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Design and Development of Tilted Single Axis and Azimuth-Altitude Dual Axis Solar Tracking Systems

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***Abstract*—The green energy also called the renewable energy, has gained much attention nowadays. Among the renewable energy solutions, solar energy is the very vital source that can be used to generate power. Electricity from the sun can be converted through photovoltaic (PV) module. The efficiency of solar module depends on sun intensity, if the intensity is more then efficiency is more. Since the position of sun continuously changes throughout the day, the intensity of sun rays is not uniform on PV module. So, for getting more sun rays on PV module solar tracker plays a much vital role. A solar tracker is a device for operating a solar photovoltaic panel, especially in solar cell applications and requires high degree of accuracy to ensure that the concentrated sunlight is dedicated precisely on to the power device.**

This paper describes in detail about the design, development and fabrication of two Prototype Solar Tracking Systems mounted with a single-axis and dual-axis solar tracking controllers to generate 10.3 volts, 1.5 watts capable of charging mobile batteries. The rays from the sun should fall perpendicularly onto the solar panels to maximize the capture of the rays and this is done by pointing the solar panels towards the sun and following its path across the sky. The solar tracking systems -Tilted Single Axis Tracker (TSAT) and Azimuth-Altitude Dual Axis Tracker (AADAT) are designed, implemented and experimentally tested. The design details of TSAT and AADAT are described which detect the sunlight using Light Dependent Resistor (LDR) sensors. The control circuit for the systems is based on Atmega8 Microcontroller which is programmed to detect the sunlight through the LDR sensors and then actuate the DC geared motor using L293D motor driver to position the solar panel where it can receive the maximum sunlight.

Keywords—Solar Energy; Solar Tracker; Photovoltaic Module; AADAT; TSAT

I. INTRODUCTION

Solar energy is the best alternative of electric power generation among all renewable energy. In solar energy solar power can be converted in to electric power by the use of solar photovoltaic panel which are usually made from silicon [1]. Photovoltaic (PV), is a technology in which light is converted into electrical power. One of the applications of PV is in the solar tracker system.

Sunlight has two components, the direct beam that carries about 90% of the solar energy, and the diffuse sunlight that carries the remainder. As the majority of the energy is in the direct beam, maximizing collection requires the sun to be visible to the panels as long as possible. The energy contributed by the direct beam drops off with the cosine of the angle between the incoming light and the misalignment of the panel also known as angle of incidence.

The sun travels through 360 east to west a day, but from the perspective of any fixed location the visible portion is 180 during a half day period. Local horizon effects reduce this somewhat, making the effective motion about 150 . A solar panel in a fixed orientation between the dawn and sunset extremes will see a motion of 75 on either side, and will lose 75% of the energy in the morning and evening. Rotating the panels to the east and west can help recapture these losses. A tracker rotating in the east-west direction is known as a single-axis tracker. The sun also moves through 56 degrees north to south over the period of a year. The same set of panels set at the midpoint between the two local extremes will thus see the sun move 23 on either side, causing losses of 8.3%. A tracker that accounts for both the daily and seasonal motions is known as a dual-axis tracker.

The main challenge is to maximize the capture of the rays of the sun upon the solar panels, which in turn maximizes the output of electricity. A practical way of achieving this is by positioning the panels such that the rays of the sun fall perpendicularly on the solar panels by tracking the movement of the sun [2]. This can be achieved by means of using a solar panel mount which tracks the movement of the sun throughout the day. A Solar Tracker is a device in which solar panels are fitted which track the motion of the sun across the sky ensuring that the maximum amount of sunlight strikes the panels throughout the day. It will attempt to navigate to the best angle of exposure of light from the sun. In order to produce maximum power output, the solar tracker is designed with a motor so that the solar panel will move towards the position of the sun. It moves according to the sun's movement and is controlled by the continuous rotation of the motor or actuator which is programmmed to control the tracking system. Hence, it is able to extract useable electricity from the sun at maximum power output by maintaining the angle of incidence. Since the solar panels are very expensive, the solar tracker should be designed at low cost and to be used comfortably.

