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Comparison study in terms of the results of photovoltaic solar energy systems designed with PVsyst and MATLAB Simulink software

PVsyst ve MATLAB Simulink yazılımı ile tasarlanan fotovoltaiik güneş enerjisi sistemlerinin sonuçları açısından karşılaştırma çalışması

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Comparison Study in Terms of The Results of Photovoltaic Solar Energy Systems Designed with PVsyst and MATLAB Simulink Software

Highlights

- ❖ Feasibility analysis crucial for cost-effective and reliable solar projects.
- ❖ MPPT algorithms and software sensitivity shape PV designs.
- ❖ Varied results in PVsyst and MATLAB/Simulink impact design outcomes.

Graphical Abstract

This study compares the design and performance of 75 kW photovoltaic (PV) solar energy systems in Ankara using PVsyst and MATLAB/Simulink software. Significant monthly differences, ranging from 0.36% to 49.32%, highlight the impact of temperature sensitivity, MPPT algorithms, and data input methods on PV system outcomes.

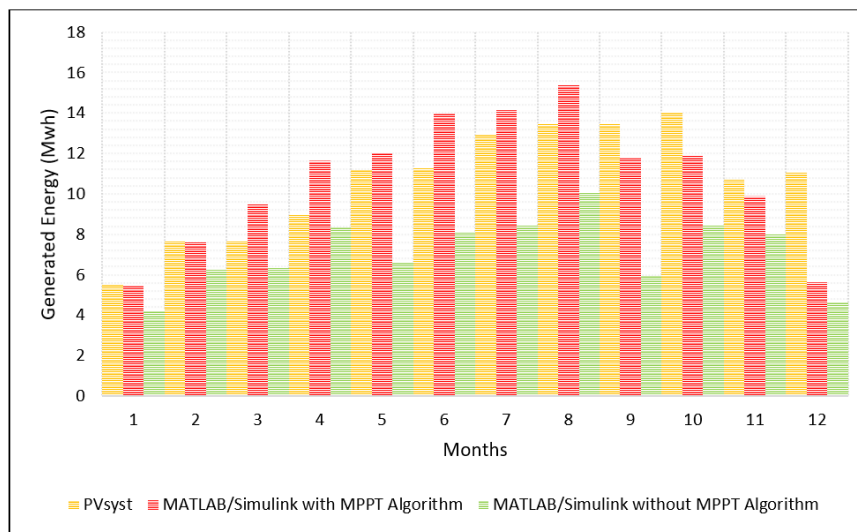


Figure. Monthly generated electricity energy graph according to the software used

Aim

To compare the simulation results of solar energy systems using PVsyst and MATLAB/Simulink

Design & Methodology

Three photovoltaic systems (PVsyst, MATLAB/Simulink with MPPT, and MATLAB/Simulink without MPPT) were designed and simulated.

Originality

Innovates by comparing PV systems using PVsyst and MATLAB/Simulink, revealing critical differences in temperature sensitivity and MPPT algorithms for improved solar project planning.

Findings

The findings of the study reveal monthly differences in the simulation outputs of 75 kW PV systems in Ankara.

Conclusion

The study underscores the substantial monthly differences in simulation outputs among 75 kW PV systems designed in Ankara, attributing these variations to higher temperature sensitivity in MATLAB/Simulink compared to PVsyst, as well as the impact of variable MPPT algorithms and data entry methods, emphasizing the significance of careful consideration in software selection and design parameters for optimal solar energy system performance.

Declaration of Ethical Standards

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

PVsyst ve MATLAB Simulink Yazılımı ile Tasarlanan Fotovoltaik Güneş Enerjisi Sistemlerinin Sonuçları Açısından Karşılaştırma Çalışması

Araştırma Makalesi / Research Article

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ÖZ

Günümüzde enerji ihtiyacının büyük bir kısmı fosil yakıtlardan karşılanmaktadır. Fosil yakıtların rezervlerinin sınırlı olması, çevreye zarar vermesi ve küresel ısınmaya neden olması gibi nedenlerden dolayı alternatif enerji kaynaklarına olan eğilimi artırmıştır. Alternatif enerji kaynakları arasında en çok tercih edilen güneş enerjisi sistemleridir. Herhangi bir fotovoltaik (PV) projeyi hayata geçirmeden önce elektrik üretimini, güvenilirliği ve maliyetleri optimize etmek için teknolojik ve ekonomik fizibilite gereklidir. Günümüzde bir PV sistemini tahmin etmek ve optimize etmek için çeşitli simülasyon araçları oluşturulmuştur. Bu çalışmada PVsyst ve MATLAB Simulink yazılımı kullanılarak tasarlanan fotovoltaik güneş enerjisi sistemlerinden elde edilen sonuçlar arasındaki farklılıklar ve bu farklılıkların sistemlerin enerji üretimi ve performansını nasıl etkilediği incelenmiştir. Çıktı verileri birbiriyle karşılaştırılarak regresyon analizi yapıldı ve hangi yönün avantajlı veya dezavantajlı olduğu belirlendi. PVsyst ve Matlab/Simulink yazılımları kullanılarak Ankara'da 75 kW'lık PV sistemi tasarlandı ve iki yazılımdan elde edilen simülasyon çıktıları karşılaştırıldı. Üç farklı PV sistemi tasarlanıp numaralandırılmıştır: Tasarım-1: PVsyst Sistemi, Tasarım-2: MPPT Algoritmali Matlab/Simulink ve Tasarım-3: MPPT Algoritmazsız Matlab/Simulink. İki yazılım ile üç tasarım sonucu arasındaki aylık farklar oldukça değişkendir. Bu farklar Tasarım-1 ile Tasarım-2'de %0,36 ile %10,72 arasındadır. Tasarım-1 ile Tasarım-3'te ise %14,21 ile %43,71 arasındadır. Tasarım-3 ile %17,65 ile %49,32 Tasarım-2 arasındadır. Analiz bulgularına göre MATLAB/Simulink yazılımının sıcaklık değişimine duyarlılığının PVsyst yazılımına göre daha yüksek olduğu tespit edilmiştir. Ayrıca MPPT algoritmalarının değişken olması ve verilerin otomatik ya da manuel olarak girilmesi gibi nedenler de farklılıkta etkilidir.

Anahtar Kelimeler: Fotovoltaik(FV), PVsyst, MATLAB/Simulink, MPPT.

Comparison Study in Terms of The Results of Photovoltaic Solar Energy Systems Designed with PVsyst and MATLAB Simulink Software

ABSTRACT

With the advancement of technology and the increase in the global population, the need for energy is growing daily. Today, the majority of energy needs are met from fossil fuels. The limited reserves of fossil fuels have increased the tendency towards alternative energy sources due to reasons such as harming the environment and causing global warming. Some renewable energy sources are sun, wave, wind, biomass, and others. Among them are the most preferred solar energy systems. Before implementing any photovoltaic (PV) project, technological and economic feasibility is required to optimize electricity generation, reliability, and costs. As of today, various simulation tools have been created to predict and optimize a PV system. This study examined the differences between the results obtained from photovoltaic solar energy systems designed using PVsyst and MATLAB/Simulink software and how these differences affect the energy production and performance of the systems. Regression analysis was performed by comparing the output data with each other, and it was determined which direction was advantageous or disadvantageous. 75 kW PV system was designed in Ankara using PVsyst and MATLAB/Simulink software, and the simulation outputs obtained from the two software were compared. Three different PV systems were designed and numbered: Design-1: PVsyst System, Design-2: MATLAB/Simulink with MPPT Algorithm, and Design-3: MATLAB/Simulink without MPPT Algorithm. The monthly differences between the two software and the three design outcomes are highly variable. These differences are between 0.36% and 10.72% in Design-1 with Design-2. It is between 14.21% and 43.71% in the Design-1 with Design-3. It is between 17.65% and 49.32% Design-2 with Design-3. According to analysis findings, it has been determined that the sensitivity of the MATLAB/Simulink software to temperature change is higher than the PVsyst software. In addition, reasons such as the variable MPPT algorithms and the automatic or manual entry of the data are also effective in the difference.

Keywords: Photovoltaic(PV), PVsyst, MATLAB/Simulink, MPPT.

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1. INTRODUCTION

The world meets most of its energy from fossil fuels such as natural gas, coal, and oil. The reserves of these fuels are limited, which is harmful to the environment. For this reason, research and development studies on alternative energy sources have intensified depending on the need to meet the energy. Alternative energy sources such as biomass, sunlight, geothermal, wind, and waves, which can exist spontaneously in nature, are inexhaustible and have little or no environmental damage [1].

Solar energy, one of the alternative energy sources, is rapidly becoming widespread due to its advantages. It is an endless and general source directly converted into electrical energy [2]. Solar energy can be used by remaking it in various ways. Solar power plants are systems that convert sunlight into electrical energy with photovoltaic (PV) panels and other components [3].

