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Araştırma Makalesi / Research Article

Uyarlamalı Sinirsel Bulanık Çıkarım (ANFIS) Tabanlı Güneş Takip Sistemi

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Anahtar kelimeler
"Güneş Enerjisi";
"ANFIS";
"Fotovoltaik";
"Güneş Takip";
"Bulanık Mantık "

Özet

Fotovoltaik panellerin güç toplama verimliliğini artırmak için genellikle güneş takip sistemleri (GTS) ile entegre edilmelidir. Bu çalışmada, uyarlamalı sinirsel bulanık çıkarım uygulaması ile GTS sunulmuştur. GTS, zenit ve azimut açılarını kontrol eden iki motora sahip çift eksenli olarak tasarlanmıştır. Bu motorların hızının kontrol edilmesi için ANFIS'in tasarlanmasından sonra bulanık mantık kontrolörünün giriş-çıkış ilişkisini öğrenmek için yapay sinir ağı eğitilmiştir. Pozisyon hatası ve hatanın değişimi modellerin girişi olarak alınmıştır. Motora uygulanan gerilim modellerin çıkışı olarak alınmıştır. ANFIS modelde, deneysel verilerden doğrudan üretilen kurallar kümesine sahip yapay sinir ağının öğrenme yeteneği ile bulanık çıkarım modeli birleştirilir. Sonuç olarak, elde edilen sonuçlar GTS için amaçlanan kontrol yaklaşımının doğru cevap ve takip etme etkinliğini doğrular.

Solar Tracking System based on Adaptive Neuro-Fuzzy Inference System (ANFIS)

Keywords
"Solar Energy";
"ANFIS";
"Photovoltaic";
"Solar Tracking";
"Fuzzy Logic "

Abstract

Solar tracking systems (STS) should usually be integrated with photovoltaic (PV) panel so that the photovoltaic panels can increase power collection efficiency. In this paper, STS with implementation of adaptive neuro-fuzzy inference system (ANFIS) is presented. STS designed as dual axis has two motors that control azimuth angle and zenith angle. After designing an ANFIS for controlling these motors' speed, a Neural Network is trained to learn the input–output relationship of fuzzy logic controller. Position error and error variation were taken as model's inputs. Applied voltage to the motor was taken as model's output. The ANFIS model is combined modeling function of fuzzy inference with the learning ability of artificial neural network that has set of rules generated directly from the experimental data. Finally, the obtained results confirm the tracking efficiency and correct response of the proposed control approach for STS.

1. Introduction

The need for energy has shown an increasing trend year by year in parallelism with the demographic and industrial developments. Decrease in the fossil fuels verges people to clean and renewable energy sources such as solar, wind, biomass, geothermal energy, etc. Most of the electricity need of our planet can be fulfilled with renewable energy sources, and thus, avoiding harmful gas emission is achieved (Tudorache and Kreindler 2010).

One of the most important renewable energy sources is surely solar power. The reason why solar power is preferred for electricity production can be listed as minimal ecological impact, practically inexhaustible and solar energy is free, it has low maintenance costs.

Photovoltaic or PV systems enable solar power to be converted into electrical power. The power that these systems produce depends upon various factors including energy quantity that they receive from sun. A great number of scientists and engineers have been investigating photovoltaic systems to acquire a bigger amount of solar energy. In a broad sense, three ways to augment photovoltaic systems efficiency are offered. The first method is to increase the efficiency of power generation of the solar cells (Sun et al. 2014; Oelhafen and Schuler 2005). The second is about the efficiency of the control algorithms for the energy conversion system included maximum power point tracking (MPPT) (Pradhan and Subudhi 2015; Daraban et al. 2014). The third approach is to adopt a tracking system to achieve maximum solar energy (Stamatescu et al. 2014).

The quantity of power produced by a PV system is mainly dependent upon the availability of solar insolation at the required location (Li et al. 2005). As a result, if solar panels are enabled to track sun, production of electricity can be increased. When viewed in general terms today, there are two types of solar trackers in terms of movement ability, which are single-axis tracker and dual-axis solar tracker.

