A Hybrid Solar Tracking Model: A Novel Approach.

*Bello Aminu Bodinga, Muzzammil Mansur & Musa Ibrahim Kamba

*Management Information System Department, Usmanu Danfodiyo University, Sokoto- Nigeria

Computer Science Department, Waziri Umaru Federal Polytechnic, Birnin-Kebbi- Nigeria

bello.bodinga@udusok.edu.ng, mmansur2001@yahoo.com, musaikamba@gmail.com

Abstract: The use of alternative renewable energy is a new direction in the energy industry. Industrial efforts and investments are being made to cut down energy cost because of economic and environmental disadvantages of the energy made from fossil fuels and coal. Increased output and energy efficiency has been the goal of the energy industry. The fundamental component for extracting power from the sun is the solar panel. Most of the solar panels nowadays are basically being fixed and therefore has lower energy production. This paper presented an intelligent sun tracking model, basically two-axis based on hybrid control strategy using Proteus professional 8.0.1 and Arduino IDE as a programming environment. This paper has presented a means of controlling a sun tracking array with an embedded microcontroller system. Specifically it demonstrates a working software solution for maximizing power output of the solar cell by positioning the system at the point of maximum light intensity. The experimental results have shown a relative error tolerance of $\pm 0.0001^0$, whatever the circumstances, specifically in case of prolonged cloud cover.

Keywords – Solar Panel, two-axis, Proteus professional, Arduino, Hybrid

I. INTRODUCTION

The use of alternative renewable energy is a new direction in the energy industry. Energy is the basis for existence and development of human society. At present, most countries in the world use petroleum, natural gas and coal as the main energy sources. However, due to the shortage of these conventional energy sources and the environmental degradation, governments over the world are focusing more on the development of renewable energy (Zhou & Zhu, 2010).

With the decrease of existing energy and the deterioration of ecological environment, it becomes urgent for people to explore new clean energy sources including water power, wind power and solar energy. "Among them, solar energy is recognized as the inexhaustible, bottomless, and safe energy" (Wang & Li, 2012).

Solar energy is the most abundant form of energy available on the surface of the earth which provides light and heat. "It has been the trend over the century to utilize this source of sustainable energy into generating electricity" (Li & Michael, 2013). The sun's light (and all light) contains energy. Usually, when light hits an object the energy turns into heat, like the warmth you feel while sitting in the sun. But when light hits certain materials the energy turns into an electrical current instead, which we can then harness for power.

Electricity is one of the most essential needs for humans today. “Conversion of solar energy into electricity not only improves generation of electricity but also reduces pollution due to fossil fuels” (Kumaresh *et al.* 2014).

Solar energy is captured using solar panels. However, at present, a lot of solar cell panel arrays are basically being fixed and cannot absorb maximum sunlight and this reduce their photoelectric conversion efficiency.

Several works (Zhou and Zhu ,2010; Jin *et al.*, 2013; Lee *et al.*, 2013) on sun tracking systems were carried out to address the optimal utilization of the sun.

However, in most of these works (Jin *et al.*, 2013; Lee, Huang and Yeh, 2013) sun tracking errors were observed to be as high as 0.35^0 and 0.06^0 respectively.

This paper is aimed at developing an intelligent photovoltaic panel tracking model that tracks sunlight from sun rise to sun set with minimal sun tracking error

II. THE SOLAR TRACKING SYSTEM

A solar tracker is a device that Orient a solar panel towards the direction where the intensity of light is maximum. Any device that can orient photovoltaic panel and other optical devices towards the sun can be referred to as a solar tracker. Since the position of the sun in the sky changes with session and time of day, the trackers are used to align the position of the system to maximize the production of energy (Rockwell, 2011). For plat photovoltaic panel system, trackers are used to maximize the angle of incidence between the incoming sunlight and a Photovoltaic panel.

Many researchers (Yakup & Malik, 2001; Bari, 2000) as cited in Zhou and Zhu (2010) have focused on the sun tracking schemes for optimizing the tilt angle and orientation of the solar panels.

Sun trackers are classified based on their movement and control capabilities.

