photovoltaic System in Eskişehir/Turkey

Eskişehir'de Şebekeye Bağlı Fotovoltaik Sistemin Performans Araştırması

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Abstract

The paper presents a performance investigation of a 3-kW grid interactive photovoltaic system located at Eskişehir Technical University using PVSYST program. The system has 260 W_p, 12 PV modules and is connected to a 3-kW inverter. Parameters like the energy from PV panels, energy fed to the utility grid, performance ratio and final yield per installed kW_p is presented. The system produces 4839 kWh/year and injects 4648 kWh/year into the utility grid. It has a performance ratio of 84.8% and the specific production of 4.08 kWh/kW_p/day. The specific production is compared to other systems in the literature review around the world. The paper concludes that Eskişehir region has a better solar energy potential than most places in Europe but not as good as the solar PV systems located in Africa or Asia.

Keywords: *On Grid Photovoltaic System, Performance Analysis, Capacity factor, Performance Ratio, PVSYST Program.*

Öz

Bu çalışmada Eskişehir Teknik Üniversitesi'nde bulunan 3 kW'lık şebeke bağlantılı fotovoltaik sistemin performans analizi yapılmıştır. Sistem 12 tane 260 W_p PV modülüne sahiptir ve 3 kW eviriciye bağlıdır. PV panellerden elde edilen çıkış enerjisi, şebekeye beslenen enerji, kurulu güç başına düşen performans oranı ve verim değerleri sonuçlarda sunulmuştur. PV sistemin üretim miktarı 4839 kWh/yıl, elektrik şebekesine gönderilen enerji 4648 kWh/yıldır. Sistemin performans oranı %84,8 ve üretimi 4.08 kWh/kW/gün 'dür. Sistemin toplam verim değerleri, dünyadaki diğer bazı sistemlerle karşılaştırılmıştır. Yapılan çalışmanın sonuçlarına göre, Eskişehir bölgesinin Avrupa'daki çoğu yerden daha iyi bir güneş enerjisi potansiyeline sahip olduğu, ancak Afrika veya Asya'daki güneş PV sistemleri kadar iyi olmadığı sonucuna varılmıştır.

Anahtar Kelimeler: *Şebekeye Bağlı Fotovoltaik Sistemi, Performans Analizi, Kapasite Faktörü, Performans oranı, PVSYST programı.*

1. Introduction

Increase in energy demand and the scarcity of fossil fuels has encouraged the scientist to do more study in the field of renewable energy particularly solar energy. The need to reduce emissions and the rise in fossil fuel's price has also pushed countries to look for alternative energy sources [1]. Solar energy is more widely used renewable energy around the World because it is readily available, non-polluting and maintenance free. The integration of solar energy into buildings helps in self-production of electricity and injects extra energy produced into the utility grid especially during summer time when electrical demand is high. For solar PV system to be feasible, there should be enough solar radiation throughout the year and for successful implementation, some knowledge is required based on its operational performance under different climatic conditions [2, 3]. Turkey has a massive solar energy potential compared to some European countries. It has a daily peak sun-hours of 7.2 hours and an average daily solar radiation of 3.6 kWh/m². Solar energy potential map of Turkey is given in Figure 1.

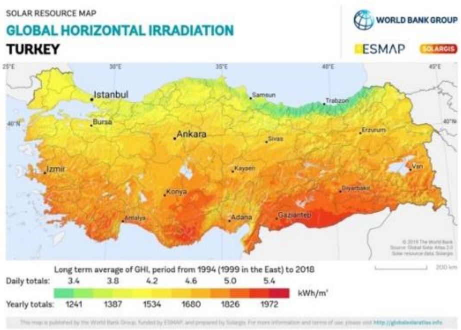

Figure 1. Solar energy potential map of Turkey (GEPA).

The country's South-Eastern Anatolian and Mediterranean regions are the areas with highest solar radiation [1, 4, 5].

By the end of January 2020, Turkey had an installed energy capacity of 91.342 GW of which 28.36% of electricity production was obtained from natural gas, 20.88% from coal, 31.21% from hydropower, 8.33% from wind, 1.66% from geothermal, 6.60% from solar energy and 2,96% from other sources [6].

By end of 2019, Turkey had 44.84 GW of installed renewable energy capacity with hydropower contributing a lot and it is expected to increase by 50% by the year 2024 to reach around 63 GW making the country one of the five countries in Europe with highest renewable share [6]. To reach this milestone in renewable energy capacity, Government, institutions and residential homes should invest in solar energy in Turkey. Hence, this paper investigates how the grid interactive PV system at Eskişehir Technical University performs and compares its performance with some of the countries rest of the world.

