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RESEARCH ARTICLE

PERFORMANCE ANALYSIS of DIFFERENT SOLAR TRACKING SYSTEMS for OFF-GRID PHOTOVOLTAIC POWER SYSTEM in BİLECİK, TURKEY USING PVSYST SOFTWARE

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ABSTRACT

It is planned to install an off-grid photovoltaic system of 550Wp to meet the energy needs of the energy measurement laboratory at Bilecik Şeyh Edebali University in Bilecik, Turkey. In this study, the performance of different solar tracking systems in the off-grid photovoltaic system that will be installed in Bilecik, was compared. Monthly available solar energy, $E_{missing}$, y_a, y_r, y_f, P_r, l_a and l_s were compared in analysis of different solar tracking systems. The analyzed solar tracking systems are fixed tilted, seasonal tilted, horizontal axis, vertical axis and double axis. PVsyst 7.2 is widely used simulation software for analyzing the efficiency of photovoltaic systems and optimizing system design. Monthly average irradiation and panel temperature data used for analysis are obtained from PVsyst database. The minimum available energy and the maximum missing energy in the fixed tilted tracking with tilt angle of 40° and an azimuth angle of 0°, are 764.77 kWh/y and 93.36 kWh/y respectively. The maximum available solar energy and the minimum lost energy in the double axis tracking system are 1049.9 kWh/y and 57.03 kWh/y in July respectively. The highest average monthly performance ratio is 0.778 for the fixed axis system and the lowest is 0.558 for the double axis system. The results of this study show the performance analysis of the off-grid photovoltaic systems power generation, and can serve for the successful development of the photovoltaic system in real application situation.

Keywords: *Solar tracking systems, Off-grid PV system, PVsyst software, Performance analysis,*

1. INTRODUCTION

With climate changes in our world, problems of conventional energy sources and developments in technology, countries prefer clean and renewable energy sources [1,2]. Renewable energy sources have many advantages. These advantages: being ready in nature, being sustainable, helping to protect environment by reducing carbon dioxide emissions and reducing dependence on energy, which are local resources. Renewable energy sources are hydrogen, geothermal, solar, wind and biomass [3]. After the energy crisis in the 70s, solar power technology has gained significant in worldwide market. It has been improving faster than other renewable energy sources in recent years. In addition, solar energy systems have started to become widespread around the world in order to reduce the amount of carbon released into the air too much [4].

Solar energy is clean energy and is abundant in our world. Photovoltaic (PV) panels, that convert the irradiation on them directly into direct current (DC) through cells, are system elements. Produced by a PV panels, the power value depends on the amount of irradiation falling on it. Since the position of solar changes throughout day, the PV panel must always be directed exactly towards the sun and adjusted to produce maximum possible power [5].

PV systems are classified as on-grid, off-grid or hybrid. For investments for only PV or hybrid PV systems, it is important to prepare feasibility studies in advance. Today, these studies and researches can be done by means of some computer programs. It is important for the power plant that is planned to be established in a region for the production data of the power plant and the cost of the installation, sizing of PV systems and accuracy of investment [6].

All over the world, different methods and simulation software programs are used for design of PV systems [7]. These simulation softwares are HOMER, RETScreen, SolarMAT, PVsol, PVGIS, SolarGIS and PVsyst [8]. PVsyst simulation software is available for on-grid connected or off-grid systems because selection parameters are suitable for the researches in studies and in literature. There are PV panels, inverters, batteries in many brands and models in the database, it is functional, economic analysis can be made, fast results and simulation data are close to reality and it is frequently used. Using numerous parameters; the final report that clearly shows estimated production data, loss values and the performance rate of the system in monthly, daily or hourly format is given to user. In addition to all these, with Meteonorm 8.0, which has a database in PVsyst, atmospheric data of the place where the PV system is desired can be produced synthetically [9].

The PVsyst software was originally developed in Geneva by Swedish scientist Andre Mermaid and his team. [10]. Mandelli et al. have done a study on the sizing methodology on the independent country electric power in Uganda, taking into account the cost and level of energy taken and lost [11]. Smiles et al. with PVsyst software made a technical and economic analysis of the situation of meeting the energy needs of the Bath Abbey building in the United Kingdom with roof-mounted PV systems [12]. Limem et al. evaluated the effectiveness of the 5.1 kW rooftop PV system installed in Kocaeli Technology Faculty building in Kocaeli climate conditions by using commonly used PVsyst software [13]. Jagadale et al. compared the two cases by placing the panels at 20° and different angles in a PV power plant with an installed power of 250 kW in Pure city of India with PVsyst [14]. Baqir et al. made a technical analysis of a PV power plant with an installed power of 700 kWp, which is planned to be built in Daikundi, Afghanistan with PVsyst [15]. Mohammed et al. selected the panels used in the PV plant with an installed power of 10 kW in Saudi Arabia using SolarGIS in CdTe, a-Si, c-Si, CSI technologies and determined the most efficient panel and made a technical and economic analysis of the plant [16]. Ghafoor et al. performed a technical and economic analysis for a single residential application of off-grid PV (OGPV) system in Faisalabad, Pakistan [17].

The performance analysis of PV power systems has been studied in several different countries by means of PVsyst or new methods. On the other hand, there is less studies in the literature on different solar tracking systems (STS) of OGPV systems in buildings. The performance of a 550Wp OGPV systems for a measurement laboratory planned to be established in Bilecik Seyh Edebali University for different STS is analyzed using PVsyst 7.2 simulation software in this study.

