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Design Optimization and Performance Evaluation of a Single Axis Solar Tracker

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Abstract The paper presents the optimization in design, construction and performance test of a microcontroller-based, single axis solar panel tracking system, using locally available recoverable materials. The tracking system consists of two light sensors and an automated microcontroller to drive the motor and three batteries. Three parameters were considered: solar intensity, voltage and time of alignment/exposure of solar panel to solar radiation. Current and power were obtained and compared with those of a fixed axis solar panel of same specifications. The solar tracker provided a constant alignment, better orientation of the solar panel relative to the sun; and ensured production of more energy by capturing the maximum of sun rays hitting the surface of the panel from sunrise to sunset. The present study has shown that the solar tracking system could both be optimized in terms of design with a performance increment of 47.5% and cost. The solar tracking system is affordable and found to cost $ 154.00. It is also a sustainable energy solution which would assist in reducing both solid and liquid wastes as well as noise and air pollution.

Keywords: *solar energy, tracking, optimisation, material re-use, low cost, sustainability*

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1. Introduction

Developing countries across the world are presently dealing with various problems ranging from poverty, hunger, population increase as well as lack of electricity for their basic primary needs. Some imported technologies do not simply fit; they are either too costly to purchase or are very difficult to repair once faulty. In the selection process of an appropriate source, form of renewable energy or technology, factors of major importance to be considered include: availability of parts and raw material, location, ease of installation, ease of maintenance, reliability, capacity, cost and environmental impact. Solar energy is readily available in most semiarid parts of tropical Africa with Nigeria receiving a yearly average of 5.61 kWh/m^2 [1] among others. However, solar power depends directly on light intensity, duration of sunshine time, geographical position and prevailing climate. To optimize the amount of energy received, a solar panel must be perpendicular to the light source; and since the sun moves both throughout the day as well as throughout the year, a solar panel needs to be able to follow the sun's movement to produce the maximum possible power.

On one hand, Asmarashid et al. [2] designed a low power single axis solar tracking system regardless of motor speed while Okpeki and Otuagoma [3] designed and constructed a bi-directional solar tracking system. Hemant et al. [4] on the other hand, presented the design and experimental study of a two axis (azimuth and Polar) automatic control solar tracking system to track solar PV panel according to the direction of beam propagation of solar radiation. The designed tracking system consists of sensor and Microcontroller with built-in ADC operated control circuits to drive motor. The results indicate that the energy surplus becomes about (45-56%) with atmospheric influences. In case of seasonal changes of the sun's position there is no need to change in the hardware and software of the system. Solar tracking systems design has received considerable attention throughout the world in recent years [5-11].

This paper presents the design optimization and performance evaluation of a sustainable single axis solar tracker for use in semi arid regions of the world with Maiduguri (Nigeria); located on latitude 11.85° North and longitude 13.08° East and an annual mean daily global solar insolation of 6.176W/m^2 – day; as the study area.

2. Materials and Methods

Two prototypes solar panels were designed and constructed for the purpose of this study; one fixed and the other one, able to move and track the sun movement from sunrise time to the sunset time of the study area (12 hrs 25 minutes = 44,700 seconds). The main components of solar tracking system are as follows: two solar panels (monocrystaline photovoltaic module. Model type= SE-20M maximum power 20watts), a used electric glass door

raising mechanism from an old car, a stepper motor designed, two sensors (light dependent resistor), three batteries (sealed lead acid battery 12volts, initial current: 2.1Amperes) and an electronic circuit (controlled by a microcontroller PIC). Other equipment include two digital thermocouples and a CASIO DATABANK stopwatch.

Sizes and other important physical characteristics of the solar tracking system and fixed axis system are determined using the formulas and correlations from the literature.

2.1. Determination of the Speed of the Stepper Motor [12]

Taking θ =260˚S (where θ is the angle tilted or covered by the solar tracker).

$$\theta = \frac{2\pi N}{60} = \omega t \quad (1)$$

ω = θ/t where t = 12hours, 25minutes = 44700 seconds
θ in radians = 260˚/180˚ × π = 4.538rads
where N is the speed of the stepper motor.

