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# Application of Mathematical Models and Sensors for Optimization of Solar Energy Collection Using a Developed Tracking Device

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***Abstract*—***Photovoltaic panels are less efficient when fixed only to a particular angle of inclination with the sun. However, its efficiency improves with the application of a solar tracker which changes the panel orientation automatically in accordance with the sun's position. In this work an automated solar tracking device was developed, whose control was from either predictive models or sensors signal. The data collected on field were analyzed and the graphical representation was used to determine the most suitable trend. The trends were of Fourier series, linear regression, hyperbolic and exponential function which stands as basis for the predictive models formulated. The most appropriate azimuth and altitude panel orientation were achieved by the developed solar tracking device with the aid of microcontroller and two linear actuators. A programmable intelligent computer (PIC) was used for controlling the linear actuators during cloudy and sunny condition with input signals from the predictive models developed and solar sensors respectively. The correlation coefficient of the models was found to be above 0.95 and 0.92 for azimuth and altitude respectively, indicating high degree of agreement of both predicted and actual angle data. The maximum percentage errors were 4.72% for azimuth and 11% for altitude of the models developed showing an appreciable level of accuracy. The tracker developed has an efficiency of 72.25%. The stationary panel generated a total of 1.458 kW of power stored per day while the average power stored by the tracking panel is 1.916 kW per day. The tracking percentage power gain was estimated to be 46.15% at peak period above the fixed panel from the analysis of the data collected.*

***Keywords*—** *Efficiency: Energy: Models: Optimize: Sensor: Solar: Tracking.*

## I. INTRODUCTION

Exploitation of renewable energy resources has been in the forefront of campaign throughout the world for the supply of significant proportion of the world energy needs (Ikuponisi, 2004). Solar radiation is the largest renewable resource on earth (Muller- Steinhagen, 2003) and Nigeria has vast solar energy potential that is yet to be fully harnessed (Ogunlowo *et al.*, 2009). Nigeria, with a land mass of $924 \times 10^3$ km$^2$ (Oyedele *et al.*, 2008), receives about $4.851 \times 10^{12}$ kWh of energy per day from sun. Furthermore, Nigeria is endowed with an annual average daily sunshine of 6.25 hours, ranging from 5.25 hours at the coastal area to 9.0 hours at the far northern boundary (Francis, 2008). It has an annual average daily solar radiation of about 5.25 kW/m$^2$/day which varies from 3.5 kW/m$^2$/day at the coastal area to 7.0 kW/m$^2$/day at the northern boundary. Ayodele *et al.*, (2006) stated that Nigeria has an average of $1.804 \times 10^{15}$ kWh of incident solar energy annually, yet the government, industries and individuals have not maximized this potential in the running of domestic and social amenities. This is probably due to the inability to optimally tap and store the energy derived from the sun, in Photovoltaic energy systems, whose power generation is largely dependent on the solar panel orientation. The Photovoltaic Power Systems has solar cells that convert sunlight directly into electricity through the photons striking certain semiconductor materials, such as silicon, they dislodge electrons which produce potential difference between the specially treated front surface of the solar cells and the its surface (De Meo and Steitz, 1990; Kaushika, 1999; Zekai, 2008). In order to increase the voltage, individual cells are combined in a panel form. These panels are positioned based on the peak value of the solar radiation in a location (Adeyemo, 2008). However the problem with solar power is that it is directly dependent on light intensity. Goetzberger *et al.*, (2002) reported that, to produce the maximum amount of energy, a solar panel must be normal to the light source. The earth moves relatively with the sun throughout the day as well as throughout the year, a solar panel therefore, must be able to follow the sun's movement to produce the maximum possible power, else electricity generated will be greatly reduced (Goswami *et al.,* 1999). The solution is to use a tracking system that maintains the panel's orthogonal position with the light source.

There are many tracking system designs available including passive and active systems with one or two axes of freedom (Mousazadeh *et al.*, 2009). The passive control unit is basically a system conducted without an electronic device and applies the principles of change in stage of liquid substance. The liquid such as chlorofluorocarbon (CFC) masses lift the solar cell based on expansion principle in order to track the solar energy and it is less fragile however, with a low accuracy. The electro-optical control unit tracks the sun by a solar detecting device that is sensitive to solar radiance. Simple equipment such as photodiodes, phototransistors and Light Dependent Resistor (LDR) are employed in the device (Koyuncu and Balasubramanian, 1991; Kalogirou, 1996). These devices under cloudy sky or lack of sunlight condition

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derive little of the solar radiation for not tracking, which leads to reduction in energy generated thereby diminishing the efficiency of the system.

