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Optimizing Electrical Power for PV Power Plants Based on Dual-Axis Solar Tracking System with Two-Rotational Degrees of Freedom

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Abstract: Renewable energy sources have gained popularity in the field of power engineering. The aim of this paper is to develop Photovoltaic (PV) panels which assure the utilization of maximum sunlight that produces maximum electrical power. In this paper, dual-axis solar tracking system is used to achieve highest sunlight on PV panels which sensed by four light dependent resistors (LDR) with the microcontroller of Arduino-UNO that drives servo motor for rotating the axis of PV panels. The experimental test results revealed that the dual-axis solar power panel was more efficient than the single-axis and fixed solar power panel. It is concluded that the solar energy is very effective in the tropical countries specially Bangladesh for producing energy from renewable resources like solar power.

Keywords: *Power; Solar tracking; Solar panel; Sunlight; Light dependent resistor (LDR)*

Introduction: Renewable energy sources have received much attention for increasing demand of energy in the world because of its higher efficiency and cost-effective approach. In last decade, it had been seen evidently that, the fast-growing technology takes place in all the branch of needs. Probably a technological explosion is coming in the next few decades which require a much amount of energy to govern this fast-growing technology [1]. An exertion has been seemed to pay attention on renewable energy sources after standing up this conviction that, the fossil fuels are not adequate to rule the vast amount of energy demand in next few decades. Geothermal, hydro, wind, biomass and solar are the main sources of renewable energy. A number of countries have started to generate electrical power from those renewable sources [2]. Solar energy can deal with the exorbitant energy demand which can provide 20TW power and this huge energy is all most two times of the expense rate of fossil energy in the world.

It had been announced from Bell Labs C. Fuller, and G. Pearson & D. Chapin had invented the first practical silicon solar cell on April 25, 1954. p-n junctions is the basic mechanism of silicon solar cell. It's known as Photo Voltaic (PV) cell which convert sunlight to DC electricity. It has appeared best output in 25 ºC ambient temperature and 1000 W/m2 solar intensity [3]. It's noticed explicitly the tropical countries are ideal place to propagate solar power plants. Its need to start with a new vigor specially for Bangladesh. It's a riverine country which located into tropical monsoon geographic region in South Asia. The temperature of Bangladesh remains average 25 ºC to 27 ºC probably over the year [4]. The temperature curve characteristics in Fig.1

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categorically. The temperature curve characteristics in Fig.1 categorically seem that, Bangladesh is faithful place propagating solar power plants to recruit present power demand. Further, the solar power plants will provide power for fast-growing technological power demand in developing country like Bangladesh.

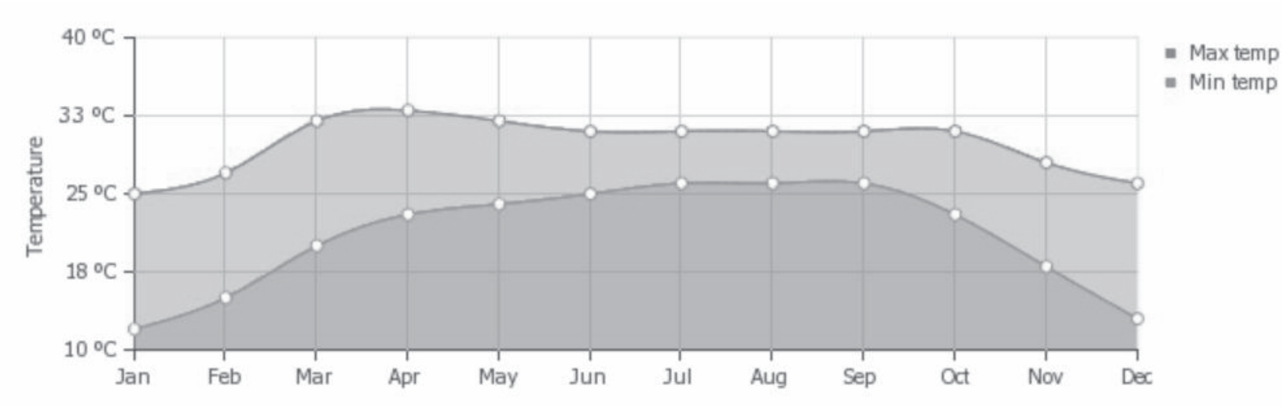


Fig. 1: The monthly mean minimum and maximum temperatures over the year in Bangladesh [4]