Regarding the movement capability, three main types of sun trackers exist: The fixed surfaces, one axis trackers and two axis trackers (Helwa *et al.*, 2000; Poulek & Libra ,2000; Abdallah & Salem, 2004). The main difference between the three categoris is the ability to reduce the pointing error, increasing the daily solar irradiation that the solar cell receives and thus, the electric energy they produce. Neville (1978) presented a theoretical comparative study between the energy available on a two axis tracker, a one axis tracker and a fixed surface. The results, shows that the annual energy available for two-axis tracker is higher by 5-10% and 50% compared to one axis tracker and a fixed surface, respectively.

Depending on the mode of signal operation, solar energy systems can be classified as closed-loop (active) and open-loop (passive) (Roth *et al.*, 2005). An open loop type of panel controller uses sun’s orbit model to adjust its tilt angle and orientation, (Zhou & Zhu, 2010), without using feedback from the detector. The open-loop system is simpler and cheaper than the closed-loop type, but it cannot correct errors that result from variability in installation, assembly, calibration, and encoder mounting and has lower tracking accuracy. While the closed-loop type of sun tracking system are based on feedback control principles. In these systems, a number of sensors detect relevant parameters induced by the sun which are transferred to a controller to manipulate the solar panels, and then yield maximal energy.

Therefore, the sun tracking system proposed in this paper will be based on a hybrid control strategy that incorporates both the open-loop and closed-loop approach. The justification for this tracker control algorithm that incorporate a hybrid control strategy is that the sun can be covered by cloud there by eliminating or distorting the feedback signals from the light detecting resistors; and the closed-loop component is needed to eliminate errors that result from variability in installation, assembly, calibration and encoder mounting.

III. RELATED WORKS

McFee (1975), one of the first works in automatic sun tracking systems, developed an algorithm to compute the total received power and flux density distribution in a central receiver solar power system using open-loop control approach. Mirror was used as sensors for measuring the angle between sunlight beam and panel. By subdividing each mirror in to elements and summing the contributions of all the elements, the author determined the sun's position with a tracking error tolerance of 0.5^0 to 1^0. Although the error is acceptable, but it is high and therefore might results to low performance.

Chen *et al.* (2006) ; Chen and Feng (2007) presented a sun sensor-algorithm based on an analogue optical non-linear compensation measuring principle. In a traditional analogue sun-sensor, a thin mask with a square aperture consisting of four slits of equal width is placed above a quadrant detector. The experimental results of the proposed sensor had an accuracy of 0.02^0 and 0.2^0 respectively.

Lee *et al.* (2013) presented a sun tracking system based on image processing. In the proposed system, four quadrant light sensors and bar shadow photo sensors were used to detect the sun's position. The experimental results showed that the proposed system track the sun with a tracking error of 0.06^0. Although the system has good accuracy, but the quadrant light sensors may lose all the information necessary to send signal to the controller in order to adjust the solar panel in a prolong cloud cover and therefore cannot search for the sun.

Bodinga, Ndajah and Mohammed(2016a) presented an improved one-axis solar tracking model to track the sun's movement from sunrise to sunset with minimal tracking error. The work is only limited to a single axis despite the need for the second axis due to seasonal variation of the sun.

Bodinga, Ndajah and Mohammed(2016b) presented an intelligent sun tracking model using fuzzy logic approach to for double axis sun trackers to track the sun's movement from sunrise to sunset with minimal tracking error. The result of the experiment has shown a relative error tolerance of $\pm 0.0001^0$, which is quite better compared to others models presented above. Despite the good result obtained, the system failed to show the actual pattern of the movement in case of prolonged cloud cover.

This research is a an extended work of Bodinga *et' al* (2016b).

IV.SOLAR TRACKER DESIGN AND CONTROL ALGORITHM

In the design process of the tracking system, the solar radiation represents the main input data. Interacting with atmospheric phenomena involving reflection, scattering and absorption of radiation, the intensity of the solar energy reaching the sun is reduced. The total solar radiation received on the earth's surface include the direct solar radiation and diffused radiation The solar radiation can be measured using traditional

ISSN 2229-5518

instruments or can be digitally recorded with a data acquisition system.

The orientation principle of the PV modules is based on the input data referring to the position of the sun in the sky. For the highest conversion efficiency, the sunray have to fall normal on the receiver surface so the system must periodically adjust its position in order to maintain this relation between the sunrays and the PV modules. Figure 1 shows the whole system design in a block diagram displaying the key components for the design. These are the hardware components that need to be used for the design of the system.