In their study, Tudorache and Kreindler (2010) have used single-axis solar tracker and chosen to adjust the second axis manually in a regular basis throughout the year. They have made use of 2 LEDs in order to find solar position. Wafa Batayneh et al. (2013) designed dual-axis solar trackers which are driven by a DC motor for each axis of tracking. They presented a fuzzy logic based controller for controlling the DC motors. They used four small PV cells as sensors to find solar position.

Clifford and Eastwood (2004) have designed one that is feasible to use only in Equator regions in the world in other words, a single-axis solar tracker. The solar tracker that they have developed is passively activated by aluminum/steel bimetallic strips and controlled by a viscous damper. They presume a 23% efficiency increase when compared to stable solar panels.

Chin et al. (2011) designed single axis solar tracker which are driven by a servo motor. The solar irradiance is detected by two light-dependent resistor (LDR) sensors. Solar tracking system is modelled by using MATLAB™/Simulink. The output power of the solar tracker was compared with the fixed panel design in order to determine the efficiency of the solar tracker system. The efficiency obtained from experimental results is around 20%.

Mohanad Alata et al. (2005) designed and simulated a time controlled step sun tracking systems that include one axis sun tracking with the tilted aperture equal to the latitude angle, equatorial two axis sun tracking and azimuth/elevation sun tracking. An open loop control system based on fuzzy decision is designed for each of the types of sun tracking systems. As a result, Amman has drawn the conclusion that the expected performance of the two axis equatorial tracking justifies paying the extra cost of installation of the sun tracker.

Abdallah and Nijmeh (2004) devised a PLC control-equipped one-axis sun tracking system, which measures the collected energy and compares it to the energy on a fixed surface with an inclination of 32° to the south. Three tracking modes consisting of the rotations of east-west and north-south and vertical axes were studied, which displayed the results suggesting increases in the solar energy measured per day, up to 19.7%, 23.3% and 24.5% respectively for the north-south, vertical and east-west tracking compared to the fixed surface tilted 32° to the south. The authors determined that the total daily collection may be increased approximately 41.34% in comparison with the fixed surface with an inclination of 32° via the usage of two axes tracking surfaces.

Eke and Senturk (2012) compared the annual power productions of two-axis STS and the latitude tilt fixed PV system in Muğla district situated in the southwest of Turkey. It is calculated that 30.79% more PV electricity is obtained in the double axis sun-tracking system.

Sharaf Eldin et al. (2016) stated in their study that in the countries with hot climates, especially sunbelt countries there is no need for STS. They claim that the overheating as a result of excessive exposure to solar irradiance is the reason underlying this.

They have observed that high level of heat in the panels affect the performance of panels in a negative way.

In this paper a dual-axis STS with implementation ANFIS is introduced. The STS consists of two photovoltaic (PV) panels that can be positioned using two DC motors. In this paper an ANFIS based controller for controlling the DC motors on STS is presented. Sun's position is calculated from formulae or algorithms according to time/date and geographical information, and then positions of PV panels are defined in order to maximize the efficiency of the PV solar panel. In addition, in this study, the effect of ANFIS controlled STS upon power performance of PV panels has been calculated. The acquired results have shown whether this system is usable in Pinarhisar, Turkey or not. The paper is organized as follows. Hardware structure of the solar tracker experimental platform is described in Section 'Solar Tracking System Descriptions'. ANFIS algorithm for STS is presented in Section 'STS using ANFIS'. Experimental results with discussions are described in Section 'Experimental Model and Results. The paper is concluded in section 'Conclusions'.

2. Solar Tracking System Descriptions

After solar panels and other parts to be used were determined, mechanical design of solar tracking system was modelled by using AutoCAD program (Figure1). In the design of STS; two 120W PV panels (Table 1), Daq card, Motor driver card, Computer, DC motor with one reductor including encoder and one DC Linear Actuator have been used. The algorithms used were developed with the Matlab®

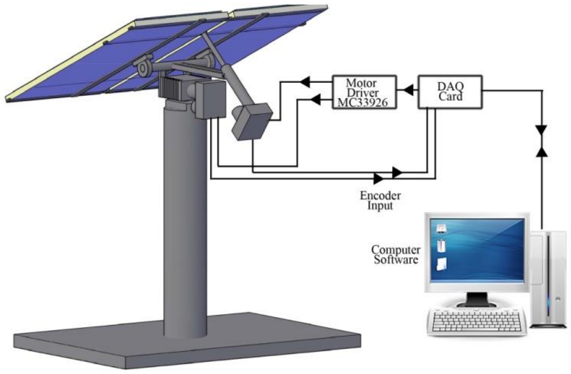


Figure 1. Design of the solar tracking system

PV panels in the STS have the ability of dual axis movement. With movement of panels in Azimuth and Zenith angles, sun can be tracked in a way that enables sun rays to fall onto the panels with right angle. Thanks to the STS designed and developed, panels make use of the lights in maximum level and have the ability to turn solar power into electrical power.

