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The Design of Two Axis Solar Tracking System Based on Fuzzy Logic Control and Efficiency Analysis

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ABSTRACT:In this study, two-axis solar tracking system with microcontrollers of fuzzy logic control was designed to increase the efficiency output obtained from solar energy and it was compared with the fixed system.In the moving system, mini PV panels are used as sensors to find the real position of the sun and that geared DC motors in the mechanism with PWM signals obtained from the fuzzy logic controllers were conducted in an intelligent way. All day long the electrical data obtained from fixed and tracking system was transferred to a computer online with the Arduino Due card.The voltage, current and power data of both systems were analysed through Matlab/Simulink software. When the data obtained from the designed prototypes was studied microcontroller-based solar tracking system was observed to have an24.64% increase in efficiency according to the fixed system.

KEYWORDS: Solar Tracking System, Fuzzy Logic Controller, Photovoltaic Panel.

I.INTRODUCTION

Today, the industry is fast evolving and the thirst for electrical energy is correspondingly increasing. As the energy produced by the electricity plants relies on the fossil fuel energy sources for the most part this consumption has caused them to rapidly deplete. In addition, when the inability to issue large amounts of storage of electrical energy was incorporated into this problem the solute on to these problems a requirement to meet the current demand of the electrical energy and much higher efficiency in production and a preference for renewable energy sources as a source of energy occurred[1].Consequentlythemethods to obtain electricity from solar energy are evolving rapidly. Though technological advances to obtain electric energy from solar cells by way of photovoltaic method are swift, a very little part of the energy that can be obtained from the sun with the help of the solar cells can be converted into electricity, when accompanied with the low efficiency of solar cells. At this point, to obtain high yields from sunlight, the necessity of using systems that follow the sun arises solar tracking systems are the tracking systems,designed to increase energy they produce as solar panels follow the sun continuously during the day. Thanks to this system, a larger amount of radiation is observed and solar panels in this way increases daily performance and yield much better values the resulting energy yield increase is in the limit values of between25% and 55% [2].

As the importance of the efficiency of photo voltaic panels and legacy systems react as fast as they can to these problems emerges, many studies have been done about it. Şenpınar and the others placed one fixed and the other two axes trackers and they compared the performance of two PV modules. They showed that the average daily output power of tracking system is 13% more efficient according to the fixed module [3]. Zakariah et al. designed two axes solar tracking system based on fuzzy logic control. They used four LDR sensors to obtain the maximum solar radiation intensity and they used the Arduino UNO microcontroller to control system. The effect of the output power of designed system was observed to have 18.13% when compared to the fixed one[4]. Kassem et al. designed microcontroller-based solar tracking system to obtain maximum efficiency from the sun and they made comparison with fixed solar panels. They used mini PV panels as sensors to get maximum output current in the three points of the system the efficiency of the system they offered showed a yield of 64% on a sunny day [5]. Abadi et al.designed single axis solar tracking system based on fuzzy logic controller and made a comparison between the fixed system and the former. Atmega microcontroller 8353 and two LDR sensors were used to increase power the yield of PV panels and 47% increase in efficiency was gained when compared to the fixed system [6]. Sohag et al.used four pieces of LDR and webcam to be able to detect the exact position of the sun.Performance of the fixed system was not just compared with that of tracking

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system that uses sensors and LDR but also with that of LDR and webcam. As a result of analysis, the system which implements the LDR and the webcam performs much better from other systems [7]. Tudorache and Kreindler designed single axis solar tracking system for PV power plants. In the system, they used two LEDs to determine the position of the Sun and an IBL2403 smart motor driver for the movement of servo motor [8]. In their study, Tina et al. developed the prototype of smart solar tracking system by using nine photo diodes as sensors. Using the Matlabsoftware position of sun was determined with the voltage information from photo diodes [9].

In this study simulation of two axes solar tracking based on fuzzy logic control system in Matlab/Simulink software was created. By assembling electrical and mechanical components of the system, fixed system and data analysis with real time were examined in the Matlab software and their performances were compared.

