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Research article

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EVALUATION OF PHOTOVOLTAIC SOLAR POWER OF A DUAL-AXIS SOLAR TRACKING SYSTEM

双轴太阳能跟踪系统的光伏太阳能功率评估

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Abstract

In this research project, a tip-tilting angle of a photovoltaic solar cell was developed to increase generated electrical power output. An active, accurate, and simple dual-axis tracking system was designed by using an Arduino Uno microprocessor. The system consisted of two sections: software and apparatus (hardware). It was modified by using a group of light-dependent resistor sensors, and two DC servo motors were utilized to rotate the solar panel to a location with maximum sunlight. These components were arranged in a mechanical configuration with the gearbox. The three locations of the solar cell were chosen according to the tilt angle values, at zero angles, which included an optimal 33-degree angle for the Baghdad location and a variable angle with the dual-axis tracking system. For maximum value of the extracted solar energy, a photovoltaic solar panel that collects sunlight should be in normal position onto this radiation. Solar trackers relocated the panel toward the path of the Sun to ensure that the collector rotated at an optimal tilt angle. The results showed that the generated power at the dual-axis position was 3.384 watts per hour (W/h), the 33-degree angle yielded 2.237 W/h, and the zero-degree angle yielded 1.09 W/h. The results confirmed that the performance of a dual-axis solar tracking system is active and efficient.

Keywords: Solar Cell, Dual-Axis, Arduino, Tracking, Tilting Angle

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摘要 在该研究项目中，开发了光伏太阳能电池的倾斜角以增加产生的电功率输出。使用 Arduino Uno 微处理器设计了一个主动，准确和简单的双轴跟踪系统。该系统由两部分组成：软件和设备（硬件）。通过使用一组与光有关的电阻传感器对其进行了修改，并利用两个直流伺服电机将太阳能电池板旋转到阳光最大的位置。这些组件与变速箱以机械配置方式排列。根据倾斜角值（零角）选择太阳能电池的三个位置，其中包括巴格达位置的最佳 33 度角和双轴跟踪系统的可变角。为了最大程度地提取太阳能，收集太阳光的光伏太阳能电池板应位于此辐射的正常位置。太阳跟踪器将面板移向太阳的路径，以确保收集器以最佳倾斜角度旋转。结果表明，双轴位置的发电功

率为 3.384 瓦/小时（瓦特/小时），33 度角的功率为 2.237 瓦特/小时，零度角的功率为 1.09 瓦特/小时。结果证实了双轴太阳跟踪系统的性能是有效的。

关键词: 太阳能电池，双轴，阿杜伊诺，跟踪，倾斜角度

I. INTRODUCTION

In recent times, many countries have faced significant problems and challenges resulting from a decrease in fossil fuel resources and a considerable increase in energy consumption. Additionally, chronic electricity shortages, along with an increase in air pollution caused by fossil fuel consumption, have exacerbated these challenges [1], [2]. In present time, the world trend to find an actual solution for all the aforementioned energy problems; thus, alternative, clean, and renewable forms of energies, including geothermal, solar, and wind, have been utilized. Due to the abundance of sunlight and its low cost and zero emissions, solar energy has been shown to be the best solution [3], [4].

The renewable energy is in a development. Denmark produced 43% of its energy from renewables, and it works towards achieving 70% by 2020. Germany, at more than 25% now and 30% soon, is going for 40% to 45% clean energy by 2025, 55% to 60% by 2035, and a possible 80% by 2050. In spite of many challenges, China, is the world’s master source of renewable investment, as well as the major solar manufacturer [5].

Several mechanisms have been put in place in order to derive maximum energy from solar power. The most commonly used mechanism is solar tracking, which maximizes energy transfer from the Sun to a solar panel by rotating the panel according to the Sun’s position [6]. Various sun-tracking systems differ in their cost, functionality, and complexity [7]. Solar tracking systems are typically classified into two categories, depending on the controlling mechanisms that drive the PV panels. These categories are active tracking systems and passive tracking systems; both are considered the most important methods to obtain tracking efficiency [8].