From the controller point of view, different control strategies are used, such as the classical techniques PID algorithm and more advanced strategy such as Fuzzy logic control. An evolution of the fuzzy control concept is the fuzzy logic neural controller (FLNC) which allows the PV modules to learn control rules.

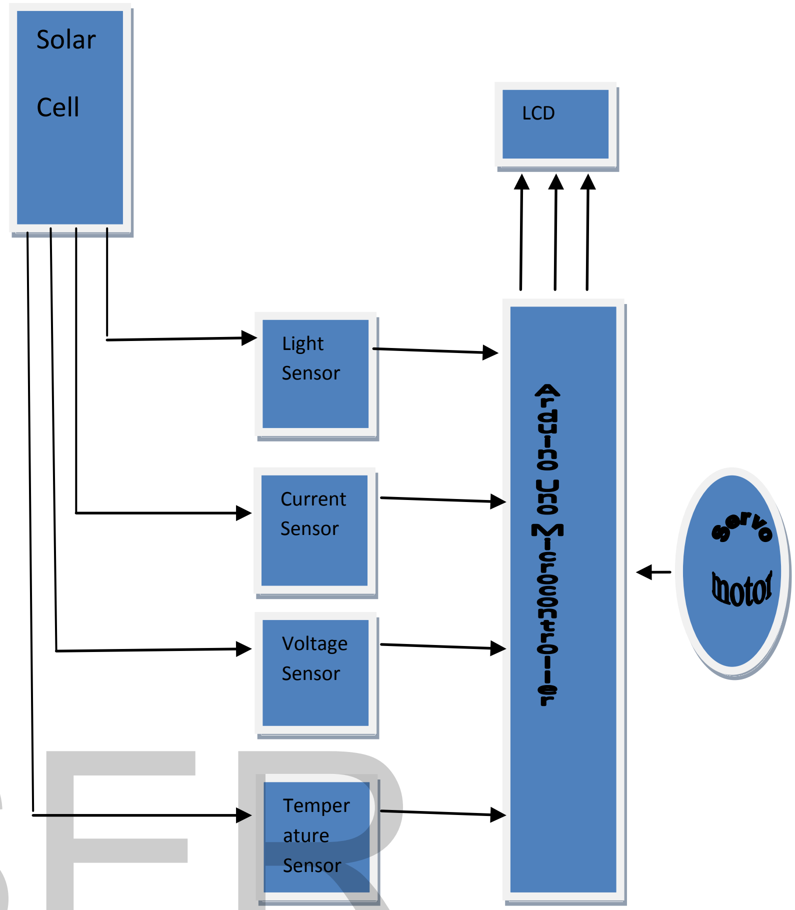

Figure 1: System Block Diagram

	Fuzzy Logic Rule
1	If LDR1 >LDR2, then Rotate Servo1 Clockwise
2	If LDR1 =LDR2, then Do not Rotate Servo1
3	If LDR1 <LDR2, then Rotate Servo1 Counter-Clockwise
4	If LDR3 >LDR4, then Rotate Servo2 Clockwise
5	If LDR3 =LDR4, then Do not Rotate Servo2
6	If LDR3 <LDR4, then Rotate Servo2 Counter-Clockwise

Table 1: Fuzzy Logic Control Rule

Fuzzy logic is a form of many valued logic or Probabilistic logic. It deals with reasoning that is approximate rather than fixed and exact. Fuzzy set theory defines fuzzy operators on fuzzy sets. The logic for the solar tracking system that tracks the sun all year round is stated in Table 1

From Table 1, LDR 1, LDR 2, LDR 3, and LDR 4 represents the four LDRs situated the four coordinates at north, south, east and west. Servo1 and Servo2 represent the servo motors for the control of east-west and north-south movement of the solar panel.

There is no "ELSE" in the rules – all of the rules are evaluated, because the Sensor 1 might be receiving higher, lower or equal intensity of light with sensor 2 and sensor 3 might be receiving higher, lower or equal intensity of light with sensor 4.

When specifying a photovoltaic control system, the control algorithm is the most important characteristic and the one to consider first.

