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Research Article

Photovoltaic Panel Efficiency Estimation with Artificial Neural Networks: Samples of Adiyaman, Malatya, and Sanliurfa

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The amount of electric energy produced by photovoltaic panels depends on air temperature, humidity rate, wind velocity, photovoltaic module temperature, and particularly solar radiation. Being aware of the behaviour patterns of the panels to be used in project and planning works regarding photovoltaic applications will set forth a realistic expense form; therefore, erroneous investments will be avoided, and the country budget will benefit from added value. The power ratings obtained from the photovoltaic panels and the environmental factors were measured and recorded for a year by the measurement stations established in three diverse regions (Adiyaman-Malatya-Sanliurfa). In the developed artificial neural network models, the estimation accuracy was 99.94%. Furthermore, by taking the data of the General Directorate of Meteorology as a reference, models of artificial neural networks were developed using the data from Adiyaman province for training; by using Malatya and Sanliurfa as test data, 99.57% estimation accuracy was achieved. With the artificial neural network models developed as a result of the study, the energy efficiency for the photovoltaic energy systems desired to be established by using meteorological parameters such as temperature, humidity, wind, and solar radiation of various regions anywhere in the world can be estimated with high accuracy.

1. Introduction

Humanity has been constantly searching for different sources of energy since ancient times. Today, due to population growth and industrialisation, the demand for electricity is rapidly increasing day by day. However, the fact that a large part of the electric energy obtained is supplied from fossil fuels (such as petroleum, natural gas, and coal) leads to environmental problems. Moreover, the fact that these fuels will soon be used up revealed the need for renewable energy sources, which are eco-friendly and inexhaustible energy sources.

In recent years, solar energy has provided a great solution for the energy needs of the world and for environmental problems. Besides, the fact that solar energy is clean, inexhaustible, and easy to use makes it more efficient among other renewable energy sources. This type of prominent energy among the self-renewing energies will maintain its efficiency for the years to come. Photovoltaic systems are systems that can meet all or some of the electricity consumption needs of the structures by converting solar energy without consuming limited nonrenewable resources. The fact that our country is among the world's richest countries in terms of solar energy potentially greatly enhances the popularity of these systems in our country.

Energy can be directly and indirectly obtained from solar energy. Solar cells, which are the smallest units of the photovoltaic (PV) systems from these methods, directly convert sunlight to DC voltage. Serial and/or parallel-connected solar cells form the PV module. By serial-parallel connecting PV modules, electric energy is obtained at the desired current, voltage, and power rating [1]. Depending on the semiconductor material of the panel, the PV panel converts solar energy to electrical energy with 6%-22% efficiency. There are many factors affecting the efficiency of PV panels with

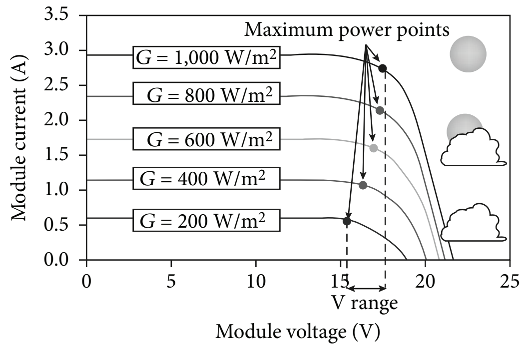


Figure 1: The effect of solar radiation on PV cells [8].

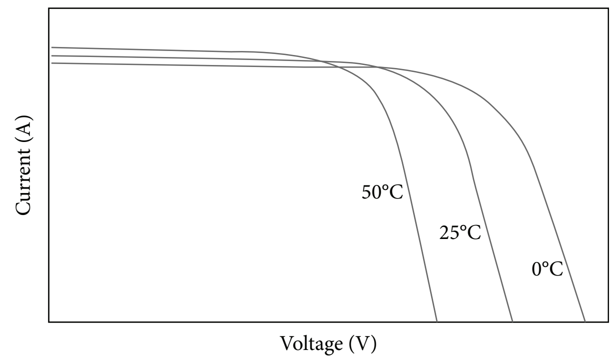


Figure 2: The effect of temperature on PV cells [10].

low efficiency. These are panel slope angle, shading, temperature, solar radiation intensity, PV temperature, wind velocity, humidity, and other losses [2, 3]. Among these factors, solar radiation intensity, temperature, wind velocity, humidity, and module temperature are the most important parameters affecting panel efficiency. Changes in atmospheric conditions such as solar radiation intensity and temperature during the day considerably affect panel efficiency. Thus, it is important to know the effect of environmental factors on the panel efficiency depending on the changing atmospheric conditions and estimate the power to be generated. The values indicated on the PV panels give the electrical values of the panel under 1000 W/m^2 solar radiation intensity, 25°C cell temperature, and A.M. 1.5 air mass ratio conditions, which are called standard test conditions (STC), as a result of tests performed in the laboratory. In the case of changes outside the STC, the electrical values of the PV panel are unknown [4–6]. Environmental factors should be taken into account when determining the correct method for evaluating the annual performance of PV systems [7].

2. Solar Radiation Effect on PV Cells

The energy radiated directly from the sun is 174 petawatt (PW), and 10 PW of it is reflected from the atmosphere, 35 PW from the clouds, and 7 PW from the surface of the earth back into space. The part absorbed by the atmosphere is 33 PW, and the part absorbed by the land and sea is about 89 PW.

Solar radiation has the greatest effect on power output in PV systems. Photocurrent (PV short-circuit current) amplitude varies in direct proportion to solar radiation. Photoconversion efficiency in the practical working range of the PV cell is not affected much by changes in solar radiation. However, this does not mean that the same power will be obtained, since the accumulated energy during a cloudy day will be low—i.e., since the input power decreases (output is constant) the output power also decreases. Additionally, the current generated in the PV panel increases with the sunlight intensity and radiation [8, 9]. Although the significant change in radiation considerably changes the current, the voltage remains nearly constant (Figure 1) [8].