PV systems are the most prominent energy generation systems recently. An economic and technological feasibility study must be done to establish a PV project. There are many software programs developed for these studies. These programs vary according to the intended use.

Before implementing any PV project, technological and economic feasibility is required to optimize electricity generation, reliability, and costs. Energy production with PV systems PVsyst, PVsol, MATLAB/Simulink, Helioscope, PVcase, etc., can be calculated using simulation software programs such as In the literature, many studies have been done on the examinations and comparisons of these programs [4]–[8]. Yecid et al. have defined analyses implemented on the sizing and simulation of a grid-connected PV system in Bucaramanga, Colombia, with the software PVsyst. Numerical calculations were applied institutionally to provide comparisons of calculated data with simulation results. They emphasized the excellent potency of the research field, with 1882 kWh/m² at optimum conformance, which would generate 1375 kWh/year for a 1 kW PV system, with a yield factor of 72.7% [9]. Krismadinata et al. In their research, an accurate PV module has been submitted and indicated in MATLAB /Simulink for a typical 125 W solar panel. The recommended modeling method averted complexities involved in PV parameter certificates while achieving comparable precision. Simulation results were confirmed by comparing the experimental results of the datasheet. It showed the effectiveness of the suggested modeling method [10]. Ceylan and Taşdelen compared the results of a solar power plant (SPP) with 1 MW installed power with absolute values by using PVGIS, Helioscope, PVsol, and Polysun simulation software programs in the simulation environment. As a result of the study, they controlled that the Helioscope program gave the nearest result to the real data [11]. Vashishtha et al. In their research, they examined SketchUp, PVsyst, HelioScope, and AutoCAD software used in simulations of PV systems. As a result of the study, they determined that the

PVsyst program is the most widely used program and the Helioscope program is the most user-friendly software due to its potential to make more diverse evaluations [12]. Selmi et al. Their research compares the performance of PVsyst and MATLAB/Simulink software for simulating a grid-connected PV system. The simulation results showed that both software produced accurate results, with a maximum deviation of less than 2%. The authors recommended using MATLAB/Simulink for designing and optimizing the system and PVsyst for foreseeing the system's long-term performance [4]. We hypothesize that there will be variations in the results generated by PVsyst and MATLAB Simulink when designing photovoltaic solar energy systems. These differences may arise due to variations in modeling algorithms, assumptions, and input data handling between the two software tools. We further hypothesize that these variations will have implications for the designed systems' energy production, performance ratio, and system losses.

This study examined PVsyst and MATLAB/Simulink programs under the same conditions. The differences between the simulation programs used today reveal which field they are more suitable for use. The advantages and disadvantages of PVsyst and MATLAB/Simulink programs have been compared with a comparison not found in the literature. The PVsyst program has no manual data entry and no chance to interfere with the circuits, making the MATLAB/Simulink program stand out. However, PVsyst is preferred for commercial purposes because it provides more straightforward online data access. MATLAB/Simulink provides ease of research and development, but the design is more complex. The simulation results showed that both software produced accurate results. Still, PVsyst was found to be more suitable for predicting the long-term performance of PV systems. In contrast, MATLAB/Simulink was found to be more appropriate for analyzing the dynamic behavior of PV systems.

2. PHOTOVOLTAİC SYSTEMS (PV)

PV cells are produced with semiconductor technology. Its surfaces are made in the form of squares, rectangles, or circles. Silicon and silicon alloys are mainly used. The PV cell consists of three layers: the n-layer, which forms the negative part of the cell, made of silicon with phosphorus atoms added; the p-layer, which includes the positive aspect of the cell, which consists of silicon with boron atoms added, and the doped layer, which is the junction of the n layer and the p-layer. Electrons separated from the p-layer by the effect of radiation accumulate in the n-layer. The movement of electrons produces energy [13], [14]. The number of serial and parallel PV cells is expressed as n_s and n_p , respectively. The output current (I_{PV}) is the difference between the produced photocurrent I_g and the diode current.

$$I_{PV} = n_p \cdot I_g - n_p \cdot I_s \left[\exp \left(\frac{q}{A \cdot k \cdot T} \left(\frac{V_{PV}}{n_s} + \frac{I_{PV} \cdot R_s}{n_p} \right) \right) - 1 \right] \quad (1)$$

In Eq. 1; A is the diode ideal factor, k is the Boltzmann constant ($1,380622 \times 10^{-23}$ J/°K), q is the electron charge ($1,6021917 \times 10^{-19}$ C), T is the temperature (°K), R_s is the equivalent series resistance [13].

$$I_g = (I_{SC} + k_i(T - T_{ref})) \frac{I_{rr}}{1000} \quad (2)$$

In Eq. 2, The current produced by the solar radiation (I_{rr}) is I_g , the I_{SC} reference temperature, and the short-circuit current in the radiation, the reference temperature of the T_{ref} cell, which is the temperature coefficient of the short-circuit current [13].

$$I_s = I_{RS} \cdot \left[\frac{T}{T_{ref}} \right]^3 \cdot \exp \left[\frac{q \cdot E_g}{A \cdot k} \left(\frac{1}{T_{ref}} - \frac{1}{T} \right) \right] \quad (3)$$

In Eq. 3; I_s is the cell saturation current, I_{RS} is the reverse saturation current and E_g is the forbidden band energy of the semiconductor [13].

Finally, the power P_{PV} supplied by the panel is calculated as Eq. 4:

$$P_{PV} = I_{PV} \cdot V_{PV} \quad (4)$$

3. PVSYST SOFTWARE

Photovoltaic (PV) solar energy systems are becoming increasingly popular as renewable energy sources for both residential and commercial applications. PV systems generate electricity by converting sunlight into electrical energy using solar panels. To optimize the performance and efficiency of PV systems, it is essential to model and simulate their performance under various conditions accurately. PVsyst is an extensively used software tool for affecting the performance of PV systems [5], [15]. PVsyst is a software tool developed by PVsyst SA that is used for modeling and simulating the performance of photovoltaic solar energy systems. The software uses a variety of inputs, including weather data, system design parameters, and component specifications, to predict the performance of a PV system under different conditions. PVsyst can simulate both grid-connected and off-grid PV systems and can be used to model systems of different sizes and configurations.

Design Optimization: PVsyst can be used to optimize the design of PV systems by simulating their performance under different design configurations. The software can be used to evaluate different system designs, such as changes in panel orientation, tilt angle, and shading, to

determine the optimal design for a particular location and application.

Performance Analysis: PVsyst can be used to analyze the performance of existing PV systems. The software can be used to compare actual performance data with predicted performance data to identify any discrepancies or issues. This analysis can help identify areas for improvement and optimize system performance.

Financial Analysis: PVsyst can be used to conduct an economic analysis of PV systems by estimating the energy production and revenue generation of the system. The software can be used to calculate the financial metrics of a PV system, such as payback period, internal rate of return, and net present value, to evaluate the economic viability of a project.

Energy Yield Prediction: PVsyst can be used to predict the energy yield of a PV system under different conditions. The software can be used to estimate the energy generation of a PV system for a particular location, taking into account factors such as weather patterns, shading, and system design.

According to the power of the system to be installed, the panel array is created, and the panel slopes are adjusted. Besides the panel tilt angle, the azimuth angle is also changed. The azimuth angle is defined as the angle between the south/north and the collector plane. Appropriate inverter selection is made for the created string. The simulation is performed after the system setup is complete [6].

4. MATLAB/Simulink Software

MATLAB/Simulink is an essential tool for modeling and simulating PV systems. It allows for the creation of detailed models of PV cells, inverters, and other system components. The software enables the modeling of the electrical behavior of PV cells, which depends on factors such as irradiance, load resistance, and temperature. Simulink also allows for the creation of models that simulate the behavior of PV arrays, which can help engineers design and optimize the size and configuration of the system. MATLAB/Simulink is developed for the simulation of dynamic systems. Thanks to block diagrams, simulation can be performed without the need to write code [16]. The software can also be used to simulate the electrical behavior of inverters, which convert the DC power output from the PV cells to AC power that can be used by households and businesses. MATLAB/Simulink has also been used to optimize the performance of PV systems. Optimization algorithms can be used to define the optimal size and configuration of the system, as well as the optimal operating conditions for the PV cells and inverters. One example of an optimization algorithm used in PV system design is the particle swarm optimization (PSO) algorithm. This algorithm can be used to optimize the placement of PV

panels in a given area, as well as the tilt and orientation of the panels for maximum efficiency. Another example is the MPPT algorithm. This algorithm is used to optimize the power output of the PV cells by adjusting the load resistance to ensure that the cells operate at their MPP. MATLAB/Simulink can be used to simulate the behavior of the MPPT algorithm and optimize its parameters for maximum efficiency.