The control algorithm describes the exact nature of the photo sensor output as a function of the input. The inputs to the algorithm are the optical signal (what the sensor senses) and any controls that are set when the system is commissioned. The output from the algorithm is the control sent as a pulse width modulation for the servo motor to adjust. The control algorithm is represented as a flow chart in Figure 2.

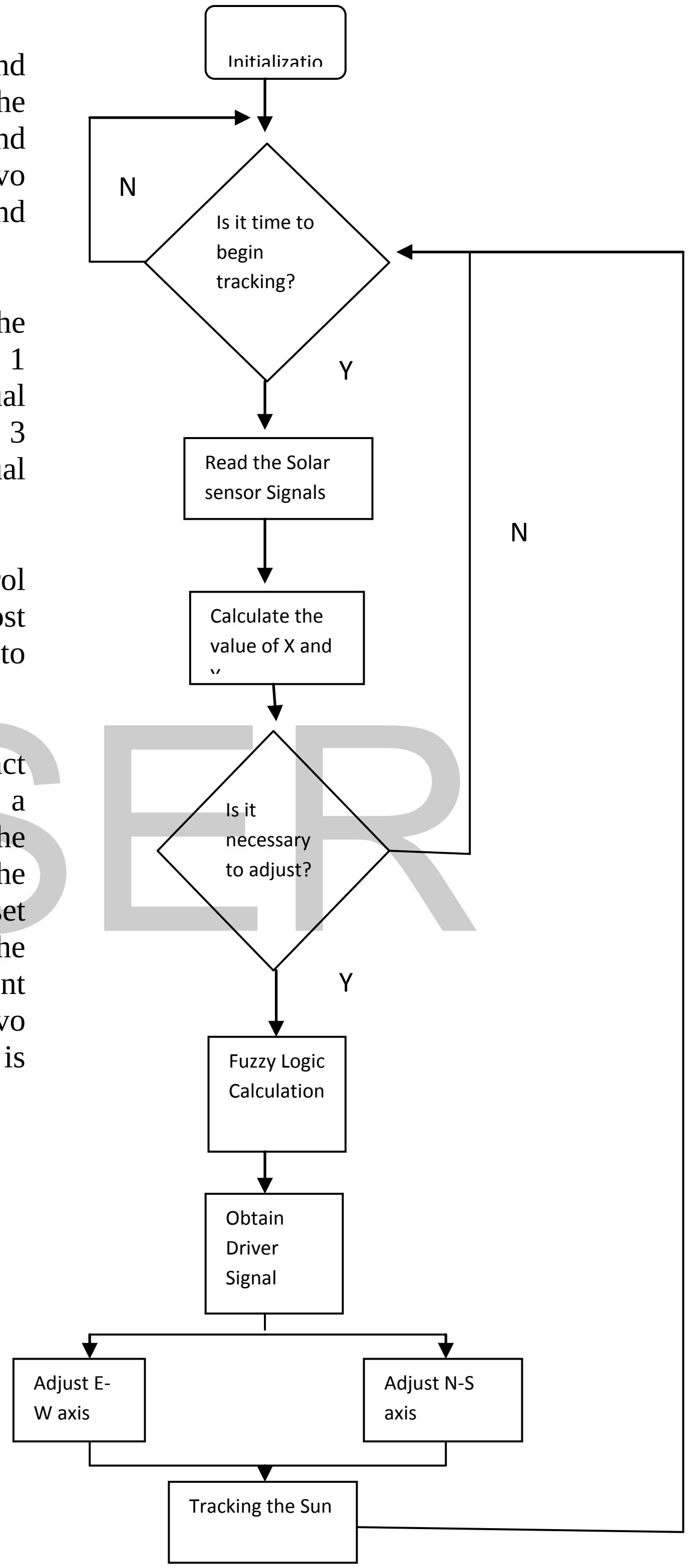

Figure 2: The Control Flowchart

V. RESULTS AND DISCUSSIONS

For identifying accurate and efficient mechanical configurations suitable for tracking systems, a structural simulation model was designed using proteus professional software version 8.0.1. The components were picked from the library and connected appropriately as represented in Figure 3. The resistors represent the sensors connected to pins A0, A1, A2, and A3 of the microcontroller respectively for providing input into the system. The actuators represent the servo motors connected to pin 9 and 10 of the microcontroller for receiving output from the system. The liquid crystal display (LCD) and the virtual terminal (VT) are connected to pins 0,1,2,3,4,6,7 and 11 of the microcontroller for displaying output from the system. The compiled program was written in Arduino IDE and transferred into the microcontroller after the design completion by uploading the *.hex file.