It has a huge distance between earth and sun about 1.49×10^8km, so the beams of sunlight envisaged as parallel [5]. The generation of maximum power from solar panel depends on the sunlight intensity and the incidence angle of sunlight's beams. When the angle becomes 90º between the surface of solar panel and sunlight's beam, it generates maximum electricity [6]. On the other side, the earth rotates round the sun which is cause to changes the position of sun in the sky of earth. So, the incidence angle of sunlight on solar panel doesn't remain 90º except at noon time which is only two hours longer. The sun rises from east horizon and sets in the west horizon which path appears an imaginary arc across the sky. This arc changes the position throughout the year like in winter season of northern hemisphere the arc moves lower or tilting toward the south. The arc seems various position over the year and the sun changes location across the arc throughout the day time [7]. This is accused for changing incidence angle of sunlight on the earth horizon and also on the solar panel. Under this circumstance, solar panel should be rotated with the corresponding position of sun to assure the 90º-incidence angle of sunlight. The dual axis solar tracker automatically rotates the solar panel for optimal incidence angle of sunlight which is difficult with single axis solar tracker and fixed solar panel [8].

Ali Al-Mohamad [6], designed a single axis solar tracker with two photo-resistors which help to track sun's location and PLC (programmable logic unit) maintains the mechanical movement of the PV module. The work was weighed with a fixed solar panel which revealed the output power increased 20% by using single axis solar tracker in comparison with fixed solar panel. Tiberiu Tudorache [9], also proposed a model of single axis solar tracker which is controlled by IBL2403 intelligent drive with DC motor. Sefa, et al. [10] worked on a single axis tracking system based on RS485 which controls the entire process. Two photo resistors sense the sun along with east-west direction. It is seen to use 24V and 50W DC motor for steering the solar panel. The job was compared with a fixed solar system and the results seemed that, the single axis solar tracker acted more efficient than fixed solar system. Mamlook, et al. [11], design a dual-axis solar tracker with programmable logic controller which controls the movements of solar panel. The job was assembled with fixed solar tracker system that uncovered the daily power output would increase more than 40% by using dual-axis solar tracker. Numerous researchers figured out dual axis solar tracker with individual microcontroller or IC [1, 12]. However, all of them used stepper motor for rotating solar panel. In this paper, dual axis solar tracker has two rotational degrees of freedom mounted by two servo motors which are governed by microcontroller and four light dependent resistors (LDR) used to sense the sun position. This is more efficient for optimizing electrical power than single axis solar tracker and fixed solar panel. The servo motor has more precise movement and optimal performance than stepper motor. Without well-defined load which is endurable with corresponding capacity of stepper motor may occur rotational errors and needed to restart or recalibrate the system. Encoder Servo motor drives its shaft precisely whatever signal of angle comes from microcontroller, even when it stands on the initial position of starting [13].

The main goal of this research paper is showing an interpretation that, the dual axis solar tracker system generates maximum power by sensing the sun's position across the sky. This has to be applied on power sector for propagating solar power plants in any tropical countries to rein the vast future demands of power. Bangladesh has a huge possibility in solar power sectors and its climate is surely compatible for emplacements of solar power plant with dual axis solar tracker system to rule the upcoming vast power demands.

Materials & Method: This is inherent ability of a solar panel to produce electricity in the attendance of sunlight. The generation of maximum power depends on the light intensity and sunlight incidence angle on the surface of solar panel which is right angle. It's needed to operate the incidence angle for correspondence sun's location across the sky. Solar tracker is an electro-mechanical device that rotates the solar panel according to sun's position, which needs to have a high degree of accuracy. Our dual axis solar tracker system has two degrees of freedom for operating rotational axis which showed in Fig. 2. Between two degrees of freedom first one controls east-to-west rotation according to sun's position over the day and second one controls north-to-south rotation for correspondence sun's location throughout the year. When it is summer in the northern hemisphere the North Pole is tilted toward the sun this causes to be higher the sun's path across the sky. The highest sun's path is shown in the Fig. 3, which is the longest day of summer (21st June) and the sunlight fall on perpendicular way in the northern hemisphere. However, when it is winter in northern hemisphere the south pole is tilted more toward the sun which causes to move the sun's path into the sky of southern hemisphere in 21st December [14]. So, the sun's path moves south-to-north over the year and second degree of freedom has been recommended as an essential part to move solar panel south-to-north for generating maximum power. Four light dependent resistors (LDR) have used to sense the sun's path across the sky, mainly it deals with the intensity of sunlight. It is made with semiconductor materials which have a changeable high resistance. It belongs to high resistance in dark condition and decreases resistance drastically when increase light intensity. Resistance higher and lower means less intensity of light and much intensity of light correspondingly. When light beams fall on a surface perpendicularly, the surfaces have been gotten maximum intensity of light. The program has been uploaded on microcontroller to reach maximum light intensity. LDRs search for maximum light intensity in where sunlight beams come at right angle on the surface of solar panel. Then microcontroller takes a signal and sends a signal to rotate the servo motor for recommended position. Four LDRs creates four groups top, bottom, left and right. The analog values from two top LDRs and two bottom LDRs are compared in the time of east to west tracking. When the top set of LDRs receive more light or the bottom set LDRs receive more light, the vertical servo motor moves in top or bottom direction correspondingly. When the angular deflection that means the north to south tracking is occurred the analog values from two left LDRs and two right LDRs are compared. Similarly, the horizontal servo motor moves left or right according to get more light intensity.