4.1. Maximum Power Point Tracking (MPPT)

PV cells can operate in a wide voltage and current range. The maximum power point (MPP) is the point where voltage and current generation are the highest. In other words, the system produces the highest power at this point. There is one MPP for each series. Environmental factors such as radiation intensity, shading conditions, panel pollution, and air pollution affect MPP [17]. MPPT is used for MPP tracking of the system. Thanks to the algorithms placed in the MPPT with different methods, it is ensured that the system works at maximum power and that maximum efficiency is obtained. In other words, MPPT devices provide the maximum value in all environmental conditions [18], [19].

MATLAB/Simulink provides a powerful platform for modeling and simulating MPPT algorithms. The software allows for the creation of detailed models of the PV cells and the electrical circuitry of the system. MATLAB/Simulink also provides a range of simulation tools that can be used to test and analyze the behavior of MPPT algorithms under different conditions. One of the main advantages of using MATLAB/Simulink in MPPT PV systems is the ability to model and simulate the behavior of the PV cells under different irradiance and temperature conditions. This information can be used to design MPPT algorithms that can operate effectively under a wide range of conditions. MATLAB/Simulink can also be used to optimize the performance of MPPT algorithms. Optimization algorithms can be used to determine the optimal parameters for the MPPT algorithm, such as the step size and convergence criteria. One example of an optimization algorithm used in MPPT PV systems is the perturb and observe (P&O) algorithm. This algorithm adjusts the load resistance of the PV cells in small increments to find the maximum power point. MATLAB/Simulink can be used to simulate the behavior of the P&O algorithm and optimize its parameters for maximum efficiency.

In this research, the P&O algorithm was used as the MPPT algorithm because it is easy and straightforward to implement. This method is iterative. It is based on the ratio of the derivative of the output power to the result of the maximum capacity is 0. It calculates the output power by measuring the output current and voltage at regular intervals. Each measurement is compared with the previous size. An increase indicates that the maximum capacity is approached. If it starts to decrease, it means that it is moving away from the MPP. In this case, the point at which the maximum power is obtained is determined by going back.

Table 1. P&O algorithm used in MATLAB/Simulink design [20]

```
function D = PandO(Vpv, Ipv)
persistent Dprev Pprev Vprev
if isempty (Dprev)
    Dprev = 0.7;
    Vprev = 190;
    Pprev = 2000;
end
deltaD = 125e-6;
% Calculate measured array power
Ppv = Vpv*Ipv;
% Increase or decrease duty cycle nased on conditions
if (Ppv-Pprev) ~= 0
    if (Ppv-Pprev) > 0
        if (Vpv-Vprev) > 0
            D = Dprev- deltaD;
        else
            D = Dprev + deltaD;
        end
    else
        if (Vpv - Vprev) > 0
            D = Dprev + deltaD;
        else
            D = Dprev - deltaD;
        end
    end
end
else
    D = Dprev;
end
% update internal values
Dprev = D;
Vprev = Vpv;
Pprev = Ppv;
```

P&O is an easy and straightforward method to implement. However, the disadvantages, such as excessive oscillation around the MPP, especially under partial shading conditions, have led to the development of alternative methods [21]. The algorithm was added to the MATLAB Function element in the design and integrated into the software program. Current and voltage values taken from the panel are entered into the input of

the Function element. The duty data, which is output in the algorithm, is the processed panel current and voltage. The codes of the P&O algorithm are given in Table 1.

5. PROJECT DESIGN

In this study, a system design planned to be established in Ankara was made. The installed power in the design is determined as 75 kW. Two different software programs, PVsyst and MATLAB/Simulink, were used for system design. 216 PV with CSUN-350Wp-32V-72M were used in both programs. The array is designed so the panels are 12 in series and 18 in parallel. Huawei Sun2000-70 kW inverter in PVsyst database is operated. (In

MATLAB/Simulink, inverter circuit is designed by the user. Therefore, a different inverter circuit was intended.) The inverter circuit is also designed in MATLAB/Simulink. In addition, a design was made using MATLAB/Simulink without adding the MPPT algorithm. The PV designs are numbered: Design-1: PVsyst System, Design-2: MATLAB/Simulink with MPPT Algorithm, and Design-3: MATLAB/Simulink without MPPT Algorithm.

Monthly irradiance and temperature values for Ankara province were manually added to MATLAB/Simulink while they were available in PVsyst's database.

Table 2. Irradiation and temperature data for Ankara province [7]

Months	Monthly Avg. Radiation (kWh)	Monthly Avg. Daily Sunbathing Time (h)	Total Sunbathing Time (h)	Monthly Total Irradiance Average (W)	Monthly Average Temp. (°C)	Monthly Avg. PV Temp. (°C)
January	74.1	2.6	78	950.00	0.81	25.81
February	105.3	3.8	106.4	989.66	1.68	26.68
March	126.9	5.1	153	829.41	2.38	27.38
April	163.9	6.5	195	840.51	12.66	37.66
May	165.5	8.4	252	656.75	14.85	39.85
June	198.2	10	300	660.67	21.08	46.08
July	214.1	11.2	336	637.20	25.84	50.84
August	226.9	10.6	318	713.52	27.56	52.56
September	162.6	9.1	273	595.60	18.93	43.93
October	167	6.7	201	830.85	16.03	41.03
November	135.7	4.6	138	983.33	7.56	32.56
December	76	2.5	75	1013.33	1.43	26.43
Annual	151.35	6.76	202.75	746.49	12.62	37.62

The PVsyst database includes the data in Table 2. Monthly total irradiance average and PV average temperature data were manually entered into MATLAB/Simulink for each month one by one. In MATLAB/Simulink, the PV array element has two inputs for entering radiation and temperature data. Radiation and temperature values of each month are entered into these fields, and it is ensured that they work at the desired level. Switching the input data takes Current and voltage values at the output. The output power is obtained by multiplying these values with the product. While the energy injected into the grid is given in the report in PVsyst, the output received as power in MATLAB/Simulink is calculated into electrical energy by multiplying the monthly average sunshine duration. MATLAB/Simulink is mainly used for computation. It does not offer a design opportunity to be implemented concretely. Panel layout does not deal with information such as inverter location. PVsyst places the system based on geographic location. By adjusting the inclination of the panels, it is ensured to get the most efficiency from

the sun. It provides the opportunity to make a real design that can be implemented [22]. The panel tilt is set to 40° and the azimuth angle to 0°. According to this adjustment, 1900 kWh/m² solar radiation will fall globally on the system installed.

