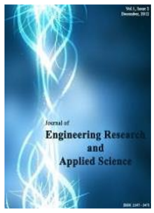
Journal of Engineering Research and Applied Science
Available at www.journaleras.com
Volume 12 (2), December 2023, pp 2414-2424
ISSN 2147-3471 © 2023



# 2,5 MW Photovoltaic Solar Power Plant Maintenance, Operation and Design: Konya/Comaklı Case

Unal Kurt[1,*], Ömer Çıkışır[2]

[1]Amasya University, Electrical and Electronics Engineering, Amasya, Turkey
[2]Amasya University, Instute of Science and Technology, Amasya, Turkey

Accepted 13 October 2023

## Abstract

In this study, routine maintenance techniques such as planned and unplanned maintenance activities, regular inspections and cleanings, which are the types of maintenance activities in a photovoltaic power plant, are described. A solar power plant with a power of 2.5 MW in the Comaklı region of Konya province was designed by the PVsyst program, and a simulation report was prepared. According to the simulation report, it is seen that the highest energy production is in August, and the lowest energy production is in December. The annual energy the plant supplies to the grid is 4113.7 MWh, and the plant performance ratio is 82%. Since the energy source in photovoltaic solar energy is the sun, there is no depletion of the energy source as in fossil fuels. With the increase in the world population and its dependence on technology, energy consumption is increasing daily. People have started to consume limited resources on Earth to meet their unlimited needs and have begun to turn to renewable energy sources from fossil fuels, which are decreasing daily. Renewable energy sources help to protect the environment by reducing carbon dioxide emissions and reducing foreign dependence on energy. Our country is fortunate in terms of solar energy compared to many countries. The annual sunshine duration is 2,741 hours, and the average yearly total radiation value is calculated as 1,527.46 kWh/m$^2$.

**Keywords:** *PVsyst, photovoltaic energy, inverter, solar cell, tilt angle, azimuth angle, Comakli*

## 1. Introduction

### 1.1. Operation and Maintenance in Photovoltaic Energy Systems

Maintenance and operation in photovoltaic solar power plants is a set of works to be carried out for the plant to provide the best performance. Correct operation and timely maintenance ensure that the equipment in the plant generates the maximum amount of energy throughout its operational life, maximizing the interests of customers and investors.

The performance of photovoltaic solar power plants is adversely affected by dust accumulation on the equipment, shading, improper installation, improper connection not following standards, improper cable selection, and improper cable termination. Especially in solar panels installed in dirty and dusty environments and kept outdoors 24/7, a power loss of 30 percent can be experienced. Figure 1.1. Factors affecting the performance of PV power plants.

Figure 1.1. Factors affecting the performance of PV power plants.

Pollution and dust in the panel cause hot spots in the photovoltaic cell, reducing energy production efficiency and panel lifetime. Figure 1.2. Hot spot in PV cell. The monthly production effect in a 10kWp PV plant is 1443kWh for a clean module and 1143kWh for a dirty module. It causes 300kW energy loss per hour.

[a]Corresponding author: unal.kurt@amasya.edu.tr

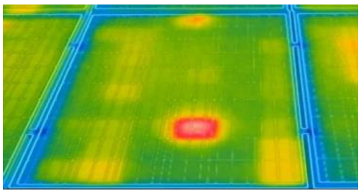


Figure 1.2. Hot spot in PV cell

## 1.2. Types of Maintenance

### 1.2.1. Planned maintenance

It is also defined as preventive maintenance. It aims to reduce the probability of equipment failure. The possibility of malfunctioning is also reduced by regular maintenance work on the equipment. For newly commissioned equipment to operate efficiently during its service life without any problems, routine maintenance work must be carried out. These are the periodic activities in the maintenance control timetable specified in the user manual of the equipment. [8]

### 1.2.2 Unplanned Maintenance

It is called Corrective maintenance too. It is a restorative activity carried out for the commissioning of the power plant in an unplanned shutdown that occurs when it is not known when the equipment will be out of service. When the malfunction occurs,

production planning is adversely affected by this situation as it is unknown. Minimizing unplanned maintenance depends on correct and timely planned maintenance.

## 1.3. Maintenance and Periodic Controls of Photovoltaic Modules

Photovoltaic panels are generally considered to be maintenance-free. To make the panels more efficient and to prevent unplanned downtime and loss of production, maintenance, and periodic checks should be carried out. In daily visual inspections, modules are checked for cracks, rain-snow water leaks, snail marks, bird droppings, and discoloration. In periodic maintenance, physical control of the DC connectors on the modules, corrosion control between the module-profile connection, control of shading that may occur due to a tree or other object, control of whether the connection hooks between the module and the profile are properly mounted on the panel or the tightness of the connection, control of whether there is any deformation in the cables on the cable route of each panel, control of the grounding of each module, thermal controls of the modules. [8]

The detected problems should be solved in planned or corrective maintenance according to the urgency. Before starting panel cleaning, it must be checked whether there is a damaged panel. During cleaning, a crack in the panel, a broken area, or a loose connection may cause electric shocks. Panel cleaning is done with water, manually or automatically. The cloth or brush used should be soft, and the detergent should not have abrasive properties. The panels should not be stepped on during cleaning; even if there is no visible crack on the panels stepped on, it causes micro-cracks.

## 1.4. Periodic Controls of Inverter

The inverter must be easily accessible in case of malfunction or during maintenance. It should be checked for abnormal conditions, such as odor, heat, or sound. The cooling fan control and the filter used must be cleaned and replaced if necessary. Whether there is any alarm or warning on the inverter display to be checked. The inverter against dust and pollution to be checked. String connection connectors and earthing cables to be checked for looseness.

## 1.5. Periodic Controls of Distribution Panels, Cables and Connections

In distribution panels, earthing connection, panel cable glands, tightness control of cable terminal connections inside the panel, whether there is insulation weakness of the cables inside the panel, whether there is any sign of heating in the equipment inside the panel, control of panel fixing bolts, damage, and control of the panel cover against corrosion. In addition, the panel must be checked for tightness against rainwater. In case of heavy rain, rainwater may enter the panel. The worn, torn panel cover gasket must be replaced.

