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Efficiency of Solar Tracking System for Photovoltaic Cells

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Abstract
Most recently, diversification in the energy sector is demanding due to the population growth of the world, advancement in technology and the need to have clean, safe and unpolluted means of electricity generation. Solar energy has stands this challenge of providing renewable energy at affordable cost and reliable means at long run. To improve the efficiency of the photovoltaic cells, the solar panel is kept at constant proportion to the direction of sunlight throughout the period of its intensity in order to attain efficient energy. A dual-axis solar tracker was designed to tilt the solar panel continuously in an azimuth and zenith directions using active tracker method to control the movement. Elevation and azimuth angles were carefully calculated to maintain the position of the solar panel, energy expense on operating the system and comparison of the energy gain to obtain maximum efficiency over a fixed oriented solar panel. Moreover, a sensor circuit was designed using four light dependent resistors to compare the sun's intensity so as to keep the photovoltaic cells at the appropriate tracking position. The device is controlled using ARDUINO Uno interface. Consequently, a dual-axis solar tracker was found to have 35% efficient energy than the fixed solar tracker even when the sun intensity is low during winter season.

Nomenclature and units

$\boldsymbol{\delta}$	Declination angle
α	Elevation angle
$\emptyset$	Latitude
HRA	Hour angle
LST	Local Solar Time
d	Number of days of interest
TC	Time Correction

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1.0 Introduction

A report in 2008 by the International Energy Agency (IEA) said that more than one and half million people had difficulty in accessing electricity which more than 80% were domiciled in the local communities (Pereira et al., 2011). The need for integration of sources of energy in recent years is demanding due to the growth in population as well as diversification in electricity generation. In the developing countries, especially the sub-Saharan Africa, Asia, Latin America, most of the population have no access to constant electricity as of 2015 due to the predicaments involved in the generation and distribution of this much needed energy in fostering fundamental development and industrialization (Panos et al., 2016). Due to the cost and access to affordable electricity, a cluster generation and distribution came up as simplicity to this menace. Solar energy as one of the clean and natural energy from the sun uses photovoltaic cells as collectors to convert solar energy into electrical energy. The solar panel is made up of solar cells arranged in a predefined order. The instantaneous power output of the solar panel is based on the Standard Time Conditions (STC) rated at the intensity of the sun ($1000W/m^2$), temperature of about 25^0C and the angle at which light is hitting the panel (Ahmed & Khan, 2014). The solar panel is dependent of the radiation of the sun which alters time to time within the duration of the sun's intensity in a day and throughout the year. Therefore, the amount of power generation from this source can be more efficiently utilize if the solar panel is been oriented in the trajectory of the sun from sunrise to sunset (Barsoum & Vasant, 2010).

However, the cost of producing the solar cells for the panels were unaffordable by many but the fact remains that the driving force has been the reliability. There was a deliberate increase in the production of semiconductor using silicon due to its availability and cost in manufacturing single crystal solar cells and P-n junctions. Some years later, there was a modification in manufacturing of the solar plates and panels modules into flat-plate silicon to suite the climatic condition in terms of resistivity. With this, the efficiency has increase to 25% and so the cost became less expensive to some extent and affordable. So the effects appeared openly increase the total production in 2002 to more than 1GW and tremendous increment in 2006 to 3.8GW per year (Marks et al., 2013). It is very important in the field of Engineering, cutting cost in order to make the system affordable and reliable (Jaen et al., 2009). Different varieties of silicon have been used in the development of the solar cells. The photovoltaic cells much more adapt the silicon crystals in its production because of the application potentials and low-cost it's possessed in the electric power market (Fraas & Partain, 2010). In the meantime, different methods were applied to increase the intensity of the solar cells. One of which was the Binary threshold technique used in the image processing where contours of different images such as the sun, cloud and other obstacles were compared using their coordinates to determine the one with the highest intensity. This implies that the efficiency of the solar tracking system in terms of the power is more reliable (Sohag et al., 2016). Furthermore, another practical experiment was conducted in the University of Louaize where the used three sensors to tilt the solar panel in three different directions (Member & Member, 2016).

To improve the efficiency of the power output on the solar panel, the panel needs to be tilted in the direction of the sun. This can be achieve by either applying single-axis solar tracking system where the panel rotates azimuthally or dual-axis solar tracking system which involves the movement of the panel in both azimuth and zenith directions. This will increase the efficiency of the system more than 50% (Ahmed & Khan, 2014).

