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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

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.[1] 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.[2]

On one hand, Asmarashid et al. designed a low power single axis solar tracking system regardless of motor speed while Okpeki and Otuagoma designed and constructed a bi-directional solar tracking system. Hemant et al. 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 [3-5].

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.

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.[6]

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.

1. Determination of the Speed of the Stepper Motor

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

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

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

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

3. Determination of the Thickness of the Teeth

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

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

4. Determination of the Power Required by the Stepper Motor to Drive the Mechanism

$$P = I \cdot U; \quad (3)$$

5. Efficiency of the Solar Tracker

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

Results and Discussion

Two solar collection systems were constructed and tested. The solar tracking system (Illustration 1) was powered by a motor and controlled by a microcontroller PIC. Tests were conducted with the solar tracker and results were compared to the fixed type from 19thJanuary 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.

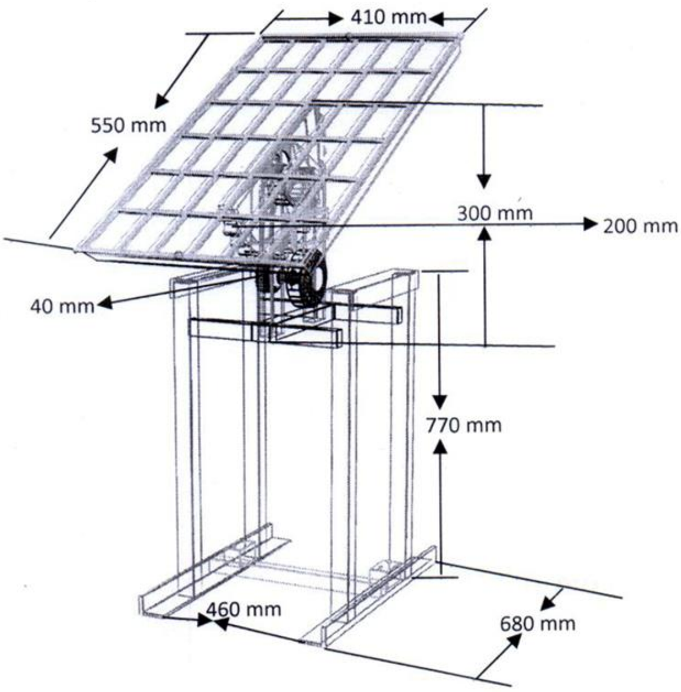

Illustration 1 – Isometric View of the Designed Solar Tracker

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

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

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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