The cable installation should be checked for any insulation weakness, crack in the cable, damage, or deterioration in the cable. Rodents may cause short circuits and fire due to gnawing the cables. Distribution panels should be checked against rodent nesting.

## 1.6. Test Equipment and Hand Tools to Be Used During Maintenance

The first goal of the enterprise is to protect the safety, health, and business of the employees. To serve this purpose, the employee and the enterprise must comply with occupational health and safety rules. Since these rules are not an option but necessary, personal protective work safety equipment must be used during work and in the field. The enterprise is obliged to provide this equipment to its employees, and the employee is obliged to use them. Figure 1.3. work safety equipment and hand tools.

**Occupational health equipment**
- Helmet
- Safety Glasses
- Safety shoes
- Flame resistant workwear
- Firt aid kit

**Test equipment and instruments**
- Digital multimeter
- Thermography camera
- Angle gauge, IV Meter
- Compass
- Hand tools, (must be insulated)


Figure 1.3. Work safety equipment and hand tools.

**1.7. Locking and Labelling of Equipment Used in Photovoltaic System**

All equipment must be labeled (inverters, strings, arrays, modules). During the periodic maintenance check, it is necessary to check whether the equipment labels are in place, and if there is an old or difficult to read label, it should be replaced with a new one. In addition, the labels of the equipment used in the outdoor environment should be resistant to the external environment (factors such as rain and sun) that are not easily deformed.

The lock-out tag-out (LOTO) system is a fundamental occupational safety rule to prevent any person from accidentally switching off the power supply switch of the equipment being maintained or repaired and to avoid electrical accidents. Electrical panels, inverters, batteries, and equipment must be labeled, locked, and electrically isolated before maintenance. Thus, precautions are taken against electric shocks due to uncontrolled energization.

**2. Design and Simulation of A 2.5 Mw Grid-Connected Photovoltaic Energy Power Plant in Konya Comakli with PVsyst Programme**

**2.1. Konya Comaklı Geographical Location, Plant Technical Data**

The coordinates of the facility to be installed from Google Earth were found as latitude 37,7437022, longitude 32,5426689, and altitude 1.008m. The plant power will be 2.5MW DC and connected to the grid. Figure 2.1. Google Earth Konya Comaklı geographical location.[1]

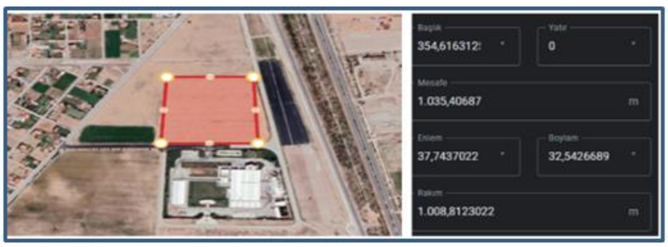



Figure 2.1. Google Earth Konya Comaklı geographical location.

**2.2. Adding Geographical Location of Comaklı Region to PVsyst Program**

The coordinates of the plant to be established in Konya Comaklı taken from Google Earth are latitude 37,7437022, longitude 32,5426689, and altitude 1.008m. In the window opened in the PVsyst program, click on "Databases," "Geographical sites," and then "New" icon. Figure 2.2. PVsyst Database, geographical locations.

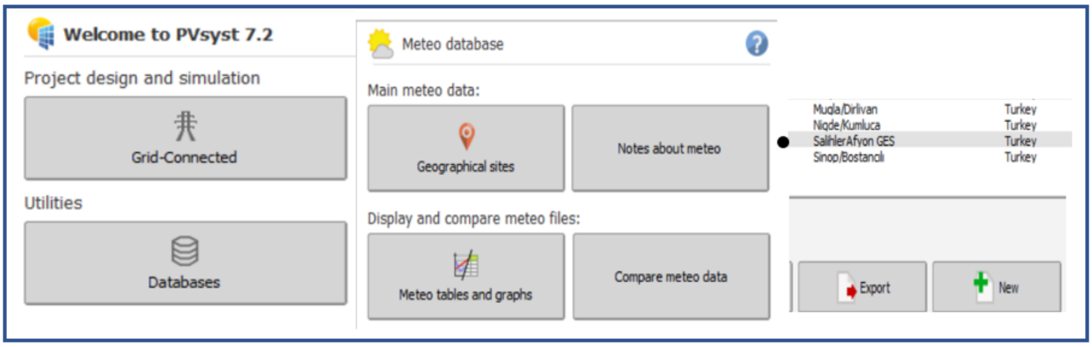



Figure 2.2. PVsyst Data base, Geographical Locations

In the geographical coordinates window, enter the latitude, longitude, and altitude information of the detected region. When the "Get from coordinates" icon in the upper right corner is clicked, the Comaklı location name is automatically added to the program. Figure 2.3. PVsyst geographical coordinates

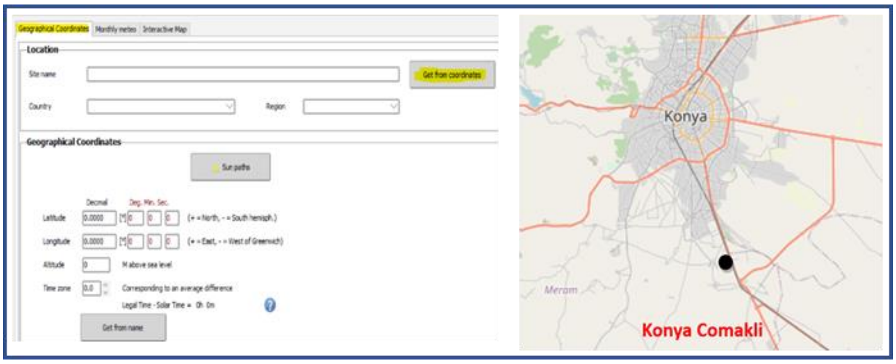



Figure 2.3. PVsyst geographical coordinates

### 2.3. Retrieval of Konya Comaklı Annual Irradiance Data to the Database in PVsyst Programme

To obtain the weather data of Comaklı, the "Metronom8.0" box under the geographical coordinates heading is ticked and the "Import" icon is pclicked. Figure 2.4. PVsyst Metronome 8.0 Global horizontal irradiation, horizontal diffuse irradiation, temperature, wind speed, relative humidity and total annual solar radiation of Konya Comaklı region are calculated as 1770 KWh/m2 by the programme. The collected data is saved to the database by clicking the "OK" icon. Table 2.5. PVsyst monthly weather forecast.