2. MATERIAL AND METHOD

2.1. Meteorogical Data of Bilecik

Bilecik city has three different climate types due to its location in the transition region, its proximity to water resources and its geographical location. In addition, the number of sunny days is quite high due to its latitude and longitude points. The region, where Bilecik Seyh Edebali University is located and this study was conducted, generally shows the climate characteristics of Central Anatolia Region. The city has an average of 2.190 hours of sunshine per year. With this advantage, Bilecik is among the provinces with high solar energy potential in Turkey [18].

In order to analyze the performance of the PV panel system, data such as solar irradiation and ambient temperature from the atmospheric data of the region are used. Before performing the simulation, meteorological data of the region should be taken from the database of program. Therefore, the region should be marked on the map in the geographic area management region in the PVsyst simulation software [19]. However, due to the project region is not available in Meteonorm 8.0., that is used to generate hourly synthetic data of the region with PVsyst 7.2, then the coordinate data of the region is introduced to simulation study [9].

Figure 1 shows the monthly average solar irradiation values, ambient temperature values, horizontal diffuse irradiation and global incident collector plane at tilt angle 40°, azimuth angle 0° and albedo 20% at the location of the PV system planned at Bilecik Seyh Edebali University.

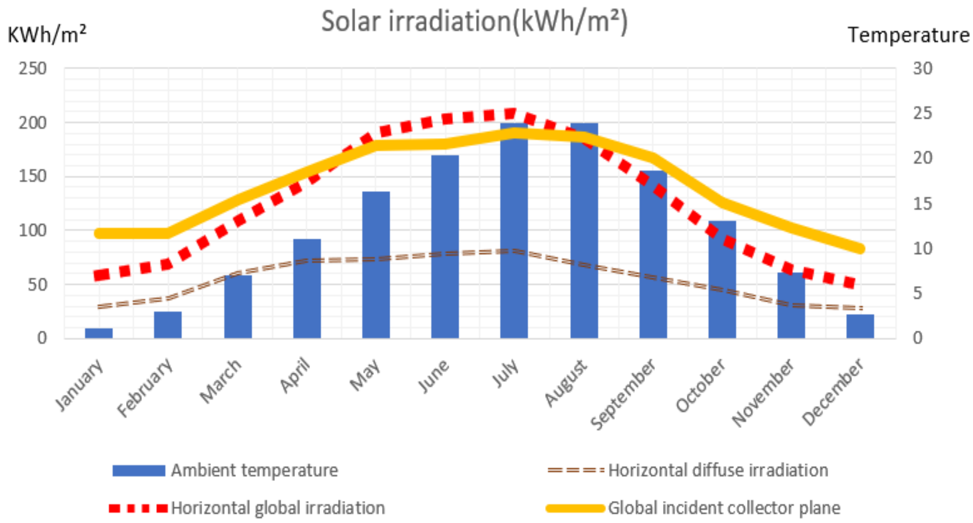

Figure 1. Monthly average solar irradiation and ambient temperature in Bilecik.

First of all, the monthly average horizontal global irradiance is between 50 kWh/m² in December and 208.5 kWh/m² in July. The monthly average horizontal irradiance is 29.7 kWh/m² in January and 81.2 kWh/m² in July. The monthly average global irradiance to the PV panel is 83.2 kWh/m² in December and 189.9 kWh/m² in July. The monthly average ambient temperature varies by 1.19 °C in January and 23.97 °C in July. Finally, the average ambient temperature is 12.41 °C throughout the year.

2.2. Parameters of PV Power System

The parameters used in the literature to analyze the performance of the PV system give a complete preliminary feasibility analysis of the PV system. These parameters are the efficiency of the PV system, the loss between the energy produced and the consumed, the system yields, the performance and the losses of the system at the full analysis report [20]. Daily, monthly and annual total AC energy values produced by the PV panel are obtained by using Eq. 1, Eq.2 and Eq. 3 for the desired time [21].

$$E_{(AC,d)} = \eta_{inv} \sum_{t=1}^{24} E_{(DC,t)} \quad (1)$$

$$E_{(AC,d)} = \eta_{inv} \sum_{t=1}^{24} E_{(DC,t)} \quad (2)$$

$$E_{(AC,y)} = \eta_{inv} \sum_{m=1}^{12} E_{(DC,m)} \quad (3)$$

Here, these values show that DC energy value is produced by for hourly $E_{(DC,t)}$, for daily $E_{(DC,d)}$, for monthly $E_{(DC,m)}$ and AC energy value is determined by for daily $E_{(AC,d)}$, for monthly $E_{(AC,m)}$, for annual $E_{(AC,y)}$ in addition N_d days, and η_{inv} the yield of the DC-AC inverter. Daily, monthly and annual energy and daily, monthly and annual energy values transferred to the user are used to calculate the daily, monthly and annual values of the lost energy consumed in the PV power system [4].

$$E_{(loss,d)} = E_{(load,d)} - E_{(user,d)} \tag{4}$$

$$E_{(loss,m)} = E_{(load,m)} - E_{(user,m)} \tag{5}$$

$$E_{(loss,y)} = E_{(load,y)} - E_{(user,y)} \tag{6}$$

The panel reference yield of the PV system is indicated by y_r. The panel producers have defined the efficiency of the panel in the standard test condition (STC) in the datasheet. It is calculated as the ratio of total irradiation to global irradiation. y_r is expressed numerically in kW/m² unit [22].