Single-Axis Solar Tracking System

The single-axis solar tracking system is built such that the photovoltaic cells tilt through the East to the West directions of the sunshine, most at times in 180^0 Celsius from the elevation of the sun to sunset. The rotation is in one way which limits the maximization of the photovoltaic cells since it can be actuated to move or rotate from East to West and North to South (Lazaroiu et al., 2015). Furthermore, there was a 20% increment in this system when compared with the traditional fixed position solar panel (Dolara et al., 2012). This is exactly what brought about the dual-axis Solar tracking system due to the limitation that this system employed in providing efficiency for the system.

Dual-Axis Solar Tracking System

The dual-axis solar tracking system accomplishes the limitations of the single-axis system which rotates in only one direction (Azimuth), (Mustafa et al., 2018). The dual-axis tracking system is carried out both in azimuth and zenith directions. This implies the movement of the panel vertically and horizontally in the direction of the sunlight. Therefore, the energy obtained is increase as well as the reliability (Wang et al., 2008).

This paper focused on the improve efficiency and analysis of solar tracking system for PV cells by making clean energy easily accessible, efficient, simple, durable and reliable. This introduces the general concept of solar tracking system, aim and objectives of the study and the methodology involved.

2.0 Materials and Methods

The project was implemented in three stages, the first of which was the software section; hardware formed the second aspect, while the electrical part completes the system. An active tracking approach was applied in developing the controlling section of the device for optimum tracking. The engineering design was carried out by adhering to the requirement and specification of the design, considering the dimensions of the solar panel and the weight of the frame as well as developing the solar panel tracking system in keeping the details of all the materials used in the implementation of the design and the circuit building with their mathematical analysis.

Solar Tracker

Solar tracker can be describes as a system that directs the solar panel towards the rays of sunlight throughout the period of sunshine in order to maximize the output of the photovoltaic cells. The solar tracker receives signals from set instructions which are loaded actively or passively depending on the available method to drive the system. The position of the tracker is determined by the active solar tracker system maintaining the photovoltaic cell to tilt in the direction of the sun in both azimuth and zenith directions. The active system also involves the movement and energy utilization of the motor and actuators. Meanwhile, a passive solar tracker makes use of sensors to maintain the sun's direction. It requires low energy consumption prone less in mechanical operational damages due to less involvement of drives (Amelia et al., 2020).The dual-axis solar tracking system accomplishes the limitations of the single-axis system which rotates in only one direction (Azimuth), (Mustafa et al., 2018). In this development, the frame can be constructed in a way that suites the rotation so as to move the tracker in its optimum axle of rotation adjustably (Poulek & Libra, 1998).

Sun Tracker Hardware Design The system has two hardware circuit developments. The first of which illustrates one of the hardware circuits for the solar tracking system in azimuth and altitude directions as shown in the figure below. The sensing circuit composed of four Light Dependent Resistors together with equal number of resistors for voltage regulation.

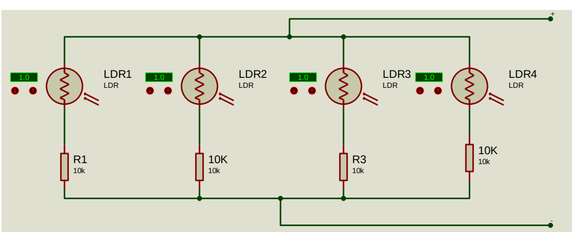

Figure I: The Sensing Circuit

Mechanical Design The frame for the solar tracking system was built using steel metal to hold the panel. The two edges were weld together with two other handles facing upward at the sides. The stepper motor screwed at one side of the panel to rotate it in the azimuth direction while the stepper motor rotates the panel in the zenith direction. This movement was achieved with the aid of the sensor device which controls the panel through the motors. The driver ULN2003 controlling the motor was connected through the Microcontroller to minimize the voltage input.

Electrical Design All the components and basic electrical and electronic materials used in the designing of the whole device were explained in detail in this section.

For the tracking unit to function properly, the panel needs to be tilted to a position that is perpendicular to the incident ray of the sun for the period of sunshine. The LDR sensing circuit was built to cater for positioning the panel to that effect and to keep the track continuously for the period of sunlight.

