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PHOTOVOLTAIC SOLAR POWER PLANT OF SOGUKSU: A CASE STUDY

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ABSTRACT

Investments in photovoltaic solar power plants continue to increase across all provinces of Türkiye. However, Bursa is not among the regions that receive the highest levels of solar radiation compared to the eastern parts of the country. The Soğuksu power plant, located in the village of the same name in Bursa, was commissioned in March 2017 with an installed capacity of 7 MW. In this study, the actual generation data of the power plant for 2022 were analyzed, and the performance ratio (PR) and capacity factor (CF) were calculated. The results show that the minimum electricity generation occurred in December 2021 with 401.21 MWh, while the total electricity production in 2022 reached 10.64 GWh. During the summer season, the plant generated 7,262.8 MWh, corresponding to 68% of its annual production. The lowest performance ratio was observed in June at 75.1%, while the highest capacity factor was recorded in July at 28%. Furthermore, the performance ratios for November, December, and January exceeded 100%. Since the PR is calculated based on the solar energy values reported in the regional solar atlas, such results indicate a notable discrepancy between the published data and the actual site conditions. The exceptionally high PR values during the winter months may suggest that the region experiences milder winters and receives higher solar radiation than the atlas values imply.

Keywords: Solar power plant, Electricity generation, Performance ratio, Capacity factor, Soğuksu- Türkiye.

1 INTRODUCTION

Global warming, environmental issues and climate change are among the important problems of today world. Renewable energy sources with solar energy technologies can be assisted to solve previous problems. Electricity production from fossil fuels is inexpensive but finite and main sources of greenhouse gasses. However, the sun provides an infinite supply of energy, although factors such as geographical location, seasons, clouds, and dust affect its availability. There are numerous studies on the solar potential and solar energy systems of Türkiye. Hepbaslı et al. [1] defined the industrial use of solar energy in Türkiye starting in 1988 and emphasized the continuous increase of photovoltaic (PV) installations in the country. Kaygusuz [2] determined that Türkiye is a suitable country for utilizing concentrating solar power (CSP) technology, which offers significant opportunities.

Several other studies have focused on solar potential analysis and projections for future years. Hrayshat [3] conducted a feasibility study on a pilot solar PV power plant with a 15 MWp capacity, proposed for installation in two different cities in eastern Morocco. Merrouni et al. [4] analyzed the solar irradiation values of the eastern region of Morocco. According to photovoltaic data for Serbia, 43% of the electricity was generated by two thermal power plants [5]. Edalati et al. [6] discussed the recent developments in Iran's prospective renewable energy policy. Kumar and Sudhakar [7] evaluated the performance of a solar PV power plant in India with a peak capacity of 10 MW.

Incekara and Ogulata [8] declared that a big potential of electricity generation will be done by solar energy at 2030 for Türkiye. Also, according to Boran et al. [9] Bodrum is the best area for installing PV power plant in Türkiye.

According to Parhamfar et. al. [10] photovoltaic systems play a pivotal role in addressing the growing global demand for sustainable and renewable energy sources, offering a crucial solution to mitigate climate change and reduce dependence on fossil fuels. Salameh et al. [11] have addressed the fundamental challenge of accurately forecasting power generation from photovoltaic systems, which is crucial for effective grid integration and energy management. Al Mehadi et. al. [12] have described the design and simulation of a 50 MW floating Solar photovoltaic system that generates an annual energy yield of 76916 MWh.

The Soğuksu (Bursa province) PVPP has started to produce power since March 2017. It has a 7MWe capacity and one of the new power investments. Hydrogen production from renewable energy sources has increasingly become a popular research area among researchers,

driven by the growing interest in sustainable and carbon-neutral energy systems [13]. Saka and Canbolat [14] studied on hydrogen production investigation of this solar plant based on the actual electricity generation. Saka [15] showed effect of bad weather conditions on power production of Soğuksu solar plant and provided the first-year electricity production values of the Soğuksu solar plant [16]. Saka [17] presented a study on seasonal generation of Soğuksu power plant. Also, he has focused on a new study of the Soğuksu power plant in terms of performance and agrivoltaic aspects [18]. In another study, Saka and Orhan [19] have studied on performance assessment and useful solar radiation analysis of this plant and biomass potential of Yenişehir [20].

Main objectives of studies on the Soğuksu PVPP are given in Table 1.

Table 1. Main objectives of studies on the Soğuksu PVPP.

