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A COMPARISON OF ACTUAL AND SIMULATED DATA TO DETERMINE THE EFFECT OF LOSS PARAMETERS ON THE PERFORMANCE OF BUILDING-INTEGRATED PHOTOVOLTAIC SYSTEMS

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Highlights

- Photovoltaic system simulation with PVsyst 7.2.14
- Comparison of simulation and actual data of a building integrated photovoltaic system
- Determining the effect of loss parameters to system performance

Graphical Abstract

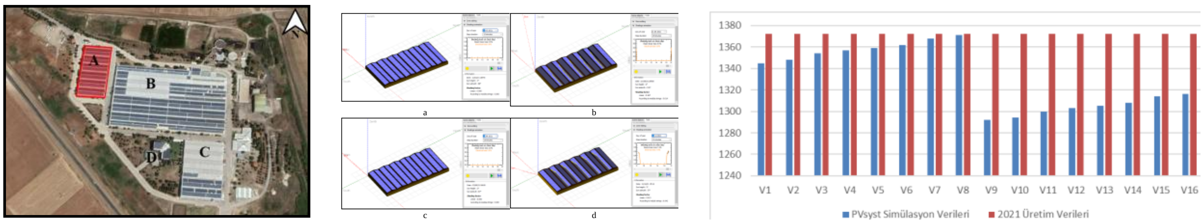

Figure Simulation and comparison phases

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ABSTRACT: The efficiency of photovoltaic systems is not very high, but the initial investment costs are high. Simulation programmes are used to determine the efficiency of the photovoltaic system to be installed and to calculate the energy production values. However, there are differences between the simulation data of the photovoltaic system and the actual production data. The aim of this study is to compare the actual production data and simulation data of a photovoltaic system in use. For this comparison, a factory building in Beyşehir, Konya, which has a photovoltaic system integrated on its roof, is analysed. PVsyst 7.2.14 tool was used for the simulation of the photovoltaic system. The simulation data obtained from the PVsyst tool of the photovoltaic system were compared with the actual production data of 2021. While the actual production data of the system in 2021 is 1372,2 Mwh, the production data obtained from the simulation is 1345,1 Mwh. In order to determine the reason for this difference, the effect of dusting loss, temperature loss, module mismatch loss and aging loss parameters on energy production was analysed through different variations.

Keywords: *Solar Energy, Simulation, Building Integrated Photovoltaic Systems, Loss Parameters*

1. INTRODUCTION

In the last 20 years, a return to renewable energy has started due to its favourable characteristics such as environmentally friendly, inexhaustible, abundant and widely available resource infrastructure. In addition to these, factors such as technological developments and favourable policies have also helped the rapid development of renewable energy [1]. In 2020, energy generation from photovoltaic systems, which accounted for 3.2% of global electricity generation, increased by 156 TWh compared to 2019 and reached 821 TWh. This corresponds to a growth of 23% [2].

Buildings have a big role in world total energy consumption. Looking at 2019 total energy consumption data by sectors, the building sectors, including residential, commercial and public buildings, is responsible for 29% of energy use in the world [3]. Buildings, which account for almost one-third of the world's energy consumption, are also major cause of carbon dioxide (CO_2) emissions. Looking at CO_2 emissions by sectors in 2019 in the world, the construction sector is responsible for 8%. In Turkey, this rate is 16% [4]. Energy efficient designs have emerged with the development of technologies that use energy consciously in buildings. Research has found that it is possible to reduce the energy consumption of a building by 30% to 50% by using existing technologies [5].

The effective use of solar energy in buildings is realised in the form of energy generation from photovoltaic panels mounted on the roof and facade of the building as a surface covering element, shading element or skylight [6]. Recently, attempts have been made to install photovoltaic systems on the roofs of office buildings, houses, institutions and industrial buildings to overcome the crisis arising from the increase in energy consumption. These attempts will not only solve the energy crisis but also reduce the harmful effects of greenhouse gas emissions from fossil fuels [7]. In recent years, the increase in grid-connected building integrated photovoltaic systems has also led to an increase in installed power

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photovoltaic systems. The term building integrated refers to photovoltaic systems mounted on the roof or facade of buildings. In order to get the highest level of energy production data, the installation area and the system must be utilized very well [8].

Photovoltaic systems have high initial investment costs and not very high efficiency. For this reason, various simulation tools are used to define the energy production potential and efficiency of the system before the photovoltaic systems are installed. Thus, a feasibility study is carried out before the photovoltaic system investment is made. However, there are differences between the actual energy production data of each system and simulation data. The aim of this study is to compare the simulation data and actual energy production data of a photovoltaic system integrated into the building and put into operation. There are many parameters that affect the efficiency of the photovoltaic system such as climate data, solar radiation, dusting, shading, cable losses, inverter losses, mismatch losses etc. The research question is: How do these parameters affect the efficiency of the building integrated photovoltaics? The problem of the study is to determine the effect of loss parameters on the performance of building integrated photovoltaic systems through the comparison of actual energy production data and simulation data. The study is limited to the effect of temperature loss, module mismatch loss, dusting and aging loss on system performance.

2. LITERATURE SURVEY

2.1. Photovoltaic System Losses

Performance ratio is a significant parameter which measures the photovoltaic system’s efficiency. The performance ratio is the ratio of the energy produced in the photovoltaic system to the highest theoretically possible energy production and reveals the quality of the system. The lower the losses, the higher the performance ratio of the photovoltaic system. The performance ratio is independent of the orientation of the system and the instantaneous solar radiation [9, 10].