II.MATERIAL AND METHODS

Solar cells consist of a combination of thin layers of $P - N$ semiconductor. In the dark $I - V$ characteristics of photo voltaic cell output are very similar to diode characteristics. When exposed to the light thanks to photons the current is supplied through electron movement. In the equivalent photovoltaic cell model, the basic model, an advanced diode model, an advanced two diode model and the other original models are implemented. A single diode model is the simplest model that is used to simulatea photo voltaic solar cell [10].

A. MATHEMATICAL MODELING OF PV CELLS

The circuit model equivalent to a single diode model commonly used for solar cells is given in Fig 1.The current source $I_{ph}$is the one generated depending on the solar radiation $(G)$and under the constant radiation and temperature its value is fixed. In the equivalent circuit model the given parallel resistanceR_p represents leakage current of the voltage and serialR_s resistance represents drop in the output.

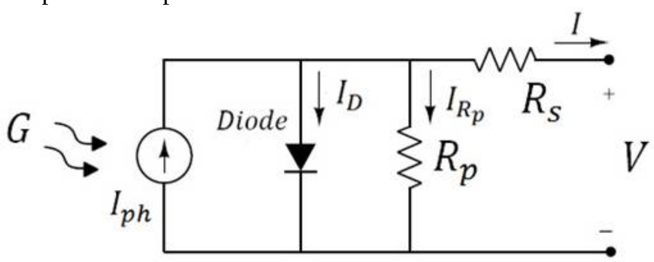

Fig.1 Equivalent circuit of a PV cell

Mathematical expression for the behaviour of the equivalent circuit model given in Fig 1 can be seen in equation (1).

$$I = I_{ph} - I_0 \left(exp \left(\frac{V + IR_s}{N_s V_{TH}} \right) - 1 \right) - \frac{V + IR_s}{R_p} \quad \textbf{(1)}$$

Where V is the module voltage, I_0 is the diode dark current, N_s is the number of cells in series in the module and V_{TH} is the PN junction thermal voltage defined as:

$$V_{TH} = \frac{k(T_C + 273)}{q} \quad \textbf{(2)}$$

Where $k = 1.38x10^{-23}\ j/K$ (Boltzmann constant)$q = 1.6x10^{-19}\ C$ is the electrical load, T_C is the temperature of the cells in degrees Celsius [11].

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B. FIXED SYSTEM

In fixed systems, solar cells are placed with a certain slope. Tilt angle will show variations according to regions and seasons. In the northern hemisphere PV systems are usually placed to the South with a particular point of view. To get the maximum yield from a fixed system the region's latitude angle $\emptyset$ and the sun's the position in the noon hours δ (north positive) should be taken in consideration. Accordingly, on 04 December 2016 the divergence angle of Afyonkarahisar, where the PV system was established was obtained from the equation (3) and equation (4) was obtained from the angle PV module formed with the horizon [12].

$$\delta = 23.45 \sin\left(\frac{360(284+n)}{365}\right)^{\circ} \tag{3}$$

$$\theta = (\emptyset \pm \delta)^{\circ} \tag{4}$$

Where n is the day of the year and $\emptyset$ is the latitude angle of the region, "+" for winter and "-" for summer. Fig 2 shows how monthly performance depends on PV module tilt angle.

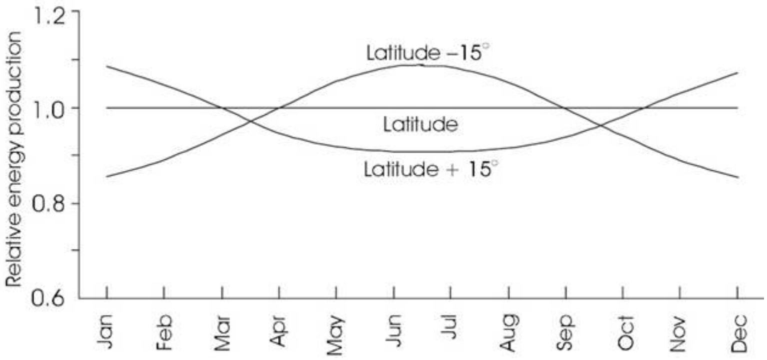

Fig.2 Monthly PV cell performance as a function of collector tilt angle [13].