2.2. Determination of the Number of Revolution of the Electric Motor Per Teeth

Number of revolution of electric motor in 12hrs 25minutes.

2.3. Determination of the Thickness of the Teeth

Taking the diameter of the pinion to be 92 mm (pitch circle diameter PCD)

$$Module = \frac{pitch\ circle\ diameter\ PCD}{Number\ of\ teeth\ (T)}. \quad (2)$$

2.4. Determination of the Power Required by the Stepper Motor to Drive the Mechanism [13]

$$Power = Current(I) \times Voltage(V) \quad (3)$$

2.5. Efficiency of the Solar Tracker

$$= \frac{Outputpower}{Inputpower} \times 100\% \quad (4)$$

The power required by the electric motor (consumption)

$$P = I \times V \quad (5)$$

3. Results and Discussion

Two solar collection systems (Plate 1) were constructed and tested. The solar tracking system (Figure 1 and Figure 2) was powered by a motor and controlled by a microcontroller PIC, whose circuit diagram is shown in Figure 3. Tests were conducted with the solar tracker and results were compared to the fixed type from 19th January 2014 to 24th July 2014, within the same test periods. Table 1 shows a summary of calculated characteristics of the designed solar panels. Table 2 shows the summary of the monthly average results from the performance evaluation tests conducted during the period of study, while Figure 4, Figure 5, Figure 6 and Figure 7 depict the graphical behaviour of both the fixed solar collector and the one equipped with the tracking system, during the months of January through April of the test period.

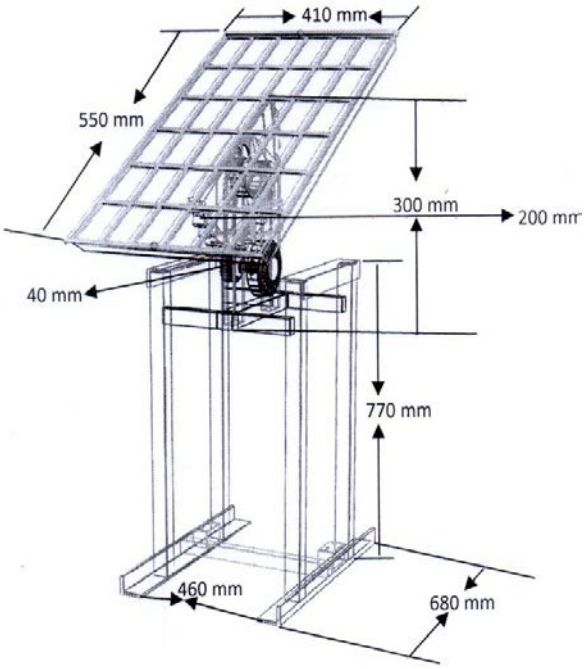
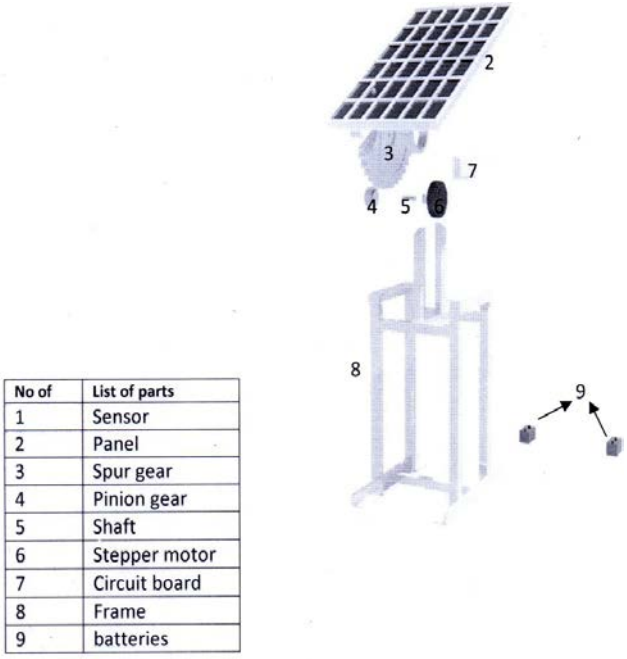


