Investigating the Potential of Solar Trackers in Renewable Energy Integration to Grid

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Abstract. Over the years, there has been a continued effort aimed at enhancing the energy output of PV panels. One of such innovations is in the use of solar trackers to improve the overall performance and efficiency of solar systems. This paper presents a critical review of various types of solar tracking systems, highlighting their key characteristics, merit, and demerits. In addition, a prototype double axis solar tracker was developed and tested. The results show the power output of the prototype double axis solar tracker to be 30.5% higher than that of a fixed PV system, also an increase in efficiency from 35.91% to 45.45% was observed. Finally, the research reveals that a double-axis solar tracked PV system in Nigeria will deliver an estimated 823,150,000Wh more energy than PV system without the use of solar tracker in the long term, which further justifies the importance of solar trackers in renewable energy integration to grid.

1. Introduction

The increasing obvious devastating effect of climate change around the world has led to a deliberate effort to reduce the use of fossil fuel fired generators, while encouraging the use of renewable energy sourced generators [1]–[6]. Thankfully, the world is blessed with a plethora of renewable energy sources suitable for power generation such as solar, wind and hydro resources. It is therefore important to harness this resources optimally in order to meet the increasing energy demand of the world’s populace.

On the other hand, solar energy remains the most abundant and widely used renewable energy source, thus technological advancement in solar energy system is focused on ways to enhance energy extraction from Photovoltaic (PV) systems. One of such innovations is in the design and development of solar trackers in order to increase the efficiency of PV system [7]. Furthermore, there have also been various innovations provided to solar tracking devices with different types having varying performance characteristics. This research is therefore aimed at reviewing the characteristics, merit and demerits of various types of solar tracking system, while also developing a prototype double axis solar tracker which helps to keep the PV panel continuously aligned in coordinates with the highest solar intensity.

Section 2 gives a brief introduction to photovoltaic (PV) system and discusses the various types of solar tracking systems with their characteristics, outlining its merit and demerit. Furthermore, design, development, and performance evaluation of a double axis solar tracking was discussed in section 3 and 4, while section 5 gives the conclusion of the research.
2. Introduction to Photovoltaic (PV) And Solar Tracking Systems

Photovoltaic cells basically convert solar energy into electrical energy. They are made from semiconductors mainly silicon and they exist in different types depending on their production material.

2.1 Solar tracking system

The conventional fixed PV panels are ineffective in harnessing the optimal energy from the sun because of the continuous rotation of the earth throughout the day. Therefore, in order to harness solar energy optimally, solar tracking systems (STSs) have been developed to align the PV panels perpendicular to the solar radiation, thus increasing the amount of solar irradiance incident on the solar panel. Solar tracker is an electromechanical system which tracks the direction of maximum solar irradiance and constantly aligns the solar panel module to this direction, thus ensuring maximum power delivery by the PV module at all times.

Solar trackers play an important role in various PV applications, such as in PV-pump storage systems, rooftop PV systems and large-scale PV plants. In general, solar trackers increase the overall efficiency of PV systems [8]- [9].

2.2 Classification of solar trackers

Solar tracking systems can be mainly classified into two types based on the number of rotational axis of the solar tracker [8].

2.2.1 Single Axis Solar Tracking System. This is a solar tracking system which has only one rotational axis. These trackers are generally cheaper and less complex than the double axis solar trackers, however they are less efficient in comparison with the double axis solar trackers.

The single axis solar trackers can be further divided into four types based on the direction of rotation of the solar trackers. (i) North-South (NS) Single axis tracking: These type of solar trackers rotates around the horizontal axis arranged in the north-south direction, (ii) East-West (EW) Single axis tracking: These type of solar trackers rotate around the horizontal axis arranged in the east-west direction, (iii) Vertical-axis Single axis tracking: These type of solar trackers rotate around the vertical axis with a PV panel tilted at an optimal tilt angle, and (iv) IEW- Single axis tracking: These type of solar trackers operates by tilting its rotation axis from the horizontal surface by an optimal angle in the east-west direction. Figure 1 shows the different types of single axis solar trackers based on its direction of rotation.