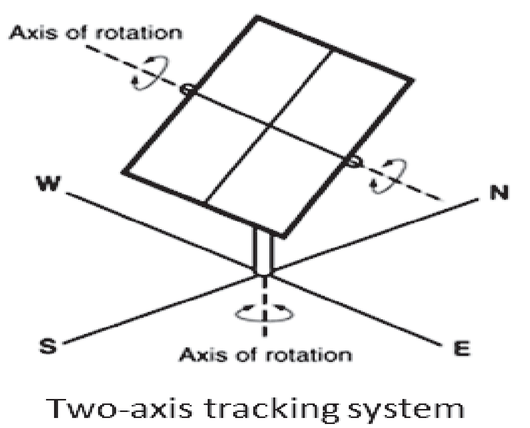


Fig. 2: Dual axis rotation which controlled two degrees of freedom

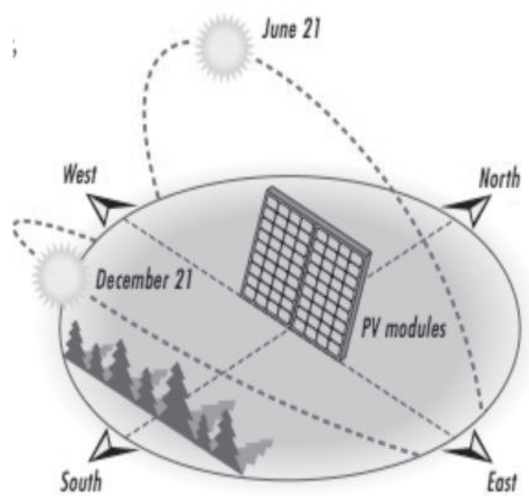


Fig. 3: The path of sun across the sky

The whole system works step by step which is showed in Fig. 4 with Block Diagram. The program has uploaded on microcontroller with Arduino software 1.8.2 (IDE). After sensing the intensity of light the through LDRs the microcontroller takes a signal and send a corresponded signal to motor drive for rotating the solar panel in recommended angle of position.