The goal of this work is to design and construct an active, dual axis, and economically feasible solar tracker with minimum allowable error suitable for use in Nigeria. The data derived from experimentation served as the basis of the mathematical model developed in determining the tilt angles such as the solar altitude and azimuth for the solar flat-plate collectors. The collectors positioned at appropriate tilt angles in different stations will receive maximum radiation. The solar altitude is the vertical angle between the horizontal plane and the line connecting to the sun, whereas the solar azimuth is the angle within the horizontal plane measured from true North. The automated controlled device which combines mechanical elements with electronic components, including computers and/or microcontrollers, operates by tilting the panel in the direction of solar radiation along a path perpendicular to it in order to optimize the energy to be collected by the solar panel. The solar tracker will tend to make adjustment along the North-South direction in addition to following the sun's East-West movement, thereby increasing energy collection and consequently, the electricity output from the solar panel. To achieve the foregoing, a control mechanism with microprocessor was developed for determining the solar panel orientation by either the phototransistor signal or the predictive models developed for both cloudy and sunny condition. This is expected to be more accurate and effective in collecting and storing energy as a remedy to the present day epileptic power supply in the country. The developed solar tracking device will be fabricated majorly from locally sourced materials that are readily available and possesses the desirable engineering properties.

Substantial progress has been made in the generation of electricity through solar technology. The development of photovoltaic panels has brought great patronage to the industry. These panels are positioned to access the peak value of solar radiation in a location. There has been advancement in solar tracking systems which include the passive type that uses chlorofluorocarbon fluid, mechanically driven type that is either a linear actuator drive type or gear box driven type (Roth *et al*., 2004). These devices have limitations of refrigerant leakage, premature failure of components, mute in cloudy condition, no user repairable components in Nigeria, less degree of freedom and maximum extension parallel to the structure. There is a need therefore, to develop an alternative tracking device that will minimize the aforementioned limitations of the passive type and the electro-optical type that moves in one degree of freedom and maximize the stored energy. The initial cost of generating electricity from a solar tracking system is usually very expensive because of the high cost of importation of device components. The tracker whose control is mainly through solar sensors tends to move its panels haphazardly, during cloudy condition, thereby reducing the lifespan of the tracking motor. These problems are intended to be fixed by combining the signals generated from both predictive models and solar sensors for tracking in cloudy and sunny conditions simultaneously. The production cost of the solar tracker is expected to be reduced by utilizing locally available materials. Computer program application for rapid azimuth and altitude angles estimation will facilitate the tracking mechanism in cloudy conditions, thereby increasing the overall efficiency of the solar panels. Solar street lights are independent of the utility grid. Their operation costs are lesser than other generating sources. The application of solar street lights requires less maintenance than the conventional types. Above all, it is a non polluting source of electricity and possesses higher level of portability.

## II. Overviews of Existing Works

Overviews of the contributions of some authors in solar tracking technology are shown in Table 1 highlighting some disadvantages that are were tackled.

The previous works carried out on solar tracking system had some disadvantages that are expected to be tackled by the developed automated solar tracking device. These disadvantages experienced by some of the previous solar trackers include the vector analysis method developed by Stine and Harrigan (1985) for estimating the sun position from the earth centre frame. The area cover by this method was of a wide range, resulting to an increase in orientation error. Grena (2008), Chen *et al*., (2006), Chong and Wong (2009) developed sun tracking formula of mainly sinusoidal function, this formula has limitation in prediction of positions that are of other trends. Luque-Heredia *et al*., (2004) and Chen *et al.*, (2001) designed an open loop tracking system whose panel orientation output has no interaction with the tracking controller. Shanmugam and Christraj (2005) and Arbab *et al*., (2009) developed parabola dish for maximizing radiation mainly for heating purpose. Berenguel *et al.,* (2004) and Aiuchi et al., (2006) worked on heliostat, an astronomical instrument used for reflecting sun light mainly on a constant direction. Chong *et al.* (2009), Abdallah and Nijmeh, (2004) designed tracking mechanism without feedback application to ascertain the effectiveness of the device. Blanco-Muriel *et al.* (2001), Chen and Feng (2007) developed formula and sensors device limited to altitude orientation and one degree of freedom movement respectively. Clarke (2008) and Rahman (2012) utilized photovoltaic panels for street lighting without applying tracking devices, thereby requiring more panels to generate same energy as panels controlled by tracking device. The construction of solar tracking system by Akinkuade and Fasae (2006) and Tudorache *et al*., (2012), where an Intel microcontroller and only 2 sensors, with angular direction limited to 45° East and 45° West in sensing the intensity of light was used. The motor tends to work on a continuous interval during cloudy condition as a result of continuous inferences on the solar radiation received by the sensors. Tudorache and Kreindler (2010) utilized PIC16F877A microcontroller and 6 sensors positioned at 30° from East to West in sensing the light intensity and moving the panel mainly along one degree of freedom, thereby increasing the number of components. Whereas the current work utilizes PIC18F45K22 microcontroller, 4 sensors with two stepper motors for the panels to obtained two degree of freedom along the East-West and North-South axis. This will make the rotation of solar panel in the current work more precise compared to the previous project coupled with added advantage of utilizing mathematical model that will controlled the motors in case of cloudy conditions. The application of the tracking device in street lighting leads to the optimization of solar energy stored. Solar street lights are independent of the utility grid. Their operation costs are lesser than other generating sources. These solar street lights require less maintenance than the conventional types. The use of external wires from pole to pole will be greatly reduced when compared to the national power grid. Above all, it is a non polluting source of electricity and possesses higher level of portability.

