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Design and Implementation of an Off-Grid Solar Tracker Control System using Proteus Version 8.1

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Abstract: Most standalone Solar Photovoltaic (PV) systems in Nigeria are of the fixed standalone type and are fixed either on the roof of a building, at the top of an iron pole or other unmovable positions and so, do not produce required maximum energy conversion due to the varying movement of the sun in the sky. Recent studies have shown that the amount of electric power generated by PV arrays varies continuously with weather conditions. Even under clear weather conditions, the position of the sun changes during the day, which in the case of fixed installed solar panels leads to changes in the effective surface of the solar panels towards the sun and a decreased output power. At present, PV energy conversion efficiency stands at between 9% and 18% depending on the solar cells used, especially in low irradiation conditions. For any PV system, therefore, one option is to increase the energy produced by solar panels through solar tracking. The paper focuses on developing an automatic sun tracking system with the ability to direct solar panels continuously in optimal position to the sun, thus improving the overall efficiency of the PV system.

Keywords: Energy Efficiency, Solar Energy, Solar PV Systems, Off-Grid PV Systems, Renewable Energy
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I. INTRODUCTION

Energy crisis is the most important issue in the world today. Conventional energy resources e.g. petroleum, coal and natural gas are not only getting depleted but also pollute the environment. As energy consumption and demand levels continue to rise with rising global population therefore, experts are looking out for means of filling the gap through renewable energy supplies. The current focus on renewable energy resources is to lessen the dependency on the conventional energy resources. Energy derived from the sun otherwise called solar energy, is particularly and rapidly gaining attention as it is clean, environmentally friendly, readily available and an infinite source of energy especially in the tropical regions of the world. This renewable energy type has so far proven to be the most dependable and sustainable source of renewable energy globally. However, Solar PV panels which converts solar energy into electrical energy are costly and inefficient. There are three methods by which the efficiency of PV systems could be improved. The first method is to increase the generation efficiency of solar cells; the second one is related to the energy conversion system using maximum power point tracking (MPPT) control algorithms; and the third approach is to adopt solar tracking system to obtain maximum solar energy input from the sun. The energy delivered by solar panels depends on various factors; the construction and efficiency of the solar cells, the temperature and the intensity of the irradiated light. Even under clear weather conditions (steady amount of solar radiation) the position of the sun changes during the day, which in the case of fix installed solar panels leads to changes in the effective surface of the solar panels towards the sun and a decreased output power. The optimum position is, when the solar panels are perpendicular to the light, in this case the effective surface equals the surface of the solar panels. It has been estimated that the use of sun tracking system over a fixed system, can increase the power output by 30% -60%.A solar tracking system orients or directs solar photovoltaic panels by keeping track of the sun's movement from dusk to dawn, thus maximizing solar energy power generation efficiency [1].

There are two methods of solar tracking, namely Single axis and Dual axis solar tracking systems. When tracking the sun, it is noted that the direction of the sun, as seen by the solar panel, will vary in two directions. The azimuth angle is the horizontal direction from the observer to sun, while the zenith or altitude angle represents the vertical direction from the Observer to the sun. The horizontal direction is used for single axis solar tracker while the combination of the horizontal and vertical directions is referred to as two axis or dual axis solar trackers. A single-axis solar tracking system (Shown in Fig.1) uses a tilted PV panel mount and a single electric motor to move the panel on an approximate trajectory relative to the Sun's position [2]. Since solar tracking involves moving parts and control systems that tend to be expensive, single axis tracking system seem to be the best solution for small PV power plants.

Sun tracking systems are usually classified into two categories, namely passive (Mechanical) and active (Electrical) trackers. Passive solar trackers do not incorporate sensors or actuators but are based on thermal expansion of a matter (usually Freon) or on shape memory alloys. Usually this kind of tracker is composed of couple of actuators working against each other which are, by equal illumination, balanced.