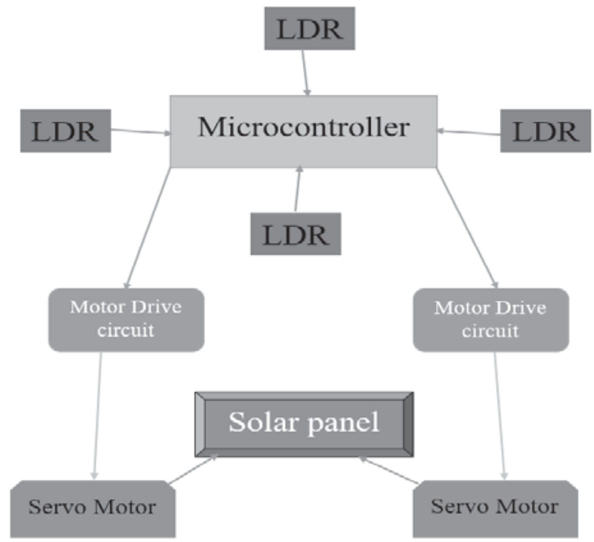


Fig. 4: Block diagram of dual axis solar tracking system

Working Process of Photovoltaic (PV) Cells: Basically, Photovoltaic (PV) Cells are made with semiconductor materials, like Silicon (Si) or Germanium (Ge) which are situated at group IVA or group 14 in periodic table. Semiconductor materials are such kind of materials which can conduct electricity under some conditions but not others. Usually, Silicon is used to made photovoltaic cells which has two electrons in 1st shell, eight electrons in 2nd shell and four electrons in outer most shell which is intrinsic semiconductor material. After doping intrinsic semiconductor materials, those become to impure semiconductor materials that have two types one is n-type and other one is p-type semiconductor materials. There have majority carriers and minority carriers which are causes to flow electricity. In n-type semiconductor materials have free electrons which are the majority carriers and positively charged hole are the majority carriers in p-type semiconductor materials. Similarly, the minority carriers are reverse of this. The solar cells are made with two semiconductor panels sandwich together which top one is n-type and bottom one is p-type semiconductor material. The surface of top and bottom are covered with two conductive layers and the glass is installed outer most surface to avoid electrical contact and protect cells from damages. In normal condition the majority carriers of n-type and p-type materials can't jump the common sandwich layer. However, when the incident sunlight's photons hit on the top layer of n-type materials the electrons jump to the bottom layer of p-type materials and the corresponding positively charged holes also jump to the n-type materials. The system is fallen into a stage of imbalance and electrons get rampage energy. If this layer is connected with a conductive layer, the electrons will flow through it and travel to the bottom conductive layer. The majority carriers of p-type materials which are positively charged holes receive those electrons and again pass it to top layer of n-type materials. This flow causes to electricity. If we connect a load in middle point of this flow path, we will get a voltage and corresponding current.

Equipment's:

Solar Panel: Photovoltaic cells or solar cells are interconnected to each other and appeared as a packaged rally which known as photovoltaic module or photovoltaic panel. Normally a solar cell produces about (0.5 – 0.6) V DC in open-circuit conditions which also depends on materials of solar cell. The current and power output depend upon the surface area and sunlight intensity [15]**.** In here a small solar panel is used which has 9V voltage-rating, 560mA current-rating and peak power-rating is 5W. Its open circuit voltage 9.6V and short circuit current rating 1A. It can be used in -40ºC ~ 80ºC environmental temperature. It's length 135mm (5.31") & width 125mm (4.92") and has 36 silicon solar cells. Those electrical activities are measured in standard condition which is light intensity 1000 W/m^2 and 25 ºC cell temperature.

Arduino-UNO: It's a microcontroller which board based on the A Tmega 328P. It carries 6 analog inputs, a 16 MHz quartz crystal and 14 digital input/output pins in which six can also be used as PWM outputs. It also has ICSP header and a reset button, power jack and USB connection [16]. The program has been written by Arduino software 1.8.2 (IDE) to control and rotate the servo motor.

Servo Motor: This is an upgrade version of DC motor which has a precise control of velocity and acceleration across angular and linear path. Servomotors are used in automated manufacturing, CNC machinery and robotics for its relatively sophisticated control. In many papers, stepper motors are taken to control solar panel but Servomotors are high-performance than stepper motors. As like, after acquiring the instructed position Servomotors stop to consume power and hold this position but stepper motors continue to consume power for holding this position [17]. Servo motor has three wires in which two wires are used to provide power supply and last one is used to send PWM signals to motor. Servo shaft is rotated by an angle depending on the ON-Time and OFF-time of the pulse. In this research we have used two servo motors which one for horizontal movement and another one for vertical movement.

Light Dependent Resistors (LDR): It is made with semiconductor materials which have a changeable high resistance that varies with the incident light intensity on it. This is used as a sensor which deals with light intensity and sends a signal to its control panel. In dark condition its resistance remains in several mega-ohms range like 10^{12} Ω. When photon's frequency of incident light surpasses a particular limit, the bound electrons absorb enough energy to jump into the conduction band that causes to flow free electrons which conduct electricity [18]. This result decreases the resistance of LDR and sends a signal of high light intensity, as decreasing resistance means increasing light intensity respectively.

Resistor: It's an electrical circuit element which has a highly significance that is used in electrical networks to reduce current, divide voltage, adjust signal levels etc. Generally, it's a passive two terminal electrical-element. In power system and electronic sector, various types of resistor are used to adjust circuit elements. Here we have used 680 Ω resistor in sensor circuit. Male to male and male to female wire also have been used to connect circuit.