TABLE 1. Contributions of some authors in solar tracking technology.

| S/N | Title of Paper | Area of Contribution | Author(s) Year |
|---|---|---|---|
| 1. | The sun's position | Developed sun's position vector relative to the earth-centre frame | Stine and Harrigan, (1985) |
| 2. | Non-imaging, focusing heliostat. | Introduced an open-loop sensors that do not require any solar image as feedback | Chen *et al.*, (2001) |
| 3. | Computing the solar vector | Developed sun's position vector for altitude angles | Blanco-Muriel *et al.*, (2001) |
| 4. | Two axes sun tracking system with PLC control | Designed a tracking system operated by an open-loop control mode | Abdallah and Nijmeh, (2004). |
| 5. | An artificial vision-based control system for automatic heliostat positioning offset correction in a central receiver solar power plant. | Applied Video system to controll heliostat position | Berenguel *et al.*, (2004) |
| 6. | A PI based hybrid sun tracking algorithm for photovoltaic concentration. | Designed a tracking system that is operated in open-loop mode | Luque-Heredia *et al.*, (2004) |
| 7. | The tracking of the sun for solar paraboloidal dish concentrators. | Utilized parabola dish to obtained increased solar radiation for heating. | Shanmugam and Christraj, (2005). |
| 8. | Sensor-controlled heliostat with an equatorial mount. | Developed a heliostat with an equatorial mount and a closed-loop photo-sensor control system | Aiuchi et al., (2006) |
| 9. | Design and Construction of a Sun Tracking System | Utilize 2 sensors to determined maximum panel radiation section | Akinkuade and Fasae, (2006) |
| 10. | General sun tracking formula for heliostats with arbitrarily oriented axes. | Derive a general sun-tracking formula for heliostats with arbitrarily oriented axes | Chen et al., (2006). |
| 11. | Digital sun sensor based on the optical vernier measuring principle. | Design digital sun sensor with optical vernier measuring principle. | Chen *et al.*, (2006) |
| 12. | Analogue sun sensor based on the optical nonlinear compensation measuring principle | Proposed an analogue sun sensors that have accuracy of 0.2° | Chen and Feng, (2007) |
| 13. | An algorithm for the computation of the solar position | Obtained special formula /algorithm for calculating collectors angle | Grena, (2008) |
| 14. | A computer tracking system of solar dish with two-axis degree freedoms based on picture processing of bar shadow | Computer program where developed for maximum tracking of radiation with solar dish | Arbab et al., (2009) |
| 15. | General formula for on-axis sun-tracking system and its application in improving tracking accuracy of solar collector | Proposed an on-axis general sun-tracking formula to track the sun for accurate orientation | Chong and Wong, (2009) |
| 16. | Integration of an on-axis general sun-tracking formula in the algorithm of an open-loop sun-tracking system | Obtained analytical solutions for the three orientation angles based on the daily sun-tracking | Chong *et al.*, (2009) |
| 17. | Design and construction of non-imaging planar concentrator for concentrator photovoltaic system | Applied the concept of non-imaging optics to achieve good uniformity of the solar irradiation | Chong *et al.*, (2010) |
| 18. | Optical characterization of non imaging planar concentrator for the application in concentrator photovoltaic system | Developed sun tracker to maintain its good performance when highly concentrated sunlight is involved | Chong *et al.*, (2010) |
| 19. | Solar Tracking System | Utilize LDRs to sense the intensity of light and sent the data to the microcontroller. | Tudorache and Kreindler, (2010) |

Based on these advantages as seen in the application of solar lighting system, it is incumbent that an automated solar tracking device for street lighting be developed for optimal, efficient energy collection and storage in electricity generation.