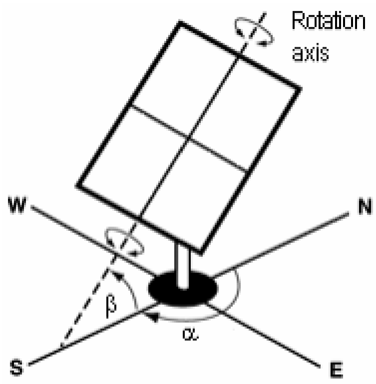

Fig. 1: Principle of the Single-axis Solar Tracking System

Passive solar trackers, compared to active trackers, are less complex but work in low efficiency and at low temperatures they stop working. Tests have shown that passive trackers are comparable to electrically based systems in terms of performance. Although passive trackers are often less expensive, they have not yet been widely accepted by consumers.

Active trackers are systems whose motion is performed by actuators controlled by signals of a sensor. Active trackers can be categorized as microprocessor and electro-optical sensor based, PC controlled date and time based, auxiliary bifacial solar cell based and a combination of these three systems. Refs [3][4] and [5] used LDR and photodiode as sensors, geared DC motor and stepper motor as the actuator. Those projects have disadvantages such as high cost during development, difficult to control motor speed and difficult to program because of using microprocessor.

Refs [6] and [7] presented general sun tracking formulas for open–loop type of sun tracking system to solve the problem of any arbitrarily oriented sun tracking axes for off-axis and on- axis solar collector respectively. Ref [8] investigated the design, development and evolution of a Mikro Computer-based solar tracking and control system (TACS). It was capable of maintaining the peak power position of a photovoltaic (PV) array by adjusting the load on the array for maximum efficiency and changed the position of the array relative to the sun.

Ref [9] used a programmable logic controller (PLC) to control a photovoltaic module for following the sun's radiation. It was shown that by collecting and storing the data relating to the sun's radiation, and using this information to control the photovoltaic module, the daily output of the PV system could be improved by more than 20% relative to that obtained from fixed module. Ref [10] proposed a robust oscillation method used for implementing the maximum power point tracking for the solar arrays. The method uses only one variable that is load current for detecting the maximum power. This method is suitable for the battery charging application where MPPT is to be implemented. Recent studies have shown that the amount of electric power generated by PV arrays varies continuously with weather conditions. Even under clear weather conditions, for instance, the position of the sun changes during the day, which leads to changes in the effective surface of the solar panels towards the sun and a decreased output power. At present, PV energy conversion efficiency stands at between 9%and 18% depending on the solar cells used, especially in low irradiation conditions. For any PV system, therefore, one option is to increase the energy produced by solar panels through solar tracking. The aim of this paper is to develop an automatic sun tracking system with the ability to direct solar panels continuously in optimal position to the sun, thus improving the overall efficiency of the PV system. There are two main types of photovoltaic (PV) systems, grid connected system and off-grid or standalone system. This work is based on the off-grid PV systems, which are those PV systems that are not connected to the National electricity grid.

II. METHODOLOGY

In this study, Nkpor Village near Port Harcourt, Nigeria (See Table 1) was selected as the site for installation of the Solar Tracking PV System and the weather data used was supplied by Simba Solar, Abuja as was obtained from the NASA Langley Research Centre and GAISMA Research centre, Finland (See Table 2).

Table 1. Geographical Profile of Nkpor Village, near Port Harcourt, Nigeria [Authors, 2014]

Latitude	Longitude	Time Zone	Altitude
+4.81 (4º 48'' 36'' N)	+7.01 (7º 00'' 36'' E)	UTC+1 hour	~460m

Proposed Technology

Since the main objective of this project is to improve the overall electricity generation of a PV system using tilted single axis tracking system and also to provide the design for residential use; light dependant resistor (LDR) was chosen as the sensor, due to its sensitivity to light. For the controller, PIC 16F877A was chosen, and for the driver, a bi-directional DC motor control using relay was used. The motor controller was chosen because it can control the motor to rotate clockwise and counter clockwise easily. Brushed DC geared motor was chosen because it has a high starting torque, low rpm, high efficiency and a linear speed/torque curve.