Experimental Setup: Hardware impersonation is mechanical part of a research that holds the whole system and electrical network. The instrumental specifications have already done in previous paragraph. Fig. 5 shows that, Arduino-UNO has several pins among which are needed those are used. Yellow wires of servomotors have been used to send PWM signal to motor which is connected in Digital pin-9 and pin-10. Rest of two wires of each servomotor red and black are connected to 5V Power pin and Ground pin on Arduino respectively.

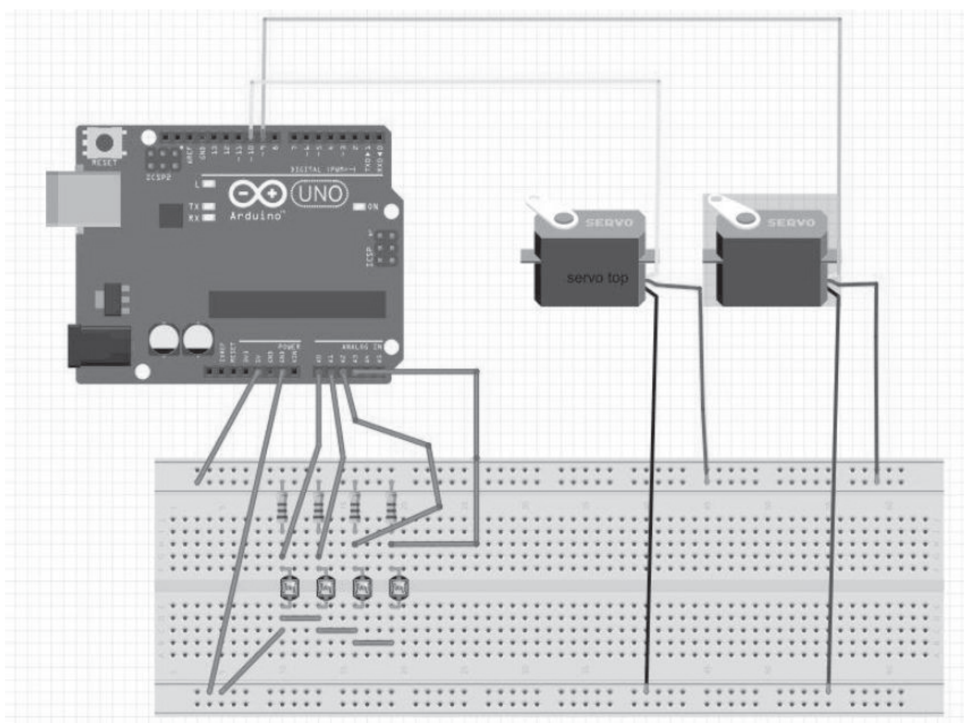


Fig. 5: Circuit layout of system [19]

First terminal of four LDRs need to be made one common node which is connected to common Ground pin. Second terminals of LDRs are separately connected to Analog pin (0,1,2 & 3) one after another. Four 680-ohm resistor's first terminals are also connected separately to Analog pin (0,1,2 & 3) and second terminals of each resistor need to be made one common node which is connected to 5V Power pin on Arduino board. In Fig. 5, this combination of electrical network has been exposed. In Fig. 6, system hardware structure has been showed which is made by steel to hold solar panel. When large solar panel will be used to hold it, this steel structure and servomotor should be large correspondingly.