Active tracking systems utilize motors and gears to guide the panels in the direction of the Sun, while passive tracking systems utilize compressed gas fluid with a low boiling point and that boils with heat generated from the Sun. Active tracking devices can be classified into two types, depending on the number of axes that are utilized to adjust PV panels: single-axis tracking systems and dual-axis tracking systems. Both types of systems were designed to mechanically track the Sun [9], [10]. Both mechanisms follow the Sun from east to west through direction and tilt angle, and the location of the panels changes according to the seasons. The essential difference of a dual-axis tracking system is that it measures both the horizontal axis and the vertical axis—a single-axis tracker only measures one of these. This classification is considered an important parameter for all solar trackers [11].

Computer systems and microprocessors can control solar tracking systems so they follow the Sun’s location. As an alternative to using sensors, these apparatuses depend on mathematical relations and functional algorithms to accurately locate the position of the Sun. Low-cost microprocessors, such as a programmable logic controller (PLC) and a microprocessor (e.g., Arduino Uno), are utilized in many devices. Microprocessors can follow a tracking algorithm that utilizes information to investigate and recognize appropriate movement [12], [13].

II. SYSTEM DESCRIPTION

In this study, a solar tracking system was implemented by using a microcontroller based on a dual-axis solar tracking technique that consisted of Arduino Uno microprocessors, DC servo motors, a gearbox, a light-dependent resistor (LDR), an angle sensor, a timer circuit, a Bluetooth unit, and a motor module. The Arduino Uno microprocessor sent the order to the DC servo motor to identify the angles of the attitude and the azimuth of the solar panels to keep the panel close to sunlight [3], [4], [5], [6]. Two sensors were utilized to calculate the two angles so the outlet shaft coupler could ensure achievement of the required angles (attitude and azimuth). Four LDR units were applied to trim error in the above angles. Tracking factors were managed remotely by a supervisor who had access to a computer and a Bluetooth unit. The results of the experiment confirmed that the power created by using a dual-axis tracking system is 10–40% more efficient than a fixed-angle system.

The microcontroller board depends on the utilization of an algorithm that measures the location and direction of the solar panel. The algorithm calculates the difference in time between the microcontroller and the displayed time [14], [15]. Tilt and orientation angles are significant factors for the workability of tracking devices. Tilt angle is defined as the angle that lies between the solar tracking system surface and the horizontal axis [16], [17]. The incidence angle is a form of the tilt angle, that is about 40 degree in the east direction in Iraq. The orientation angle can be utilized to the movement of a solar tracking system to keep the solar PV panel vertical to the Sun to achieve the best power generation, as shown in Figure 1.

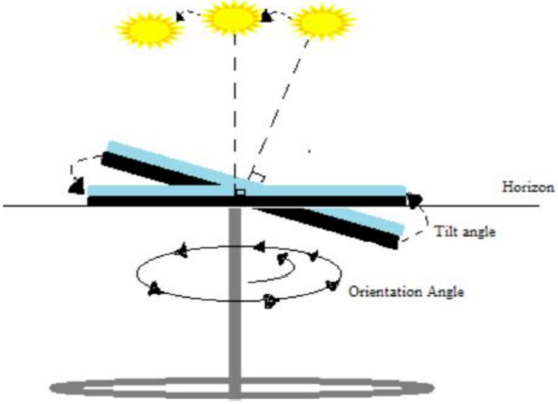


Figure 1. Tilt and orientation angles [1]

The Arduino Universal Network Objects (UNO) controller computes the parameters for tracking the theoretical location of the Sun by using the following equations [14]:

$$\text{Altitude} = Sin^{-1}(Sin\delta\ Sin\varphi) \quad (1)$$

$$Azimuth = Cos^{-1}[(sin\delta\ cos\varphi - cos\delta\ sin\varphi\ cos\omega)] \quad (2)$$

Where: δ is the declination angle, φ is the local latitude, and ω is the hour angle. The equation varied with varying the angle between 0-360 degree depending on the suns location from the east to the west, as illustrated in Figure 2.