The block diagram of the fixed system whose experimental study was done is provided in Fig 3. This system is generally, composed of solar panel, solar charge regulator, battery, measurement group, invertor and electronic load.Numeric data such as current, voltage and power of the electricity derived from solar panel in the fixed system, was recorded by Matlab software running on an online computer.

C. TRACKING SYSTEM

The solar tracking system whose prototype was produced has the capability to capture sun rays perpendicular to the panel from the sunrise to the sunset during the day. So by using sun rays in the most efficient way during the day it is possible to get the highest value from the solar energy. Solar tracking systems can be built with two axes just like single axis the system we designed has the ability to move along two axes to obtain full yield from the sun. System consists of the actuator motor, driver card, the Arduino microcontroller, 4 mini PV sensors determining the position of the sun, a computer which the data is recorded with Matlab/Simulink software, a battery, an inverter and an MPPT charging module. The block diagram of the system is given in Fig3.Sensors were placed on the four corners of the solar PV Panel. The resulting electrical data obtained from sensors were used as input variables for the fuzzy logic unit used in Arduino Due. Here FLC processes data obtained from sensors in accordance with the base rule and sends the result obtained to motor driver card.Finally, actuator motors, solar PV panel are positioned to the position of the sun in the horizontal and vertical positions.

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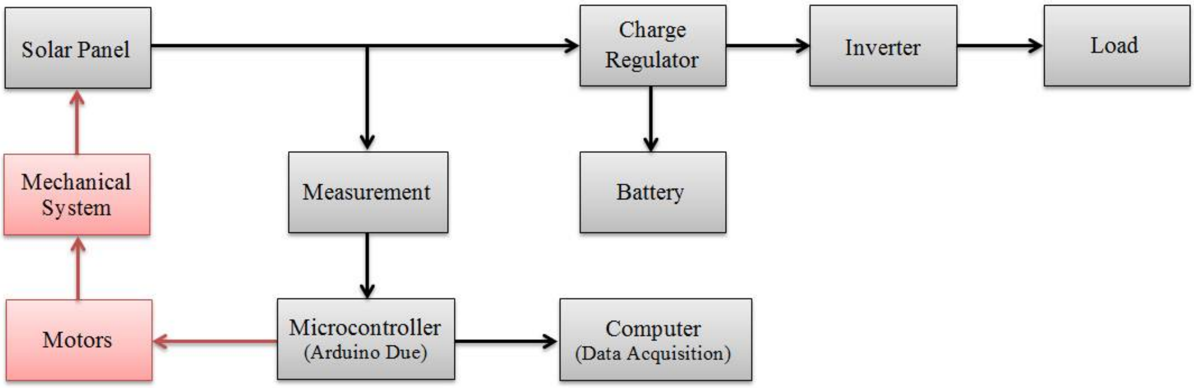

Fig.3 The block diagram of fixed and tracking system.

D. ELECTRICAL PARTS

In this study, 4 mini PV panels were used to determine the position of the sun automatically to increase the efficiency of 20 watt electrical energy power obtained from solar panels. While ACS712 microcontroller current transducer supplies the current data of the panel, data of the voltage is provided with the trimpot of 100KΩ on the newly designed feeding card. Also the temperature of the panel is instantly checked with the PT100 temperature sensor. Linear actuator motors which provide the movement of the mechanical mechanism bearing the panel in two axis is controlled with MC33926 with motor driver and limit switches on actuator motors are used to prevent strain on mechanical parts. The data from sensors is collected in an online computer via the Arduino Due microcontroller. Fig 4 shows the correlation of the electrical and mechanical parts used in the system.