## III. Methodology

This study commenced with exhaustive and adequate literature survey followed by the determination of the magnitude and direction of the sun radiation. Azimuth and altitude angles data were generated for sun rays from field work carried out at Ado-Ekiti with the aid of a theodolite and a precision compass. Ado-Ekiti is located at 7.6211° N latitude and 5.2214° E longitude of Ekiti state. The data collected were examined, analyzed and utilized in determining the trend of solar radiation in the said location. Using Fourier series, hyperbolic and exponential functions, predictive models were developed based on the positional solar radiation trend to determine the azimuth and altitude orientation, which were given in equations (1) - (7) as given by Ejiko *et al.*, (2015). Models developed were implemented on Programmable Intelligent Computer (PIC) as the main control core in engaging the stepper motors for moving and adjusting the solar tracking mechanism. The developed tracking mechanism was based on signals from predictive models and photoresistors for moving the solar panel along the longitudinal and latitudinal axis. The developed device was tested for six months at different time interval to monitor the angles and output results of the tracking device solar panel in terms of power measured at each interval. These results were compared with the actual sun's angles and the power measured at same interval by panel at fixed position.

$$\gamma_1 = 180.5 + 65.5\tanh\left(\frac{6T}{11.5} - 6.65\right) + \left|22.325 + 24\cos(0.984D)\right| \quad (1)$$

$$\gamma_2 = 180.5 + 65.5\tanh\left(\frac{6T}{11.5} - 6.65\right) + \left|22.325 + 24\cos(0.984D)\right| \quad (2)$$

$$\gamma_3 = 38 - 32\tanh a - \left|-23 + 24\cos(-0.984D)\right| \quad (3)$$

$$\gamma_4 = 348 - 56\tanh a - \left|-23 + 24\cos(-0.984D)\right| \quad (4)$$

$$\gamma_5 = 93 + 24\cos(0.984D) + 310T - 3720 \quad (5)$$

$$\alpha_1 = 9.667T - 66.669 + 1.8\ell^{(\sin 0.492D + 0.3t - 2.1)} \quad (6)$$

$$\alpha_2 = -10T + 198.2 + 1.8\ell^{(\sin 0.492D - 0.3t + 5.7)} \quad (7)$$

where, $\gamma_1$ to $\gamma_5$ are for the azimuth angle at various period of the year, D is the number of days of the year and T is the time in hour per day. $\gamma_1$ is the azimuth angle for days 1 to 78 and 273 to 366; $7 \le T < 13$, $\gamma_2$ is the azimuth angle on same days as $\gamma_1$; $13 \le T \le 18.5$, $\gamma_3$ and $\gamma_4$ are for azimuth angle on day 79 to 272; $7 \le T < 12$ and $13 < T \le 18.5$ respectively, while $\gamma_5$ is the azimuth angle for day 79 to 272 at 12hours to 13hours. a is a function of T as in $\gamma_1$. $\alpha_1$, is the altitude angle on either 365 or 366 days for $7 \le T < 13$ and, $\alpha_2$ is the altitude angle on either 365 or 366 days for $13 < T \le 18.5$ (Ejiko *et. al.*, 2015). The developed models were compared with the actual data of the first six months in year 2015.

A tracking mechanism was developed based on the predictive models to move solar panel along the longitudinal and latitudinal axis. This mechanism provides a means of changing the orientation of a Photovoltaic (PV) panel mounted on it to maximize the solar radiation reception. The design was done by applying linear actuator with two stepper motors for motion and power transmission along the axis through various link connectors. The design was analyzed under mechanical and electrical sections to ascertain the specific parameters of the developed automated tracking device.

## IV. Design of Framework Support Structures

The framework support structure consists of the stem (super structure) and base (sub structure) which unite the two separate collectors. The procedure specified for the design of the framework support structures by the American institute of steel construction (AISC) as presented by Shigley and Mischke (2001) was adopted for the design of the structural support of the solar collectors system. The ASIC defines allowable stresses as the specified minimum strengths reduced by multiplication factors varying from 40 to 90 percent to ensure safety. Designating allowable normal stress as $\sigma_{all}$ and allowable shear stress as $\tau_{all}$, the relationship between allowable stresses and minimum strengths using the AISC code are specified. The loads acting on the support bearings were estimated as 0.307 kN and 0.621 kN for the two pivot points. A factor of safety 2 was selected according to Shigley and Mischke (2001) in order to accommodate the support for elevators. The total mass of the component parts is 139.45 kg. This is made up of the masses of the shafts (5.6 kg), solar panel frame (26 kg), 2 solar panels (22 kg), perforated metal box (14.3 kg), 2 hundred ohms batteries (48 kg) optimal movement pipe (5.4 kg) frame stand (15.2 kg) and the Bolts and Nuts (2.95 kg). The solar panel frame dimension is 1.49 m by 1.6 m of 38.1 mm angle iron of 3 mm thickness. The frame stand is made up of 75 mm diameter by 1.5 mm thick hollow pipe.