The performance of photovoltaic systems is affected by environmental factors related to local conditions such as temperature, dusting and snow. Factors such as shading, direct current (DC) and alternating current (AC) cable losses are related to system design. Incompatibilities between modules and inverter losses are related to the quality of the materials in the system [10]. There are many parameters such as losses of the photovoltaic system due to panel tilt angle, radiation losses in the modules, inverter losses, structural losses of photovoltaic components and losses due to the environment. The characteristic values of the system components, geographical location, surrounding structures and system failures affect the energy produced. The losses occurring in the photovoltaic system are mostly caused by shading and the least loss is caused by AC cable losses. The performance ratio, which reveals the quality of the system, is important in the evaluation of losses [9].

The angles at which the sun rays fall on the earth and the annual insolation values of the location of the building vary from region to region affect the energy to be obtained from the panel in the design of the building integrated photovoltaic system. The decrease in solar radiation intensity also decreases the panel power. [11]. Another factor affecting the efficiency of photovoltaic panels is shading. Factors such as buildings, tree branches, chimneys that cast shadows on the panel, reduce the efficiency of the system. For this reason, while designing the system, attention should be paid to the elements that create shadow on the panels [12]. In land or roof applied installations, the shadowing of the photovoltaic arrays on the trestles affects the efficiency. For this reason, attention should be paid to the distance to be left between the photovoltaic arrays. [13]. Another important parameter affecting the panel efficiency is temperature. The relationship between panel temperature and panel power is inversely proportional. This shows that the increase in temperature decreases the power of photovoltaic modules. The efficiency of the panels decreases by 1% for every 10°C temperature increase. Providing air flow on the back side of the panels minimises the heating of the photovoltaic modules [9, 14]. Cable losses are the losses occurring in the cables used for energy transmission in photovoltaic systems, also called ohmic losses. Cable losses are of great importance in roof integrated photovoltaic systems. In order to minimise the loss, the cable cross-sections should be increased [15].

Yet another important losses in photovoltaic systems are mismatch losses. The difference in the energy produced by two or more arrays causes mismatch losses in the modules. This difference is caused by factors such as partial shading, dusting, different operating temperatures, different irradiance values or solar panel power tolerance. The severity of mismatch losses increases or decreases depending on the differences between the power tolerances of the modules connected in series in the array [10, 16]. Panel losses are the losses that occur in solar panels due to ageing and power tolerance. In photovoltaic systems, losses due to aging increase as the years of use of the panels increase. Solar panel manufacturers provide a 25-year performance power guarantee. In addition, since the use of panels with high power tolerance in photovoltaic systems will further increase the mismatch losses, solar panels with low power tolerance should be preferred [17]. Inverter losses occur during the conversion of DC to AC and as a result of not calculating the inverter power correctly. The maximum power that solar panels can produce and the inverter power should be selected to be equal or higher. The ratio of the rated module power to the rated AC output power of the inverter under standard test conditions (STC) affects the inverter efficiency. This may prevent the inverter from transferring all of the generated power to the grid. [10, 17]. Dusting and snowing losses are the losses caused by the contamination of the surfaces of photovoltaic modules, which reduces the amount of radiation reaching the modules. Industrial air pollution, road dust, meteorological dust transport, exhaust fumes, bird droppings are the factors that cause pollution. Dusting causes power loss in solar collectors. Losses due to dusting reach up to 15% in regions with low rainfall. If the angle of the panel with the horizontal is more than 15°, it is supposed that rain can clean the panel and the efficiency loss due to dusting is limited to 0,5%. If the panel angle is less than 15° and the region where the system is installed receives little rainfall, the efficiency loss rate exceeds these values. According to the researches, losses due to dusting rarely exceed 4%. In regions where snowfall is frequent, 2% snow loss can be assumed in roof systems [10]. It is possible to give values such as 1% when the photovoltaic systems are outside the city centre, 2% when they are in the city centre, and 3% when they are in the industrial zone and city centre [18]. While some of the radiation coming to the photovoltaic modules is absorbed by the cells, the module surface reflects some of it. Losses due to reflected radiation are called reflection losses. The glass on the surface of the photovoltaic modules has a tempered structure to maximise absorption and minimise losses due to reflection. The cells are coated with an anti-reflection coating to prevent light reflection [16].

2.2. Photovoltaic System Simulation and Comparison Studies

Kandasamy et al. [19] used PVsyst 5.59 tool and simulated a 1 MW grid connected photovoltaic solar PV system. By comparing the energy production, performance ratio, efficiency and cost, the feasibility of grid connected photovoltaic system in the southern region of Tamil Nadu is discussed. Kumar et al. [20] simulated 100 kWp grid connected photovoltaic system using PVsyst 6.52 tool. Temperature and solar radiation values were taken from Meteonorm 7.1, the database of the simulation programme, and a system was installed to meet the energy needs of the campus. They concluded that the performance capacity of the system is 80%. Sadikoglu [21] examined the dusting effect on the performance of a 1 MWp photovoltaic system installed in Konya Organised Industrial Zone. The 1-year energy production values of the panel groups with and without cleaning in the same climatic conditions and location were observed, and it was concluded that panel cleaning contributed 3,92% to the performance. The effect of the performance increase is estimated to increase to 5,65% if the whole system is cleaned.

Sharma et al. [22] analysed the performance of a 190 kWp photovoltaic system installed in India. The average annual performance rate of the photovoltaic system is 74%, the capacity factor is 9,27% and the system efficiency is 8,3%. Measured solar radiation data of the power plant were entered using PVsyst tool and the system was simulated. In 2011, the plant provided 154,43 MWh of energy, while the annual energy output given by PVsyst is 156,40 MWh. PVsyst simulation results were compared with the results of the photovoltaic system. The estimated energy yield from the simulation result is close to the monitored result with a difference of 1,4%. Okello et al. [23] compared the actual production data of a 3,2 kWp grid-connected photovoltaic system at the Outdoor Research Facility at the Nelson Mandela Metropolitan University in South Africa with simulated performance data using PVsyst tool. In 2013, the photovoltaic system produced 5757 kWh/year, while 5754,5771 kWh/year was obtained for the simulation performed using measured and weather variables obtained from Meteonorm. Despite the similar simulation results, it was observed that the simulation result using in-situ measured climate data was closer to the measured monthly energy data.