![Figure 1](image)

**Figure 1.** Schematic diagrams of different types of single−axis tracking systems. (a) NS-axis; (b) EW-axis; (c) V-axis; (d) IEW-axis [10].

2.2.2 Double−Axis Solar Trackers. These are solar trackers having two rotational axes which are perpendicular to each other, whilst ensuring that the solar panel receives maximum solar irradiiances at
all times [10]- [11]. These solar trackers track the sun’s movement on its vertical as well as horizontal axis. Double–axis Solar trackers have more output power and higher efficiency (15%–17%) compared to single axis trackers as seen in Table 1, because of the increased solar irradiance incident on the PV panel, however they are limited by its relative higher cost [8]- [12]. Figure 2 shows the schematic diagram of the double axis solar tracking system, showing its two rotational axis (vertical and horizontal), while Table 2 compares the characteristics of fixed, single and double axis solar tracked PV systems.

![Figure 2. Schematic diagram of the double–axis tracked PV system [7].](image)

| Types of Solar Tracker | Merits                                                                 | Demerits                                                                 | Refs. |
|------------------------|------------------------------------------------------------------------|--------------------------------------------------------------------------|-------|
| Single-axis Solar Tracker | Lower cost, lower energy consumption, 23% improvement on the output power, percentage of solar irradiance capture is between 78.56% and 95.79%. | Lower energy yield compared to double axis trackers | [10]  |
| Dual-axis Solar tracker | Improved power production by between 32 to 45%. Higher energy yields (91–94%). Higher percentage of solar irradiance capture (96.40%). | Higher cost                                                               | [13]  |

| Comparative metrics | Fixed Panel | Single axis | Double axis |
|---------------------|-------------|-------------|-------------|
| Energy loss(%)      | 50          | 5-10        | 0-1         |
| Efficiency (%)      | 25-35       | 35-42       | 42-55       |

3. Methodology
This section explains the principle of operation of solar trackers and further discusses the design and development of a prototype double axis solar tracker.

3.1 Basic principle of operation of Solar trackers
Solar trackers operate by consistently tilting the solar panel to be perpendicular to the Sun with the aid of a motor which controls the angle of inclination of the solar panel. Solar tracking system basically consists of the sensory unit, the control unit (Microcontroller), and the driver Unit which comprises of the motors and actuators.

The sensory unit comprises of photo resistors or light dependent resistors(LDR), which basically measures the intensity of solar irradiance and thus detects the coordinates with the highest solar irradiances. The resistance of LDR decreases with increase in solar intensity so using this property, it is able to detect areas with high solar intensity [9]- [14]. The output of the sensory unit is sent to the microcontroller unit which acts as an analog to digital converter (ADC). The microcontroller processes the analog signal and converts it to digital signal, which is then sent to actuate the motor through its output terminals. The digital output signal from the microcontroller determines the movement of the
motors via its in-built driver. Finally, the movement of the motors determine the rotation of the solar panel. Servo motors are often used for PV panel rotation because of its low cost and light weight [15]. Figure 3 shows the diagram of a light dependent resistor (LDR), while figure 4 shows the diagram of the microcontroller, motor driver and linear actuator.

![Figure 3. Showing the diagram of a typical light dependent resistor (LDR) [14],[12],[16].](image)

![Figure 4. Diagram of Solar tracking components (a) linear actuator; (b) motor driver ; (c) microcontroller [14].](image)

3.2 Design Components of a Typical Double -Axis Solar Tracker

In this sub-section, the method used in designing and developing a simple prototype double-axis solar tracker using basic electronic components is highlighted. The driver unit consists of two servo motors, while Adruino NANO was used as the controller. The sensory unit also consists of four light dependent resistor (LDR). Table 3 gives the specification of the PV used while, Table 4 shows the bill of materials used for the design of the double axis solar tracker with an estimated cost of sixty (60) USD.