## V. Design of the Linear Actuator Shaft

The linear actuator shaft diameter used for transmitting power under various operating and loading conditions of tension, bending and axial loads was determined from various parameters which includes the torque, bending moment, material strength and the modification factor. The torque generated by the electric motor on the shaft was determined from the motor power and the maximum bending moment was utilized to estimate the shaft diameter using Ejiko *et al.*, (2010) equation. A fatigue modification factor (K) of 0.33, factor of safety ($\lambda$) 2, yield strength ($S_y$) of 454.74 MN/m$^2$ and Tensile strength ($S_e$) of 88.67 MN/m$^2$was applied for AISI type metal number 1020 as given by Khurmi and Gupta, (2006) to established the shaft diameter. The estimated shaft diameter is 32mm.

## VI. Principle of Operation

The system (automatic solar rays' follower) is designed in a way that a solar panel is mounted on an intelligent tracking system which has the ability to sense the direction of the highest magnitude of light intensity from the sun whose flow chart is as shown in Fig. 1. The tracking system performs the action of tilting the solar panel to the direction of that ray of light for the purpose of increasing the efficiency of the charging system. The system has four sensors and is paired in twos that are capable of capturing light rays from the sun over a range of 90°. Each sensor is designed to capture the sun from the four cardinal point of a location such that the differences between two opposite sensors in intensity is used to balanced the panels via the signal supplied to the microcontroller which in turn drives the motors along the East-West and North-South axis, the module is as illustrated in Plate 1 to 3. The sensor sends electrical signal derived from sun to the comparator input. The comparator receives the input values and compares the electrical voltage between each pair. The differences between the light intensity as derived by the comparator serve as an input to the microcontroller circuit. This indicate the actual orientation required, subsequently the stepper motor will drive and position the solar panels in the appropriate orientation for optimum solar energy collection using the values from the microcontroller. The values provided by the microcontroller contain machine codes which pass through a buffer section (Stepper motor driver) for controlling the motors in driving the tracking system/mechanism as shown in Plate 2. A Software program written in C$^{++}$ through KEIL IDE and converted into Intel Hex code was burnt into the microcontroller (PIC18F45K22) through a Flash programmer.

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The software uses the output of the comparator to generate codes for the microcontroller that turns the stepper motor shaft to a desirable angle. The outcome of the software is passed out through the port 2 of the microcontroller buffer (Stepper motor driver) in discrete values that the motors understand.