Özerdem et al. [24] evaluated the 1,2 MW Serhatköy power plant's performance, the first grid-connected photovoltaic system in Northern Cyprus. Serhatköy photovoltaic power plant was simulated using PVsyst tool and the annual energy given to the grid was 2145 MWh. When the simulation results of the power plant and the results obtained from the actual plant production were compared, it was found that in 2012, the power plant produced 1985,21 MWh of energy, 7,47% less than the simulation data, and in 2013, the power plant produced 2152,36 MWh of energy, 0,32% more than the simulation data. Haydaroğlu and Gümüş [25] simulated the 250 kWp solar power plant installed at Dicle University Faculty of Engineering with PVsyst 6.39 simulation tool and analysed its compliance with the performance criteria specified in the standards. They also compared the simulation results with the actual production data between December 2015 and April 2016. It was determined that the actual production data was higher than the simulation data except January.

Şimşek [15] calculated the performance parameters and factors affecting the efficiency of solar power plants located in Torbalı and Gölbaşı. Modelling and simulation of the field was performed in PVsyst tool. Actual energy production data and simulation data were evaluated and compared over the parameters. It was found that the results were similar. It was observed that the most loss was caused by temperature. Other losses were caused by dusting, reflection and array mismatch loss. Keskin [26] simulated a 1 MW solar power plant installed in Niğde using PVsyst tool. The actual production data of the power plant and PVsyst simulation results are compared. The actual energy production data was 1,72% higher than the simulation data. Atlım [13] compared the effect of panel tilt angle on the system efficiency of 2 different power plants in Balıkesir Bandırma. Simulations of both plants were performed in PVsyst 6.7.6 tool. The energy production data of the plants were compared with the simulation results and it was determined that the panel tilt angle for Balıkesir would be between 28°-30° in the south direction. Bolat et al. [27] entered the information of the grid-connected Lebit Energy Solar Power Plant (SPP) with an installed power of 200 kWp into PVsyst tool and simulated the plant in the light of the data obtained from the database. The actual energy production data of Lebit Energy SPP and PVsyst simulation data were compared. The simulation data was 0,56% higher than the actual production data. Vidal et al. [28] simulated a grid-connected 8,2 kWp photovoltaic system installed in Punta Arenas (Chile) in 2018 using PVsyst tool. The annual and monthly performance of the system is evaluated and compared. A comparison between the results measured in the photovoltaic system and the results simulated in PVsyst tool made. As a result of the comparison, it is observed that the photovoltaic system produces more energy than the simulated photovoltaic model in PVsyst.

Çınaroğlu and Nalbantoğlu [29] analysed three solar power plants located in Kilis by modelling in PVsyst 7.1. tool. The three-year energy production data of the power plants and the production data in the PVsyst 7.1. simulation report were compared. As a result of the comparison, it was observed that the data obtained were close to each other, but the power plant energy production data were less. It was determined that the differences may be caused by factors such as weather events, cloudy days, changing air temperature, dust and snow accumulated on the panel. Srivastava et al. [30] conducted a one-year performance evaluation of a university park integrated grid-connected photovoltaic system located in the north of India. Partial shading photovoltaic power plant was simulated by creating a real 3D environment in PVsyst and PV*SOL tools. The results of the real plant and the results obtained from these two tools are compared, and it is seen that the simulation results do not match the real system results due to the effect of shading.

There are studies in the literature in the field of comparing the actual energy production data of photovoltaic systems with the energy data estimated using PVsyst simulation tool. The novelty of this study is to determine the possible differences that may arise as a result of the comparison of actual energy production data and simulated energy data through independent variables by giving different values to the loss parameters.

3. MATERIAL AND METHOD

3.1. Material

Approximately 30% of the energy requirement of the facility with an installed capacity of 4788,72 kWp operating in Beyşehir district of Konya province, which is examined in this study, is met by the grid-connected photovoltaic system. The actual energy production data of the photovoltaic system integrated into the building between 1 January 2021 and 31 December 2021 and the PVsyst 7.2.14 tool were used as material.

Simulation programs analyse the operating behaviour of photovoltaic systems and can predict energy production data. By using simulation programs, the placement direction, angle, position and shadow falling on the panels can be analysed and designed as 3D in the program [31]. There are many paid or free simulation programmes used for photovoltaic system and performance worldwide. The most widely used among these programmes are PV*SOL, RETScreen, TRNSYS, HOMER, INSEL, PVSYST [32]. PVsyst tool contains location, meteorological data and photovoltaic system elements in its infrastructure, the losses in photovoltaic systems can be transferred to the system in detail, shading losses can be analysed with 3D drawing feature and feasibility cost analysis can be done [27]. In this study, PVsyst tool was preferred for 3D modelling. PVsyst has a wide meteorological database for different areas for the whole world. It also allows manual addition of data for sites not registered in the tool [33]. It gives the results as a full report with specific tables and graphs, and allows the export of the data to be used in other softwares. To get the results, some input to the tool is required [34]. PVsyst is the most widely used analysis programme in the world and is also known as the most trusted programme because it contains many parameters in its database. The database contains details such as location, meteorological data, panel angle and orientation, panel and inverter specifications, annual power reduction rates of panels, detailed solar radiation values, shading analyses, regional pollution rates, ground reflection rates (albedo), grid specifications, cable distances [35].

A grid-connected photovoltaic system was installed on the roof of the factory located at 37°45' north latitude and 31°40' east longitude in Beyşehir district of Konya province, with an area of 315304,79 m^2 and consisting of 4 different buildings named as A, B, C, D in this study. Building D in the facility, whose Google Earth image is given in Figure 1, started energy production for the first time in August 2018, and the system of the other buildings started energy production in August 2020.