The value of solar radiation reaching the earth is considered as approximately 1000 W/m^2. Since Turkey is located in the northern hemisphere between 36° and 42° latitudes, its solar energy potential is quite high. The annual solar energy potential of Turkey is equal to 1.3 billion tonnes of oil. It has been found that Turkey's average annual total sunshine duration is 2640 hours; the average total radiation intensity is 3.6 kWh/m^2 per day.

3. Temperature and Humidity Effect on PV Cells

The operating temperature of the photovoltaic cells varies in a wide range, depending on the various usage areas. Therefore, the effect of temperature on the efficiency of the photovoltaic cell should be known. The photovoltaic cell short-circuit current tends to increase slightly as the temperature increases. The reason is that with the increase in temperature, the semiconductor forbidden gap is reduced and consequently it is increased with radiation absorption [10]. Because the change in temperature affects the open-circuit voltage more, high-operating temperatures negatively affect power and efficiency in PV systems. The efficiency of the cell decreases with increasing temperature.

In Figure 2, the effect of temperature on the current-voltage (I-V) curve of crystalline silicon cell PV modules is shown. Each 1°C increase in temperature reduces the power obtained by 0.5%. The excess water vapour in the atmosphere causes the radiation to be screened. When the water in the air is condensed in the form of rain and snow, the atmosphere is clearer and the radiation is blocked at the minimum level [11].

4. Wind Velocity Effect on PV Cells

Weather conditions affect power output in energy production. Module temperature is affected by ambient temperature, cloudiness, wind velocity, and position of the PV system. Since the wind velocity will decrease the temperature of the PV panel, the PV cell temperature is highly sensitive to wind velocity and lowly sensitive to wind direction [12].

In the literature scanning regarding the subject, in the study called structural properties and characteristics of the photovoltaic solar cells published by Altaş, the way output voltage and currents change under load according to temperature and light intensity were examined, and it has been determined that the photovoltaic batteries are negatively

(a) (b) (c)

Figure 3: Application images of terminal measurement station (a) Adiyaman, (b) Malatya, and (c) Sanliurfa.

affected by the temperature. As the temperature increases, the output voltage and power of the photovoltaic battery decreases [13].

As a result of the study carried out by Yilmaz et al., it has been indicated that as ambient temperature increases, the efficiency of the photovoltaic modules decreases. The power generated in the temperature zone to which the photovoltaic modules are exposed is not linear. Photovoltaic modules are exposed to sunlight; they absorb the infrared rays generated by the sun and get heated. Also, the dark-coloured modules reach quite high temperatures as 80°C when no wind is blowing [14]. In the study carried out by Fesharaki et al., a

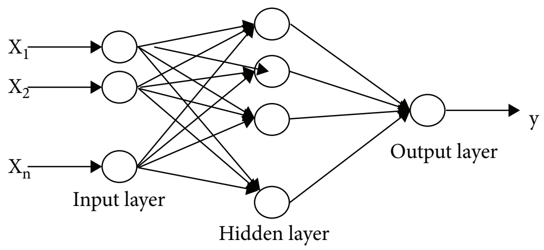


Figure 4: Model of artificial neural networks [29].

Table 1: ANN algorithm estimation results in Adiyaman.

Months	ANN algorithms					
	trainbfg	trainbr	traincgb	traincgf	trainrp	trainlm
August	0.9966	**0.9980**	0.9966	0.9963	0.9956	0.9975
October	0.9957	**0.9984**	0.9963	0.9967	0.9965	0.9982
January	0.9943	**0.9970**	0.9939	0.9947	0.9935	0.9970
April	0.9852	**0.9889**	0.9842	0.9852	0.9845	0.9869

Table 2: ANN algorithm estimation results in Malatya.

Months	ANN algorithms					
	trainbfg	trainbr	traincgb	traincgf	trainrp	trainlm
August	0.9990	**0.9994**	0.9981	0.9987	0.9987	0.9992
October	0.9978	**0.9986**	0.9970	0.9975	0.9964	0.9984
January	0.9889	**0.9936**	0.9889	0.9888	0.9863	0.9919
April	0.9935	**0.9957**	0.9934	0.9933	0.9911	0.9948

Table 3: ANN algorithm estimation results in Sanliurfa.

Months	ANN algorithms					
	trainbfg	trainbr	traincgb	traincgf	trainrp	trainlm
August	0.9982	**0.9991**	0.9983	0.9984	0.9980	**0.9991**
October	0.9948	**0.9977**	0.9952	0.9947	0.9937	0.9969
January	0.9631	**0.9936**	0.9563	0.9662	0.9332	0.9830
April	0.9979	**0.9989**	0.9980	0.9984	0.9975	0.9988

simulation was carried out by especially considering the cloudy weather conditions, and as a result of the simulation, it has been demonstrated that the efficiency of the photovoltaic panels decreases with the increase in temperature [15]. Omubo-Pepple et al. examined the effects of temperature, sunlight intensity, and relative humidity on photovoltaic panels. In the study, they stated the ambient temperature had no direct effect on the efficiency of the panel; however, panel temperature and relative humidity affected the efficiency of the panel [16]. Skoplaki and Palyvos examined the relationship between temperature and electrical performance of the photovoltaic panels. As a result, they have stated the panel's operating temperature is the most important factor in the photovoltaic conversion process. Furthermore, it has been indicated that the effect of temperature varies according to the way panels are assembled and the places where they are used [17].