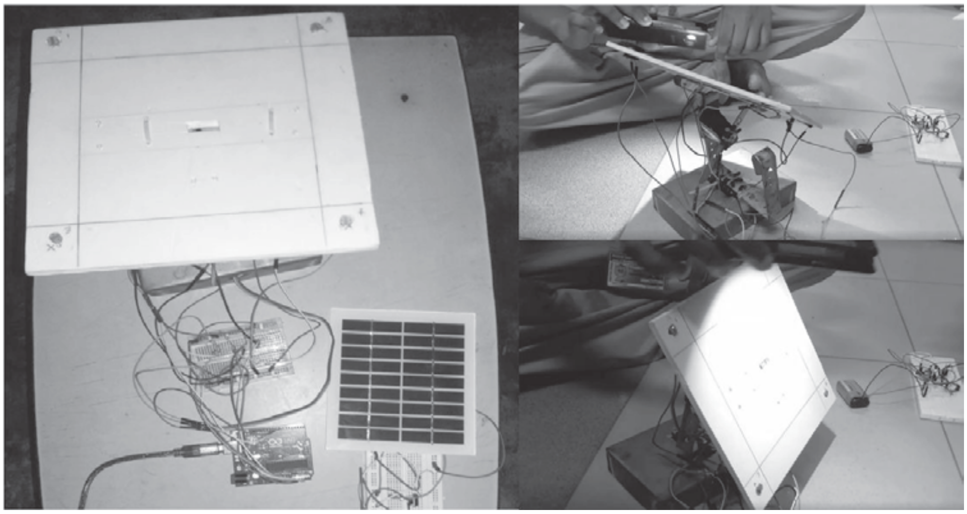


Fig. 6: Dual axis solar tracking system's hardware structure

Results and Discussion: This is the most cabalistic part of a research paper to expose the experimental findings. The final hardware design was performed in the outdoor for observing and searching our recommended experimental findings. We observed in three different conditions which were Fixed solar panel, Single axis solar tracker and Dual axis solar tracker, those three conditions were given back some data-sets which were collected in terms of Voltage and Current with respect to day light time from 7:00am to 6:00pm. Those performances were occurred in sunny day and observed gingerly.

Table 1. Experimental data for fixed solar panel

Day light time	Voltage (V)	Current (mA)	Power (W)
7:00 am	1.02	1.00	0.00102
8:00 am	2.81	46.50	0.130665
9:00 am	3.255	100.01	0.325533
10:00 am	5.64	373.33	2.105581
11:00 am	6.39	433.06	2.767253
12:00 pm	6.43	436.80	2.808624
01:00 pm	**6.64**	**440.53**	**2.925119**
02:00 pm	6.63	332.27	2.20295
03:00 pm	6.66	350.93	2.337194
04:00 pm	5.63	194.13	1.092952
05:00 pm	2.36	44.80	0.105728
06:00 pm	2.36	37.33	0.088099

Table 2. Experimental data for single axis solar tracking system

Day light time	Voltage (V)	Current (mA)	Power (W)
7:00 am	1.50375	0.373333	0.000561
8:00 am	1.71375	201.6	0.345492
9:00 am	3.36375	272.5333	0.916734
10:00 am	5.5125	492.8	2.71656
11:00 am	6.16875	485.3333	2.9939
12:00 pm	5.35125	504	2.69703
01:00 pm	**6.17625**	**510.45**	**3.1526**
02:00 pm	5.68125	429.3333	2.43915
03:00 pm	5.93625	421.8667	2.504306
04:00 pm	5.94375	440.5333	2.61842
05:00 pm	5.05125	224	1.13148
06:00 pm	1.9875	59.73333	0.11872

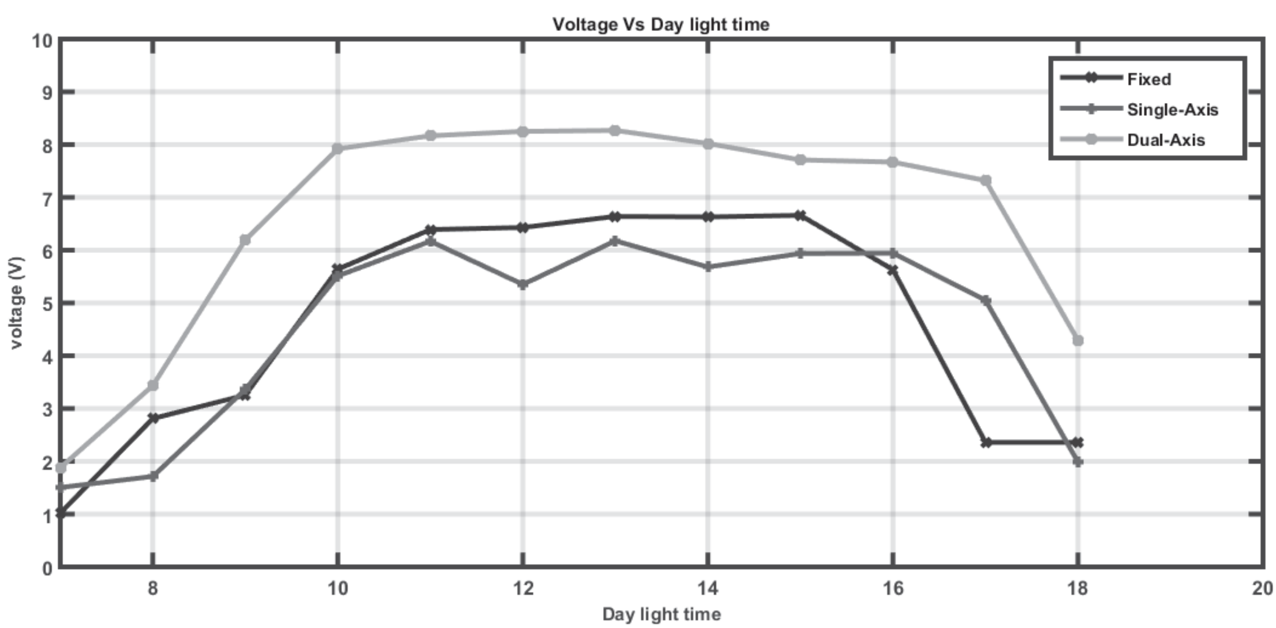
Table 3. Experimental data for dual axis solar tracking system