The system is designed with panels integrated into the roof with a 12° slope in two different directions by limiting the roof areas of the buildings. The facility consists of a total of 17736 domestic production Gazioglu Solar Energy brand polycrystalline panels with a total installed power of 4778,72 kWp and a total of 74 Huawei brand inverters. 72 of the inverters are 60 kW and 2 of them are 30 kW. Building A was used in this study since the entire roof surface of building A was covered with photovoltaic panels (Figure 2) and energy production data of the building was obtained.

Meteorological data for the location of the factory building is not available in the database of PVsyst tool. The meteorological data of the location was synthetically generated from the data obtained from satellites between 2003-2013 via Meteonorm 8.0. Monthly irradiance values and sunshine hours of the region obtained from the Solar Energy Potential Atlas of the Enerji İşleri Genel Müdürlüğü (EİGM) were analysed. When the annual averages of the data are compared, the value of 4.76 kWh/m^2/day in the Meteonorm database is 4,48 kWh/m^2/day in the EİGM data. It is seen that there is not much difference between the meteorological data provided by the simulation tool and the data provided by EİGM.

Figure 1. Google Earth Image of the Factory

Figure 2. Building Integrated PVs on the roof of Building A

In the photovoltaic system of building A, 3480 pieces 270 Wp polycrystalline panels of Gazioglu Solar Energy brand were used. Table 1 shows the electrical characteristics, mechanical data and thermal characteristics of this panel under STC.

Since the module of Gazioglu Solar Enerji brand is not included in the database of PVsyst tool, the specifications given in Table 1 were defined to the system. Photovoltaic modules were placed on the 12° sloping sandwich panel roof surface of building A, whose dimensions are 62 m*123 m. A total of 3480 modules on 12 surfaces with a gap of 10 cm between the roof and the module, 5*58=290 modules were placed in the vertical direction on each surface.

In the photovoltaic system of building A; Huawei brand 14 inverters with 60 kW power and 1 inverter with 30 kW power were used. The specifications of 30 kW and 60 kW inverters are given in Table 2. Since the Huawei brand inverter was not included in the database of PVsyst software, the specifications given in Table 2 were defined to the system. A total of 240 panels (20 series 12 parallel) were connected to a 60 kW inverter and a total of 120 panels (20 series 6 parallel) were connected to a 30 kW inverter.

Table 1. Gazioğlu Solar Enerji 270 Wp panel specifications [36]

ELECTRICAL CHARACTERISTICS (STC)			
Maximum Power (Pmax)		270 Wp	
Open Circuit Voltage (Voc)		38,8 V	
Short Circuit Current (Isc)		9,21 A	
Mpp Voltage (Vmpp)		31,3 V	
Mpp Current (Impp)		8,63 A	
Efficiency (%)		%16,62	
MATERIAL AND DIMENSIONS		**THERMAL CHARACTERISTICS**	
Cell Type	Polycrystalline	Nominal Operating Cell Temperature (NOCT)	46 °C
Number of Cells	60	Pmax	-0,43%/K
Length	1647 mm	Voc	-0,31 %/K
Width	992 mm	Isc	0,073 %/K
Height	40 mm		
Weight	17,2 kg		

Table 2. Huawei 30 kW and 60 kW invertor specifications [37, 38]

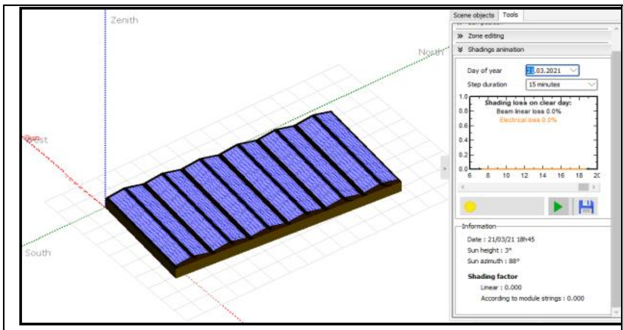
	HUAWEI 30 kW	HUAWEI 60 kW
	INPUT	
Max. DC Power	33900 W	67400 W
Max. Input Voltage	1100 V	1100 V
Max. Current per MPPT	22 A	22 A
Max. Short Circuit Current per MPPT	30 A	30 A
Start Voltage	200 V	200 V
MPPT Operating Voltage Range	200 V-1000 V	200 V-1000 V
Rated Input Voltage	400V	380/400V
Number of Inputs	8	12
Number of MPPT Trackers	4	6
	OUTPUT	
Rated AC Active Power	30 kW	60 kW
Max. AC Apparent Power	33 kVA	66 kVA
Rated Output Voltage	230 V/ 400 V	230V / 400V
Rated Output Current	@400V	79.4A @480V
Max. Output Current	48.A@400V	95.3A @400V
Rated AC Grid Frequency	50/60 Hz	50/60 Hz
Weight	62 kg	74 kg