The performance of a solar PV system not only depends on PV cell technologies, geographic position but also depends on environmental factors such as global solar irradiation and ambient temperature [7, 8].

1.1 Literature review

In this section, several studies based on performance study of photovoltaic systems using PVSYST software are discussed.

Dondariya et al. [2] analysed the feasibility of an on-grid rooftop photovoltaic system in Ujjain, India. Different simulation software like PVSOL, PVGIS, SOLARGIS and SISIFO were used for performance analysis. The results showed a performance ratio and final yield of 75%, 4.1867 kWh/kW$_p$ respectively. Out of the different software used, PVSOL was found to be easy, fast and reliable software.

Attari et al. [9] assessed the performance study of an on grid photovoltaic system installed on a rooftop of a government building in Tangier, Morocco. The system is being monitored for one year. They found the annual performance ratio and capacity factor of 79% and 14.83%, also they found the system's final yield of 4.45 kWh/kW$_p$ per day.

Kumar and Sudhakar, [10] analysed the performance of 10 MW grid connected solar power plant in India and they found that the annual performance ratio, final yield and capacity of the plant was 86.12%, 4.33 kWh/kW/day and 17.68% respectively. They compared the result of the plant with the results of PVSYST and solar GIS software and they realized that measured result of the plant operates near to the predicted results of the two software.

Kumar et al. [11] studied how 100 kW_p on grid photovoltaic system performs and how it can supply power to an institution of education in India using PVSYST software and the results showed a performance ratio of 80% and final yield of 4.42 kWh/kW_p per day.

Sharma and Goel, [12] analysed the performance of a 11.2 kW_p grid connected rooftop photovoltaic system located in eastern part of India. According to the results, they found a final yield and performance ratio of 3.67 kWh/kW_p/day and 78%, respectively. The result was compared with other systems around the world.

Sharma and Chandel, [13] examined how a 190 kW_p grid connected power plant in India performs. They used PVSYST software for simulation purposes and came up with a performance ratio and capacity factor of 74% and 9.27%. The energy yield of the solar structure was measured 2.23 kWh/kW_p while the predicted energy yield using PVSYST software was 2.25 kWh/kW_P. Therefore, the measured and the estimated energy yield were found to be close with variation of about 1.4%.

Ayompe et al. [14] measured how a 1.72 kW on grid photovoltaic system located in Ireland performs. The place was studied for one year and they came up with a final yield of 2.41 kWh/kW_p per day and performance ratio of 81.5%. The system's final yield when compared to some locations in Europe is better than Germany and Poland.

The aim of the paper is to find out how the PV system at Eskişehir region performs and compare the results with some other systems which are explained in the literature review. Photovoltaic system is signified with a performance parameter such as: reference yield, final yield, system losses, capacity factor and performance ratio. The feasibility of a solar photovoltaic plant at a given location can be examined by using some simulation tools like PVSYST, solar GIS and many other software programs. In this study, the PVSYST software is applied to find the performance of a 3 kW_P on grid photovoltaic system at Eskişehir Technical University.

2. Methodology

2.1 The on grid photovoltaic structure in Eskişehir, Turkey- a case study

Turkey is located in eastern Europe and western Asia, with a population of 80 million. The country imports approximately 70% of its energy needs. The energy produced in the country is mainly from fossil fuels, but in 2019 renewable energy accounted for 49.09% with an installed capacity of 44.84 GW, hydropower with the largest share.

2.2 Layout of the solar PV structure

The system located at Eskişehir Technical University's Renewable Energy Laboratory has 12 polycrystalline PV modules, each with 260 Wp and making a total of 3.12 kW_P. It covers an area of 20 m^2 and is being installed at 35° facing south. The arrangements of the PV modules are in series and it is connected to a 3 kW Fronius International Inverter which feeds to the grid. The efficiency of the inverter is 96% in the worst-case situations and single-phase AC voltage of 220 V, 50 Hz. The PV modules specifications are given in Table 1.

Table 1. Details of PV modules.

Solar Panel	Details
Power rating	260 Wp
Efficiency	15.98%
Cell numbers	60
V_{mp}	30.56 V
I_{SC}	8.51 A
I_{mp}	8.99 A
V_{OC}	38.17 V
Maximum voltage	600 V

The solar PV structure is modeled by using PVSYST program and aims to find the yearly energy output and performance ratio, but different parameters are also assessed for better performance analysis. Figure 2. and Figure 3. show the actual system (renewable energy laboratory) and the schematic diagram of the case study, respectively.