The solar tracker was designed by separating the four light dependent resistors with a dark wooding material to provide shadow to allow each of the sensors, so as to compare the light intensities for proper rotation of the panel. Two out of the four sensors moves the panel in the azimuth direction East/West while the other two for the zenith movement that is South/North. This device was attached to the sitting panel to provide easy detection of the sun and position the Photovoltaic panel to that effect. The Light Dependent Resistors were arranged two to each side, two of the LDR's determine the movement in one way by tilting the panel to either move right or left of the orientation drives one of the stepper motor while the other two LDR's were used to drive the other stepper motor

Electronic components are printed on board using copper track to trace the lines of connection from one component to another. This is done by copying a drawn sketch for a given circuit diagram, it also reduce the chances of burning some sensitive components rather, it gives a cleaner finished circuit that is less prone to damage. The production of circuits on printed circuit boards makes it possible for mass manufacturing of board in a short period and this improve the reliability.

The following parameters were used for carrying out the design analysis.

Azimuth angle can be calculated when the declination angle is known considering the latitude of the reference location as presented in equation (1).

$$Azimuth = \cos^{-1}\left(\frac{\sin\delta\ \cos\theta - \cos\delta\sin\theta(\cos \mathrm{HRA})}{\cos\alpha}\right) --- (1)$$

Azimuth =Azimuth for Local Solar Time (LST) < 12 or Hour angle (HRA) while < 0

Azimuth = 360 – Azimuth, for Local Solar Time (LST) > 12 or the Hour Angle (HRA) > 0

The zenith angle is considered as the angle between the sun and the vertical. The angle is measure in clockwise direction reference from the vertical contrast to the elevation angle that is measured from the horizontal. The figure below illustrates the zenith angle.

The declination angle of the sun is that angle which exists between the equator and the middle of the sun while referencing from it. However, the earth rotates around the sun while the earth seasonally tilts on its axis. The tilting angle of the earth is at 23.45^0 and this also indicates how the declination angle changes with respect to the season of the year (Abdurrahman et al., 2019).

Furthermore, in the Northern hemisphere, the declination angle is 23.45^0 during the summer solstice while in the winter period, it is -23.45^0 and for the spring equinox, the declination angle for both Northern and the Southern hemisphere remains at 0^0. The angle of declination is denoted by $sigma\ (\delta)$

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The declination angle can be calculated using the following relationship.

$$(\delta) = \sin^{-1}[\sin(23.450)\sin((360/365)(d-81))] - - - (2)$$

Where δ *is the elevation angle* and d is the number of the day of interest starting from January.

Mathematically, the elevation angle at 35^o for a fixed solar panel was used to calculated the voltage, current

Sunrise can be described as the time at which the sun is rising from the East while sunset is the time at which the sun set at the West. The appearance and disappearance of the sun from the sky depends on the geographical location on the surface of the earth. Here, the elevation angle is very essential in determining the times of sunrise and sunset. At sunrise, the elevation angle is equal to zero. The equation employed determining the sunrise and sunset are presented in equation (3) and equation (4) respectively.

$$Sunrise = 12 - \frac{1}{15^0}\cos^{-1}\left(\frac{-\sin\phi\sin\delta}{\cos\phi\cos\delta}\right) - \frac{TC}{60} - - - - (3)$$

$$Sunset = 12 + \frac{1}{15^0}\cos^{-1}\left(\frac{-\sin\phi\sin\delta}{\cos\phi\cos\delta}\right) - \frac{TC}{60} - - - (4)$$

3.0 Results

It can be seen clearly that there was an improved output of power when the intensity of sun was been received by the solar panel especially between 11:00am and 15:00pm. This is because of the high intensity the solar photovoltaic cells received during this period. Generally, there are about four factors that militate against the effective utilization of the solar energy, panel orientation, array size, angle to which the panel is position and shading. The way to avoid major shading is to place the solar panel some meters away from an existing shadow. Meanwhile, the solar tracking system is built in a proper orientated manner, angle of elevation and the array size will have better performance, efficiency together with energy gain when all these criteria are properly tackled.