Photovoltaic trackers can be classified into two types: Non Concentrating or Standard Photovoltaic (PV) Trackers and Concentrated Photovoltaic (CPV) Trackers [3]. Each of these tracker types can be further categorized by the number and orientation of their axes, their actuation architecture and drive type, their intended applications, their vertical supports and foundation type. Considering the number and orientation of the tracker's axes, the trackers are grouped as single axis and dual axis trackers.

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Single axis trackers have one degree of freedom that acts as an axis of rotation. The axis of rotation of single axis trackers is typically aligned along a true North meridian. It is possible to align them in any cardinal direction with advanced tracking algorithms. There are several common implementations of single axis trackers and one of them is tilted single axis tracker (TSAT). All trackers with axes of rotation between horizontal and vertical are considered tilted single axis trackers. Typically they have the face of the module oriented parallel to the axis of rotation. As a module tracks, it sweeps a cylinder that is rotationally symmetric around the axis of rotation.

Dual axis trackers have two degrees of freedom that act as axes of rotation. These axes are typically normal to one another. The axis that is fixed with respect to the ground can be considered a primary axis. The axis that is referenced to the primary axis can be considered a secondary axis. Dual axis trackers allow for optimum solar energy levels due to their ability to follow the sun vertically and horizontally. No matter where the sun is in the sky, dual axis trackers are able to angle themselves to be in direct contact with the sun. One of the common implementations of the dual axis tracker is azimuth altitude dual axis tracker (AADAT).

An azimuth altitude dual axis tracker has its primary axis vertical to the ground. The secondary axis is then typically normal to the primary axis. One axis is a vertical pivot shaft or horizontal ring mount that allows the device to be swung to a compass point. The second axis is a horizontal elevation pivot mounted upon the azimuth platform. By using combinations of the two axis, any location in the upward hemisphere may be pointed. Such systems may be operated under computer control according to the expected solar orientation, or may use a tracking sensor to control motor drives that orient the panels toward the sun.

According to [4], the use of single-axis tracking can increase the electricity yield by as much as 27 to 32 percent. On the other hand, a dual-axis solar tracker follows the angular height position of the sun in the sky in addition to following the suns east-west movement reports that dual-axis tracking increases the electricity output as much as 35 to 40 percent [5].

II. Design and Working of TSAT

A. Mechanical Design

The complete mechanical design of TSAT having one solar panel is shown in Fig. 1. The base of TSAT has the dimension 20in 15in on which a tilted upper base is mounted and the tilt angle of the upper base is 21. On the upper base the two columns are made to support the upper most rotating base on which the sensor and solar panel are mounted. The sensor senses the sun rays and sends the analog signal to the microcontroller which in turn controls a DC motor through the motor driver.

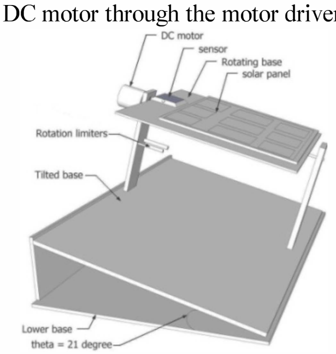

Fig. 1: Mechanical Design of Tilted Single Axis Tracker

The movement of rotating base is controlled by the DC motor, which is mounted on one of the columns to align the solar panel perpendicular to the sun. The rotation limiters are provided to limit the rotation of upper base, the function of the limiters or stoppers is to stop the rotation of the rotating base at final position at the evening and reset at its initial position, when the lightening condition falls below certain threshold value.

Figure 2 shows the position of stoppers or rotation limiters. In TSAT two stoppers marked as Stopper1 and Stopper2 are used which are connected to microcontroller pins, one for the initial position and the other for final position. Two metal contacts are attached in rotating base, these contacts are connected to 5 volts supply. When either of the metal contacts touch the nearest stopper, then the respective pin of microcontroller goes high and following the programmed algorithm the motor stops rotating.