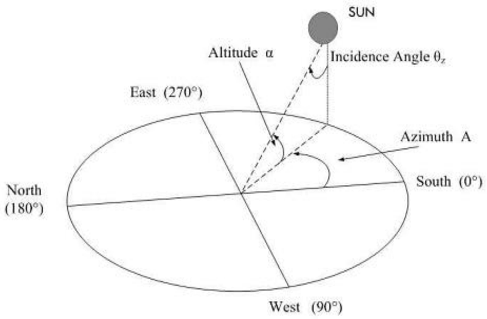


Figure 2. Azimuth and altitude angles [3]

The system automatically trims the azimuth and altitude angles of the photo-voltaic (PV) board based on the feedback signal of the suggested photoresistor (LDR) sensor:

The sunlight sensor module was composed of four LDR sensors. Two angle sensors were located on outlet shafts at the altitude and azimuth angles in order to calculate the final values of these angles and send them to the observing computer interface [18], [19].

A. Diagram Description

The essential aim for this procedure is to design an active and accurate tracking device for a solar cell according to a tilt angle of 0° and a tracking angle of 33°. The procedure consists of two parts: software and hardware. Figure 3 represents the essential components of the tracking system unit. The hardware consists of: solar panel, drive motors, gearbox, LDR sensor unit, and control circuit.

B. Sun Location-Sensing Technique

The tracking system employed to identify the Sun's location was implemented in two stages: primary (indirect sensing) and secondary (direct sensing). During the first stage, the tracking system utilized the Sun-Earth geometrical relationship to determine the Sun's position, so the location of the Sun could be found irrespective of the weather conditions, e.g., dusty or cloudy. The second stage included the use of a group of LDR sensors that acts as a resistor, whose resistance decreased with increasing light intensity, for output tuning to trim the angles (azimuth and altitude). This stage also included calculations of the surrounding conditions. The LDR sensor unit was composed of four light dependent resistors or cadmium sulfide cells.

The LDR unit was located on a circular plate separated by a 90° space and rotated by using vertical rectangular plastic layers. Each LDR was connected in series with 1 kΩ resistor, so, all four LDR units or resistors would configure a Wheatstone bridge circuit, as indicated in Figure 4.

In this procedure, an Arduino UNO was used as a controller unit.

Two LDRs were connected to analog pins of the Arduino.