To increase the efficiency of the photovoltaic panels, generally the methods of Perturb & Observe (P&O), Hill Climbing, Incremental Conductance (IncCond), Fractional VAD, and Fractional IKD are used to monitor the maximum power point of a PV system usually under the same sunshine conditions [18, 19]. However, the mentioned maximum power point monitoring methods are the methods that can be applied to homogenous operating conditions, where all the PV modules and cells have the same radiation. The rapid changes in solar radiation and the effects of other environmental factors disturb this and reduce efficiency.

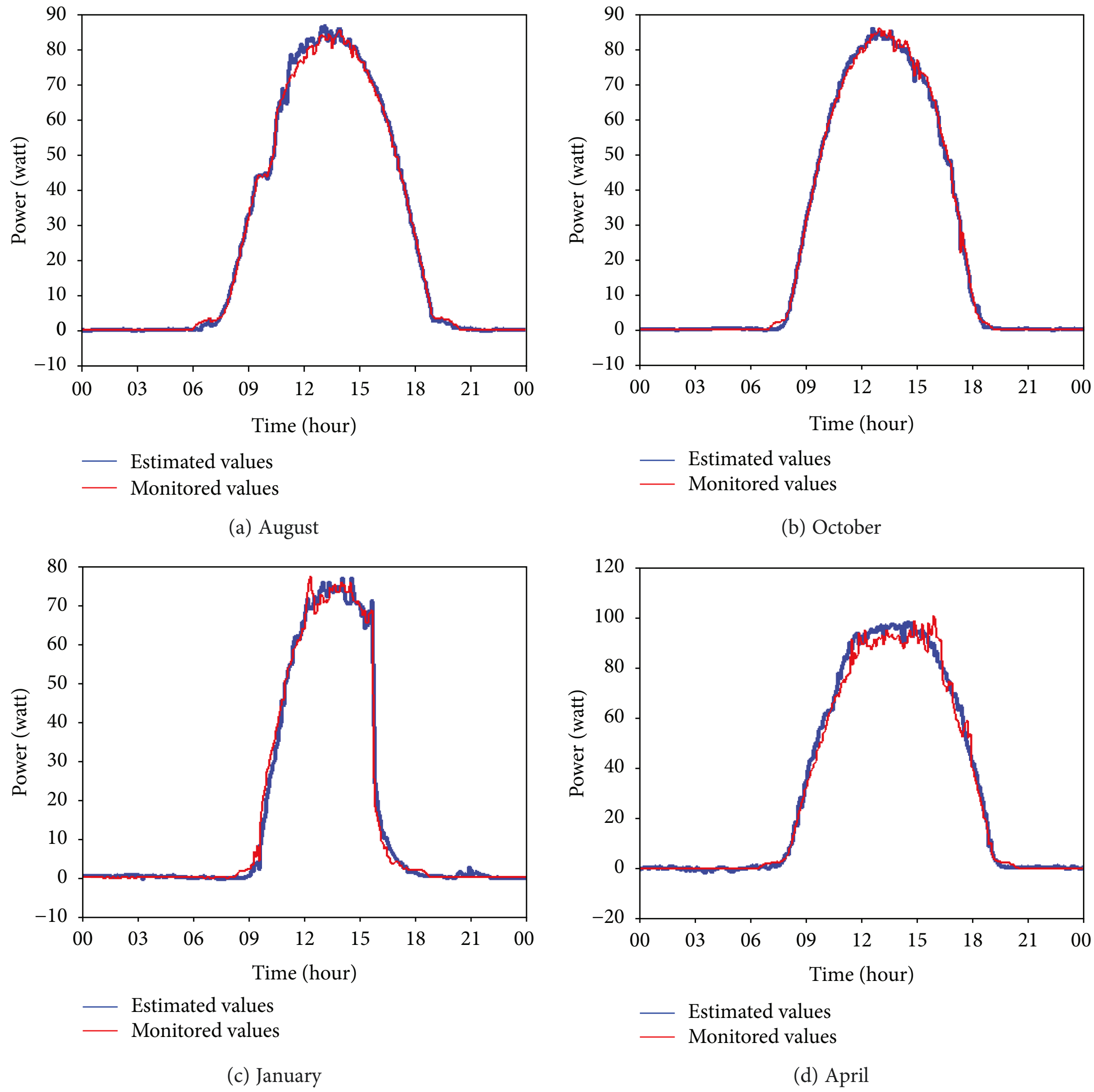
Prediction of the efficiency that can be obtained from environmental factors in areas where photovoltaic power systems will be installed plays a critical role in avoiding erroneous installation and prevention of unnecessary investments. Artificial neural network applications—such as estimation and modelling of daily solar radiation data by using sunshine duration and temperature data in the photovoltaic power system [20], radial basis function for the estimation of output characteristic of the photovoltaic module by using solar radiation and temperature [21], performance estimation by using solar radiation in an on-grid-connected photovoltaic power system [22], estimation of power output by using solar radiation and temperature in a 1 MW solar power plant [23], estimation of the power for the photovoltaic system a day ahead by using the solar radiation parameter [24], use of solar radiation and temperature parameters as input for performance estimation of a 20 kWp grid-connected photovoltaic plant [25], modelling by using temperature and solar radiation and neighbouring photovoltaic system data in power estimation [26] and estimation of module temperature and efficiency of the photovoltaic modules for all regions in Turkey by using ambient temperature and solar radiation [27], and estimating the efficiency of a photovoltaic cell of 4.2 V-100 mA depending on wind velocity, temperature, humidity, and horizontal angle of the cell [28]—draw attention.