Table 2: Port Harcourt Solar Energy and Surface Meteorology [Authors, 2014]

VARIABLE	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	NOV	DEC
INSTALLATION, KWH/m^2/day	5.78	5.87	5.43	5.09	4.47	4.36	3.89	3.79	3.96	4.27	4.89	5.41
CLEARNESS, 0-1	0.61	0.59	0.52	0.49	0.47	0.44	0.39	0.37	0.39	0.43	0.51	0.59
TEMPERATURE, ºC	25.43	25.86	25.81	25.77	25.67	24.75	24.04	23.94	24.15	24.44	24.68	24.73
WIND SPEED, m/s	2.75	2.97	2.71	2.39	2.23	2.81	3.21	3.37	2.96	2.35	2.25	2.40
PRECIPITATION, mm	3.6	6.7	149	200	252	295	359	318	382	288	100	32
WET DAYS, d	3.2	5.4	10.0	13.2	15.9	17.7	20.4	20.4	21.6	17.1	7.4	3.3

The "Watt- Hour" method was used to decide the number and type of solar panels required to capture the solar energy, the capacity of the battery that would store the energy for the period of no sun, and to be able to determine the required characteristics of the rest of the elements that fit into the system (controller, converter, cables etc.). The watt-hour method enables the standalone PV system to work reliably in the months in which the demand of energy is greater with respect to the solar energy available. It also fixes the maximum numberofdaysthatthesystemcanworkwithoutreceivingsolarradiationand all the consumption is made solely at the expense of the energy stored in the battery. A scale model is a physical model, a representation or copy of an object that is larger or smaller than the actual size of the object, which seeks to maintain the relative proportion (the scale factor) of the physical size of the original object. Very often the scale model is smaller than the original and used as a guide to making the object in full size. Scale models are built by researchers and engineers who required scale models to test the likely performance of a particular design at an early stage of development without incurring the full expense of a full – sized prototype. PV system is a modular project which can be built by either connecting the chosen PV panels in series to increase the output voltage or in parallel to increase the output current respectively. Due to the high cost of PV Panels and its accessories for a PV system, this project will adopt and built a scale model prototype that will be 2500 times smaller than the designed full – size PV system (2500:1 ratio).

A solar tracking system is a support platform that orients or directs solar photovoltaic panels by keeping track of the sun's movement from dusk to dawn, thus maximizing solar energy power generation efficiency [11]. The solar tracker for this project is of the active class, constructed to track in single axis mode. It consists of a tilted panel mount, three (LDR) light intensity sensors, PIC16F877A microcontroller, a slow speed dc gear motor with linear actuator, and a relay/drive circuit.

The mechanical diagram of the tracking system is as illustrated in Fig. 2, while Fig. 3 is the block diagram of the tracking system.

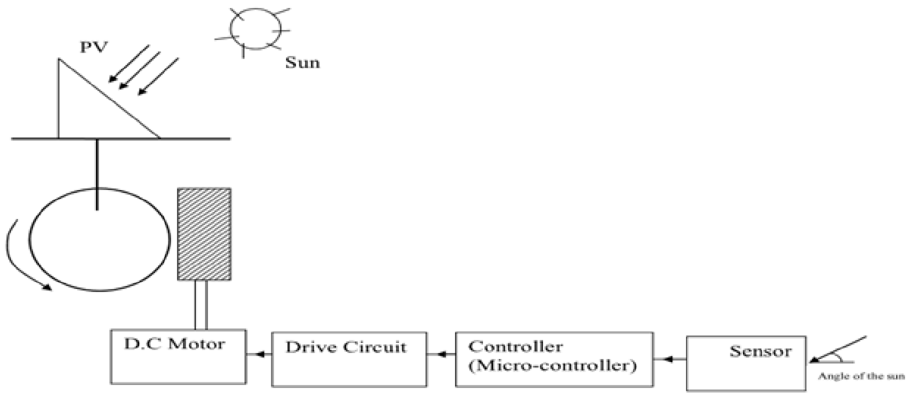

Fig. 2: Mechanical diagram of the tracking system

This work deployed a single axis tilted solar tracker in other to maximize power output from the solar panels.