$$y_r = \frac{H_t}{G_0} \tag{7}$$

Here, H_t is the total horizontal irradiation in kW/m² and G_0 is the global irradiation in months/days kWh/Sq. The array yield of the PV system is indicated by y_a. It is obtained by dividing the power obtained at the PV panel output by the power of the PV panel. y_a is calculated using Eq. 8 [22].

$$y_a = \frac{E_{DC}}{P_0} \tag{8}$$

Here, E_{DC} shows the generated power value of the PV panel on a daily, monthly or yearly basis, and P_0 shows the nominal output power value of the PV panel in the STC.

$$E_{DC} = V_{DC} * I_{DC} * t \tag{9}$$

Here, V_{DC} and I_{DC} are the output voltage and the output current of the PV panel respectively, and t is the time in hours. The ratio of the AC energy output at the inverter output to the maximum power of the PV panel in the STC is defined by the final efficiency y_f. It is calculated on a daily, monthly or annual basis using Eq. 10.

$$y_f = \frac{E_{AC}}{P_P} \tag{10}$$

Here, E_{AC} is the daily, monthly or annual AC energy value at the inverter output of the PV system and P_P is the maximum power of the PV panel in STC.

Besides efficiency parameters, loss parameters also affect the performance of a PV power system. There are losses in all components used when designing a OGPV system. These loss parameters are panel capture losses, system losses and performance ratio.

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The PV system performance ratio is indicated by P_r and is defined as the ratio of the energy supplied to the grid to the nominal power specified in the PV catalog. The performance ratio gives information about all losses of energy converted from DC to AC. Therefore; The energy remaining after energy losses is expressed as a percentage [23].

$$P_r = \frac{y_f}{y_r} = \frac{E_{AC}}{Glob\_Irr} \quad (11)$$

Here, y_f is the panel final yield of the PV system and y_r is the panel reference efficiency. E_{grid} is AC injected energy into the grid and Glob_Irr is PV panel global irradiation.
System losses are expressed as l_c and are expressed as the difference between the panel reference efficiency of the PV system and the panel efficiency. The main components that make up this loss value are; the increase in PV panel temperature values, partial shading, the amount of dust accumulated on the panel, tracking errors and incompatibility between the PV panels are calculated using Eq. 12 [19].

$$l_c = y_r - y_a \quad (12)$$

Capture loss is obtained the difference between the panel yield of the PV system and the panel final yield. It is indicated by l_s. System loss value originates from the inverter and other devices used in the PV system and is calculated using Eq.13.

$$l_s = y_a - y_f \quad (13)$$

Using the equations given above, the relationships between performance evaluation parameters are given in Figure 2.

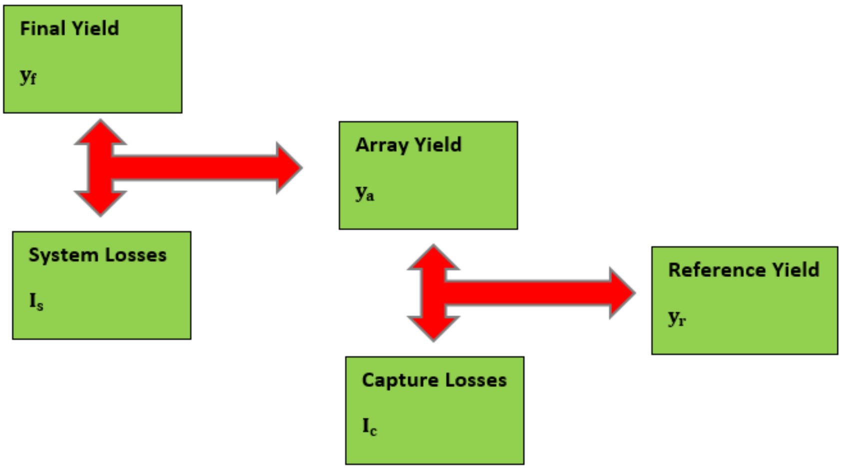

Figure 2. Performance evaluation parameters.

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2.3. Off-Grid PV (OGPV) System Components
OGPV systems are used in places that are far from the grid and require little energy. These systems are compared to systems that meet their energy from fossil sources, they are advantageous because of low operating, maintenance and cleaning costs [24].

The main components of OGPV systems consist of PV panels, battery pack, DC-AC inverter and charge controller, DC and AC load and connectors required for system integration. The model of OGPV system is shown in Figure 3.

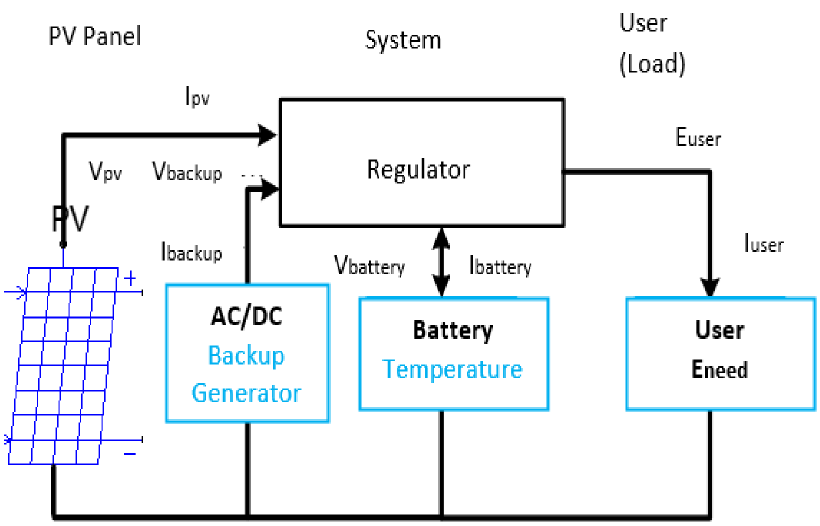

Figure 3. Model of OGPV system.