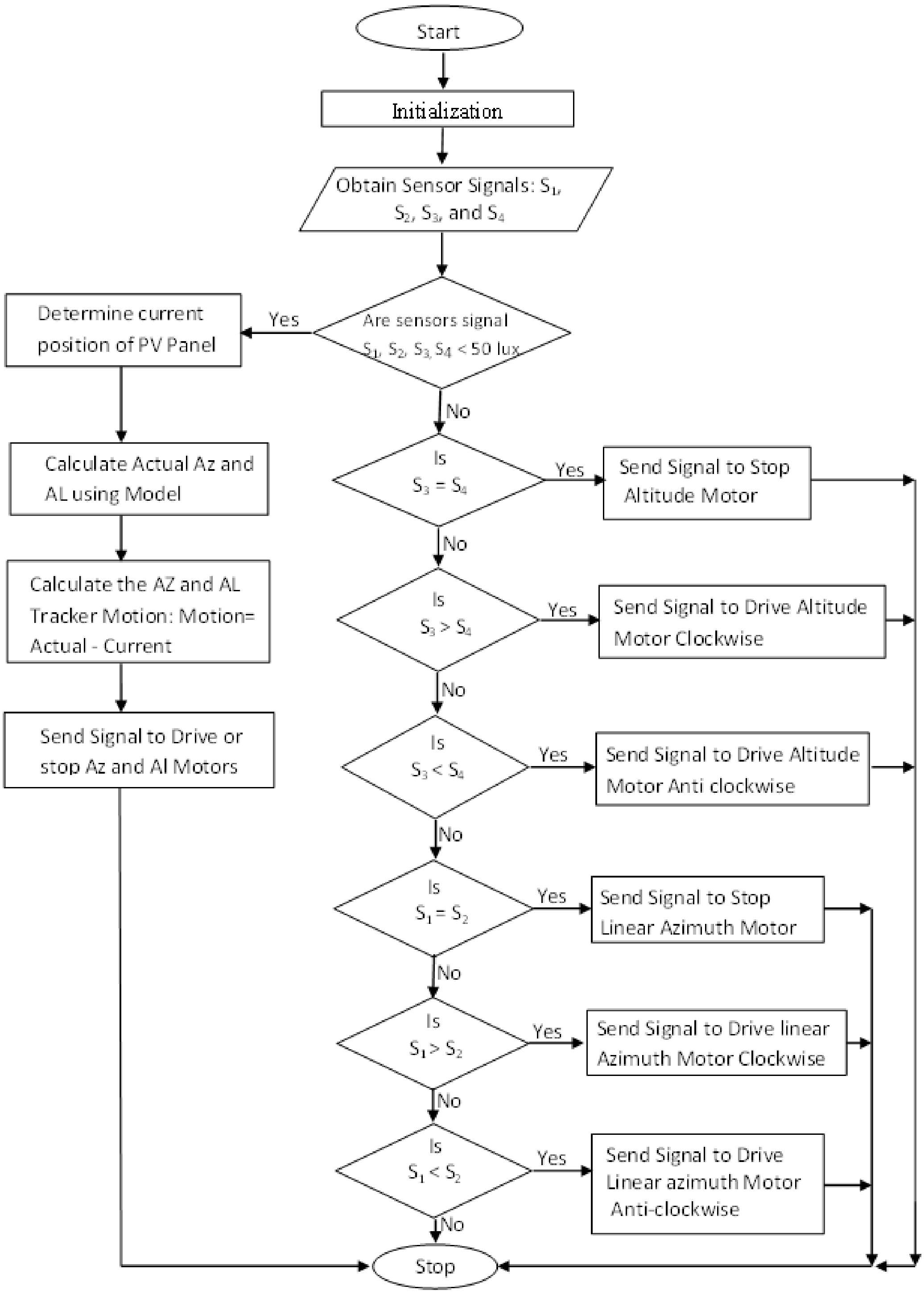


Fig. 1. Flowchart for microcontroller operation.

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Plate 1. Assembled solar tracker.

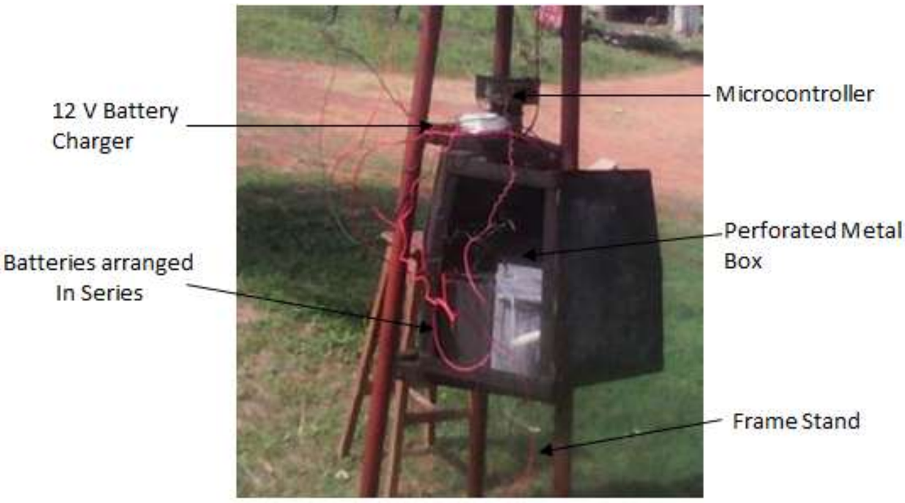


Plate 2. Perforated metal box for housing batteries.


Plate 3. Steet lighting demonstration.

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## VII. Results and Discussion

The developed models was found to have a maximum error of 4.72% for azimuth angle comparisons and a correlation coefficient above 0.95 between the predicted and actual azimuth angles and maximum error of 11% for altitude angles. The developed altitude predictive models has a correlation coefficient of 0.92 and above with respect to the actual altitude angles indicating high degree of agreement of both actual and predicted data.

The azimuth and altitude angles for daily basis are presented in Fig.2. These figures show thirty (30) minute interval changes in azimuth and altitude angle for 25th January, 2015. The azimuth angles from January to March tends to increase steadily from 8:00 am to 6:00 pm in hyperbolic form, while the altitude angle increases in a linear format from 8:00 am to 1:00 pm and declines gradually as it gets toward to evening time. The maximum altitude angle usually occurs at 1:00 pm. It could also be seen that the major variation in altitude angles occur toward 6:00 pm, while that of the azimuth occurs between 12:00 pm and 1:00 pm. The changes in azimuth angles for April to September show an hyperbolic decline from 8:00 am to 12:00 pm and a sharp linear increase from 12:00 pm to 1:00 pm as shown in Fig. 3. The azimuth angle then decreases in hyperbolic trend from 1:00 pm to 6:00 pm as shown in Fig. 4.