The process started as sensors read input parameters (light intensity) induced by the sun and passed same into the microcontroller. For Arduino, the analog-to-digital converter (ADC) already exists on the input pins. Therefore, the sensors can be directly connected into it. Inside microcontroller a comparison between the signal values from each LDR is made in order to send control signals to the appropriate motor to move. In this simulation, the highest intensity of light is fixed to 15.1 lux and the lowest is at 0.1 lux. There are 6 cases involved in the process. Servo motor movement will follow the condition specified by the microcontroller after signal comparison from each of the LDRs. In dual axis solar tracking system, there are two servo motors. One motor is used to control elevation axis and another motor is used to control azimuth axis.

The Servo Motor movement is fixed between -90^0 to $+90^0$ since it can move for 180^0. This is set because the angle of inclination of the sun is -90^0 after sun rise and $+90^0$ before sun set. Figure 3 shows the solar tracker simulation test.

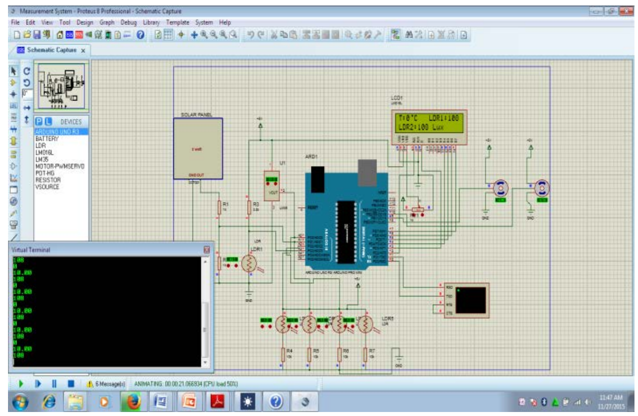

Figure 3: Solar Tracker Simulation Test

There are two motors involved as it is a dual axis solar tracker. Each of the motor movement is given below:

Servo Motor 1 (East – West Motion)

Due to the daily motion of the sun from east to west every day, the east west motor has three cases as follows:

CASE 1. Motor 1 is in initial position; if LDR1 (E) is higher than LDR2 (W), that means the light intensity affecting LDR1 is higher than that affecting LDR2 and this is the first motivation of the day. In the morning Servo1 start to rotate clockwise (from east to west) until the two sensors are receiving the same value (LDR1=LDR2). This is represented in Figure 4.

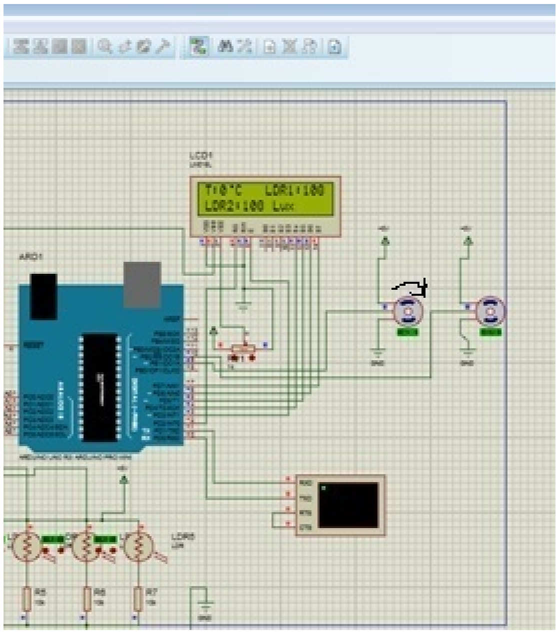

Figure 4: Clockwise Movement of Servo Motor 1

CASE 2. After case 1, if (LDR1 =LDR2) the sensors measured the same value. The motor will not rotate. That means the solar panel is now facing the sun correctly.