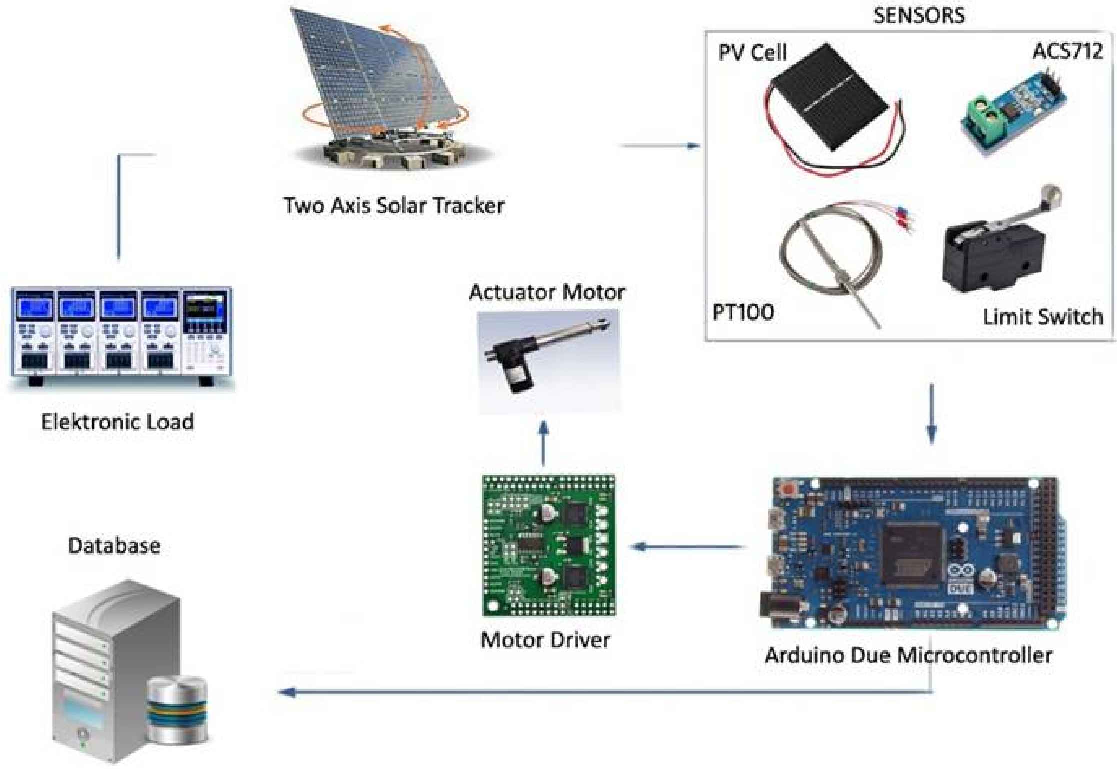

Fig.4 Electrical and mechanical parts of the two axis tracker [9].

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i. Photovoltaic (PV) Panel

Solar panels convert sunlight into electrical energy. When the sunlight hits the panels, direct current begins to be produced at the panels.Solar energy cells are connected according to the preferential power choices, either serial or parallel. The energy efficiency of a solar cell is measured with its yield. View of monocrystalline PV panelthat we use in this study is given in Fig 5.

Fig. 5 View of the two axis tracking system

ii. Arduino Due Microcontroller

Arduino Due is an Atmel SAM3X8E ARM Cortex-M3 based 32 bit microcontroller board. On the board are 54 digital input/output pins (12 of them can be used as PWM outputs), 12 analog inputs, 4 UART (hardware serial port), 84 MHz crystal, usb otg socket, 2 DAC (digital to analog converter), 2 x I^2C, Jtag connector, ICSP connector, power socket, reset and erase button. Arduino Due microcontroller card used in the system can be seen Fig 6.