The PV panel converts the irradiation into electrical energy. The charge controller sets the desired current and voltage. When not all of the generated voltage is consumed, it is stored using the battery. When there is no or little irradiation, the voltage stored in the battery is used. Conventionally, it contains that battery charge controller and MPP tracking system for PV panels. DC-AC inverter converts DC-AC to drive AC system [25].

In this study; belonging to JINKO SOLAR company JKM275PP-60 model, 275Wp Si-poly 2 units PV panels were used. The selected panel has a weight of 19 kg, dimensions of 1.65 x 0.992 x 0.04 m and a surface area of 1.64 m². Table 1 shows the parameters of the PV panel using PVsyst simulation software STC at 1kW/m² irradiance and 25°C temperature. The open circuit voltage of the PV panel is 39.1V and the short circuit current 9.15A. The current in MPP is 8.61A and the voltage in MPP is 31.9V. In the simulation, 2 PV panels are connected in series and voltage 78.2V is obtained.

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Table 1. The parameters of PV panel.

Model	JKM275PP-60
Technology	Si-poly
Nominal Power	275 Wp
Dimension	1.65x0.992x0.04m
Surface Area	1.637 m²
Weight	19 Kg
Number of Cells N_s	60
Short Circuit Current I_{sc}	9.15 A
Open Circuit Voltage V_{oc}	39.1 V
Current in MPP I_{mpp}	8.61 A
Voltage in MPP V_{mpp}	31.9 V
Operating Temperature T_o	45 °C
Temperature Coefficient C_t	-0,39 %°A/C

In this study, belonging to TN POWER Company 1 unit TNG 12-200 model lead-acid battery was used. Lead acid batteries are frequently used in PV systems due to their low cost, high operating efficiency, fault free and long life. The parameters of the selected battery are presented in Table 2. The nominal voltage of the used battery is 12V and its rated capacity is 200Ah at C10. In addition, a 1000W, 12 V charge controller for MPP tracking system and battery charge with a maximum charge current of 16 A and a discharge current of 10 A was used. Since PV system is designed for 550 W, the DC-AC inverter is selected as 1kW according to the maximum power value.

2.4. Load Details

In this study, the electrical load representing the nominal consumption is acquired for the energy measurement laboratory. The power of an energy measurement laboratory is simulated from a OGPV system. Loads consist of LED, laptop, printer and fan. Load utilizations are assumed to be constant throughout the year. The daily energy consumption of the energy measurement laboratory is 2.094 kWp/day throughout the year. Table 3. shows the minimum daily electricity consumption required for the energy measurement laboratory.

Table 2. The parameters of Battery.

Model	TNG 12-200
Technology	Lead-Acid
Dimension	0.52x0.239x0.225 m
Weight	63.2 Kg
Internal Resistance	2.7 mΩ

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Nominal Voltage	12 V
Capacity	200 Ah
Coulomb Yield	%97
Number	1
Nu. of Autonomous Day	4 Day
Static life at 20 °C	5 Year

Table 3. Power consumption for the energy measurement laboratory.

Device	Power (kW)	Number	Average Daily Use	Daily Energy (Wh)
LED	15 W	5	6 Hour	450
Laptop	120 W	2	6 Hour	1440
Printer	30 W	1	2 Hour	60
Fan	2 W	10	6 Hour	120
Stand-by mode	1 W		24 Hour	24
Total daily energy				2094 Wh/day
Total monthly energy				62.82 kWh/month

3. FINDINGS and DISCUSSION

The simulation steps in this study are given as:1-The irradiation data of the region, where the power plant is located, are taken from the database of the program. The region is marked on the map in the geographical area management part of the simulation program [10]. The coordinate data (40.1933 °N, 29.9664 °E, altitude: 540 m) is manually introduced into the program.

2-The placing of the panels in the PV system has been done. In the study, the panel tilt angle is determined as 40°, the azimuth angle is 0° and the albedo value is determined as 20% for fixed angle system [26].

3-In the database of the program, there are electrical and mechanical data of system elements such as panels, inverters, batteries belonging to many companies. If the database of the program does not have system elements information, this information can be defined manually. PVsyst simulation software for the analyzed plant, the panel and battery in Table 1 and Table 2 are defined.

4-When all definitions which are essential for system design, done correctly, PVsyst program gives a warning that you are ready for the simulation. The report created as a result of the simulation includes system components, solar irradiation amount, product status and loss diagram.

Different STS are analyzed in the PVsyst program: fixed axis, seasonal axis, horizontal axis, vertical axis and double axis. The monthly usable available solar energy production values of different STS are given in figure 4. It can be seen from Figure 4 that the highest annual total available solar energy

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is 1049.9 kWh/y in the double axis STS, and the lowest 764.77kWh/y in the fixed axis STS with an inclination angle of 40° and azimuth angle of 0°.