| Parameters       | Specifications  |
|------------------|-----------------|
| Type             | Monocrystalline|
| Weight (grams)   | 99              |
| Size (cm)        | 13.6 x 11.2 x 0.5|
| Efficiency       | 19%             |
| Open circuit Voltage | 7.7V         |
| Peak Voltage     | 6.5V            |
| Peak Current     | 340mA           |
| Peak Power       | 2.2W            |
| Power Tolerance  | +/-10%          |

**Table 3. Specification of PV Panel.**

| Components/items | Quantity | Cost(USD) |
|------------------|----------|-----------|
| 1k resistors     | 4        | 1         |
| light dependent resistor(LDR) | 4 | 2 |
| Adruino NANO microcontroller | 1 | 18 |
| Servo motor      | 2        | 10        |
| DC power Source  | 2        | 4         |
| 3-D printing of Solar tracker housing | 1 | 20 |
| 2W, PV panel     | 2        | 5         |
| Total cost       |          | 60        |

**Table 4. Bill of Materials for the Designed Double Axis Solar Tracker.**
3.3 Design and Operation of the Double-Axis Solar Panel

The Solar panel is attached to the servo motors which receives digital control signal from the Arduino Nano microcontroller. The digital output signal from the microcontroller depends on the output of the four LDR which are strategically located on top of the solar panel to indicate four key directions (East, West, North, South). The four strategically placed light dependent resistors (LDR) and 1kΩ resistors are used in the sensory unit, with each of the LDR and 1kΩ resistor connected in parallel, thus forming four voltage divider network which is supplied from a 5V DC source. The output from the voltage divider network varies because the resistance of the LDR changes with light intensity. The output from the four voltage divider network is then fed to the analog pins of the Arduino Nano, which then processes it. The output from the controller can be read using the “analogRead()” function of the Arduino. The Arduino then compares the output voltages received from the four voltage divider network and determines the direction with highest light intensity. Furthermore, the Arduino then sends digital control signals to the servo motors connected to its digital pins, which then controls the movement of the servo motors via its in-built driver. The motors are powered by a 24V power source, while the microcontroller was supplied by a 5V power source. This process repeats after an interval of 60 minutes to observe changes in the direction of solar intensity as the servo motors continually aligns the solar panel in the direction with the highest light intensity. Figure 5 gives the 3-dimensional (3-D) printed design of the double-axis solar tracker casing using AUTOCAD, while figure 6 gives the complete experimental setup of the prototype double-axis solar tracking system.

![Figure 5](image)

**Figure 5.** (a)-(b) 3-dimensional (3-D) printed housing design for Servo motors; (c)-(d) 3-D printed design for Solar tracker base.

![Figure 6](image)

**Figure 6.** Practical experimental setup of the prototype double axis solar tracker.

Furthermore, figure 7 gives the flowchart for the operation of the double axis solar tracker.
4. Results and Discussion
This section gives the results of the performance evaluation of the prototype double axis solar tracker. Figure 8, shows the performance of the double axis solar tracker on an hourly basis from 8 am to 6 pm. Also, Table 5 and figure 8 further shows that the double-axis solar tracker performs better than the fixed solar panel at all times during the day (8 am to 6pm) with an average efficiency of 45.45% compared with the fixed PV with an average efficiency of 35.91%. Furthermore, it was observed that the double axis tracking system can harness about 30.5% more energy than the fixed PV system, with an increased power of 3.26W between 8am and 6pm.

Figure 7. Flow chart for the double axis Solar Tracker.
Figure 8. Power Output from Double-axis solar tracker and fixed solar panel.