Table 1 Tested photovoltaic panel specifications (120W)

Parameter	Value
Typical peak power (P_p)	120 W
Voltage at peak power (V_{mp})	17.2 V
Current at peak power (I_{mp})	6.98 A
Short-circuit current (I_{SC})	7.51 A
Open-circuit voltage (V_{OC})	21.6 V
Output tolerance	±3%
Operating Temperature	-40ºC to +80 ºC

3. Zenith–Azimuth Formulas for Sun Tracking

In the designed system, any sensor for the sun has not been used to pinpoint the solar position. Momentary position of the sun throughout the year was determined with algorithm by taking latitude, longitude and local time information of the region where panel was planned to be used into account. According to the results of algorithm, azimuth (East-West) and zenith (High-Low) which are angle parameters of the system are defined (Figure2).

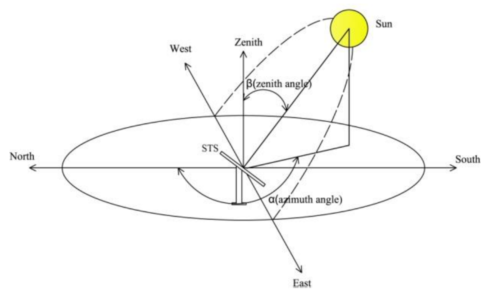


Figure 2. Definition of the angles for the description of the position of the sun

While solar position is being calculated, declination angle should be taken into consideration. Declination angle is the angle that sunrays draw with equator level. This angle is due to the 23°27' angle that revolution axis of the Earth makes with the trajectory level normal. Due to this angle sun rises exactly from the East, and sets exactly on the West on 23rd September and 21st March according to the coordinates that STS has been located. On 21st December and 21st June, there are almost 23° deviations in the rising and setting angles of the sun when compared to those on 23rd September and 21st December. The Cooper equation can be utilized to determine the solar declination angle (°) for any day in a year (N) (Cooper 1969; Stanciu and Stanciu 2014).

$$\delta = 23.45 x \sin\left[\frac{360x(284+N)}{365}\right] \qquad (1)$$

Solar zenith angle (β_z) is known as the angle between vertical level normal of the Earth and solar radiation. When sunrays fall perpendicularly on the vertical level it is 0° while it is 90° on the rising and setting moments of the sun (Stanciu and Stanciu 2014).

$$\cos\beta_z = \cos\varphi\cos\delta\cos\omega + \sin\varphi\sin\delta \qquad (2)$$

Solar azimuth angle (α_S) can be defined as the angle that shows the clockwise deviation, according to north direction of sunrays' projection on the vertical level. Azimuth angle is determined with the equation below (Guo et al. 2011);

$$\alpha_S = sign(\sin\omega)\arccos\left(\frac{\cos\beta_z\sin\varphi - \sin\delta}{\sin\beta_z\cos\varphi}\right) \qquad (3)$$

Where φ is the site latitude (northward is positive), ω is the hour angle, and δ is the solar declination.

Throughout the year, once in every two minutes azimuth and zenith angle values are determined by the software. According to the two angle values, appropriate signals are sent to the driver circuit of the motors so as to provide two-axis movement of the system. Two-axis movement of the photovoltaic panels is enabled by motors moving according to the signals. Thanks to the encoders bound to the motors, which angles panels are located, is determined with the help of pulses produced. Information gained from encoders is observed by the control algorithm and a control signal is produced accordingly. This system works continuously as closed cycle.