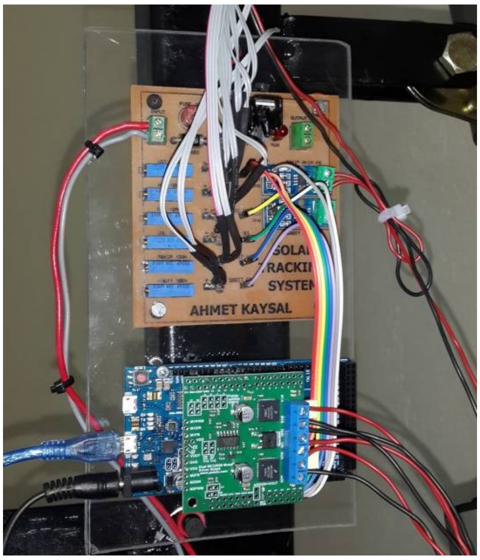

Fig. 6 Arduino Due microcontroller connection

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iii. Motors and Driver Module

The actuator motors used in the system convert rolling motion of electric engine to push and pull motion. While one of the actuator motor provides the movement of the panel in the East-West axis direction, the other provides a movement along the axis of North-South.

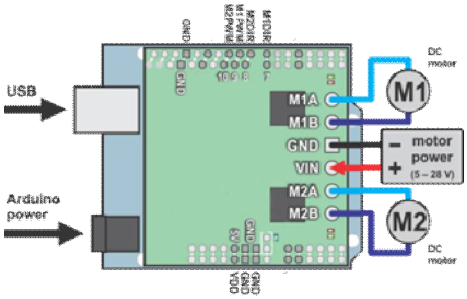

Fig.7 Using the dual MC33926 motor driver shield with an Arduino

Motor driver card which was designed with Arduino to drive engines which require high power bears two MC33926 ICs. The driver that supports from 5 to 28V voltage is able to provide a current of 3A per-motor. To be able to use without the Arduino, MC33926 card that supports up to 20 kHz PWM frequency was also equipped with control pins along the edge of the card. Connection of motor driver card with the Arduino Due can be seen in Fig 7.

A. TRACKING SYSTEM MODEL AND FUZZY LOGIC CONTROLLER DESIGN

In a fuzzy system fuzzy inference engine uses fuzzy sets and rule base instead of mathematical equations. In the fuzzy system two sources of information are taken in consideration as a combination,one being observation and measured values, and the other being the opinions of experts .This means that in addition to the numeric data base, existence of the verbal rule base is available. Expert opinions work to model out the uncertainties unknown in the system [14].

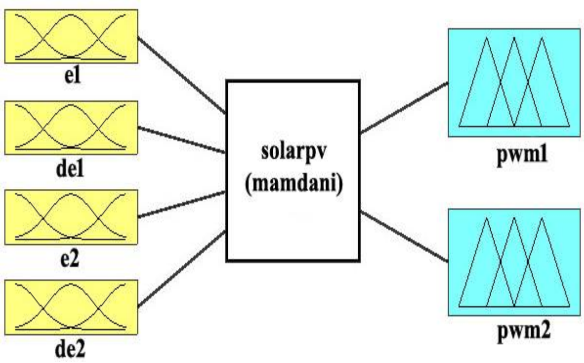

Fig.8 The block diagram of fuzzy logic controller

Fuzzy logic controller (FLC) based on Mamdani fuzzy inference system was designed to increase the efficiency of the energy obtained from track system and to obtain the desired quality power. The first of the two input signals is error signal$e(t)$, and the second one is $de(t)/dt$ the change of error signal according to time.Controller's output signal is PWM control signal that provides controls of dc motors to set the desired extent according to the position of the sun. For each rule, holistic inference of inference system is calculated with the equation (5).

$$PWM = \frac{\sum_{i=1}^{N} w_i z_i}{\sum_{i=1}^{N} w_i} \qquad (5)$$

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Here, N; number of rules, W; the weight of rules, Z; output level. The error signal $e(t)$from the input variables of FLC and change signal in the error $de(t)/dt$are NB (negative big), NS (negative small), ZE (zero), PS (positive small) and PB (positive big)as linguistic variables. Triangle type the membership function was used in fuzzy inference system. When creating rule base"and" operator of logical operations is used. In Fig8 a block diagram of fuzzy logic controller designed in the system with four entries and two output variables is given.Table 1 shows the control rule base for the fuzzy logic controller.