Main objectives	Studies
Investigation of daily theoretical hydrogen production performance	[14]
Investigation on theoretical hydrogen production capacity yearly	[15]
Effect of overcast weather on electricity generation	[16]
Investigation on seasonal generation	[17]
Investigation of performance ratio and seasonal effect factor	[18]
Performance assessment and useful solar radiation analysis	[19]

Performance evaluation of Serhatköy PVPP (Northern part of Cyprus) was done by Özerdem et al. [21], capacity of the power plant was 1.2 MW and calculated capacity factor (CF) and performance ratio (PR) of a solar plant. The best PR value of the power plant was %93.31. İnan and Şimşek [22] investigated design and analysis of 1 MW solar power plants with a software. As a result, the annual PR of the power plant was %87.52 in Istanbul.

The present study was conducted from December 2021 to November 2022 for analysis of the electricity production at the Soğuksu PVPP by evaluation of real data. The data was obtained from the company that operates the power plant. Solar radiation of the Bursa is relatively lower compared to southern regions; especially for winter season. This situation requires an examination the effect of weather conditions on the power plant productivity. Monthly electricity generation was compared with solar radiation of the province and the seasonal performance of the solar plant with performance ratio were calculated.

2 MATERIAL AND METHOD

2.1 Description of the Soğuksu PVPP

PV solar panels are connected to strings in series in Soğuksu PVPP and the strings connected to inverters;

- Each 1 MWp scale power plant has 20 inverters.
- Each inverter has 10 strings,
- Each string has 22 panels,

Inverters are electronic circuits which alert current rate. An inverter converts direct current (DC) to alternating current (AC). There are many type of panels which have high efficiency in the market. Besides at open literature, there are theoretical or experimental point of views but aim of this study which reach to close data of other studies.

Information on power plant:

- Model of panel is UP-M270P,
- Type of panel is polycrystalline silicone and each panel has 60 cells,
- Panel has a 270 W power rating with %16.6 peak efficiency.

The electricity is produced by solar power plant as function of:

i) Total cell surface,

ii) Sunny daily numbers,

iii) Panel efficiency,

iv) Inverter efficiency.

The view of Soğuksu solar power plant transferred energy to grid, located province of Yenişehir, Bursa and established since 20 March 2017, given at Figure 1 and solar map shown at Figure 2. Some information about the power plant such as:

- Coordinates of the power plant are 40º12’57’’N and 29º25’50’’E,
- The power plant was installed on an area of 170000 m^2,
- Number of panels used in the power plant are 30800,
- General efficiency of inverter is 97%.



Figure 1. The view of Soğuksu PVPP.



Figure 2. Location of the power plant on solar map.

2.2 Energy Equations

The results presented in this study which take into account all losses since obtained by using actual data. Energy equations can be defined as follow for electricity generation of PVPP.

$$E_G = N_P E_S \eta_P \eta_{inv} \eta_{los} \tag{1}$$

where;

N_P Panel number,

E_S Radiation on panel,

E_G Electricity generation,

η_P Panel conversion efficiency is calculated by

$$\eta_P = \frac{E_{el}}{E_S} \tag{2}$$

where;

E_{el} Electricity production by panels,

η_{inv} Efficiency of inverter.

In order to maximize electricity production from solar power plants, energy losses must be minimized.

η_{los} shows the total efficiency account for all losses as:

- Conduction losses,
- Module mismatches,
- Wiring,
- Temperature effects,
- Humidity,
- Soiling,
- Wind speed,
- Dust or snow on the panel.

3 RESULTS AND DISCUSSION

Solar potential maps have solar radiation values and prepare to reveal the average sunbathing potential of a region [23]. Figure 3 presents Global Solar Radiation Values (GSRVs) of Yenişehir and produced electricity per month for each year at power plant. The electricity potential of the power plant can be calculated by GSRVs. Equation 4 shows relation between power potential and GSRVs. For example, GSRV in April was 4.59 and the potential of the plant can be find as 1028 MWh but it was actual value as 1038.74 MWh. But calculation of overall plant peak efficiency was not ignored with real values. Thus, calculation is required to correct by correlation factors.

Consequently, solar radiation values can give an idea about potential solar energy region but not an exact generation value. At 2022, total power production of the solar plant was 10.64 GWh and between April to September (for six months) 7.26 GWh electricity generation which was equal to % 68 of total generation for a year.

Electricity generation percentages for each month was given in the Figure 4 for 2022. On a monthly basis, maximum generation was obtained at July for 1455 MWh at percentages of 13.7. The minimum one was obtained in December with 401.21 MWh and %3.8.

$$E_P = GSRV\ x\ Day\ number\ x\ Panel\ area\ x\ Panel\ efficiency \tag{3}$$

where;

E_P Electricity potential

The Performance Ratio (PR) of the Soğuksu PVPP for each month is calculated by using Equation 4. The PR enables a comparison between actual and the calculated energy ratio. Also, which is influenced by losses of power plant.