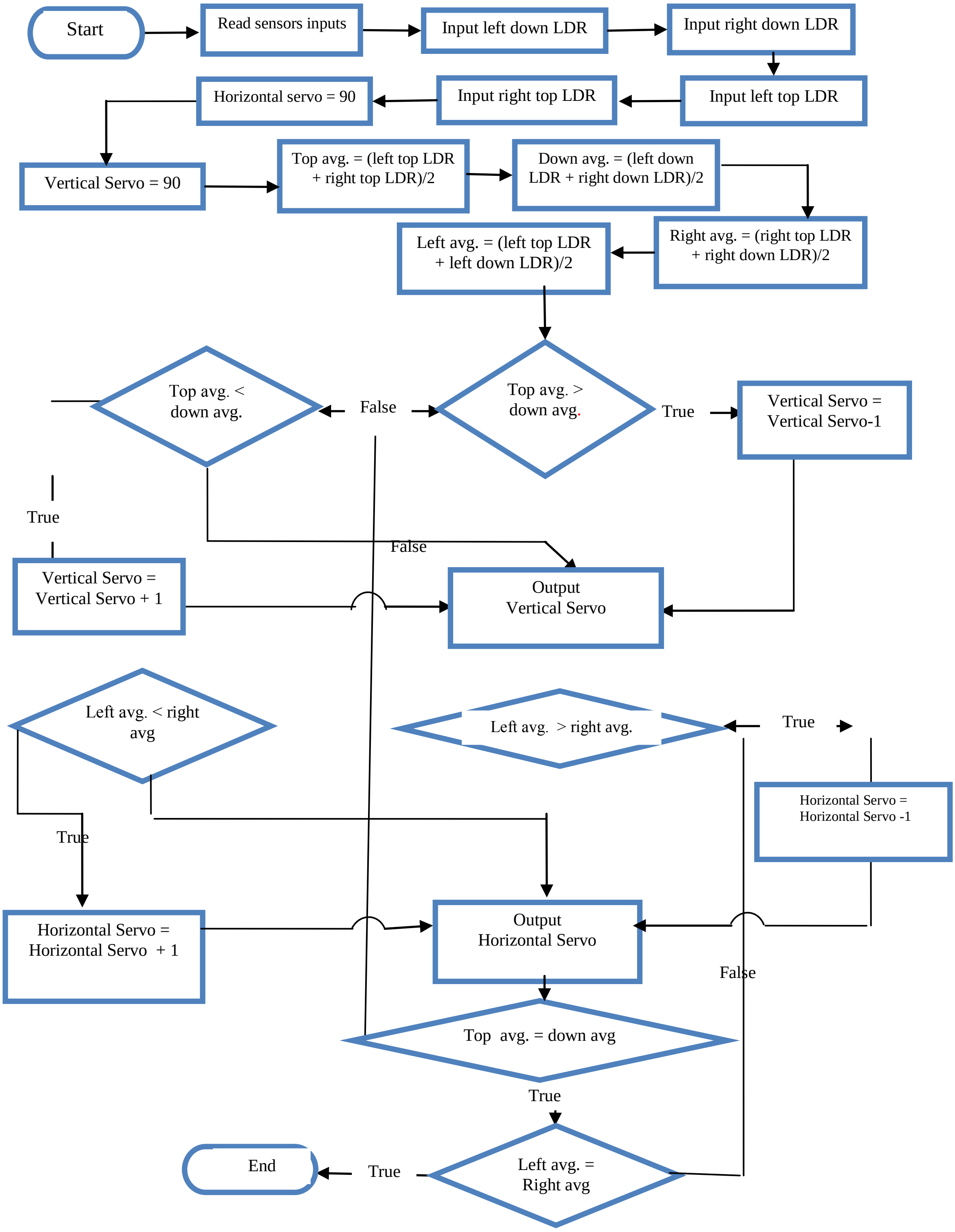
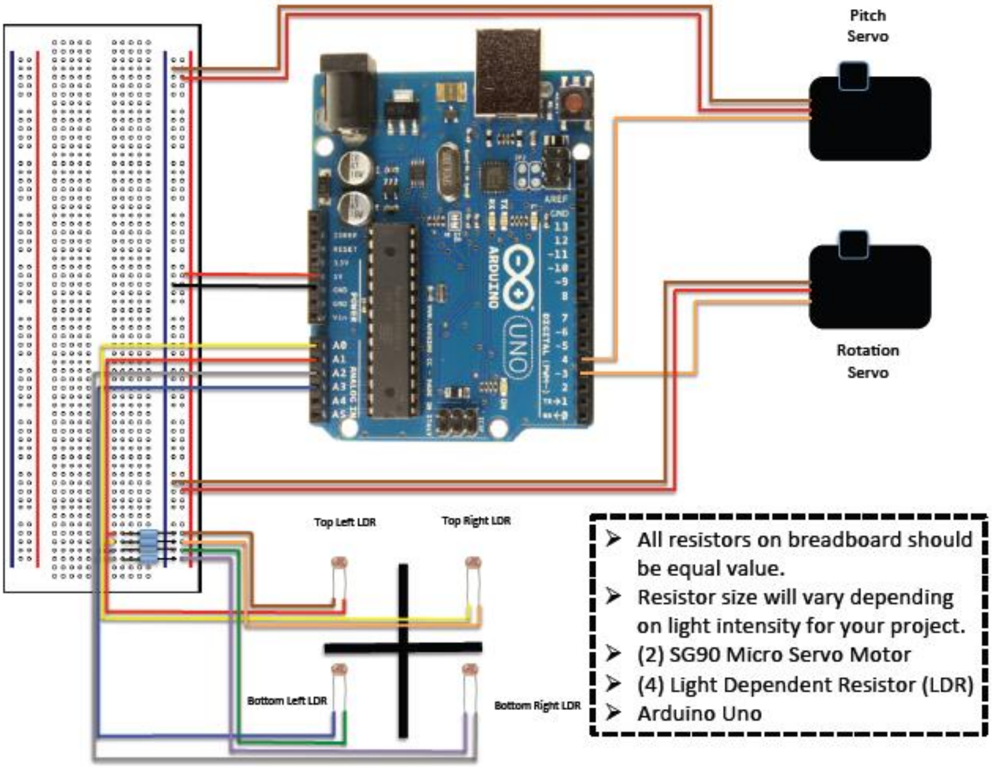


Figure 3. An algorithm for essential components of the tracking system

C. Overview of Arduino

Dual-axis tracking can be developed by using the Arduino as a programming platform. Arduino is an open-source electronics platform, based on small, easy-to-use hardware and a clockwise obtained by bar shadows on LDRs. If the location of the Sun is central, then sunlight falls on the four sensors equally, and the output analog signal (as a voltage) produces equal values and the microcontroller will not produce any logic signal to activate the motors [6].