Figure 1. Isometric View of the Designed Solar Tracker



No of	List of parts
1	Sensor
2	Panel
3	Spur gear
4	Pinion gear
5	Shaft
6	Stepper motor
7	Circuit board
8	Frame
9	batteries

Figure 2. Exploded View of the Solar Tracker

Table 1. Summary of Calculated and Generated Characteristics of the Designed Solar Panels

Calculated & Test Parameters	Fixed Axis Type	Solar Tracker Equipped type
N (rpm)	Nil	9.693×10^{-4}
Revolution of electric motor per teeth (rev/teeth)	Nil	0.04012
Power (P) required to drive mechanism (Watts)	Nil	11.5
Efficiency of collection (%)	41.25	88.66

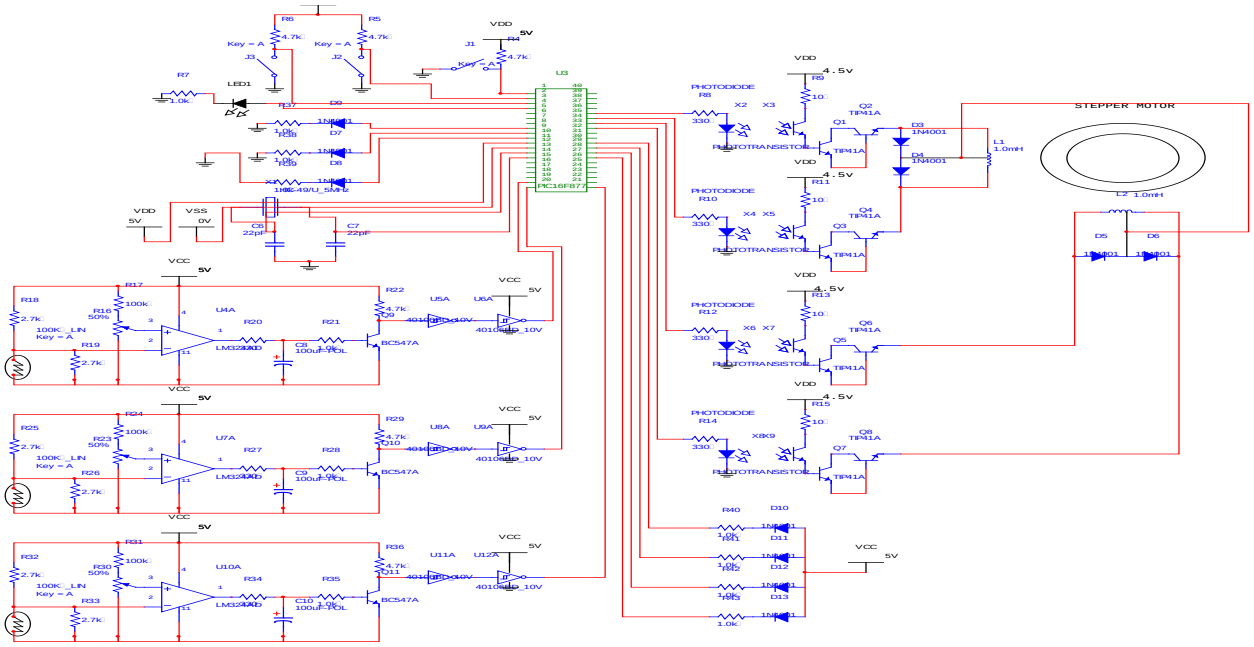


Figure 3. Solar Tracker Circuit Diagram

Table 2. Summary of the Monthly Averages of the Performance Evaluation Test Results