Table 1. The membership functions for FLC

e(t)/de(t)	NB	NS	ZE	PS	PB
NB	NB	NB	NM	NS	ZE
NS	NB	NM	NS	ZE	PS
ZE	NM	NS	ZE	PS	PM
PS	NS	ZE	PS	PM	PB
PB	ZE	PS	PM	PB	PB

The FLC model in Matlab/Simulink software was used in the system. As seen in the block diagram of simulation given in Fig 9 data about the position of the sun provided by 4 sensors was read by 0, 1, 2, and 3 ADC input pins of Arduino Due microcontroller and after the difference was taken $e1$and $e2$ error signals were obtained. These error signals and the change of error according to time were applied to FLC block. According to the rule base of FLC output PWMsignals were obtained from the 9 and 10 pins and they were applied to MC33926 motor driver module.

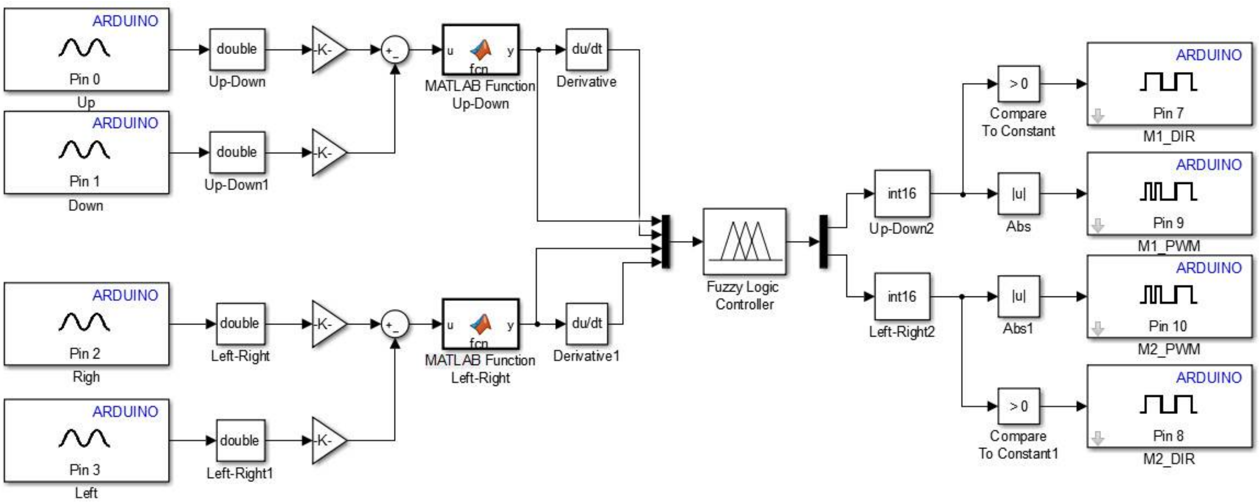

Fig.9 Simulation block diagrams of solar tracking system

As the system tracks the sun voltage and current data of the PV panel is multiplied and the power of the panel is calculated. With the blocks of the scope and workspace, voltage, current and power data of fixed and movable panels was recorded by Matlab and yield analysis was conducted. In Fig 10 connection blocks of Arduino Due microcontroller card of the fixed and movable panels can be seen.

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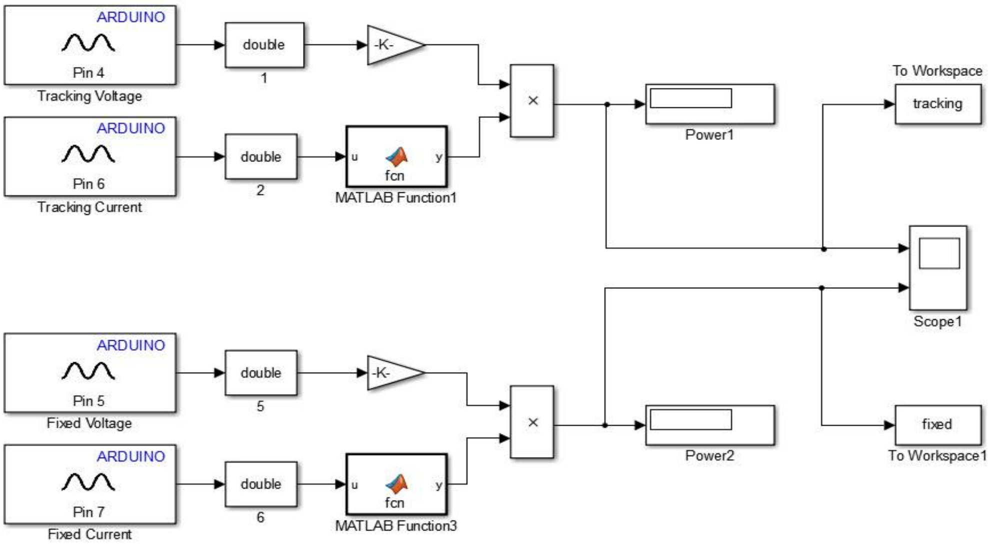