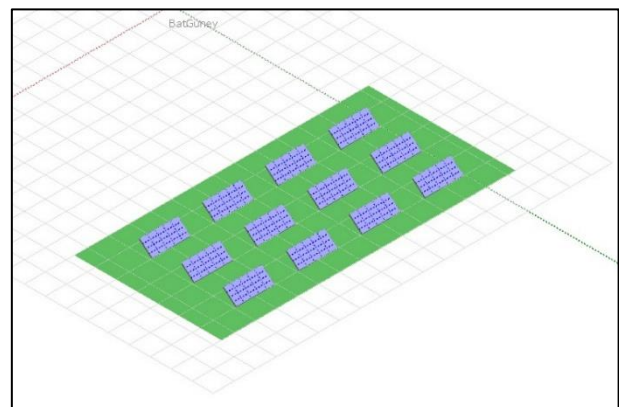


Figure 1. PVsyst PV layout

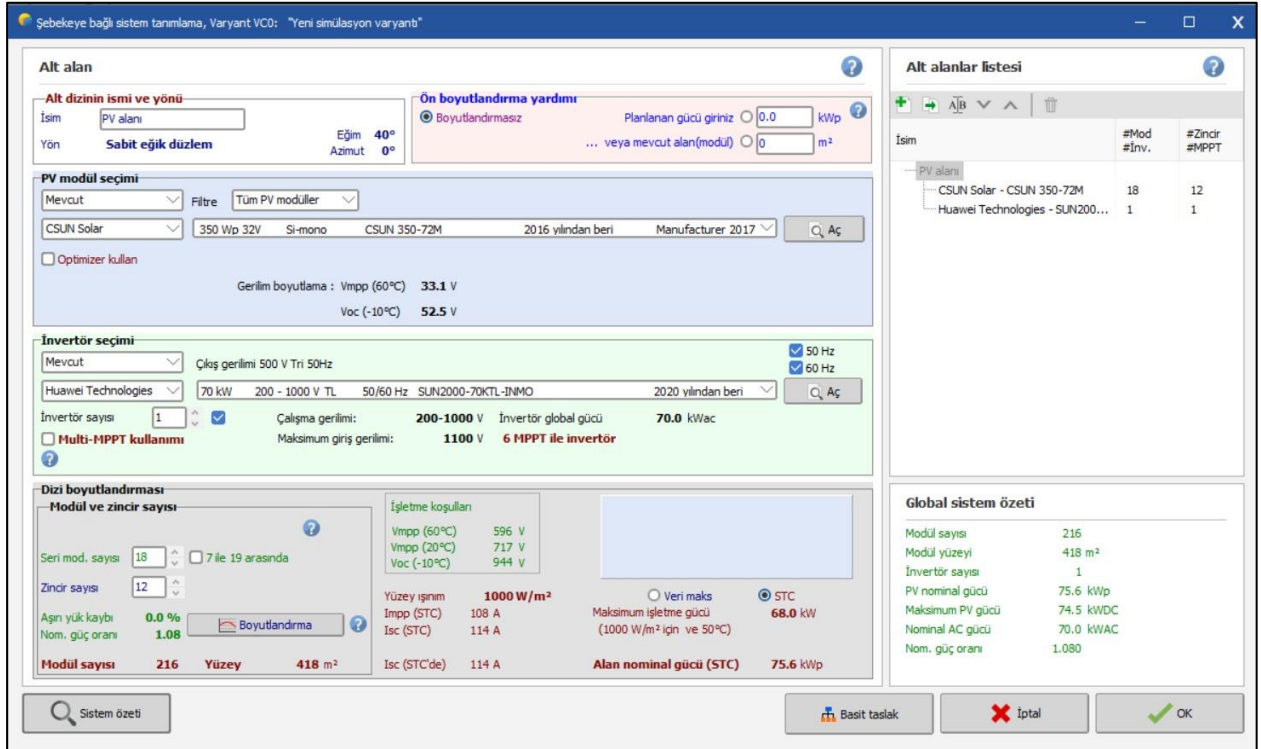


Figure 2. System Design-1

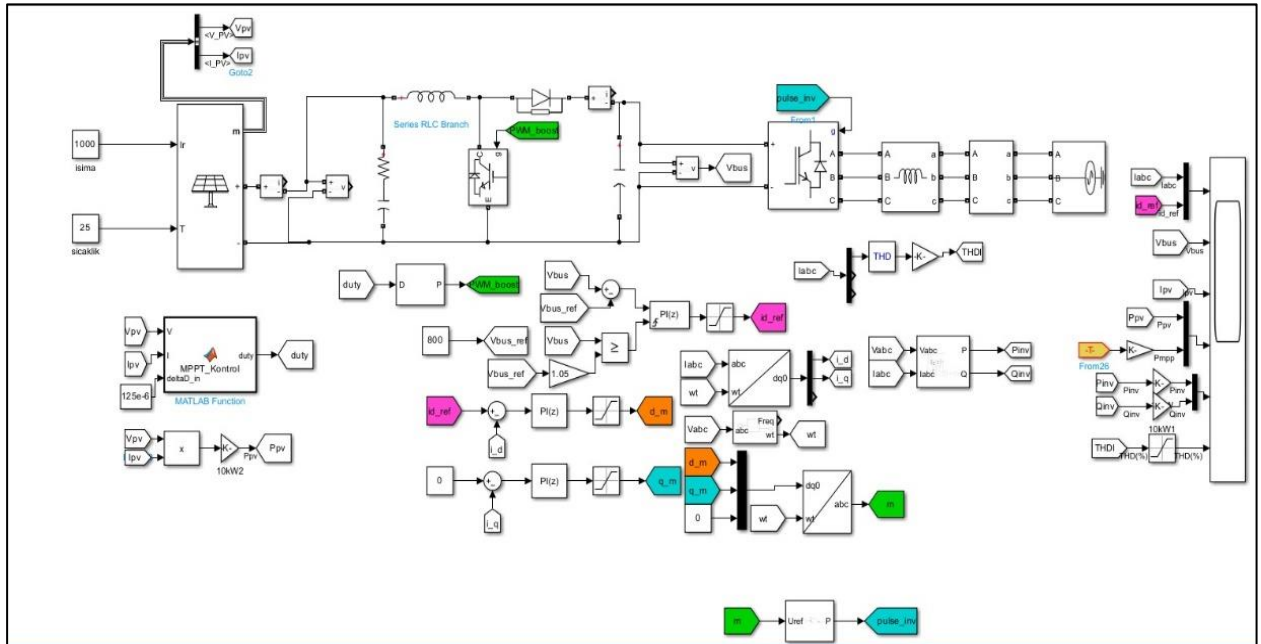


Figure 3. System Design-2

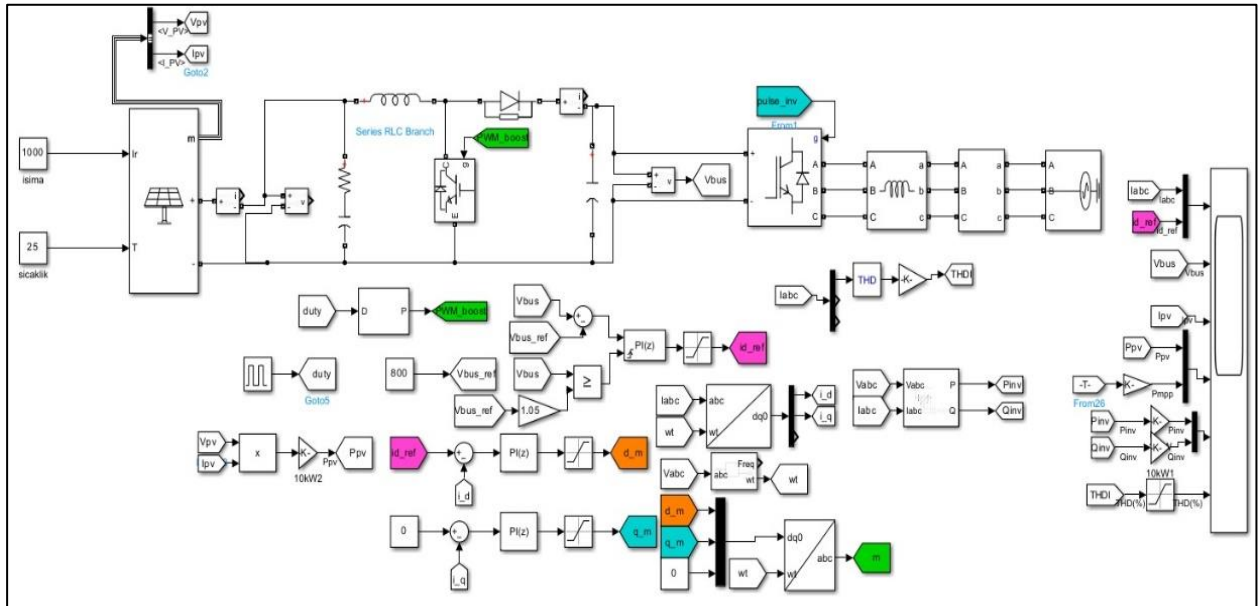


Figure 4. System Design-3

In MATLAB/Simulink, it is added to the PV panel data using a PV array. In this state, it is ensured that the panel generates electricity according to the operating

temperature and radiation values. By entering the monthly average irradiance and temperature values, the differences between them and PVsyst are revealed.

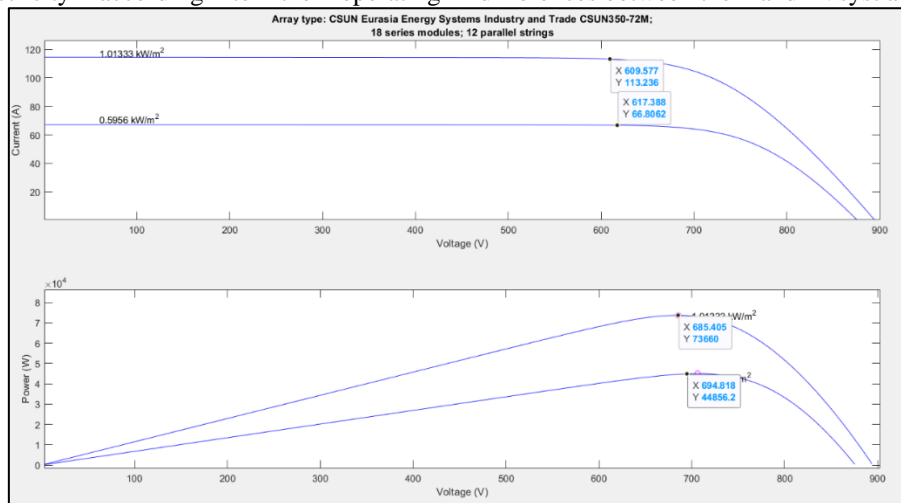


Figure 5. Csun panel array current-voltage and power-voltage curves in variable radiation