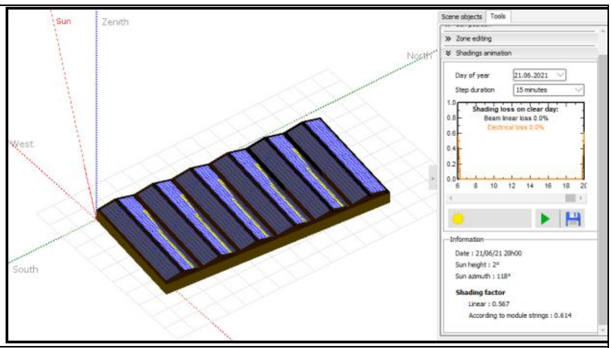
3.2. Method

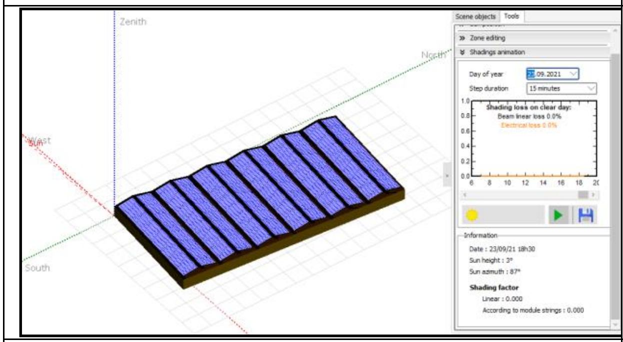
In the method of the study, the electrical and technical information of the factory building was entered into the PVsyst 7.2.14 simulation programme, the building was modelled and simulated in 3D. The one-year energy production data of the factory building and the simulation data obtained in PVsyst 7.2.14 software were compared and the differences and the factors that may cause the differences were analysed. In addition, the performance analysis of the system was also performed. The International Energy Agency (IEA) developed performance parameters within the scope of IEC 61724 [39] standard to analyse the grid connected photovoltaic system's performance.

In PVsyst tool, the close shading analysis of the building is made according to the position of the sun as 3D design. According to the shading factor table obtained as a result of the simulation of the factory building, it is observed that shadow is formed in the system when the sun height is 10° and below. The angle of incidence of the sun's rays on the earth varies from day to day and time of day. Sun rays make a higher angle with the horizontal surface at noon in summer compared to winter months. Radiations coming steeply in summer fall at a narrower angle in winter. For this reason, performing the shading analysis on December 21 (the day with the lowest solar elevation angle) gives the best results. The shading scenes on March 21, June 21, September 23 and December 21 according to the orientation of the building and the placement of the photovoltaic modules are shown in Figure 3.

After defining all the necessary information for the photovoltaic system, detailed losses related to the system were entered and detailed loss parameters affecting the system performance were defined. If the temperature measurement values of the photovoltaic system components are not available, the PVsyst temperature loss parameter can be taken as 29 W/m^2K for free-standing systems with air circulation on all sides of the PVsyst temperature loss parameter, 15 W/m^2K if there is no heat exchange at the back of the modules when the wind blows and the modules receive the wind in a limited way, and 20 W/m^2K if the modules receive the wind through air ducts when the wind blows [40]. In this study, since there are no temperature measurement values in the roof integrated photovoltaic system design, the temperature loss parameter is assumed to be 20 W/m^2K assuming that the modules receive the wind through air ducts. If detailed information such as the average length of the DC cables between the modules, the cross-section and length of the cables between the module and the inverter, and the length between the module and the DC collection box are known, the percentage of DC ohmic loss can be calculated in detail [26]. According to PVsyst, the default power loss rate is 1,5%. Since detailed information about the cable cross-sections and lengths of the factory building was not available, the default value of 1,5% DC ohmic loss was accepted.


a-March 21


b-June 21


c-September 23

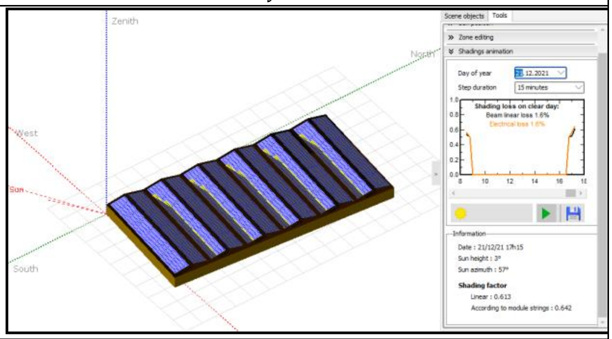

d-December 21

Figure 3. Shadow analysis of building A

The AC losses are also not defined as detailed information is not available. For module quality loss PVsyst selects one quarter of the difference between the values according to the tolerance of the photovoltaic module manufacturer. The mismatch loss is due to the fact that in an array of modules, the lowest current drives the current of the entire array. By default, the PVsyst programme assumes a loss of 2% for power losses and 2.5% for constant voltage uses [40]. Since the tolerance value of the modules used in the factory building in this study is -0/+5 Wp, one quarter of the difference between the tolerance values-1.25% is determined as the module quality loss value. Module mismatch loss default value of 2%, constant voltage loss of 2.5% and string voltage mismatch default value of 0,1% were accepted.

In order for the solar panels to work efficiently and healthily, maintenance instructions are applied at certain time intervals in the factory. Cleaning and maintenance of the panels are carried out; once a month in December, January, February, March and once every 2 weeks in other months. The surface of all panels is cleaned with water with the help of an equipment in a way to remove dust and any substance that will reduce efficiency. While cleaning, damage controls of the panels, cables of the panels and socket places are also carried out. In addition, the energy values produced by the panel groups are also checked at regular intervals and fault detection is carried out. These controls ensure the continuity of the energy production of the system. In PVsyst tool, dusting loss can be entered monthly or annually. Since the facility is located outside the city centre and cleaning is carried out regularly, dusting loss is accepted as 1% per year. The radiation that reaches to the surface of the photovoltaic cells decreases due to reflections. In PVsyst tool, the annual reflection loss value was calculated with fresnel-normal glass technique and the default value was accepted. Aging in photovoltaic systems causes gradual loss of efficiency. Gazioglu Solar Energy provides 25 years linear performance guarantee for the panels. PVsyst defines an average degradation rate. Since the facility was commissioned in August 2020, the aging factor was assumed to be 0,20% for 1 year in the simulation. Losses caused by the cessation of production due to malfunction and maintenance in the photovoltaic system are unavailability losses. Since the periods when the system could not produce could not be determined, no value was defined in the PVsyst tool.