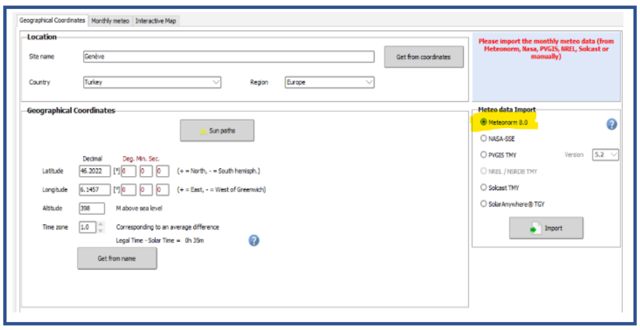


Figure 2.4. PVsyst Metronome 8.0

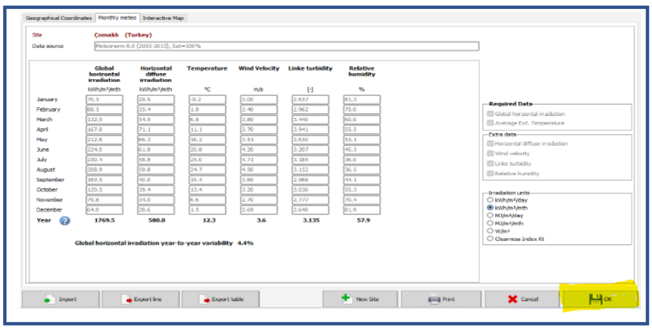


Table 2.5. PVsyst monthly weather forecast.

### 2.4. Creating a New Grid Connected Project

Since the photovoltaic solar power plant to be installed will be a grid-connected facility, "New grid connected project" is selected from the "Project" menu in the PVSyst program. Figure 2.6. PVsyst new grid-connected

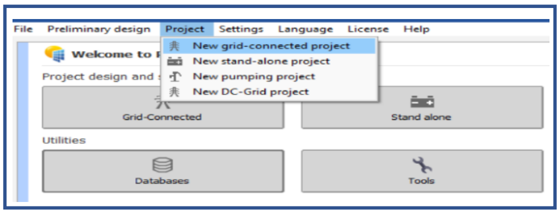



Figure 2.6. PVsyst new grid-connected

In the window that opens, "Project name" is entered (Figure 2.7. PVsyst project name) and the region previously added to the Comaklı geographic information database from the location file is called from the project list. Table 2.8. PVsyst Metronom8.0 monthly weather zone list. The "Save" icon is clicked.

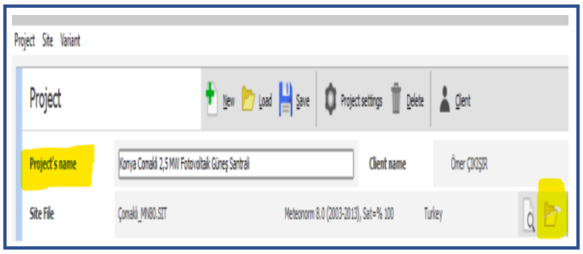
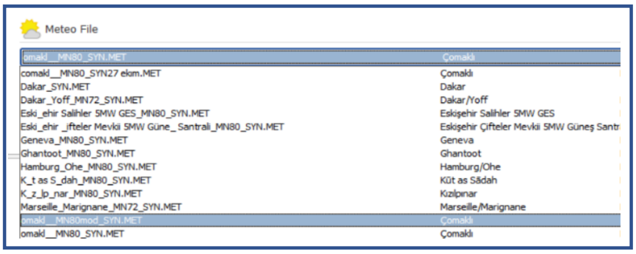



Figure 2.7. PVsyst project name



Meteo File

| | |
|---|---|
| comakl__MN80_SYN.MET | Comaklı |
| comakl__MN80_SYN27 ekım.MET | Çomaklı |
| Dakar_SYN.MET | Dakar |
| Dakar_Yoff_MN72_SYN.MET | Dakar/Yoff |
| Eski_ehir Salihler 5MW GES_MN80_SYN.MET | Eskişehir Salihler 5MW GES |
| Eski_ehir _ifteler Mevkii 5MW Güne_ Santrali_MN80_SYN.MET | Eskişehir Çifteler Mevkii 5MW Güneş Santr |
| Geneva_MN80_SYN.MET | Geneva |
| Ghantoot_MN80_SYN.MET | Ghantoot |
| Hamburg_Ohe_MN80_SYN.MET | Hamburg/Ohe |
| K_t as S_dah_MN80_SYN.MET | Kût as Sâdah |
| K_z_lp_nar_MN80_SYN.MET | Kızılpınar |
| Marseille_Marignane_MN72_SYN.MET | Marseille/Marignane |
| omakl__MN80mod_SYN.MET | Comaklı |
| omakl__MN80_SYN.MET | Çomaklı |

Table 2.8. PVsyst Metronom8.0 monthly weather zone list

## 2.5. Entering Panel Tilt Angle and Azimuth Angle for Comaklı Region

Click the "Orientation" symbol in the variant section and enter the plane inclination information. Figure 2.9. PVsyst variant.