CASE 3. After case 2, Servo1 will stop rotating and then the sun continues moving towards west and the western sensor, LDR2 begins to have higher value than LDR1, so Servo1 will rotate anticlockwise until the 2 sensors reads the same value (LDR1=LDR2). This is represented in Figure 5

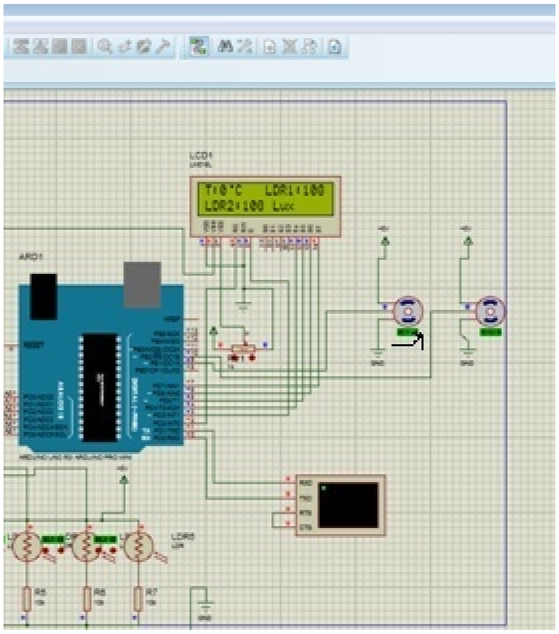

Figure 5: Anticlockwise Movement of Servo1

Servo Motor 2 (North – South Motion)

The seasonal variation makes the sun path dynamic all the year round. The sun trajectory at the summer and winter periods differs. This necessitates the second axial issue.

CASE 1. The northern sensor (LDR3) is higher than the southern sensor (LDR4). Here servo 2 start to rotate clockwise. So value of LDR4 increases until the two sensors are having the same value (LDR3=LDR4). This is represented in Figure 6.

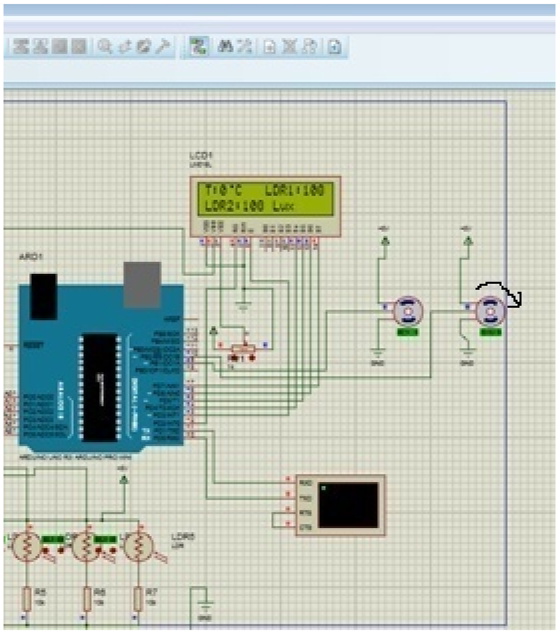

Figure 6: Clockwise Movement of Servo Motor 2

CASE 2. These case happens when the two sensors reads the same value (LDR3=LDR4). The motor will not rotate, that means the solar panel is now in the correct position facing sun.

CASE 3. The southern sensor (LDR4) is higher than the northern sensor (LDR3). Here servo 2 starts to rotate anticlockwise. So value of LDR3 increases until the two sensors are having the same value (LDR3=LDR4). This is represented in Figure 7.