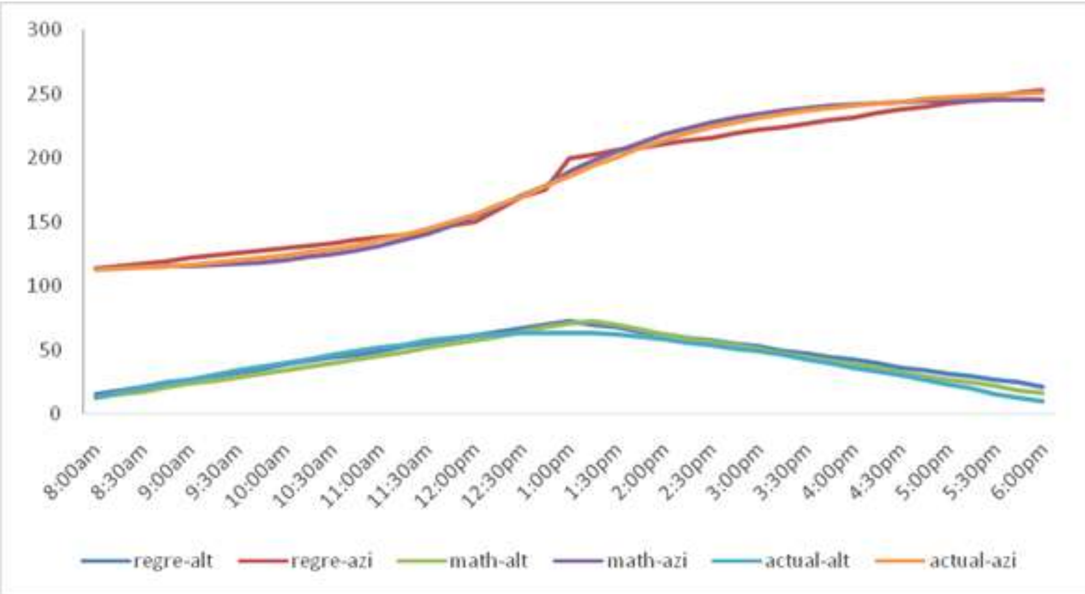


Fig. 2. Comparison of actual and predicted azimuth and altitude angles for 25-1-2015.

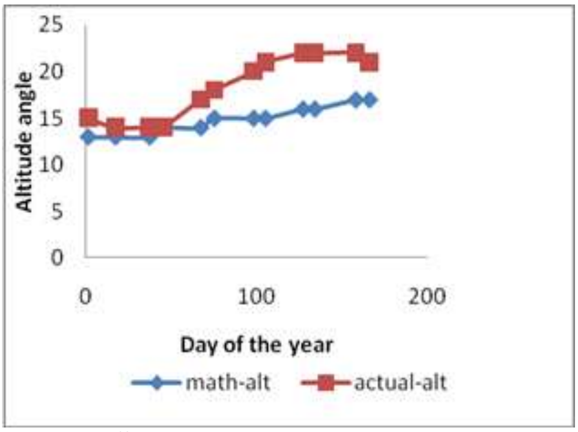


Fig. 3. Differences between predicted and actual altitude.

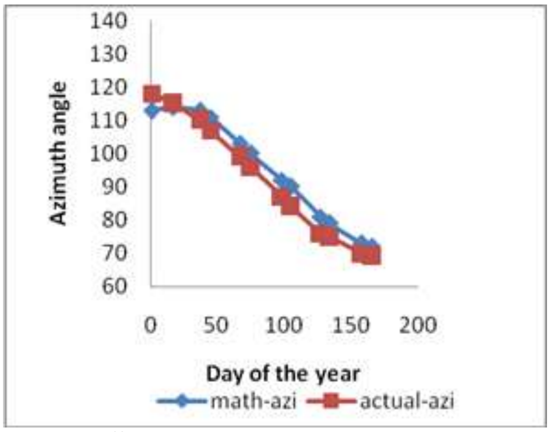


Fig. 4. Differences between Predicted and Actual Azimuth.

*Power Obtained by the Static and Tracking PV Panels*

Table 2 shows the power obtained by tracking the sun is higher than the one obtained without tracking it. Also, that at a point the power output from both panels (with and without tracking devices) was the same. This is because both panels were either facing the sun at the same time or subjected to identical cloudy condition. The solar collection system was constructed and tested with a fixed best position solar panel. The solar tracking system as shown in Plate 1 was powered by a motor and controlled by a microcontroller PIC base on the circuit control diagram. Tests were conducted with the solar tracker and results were compared to the static position type in June 2015, within the same test periods.