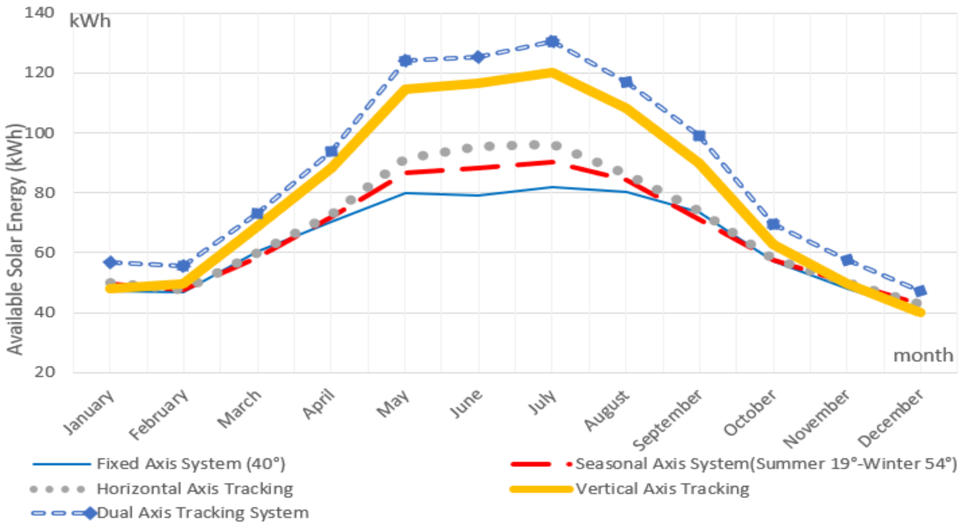

Figure 4. Monthly available solar energy obtained from different STS for OGPV system in Bilecik, Turkey

The monthly missing energy values of different STS are shown in figure 5. Figure 5 shows that the highest annual total missing energy value is in the fixed axis STS with 93.36 kWh, and the lowest in the double axis STS with 57.03 kWh. Missing energy increases mainly in December and January, when solar irradiation is lowest. In December and January, the minimum values of 20.39 kWh and 13.57 kWh are respectively in the double axis STS, while the maximum values are 27.78 kWh and 19 kWh in the fixed-axis STS respectively.

Figure 6 shows that monthly array yields of different STS are variable throughout the year. The highest array yield is 4.44 hours/day in the double axis STS in July. The lowest array yield is 2.47 hours/day in the vertical axis STS in December. Because the global irradiation and the PV temperature are higher in July and are lower in December. In general, array yield values increase in the summer months and decrease in the winter months in different STS.

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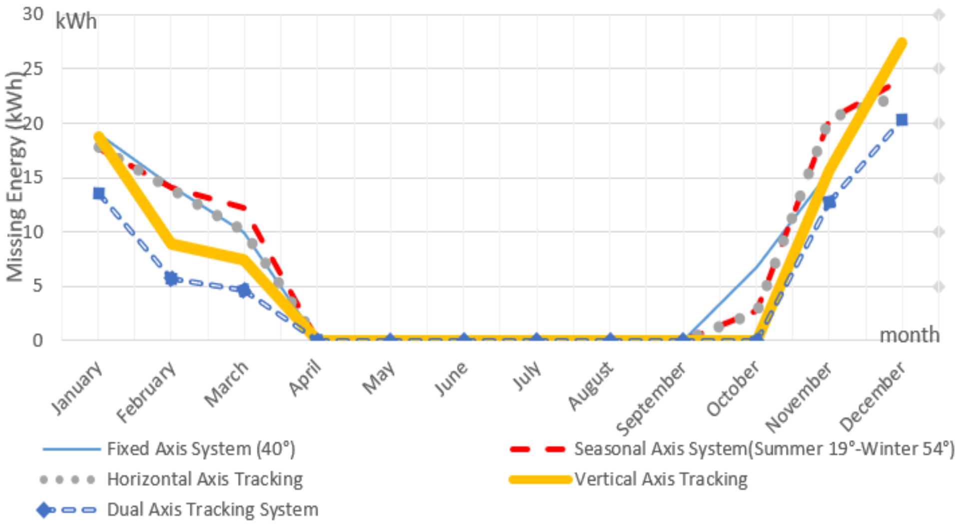

Figure 5. Monthly missing energy obtained from different STS for a OGPV system in Bilecik, Turkey

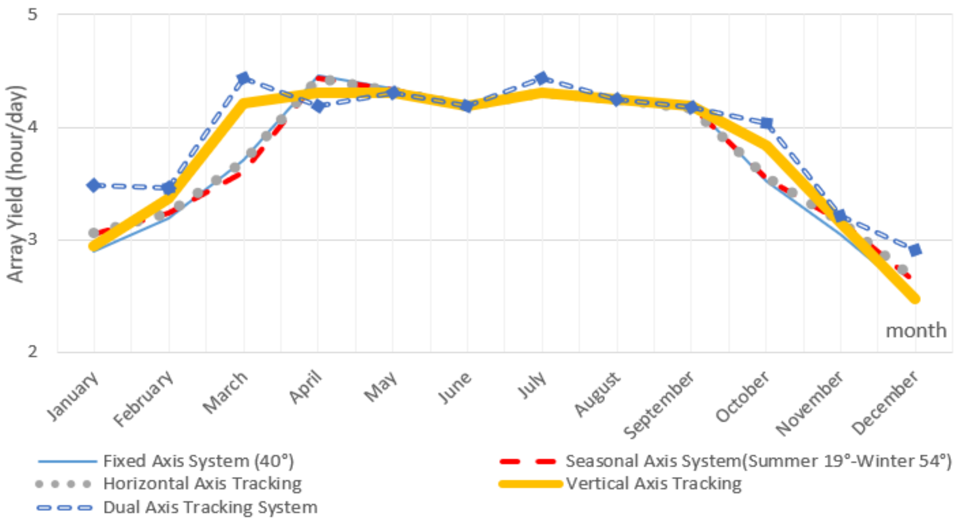

Figure 6. Monthly panel yield obtained from different STS for OGPV system in Bilecik, Turkey

The monthly final yield values of different STS are showed by Figure 7. It shows that monthly final yields are relatively stable, except for the winter months. Final yields are highest in between April and October with 3.81 hours/day. The reason for this situation is that especially the solar irradiation and

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the number of sunny days is high. The system with the lowest final yield value is the fixed axis STS in December with 2.07 hours/day.