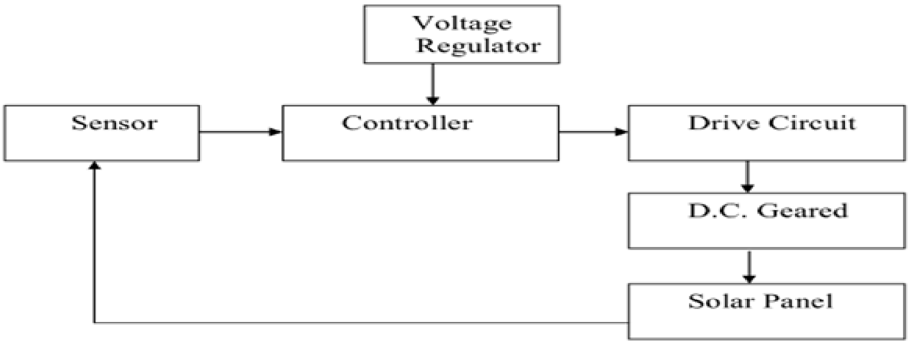

Fig. 3: Block diagram of the solar tracking system

Single axis trackers usually have a single axis tilt movement, whereas dual axis trackers move in regular intervals adjusting for an angular position. Single axis trackers compared to fixed stationary tilted PV support systems increase solar power capture by about 20 to 30 percent.

The Solar tracking equipment automatically searches the optimum PV panel position with respect to the sun by means of an electric gear motor with linear actuator. The gear motor will be controlled by a microcontroller PIC16F877A that receives input signals from light intensity sensors. The Solar Tracker uses a programmable intelligent computer (PIC) which receives analogue signals from positioned LDR sensors, analyzes it and thus actuates the electric gear motor to move the solar panels into a position where maximum sunlight will be received. Fig. 4 is the Photo diagram of the Solar Tracking System.

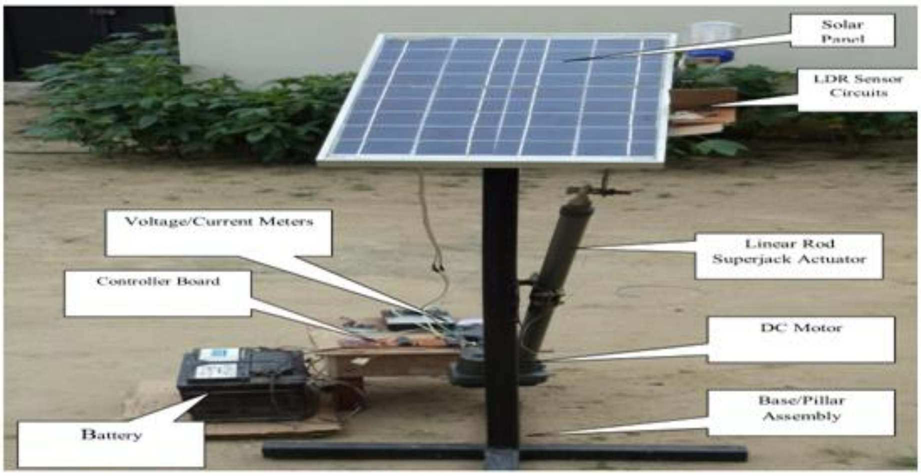

Fig.4: Photo diagram of the Solar Tracking System (Authors, 2014)

Light dependent resistor

Light dependent resistor or LDR was chosen as the sensor because of its sensitiveness to light. The resistance of LDR decreases with increasing incident light intensity. LDR is used in this project to detect the direction of the sunlight.

Microcontroller

For automatic control of the tracker and solar movement, a microcontroller system is required. This work deployed the microcontroller PIC16F877A.