Table 5. Showing the Performance of the Prototype Double-Axis Solar Tracker in relation to a Fixed PV Panel.

| Time  | Gross Power Output Watt(W) from Double-Axis Solar Tracking | Power consumed by Solar tracker | Net Power Output | Power Output Watt(W) from Fixed PV Panel | Difference In Output Power(W) | Average Efficiency of Double Axis Solar Tracker Per Time(%) | Average efficiency of Fixed PV Panel Per Time(%) |
|-------|-------------------------------------------------------------|---------------------------------|------------------|------------------------------------------|-------------------------------|----------------------------------------------------------|-----------------------------------------------|
| 8:00  | 0.602                                                      | 0.002                           | 0.6              | 0.5                                      | 0.1                           | 27.27273                                                 | 22.72727                                     |
| 9:00  | 0.8526                                                    | 0.0026                          | 0.85             | 0.72                                     | 0.13                          | 38.63636                                                 | 32.72727                                     |
| 10:00 | 0.9222                                                    | 0.0022                          | 0.92             | 0.81                                     | 0.11                          | 41.81818                                                 | 36.81818                                     |
| 11:00 | 1.426                                                     | 0.006                           | 1.42             | 1.12                                     | 0.3                           | 64.54545                                                 | 50.90909                                     |
| 12:00 | 1.5376                                                    | 0.0076                          | 1.53             | 1.15                                     | 0.38                          | 69.54545                                                 | 52.27273                                     |
| 13:00 | 1.6486                                                    | 0.0086                          | 1.64             | 1.21                                     | 0.43                          | 74.54545                                                 | 55                                           |
| 14:00 | 1.6784                                                    | 0.0084                          | 1.67             | 1.25                                     | 0.42                          | 75.90909                                                 | 56.81818                                     |
| 15:00 | 1.6082                                                    | 0.0082                          | 1.6              | 1.19                                     | 0.41                          | 72.72727                                                 | 54.09909                                     |
| 16:00 | 1.5276                                                    | 0.0076                          | 1.52             | 1.14                                     | 0.38                          | 69.09091                                                 | 51.81818                                     |
| 17:00 | 1.2078                                                    | 0.0078                          | 1.2              | 0.81                                     | 0.39                          | 54.54545                                                 | 36.81818                                     |
| 18:00 | 1.0042                                                    | 0.0042                          | 1                | 0.79                                     | 0.21                          | 45.45455                                                 | 35.90909                                     |

4.1 Feasibility Analysis of Solar Tracker in Nigeria

Nigeria is a west Africa country with enormous solar energy potential, having a mean solar radiation of about 4.2 kWh/m2/day with an average solar hours of six (hours). The country also has an estimated population of 200 million people, with an average power generation of 5000MW. In order to improve the per capita power capacity in Nigeria, more renewable energy generators must be integrated to the grid.

Furthermore, the capacity of Solar energy in Nigeria is expected to increase from 5MW to about 505MW in the long term, such that from this research, double-axis solar tracked PV system in Nigeria will deliver \( \frac{3.26 \times 505,000,000}{2} = 823,150,000 \text{Wh} \)

more energy than PV system without the use of solar tracker. Therefore, Solar trackers is highly recommended in Nigeria, in the bid to increase its power capacity using renewable energy sourced generators.
5. Conclusion
This paper presents a critical review of various solar tracking systems highlighting their key characteristics, merit, and demerits. The review further revealed that solar tracking systems increases power production of PV systems by an average of 23% to 45% with a minimal increase in the cost of energy (COE). Furthermore, in this research a prototype double axis solar tracking device was designed, developed and tested. The solar tracker tracks the coordinates with the highest solar intensity on an hourly basis, thus ensuring the solar panel constantly receives maximum solar irradiance and subsequently maximum solar energy extraction. The results of the prototype double axis solar tracker design showed a 30.5% increase in power output compared to that of a fixed PV system within a cost range of sixty (60) USD, also an increase in average efficiency from 35.91% to 45.45% was observed. Finally, this research revealed that a double-axis solar tracked PV system if used in Nigeria will deliver an estimated 823,150,000Wh more energy than PV system without the use of solar tracker in the long term, which further justifies the importance of solar trackers in renewable energy integration to grid.

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