Temperature and solar radiation were generally used as input criterion in these studies. However, the influence of humidity, wind, and module temperature parameters is extremely important. Examining the effect of solar radiation, temperature, wind, humidity, and module temperature on photovoltaic panels will yield more effective results in the estimation of efficiency from panels.

In this study, it is aimed at estimating the efficiency of the photovoltaic panels in the provinces by using solar radiation, temperature, wind, humidity, and PV module temperature parameters and at estimating the efficiency of other provinces with the data of a province. By this means, in the planning and projecting of PV systems that provide direct electric energy and still lead to large plant costs in the initial installation phase, added value will be provided to the country's budget by determining the power efficiency of the region where the system will be installed.

5. Materials and Methods

5.1. Installing Measurement Stations. In order to examine the parameters that affect the efficiency in solar energy systems, terminal measurement systems that will take measurements



(a) August (b) October (c) January (d) April

Figure 5: Sample estimation graphs for Adiyaman.

from Adiyaman-Malatya-Sanliurfa regions have been designed. These terminals measure the temperature, humidity, wind, solar radiation, current, and voltage ratings obtained from the panel and send them to the main terminal in the Vocational School of Adiyaman University as text messages via GSM, and in the main terminal, this data is processed after being saved on the SD card.

In the design of the cards, the DSPIC 33F series processor was used to process the information coming from the sensors. The data obtained from the regional terminals is transmitted to the main terminal by using the SIM900 module. Regional measurement terminals are made up of 120 W monocrystalline panel, 100 Ah gel battery, 10 A-12 V MPPT charge controller, and 4 resistive loads for consumption of energy obtained from panels, temperature-humidity-solar radiation-wind-current-voltage sensors, a card designed for measurement, and board to store the materials.

The main terminal allows the information, which is from regional terminals and which contains ratings measured with 5-minute intervals, to be saved on an SD card and allows the information on the SD card to be processed after being transferred to the computer environment. For measuring solar radiation, first class pyranometer with analogue voltage output was used in experiment; its measuring range is between 0 and 2000 W/m^2, and reaction time is shorter than 1 msn. To measure ambient humidity and temperature, first class sensor with analogue voltage output range between -40°C and +80°C, and 0.01°C resolution, and the instrument is covered with radiation protection sheath, was used. To measure wind speed, first class anemometer with analogue voltage output, with 0-50 m/s measurement interval, with 0.02 m/s tolerance, and with 0.05 m resolution, was used.

Energy produced by the 120 W monocrystalline panel is charged to MPPT controlled charge controller, and by consuming the energy obtained from the energy with resistive load connected to battery outlet, the panel's generation efficiency is examined according to ambient conditions. The application views of the terminal measurement stations installed in the regions of Adiyaman-Malatya-Sanliurfa are given in Figure 3.