4. RESULTS AND DISCUSSION

4.1. Photovoltaic System Simulation Results

As a result of the simulation of the photovoltaic system of the existing factory, monthly and annual energy production data of the system, energy loss percentages, the amount of radiation on the panel surface, average temperature values were received. In addition, according to standard of IEC 61724 [39], the performance parameters of the system were obtained and performance analysis was performed. The annual loss diagram obtained as a result of the simulation is given in Figure 4. In the diagram, it can be seen that the annual global irradiation to the horizontal plane is 1737 kWh/m². Photovoltaic panels were placed 12° angled depending on the roof slope of the building. The amount of radiation on the surface of the panel decreased by 1,2%. According to the modelling, the loss due to shadowing on the panels was recorded as 0,2%. The loss due to reflection was 4,4% and the loss due to dusting and snowing was 1%. When these losses, which can be defined as optical losses in general, are summed up, the effective radiation to the panel surface at the selected geographical location is 1621 kWh/m² per year. The efficiency of the panel used in the photovoltaic system under STC is 16,53%. In relation to the panel efficiency, 16,53% of the energy that could be produced was converted to photovoltaic and as a result, the nominal energy in the panel array was determined as 1524 MWh.

Losses due to photovoltaic panel characteristics are defined as array losses. After 1 year, module degradation loss is 0,2%, irradiation loss is 0,7%, thermal loss is 7,6%, array mismatch loss is 2,1%, DC ohmic loss is 1,1%. As a result of 11,7% total array losses, the amount of energy at the array output, defined as the assumed array energy, was determined as 1368 MWh. Losses related to the inverter and grid connections are defined as system losses. Inverter losses are calculated as 1,7%. The available energy at the inverter output was determined as 1345 MWh. As a result of all losses, the simulation gives that 1345 MWh of energy can be produced from the photvoltaic system in 1 year. The performance parameters for comparison of PVsyst simulation results; reference yield (Y_R), array yield (Y_A), final yield (Y_F) and performance ratio (PR) are given in Table 3.

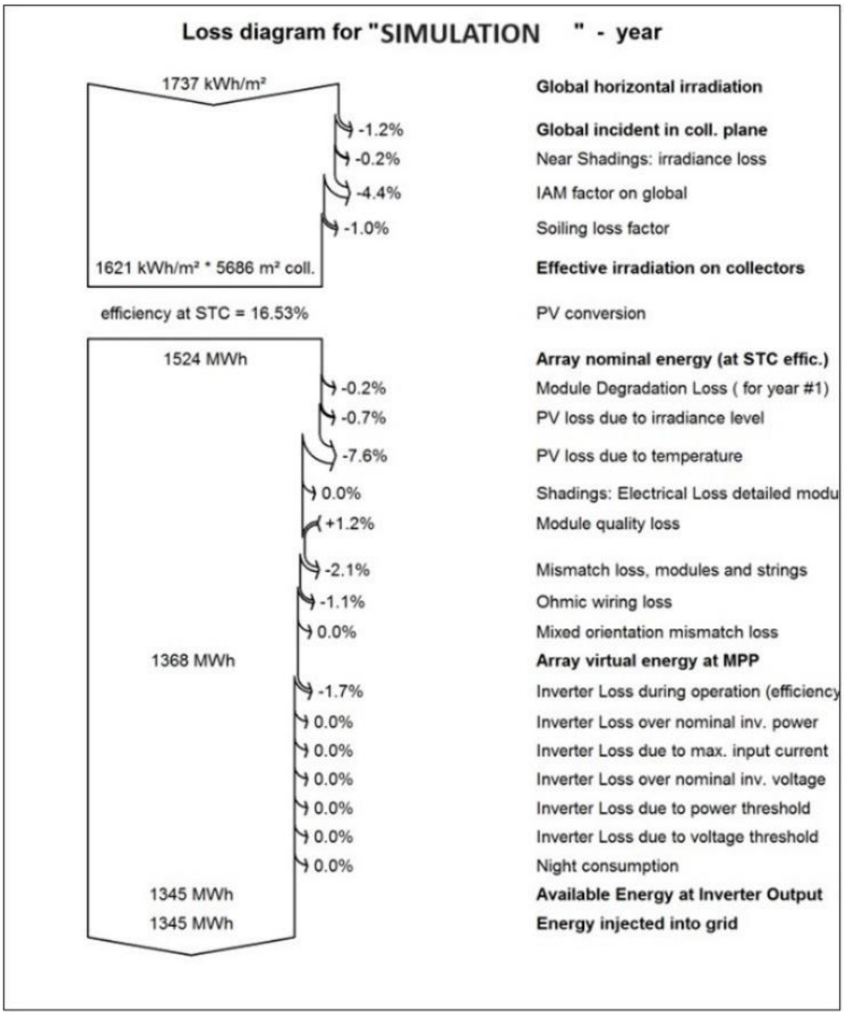


Figure 4. Yearly loss diagramme derived from PVsyst

According to Table 3, the highest performance rate was 89,6% in February and the lowest was 79,0% in July. The annual performance ratio is 83,4%. Depending on the temperature increase, system performance decreases in summer months and increases in winter months. The actual energy production data of the factory building and the simulation data obtained using PVsyst tool are given in Table 4. When the table is analysed; it is predicted that the factory building can produce a total of 1345,1 MWh of energy in 1 year according to PVsyst simulation results, while the factory building produces 1372,2 MWh of energy in total for 1 year. There is a difference of 27,1 MWh between actual energy production data and simulation data. Thus, the 2021 energy production data of the factory is 2% higher than the PVsyst simulation data. This shows that the factory building realises a higher performance than the predicted production data.