4. STS Using ANFIS

The adaptive network based fuzzy inference system (ANFIS) was developed by Jang in 1993. In this method, to obtain presumed input-output pairs appropriate membership functions as well as "If-then" fuzzy rules have been used. The ability to decide of Jang's ANFIS model has been made by applying a hybrid learning rule which is a combination of back-propagation algorithm and least squares estimation methods (Jang 1993).

In this study, ANFIS with one-output single-rule first degree Sugeno fuzzy model with two inputs such as x_1 and x_2 has been used. For a first order two-rule Sugeno fuzzy inference system, the two rules may be stated as (Buragohain and Mahanta 2007);

$$\text{Rule1: If } x \text{ is } A_1 \text{ and } y \text{ is } B_1 \text{ then } f_1 = p_1x + q_1y + r_1$$
$$\text{Rule2: If } x \text{ is } A_2 \text{ and } y \text{ is } B_2 \text{ then } f_2 = p_2x + q_2y + r_2$$

Where *x* and *y* are the inputs of ANFIS, *A* and *B* are fuzzy sets defined for *x* and *y* membership functions, p_i, q_i and r_i are the parameters set, referred to as the consequent parameters.

In this inference system the output of each rule is a linear combination of input variables added by a constant term. The final output is the weighted average of each rule's output. In this study, ANFIS consists of five layers. Functions of each layer are as presented below (Buragohain and Mahanta 2007);

Layer 1: Every node *i* in this layer is adaptive with a node function

$$O_i^1 = \mu_{A_i}(x) \quad (4)$$

Where *x* is the input to node *i*, A_i the linguistic variable associated with this node function and is the membership function of A_i. Usually μ_{Ai} is chosen as

$$\mu_{A_i}(x) = \frac{1}{1+\left[\left(x-c_i/a_i\right)^2\right]^{b_i}} \quad (5)$$

Or

$$\mu_{A_i}(x) = \exp\left\{-\left(\frac{x-c_i}{a_i}\right)^2\right\} \quad (6)$$

The input is indicated as *x* and $\{a_i, b_i, c_i\}$ is the set of basis parameters

Layer 2: All nodes within this layer are fixed nodes, each of which calculates the firing strength w_i of a rule.

Each node produces an output via the entirety of the incoming signals and is provided by the following formula:

$$O_i^2 = w_i = \mu_{A_i}(x) \mathrm{x} \mu_{B_i}(y), \quad i = 1,2 \quad (7)$$

Layer 3: All nodes within this layer are fixed nodes, each of which calculates *i* th rule firing strength ratio to make up all the rules' total firing strengths. The *i* th node output is the generalized firing strength and is provided by:

$$O_i^3 = \bar{w}_i = \frac{w_i}{w_1 + w_2}, \quad i = 1,2 \quad (8)$$

Layer 4: All nodes within this layer are adaptive nodes, each having a node function provided by,

$$O_i^4 = \bar{w}_i fi = \bar{w}_i\left(p_i x + q_i y + r_i\right), \quad i = 1,2 \quad (9)$$

Layer 3 output is indicated as w_i and $\{p_i, q_i, r_i\}$ is the set of ensuing parameters.

Layer 5: Only one fixed node, which calculates the general output as the sum of all incoming signals, constitutes this layer (Singh et al. 2012), i.e.

$$O_i^5 = \text{overall output} = \sum_i \bar{w}_i f_i = \frac{\sum_i w_i f_i}{\sum_i w_i} \quad i = 1,2$$

The ANFIS can be trained by a hybrid learning algorithm which combines the back propagation learning and least square method. The ANFIS architecture and training parameters were illustrated in Table 2.

Table 2. ANFIS architecture and training parameters

Parameter	Value
Number of layer	5
Number of output	2
Size of input data set	24x2
Membership function	Gauss
Learning rules	Least square estimation
Number of epoch	500
Momentum constant	-0.9

5. Results

The communication between the STS and the personal computer (PC) was executed with the help of an Arduino card. In other words, arduino card is used as daq (data acquisition) card. That two DC motors used in the STS are directly connected to Arduino card has been presumed to result in harm to the card. As a result, Dual MC33926 motor driver has been used to cater for the connection in between. Among these motors, DC motor with reducer controls azimuth while linear actuator motor controls zenith angle. The view of the system upon locating the motors on the appropriate places is shown in Figure 3.