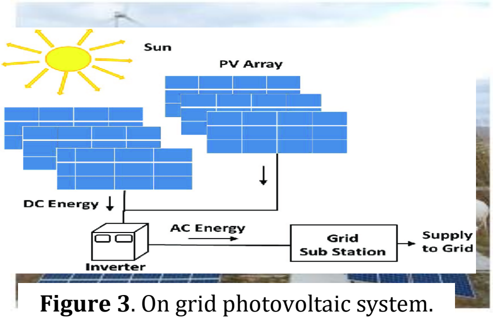

Figure 3. On grid photovoltaic system.

Figure 2. Renewable Energy Research Home at Eskişehir Technical University.

2.3 Parameters used for the performance study

The International Energy Agency (IEA) established to analyse the performance of solar energy systems. Some parameteres are used to make the complete preliminary assessment of a solar photovoltaic system, i.e final yield (Y_f), panel yield (Y_a), reference yield (Y_r), efficiency of system (η), performance ratio, capacity utilization factor, losses from the system and energy output E_{AC}.

2.3.1 Solar panel yield

Solar panel yield (Y_a) is defined by dividing energy output from a PV panel by the rated power of a panel and it's calculated as:

$$Y_a = \frac{E_{DC}}{P_{PV,rated}} \quad (1)$$

Hence, E_{DC} is the PV module's energy output in the form of direct power (kWh) [9, 11].

2.3.2 Specific production

Specific production is the energy fed to a grid based on yearly, monthly or daily. It is calculated by dividing AC energy generated by the panel's rated power. This is a vital parameter for comparing a system's performance with other solar energy systems around the world [15].

$$Y_{f,d} = \frac{E_{AC,d}}{P_{PV,\mathrm{rated}}} \quad (2)$$

where E_{AC} is the output energy from the inverter [10].

2.3.3 Reference yield

Reference yield which is also known as peak sun hours is determined by dividing the global solar insolation by the solar PV's reference irradiance [10].

$$Y_r = \frac{H_t(kWh/m^2)}{H_R} \quad (3)$$

where H_R= kWh/m^2.

2.3.4 Performance ratio

Plant quality factor which another term for performance ratio is the main performance indicator used to compare the performance of solar plant located at different places around the world. The performance ratio depends on losses found in the PV system due to conversions of energy and losses from cables. Other features such as ambient temperature are also considered.

Performance ratio (PR) is calculated by dividing the system's final yield to the system's reference yield. It can be calculated also by the ratio of energy fed into the utility grid to the rated power of solar panel [9, 16] and it is given as:

$$\mathrm{PR} = \frac{Y_f}{Y_r} \quad (4)$$

2.3.5 Capacity factor

Capacity factor (C_f) is also known as load factor it is defined by dividing the actual AC energy produced by the energy that would have been produced if the plant operated at maximum rating for 24 hours per day. It is given as [12, 16, 17].

$$C_f = \frac{E_{ac}}{P_{pv,rated} \times 8760} \quad (5)$$

Different solar PV efficiencies are solar panel efficiency, efficiency of inverter and system efficiency.

2.3.6 Solar panel efficiency

$$\eta_{PV} = \frac{100 \times EDC}{H_t S}(\%) \quad (6)$$

where S (m^2) is an area covered by PV panel, H_t is global solar radiation and E_{DC} is energy generated by the PV panel [9].

2.3.7 Inverter efficiency

Efficiency of an inverter is a division of AC energy after the inverter to the energy from the panel [10]. The inverter efficiency is given as:

$$\eta_{inv} = \frac{100 \times E_{AC}}{E_{DC}}(\%) \quad (7)$$

2.3.8 System efficiency

Efficiency of solar PV structure is a product of the panel's efficiency by inverter efficiency [17, 18].

$$\eta_{syst} = \eta_{PV}\eta_{inv} \quad (8)$$

2.4 Specific solar PV losses

Loss parameters also impact the performance of solar PV system. These losses are divided into two types: PV panel losses and system losses.

2.4.1 Panel capture losses

PV panel capture losses is denoted by (L_C), also known as the PV panel loss [9] and is given as:

$$L_c = Y_r - Y_a \quad (9)$$

2.4.2 System losses

The system losses denoted by (Ls) is the inverter losses [9, 16, 17]. It is calculated as

$$L_S = Y_a - Y_f \quad (10)$$

Temperature loss coefficient is symbolised by (η_{tem}) and it is calculated by the equation below [9]:

$$\eta_{tem} = 1 + \beta(T_c - 25) \quad (11)$$

where (T_c) is a cell temperature of a panel, (T_a) is ambient temperature and β is solar panel's temperature factor [9].

$$T_c = T_a + \frac{G}{800}(T_{NOCT} - 20) \quad (12)$$

where G is full sun hours and T_{NOCT} is normal operating cell temperature.