Plane inclination=Latitude angle x 0,87+3.1 =38x0,87+3.1=36º. [7]

The azimuth angle is the angle at which the panels face south and is zero degrees. The panels are mounted on a fixed inclined plane with no sun tracking system, they are motionless. Figure 2.10. PVsyst plane tilt and azimuth.[2]

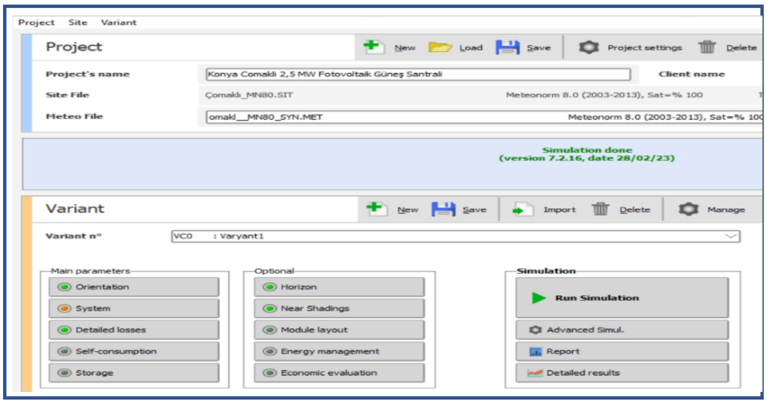



Figure 2.9. PVsyst variant

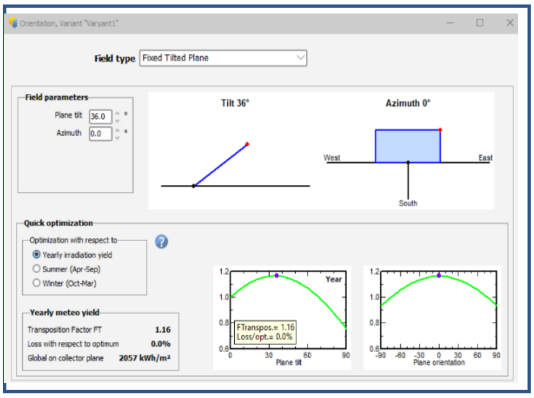



Figure 2.10. PVsyst plane tilt and azimuth

## 2.6. Determination of the Inverter and Panel Model to be used, Determination of the Number of Panels according to the Power Plant Power

From the variant menu shown in Figure 2.9, the system connected to the grid is defined by clicking the "System" icon. Figure 2.9. PVsyst variant.

Power plant DC power is 2500kWp, PV module Vikram Solar 540Wp35VSOMERAVSMH, Inverter: Conergy270kW450-800VTL50/60Hz400VAC three-phase. Figure 2.11. PVsyst variant system

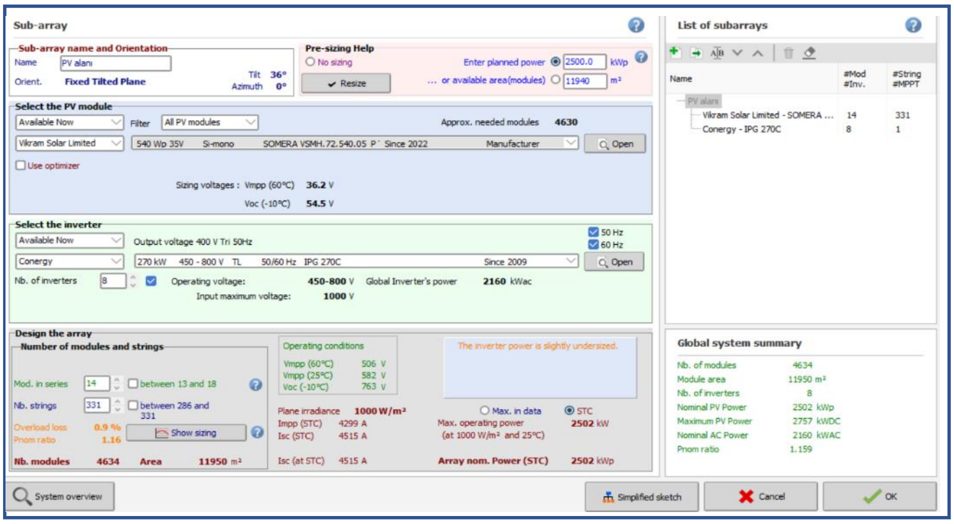



Figure 2.11. PVsyst variant system

Inverter DC input minimum MPP voltage is 450V, and maximum MPP voltage is 800V. With 14 string modules and 331 strings, the total number of panels to be used is calculated by the program as 4634. In this case, the voltage to be produced by 14 string modules at -10oC is 763V, and the voltage to be produced at 60oC is 506V and is within the operating conditions of the inverter. (The operating condition of the inverter is between 450-800V). The nominal panel DC power is 2502 kWp, the maximum panel power is 2757 kWDC, and the nominal AC power is 2160 kWp. [4]

## 2.7. Losses

Power plant losses are defined by clicking the "Detailed losses" icon from the variant menu shown in. Figure 2.12. PVsyst losses.

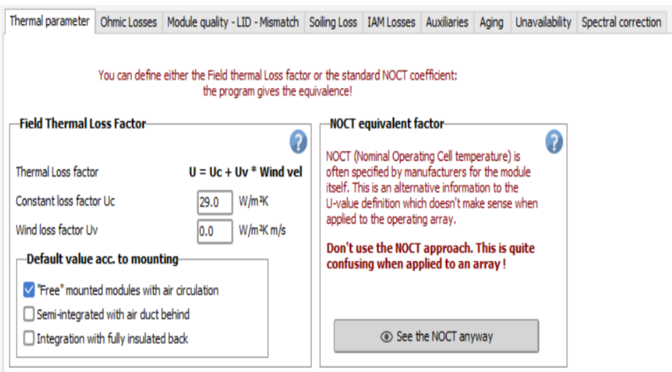



Figure 2.12. PVsyst losses

The panel using IAM (Incidence angle modifier) incidence angle losses is coated with AR (anti-reflected) anti-reflector (Figure 2.13. Panel data sheet). The model of the reflection angle is selected as anti-reflective. Figure 2.14. PVsyst IAM losses. [6]

| Mechanical Data | |
|---|---|
| Length × Width × Height | 2274 x 1134 x 35mm (89.53 x 44.65 x 1.38 inches) |
| Weight | 28.2 Kg (62.17 lbs) |
| Junction Box | IP68, Split Junction Box with individual bypass diodes |
| Cable & Connectors* | 200 mm (+ve terminal) and 300 mm (-ve terminal) length cables,MC4 Compatible/MC4 Connectors |
| Application Class | Class A (Safety class II) |
| Superstrate | 3.2 mm (0.125 inches) high transmission low iron tempered glass, AR coated |
| Cells | 72 Mono PERC (144 half-cells) P-Type solar cells |
| Back Sheet | Composite film |
| Frame | Anodized aluminium frame with twin wall profile |
| Mechanical Load Test | 5400 Pa (Snow load), 2400 Pa (Wind load) |
| Maximum Series Fuse Rating | 25A |