Table 3. PVsyst monthly performance parameters

	Reference yield Y_R (kWh/m²/day)	**Array yield Y_A (kWh/m²/day)**	**Final yield Y_F (kWh/m²/day)**	**Performance rate PR (Y_F/Y_R)**
January	2,14	1,92	1,88	0,883
February	2,96	2,70	2,65	0,896
March	4,06	3,64	3,58	0,881
April	5,38	4,73	4,65	0,864
May	6,67	5,69	5,59	0,839
June	7,42	6,12	6,01	0,810
July	7,47	6,01	5,90	0,790
August	6,62	5,36	5,26	0,796
September	5,48	4,55	4,48	0,817
October	3,65	3,14	3,09	0,845
November	2,58	2,26	2,22	0,858
December	1,92	1,70	1,67	0,871
Average	4,70	3,99	3,92	0,834

Table 4. Real production data of factory building in 2021 and PVsyst simulation data

	PVsyst Simulation Data (kWh)	**Real Production Data of 2021 (kWh)**	**Realisation Rate %**
January	54902	48148	%87,69
February	69843	80966	%115,92
March	104216	95611	%91,74
April	131161	134995	%102,92
May	162912	174954	%107,39
June	169456	165612	%97,73
July	171990	182800	%106,28
August	153321	159199	%103,83
September	126175	124143	%98,38
October	89885	107230	%119,29
November	62523	67969	%108,71
December	48684	30586	%62,82
TOTAL	1345068	1372213	%102,01

When the actual generation data and simulation data are compared, it is seen that in February, April, May, July, August, October and November, the actual generation data is higher than the simulation data, while in January, March, June, September and December, the simulation data is higher than the actual generation data of the factory building. The highest generation in the factory building was in July with 182,800 MW and the lowest generation was in December with 30,586 MW. The reason for this situation is that the highest radiation is obtained in July and the lowest radiation is obtained in December. The difference between the production data of the factory building and the simulation data was the lowest in September and the highest in December. This difference in December may be due to the harsh climatic conditions of the region and the snow falling on the panels for a long time.

4.2. Determination of the Effect of Loss Parameters to Photovoltaic System Performance

There are various approaches to determine the effect of parameters on system performance. The simplest and most widely used method is the "one at a time (OAT)" approach, where one parameter at a time is varied by a certain percentage while keeping the others constant. With this method, the effective parameters in the variation of the result can be obtained. This type of analysis is one of the "local" sensitivity analysis methods, as it deals only with sensitivity with respect to selected point estimates and not for the entire parameter distribution [41]. Sensitivity analysis is the study of how the variation in the model result can be qualitatively or quantitatively allocated to different sources of variation in the model input. Many sources of uncertainty such as measurement errors, lack of information or misunderstanding of mechanisms constitute the input factor in sensitivity analysis [42]. Sensitivity analysis is necessary to identify the input parameters that contribute the most variability in the output, the unimportant parameters and the parameters that interact with each other [43].

Within the scope of this study, the effect of temperature, module mismatch, dusting and aging loss parameters on the result is evaluated with the "one at a time" method of the difference arising as a result of the comparison of 1-year energy production data and simulation data of the photovoltaic system. The system was simulated by taking the temperature loss value of 15 W/m^2K as an independent variable and new data were obtained. The default value recommended by PVsyst for mismatch losses was set as 1% in previous versions and twice as 2% for constant voltage uses. However, it is reported in PVsyst documentation that there is no absolute value for mismatch losses [40]. In this study, module mismatch losses were simulated by defining 2% as recommended by PVsyst 7.2.14 as default and 2,5% for constant voltage usage. However, since detailed calculation of mismatch losses was not performed, the simulation data were obtained again by defining the mismatch loss value of 1% and 2% for constant voltage usage as an independent variable while examining the effect of the parameters on the system performance. Since the factory building is located outside the settlement boundaries, the annual pollution loss was defined as 1% and simulated according to this value. However, since there is no device to measure the annual pollution loss of the modules, this loss percentage is not precise. Based on the information that the modules are cleaned once a month in the winter months and twice a month in the other months, the dusting loss was entered as 1% in December, January, February, March and 0% in the other months. The annual dusting loss of the system was defined as 0,3% as an independent variable. Since the installation of the photovoltaic system was completed in August 2020, the aging loss was defined as 0,2% for 1 year. Since the system has not yet completed one year in the one-year total energy data used in this study, the annual aging loss of the system is defined as 0% as an independent variable. In the simulation, the results and performance ratios of 16 different variations obtained by giving 2 different values to 4 independent variables determined to evaluate the effect of loss parameters are given in Table 5. "15-20" for temperature loss, "2/2.5%-1/2%" for module mismatch loss, "1%-0,3%" for dusting loss and "0,2-0%" for aging loss alternative values are used. V1 variation is the result obtained according to the loss values defined in the PVsyst tool according to the default values.

Table 5. Given values to independent variables and acquired energy production data

	Temperature Losses (W/m2K)	Mismatch Losses %	Dusting Losses %	Aging Loss %	Energy Production (MWh)	Performance Ratio (PR) %
V1	20	%2 / %2,5	%1	1 year %0,20	1345	%83,4
V2	20	%2 / %2,5	%1	0	1348	%83,5
V3	20	%2 / %2,5	%0,3	1 year %0,20	1354	%84
V4	20	%2 / %2,5	%0,3	0	1357	%84,1
V5	20	%1 / %2	%1	1 year %0,20	1359	%84,2
V6	20	%1 / %2	%1	0	1362	%84,4
V7	20	%1 / %2	%0,3	1 year %0,20	1368	%84,8
V8	20	%1 / %2	%0,3	0	1371	%85
V9	15	%2 / %2,5	%1	1 year %0,20	1292	%80,1
V10	15	%2 / %2,5	%1	0	1294	%80,2
V11	15	%2 / %2,5	%0,3	1 year %0.20	1300	%80,6
V12	15	%2 / %2,5	%0,3	0	1303	%80,8
V13	15	%1 / %2	%1	1 year %0,20	1305	%80,9
V14	15	%1 / %2	%1	0	1308	%81,1
V15	15	%1 / %2	%0,3	1 year %0,20	1314	%81,4
V16	15	%1 / %2	%0,3	0	1316	%81,6

It was previously stated that there was a difference of 2% between the simulation result and the actual production data. When the ratios given in Table 5 are analysed, the closest to the actual production data is V8 variation with 0,07% and the furthest is V9 variation with 6,19%.