Figure 3. The view of STS

Azimuth and zenith angle values are obtained after determination of sun position according to time/date and geographical information. Error value and error change data in the next step are acquired according to the angle values obtained. This set of data provides input for ANFIS algorithm that controls STS. Since two different motors are expected to be controlled, ANFIS algorithm has been applied to both engines. Within ANFIS Sugeno approach has been used. For creating rules, expert opinion was made use of and for this 533 training and test data were used.

25 probable rules have been assigned to the model by ANFIS. The network created was trained with hybrid learning algorithm which used least squares method and back propagation learning simultaneously. ANFIS structure is shown on Figure 4. Membership functions can be triangle, trapezium, rectangle and Gaussian. In application; triangle type membership functions have been selected upon investigating success status and data set (Figure 4).

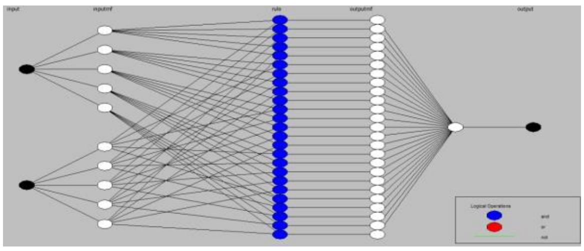
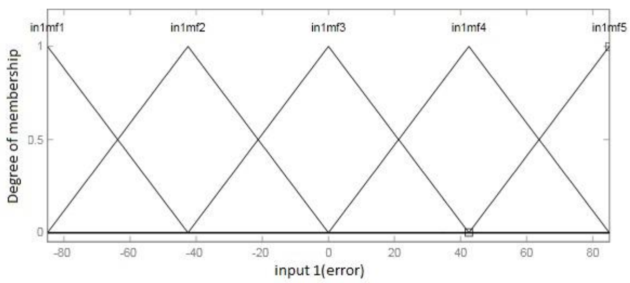


Figure 4. ANFIS structure for modelling the STS

Geographical location of STS directly affects the inputs of ANFIS algorithm. STS has been located at Kirklareli University Pinarhisar Vocational High School. Pinarhisar is situated in northwest of Turkey (latitude: 41.62+N, longitude: 27.53+E, altitude: 212 m). Taking these coordinates into consideration, installation is done on the ground. While the maximum value of azimuth angle is being calculated, declination angle should be taken into account. By taking cognizance of declination angle, azimuth angle revolution ability of STS has been found as 226°. Revolution ability of zenith angle has been defined as 85 degrees. As a result, ANFIS input used for zenith angle varies between -85 and +85 (Figure 5). ANFIS inputs used for the control of azimuth angle vary between -226 and +226 (Figure 6).



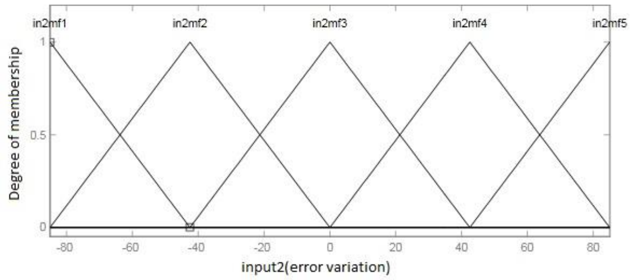


Figure 5. Zenith angle input1 (error) and input2 (error variation) membership function