4.0 Discussions

An experiment carried out on the 22nd of June 2016 with the Mono-crystalline solar panel of 50W power. The table 1 shows the recoded values obtained in the fixed solar system oriented at an angle of 35 degrees due south for fourteen hours. This was achieved between 8:00am and 8:00pm, using a Multi-meter to take the readings of the open circuit voltages and short circuit currents throughout the day. The parameters used were compared to the solar panel specifications in terms of the maximum power which is 50W, with 22.5 V DC open circuit voltage of the panel and short circuit current of 2.9A. The power of the solar panel is at maximum when the solar irradiation was high at noon. This provides the maximum current that can be obtained at this orientation. The fixed angle of 35 degrees was achieved by calculating the elevation angles as well as and the angle of the solar panel. This is relevant due to the rising of the sun and the horizon.

The table 2 shows the recorded values of the same module tilted according to the calculated angles of elevations and azimuth angles. This was oriented such that the solar panel faced the direction of the sun throughout the day. The experiment took stage on the 26th of June 2016 with the aim of achieving a greater increase in the power and energy gain by the solar panel, since the sun energy is the main power source; it is paramount to have an efficient energy that will supply enough to defile alternative sources. The system's monitoring unit was calibrated such that the sensors compared the sun intensities received to tilt the solar panel to focus properly and align continuously to track the sun throughout the day. The mono-crystalline cell type is manufactured so as to minimize the area and space when installing the solar panel especially in some roofs that have less to carry or space to occupy. The latitude of the region should be used when calculating for elevation angles; the solar tracker system is either made to tilt in a day between +/- 70^0 or seasonal tracking which ranges from 10^0 to 70^0.

5.0 Conclusions

The performance of a fixed mono-crystalline solar panel oriented due south at an angle of 35 degrees has been compared to the same panel oriented at different angles of elevation due to the solar radiation, making the system to operate in an automated tracking manner. The performance of the dual-axis solar tracking system has been found to have increased the energy gain efficiently through the process of analyzing the open circuit voltage, short circuit current while tilting the panel to align with the sunlight throughout the day. With the maximum efficiency of 34.4% when compared to a fixed solar system, the energy gain increases the solar panel output significantly, maximize the power usage per unit area of the panel per hour and maintain a reasonable amount of energy. Furthermore, the energy expense on the system is minimal compare to the energy remaining for onward distribution. The materials used for the project were carefully selected to consume less energy and deliver more as well as the sensor circuit which keeps the solar panel in the trajectory of the sun intensity. It is recommended that the mechanical design can be improve upon by introducing more efficient technology that will cater for the maintenance and simplify the coding process and algorithm in controlling the solar panel.

Table 1 Collated values obtained on a Fixed Solar Panel

TIME	ANGLE(◦)	VOLTAGE V_{OC} (V)	CURRENT I_{sc} (A)	POWER (W)
08:00	35	19.1	1.63	31.133
09:00	35	20.2	1.99	40.198
10:00	35	20.4	1.84	37.536
11:00	35	21	1.73	36.33
12:00	**35**	**21.3**	**2.38**	**50.694**
13:00	35	20.9	1.04	21.736
14:00	35	19.5	1.04	20.28
15:00	35	20.1	2.17	43.617
16:00	35	20.4	0.68	13.872
17:00	35	20.2	0.75	15.15
18:00	35	21.5	1.24	26.66
19:00	35	20.7	0.65	13.455
20:00	35	20.4	1.02	20.808
TOTAL		**265.7**	**18.16**	**371.469**

Table 2 Collated values obtained on a Solar Tracking Panel

TIME	Angle (°)	VOLTAGE V_{OC} (V)	CURRENT I_{sc} (A)	Power (W)
08:00	26	21.1	0.65	13.715
09:00	35	21	1.65	34.65
10:00	45	20.6	1.63	33.578
11:00	54	21.8	2.18	47.524
12:00	58	22.3	2.53	56.419
13:00	61	22.2	2.01	44.622
14:00	58	21.2	1.83	38.796
15:00	53	21.5	2.18	46.87
16:00	45	21.8	2.35	51.23
17:00	36	20.5	0.39	7.995
18:00	26	21.13	1.24	26.201
19:00	18	19.9	1.17	23.283
20:00	9	19.9	0.65	12.935
TOTAL		**274.93**	**20.46**	**437.818**

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Declaration of conflict of interest

I declare that, I have no conflict of interest in any form in the processes to influence the decision by the members and committee in relation to this publication.