3. Results

This section discusses the simulation results of the proposed 3 kWp solar photovoltaic system located at Eskişehir Technical University where is located at latitude of 39.70^{0}N and longitude of 30.50^{0}E. The results are attained by simulating the system by using PVSYST program. From the obtained results, energy generated, specific production, performance ratio and loss diagram are examined to see how the system performed.

3.1 Main modeling Results

After modeling the system, four major parameters are presented. The first one is energy obtained from the 3 kWp system on a yearly basis i.e. 4648 kWh/year. The second is the specific production per kW which is 1490 kWh/kW$_p$. The third and four are performance ratio (PR) and load factor of about 85% and 17.39%.

Global solar radiation, air temperature, and the energy produced by the system on a monthly and yearly basis are given in Table 2.

Table 2. Energy generated, performance ratio and global solar radiation of the 3 kWp photovoltaic system.

Month	Global solar radiation (kWh/m^2)	Electricity generated (kWh)	Performance ratio (PR)
January	54.1	255.9	92.16%
February	72.5	293.5	90.45%
March	116.5	391.7	87.91%
April	143.6	409.3	86.25%
May	174.7	436.3	83.29%
June	197.2	462.5	82.04%
July	x2.4	498.8	80.46%
August	192.8	504.4	79.92%
September	149.1	453.2	82.53%
October	102.8	374.1	85.83%
November	69.8	315.2	89.25%
December	51.4	253.2	91.49%
Year	**1536.9**	**4648**	**85.00%**

The highest energy is generated in August and lowest energy is obtained in December in Table 2. Low performance ratio is seen in August due to high temperature leading to losses while in the month of January high performance ratio is experienced.

According to Table 2, the monthly performance ratio differs from 79.92% to 92.16% during the months of January and August. Performance ratio is compared to some other systems around the world. For example, Tangier, Morocco's PR ranged from 58% to 98% [9], Ramagundam, India's PR ranged from 73.3% to 79% [10], Crete island, Greece's PR ranged from 58% to 73% with average of 67.36% [19] and Warsaw, Poland's PR ranged from 60% to 80% [20].

3.2 Normalized energy productions

Standardised parameters such as PV array loss, system loss and energy generated per kW_p are presented in Figure 4. From this figure, L_C is the PV array loss of 0.56 kWh per kW_p, L_S is system loss of 0.17 kWh per kW_p and Y_f is output power from inverter which is 4.08 kWh/ kW_p.

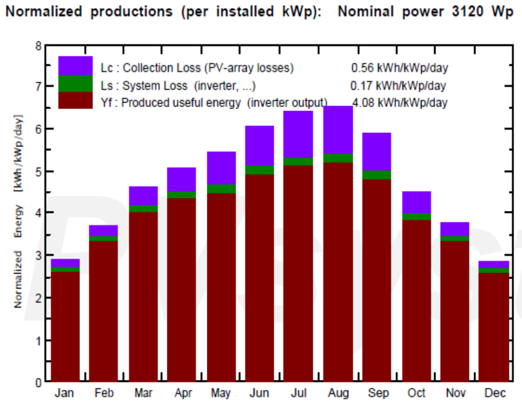

Figure 4. Normalized energy production.

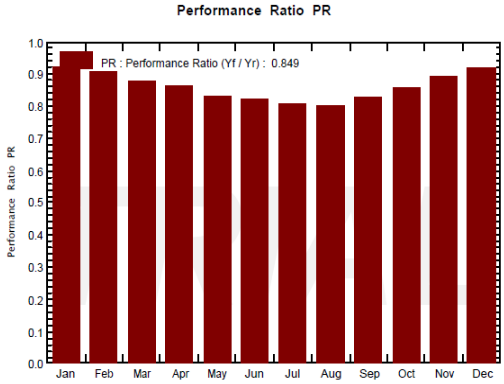

Figure 5. Performance ratio (%).

3.3 Energy fed to utility grid

Energy produced by PV panels is different from the energy fed to the utility grid due to losses that occur when converting DC energy to AC to match the grid electricity. The 3 kWp on grid PV system at Eskişehir Technical University injects 4648 kWh of energy to the utility grid annually. Considering Table 2, 504.4 kWh of energy is fed into the utility grid during the month of August which is the highest energy produced while the lowest energy fed to the utility grid is generated during the month of December which is 253.2 kWh.

3.4 Performance ratio

The system's performance ratio (PR) is about 85% which varies according to months as can be seen from Figure 5.