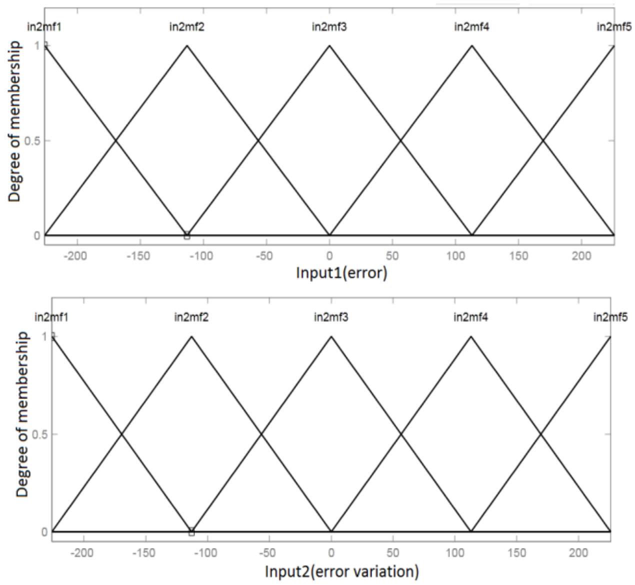
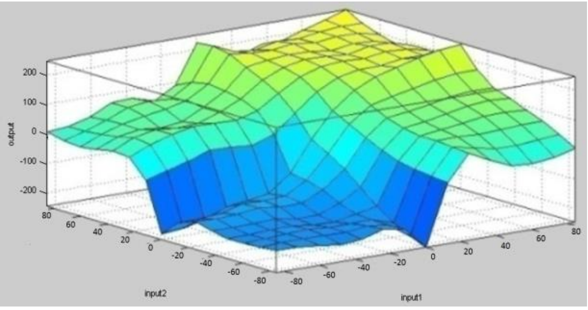
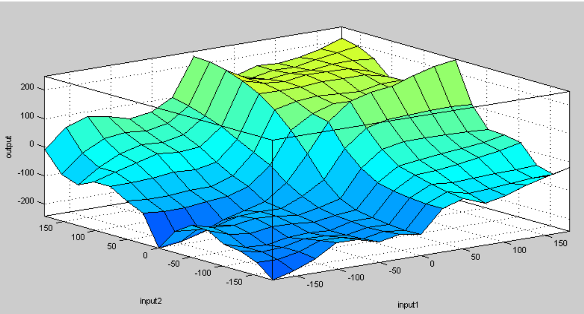


Figure 6. Azimuth angle input1 (error) and input2 (error variation) membership function

Error between the solar position and panel position while the system is working *e(k)* and change in the error *de(k)* constitute the exact inputs of the system. The system is of one output used to send PWM (Pulse With Modulation) signal to the motors. Values that according to input values PWM outlet signal can receive which enables Azimuth and Zenith angles to be located at the desired values are shown on surface chart (Figure 7).



(a)



(b)

Figure 7. (a) Zenith (b) Azimuth surface comparison between the input values of the ANFIS.

Comparison of results gained according to expert opinion and ANFIS results has been made graphically (Figure 8). When the graphic is inspected, results are seen to be close to each other.

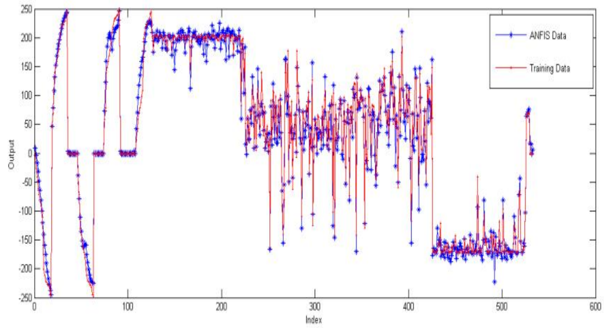


Figure 8. Comparison of Experimental study and ANFIS Model Results

Measuring the power productions of panels is needed in order to determine STS's effect on PV panels' power performances. Measurements were made via a 120W monocrystal panel. Optimum resistance value that will approximate PV panel to maximum working points has been found as 2.46 ohm.

Performance analysis of STS located at Kirklareli University Pinarhisar Vocational High school and stable panel was made on the clear day of 16.09.2015. On this date, according to the mentioned location, the movement of Sun related to time is presented in Figure 9.

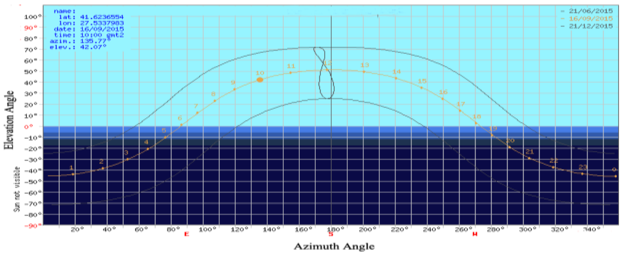


Figure 9. The movement of Sun on the date 16.09.2015 at Kirklareli University Pinarhisar Vocational High School

It can be seen that Sun rises at around 6 and sets at around 18. At around 12 Sun reaches its highest position. Time-related variation in solar radiation whose measurement was made all throughout the day is presented in Figure 10.