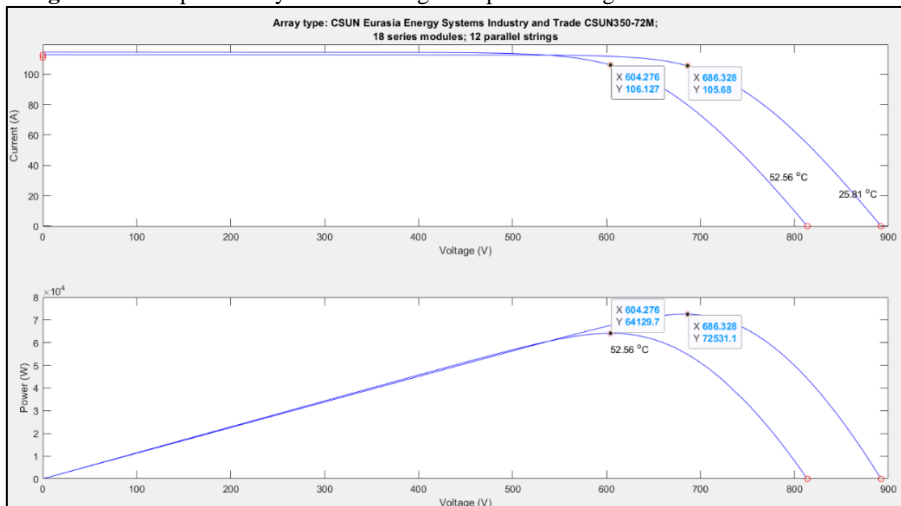


Figure 6. Csun panel array current-voltage and power-voltage curves in variable temperature

In Figure 5, the current, voltage, and power values that the PV array can produce according to the highest and lowest radiation values for the province of Ankara are given. For the highest irradiance 1013.33 W/m², the power to be generated is 73.66 kW, the current is 113.54 A and the voltage is 609.58 V; For the lowest radiation 595.6 W/m², the power to be produced is 44.87 kW, the current is 66.81 A, and the voltage is 617.39 V. In Figure 6, the voltage, current, and power values that can be produced for Ankara province according to the highest and lowest PV panel temperature values are given. For the highest temperature 52.56 °C, the power to be generated is 64.13 kW, the current is 106.13 A and the voltage is 604.67 V; For the lowest temperature 25.81, the power to be produced is 72.53 kW, the current is 686.33 A, and the voltage is 105.68 V.

Table 3. Csun PV panel parameters [23]

Maximum power (W)	337.185
Number of cells	72
Open circuit voltage, Voc (V)	49.7
Short circuit current, Isc (A)	9.25
The voltage at maximum power point ,Vmpp (V)	38.1

Table 3 continued. Csun PV panel parameters [23]

Current at maximum power point, Impp (A)	8.85
Open circuit temperature coefficient (%/°C)	-0.3269
Short circuit temperature coefficient (%/°C)	0.055103

6. RESULTS AND DISCUSSIONS

In MATLAB/Simulink designs, an inverter circuit is added to the PV array element. In the design in which the MPPT algorithm is used, the duty value, which is the output of the algorithm, is connected to the gate input of the IGBT by passing it through the PWM generator. In Design-2, pulse modulation is added to the gate input since there is no duty data. Outputs are taken as voltage and current, then the power data is obtained by multiplying by the product element. The highest power outputs were obtained in August, while the lowest was obtained in January.

The P&O algorithm is one of the most used algorithms because it is easy to implement in MPPTs. Although it is not suitable in all conditions, the MPPT algorithm provides quite high power compared to the unused situation. In Figure 7, The power change obtained within the 20-second period determined for the simulation is shown.

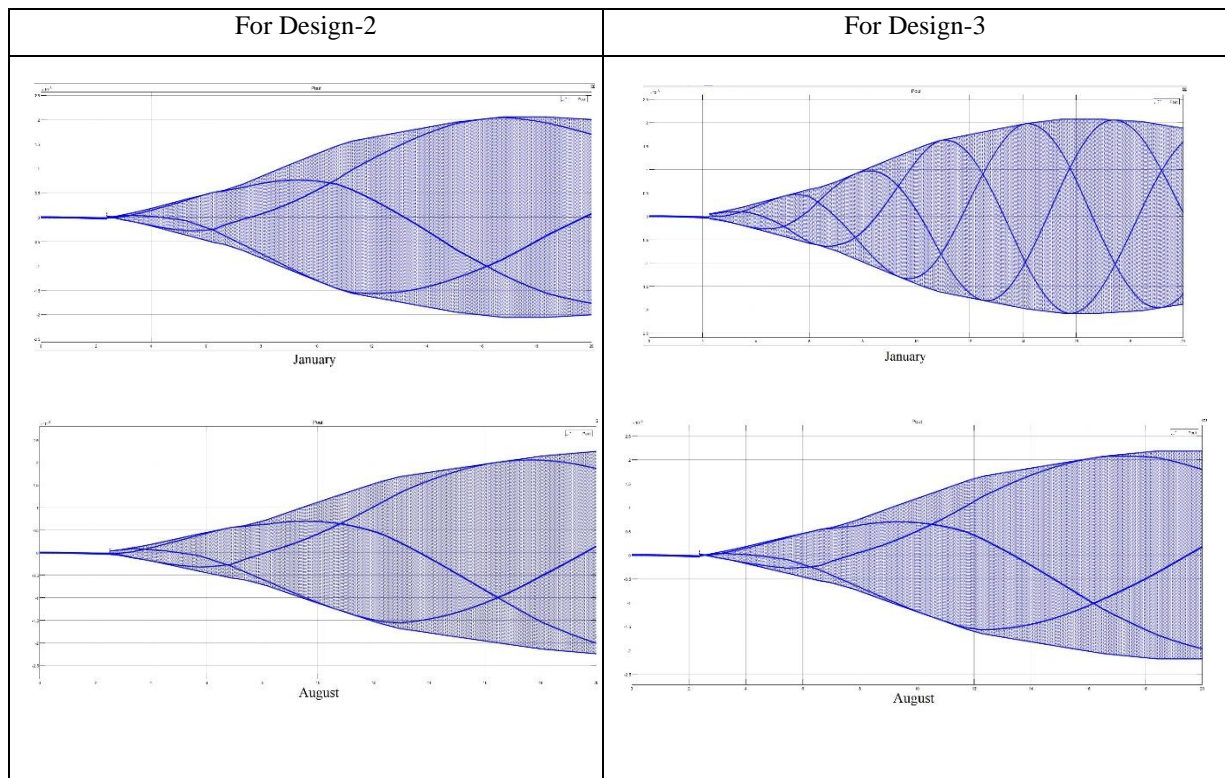


Figure 7. MATLAB/Simulink power-simulation in the first 20-second period graphics (January and August)

PVsyst can capture the radiation and temperature data of the selected location online. The same data is taken from the pages of the General Directorate of Meteorology and the Ministry of Energy. This data was manually added to the MATLAB/Simulink designs. The monthly average radiation duration for Ankara province in January is 950 W, the average PV temperature is 25.81 °C, and the total sunshine duration is 78 hours. The power to be transferred to the grid with this data is 5.43 kWh for PVsyst, 5.45 kWh for Design-2, and 4.23 kWh for Design-3.

In August, the monthly average radiation duration for Ankara province was 713.52 W, the average PV temperature was 52.56 °C, and the total sunshine duration was 318 hours. The power to be transferred to the grid with this data is 13.89 kWh for PVsyst, 15.38 kWh for Design-2, and 10.03 kWh for Design-3. When all these output data are examined, the design, including the MATLAB/Simulink MPTT algorithm, provides higher results. The variability of the MPTT algorithms and the fact that the radiation and sun exposure times are more prominent bring these results together.