Time	Month One		Month Two		Month Three		Month Four		Month Five		Month Six	
	Tracker	Fixed	Tracker	Fixed	Tracker	Fixed	Tracker	Fixed	Tracker	Fixed	Tracker	Fixed
8 am	0.83	0.58	0.8	0.6	0.76	0.5	0.85	0.61	0.73	0.5	0.68	0.5
9am	0.88	0.61	0.87	0.71	0.8	0.63	0.88	0.66	0.87	0.64	0.82	0.6
10 am	0.93	0.76	0.88	0.74	0.83	0.65	0.98	0.72	0.9	0.72	0.85	0.62
11 am	0.96	0.75	0.96	0.77	0.98	0.82	1.16	0.9	0.92	0.73	0.92	0.74
12 am	1.15	0.88	0.98	0.79	1.2	0.8	1.28	1	0.94	0.74	0.96	0.76
1 pm	1.26	1.08	0.99	0.83	1.26	0.96	1.48	1	0.97	0.76	1.02	0.81
2 pm	1.26	0.96	0.85	0.74	1.57	1	1.66	1.28	1.02	0.78	1.26	0.94
3 pm	1.18	0.76	0.82	0.7	1.59	0.99	1.48	1.24	0.90	0.68	1.01	0.82
4 pm	0.91	0.69	0.8	0.69	1.36	0.96	1.29	0.92	0.83	0.61	0.95	0.70

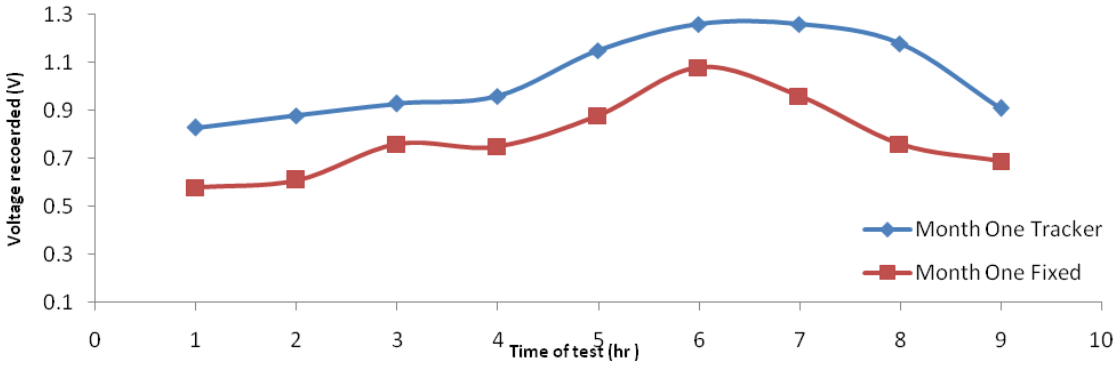


Figure 4. Average Voltage produced by the Solar collection systems in January/ February

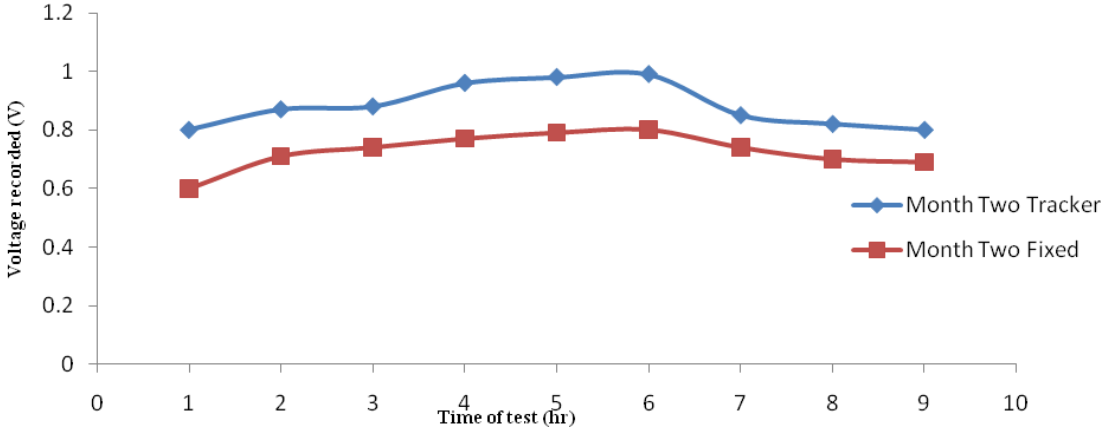


Figure 5. Average Voltage produced by the Solar collection systems in February / March