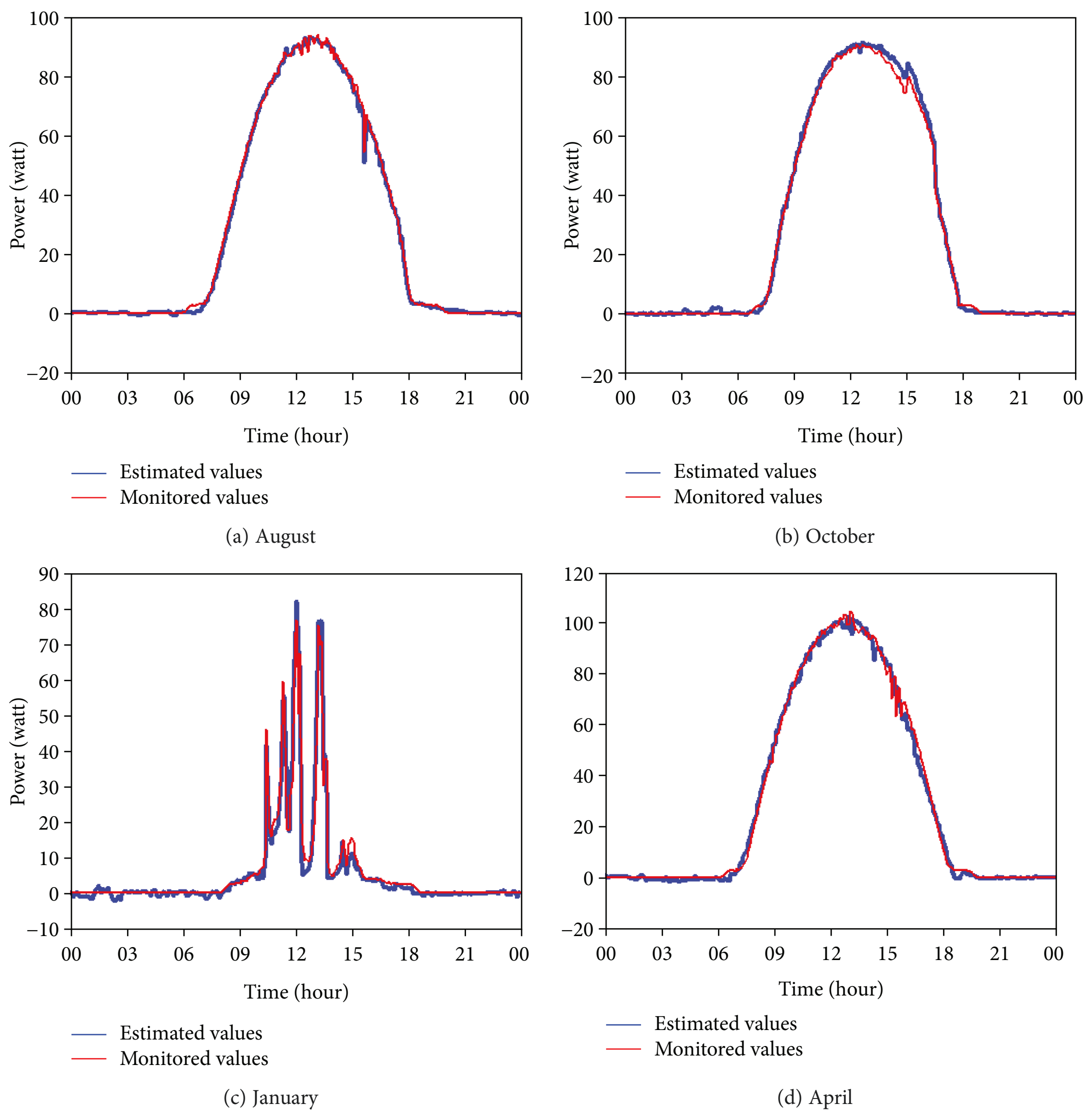
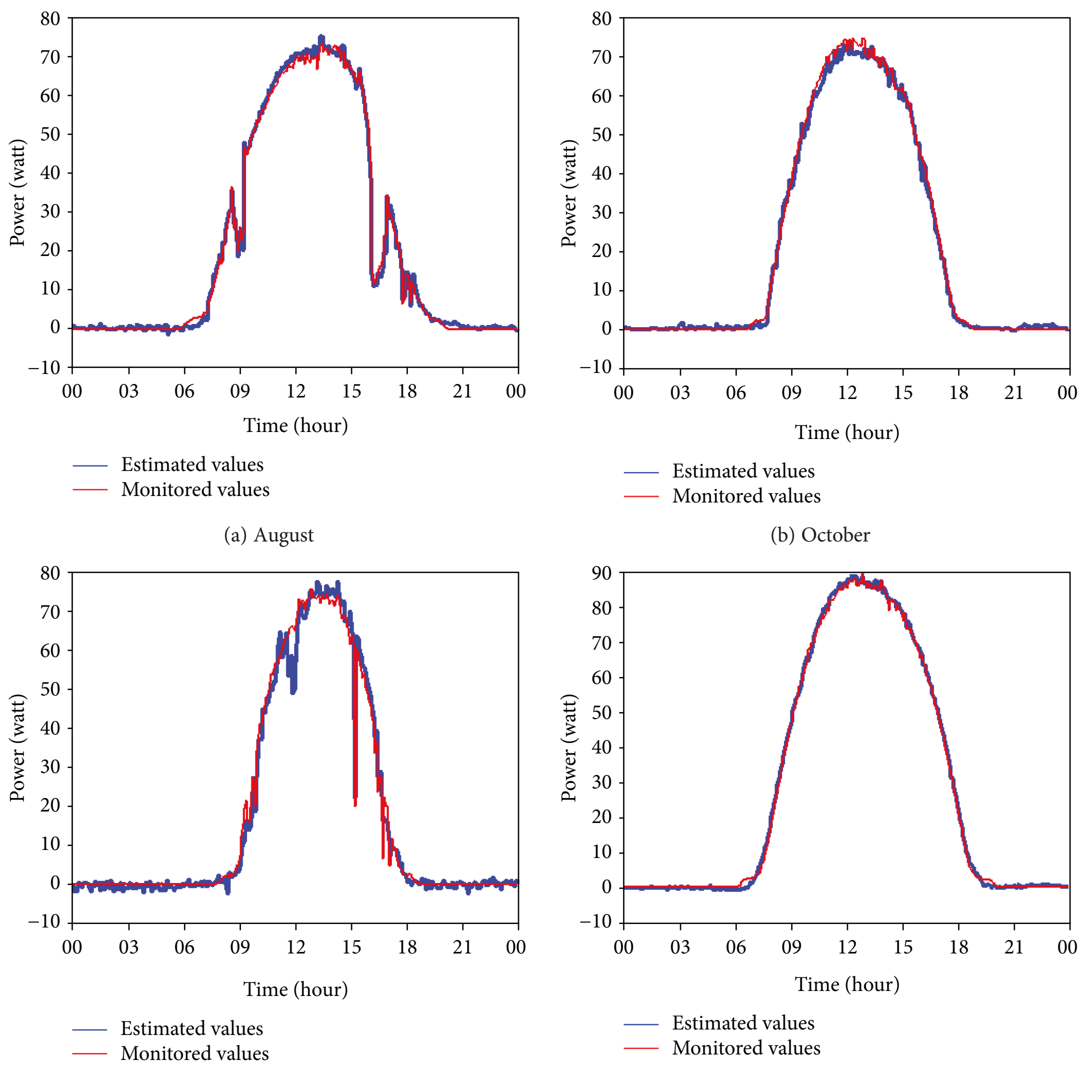


Figure 6: Sample estimation graphs for Malatya.

5.2. Artificial Neural Networks. Scientifically, with the presentation of the neuron cell structure in the human brain as a model, artificial neural networks (ANNs) have been developed and begun to be used today as a tool in many fields. Today, the ANN is used in many engineering and medical fields due to its unique topological and intuitive structures [29].

The ANN structure generally consists of an input layer, an output layer, and occasionally hidden layers. The ANN's input layer is the first layer from which data is retrieved into the system. In this layer, a threshold value is added to the retrieved data and it is multiplied by the weighting coefficients and sent to the next hidden layers. A hidden layer can be made up of one or more layers. In this layer, the data from the input layer are collected and the activation function is applied. The output is obtained by evaluating the data processed in the output layer (Figure 4) [30].