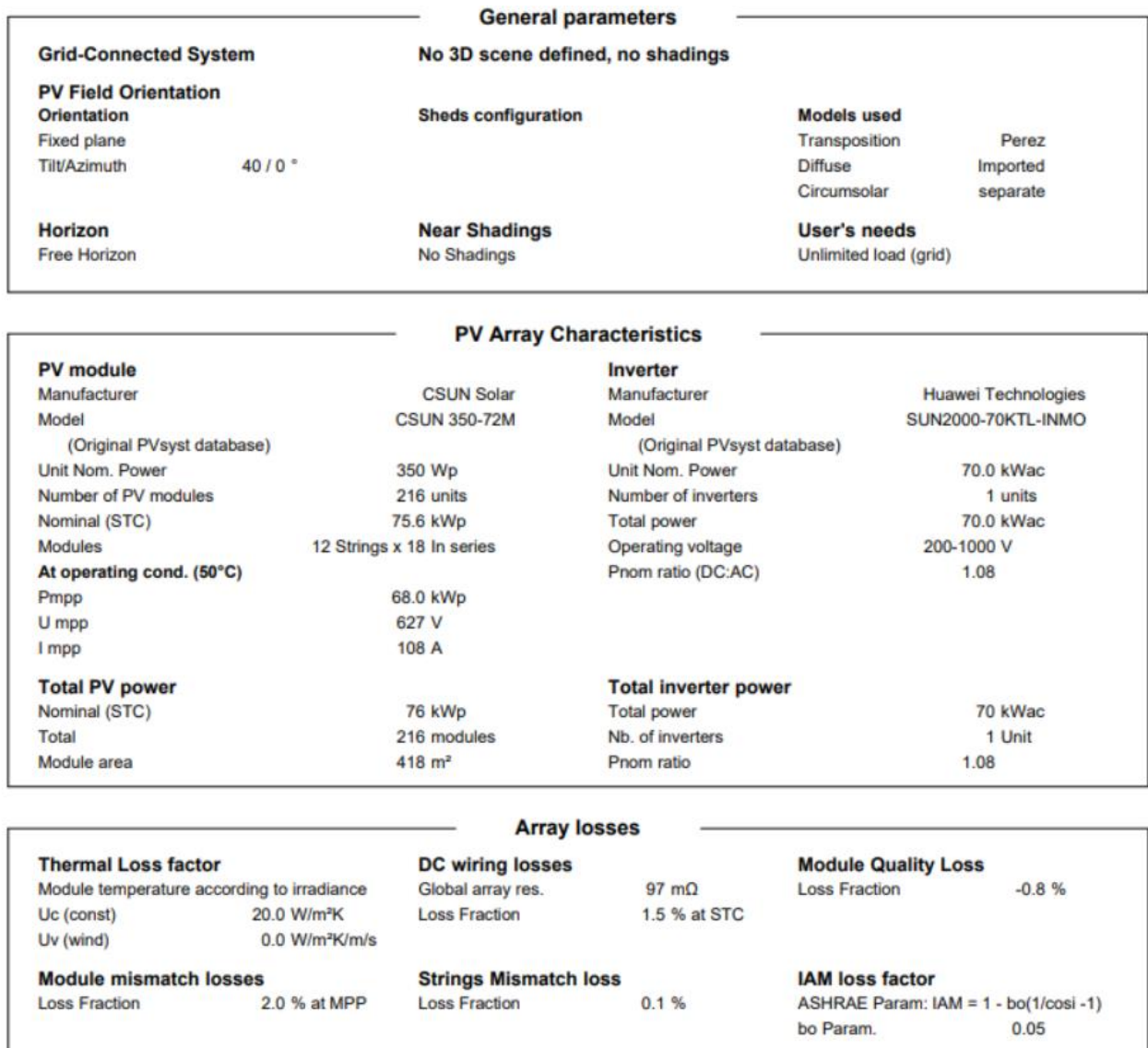


Figure 8. PVsyst general parameters, collector field characteristics, and array losses

The general parameters of the PV system are given in Figure 8. On this page, which is in the PVsyst result report, panel brand and operating values, inverter brand, and operating value are given. In addition, string losses

such as thermal loss factor, DC wiring loss, module quality loss, module mismatch loss, string mismatch loss, and IAM loss factor are calculated in order to find out the power to be transferred to the grid more clearly.

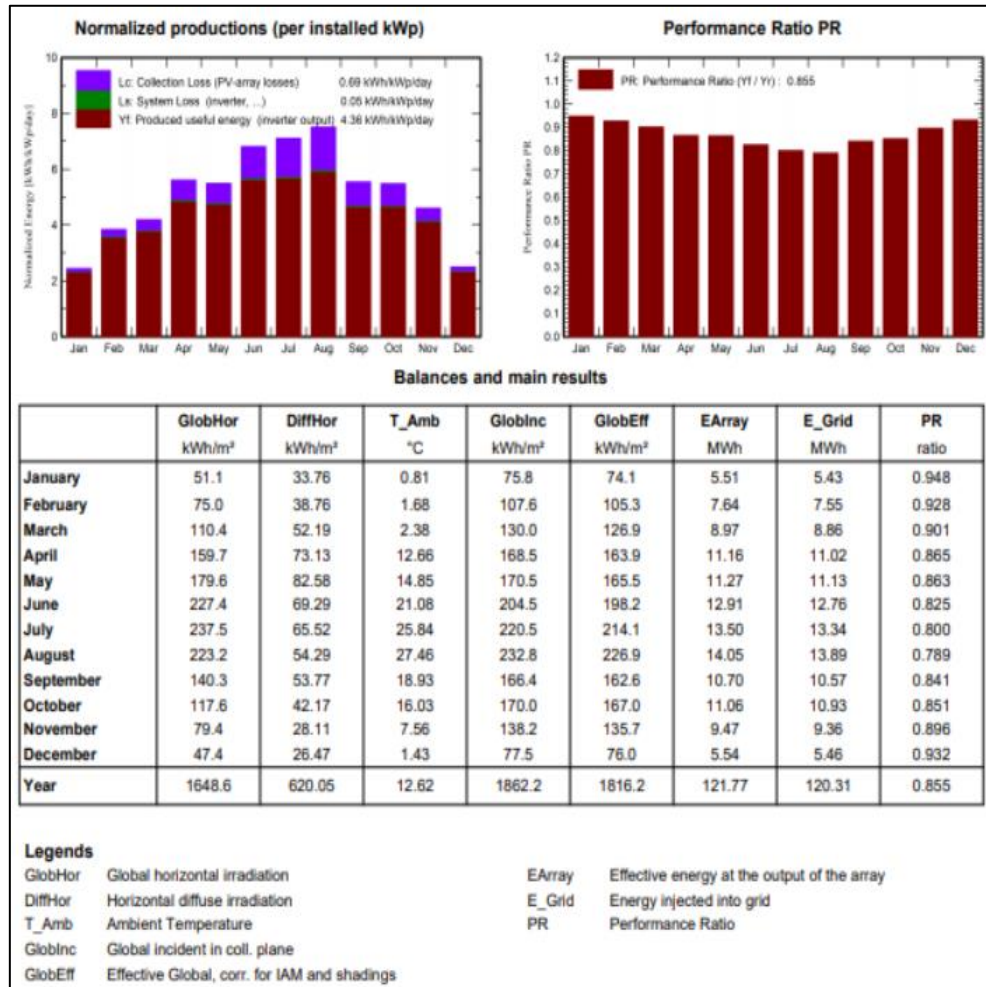


Figure 9. PVsyst overall results

Figure 9. Some data and output powers used by PVsyst are given. Data using ambient temperature irradiation values; the output power of the array is the energy output

data injected into the grid. The annual generated energy is 120.3 MWh, and the performance rate is 85.45%.

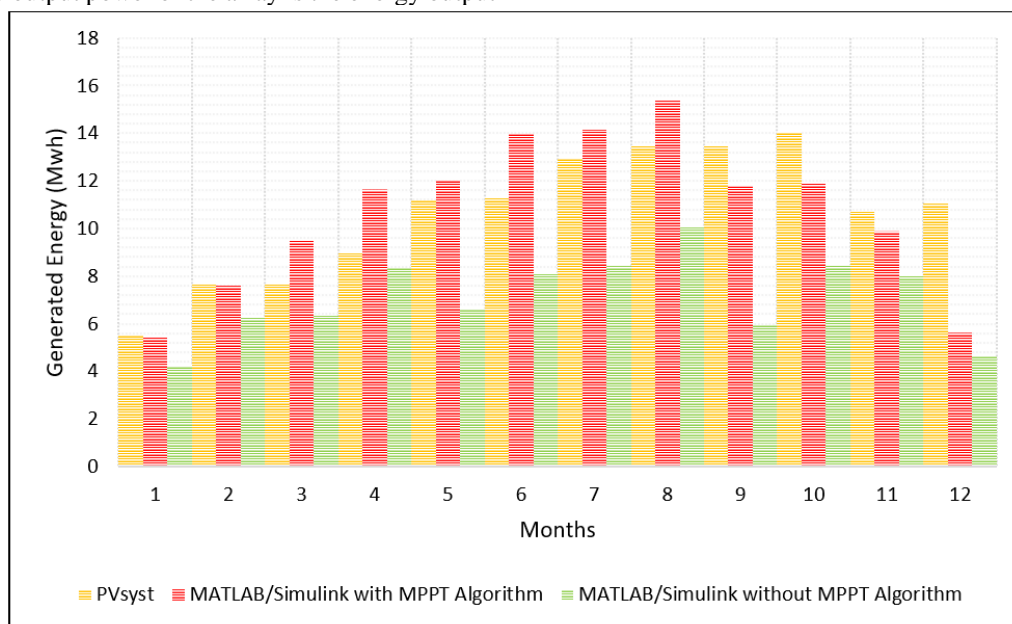


Figure 10. Monthly generated electricity energy graph according to the software used

As a result of the designs made, the output data of the design containing the MATLAB/Simulink MPPT algorithm is higher than Design-1 and Design-3. The

output data of the Design-3 is relatively low. This shows that the output power can be increased by using more effective algorithms.