Furthermore, Capacity Factor (CF) of power plant for each month can be computed by using Equation 5. The CF is the ratio of the monthly average energy production of an energy generation plant to theoretical maximum monthly energy production of a plant that assumed its' operation of peak rated capacity for every hour of the month.

$$PR = \frac{E_G}{E_P} \tag{4}$$

$$CF = \frac{Real\ Power\ Generated}{30x24xNominal\ Power} x100 \tag{5}$$

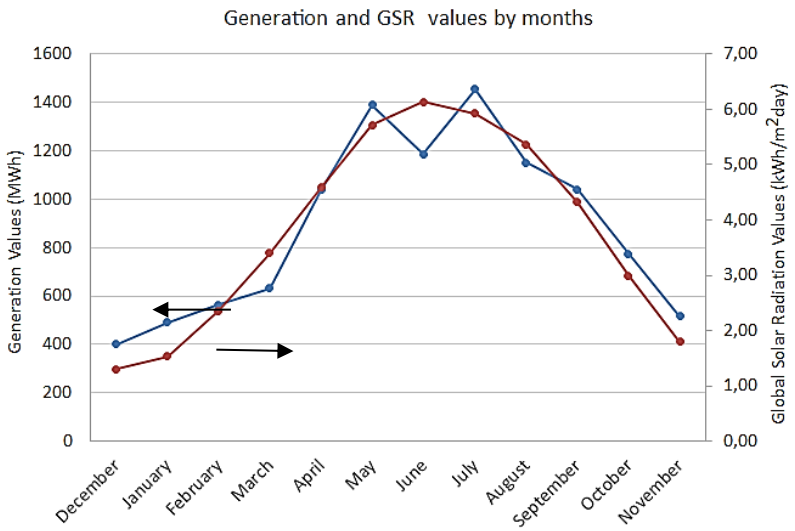


Figure 3. GSRVs of the Yenişehir city and the electricity generated by the PVPP.

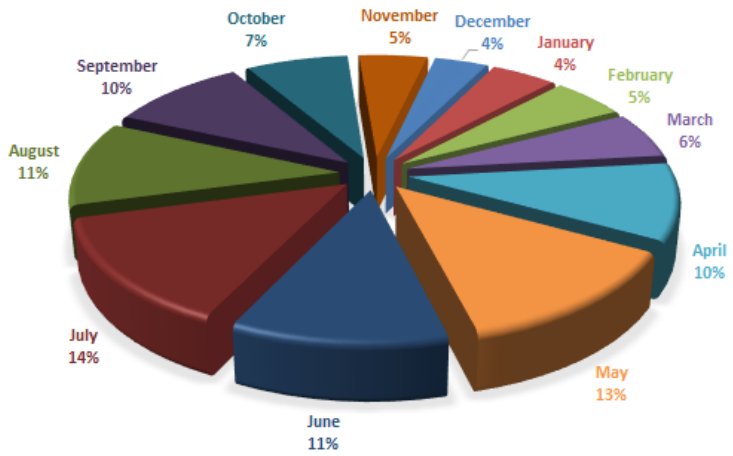


Figure 4. Electricity generation percentages for each month of 2022.

Based on the generation rates which were given in the figures, the ranking between the produced electricity and GSRV due to months is incompatible. June is the highest global radiation value inversely July is the month which can be produced extra electricity production. The incompatibility can be defined by daily generation quantities. Thus, Northwestern Anatolia where the power plant is located at Bursa province, has low solar radiation according to South and Southeast Anatolia region. In winter, the effect of cloud cover on the power plant is significant to decrease performance and production of electricity. Moreover, effect of bad weather on the production performance of the plant has to be determined. While a relatively stable generation profile is generally expected, seasonal variations are readily evident in the daily generation data.