In artificial neural networks, as in traditional programming, information is stored not in a database but throughout the network. ANNs can produce output even if the data contains incomplete information after being trained. The deterioration of one or more cells of ANN does not prevent it from generating output. A network undergoes a slow and relative deterioration over time; ANNs can learn the events and make decisions by commenting on similar events. ANNs have the power to perform more than one job at the same time. In addition to these advantages, ANNs have some disadvantages. Due to their structure, ANNs require processors with parallel processing power; therefore, their implementation is hardware dependent. When ANN generates a solution to a problem, it does not give a clue as to why or how it is; this is a factor that reduces trust in the network. There is no specific rule in determining the structure of ANNs. The appropriate network structure is obtained by experience and trial and error. ANNs are able to work with numerical information. Problems must be converted to numerical values before being introduced to ANNs. Lowering the network's error on the samples below a certain value means that the training is complete. This value does not give us optimal results [31].



(a) August (b) October (c) January (d) April

Figure 7: Sample estimation graphs for Sanliurfa.

Table 4: Meteorological data statistics of provinces.

Meteorological data	Malatya	Adiyaman	Sanliurfa
Temperature (annual average)	13.6	**17.3**	18.3
Sunshine duration (hour)	91.7	**92.4**	96.5
Average number of rainy days	85.4	**83.5**	73.9

Table 5: ANN algorithm estimation results in Malatya.

Months	ANN algorithms					
	trainbfg	trainbr	traincgb	traincgf	trainrp	trainlm
August	0.9866	0.9840	**0.9874**	0.9861	0.9688	0.9792
October	0.9772	**0.9797**	0.9784	0.9807	0.9671	0.9612
January	**0.9589**	0.9407	0.9560	0.9603	0.9583	0.9604
April	0.9760	0.9714	0.9689	**0.9770**	0.9642	0.9643

6. Results and Discussion

Temperature, humidity, wind, solar radiation, panel temperature, current, and voltage values obtained from the panel measured in 5-minute intervals in terminal measurement systems measuring from Adiyaman-Malatya-Sanliurfa regions are saved on SD cards at terminal measurement stations and also are sent to the main station via GSM module. The information arriving at the main station is saved on the SD card and is analysed by the MATLAB program after being transferred to the computer environment. A total of 2016 data, which is 288 data per day, was obtained from each terminal for the parameters (temperature, solar radiation, wind, humidity, module temperature, current, and voltage). Measurements were taken for a year between August 2017 and July 2018. In the study, the data of August, October, January, and April, in which the environmental factors of each season were observed most effectively, has been used.

Table 6: ANN algorithm estimation results in Sanliurfa.

Months	ANN algorithms					
	trainbfg	trainbr	traincgb	traincgf	trainrp	trainlm
August	**0.9957**	0.9945	0.9945	0.9953	0.9902	0.9941
October	0.9862	0.9820	0.9876	**0.9892**	0.9828	0.9746
January	0.9578	0.9562	0.9529	**0.9628**	0.9244	0.9518
April	**0.9900**	0.9888	0.9837	0.9882	0.9823	0.9823

6.1. Estimation Results of the Provinces (Module 1). The data obtained from the provinces of Adiyaman, Malatya, and Sanliurfa for August-October-January-April has been analysed by using ANN algorithms in the MATLAB environment. The algorithms of trainbfg, trainlm, traincgb, traincgf, trainrp, and trainbr were used for the estimation process. The estimated results for the provinces of Adiyaman, Malatya, and Sanliurfa are given in Tables 1, 2, and 3, respectively. Example estimation graphs of the provinces of Adiyaman, Malatya, and Sanliurfa are given in Figures 5–7, respectively.

Parameters used in artificial neural network method are as follows: input layers: 5 (temperature, solar radiation, wind, humidity, and PV module temperature), hidden layer neurons: 27, train data: 6250, test data: 1339, validation data: 1339, and activation function: sigmoid function.

6.2. Estimation Results of the Provinces Compared to the Reference Province (Module 2). The data obtained from the provinces of Adiyaman, Malatya, and Sanliurfa for August-October-January-April has been analysed by using ANN algorithms in the MATLAB environment. The algorithms of trainbfg, trainlm, traincgb, traincgf, trainrp, and trainbr were used for the estimation process.

Parameters used in the artificial neural network method are as follows: input layers: 5 (temperature, solar radiation, wind, humidity, and PV module temperature), hidden layer neurons: 27, train data: 8928, test data: 8928, validation data: 8928, and activation function: sigmoid function.

Considering the data from the General Directorate of Meteorology, it can be seen that Adiyaman province can be statistically taken as reference for the other two provinces in terms of temperature and sunshine duration (Table 4) [32]. Therefore, Adiyaman province is used for training, and Malatya and Sanliurfa provinces are used for testing.

By using Adiyaman province for training and Malatya and Sanliurfa data for testing, the estimation results of Malatya and Sanliurfa are given in Table 5 and Table 6. Example estimation graphs of Malatya and Sanliurfa provinces are given in Figures 8 and 9.

6.3. Performance Comparisons. In this study, the data obtained from the measurement stations installed in the provinces of Adiyaman, Malatya, and Sanliurfa in August-October-January-April has been used. In the first part of the study, the provinces were estimated by the ANN algorithm individually developed in its entirety (Module 1), and in the second stage, Adiyaman province's data was used for training in the developed ANN algorithm and separate estimations were carried out for Malatya and Sanliurfa (Module 2). The obtained results have been compared with the other studies in the literature in Table 7.

7. Conclusions

One of the biggest problems in photovoltaic panel applications is that they are not cost-efficient in the initial installation stage. Despite serious declines in recent years, the amount of energy these systems generate is not high compared to the plant costs. It is extremely important to know the project and investments regarding photovoltaic power plants, and the solar energy potential of the region where the power plant will be installed. The amount of electric energy produced by photovoltaic panels depends on air temperature, humidity rate, wind velocity and photovoltaic module temperature, and particularly solar radiation.