Day light time	Voltage (V)	Current (mA)	Power (W)
7:00 am	1.87875	3.733333	0.007014
8:00 am	3.435	197.8667	0.679672
9:00 am	6.195	429.3333	2.65972
10:00 am	7.92	496.5333	3.932544
11:00 am	8.1675	530.1333	4.329864
12:00 pm	8.25	548.8	4.5276
01:00 pm	**8.26875**	**556.2667**	**4.59963**
02:00 pm	8.02125	522.6667	4.19244
03:00 pm	7.71	485.3333	3.74192
04:00 pm	7.66875	470.4	3.60738
05:00 pm	7.32	451.7333	3.306688
06:00 pm	4.29375	227.7333	0.97783

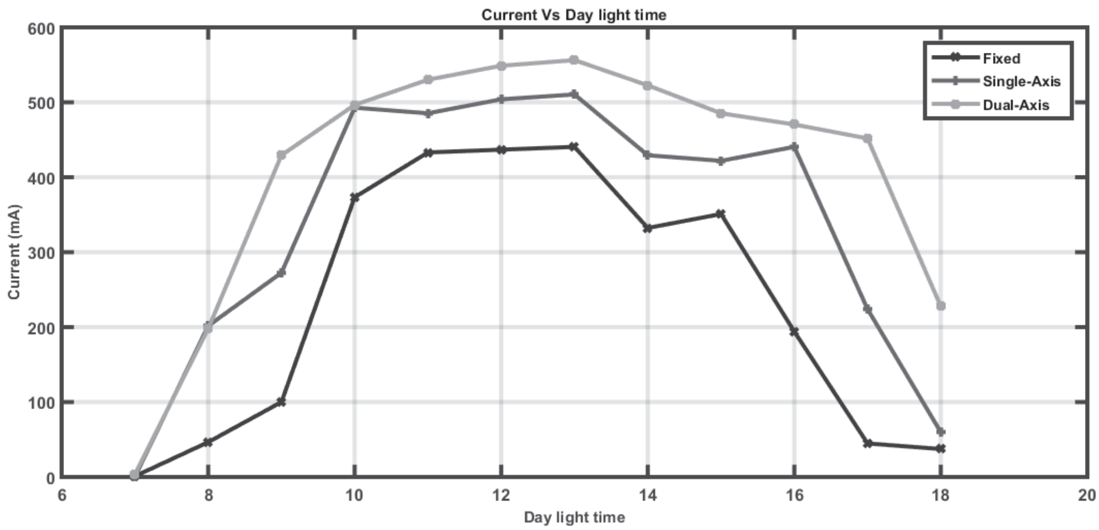
After collecting Voltage and Current, we calculated Power through this equation (P=VI). Table.1 shows the collecting tabular data of fixed solar panel. Table.2 and Table.3 are correspondence to Single axis solar tracking system and Dual axis solar tracking system.

At first, we can shortly discuss about power which is produced through all conditions. This was a 9V voltage-rating and 560mA current-rating solar panel which peak power-rating was 5W. So, Voltage, Current & Power could not exceed the rating voltage, current & Power. However, it was seen that dual axis solar tracking system increased power nearly of rating-power. At 1pm fixed solar panel and single axis solar tracker were given power respectively 2.925119W and 3.1526W. Consequently, dual axis solar tracker was given 4.59963W which reached nearly the rating power of solar panel. This means that dual axis solar tracking system optimizes sunlight to produce electrical power.