The DC Motor Control and Drive Circuit

The drive unit consists of a 370W, 48V DC motor driving a 100KN screw jack linear actuator. The actuator rotates the PV through pushrod and multiple lever arms attached to a row of PV modules. To control the direction and speed of the DC motor used for the tracking system, a drive circuit was interfaced between the microcontroller and the dc motor. The drive circuit used is L293D motor driver IC. L293D is a typical motor driver IC which allows DC motor to drive on either direction. As shown in Fig. 5, it is a 16 pin IC which can control a set of two DC motors simultaneously in any direction.

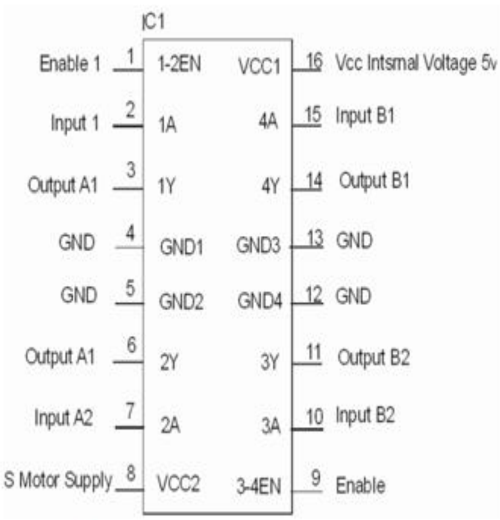

Fig. 5: Pin diagram of a L293D motor controller

It means that two DC motors can be controlled with a single L293D IC. It works on the concept of H-bridge, which allows the voltage to be flown in either direction. In a single L293D chip, there are two h- bridge circuit inside the IC which can rotate two dc motor independently. Due to its size, it is very much used in robotic application for controlling dc motors.

Relay Circuit

This work deployed an electromagnetic relay. When the L293D motor driver IC sends base current through pin 3 to the diode D1, collector current will flow through the RL1 relay coil, which will energize the relay (now a switch) and the switch button will move from NC to NO, and since NO is connected to +24V, a complete circuit is formed and the dc motor will run in clockwise direction. When the output of pin 3 becomes zero, no base current flows through D1, hence no collector current, and the switch button will return to NC. The circuit is now open and the dc motor will stop running. When pin 6 of L293D sends base current to diode D2, collector current will flow through the RL2 relay coil, hence the motor will run in anticlockwise direction.

Inverter

Inverter or power inverter is a device that converts DC sources to AC sources. Power inverters produce one of the three different types of wave output, namely (i) Square wave (ii) Modified square wave (modified sine wave). (iii) Pure sine wave (True sine wave). The Pure Sine Inverter though more expensive than the other types of Inverters, was used in this work because it has the unique advantage that it produces waveforms which are the same as the power delivered by the utility grid.

The Simulation System

The Solar Tracker Control System was implemented through simulation. The simulation circuit was designed using the Proteus Professional Software version 8.1.The components were picked from the Proteus Library and connected appropriately. The outputs of the sensor circuits were connected to pins 2, 3 and 4 of the microcontroller. The outputs from pins 33 and 34 of the microcontroller are connected to the input ports 2 and 7 of the motor driver which controls the directions of motor movement through its output ports, pins 3 and 6. The open circuit voltage and short circuit current of the PV panels was measured using digital AVO meter and current probe respectively. The results of the fixed and the tracking system are as recorded below. Fig.6 shows the simulation diagram of the Solar tracking system control system.