References

Abdurrahman, M., Gambo, J., Shitu, I. G., Yusuf, Y. A., Dahiru, Z., Idris, A. M., & Isah, A. A. (2019). Solar Elevation Angle and Solar Culmination Determination using Celestial Observation; A Case Study Of Hadejia Jigawa State, Nigeria. *International Journal of Advances in Scientific Research and Engineering*, *5*(9), 08–17. https://doi.org/10.31695/ijasre.2019.33482

Ahmed, A. J., & Khan, S. N. (2014). Performance evaluation of solar panel and proposed new algorithm of solar tracking system. *2014 2nd International Conference on Green Energy and Technology, ICGET 2014*, *September 2014*, 9–13. https://doi.org/10.1109/ICGET.2014.6966652

Amelia, A. R., Irwan, Y. M., Safwati, I., Leow, W. Z., Mat, M. H., & Rahim, M. S. A. (2020). Technologies of solar tracking systems: A review. *IOP Conference Series: Materials Science and Engineering*, *767*(1). https://doi.org/10.1088/1757-899X/767/1/012052

Barsoum, N., & Vasant, P. (2010). *Transaction in Controllers and Energy SIMPLIFIED SOLAR TRACKING PROTOTYPE*. www.pcoglobal.com/gjto.htmES-E11/GJTO

Dolara, A., Grimaccia, F., Leva, S., Mussetta, M., Faranda, R., & Gualdoni, M. (2012). Performance analysis of a single-axis tracking PV system. *IEEE Journal of Photovoltaics*, *2*(4), 524–531.

https://doi.org/10.1109/JPHOTOV.2012.2202876

Fraas, L., & Partain, L. (2010). *Solar Cells and Their Applications, 2nd Edition (Wiley Series in Microwave and Optical Engineering)*.

Jaen, C., Pou, J., Capella, G., Arias, A., & Lamich, M. (2009). On the use of sun trackers to improve maximum power point tracking controllers applied to photovoltaic systems. *CPE 2009 - 6th International Conference-Workshop - Compatability and Power Electronics*, 67–72. https://doi.org/10.1109/CPE.2009.5156015

Lazaroiu, G. C., Longo, M., Roscia, M., & Pagano, M. (2015). Comparative analysis of fixed and sun tracking low power PV systems considering energy consumption. *Energy Conversion and Management*, *92*, 143–148. https://doi.org/10.1016/j.enconman.2014.12.046

Marks, Z. D., Haygood, I. W., & Van Zeghbroeck, B. (2013). Analysis of the GaAs/GaAsBi material system for heterojunction bipolar transistors. *IEEE Transactions on Electron Devices*, *60*(1), 200–205. https://doi.org/10.1109/TED.2012.2226592

Member, A. K. I., & Member, M. H. I. (2016). *A Microcontroller-Based Multi-Function Solar Tracking System*. *November*. https://doi.org/10.21700/ijcis.2016.101

Mustafa, F. I., Shakir, S., Mustafa, F. F., & Naiyf, A. T. (2018). Simple design and implementation of solar tracking system two axis with four sensors for Baghdad city. *2018 9th International Renewable Energy Congress, IREC 2018*, 1–5. https://doi.org/10.1109/IREC.2018.8362577

Panos, E., Densing, M., & Volkart, K. (2016). Access to electricity in the World Energy Council's global energy scenarios: An outlook for developing regions until 2030. *Energy Strategy Reviews*, *9*, 28–49. https://doi.org/10.1016/j.esr.2015.11.003

Pereira, M. G., Sena, J. A., Freitas, M. A. V., & Silva, N. F. Da. (2011). Evaluation of the impact of access to electricity: A comparative analysis of South Africa, China, India and Brazil. *Renewable and Sustainable Energy Reviews*, *15*(3), 1427–1441. https://doi.org/10.1016/j.rser.2010.11.005

Poulek, V., & Libra, M. (1998). New solar tracker. *Solar Energy Materials and Solar Cells*, *51*(2), 113–120. https://doi.org/10.1016/S0927-0248(97)00276-6

Sohag, H. A., Hasan, M., Khatun, M., & Ahmad, M. (2016). An accurate and efficient solar tracking system using image processing and LDR sensor. *2nd International Conference on Electrical Information and Communication Technologies, EICT 2015*, 522–527. https://doi.org/10.1109/EICT.2015.7392008

Wang, X. C., Liu, Q. Q., Lv, Y. X., Gao, W. B., Yang, L. X., Yu, R. C., Li, F. Y., & Jin, C. Q. (2008). *The superconductivity at 18 K in LiFeAs system*. *538*, 1–13.