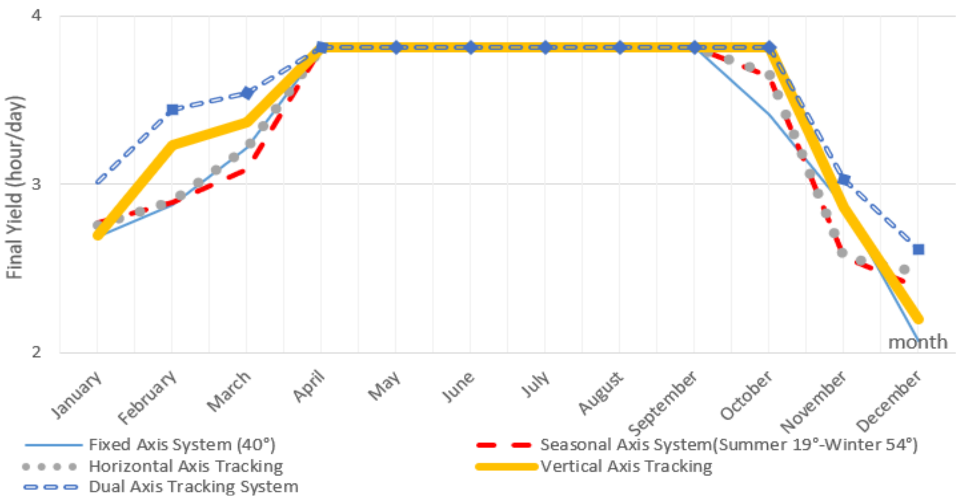

Figure 7. Monthly final yield from different STS for OGPV system in Bilecik, Turkey

The monthly yf values of different STS are showed by Figure 8. In July, the highest reference yield is 9.58 hours/day in the double axis STS and the lowest reference yield is 6.12 hours/day in the fixed axis STS.

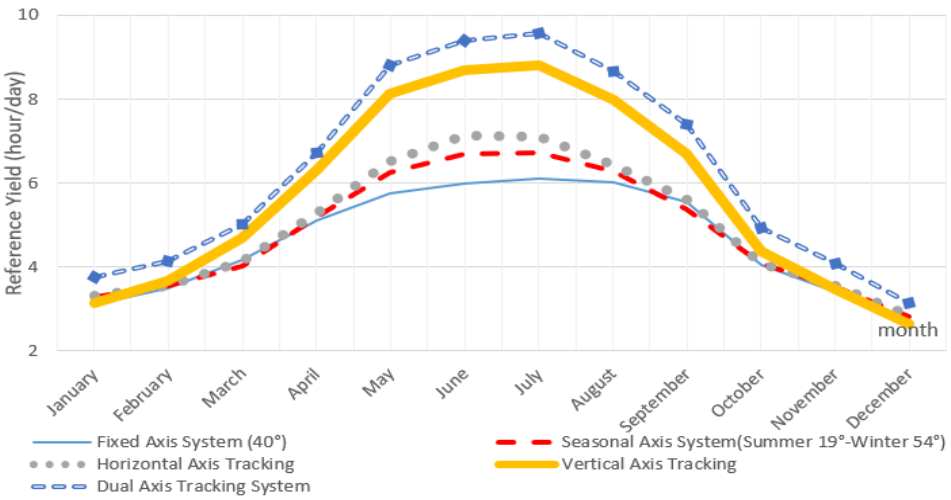

Figure 8. Monthly reference yield obtained from different STS for OGPV system in Bilecik, Turkey

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Figure 9 shows the P_r values of different STS. It is seen from Figure 9 that the highest average monthly P_r for the fixed axis STS is 0.778, while the lowest average monthly P_r for the double axis STS is 0.558. In general, the monthly P_r value for different STS increases in winter and decreases in summer. P_r value is affected by reasons that are PV panel temperature rise, inverter incompatibility and losses, shading, pollution factor.