Figure 2.13. Panel data sheet

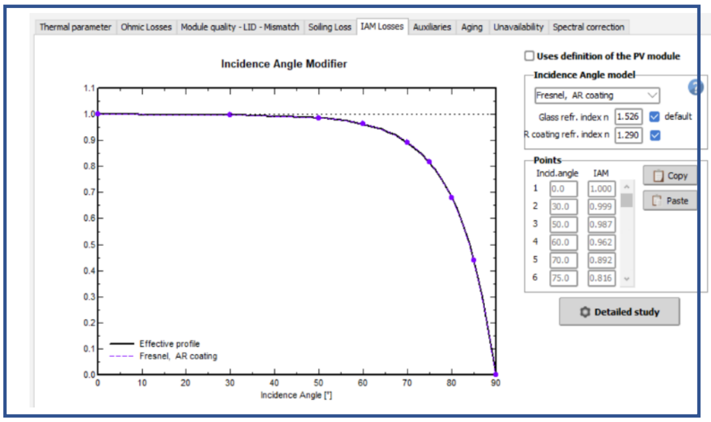



Figure 2.14. PVsyst IAM losses

## 2.8. Retrieval of the year-round solar horizon line of the region from the Web to the Programme Database

The grid connected horizon is defined for Comaklı region by clicking the "Horizon" icon from the variant menu shown in Figure 2.15. PVsyst variant horizon.

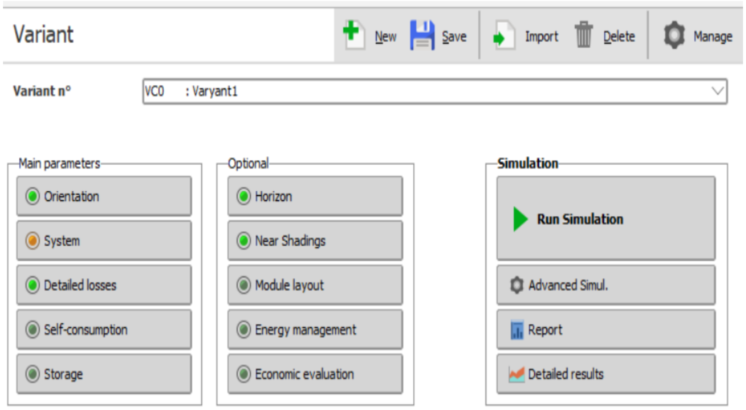



Figure 2.15. PVsyst variant horizon

In the window that appears, the PVGIS horizon is selected from the Web by clicking the Read/retrieve icon, and the year-round horizon line of the Konya Comaklı power plant region, whose geographical coordinates are automatically retrieved, is imported from the Web. Figure 2.16. PVsyst horizon line legal time.

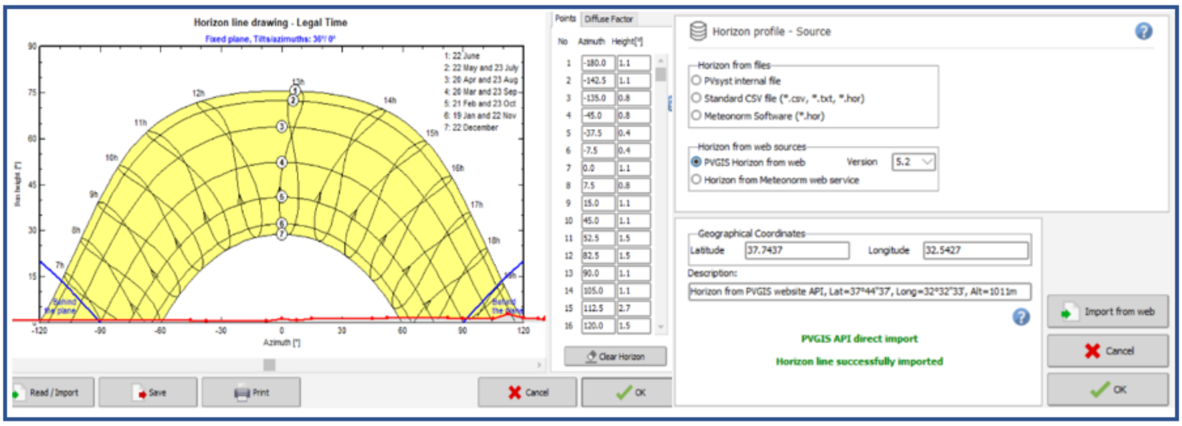



Figure 2.16. PVsyst horizon line legal time.

### 2.9. Creating Close Shading 3D Scene

The grid-connected horizon is defined for Comaklı region by pclicking the "Near shadings" icon from the Variant Menu. Figure 2.17. PVsyst variant near shadings.

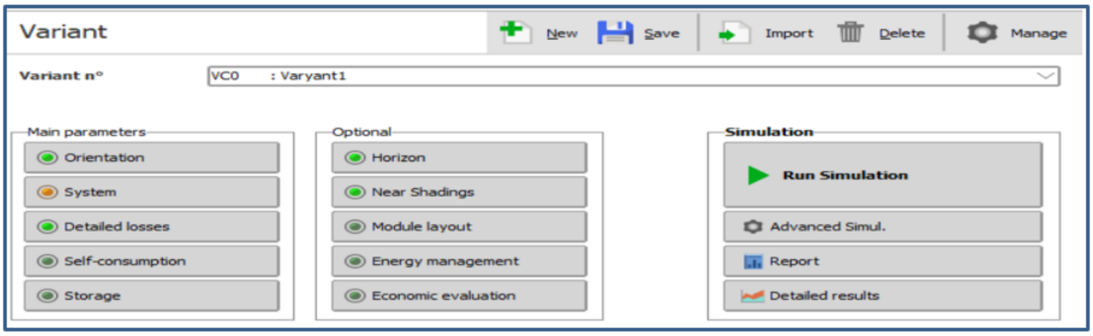



Figure 2.17. PVsyst variant near shadings

In the window that appears, click on the "Construction/Perspective" icon. Then select the table array from "Create". Figure 2.18. PVsyst near shading 3D scene.