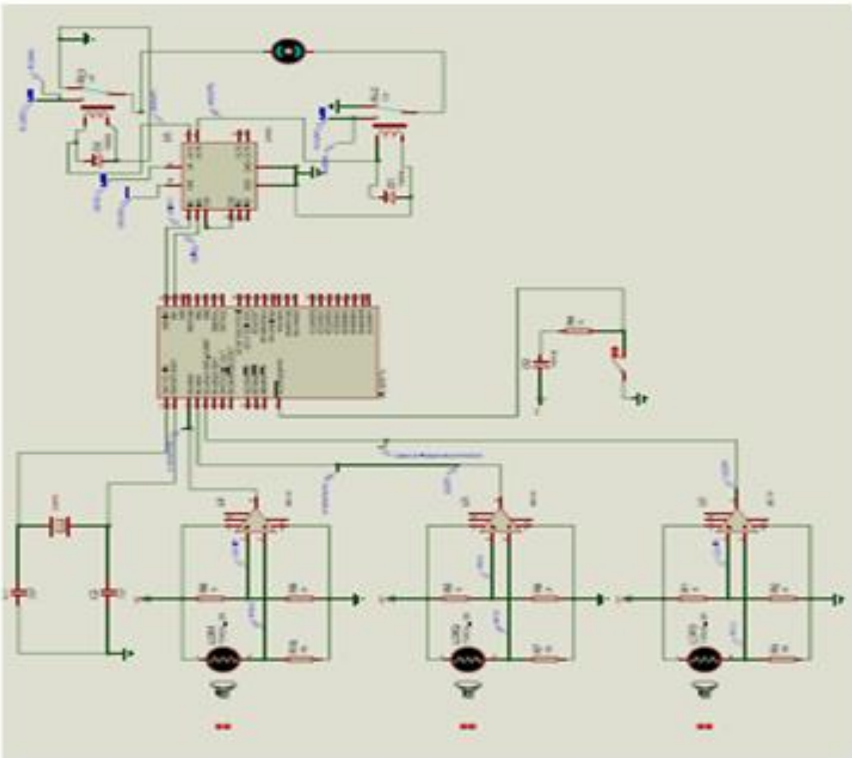

Fig. 6:The simulation diagram of the Solar tracking system control system

A high level language (Mikro Pro) was utilized for the project. It was sufficient to satisfy design objectives while enhancing the level of understanding of the language. Table 3 is the programme truth table while Figure 7 shows a flow chart of PIC16F877A programming.

Table 3: Programme Truth Table [Authors, 2014]

Input		Output		Motor Direction	
RA2	RA1	RA0	RB1	RBO	
0	0	0	0	0	No rotation
0	0	1	0	1	Rotate westward
0	1	0	1	0	Rotate eastward
0	1	1	0	0	No rotation
1	0	0	1	0	Rotate eastward
1	0	1	0	0	No rotation
1	1	0	0	0	No rotation
1	1	1	0	0	No rotation

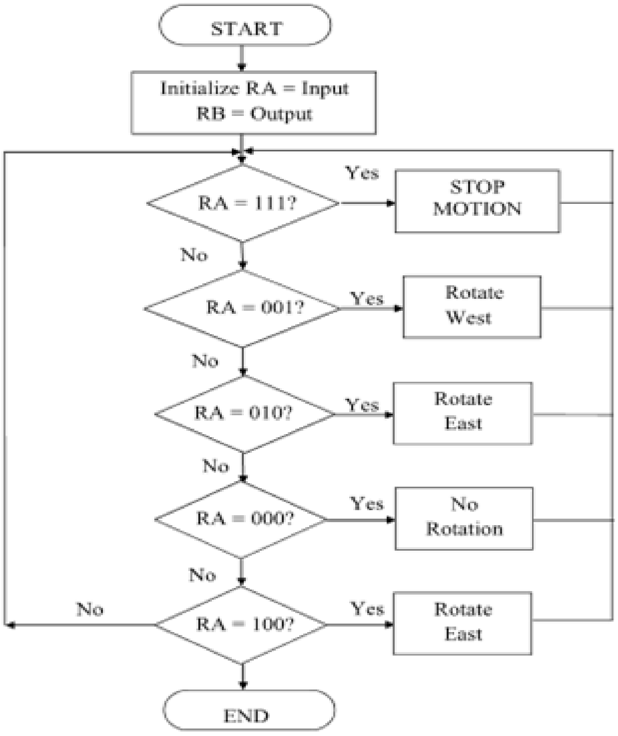

Fig. 7:Flow Chart of PIC16F877A programming [Authors, 2014]

III. RESULTS AND DISCUSSION

The data of voltage, current and power received from the Solar tracking system over a twenty-four hour period are as recorded below in Table 4.