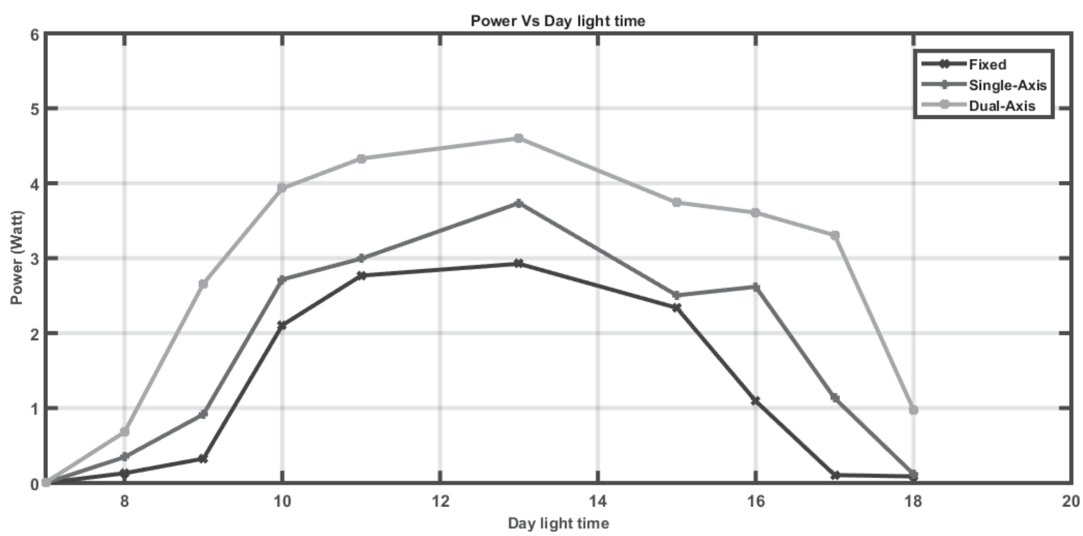
Now we can observe graphical comparison of voltage, current and power in three conditions. Those graphical representations were illustrated with MALTAB. In Fig.7(a), voltage versus day light time graph was plotted in which x-axis range is 6:00 to 20:00 (8:00pm). It was considered to get a better scale of graph but we observed 7:00 to 18:00 (6:00pm). Blue, Red and Green colors indicate fixed solar panel, single axis solar tracker and dual axis solar tracker correspondingly. Fig.7 (b) was illustrated with Current versus day light time and Fig.7(c) was illustrated with Power versus day light time graphical comparison.



(a) Voltage



(b) Current



(c) Power

Fig. 7: Graphical Comparison among dual axis solar tracker, single axis solar tracker and fixed solar panel of (a) Voltage, (b) Current and (c) Power

Circumstantially, we can observe the graph of voltage comparison (Fig.7.a) in which the fixed solar panel and single axis solar tracker have showed all most same response for voltage throughout the day. But from the curve of dual axis solar tracker in voltage comparison graph we can see that, a better outcome has appeared. On the other hand, the current comparison graph (Fig.7.b) has showed that, single axis solar tracker repercussion is better than fixed solar panel and dual axis solar tracker repercussion is much better than single axis solar tracker. Power has been calculated from the collected data of voltage and current. The power comparison graph (Fig.7.c) has exposed clearly that, dual axis solar tracker power outcome is always much better than single axis tracker and fixed solar panel over the day light. Dual axis solar tracker has reached the scale of 4.59963W which is closed to rating power (5W) of solar panel. Consequently, single axis tracker and fixed solar panel have reached the scale of 3.1526W and 2.925119W respectively. So, this is the final experimental finding of this investigation that, Dual axis solar tracking system evidently optimizes sunlight to generate maximum electrical power.

Conclusions: Experimental investigation has revealed a remarkable sequel which clearly gives an annunciation that, dual axis solar tracking system belongs to a stage of excellence for generating electrical power than single axis solar tracker and fixed solar panel. In this research paper, we have also remarked about the climate of Bangladesh which is much worthy to propagate solar power plants for governing the most recent future demands of electricity. Dual axis solar tracking system is little bit expensive for power plants comparatively. But after installing how much electrical power will be generated comparatively that recoups the primary cost. So, it should be propagated all of tropical countries significantly in Bangladesh. In future, this will be designed to extend our model with high performance degree of freedom for commercially used large solar panels which will be selected to propagate power plants. Here, some mechanical investigations will be needed to assure the degree of accuracy for large servo motors and its shafts which will hold up the commercially used large solar panels.

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