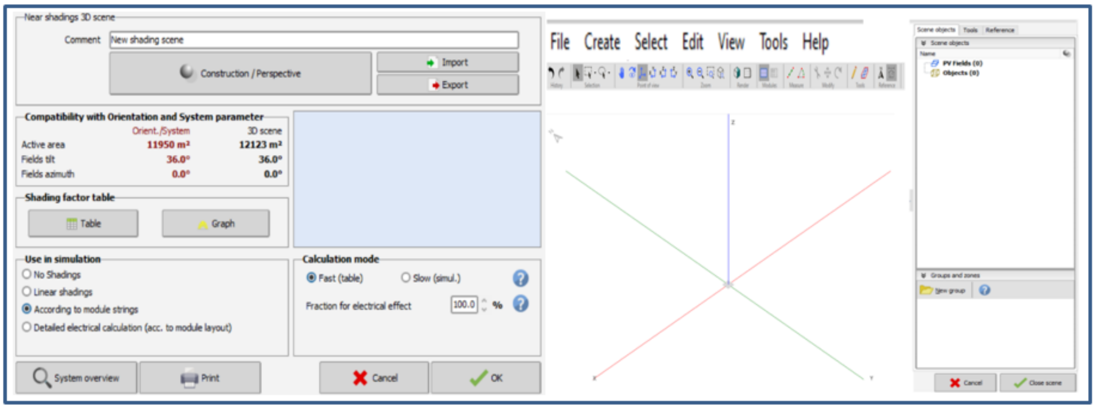



Figure 2.18. PVsyst near shading 3D scene

The required surface area of the power plant to be installed on the right side of the opened window is automatically calculated as 11949 $m^2$. North-South spacing is the distance between the arrays and is entered as 7m. Panels were used horizontally. Thirty arrays and 2x77 PV modules were designed for each array length. The panels used are single crystal SOMERA VSMH.72.AAA.05 Half-Cut, and the number of transverse rectangles is 2. The total surface area was calculated as 12123 m2 with 30 arrays X 145 modules. Figure 2.19. PVsyst near shading panel array layout

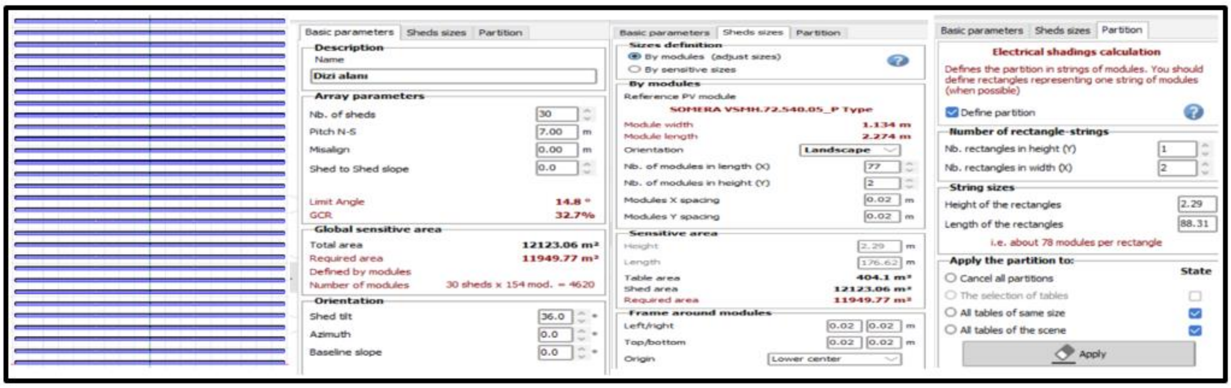
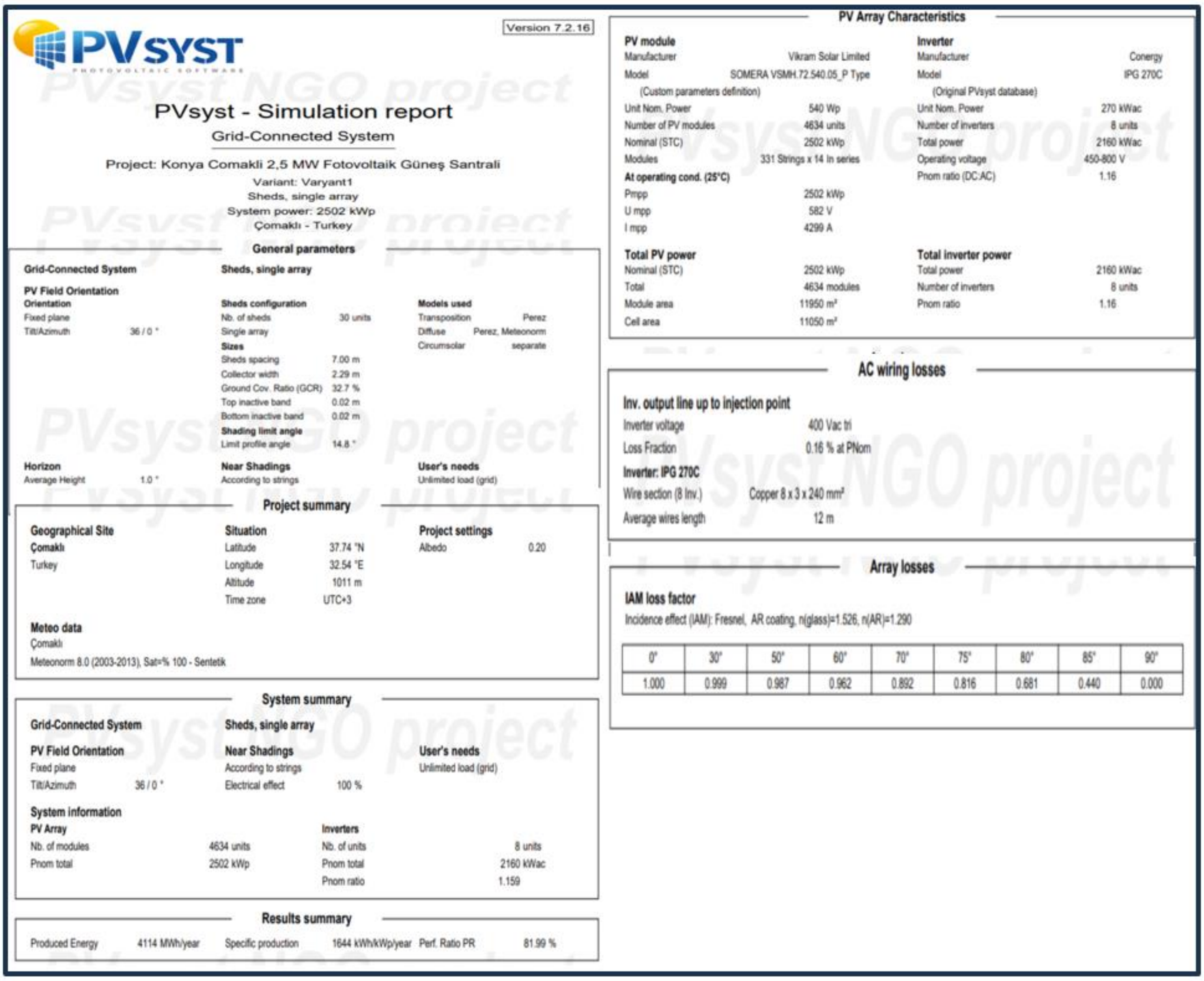