Fig.10. Connection blocks of the tracking and fixed panels in Matlab/Simulink

III.EXPERIMENTAL RESULTS AND DISCUSSION

The efficiency of sunlight can show changes according to time and geographic structure. Turkey has favourable geographic coordinates, soithas the high solar energy potential. This experimental study was carried out in Afyonkarahisar/Dinar on a sunny day on 4 December 2016. The average temperature of the experiment day was try7.5°Cand the average wind speed was $2\ m/s$[15].

Table 2. Voltage, current and power example values ofrelated to tracking and fixed systems obtained by the data recorded on the computer

Time (h:m)	Fixed Panel			Solar Tracking Panel		
	I_1 (A)	U_1 (V)	P_1 (W)	I_2 (A)	U_2 (V)	P_2 (W)
08:27	0,036	0,019	0,00067	0,050	0,026	0,00129
08:45	0,136	0,076	0,01026	0,362	0,275	0,09955
09:15	0,340	0,263	0,08942	0,613	1,189	0,72885
09:22	0,350	0,270	0,09450	0,686	1,623	1,11337
09:48	0,578	1,021	0,59013	0,975	3,730	3,63675
10:30	0,870	2,910	2,53170	1,212	5,750	6,96900
11:15	1,117	4,920	5,49564	1,382	7,490	10,3511
12:00	1,270	8,000	7,62000	1,450	8,500	11,9625
12:45	1,440	8,850	11,7360	1,515	8,950	13,5592
13:00	1,440	8,856	11,7930	1,470	8,900	12,9360
14:08	1,367	8,855	9,91075	1,407	8,900	10,3414
15:20	1,193	5,570	6,64501	1,270	6,280	7,97560
16:20	0,813	2,450	1,99185	0,979	3,712	3,63404
17:00	0,310	0,378	0,11718	0,412	0,371	0,15285
17:20	0,058	0,033	0,00191	0,086	0,047	0,00404

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The angle of the fixed solar panel with the horizon was computed using equations (4) and (5) and it read60.54°. With the Sunrise (8:27) the system started to record the data and continued until (17:20) the sunset.Voltage, current and power data of both the solar tracking system and the fixed system was collected by an online computer all day. Some of this data can be seen in Table 2. When the data was analysed, the electrical output size of the solar tracking system, as expected, was higher than the fixed system.

In the chart of Fig 11 the voltage values of the both panels are compared during the time span from the sunrise to the sunset. When the graphics are examined voltage values between 11:30 – 14:30 are very close to each other but in the early hours of the morning and the sun sets the gap between the voltages values are observed to increase.