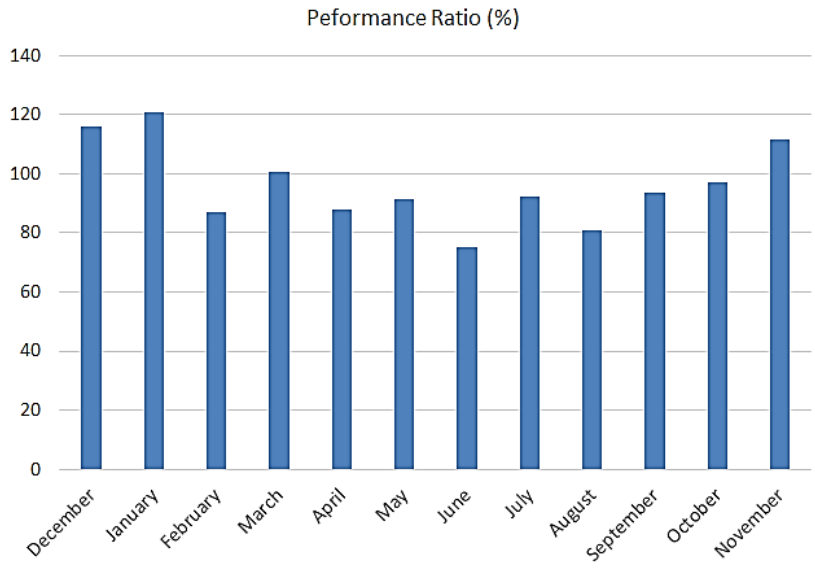


Figure 5. The PR of the power plant in 2022 for each month.

At Figure 5 is shown the PR of solar power plant in 2022 for each month. The PR exceeded 100% 4 times in 2022. The minimum performance ratio was in June as 75.1%.

Figure 6 shows the CF of the power plant in 2022 by month. The maximum CF was in July as 28%. The minimum capacity factor was in December. Finally, it can be coherence to share a current situation which encountered and conducted to present study. Especially the plant was subjected to a private investment venture. The results include a necessity to strengthen the infrastructure of the grid and to determine the rates of non-realization of applications with investigation of associated causes in order for more investments which has similarity to realize power plant of Türkiye.

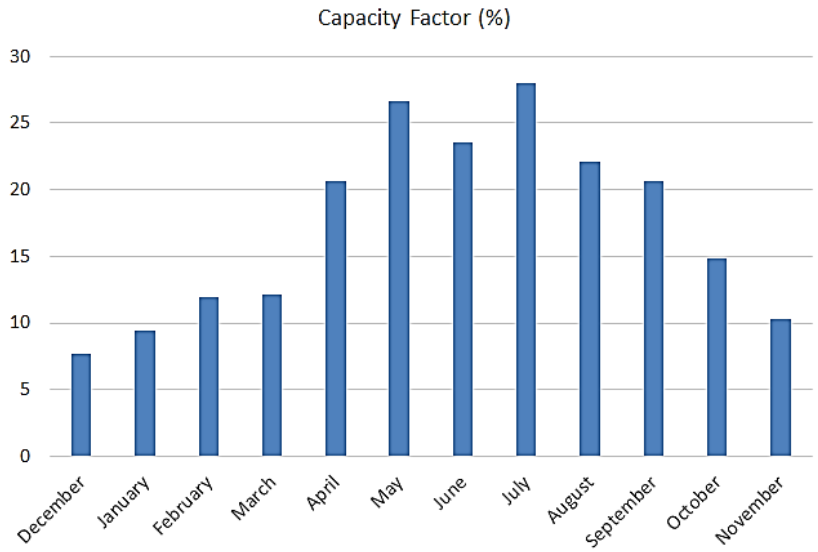


Figure 6. The capacity factor of power plant in 2022 by month.

4 CONCLUSION AND SUGGESTIONS

In this study, a generation performance analysis was conducted for a 7 MWp grid-connected photovoltaic (PV) solar power plant. The plant is a large-scale facility consisting of 30,800 panels connected in series. The analysis demonstrates how the plant, located in a region with relatively low annual insolation potential, is affected by overcast weather conditions. The total annual electricity production of the plant was 10.64 GWh. Detailed results for the six-month period from October to March, covering the winter and autumn seasons, were presented. On a monthly basis, the maximum generation was recorded in July with 1,455 MWh, corresponding to 13.7% of the annual production, while the minimum was in December with 401.21 MWh, accounting for 3.8%. The lowest performance ratio was observed in June at 75.1%, whereas the highest capacity factor was achieved in July at 28%.

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Conflict of Interest Statement

There is no conflict of interest between the authors.

Statement of Research and Publication Ethics

The study is complied with research and publication ethics.

Artificial Intelligence (AI) Contribution Statement

This manuscript was entirely written, edited, analyzed, and prepared without the assistance of any artificial intelligence (AI) tools. All content, including text, data analysis, and figures, was solely generated by the authors.

Contributions of the Authors

Kenan Saka: resources, software, supervision, review and editing

Abdulkadir Ayanoğlu: investigation, writing original draft preparation and review.

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