4.3. Discussion

When the loss parameters occurring in the system as a result of the simulation are analysed, it is seen that the highest loss is due to temperature. The temperature loss value is 7,6%. Temperature loss is one of the important parameters affecting the efficiency. Temperature loss is followed by reflection loss, array mismatch loss, inverter loss, DC ohmic wiring loss and dusting loss. Shading is one of the important parameters affecting the efficiency of photovoltaic panels. The fact that the factory surroundings are open and there are no shading factors such as buildings, trees, chimneys, electricity poles on the panel positively affects the efficiency. Panels facing north also experience shading at certain time intervals. The dusting loss of the system is 1%. The analysis of the results show that the realisation rate is the lowest in December with 62,18% and the highest in October with 119,29%.

Okello et al. [23], Haydaroğlu and Gümüş [25], Keskin [26], Vidal et al. [28], Bolat et al. [27], Çınaroğlu and Nalbantoğlu [29], compared the production data of the installed photovoltaic system with the data obtained from the PVsyst tool in their studies. In the studies of Bolat et al. and Çınaroğlu and Nalbantoğlu, the simulation data were higher than the actual production data. In other studies, real data were higher than simulation data. Comments have been made about the reasons for the difference between real data and simulation data, but no study has been carried out on this subject. This study, which examines the effect of loss parameters on photovoltaic system performance in detail, contributes to this gap in the literature.

5. CONCLUSION

In this study, the actual values and characteristics of the photovoltaic system, which was integrated on the roof of an existing facility and whose production data has been recorded since August 2020, were defined and simulated in the PVsyst 7.2.14 simulation program. In the simulation results, energy production data, loss data and performance parameters defined and IEC 61724 standard used to analyse the performance of the system.

As can be seen from the results, there are differences between the simulation data and the production data of the factory building in 2021 due to environmental factors. Since there is no on-site measurement data for factors such as temperature, radiation, wind, dusting, snow, shading, etc., the values provided by the programme for some loss parameters in the simulation study were accepted as default. Therefore, simulation results and actual production results do not exactly coincide. In general, when the annual production results are evaluated, it is observed that there are close results. Since there is no climate data for 2021 for the location of the facility, simulation was performed by taking the average of 10-year climate data obtained from the Meteonorm database. The possibility that the 2021 climate data may be different from the 10-year forecast may differentiate the simulation results from the actual production data. In addition, the OAT method of changing one variable at a time by a certain percentage was used to determine which parameters may cause the difference between actual production data and simulation data.

In this study, the importance of renewable energy source sun and photovoltaic systems is emphasised. It is aimed to contribute to the widespread use of energy production by using photovoltaic systems for Turkey with high solar energy potential. The realistic results of the simulation tool PVsyst, which is used to simulate the energy production potential and efficiency of the system before photovoltaic system designs, are mentioned. The fact that PVsyst tool produces results close to reality, shows that it is a reliable programme. Although there is a difference between the one year real production data of the photovoltaic system and the annual total production data of the PVsyst tool, close results can be obtained. However, differences may occur in monthly energy production results. These differences are due to the fact that the losses in the system cannot be fully calculated. In order to estimate the monthly production data closer to reality, as much data as possible about the temperature, radiation, wind direction, wind speed and dust parameters of the region where the system is installed are needed. In order to determine the irradiance, temperature, wind speed and dust parameters that affect the efficiency of the photovoltaic system, it is necessary to set up a device. In order to measure the amount of irradiance, a pyranometer can be connected to the output of the photovoltaic modules. In order to minimise temperature loss, temperature monitoring sensors can be installed on the modules to prevent temperature-related failures. The effect of dusting can be detected if two modules with the same characteristics are periodically cleaned at a certain time interval, one of them is periodically cleaned and the other is not cleaned and energy measurement values are recorded.

Calculation and determination of the panel optimum tilt angle value of the photovoltaic system will increase the efficiency of the system. The optimum tilt angle of the panels varies between 35°-40° depending on the latitude in Turkey. It is thought that the module tilt angle of the factory building will increase the amount of energy produced. For high performance photovoltaic systems, regular monitoring of the factors affecting the performance and efficiency of the system is required.

Declaration of Ethical Standards

The authors of this article declare that the materials and methods used in this study do not require ethical committee permission and/or legal-special permission.

Credit Authorship Contribution Statement

Selçuk SAYIN: Conceptualization, evaluation of results, writing
Fatma YETGİN: Data collection and simulation

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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Data Availability

Due to the nature of this study, no statistical or formula-based data were utilized.

Symbols

A	Ampere	kWp	Kilowatt peak
°C	Celsius degree	mm	Millimetre
GW	Gigawatt	m^2	Square meter
Hz	Hertz	MPPT	Maximum Power Point Tracking
K	Kelvin	MW	Megawatt
kVA	Kilo volt ampere	MWp	Megawatt-Peak
kg	Kilogram	MWh	Megawatt hour
kW	Kilowatt	TWh	Terawatt hour
kWh	Kilowatt hour	V	Volt
kWh/m^2	Kilowatt hour / square meter	W	Watt
$kWh/m^2/day$	Kilowatt hour / square meter / day	W/m^2K	Watt / square meter Kelvin
kWh/year	Kilowatt hour / year	Wp	Watt peak

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