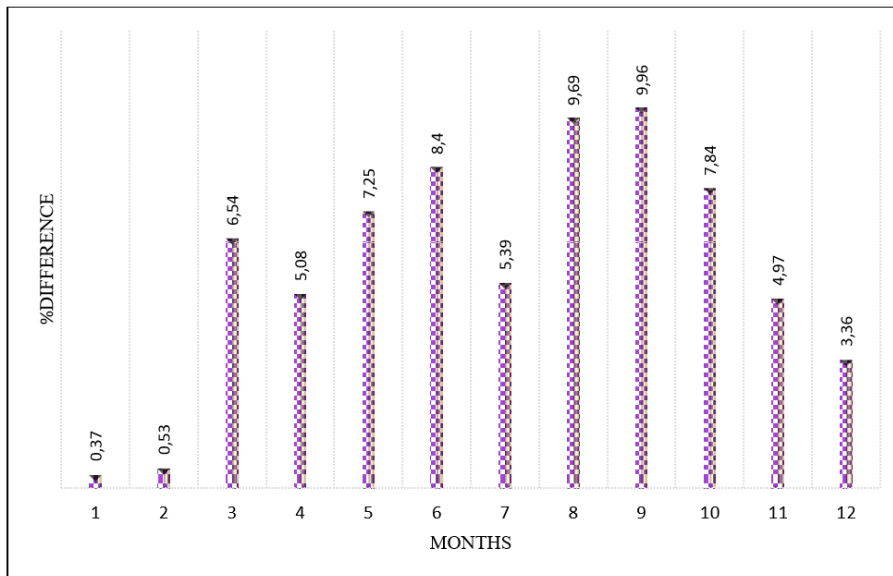


Figure 11. Design-1 and Design-2 percent difference graph

The percentage differences of Design-2 are given in Figure 12 compared to the Design-1. These differences are 0.37% in January, 0.53% in February, 6.54% in March, 5.08% in April, 7.25% in May, 8.40% in June,

5.39% in July, and August. It was calculated as 9.69%, 9.96% in September, 7.84% in October, 4.97% in November and 3.36% in December.

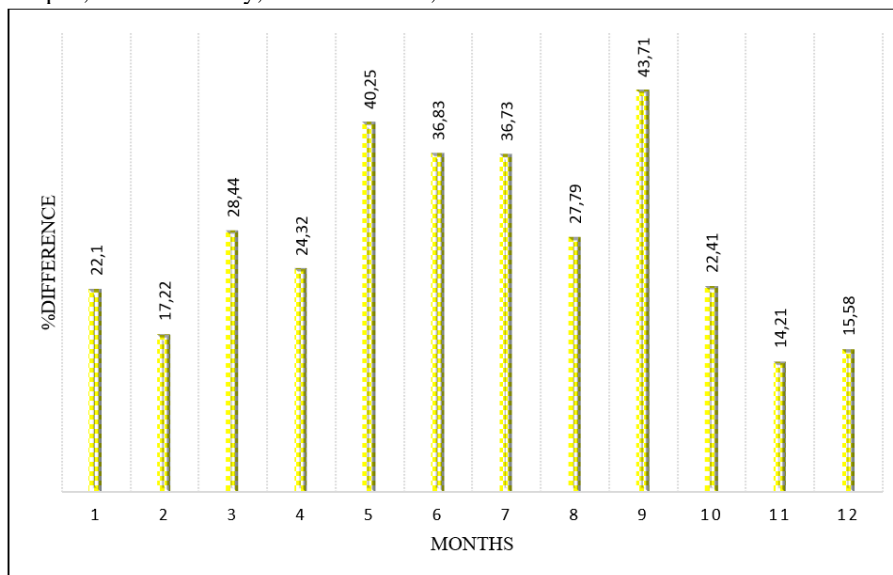


Figure 12. Design-1 and Design-3 percent difference graph

The percentage differences of the Design-1 given in Figure 13 compared to the Design-3. These differences are 22.1% in January, 17.22% in February, 28.44% in March, 24.32% in April, 40.25% in May, 36.83% in June,

36.73% in July, and August. It was calculated as 27.79%, 43.71% in September, 22.41% in October, 14.21% in November and 15.58% in December.

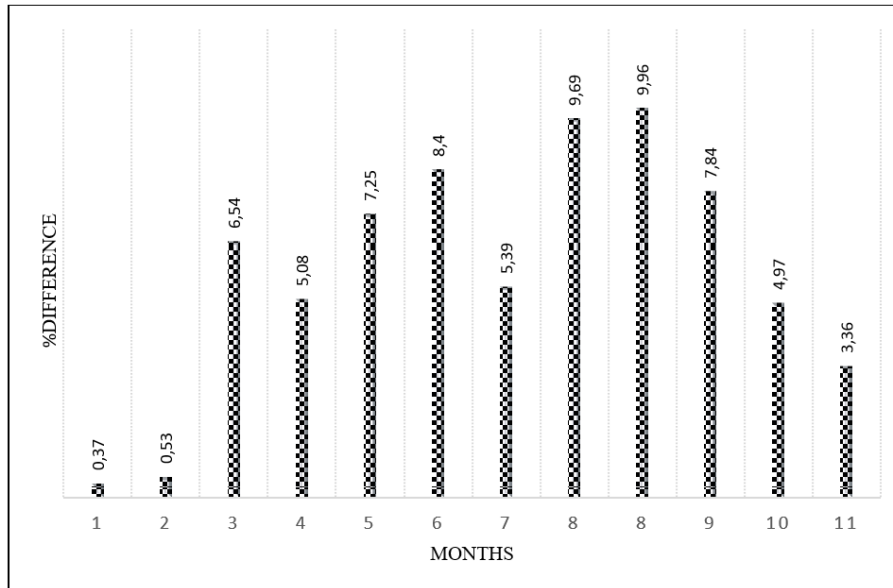


Figure 13. Design-2 and Design-3 percent difference graph

The percentage differences of Design-3 are given in Figure 13 compared to Design-2. These differences are 22.38% in January, 17.65% in February, 33.12% in March, 28.16% in April, 44.58% in May, 42.14% in June, 40.14% in July, and August. It was calculated as 34.78%, 49.32% in September, 28.5% in October, 18.48% in November and 18.41% in December.

6.1. Regression Analysis

Regression analysis encompasses a suite of statistical methodologies employed in statistical modeling to gauge the connections between a reliant variable and one or multiple autonomous variables. In the current context of solar energy systems, regression analysis plays a pivotal role in elucidating the associations among diverse parameters. It serves as a valuable tool for approximating the influence of solar radiation and temperature on solar energy generation [24]. In this section, the correlation of temperature and radiation parameters for three designs will be made by multiple regression analysis.

For Design-1, the multiple R (correlation coefficient) is close to 1 (0.998), indicating a strong linear relationship between the analyzed variables. The R Square (R^2) value of 0.996 suggests that the independent variables can explain approximately 99.6% of the variability in the dependent variable. The Adjusted R Square, which accounts for the number of predictors, is also relatively high at 0.995. The standard error of 0.189758065 represents the precision of the regression estimates, and a lower value is preferable. Design-2 exhibits similar characteristics, with a high multiple R (0.996) and a robust R Square value of 0.992. This suggests that the independent variables have a significant explanatory power over the dependent variable. The Adjusted R Square of 0.990 takes into account the model complexity. The standard error of 0.318585199 is slightly higher than in Design-1, indicating somewhat less precise estimates but still quite good. Design-3 exhibits a lower multiple

R-value of 0.907, indicating a less strong linear relationship than the previous designs. The R Square (R^2) value of 0.823 suggests that approximately 82.3% of the variability in the dependent variable can be explained by the independent variables in this design. The Adjusted R Square accounts for model complexity and is also lower at 0.784. The standard error is relatively high at 0.804, indicating less precise estimates than the previous designs.

In summary, the regression statistics provide insights into how well the regression models fit the data for each of the three designs. Design-1 and Design-2 exhibit extreme fits, with high R Square values and low standard errors, while Design-3 shows a somewhat weaker fit with a lower R Square value and a higher standard error. These statistics help assess the quality and reliability of the regression models for each design.