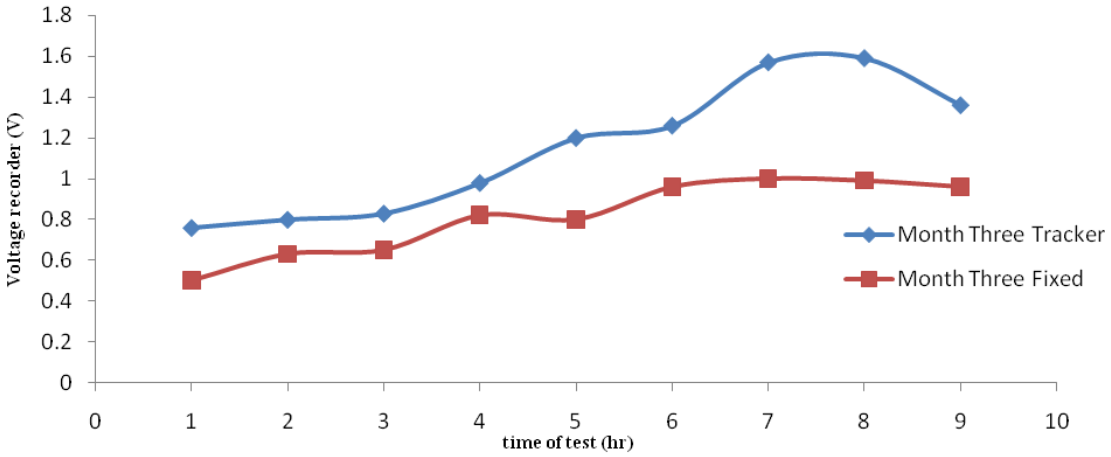


Figure 6. Average Voltage produced by the Solar collection systems in March/ April