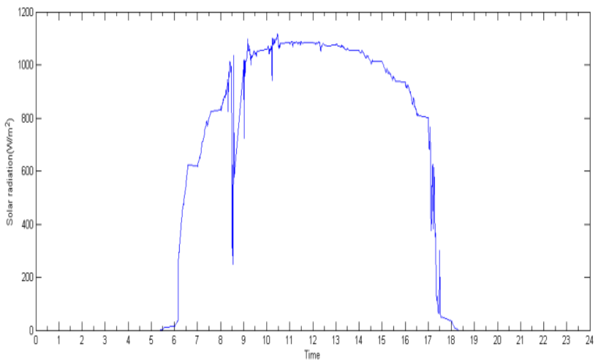


Figure 10. The results solar radiation amount on the 16th of September 2015.

At different times of the day, variations in the amount of solar radiation are observed. The variations stemming from weather conditions have an impact on the power produced by the panels. Current and voltage values that 120 Watt photovoltaic panels which are located a stable system with STS produce are measured throughout the day in every two minutes. 720 power values are obtained for both of the panels (Figure 11).

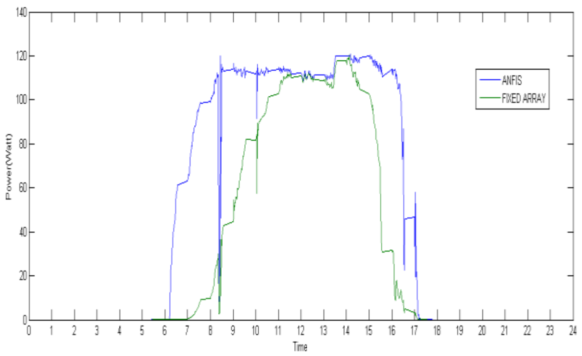


Figure 11. Power output values seems of the fixed panel and the PV panel using STS in Pinarhisar, Turkey. The results presented are on the 16th of September 2015.

During the entire day, it can be observed that the PV panel on STS possesses the highest output power as a result of the highest amount of exposure to solar irradiance. In comparison to the panel on STS, the output power of the fixed PV panel is lower on account of low solar irradiance.

It can be seen that throughout the whole day, the PV panel on STS has the highest power output due to highest solar irradiance exposure. The fixed PV panel has a lower output power compared to the panel on STS due to low solar irradiance. In Pinarhisar on the specified date it was found that the daily output power of the STS used with ANFIS was 47.76% higher than the fixed PV panel. From the charts, it can be inferred that solar radiation amount is less than 11-13 o'clock, and more power production is achieved between 14 o'clock and 16 o'clock. This may be because panel heat has negative effects on power production, and may be due to the cloud interference. In different studies, it has been proved that overheating of the panels causes panels to operate with a lower performance.

6. Conclusion

In this study, dual axes solar tracking system with implementation of adaptive network-based fuzzy inference system (ANFIS) is presented. According to the study results, some important points can be highlighted as follows:

1- Dual axes solar tracking system (STS) has been designed to increase power collection efficiency of PV panels

2- Adaptive network-based fuzzy inference system (ANFIS) model has been applied to control the speed of motors in the STS according to sun position

3- PV panel fixed position and PV panel on STS system are compared according to power measurements in Pinarhisar Vocational High School of Kirklareli University. The results show that, with the use of STS, power gain of the PV Panel has increased. This shows that the system is feasible in Pinarhisar.

4- Any sun detecting sensor has not been used in the system to pinpoint solar position. Momentary position of the sun throughout the year is determined with the help of algorithm by taking altitude, longitude and local time information of the region system was applied into consideration. Determining the solar position with this method yields more reliable results when compared to the systems using sensors. Outside conditions such as unclear weather, fouling, rain have not dragged the system into instability.

As a result, thanks to the designed and developed STS, it is made possible to benefit from solar power with maximum efficiency when sun is available. Thus, by exploiting the sunrays in the most efficient manner, the opportunity of benefiting solar power with the highest value is given.

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