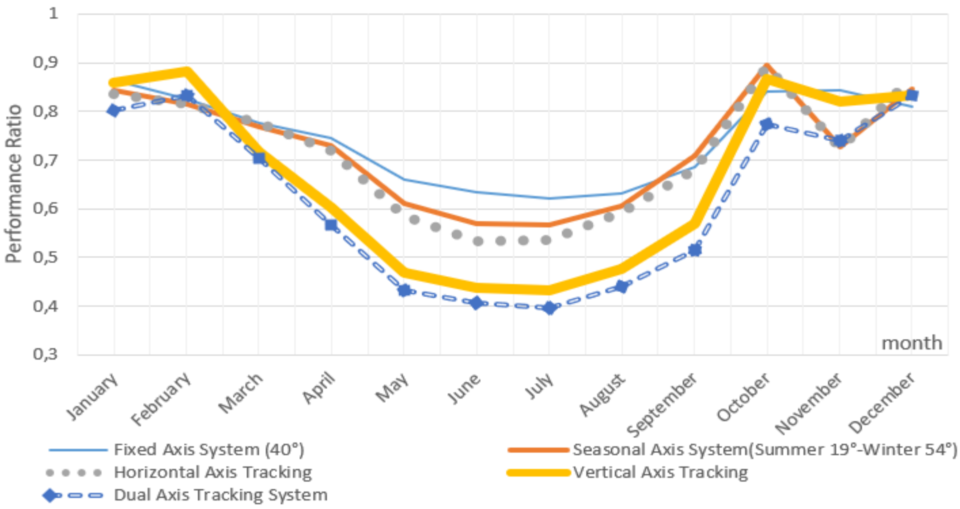

Figure 9. Monthly P_r from different STS for OGPV system in Bilecik, Turkey

The monthly la values of different STS are given in Figure 10. The highest average monthly la is 2.38 hours/day in the double axis STS. The lowest average monthly la is found 0.91 hours/day in the fixed axis STS. In the vertical axis STS, 4.51 h/day is obtained in la in July and 5.27 h/day was obtained in the double axis STS. It is observed that la was higher in the summer months in the obtained values. The highest monthly array losses in the other three tracking systems are 1.82, 2.49 and 2.93 hours/day, respectively. Because of the lowest global solar irradiation, the lowest la for all tracking systems is in January. Therefore, monthly la rises with increasing solar irradiation.

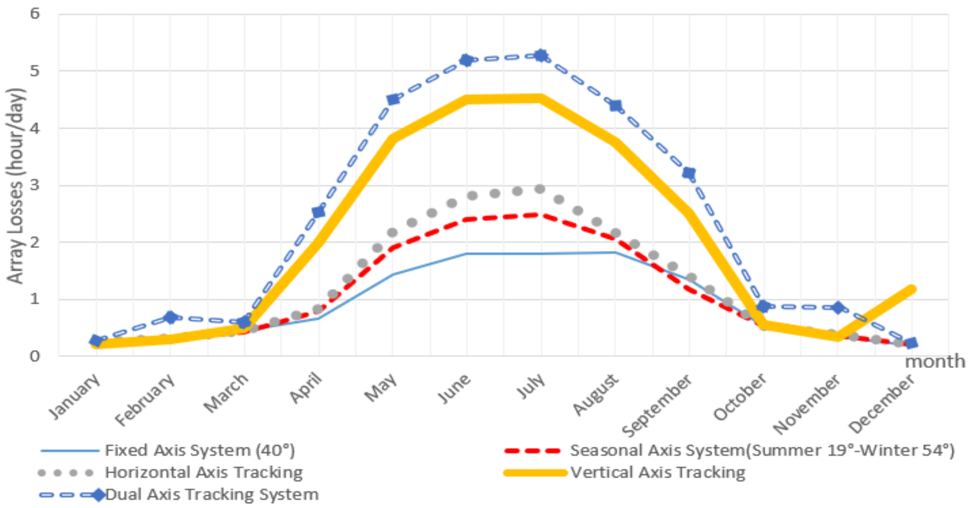

Figure 10. Monthly panel capture loss from different STS for OGPV system in Bilecik, Turkey

Figure 11 shows the monthly ls of different STS. From figure 11, it is seen that the highest monthly ls are 0.651 hours/day in April for the fixed axis STS, 0.621 hours/day in April for the seasonal axis STS, 0.636 hours/day in April for the horizontal axis STS, 0.842 hours/day in March for the vertical axis STS hours/day and 0.89 hours/day in March for the double axis STS. The lowest monthly ls were seen as 0.114 hours/day in October for the fixed axis STS, 0.103 hours/day in the seasonal axis STS, 0.101 hours/day in the horizontal axis STS and 0.03 hours/day in the vertical axis STS, and 0.016 hours/day in February in the double axis STS. Different types of field losses in off-grid photovoltaic systems all through the year are shown in Figure 12.

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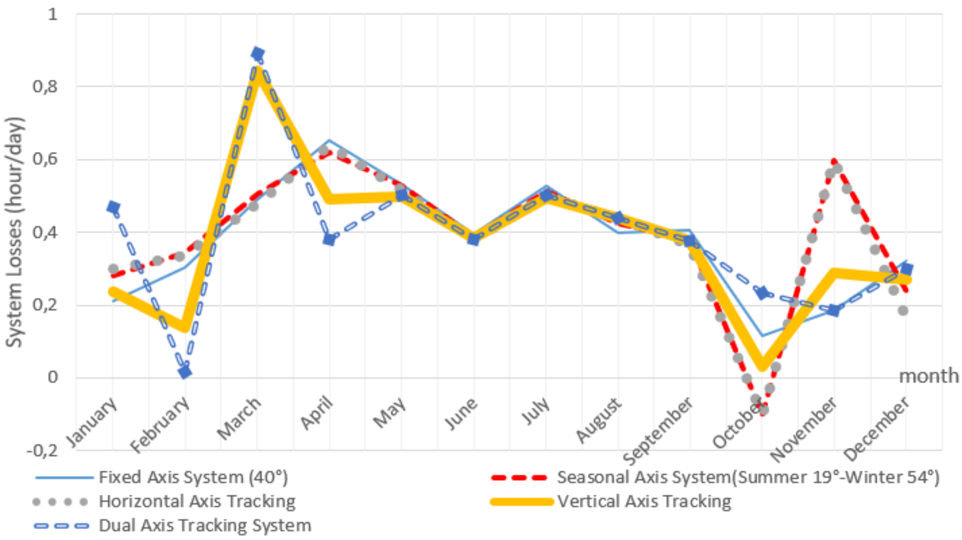