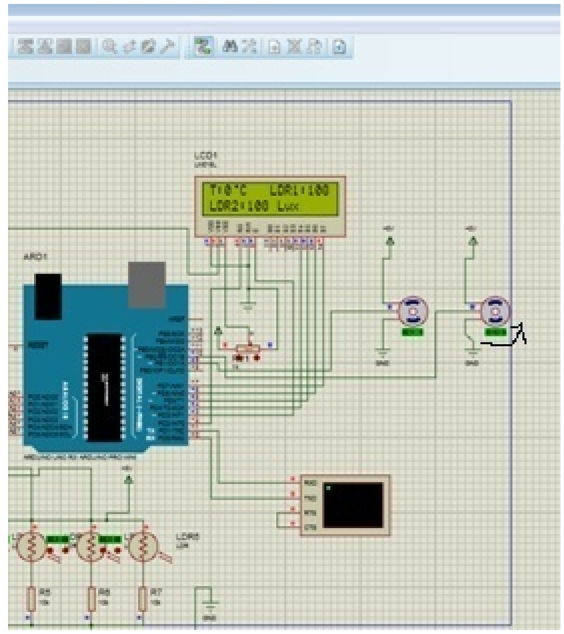

Figure 7: Anticlockwise Movement of Servo Motor 2

THE AMPLITUDE AND DISTORTION OF THE MODEL

Oscilloscopes are used to observe the change of an electrical signal over time, such that voltage and time describe a shape which is continuously graphed against a calibrated scale. The observed waveform can be analyzed for such properties as amplitude, frequency, rise time, time interval, distortion and others.

The signal displayed and measured is applied to the y-plates (the input). The larger the input voltage the greater the deflection. If the voltage alternates then the beam oscillates up and down. The amount of deflection per volt can be adjusted by changing the y-gain control on the oscilloscope.

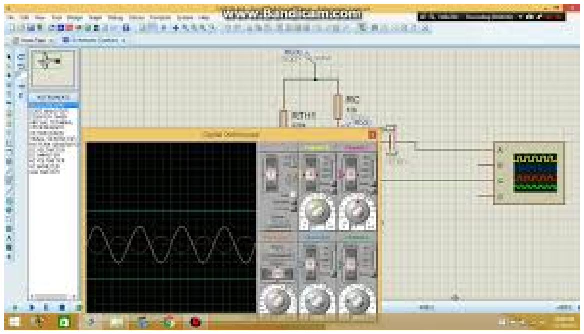

Figure 8a: Determining oscilloscope amplitude frequency measurement

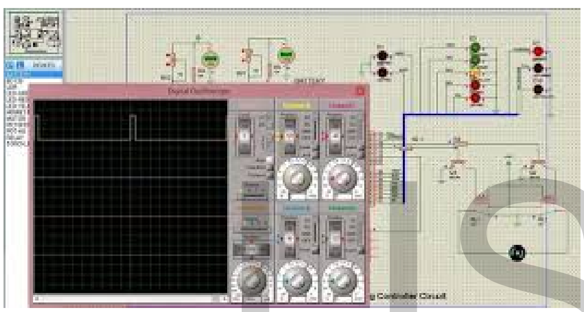

Figure 8b: Determining oscilloscope amplitude frequency measurement

From the figures above, it is clear that the oscilloscope measured the needed amplitude and frequency of the model.

To measure oscilloscope amplitude frequency, a user must first put the signal into the oscilloscope's input port. Signals can be used through a dedicated probe or through a less sophisticated cable.The user must then set a trigger source to enable the oscilloscope to start scanning. This is the time when the oscilloscope begins to display a trace. Coming from a threshold level, the trigger can alter in slope of the signal itself. It can also come from a different source.The voltage scale must be set so that the signal's full vertical range can be displayed as big as possible while still fitting within the screen of the oscilloscope. The timebase must also be set to easily spread the display of the signal's full cycle across the screen – from left to right.Then the user must decide on the starting and finish point for a full cycle. The point can be the maximum voltage to the next maximum, or the point where the voltage passes zero on its way to negative from positive, or any other easily identifiable feature on the signal.

VI. SUMMARY AND CONCLUSION

This paper has presented a means of controlling a sun tracking array with an embedded microcontroller system. Specifically it demonstrates a working software solution for maximizing power output of the solar cell by positioning the system at the point of maximum light intensity. For energy reasons, as the main objective of this strategy is the generation of energy using sun as a source, the tracker is not commanded to follow the sun at all times because this will cause continuous movement of the motors, which would, in turn result in excessive energy consumption. Instead, to prevent the system from unnecessary movement, the strategy implemented in this model is the following: the PV cell does not move as long as the tracking error is less than certain specified tolerance. Where this error is greater than this tolerance, the controller orders the motor to move to a point where the sun will arrive in a certain amount of time. Thus, the tracker waits for the sun. This process is identical and independent for each axis. However, the two motors never move at the same time. Before ordering the movement of one axis, a check is made to ensure that the other axis is not moving. The two axes are not allowed to move simultaneously.