The characteristics of products presented by photovoltaic panel manufacturers cover the standard test conditions. However, since photovoltaic panels are operated in nonstandard conditions in diverse geographies and since knowing the behaviour patterns of the panels to be used in project and planning works for photovoltaic applications will provide a more accurate cost configuration, erroneous investments will be avoided and added value will be provided to the country budget. Thus, it is very important to determine the effects of meteorological parameters involving nonstandard test conditions of the region where panels will be operated on the panel power.

In the study, with the measurement stations established in three different regions (Adiyaman-Malatya-Sanliurfa), power ratings obtained from environmental factors (solar radiation, temperature, wind, humidity, and PV module temperature) and photovoltaic panels were measured and recorded for a year. Modelling was done for estimating the power to be generated by applying artificial neural network algorithms on the large data set. The estimation success rates on the test data that are not used in the training process in the developed artificial neural network models are comparatively presented with the graphs and tables. Additionally, by taking the data provided by the General Directorate of Meteorology as reference, a model of artificial neural networks was developed by using the Adiyaman province data for training; the Malatya and Sanliurfa data was used as the test data, and the success rates were presented with graphs and tables.

It has been determined that the artificial neural network models obtained as a result of the research estimate a significant level the energy value to be obtained from photovoltaic panels in the regions themselves and in other regions according to a reference region.

In the field of researching the efficiency of photovoltaic panels, works such as determining the effect of environmental factors on photovoltaic panel efficiency, experimental determination of the relationship between panel power and environmental parameters, and estimation of efficiency in other regions compared to the reference region require a lengthy and laborious process. This negativity caused the number of studies within this scope to remain limited. The

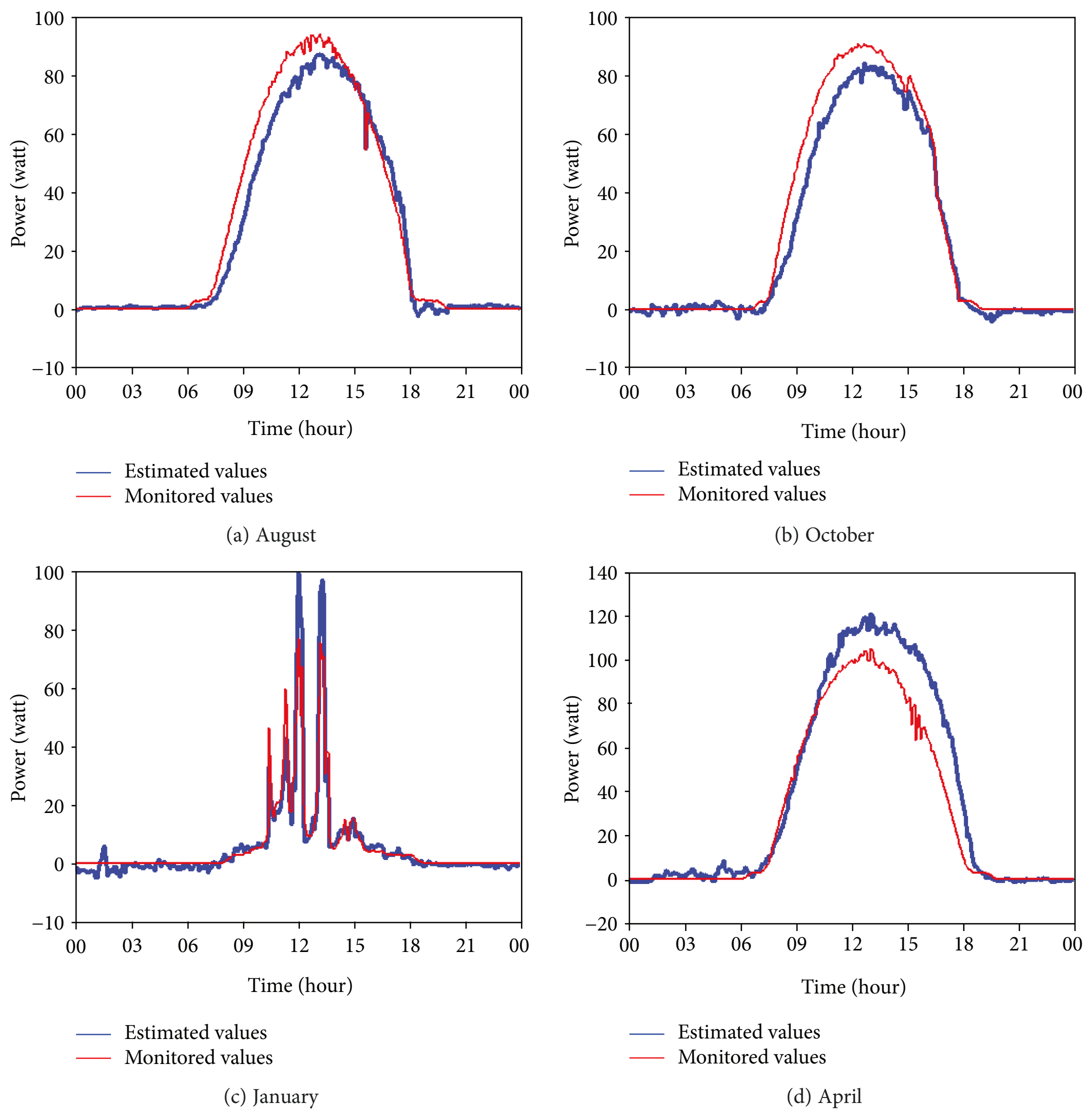


Figure 8: Sample estimation graphs for Malatya.

results we have obtained from analyses on our data set covering a year are in the comparison table given by Table 7.