Figure 2.19. PVsyst near shading panel array layout

After the shading 3D scene is completed, the design is saved by clicking the "Close scene" icon in the lower right corner of the window. Figure 2.18. PVsyst near shading 3D scene

**3. Simulation Report of Konya Comakli Power Plant in PVsyst**

Figure 2.20 and 2.21 shows simulation reports.



Version 7.2.16

PVsyst - Simulation report

Grid-Connected System

Project: Konya Comakli 2,5 MW Fotovoltaik Güneş Santrali
Variant: Varyant1
Sheds, single array
System power: 2502 kWp
Çomaklı - Turkey

**General parameters**

Grid-Connected System — Sheds, single array

PV Field Orientation
Orientation: Fixed plane; Tilt/Azimuth 36 / 0 °

Sheds configuration: Nb. of sheds 30 units; Single array
Sizes: Sheds spacing 7.00 m; Collector width 2.29 m; Ground Cov. Ratio (GCR) 32.7 %; Top inactive band 0.02 m; Bottom inactive band 0.02 m
Shading limit angle: Limit profile angle 14.8 °

Models used: Transposition Perez; Diffuse Perez, Meteonorm; Circumsolar separate

Horizon: Average Height 1.0 °
Near Shadings: According to strings
User's needs: Unlimited load (grid)

**Project summary**

Geographical Site: Çomaklı, Turkey
Situation: Latitude 37.74 °N; Longitude 32.54 °E; Altitude 1011 m; Time zone UTC+3
Project settings: Albedo 0.20
Meteo data: Çomaklı; Meteonorm 8.0 (2003-2013), Sat=% 100 - Sentetik

**System summary**

Grid-Connected System — Sheds, single array
PV Field Orientation: Fixed plane; Tilt/Azimuth 36 / 0 °
Near Shadings: According to strings; Electrical effect 100 %
User's needs: Unlimited load (grid)

System information
PV Array: Nb. of modules 4634 units; Pnom total 2502 kWp
Inverters: Nb. of units 8 units; Pnom total 2160 kWac; Pnom ratio 1.159

**Results summary**

Produced Energy 4114 MWh/year; Specific production 1644 kWh/kWp/year; Perf. Ratio PR 81.99 %

**PV Array Characteristics**

PV module
Manufacturer: Vikram Solar Limited
Model: SOMERA VSMH.72.540.05_P Type (Custom parameters definition)
Unit Nom. Power: 540 Wp
Number of PV modules: 4634 units
Nominal (STC): 2502 kWp
Modules: 331 Strings x 14 In series
At operating cond. (25°C): Pmpp 2502 kWp; U mpp 582 V; I mpp 4299 A

Inverter
Manufacturer: Conergy
Model: IPG 270C (Original PVsyst database)
Unit Nom. Power: 270 kWac
Number of inverters: 8 units
Total power: 2160 kWac
Operating voltage: 450-800 V
Pnom ratio (DC:AC): 1.16

Total PV power: Nominal (STC) 2502 kWp; Total 4634 modules; Module area 11950 m²; Cell area 11050 m²
Total inverter power: Total power 2160 kWac; Number of inverters 8 units; Pnom ratio 1.16

**AC wiring losses**

Inv. output line up to injection point
Inverter voltage: 400 Vac tri
Loss Fraction: 0.16 % at PNom
Inverter: IPG 270C
Wire section (8 Inv.): Copper 8 x 3 x 240 mm²
Average wires length: 12 m

**Array losses**

IAM loss factor
Incidence effect (IAM): Fresnel, AR coating, n(glass)=1.526, n(AR)=1.290

| 0° | 30° | 50° | 60° | 70° | 75° | 80° | 85° | 90° |
|---|---|---|---|---|---|---|---|---|
| 1.000 | 0.999 | 0.987 | 0.962 | 0.892 | 0.816 | 0.681 | 0.440 | 0.000 |