As the sun moves along its trajectory throughout the day, signals from the light dependent resistors are sent so that appropriate motor moves appropriately, thus generating the electrical energy that this research is designed to provide. The current sensor is used to confirm that the PV cell is tracking the sun correctly since it is measuring the power generated, so a decrease in the power generated (under normal external conditions, i.e. without taking into account an extended cloudy period, for example) indicates a tracking problem. It is known that the greater the error is in either of the two coordinates (azimuth and elevation), the less power is generated. As a result, if the motor is on either of the coordinates (while the other is fixed) it can be assumed that the real position of the sun for that coordinates corresponds to the point where the maximum power was produced during the movement. This is why both motors cannot move simultaneously.

This research has presented a method of searching the sun with a relative error tolerance of $\pm 0.0001^0$

REFERENCES

Abdallah, S., & Salem N. (2004). *Two axes sun tracking system with PLC control*. Energy Conversion and Management, 45(11-12), 99-103

Bari, S., (2000). *Optimum slope angle and orientation of solar collectors for different periods of possible utilization*. Energy Conversion and Management, 41(8), 855-860.

Bodinga, B.A., Ndajah, P.E., & Mohammed, A. (2016). An Improved One – axis SolTracking Model**.** International Journal Of Scientific and Engineering Research (Accepted)

Bodinga, B.A., Ndajah, P.E., & Mohammed, A. (2016). An Intelligent Sun Tracking Model using Fuzzy Logic Approach.Procedings of the 2nd Africa International Renewable Energy Confenence, Sokoto-Nigeria.

Chen, F., Feng, J., & Hong, Z. (2006). Digital *Sun sensor based on the optical vernier measuring principle.* Measurement, Science and Technology, 17, 2494-2498.

Chen, F. & Feng, J. (2007). *Analogue sun sensor based on the optical nonlinear compensation measuring principle.* Measurement, Science and Technology., 18, 2111-2115.

Helwa, N.H, Bahgat, El-Shafee, A.B.G, El-Shanawy, E.T (2000). *Maximum Collectable Solar Energy by different solar tracking systems.* Energy Sources, 22(1), 23-34.

Kumaresh, V., Mridul, M., Ramakrishma, N., & Saravana, R., (2014). *Literature Review on Solar MPPT systems*. Advance in Electronic and Electric Engineering, 4(3), 285-296.

Lee, C., Huang, H., & Yeh, H. (2013). *The Development of sun-Tracking system using Image Processing.* Sensors, 13, 5448-5459.

Li, C., & Michael,A., (2013). *Optimization of Solar Panel with solar Tracking and Data Logging*. IEEE Student Conference on Research and Development (SCOReD), 16-17 December 2013, Putrajaya, Malaysia, 15-19.

McFee, R. (1975). *Power collection reduction by mirror surface nonflatness and tracking error for a central receiver solar power system*. Applied. Optics, 14, 327-330.

Neville, R. (1978). *Solar Energy Collector orientation and sun tracking mode*. Solar Energy, 20(1), 7-11.

Poulek, V., & Libra, M., (2000). *Very simple solar tracker for space and terrestrial applicatons*. Solar energy matter solar cell, 60, 99-103.

Rockwell Automation (2011). *Solar Tracking Application [White paper]*. Retieved from http://www.rockwellautomation.com/solar-tracking-application.pdf; 02/02/2015: 14:20:20 GMT.

Roth, P., Georgiev, A., & Boudinov, H., (2005). *Cheap two axis following device*. Energy Conversation and Management,46(7-8),1179-1192.

Wang, W., & Li, S., (2012). *Model Predictive Control of 2-axis Solar Tracker for Solar Energy System.* Proceedings of the 31st Chinese Control Conference, 4177-4182.

Yakup, M. A., & Malik, A. Q., (2001). Optimum Tilt Angle and Orientation for Solar Collector. Renewable Energy, 24, 223-234.

Zhou, Y., & Zhu, J., (2010). *Application of Fuzzy Logic Control Approach in aMicrocontroller-based sun tracking system.*WASE International Confererence on Information Engineering, 161-164.