Figure 11. Monthly system loss from different STS for OGPV system in Bilecik, Turkey

4. RESULTS

In this study, the performance analysis of different STS for the 550Wp OGPV system planned for the energy measurement laboratory of Bilecik Seyh Edebali University was compared using the PVsyst 7.2 simulation program. The lowest annual total solar energy available is 764.77 kWh/y and the highest annual total loss energy is 93.36 kWh in the fixed axis STS with tilt angle of 40° and azimuth angle of 0°. However, there is only missing energy in December 27.78 kWh and January 19 kWh. The highest monthly average P_r was obtained in the fixed axis STS with 0.778 and the lowest average monthly l_a of 1.792 hours/day compared to other tracking systems. The highest annual total available solar energy is 1049.9kWh/y and the lowest annual total missing energy is 57.03 kWh in the double axis STS. At the same time, compared to other systems, the highest panel yield with 4.44 hours/day, the lowest monthly average P_r with 0.558 and the highest monthly average l_a with 5.27 hours/day were obtained from double axis STS. In this study, 137.28% more energy was produced per year and 61.08% less missing energy was obtained in the double axis STS compared to the fixed axis STS.

In addition, there are similarities between the different STS compared. The highest available energy for all systems obtained in summer, and the lowest in December. All of the missing energy takes place in December and January. y_r was obtained very close each other for all months and y_f was obtained very close to each other for the other months except December, January and February. Monthly P_r is high in October-February and low in June-July. Monthly l_a was higher in summer than all months, and l_a was lowest in January and December for the all MPPT system analyzed.

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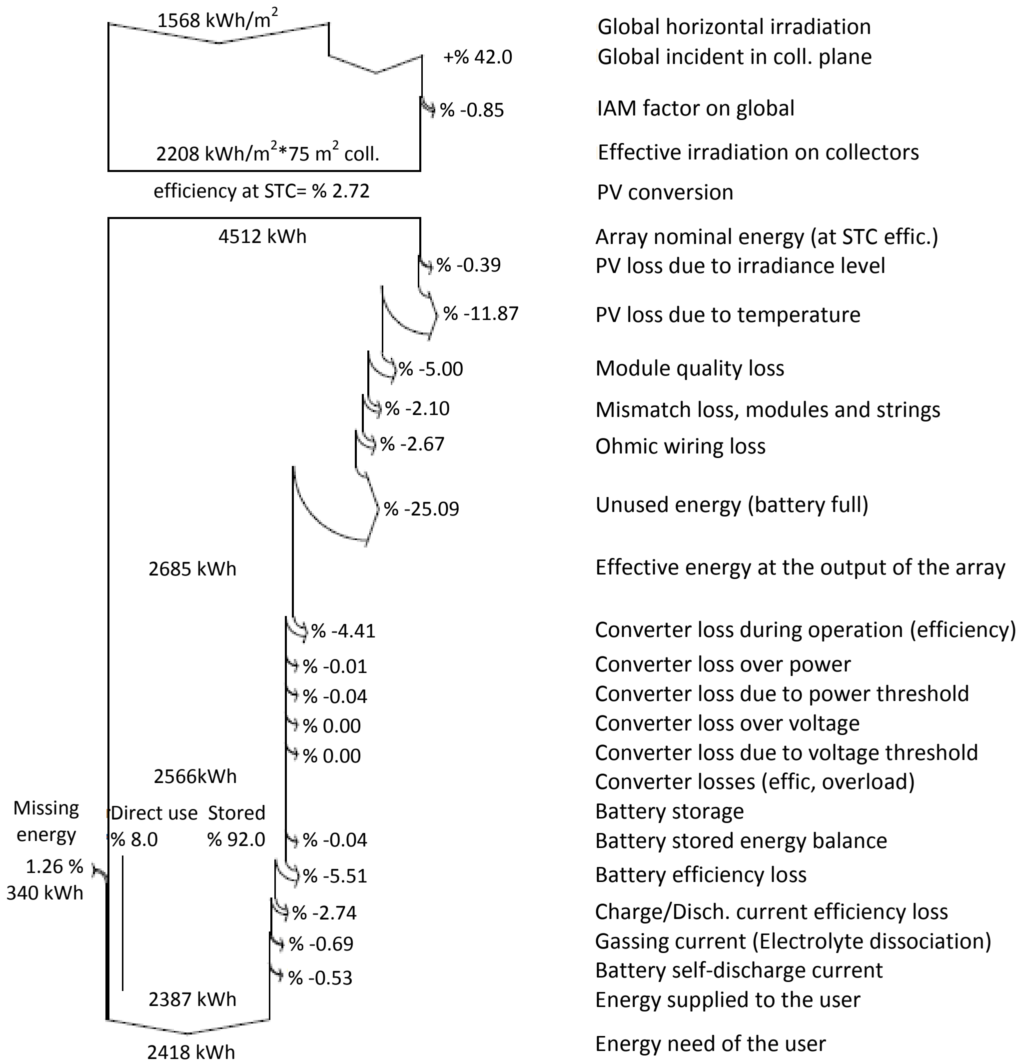

Figure 12. Energy loss diagram of the double axis STS for OGPV system in Bilecik, Turkey.

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