In the developed artificial neural network models, the estimation accuracy was 99.94%. Additionally, by taking the data of the General Directorate of Meteorology as reference, models of artificial neural networks were developed by using Adiyaman province for training; by using Malatya and Sanliurfa data as test data, 99.57% estimation accuracy was achieved.

The main reasons why the ANN models that we developed yield far better results than the previous works are as follows:

(1) Modelling carried out on the basis of a richer and more comprehensive database by considering the environmental factors affecting the energy generated by photovoltaic panels in our study

(2) The fact that measurements were not made in a certain period but in a wide range of time that would show the effect of all weather conditions for a year

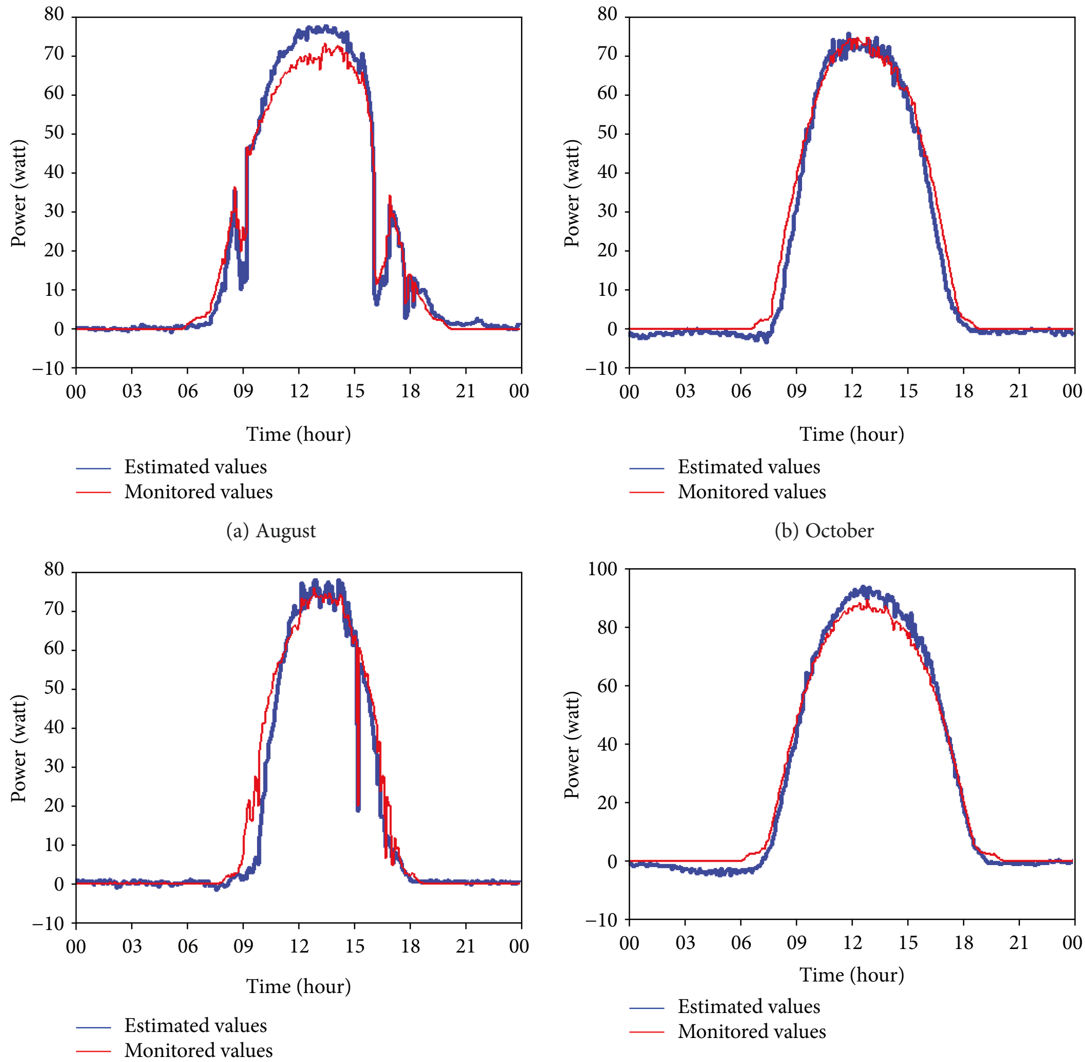
(3) The fact that, while the ANN models were being developed, the parameters and algorithms used for training were selected correctly

(4) The fact that measurements were made for 3 different regions, not for a specific region, and thus the resulting database was wider

With the artificial neural network models developed as a result of the study, the energy efficiency for the photovoltaic energy systems desired to be established by using meteorological parameters such as temperature, humidity, wind, and solar radiation of various regions anywhere in the world can be estimated with high accuracy.

Data Availability

The data used to support the findings of this study are available from the corresponding author upon request data.



(a) August (b) October (c) January (d) April

Figure 9: Sample estimation graphs for Sanliurfa.

Table 7: Performance comparison of technique results.

		Method	Used parameters	Results
Ref. [20]		ANN	SR, T	98.9%
Ref. [23]		ANN	SR, T	98-99%
Ref. [25]		**ANN**	SR, T	98-99%
Ref. [28]		R^2	T, W, H	99.97%
Ref. [33]		ANN, waveler	SR, T, H	97%
Ref. [34]		ANN	SR, T	95%
Purposed Method	Module 1	ANN	SR, T, W, H, PVT	99.94%
	Module 2			99.57 %

Temperature: T, solar radiation: SR, wind: W, humidity: H, PV module temperature: PVT.

Conflicts of Interest

The authors declare that there is no conflict of interest regarding the publication of this paper.

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