Table 4: Data of voltage, current and power received from the Solar tracking system within twenty-four hours [Authors, 2014]

Time of the Day	Open Circuit Voltage (V)	Current (A)	Power (W)
8:00 AM	16.82	0.85	14.4
9:00 AM	17.11	0.97	16.6
10:00 AM	18	1.05	18.9
11:00 AM	18.6	1.09	20.27
12:00 PM	20.3	1.13	22.94
1:00 PM	21	1.23	25.83
2.:00 PM	20.9	1.16	24.25
3:00 PM	20.6	1.12	23.1
4:00 PM	19.86	1.08	21.45
5:00 PM	18.56	1.04	19.3
6:00 PM	16.96	0.96	16.28

Fig.8 is the graphical representation of output power of the tracking PV panel against day time. From the graph, it can be seen that solar intensity increases with day time to a maximum at 1.00pm then starts decreasing, but there is some fluctuation of intensity due to flow of some cloudy sky and abnormal atmospheric condition.

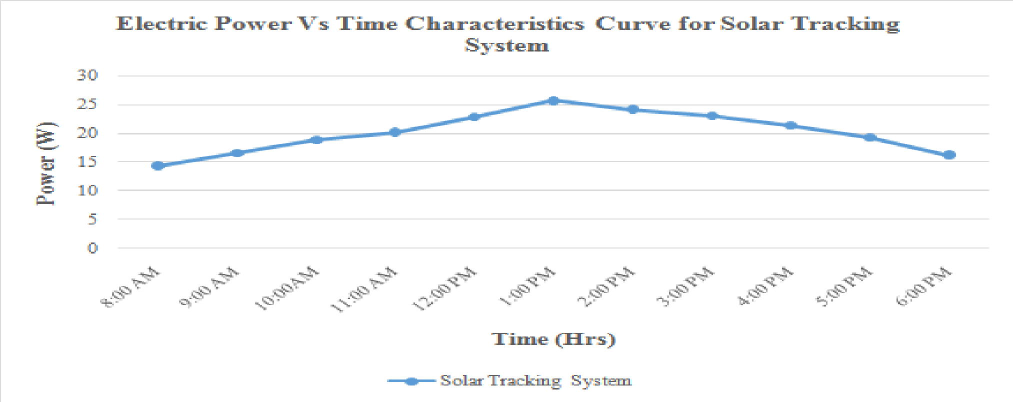

Fig. 8: Graphical representation of Output power of the Tracking PV panel Vs Time

The designed system can be installed in residential homes which will guarantee sustainable, durable and improved power supply. Although solar tracking is expensive but if installed on a large scale, PV system is worth the money spent since it guarantees uninterruptable power supply- a phenomenon that is not common in Nigeria.

IV. CONCLUSION

The work has successfully designed and implemented an automatic Solar tracking PV system which is microcontroller based. The PIC16F877A microcontroller was chosen, a high level programming language Mikro Pro was utilized. The microcontroller receives analog signals from the sensors via a comparator circuit, processes it and sends the signals in digital form to drive and control the DC gear motor via a drive circuit. The utilized control system makes the sun tracking by the PV panel easy and automatic without manual adjustments. The results of the experimental test carried out showed that the output power of the Solar tracking system increased with daytime-hours from 14.3W at 8.00am to a maximum of 25.83W at 1.00pm but decreased to 16.28W at 6.00pm. The results also indicated that at 1.00pm, the sun was perpendicular to the solar tracking PV system. The significance of the outcome is that, to produce a required electrical output power from a PV system, less PV panels would be required using solar tracking PV system. The practical and widespread implementation of this work in Nigeria will increase electricity supplies and boost commercial activities across the country. The authors further recommend the use of phototransistor light sensors for improved sensitivity and solar tracking accuracy.

V. CONFLICT OF INTEREST

The authors declare that no conflicting interests exist.

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