Figure 2.20. Simulation report data

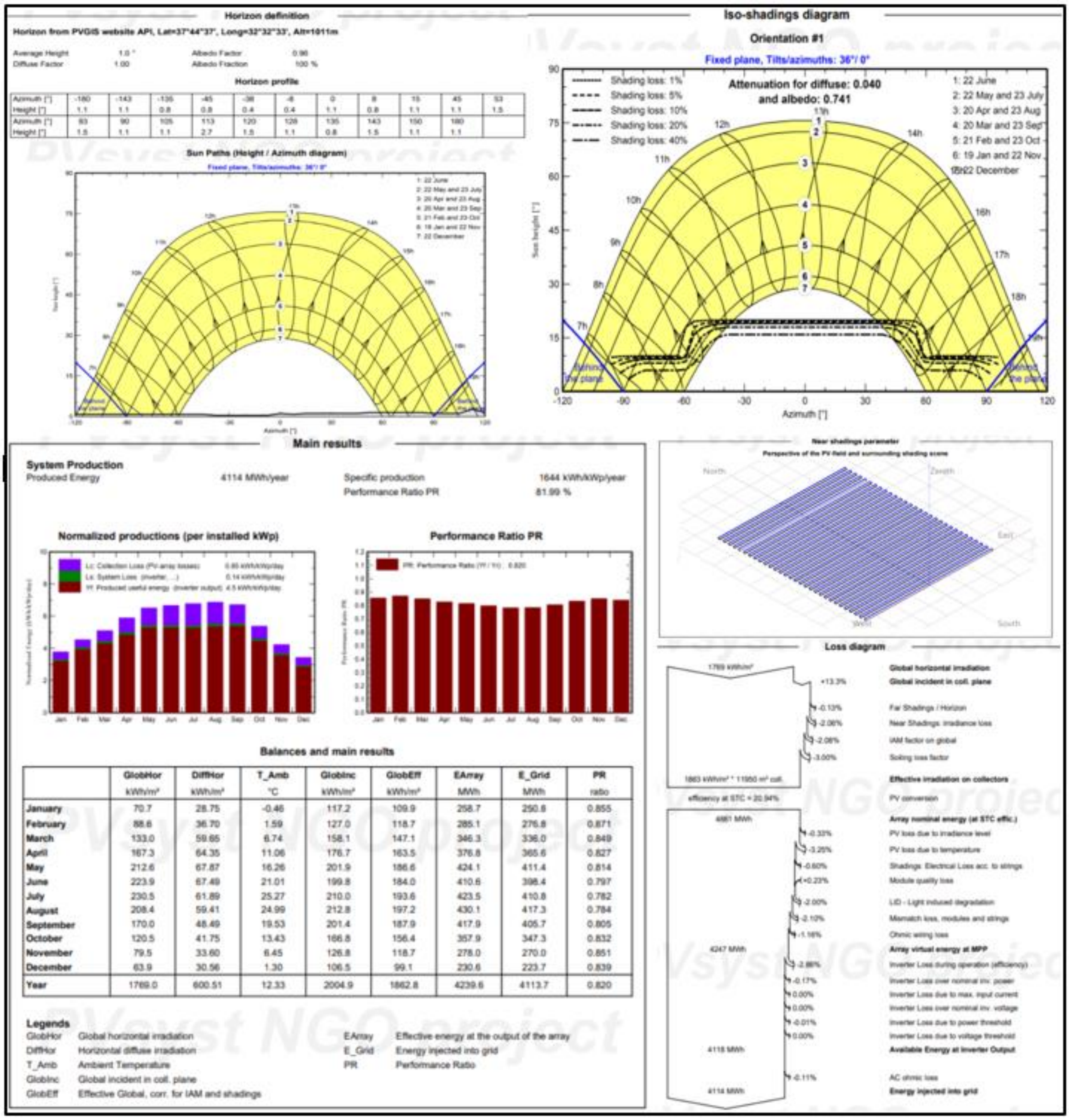



Figure 2.21. Simulation report diagrams

## 4. Conclusion and Recommendations

Photovoltaic solar energy systems have become the most preferred renewable energy source due to low facility installation costs, increasing energy production efficiency with the advancement of technology daily, decreasing panel production costs, ease of operation, and maintenance costs.

Compliance with the planned maintenance instructions of the power plant ensures that the plant operates with a longer operating life and performance, achieving maximum energy production and maximizing the interests of customers and investors.

According to the PVSyst simulation report of the 2.5 MW photovoltaic power plant designed in the Comaklı region of Konya province, the nominal power was 2502KWp using 4634 Solar Vikram panels with 540Wp capacity. The panels used were grouped in series as 14 strings and connected in parallel

as 331 strings in each string. While the performance rate was 85% in January, it decreased to 78% in July, and the annual performance rate was 82% on average. [5] According to the isometric shading azimuth/elevation diagram, the highest sun angle is 75o in July, and the lowest elevation angle is 25o in December. The reason why the performance ratio is lower in summer months compared to winter months is that the heat losses are higher due to the increased air temperature. In the PVSyst simulation program, the annual horizontal irradiation of the Konya Comaklı region is 1769Kwh/m2, and the total energy injected into the grid is 4113,7MWh. [3]

The PVsyst simulation program gives realistic results, and the simulation made using the program before the installation of a solar power plant provides benefits in terms of the amount of energy to be supplied to the grid, the overall performance of the plant, the losses, the selection of the right equipment and the choice of the location where the plant can benefit from the best solar radiation.

**Author(s) Contributions**

LU and OC did the analyses and wrote the article together. Both authors read and approved the final version of the article.

**Conflict of Interest**

The authors declare that there is no conflict of interest.

**References**

[1]. Limem, F. (2022) Evaluation of the effectiveness of photovoltaic design/simulation software used in the solar energy sector for Kocaeli province. Master's thesis 765304

[2]. Yilmaz, M (2013). Methods of obtaining electrical energy from solar energy with solar tracking system and determination of optimum efficiency Master's thesis 341350.

[3]. Ceylan, (2017). Investigation of the accuracy of simulation results of photovoltaic programs Master's thesis 487731

[4]. Cekinir, S. (2012). Modeling and Simulation of Photovoltaic Power Systems. Master Thesis, Ege University, Institute of Science and Technology, Izmir, 301878

[5]. Turmuş, A. (2018). Planar Reflectance Assisted Planar Solar Panel Design - Electricity Generation and Efficiency Analysis. Master's Degree, 492723

[6]. Internet: EMO. Solar energy systems losses. URL-8: https://www.emo.org.tr/ekler/38f0038 bf09a40b_ek.pdf. Last Access Date: 08.10.2023

[7]. Internet: Lighting portal. Recommended solar panel tilt angle. URL-9: https://www.aydinlatma.org/81-il-icin-onerilen-gunes-paneli-egim-acisi.html. Last Access Date: 10.10.2023

[8]. Internet: Field inspection guide for photovoltaic systems. URL: http://brooksolar.com/files/PV-Field-Inspection-Guide-June-2010-F-1.pdf.html. Last Access Date: 10.10.2023