- All resistors on breadboard should be equal value.
- Resistor size will vary depending on light intensity for your project.
- (2) SG90 Micro Servo Motor
- (4) Light Dependent Resistor (LDR)
- Arduino Uno

Figure 4. LDR sensor system with a Wheatstone bridge circuit

The software can analyze data and produce a logic signal that instructs the motor to rotate the tracker to a location where equal light intensity hits on a pair of LDRs [3], [4], [5], [6].

The Arduino UNO works using additional programming hardware to produce the logic signal and modifying the program of the microcontroller for azimuth plus altitude angles, followed by rotation of stepper motors to rotate the solar panel in either clockwise or anti-clockwise obtained by bar shadow on LDRs. if the location of the sun is in the middle, then sunlight on the four sensors will be equal, then the outputs analog signals of a voltage produces equal values and the microcontroller will not produce any logic signal to activate the motors [21].

In the present work, solar radiation was collected for two sources: Davis instruments type Vantage Pro2 and PVGIS website (Latitude 33.21° N, Longitude 44.21° E), at locations from weather stations installed at the ministry of science and technology, Jadryia, Baghdad. The data has been averaged to monthly values to evaluate the design of hybrid PV/Battery/DG power systems. We begin with Global Horizontal solar radiation for Iraq, and especially Baghdad city, as shown in Figure 5. The monthly average solar irradiation is shown in Table 1. The values ranged from 4.24 to 7.23 (kWhr./m^2/d), with the total annual average radiation being 5.9 kWhr./m^2/day.

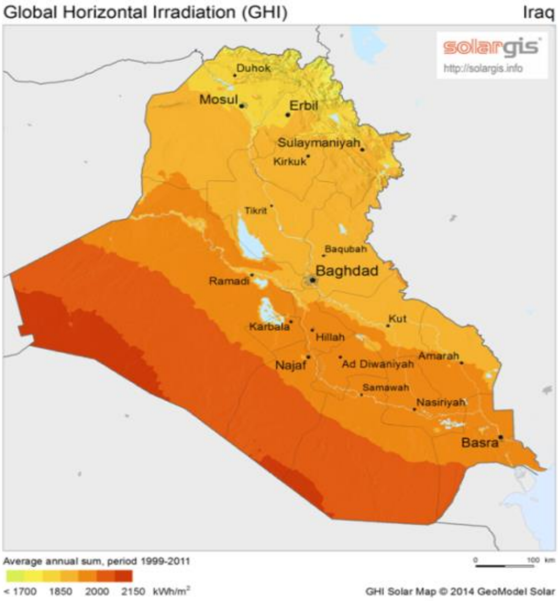


Figure 5. Iraq map of global horizontal irradiation (GHI)

Table 1.
Annual average radiation values in Baghdad

Month Baghdad	Clearness Index	Avg. radiation (kWhr./m^2/day)
Jan.	0.798	4.24
Feb.	0.787	5.24
Mar.	0.738	5.70
April	0.607	6.10
May	0.586	6.51
Jun.	0.617	7.10
Jul.	0.641	7.23
Aug.	0.687	7.15
Sept.	0.715	6.40
Oct.	0.843	6.04

Nov.	0.920	5.19
Dec.	0.868	4.30

III. EXPERIMENTAL PROCEDURE

Figure 6 illustrates the arrangement and mechanical components of a solar tracker device with dual axis. LDR sensor units are connected to UNO (Arduino) using analog pins, attached to a board in parallel with a collector. A plastic box enclosed with tin foil is employed to protect the electronic components of the control circuit. Two motors are arranged in addition to the gearbox setup to achieve the required motion. An aluminum structure is used to hold the solar panel.