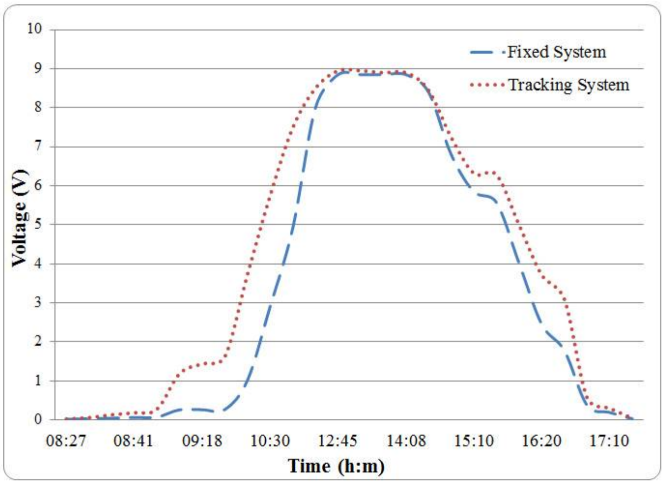

Fig.11. The voltage values of the tracking and fixed systems

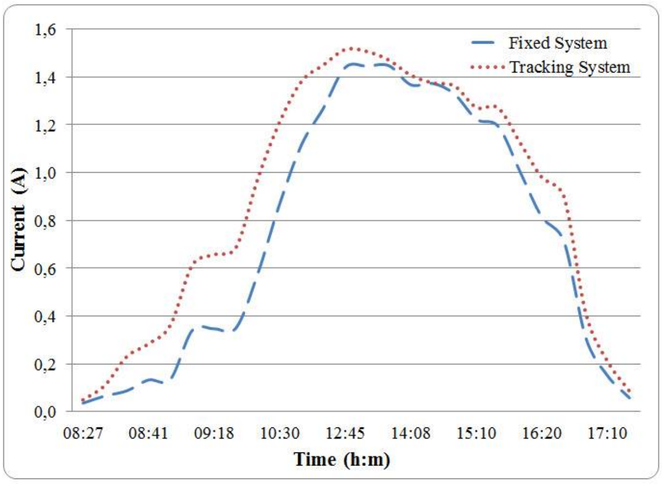

Fig. 12. The current values of the tracking and fixed systems

When the chart in Fig 12 is examined tracking system provides much more current value with the load than the fixed system at noon hours. This value around 8:45 is decreased to 166% and 2% to around 13:00. Both panels' currents are nearly the same from 12:45 to 15:20. However, from 15:20 to sunset the current levels increase gradually from 6% to 48%. Tracking system proves to be much more advantageous than the fixed system. When power data obtained from the fixed and moving panels in Fig 13 is calculated, the solar tracker has produced 24.64% more power than the fixed system.

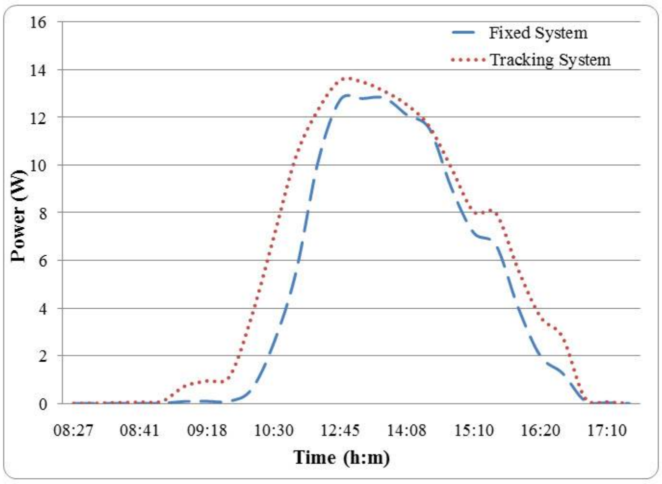

Fig.13. The power values of the tracking and fixed systems

IV. CONCLUSION

With smart solar tracking based on fuzzy logic control system it is intended the Sun's irradiance can be followed with maximum density. This experimental work proved that the tracking system is more efficient than the fixed system. Solar energy has become one of the important types of alternative energy sources, such reasons as accessibility, cost efficient in production and low priced installation costs have made it favourable. But one of the problems of solar energy technology is that we should be able to increase the yield of solar panel output power by collecting as much sun rays as possible. The system we designed will contribute a solution to this problem. Clearly the tracking system we designed improved the output yield by 24.64% when compared to the fixed panel. Besides actuator motors which enable the movement of the panel did not operate at maximum level and because it was controlled by the PWM modulation in smart mode power consumption was significantly reduced.

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