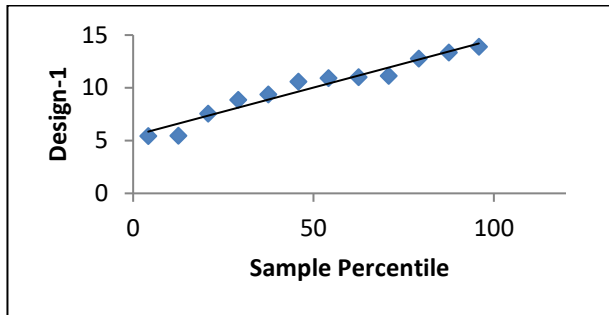
The "Avg. monthly irradiance" coefficient is 0.068192217 with a very small standard error of 0.004056628. The t-statistic is 16.81007594, and the p-value is 4.17857E-08 (close to zero). This indicates that in Design-1, "Avg. monthly irradiance" is highly statistically significant, and there is strong evidence that it has a significant positive effect on the dependent variable. The "Avg. monthly temperature" coefficient is -0.063718877 with a standard error of 0.020729908. The t-statistic is -3.073765569, and the p-value is 0.013272982. In Design-1, "Avg. monthly temperature" is statistically significant, and there is evidence of a significant negative effect on the dependent variable. The "Avg. monthly irradiance" coefficient is 0.072148321 with a standard error of 0.00681068. The t-statistic is 10.59340893, and the p-value is 2.21011E-06 (close to zero). This indicates that in Design-2, "Avg. monthly irradiance" is highly statistically significant, and there is strong evidence that it has a significant positive effect on the dependent variable. The "Avg. monthly temperature"

coefficient is -0.041275939 with a standard error of 0.034803484. The t-statistic is -1.185971471, and the p-value is 0.265998593. In Design-2, "Avg. monthly temperature" is not statistically significant as its p-value is greater than 0.05. The "Avg. monthly irradiance" coefficient is 0.061026639 with a standard error of 0.017189124. The t-statistic is 3.550305249, and the p-value is 0.00621292. In Design-3, "Avg. monthly irradiance" is statistically significant, with evidence of a significant positive effect on the dependent variable. The "Avg. monthly temperature" coefficient is -0.164280202 with a standard error of 0.087838718. The t-statistic is -

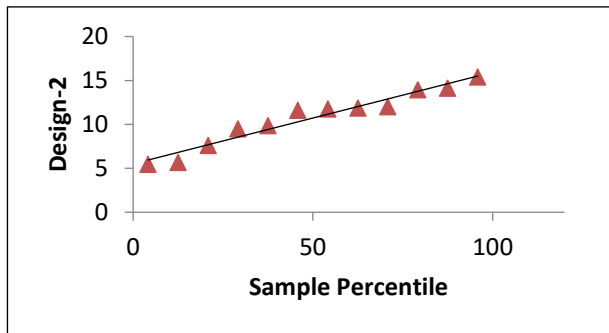
1.870248177, and the p-value is 0.094261296. In Design-3, "Avg. monthly temperature" is not statistically significant as its p-value is greater than 0.05.

In summary, the independent variables for Design-1 and Design-2 are statistically highly significant and consistent with the dependent variable. However, in Design-3, the independent variables are not statistically significant on the dependent variable, which shows that temperature and radiation values may not significantly affect the dependent variable for this design. This is due to the incompleteness of the MPPT algorithm.

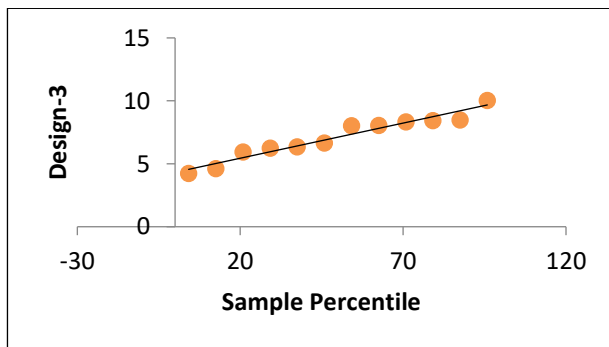
Normal Probability Plot



<i>Regression Statistics</i>	
Multiple R	0.998127438
R Square	0.996258382
Adjusted R Square	0.995426912
Standard Error	0.189758065
Observations	12



<i>Regression Statistics</i>	
Multiple R	0.995977857
R Square	0.991971891
Adjusted R Square	0.990187867
Standard Error	0.318585199
Observations	12



<i>Regression Statistics</i>	
Multiple R	0.907175213
R Square	0.822966868
Adjusted R Square	0.783626172
Standard Error	0.804060749
Observations	12

Figure 14. Regression Statistics and Normal Probability Plots for Design-1, Design-2 and Design-3

Table 4. Regression Results for Avg. Monthly Irradiance and Avg. Monthly Temperature Across Three Designs.

		<i>Coefficients</i>	<i>Standard Error</i>	<i>t Stat</i>	<i>P-value</i>
<i>Design-1</i>	Avg. monthly irradiance	0.068192217	0.004056628	16.81007594	4.17857E-08
	Avg. monthly temperature	-0.063718877	0.020729908	-3.073765569	0.013272982
<i>Design-2</i>	Avg. monthly irradiance	0.072148321	0.00681068	10.59340893	2.21011E-06
	Avg. monthly temperature	-0.041275939	0.034803484	-1.185971471	0.265998593
<i>Design-3</i>	Avg. monthly irradiance	0.061026639	0.017189124	3.550305249	0.00621292
	Avg. monthly temperature	-0.164280202	0.087838718	-1.870248177	0.094261296

7. CONCLUSIONS

In this study, a PV system with 75 kW installed power was designed using two different software programs, PVsyst and MATLAB/Simulink, using the radiation, temperature, and sunshine duration data of Ankara province. Two designs were made in MATLAB/Simulink, using the MPPT algorithm and not using the MPPT algorithm. Regression analysis was performed by comparing the output data with each other, determining which aspect was advantageous or disadvantageous. The highest energy produced in each design is provided in August, and the lowest power is provided in January. The energy produced by Design-2 is much higher than by Design-1, especially in the months of May, June, July, August, and September, when the sunshine duration is increased. In other months, the difference decreases as the sunshine duration is shortened. Considering September, Design-3 has the lowest energy value due to low radiation and temperature.

- According to the designs, annual energy production in megawatt-hours (MWh) was obtained as follows: Design-1 of 120.31 MWh, Design-2 of 128.62 MWh, and Design-2 of 85.45 MWh.
- Percentage differences per year; It is 6.46% between Design-2 and Design-1, 28.97% between Design-3 and Design-1, and 33.56% between Design-2 and Design-3.
- Comparing Design-1 and Design-2 monthly results, the highest difference belongs to September with 9.96%, and the lowest difference belongs to January with 0.37%. The reason why these differences are variable is that software programs process radiation and temperature values differently.
- Comparing Design-1 and Design-3 monthly results, the highest difference belongs to September with 43.71%, and the lowest difference belongs to November with 18.48%. These differences are mainly variable because the inverter in the PVsyst has MPPT. In this way, PVsyst is able to operate the system at a higher power level.

- Comparing Design-2 and Design-3 monthly results, the highest difference belongs to September with 49.32%, and the lowest difference belongs to February with 17.65%. The reason why these differences are variable is the MPPT algorithm. The fact that MPPT algorithms are variable means that the differences between them are also variable.
- The temperature and radiation values of Design-1 and Design-2 are statistically highly significant and consistent with the dependent variable. However, in Design-3, temperature and radiation values are not statistically significant on energy production. This is due to the incompleteness of the MPPT algorithm.
- PVsyst software presents the output data in a report. It presents MATLAB/Simulink output data with used elements such as scope and display. PVsyst software is more suitable for commercial use because it is easy to design, contains data about the location, makes economic feasibility besides energy production, and has panels and inverters ready in the database. At the same time, it can make a kind of three-dimensional design that can be implemented. It provides the whole design to be completed and calculated.
- Pvsyst is more suitable for commercial purposes due to the three-dimensional design of an SPP, the availability of geographic location data, and the calculation of losses. The most significant advantage of MATLAB/Simulink is that inverter and panel design can be made at desired values, and MPPT algorithms can be diversified.
- The inability to control the MPPT in PVsyst is a disadvantage. Some work should be done in this regard.

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DECLARATION OF ETHICAL STANDARDS

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

AUTHORS' CONTRIBUTIONS

Oğuz Kaan ÇİNİCİ: Carried out literature research, methodology, PVsyst analysis of results and writing of the study.

Büşra KARACA: Carried out literature research, methodology, PVsyst analysis of results and writing of the study.

Adem ACIR: Made comments and evaluations after the analysis.

CONFLICT OF INTEREST

There is no conflict of interest in this study.

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