Figure 6. Mechanical arrangement of the tracking system

IV. RESULT AND DISCUSSION

The data is collected from the analyzer display measuring voltage and current from the solar cell at three positions of tilt angle, as recorded in Tables 2, 3 and 4, along with the time of day in December 2018. Graphs are then drawn as illustrated in Figure 7, to calculate the power and carry out the comparison between them. The measurements have been registering daytime data for one day from 7 o'clock in the morning to 5 o'clock in the evening. The results reveal that the the two-axis system generates more energy at 33 degrees.

The tracking system increases the total power generated at θ = 0 per day by about 40%.

1) *Tilt Angle of Solar Cell $\theta = 0$ Degrees*

The total power collector for one day:

Total power = $\sum_{7}^{17} p$ = 12.027 W/Day

$$P_{AV} = \frac{12.027}{11h} = 1.09 \text{ W/h}$$

2) *Tilt Angle of Solar Cell $\theta = 33$ degrees*

Total power = $\sum_{7}^{17} p$ = 24.61 W/Day

$$P_{AV} = \frac{24.61}{11h} = 2.237 \text{ W/h}$$

3) *At Two-Axis Tracking Tilt Angle of Solar Cell*

Total power =$\sum_{7}^{17} p$ = 37.234 W/Day

$$P_{AV} = \frac{37.234}{11h} = 3.384 \text{ W/h}$$

Table 2.
For θ = 0 degree

Time (h)	**V (Volt)**	**I (Amp)**	**P (Watt)**
7	0.5	0.11	0.055
8	0.62	0.11	0.0682
9	0.68	0.12	0.816
10	1.5	0.14	0.21
11	4.2	0.33	1.38
12	7.2	0.45	3.29
13	6.8	0.42	2.78
14	5.4	0.38	2.052
15	3.2	0.31	0.992
16	2.1	0.17	0.357
17	0.3	0.009	0.027

Table 3.
For θ = 33 degree

Time (h)	**V (Volt)**	**I (Amp)**	**P (Watt)**
7	1.2	0.11	0.132
8	2.5	0.21	0.525
9	5.5	0.32	1.76
10	6.2	0.33	2.076
11	8.1	0.45	3.645
12	9.4	0.62	5.828
13	7.3	0.51	3.723
14	7.1	0.42	2.982
15	6.9	0.33	2.277
16	5.1	0.31	1.53
17	1.2	0.11	0.132

Table 4.
Tracking system

Time (hour)	**V (Volt)**	**I (Amp)**	**P (Watt)**
7	1.5	0.11	0.165
8	2.8	0.23	0.644
9	6.3	0.41	2.583
10	7.1	0.48	3.408
11	7.9	0.58	4.582
12	10.1	0.78	7.878
13	10	0.65	6.5
14	9.3	0.61	5.673
15	7.1	0.5	3.55
16	5.5	0.37	2.035
17	1.8	0.12	0.216

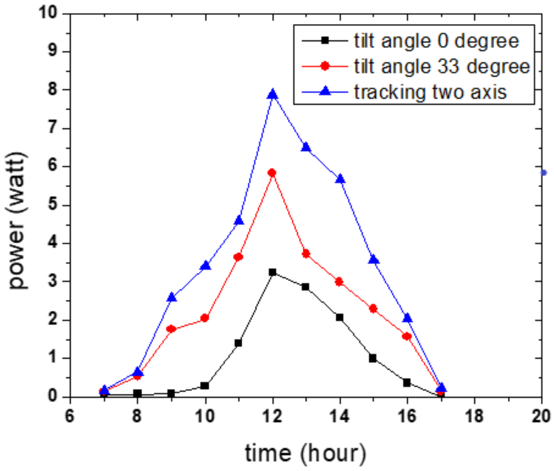


Figure 7. Power with time for three position tilt angle

V. CONCLUSIONS

A dual-axis tracker system was designed by using the Arduino UNO microcontroller and modified with a group of LDR sensors. Using the solar cell with the tracking system successfully improved the system's power generation.

Experimental data from the dual-axis tracking system were collected from the analyzer at three tilt angle positions, at zero degrees, 33 degrees (optimal for the Baghdad location), and variable angle.

The results revealed that the generated power at two axes was 3.384 W/h, whereas at 33 degrees it was equal to 2.237 W/h and at zero degrees was 1.09 W/h.

Using the solar cell with the tracking system is a good method to improve energy generation. The amount of power generated was increased compared to a fixed-axis solar cell system.

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