TABLE 2. Mean tracking and static panel power during the month of June, 2015.

| Time | Tracker (V) ± $\sigma$ | Current (A)±0.01 | Fix (V) ± $\sigma$ | Fix Current (A)±0.01 | Tracking Power (W) | Fix Power (W) |
|---|---|---|---|---|---|---|
| 8:00am | 14.56±0.04 | 4.76 | 14.18±0.04 | 4.69 | 69.31 | 66.5 |
| 9:00am | 14.03±0.07 | 4.65 | 13.96±0.03 | 4.64 | 65.24 | 64.77 |
| 10:00am | 14.43±0.48 | 4.73 | 14.13±0.05 | 4.68 | 68.25 | 66.13 |
| 11:00am | 16.7±0.46 | 6.11 | 14.95±0.08 | 4.83 | 102.04 | 72.21 |
| 12:00 | 16.71±0.05 | 6.11 | 15.34±0.21 | 4.93 | 102.1 | 75.63 |
| 1:00pm | 16.9±0.01 | 6.42 | 15.14±0.21 | 4.87 | 108.5 | 73.73 |
| 2:00pm | 16.47±0.02 | 5.77 | 15.43±0.05 | 5.01 | 95.03 | 77.3 |
| 3:00pm | 16.86±0.05 | 6.42 | 14.93±0.5 | 4.83 | 108.24 | 72.11 |
| 4:00pm | 16.18±0.18 | 5.39 | 15±0.27 | 4.84 | 87.21 | 72.6 |
| 5:00pm | 14.53±0.02 | 4.75 | 14.15±0.03 | 4.68 | 69.02 | 66.22 |
| 6:00pm | 14.04±0.03 | 4.65 | 13.96±0.05 | 4.65 | 65.29 | 64.91 |

The power generated as at when measured from the panel in Table 4 shows that the peak power ia attain at about 1:00 pm. This power generated from the panel when measured at 2:00 pm shows a gradual decrease, which implies that there is a decline in solar radiation as we tend toward evening. The figure clearly shows that there is a gradual increase of the solar radiation to 10:00 am and a sharp increase of solar radiation at 11:00 am which continues to about 4:00 pm and decline as the evening approaches.

*Efficiency of the Developed Solar Tracking Device*

The mean power generated by the panels was derived from continuous measurement of the power obtained on daily basis. The efficiency was estimated as a function of the mean power against the rated power of the panels as given by the manufacturer.

$$P_E = 160\text{W}$$

Mean power of solar panel ($P_{MA}$)

$$P_{MA} = 115.6\text{W}$$

Panel Efficiency

$$\frac{P_{MA} \times 100}{P_E} \quad (8)$$

where, $P_{MA}$ is the actual power and $P_{ME}$ is the expected power. The percentage power output gained was estimated from the data collated in Table 3 and 4 using equation 9.

$$Gain(\%) = \frac{P_{TM} - P_{FM}}{P_{FM}} \times \frac{100}{1} \quad (9)$$

Where, $P_{TM}$ is the mean power obtained by tracking panel and $P_{FM}$ is the mean power obtained by static panel.

The solar panel of 160 W was utilized for the system with a calculated efficiency of 72.25% indicating that there is minute loss in the power conversion by the tracking solar panel. The observed results for the 6 months gave a mean power of 95.795 W/hr for the tracking device of a single panel while the static panel had 72.79 W/hr. The fixed panels mean power generation was estimated to give 1.458 kW per day and the average power generation of tracking panel is 1.916 kW per day. The power percentage gain is estimated as the function of the tracking panel power generated less the motor power required and static panel power generated. The power percentage gain was estimated to be 26% for 10 hours period of engaging the motor, while for 5 hours period the gain is 46.15%. This implies that the power generated by four sets of static panels will require less than three sets of tracking panels to generate same power.

## VIII. CONCLUSION AND RECOMMENDATIONS

The objectives of this study were achieved by observing and collating the azimuth and altitude angles for optimum solar radiation at 15 minute interval for Latitude 7°02'.59"N and Longitude 2°29'05.97"E location in Ekiti State, Nigeria. The collated data were use to developed empirical models of varying trends in predicting the azimuth and altitude angles at hourly interval. These models served as the basis for programming the microcontroller. A solar tracking device was successfully developed to efficiently obtain optimal solar energy from the sun. The continuous alignment of the photovoltaic panel with the sun's position enables the panel to receive greater sunlight radiation on its surface thereby generating more electricity. In view of this work, it has been established that solar tracking system will optimize the solar energy derived from the sun. By constantly aligning the photovoltaic panel with the sun, it directly receives sunlight falling on its surface thereby generating more electricity. Different techniques have been adopted in the design of this system but the method implemented in this project is simple, easy to maintain and requires no technical attention for its operation. The software developed can be used outside the mechanical part, thus it is flexible for future modification. The solar module with tracking system, as demonstrated in the analysis, achieves about 46.15% percentage power gain and 72.25% efficiency improvement over the static solar module. Hence implementation of this technique in building solar systems will greatly improve utility satisfaction.

*Recommendations*

Effective tracking can further be improved when the models developed is based on data collected over a considerable number of years. Advance research work should be carried out in the manufacturing of the PV panels to increase the energy conversion efficiency. The design of structures and mechanisms for minimum tracking power consumption should also be considered.

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