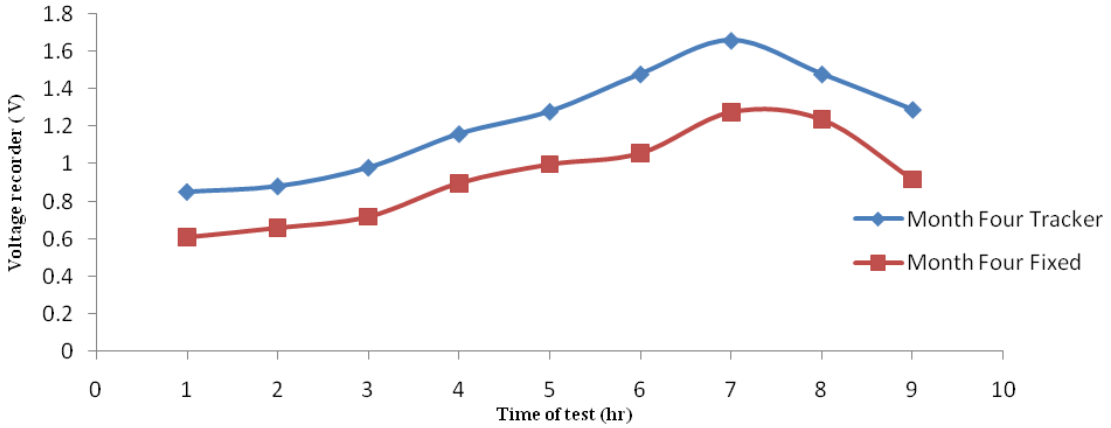


Figure 7. Average Voltage produced by the Solar collection systems in April/ May

The patterns of all graphs (i.e.: fixed axis solar collection system and solar tracker system) are closely similar, in Figure 4, Figure 5, Figure 6 and Figure 7, which shows the direct impact of the tracking system, bearing in mind the fact that the two solar collection systems share the same basic mechanical and physical characteristics. There is an average increase in voltage of 1.85 volts from the fixed solar panel to the tracked system during the period of testing as shown in Figure 4, Figure 5, Figure 6 and Figure 7. This difference in voltage is not inclusive of the battery being charged and powering of the tracking system. It is a direct comparison with the voltage being generated and produced by the fixed solar panel. Tests results (Table 2) favourably compare with those previously obtained [10], with some slight differences which are attributed to climatic conditions, experimental errors as well as other parameters, such as more sun and less clouds, moisture, haze, dust, and smog, with climate being the most important factor. This climate makes the soils dryer and the winds are lesser during that period. The period also constitutes a transitional period to the dry and hot seasons of the year in the study area. Overall, a 93% agreement was recorded between the two sets of records. However, noticeable drops in performance were mostly observed in the months of March and April (Table 2). These low performances recorded in the months of May, June and July are mainly due to the raining season which is accompanied with heavy and day long clouds as well as relatively low temperature when compared to the daily ambient temperature of 30 to 40^{o}. The results are also in good agreement with those of Small Power Systems [14] in California where annual gains between 30 percent and 40 percent are typical. They went further to ascertain that the gain on any given day may vary from almost zero to nearly 100 percent in a generally good area.

Cost had always been an important aspect of a project. It determines the affordability and sometimes the viability which is a quality dependent parameter. Since costs are subject to timely fluctuations, the analysis may only be useful for the present. In the future, increases in cost may occur.

Table 3. Bill of Engineering Measurement and Evaluation

S/No.	MATERIAL	Quantity	Cost per Unit(N)	Total Cost (N)
1	Solar panel	2	10,000	20,000
2	Material*		29,320	29,320
3	Direct labour cost			9,728
5	Total cost of production			59,048

The cost of this work (Table 3) depends on the prices of material with which the parts of the solar tracker were made of and the prevailing market price. As the main objective of this work is to design of a low cost device, the cost of the panels needs to be removed from the overall cost, to obtain the cost of the tracking system:

$$\begin{aligned} &Cost\ of\ tracking\ system \\ &= Overall\ cost - Cost\ of\ solar\ panels \\ &= 59,048 - 20,000 \\ &= N39,048 \end{aligned} \quad (6)$$

However, making use of the used electric glass window raising mechanism from the imported used cars; some developed countries of Africa (i.e.: Nigeria, Niger, Chad, Cameroon, Benin, Senegal, Mali, etc…) are being flooded with on weekly basis from Europe and America; the material cost (*) from Table (3) is reduced by =N=7,000.00. This used electric glass window raising mechanism replaces items 3, 4 and 5 of Figure (2). At the present Dollar ($) to Naira (=N=) exchange rate of 208.00 naira to a US dollar, the newly designed and improved constructed solar tracking system costs $ 154.00; $ 80 lower than the previous design proposed by Oumarou and Abdulrahim [10] even though the exchange rate of the local currency to the American dollar keeps fluctuating. This design would help in solid waste management by making use of some parts from the cars and other items brought from developing countries.

With the present situation of lack of electricity in some parts of Nigeria, it was found that 10 million naira ($48,076.00) is weekly required to provide electrical energy to the University of Maiduguri in Northern Nigeria, with over 3 million naira ($14,423.00) for lighting only. The proposed solar tracking system requires the same amount of money for the provision of nearly 100 units of the solar trackers lighting facilities. To this cost, there is need to include the influence of some implicit and explicit parameters (i.e.: transport,….) The proposed solar tracking system would, if adopted, assist in reducing solids wastes in terms of used filters, engines parts replaced, effluents as spent oil, air and noise pollution which would have been caused while using Diesel fuel power generators; bearing in mind that universities are institutions of learning where noise and other solid wastes having an immediate effect.

4. Conclusion

The present study has shown that the solar tracking system could both be optimized in terms of design, cost by making use of previously used mechanisms; recovered from cars and other similar systems. The power gained by the solar tracker system over the fixed horizontal solar collection system was 47.5%. The solar tracking system is affordable and found to cost $ 154.00. Favourable climatic conditions also play an important role in increasing the performance of solar trackers. The designed solar tracker would assist in reducing both solid and liquid wastes as well as noise and air pollution.

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