The figure shows that the PR is highest in the winter season because of the low temperature hence resulting to less losses, while the lowest PR is seen in summer, especially July and August, because of high temperature leading to high losses.

3.5 Loss diagram

Loss diagram is given in Figure 6 which helps in investigating the different losses that occur while designing solar PV plant.

After the PV conversion and losses, the PV energy output at room temperature is 4839 kWh while the panel's efficiency at room temperature is 16 %. The different losses at this point are 6.82 % losses due to outside temperature, 0.61 % loss due to solar radiation level, while 1.10 % loss is due to PV panel connection mismatch and 1.03 % loss is due to wiring losses. The energy fed to the grid after passing through the inverter is 4648 kWh, here one loss is likely to occur which is the inverter loss i.e. 3.89%.

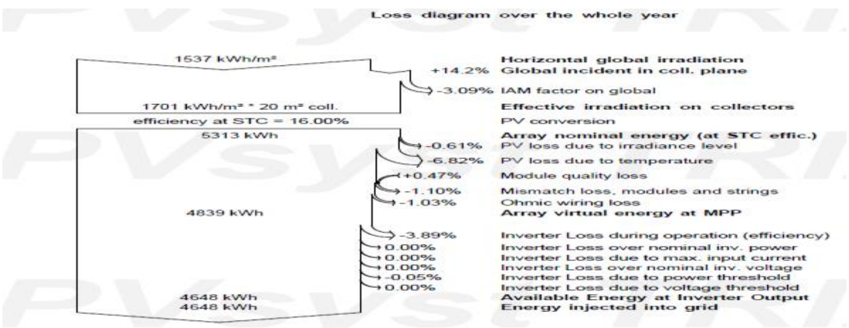

Figure 6. Loss diagram.

Comparison of performance analysis in several sites around the World using PVSYST program is given in Table 3.

Table 3. Comparison of performance analysis in several sites around the World using PVSYST program.

Site	Panel type	Size (kW_p)	Final yield(kWh/kW_p/day)	PV panel efficiency (%)	System efficiency (%)	Inverter efficiency (%)	Performance ratio (PR) %	Reference
Eskişehir, Turkey	**Poly-Si**	**3.120**	**4.08**	**15.7**	**15.08**	**96**	**84.90**	**Case study 1**
Berlin, Germany	Poly-Si	3.120	2.91	16.5	15.7	95.4	85.60	Pilot study 2
Mandera, Kenya	Poly-Si	3.120	4.32	12.9	12.4	95.9	78.60	Pilot study 3
Dublin, Ireland	Mono-Si	1.72	2.4	14.9	12.6	89.2	81.5	[14]
Tangier, Morocco	Poly-Si	100	4.45	12.39	11.99	96.7	79	[11]
India	Poly-Si	11.2	3.67	13.42	12.05	89.83	78	[12]
South Africa	Poly-Si	3.2	4.90	13.72	12.08	88.10	64.30	[21]
Italy	Poly-Si	-	3.4	7.95	7.79	98	60-62	[22]

Table 3 shows that the performance ratio is high due to low temperature leading to less losses for the regions in Europe, but their final yield is normally lower due to less sun hours. The regions in Africa and Asia have a low performance ratio due to high temperature hence leading to more losses but these regions have high final yield because they receive more sun hours in a year.

4. Conclusion

Performance study of a 3 kW_p grid interactive solar PV system at Eskisehir Technical University is simulated using PVSYST program. The study was realized to compare Eskisehir solar energy production and its performance to the rest of the world especially Europe and Africa. Since Eskisehir's weather is colder and solar panels perform well in cold temperature resulting in less losses. The PVSYST program was used as the best solar energy simulation program to determine the solar energy performance of the study area. After the simulation results, the following conclusions are remarked:

- Maximum energy is generated in the month of August due to high solar radiation in summer i.e. 504.4 kWh while in December low energy was experienced i.e. 253.2 kWh, leading to annual average energy output fed to the grid of about 4846 kWh/year.
- The quality yield also known as the final yield of the case study is 4.08 kWh/kWp which is high when compared to some systems in Europe.
- The studied area is delivered a performance ratio and load factor of about 84.9% and 17%, this shows that Eskişehir region has a good solar energy potential and total energy production is compared to most places in Europe.
- The results showed that in summer particularly in August more losses occur leading to low performance ratio because of the hotness and high capacity due to high solar radiation and vice versa in winter specially December.
- The study recommends installation of PV systems in Eskisehir region due to the high performance ratio which is as a result of low temperature and medium solar radiation throughout the year.
- Further studies can be performed using various PV panel technologies. Solar trackers can also be studied and then compare it with the system without a tracker.

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