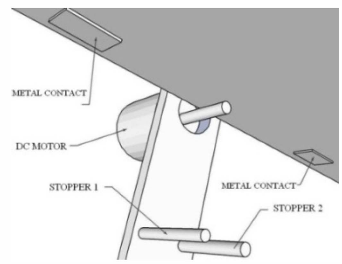

Fig. 2: Position of Stopper

The solar power incident on earth surface varies throughout the year and depends on the angle of axis of rotation of the solar panel from vertical, i.e., the tilt angle, and the geographical location of the place. The geographical location of Bhilai is 21 N 81 E. Therefore the average solar power incident through out the year on the solar panel will be maximum if we fix the axis of rotation of solar tracker at an angle 69 from vertical or 21 from horizontal facing the north.

B. Working

Initially facing the east, the tracker tracks the sun and aligns the solar panel perpendicular to the incident light. It turns the panel along the sun path in every 10 minutes. Since the sun moves with 15 per hour, i.e, in every 10 minutes it rotates 2.5, so the tracker tracks the sun with a precession of 2.5 [6]. At evening the tracker stops tracking and when light falls below the threshold value then the tracker turns the solar panel in east position. Next day it starts tracking from east and the cycle repeats.

C. Tracking Controller Circuit Design

The sensor senses the sun rays and sends signal to the microcontroller to control the solar panel's position. Each sensor consists of two Cadmium Sulphate (CdS) light dependant resistors (LDRs). The complete schematic diagram of control circuit of TSAT is shown in Fig. 3. In the control circuit two LDRs connected in series with two potentiometers form a LDR sensor. The 12 volts, 3.5 rpm DC motor positions the solar panel. Microcontroller Atmega8 is used here for storing program, receiving input from LDR sensor, converting it to digital value and giving appropriate command to the motor driver for controlling a DC motor. Motor driver IC L293D drives the DC motor forward and backward according to the input signal coming from the micocontroller. S0 is a reset switch used to reset the microcontroller and run the program from starting. S1 and S2 represent the contacts for the stoppers. Voltage Regulator IC 7805 is used to provide 5 volt supply to all the circuit components. Crystal Oscillator of 8 Mhz (shown in Fig. 3 as 'X') is used to provide a stable clock signal for the digital integrated circuits. The capacitors C1, C2, C3 are used as filters and C4 is used for decoupling the microcontroller from supply.

The block diagram of complete system is shown in Fig. 4 showing the supply distribution to the elements of the control circuit and the flow of control signal from sensor to microcontroller and from microcontroller to motor driver.

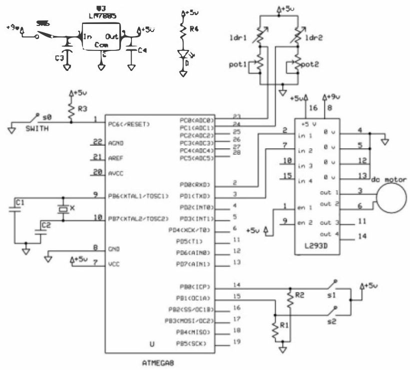

Fig. 3: Schematic Diagram of Complete System

LDR is connected in series with the potentiometer (refer Fig. 3). Output voltage taken from the junction of LDR and potentiometer changes with the change in resistance of LDR. The solar tracker panel is installed with the two LDR sensors. Assuming both the sensors are placed in parallel with the PV panel, the effective irradiance is similar. As a result, the tracker is unable to perform the tracking of the sun. To circumvent this, the two sensors are positioned at and 180 { respectively as seen in Fig. 5. When the sun rays are incident on the solar panel, the LDR sensors generate different voltages according to the changes in the sun rays incidence angle [7].

To calculate the best angle position for the LDR sensors to be placed, first a graph is plotted between the voltage difference of the two LDR sensor outputs and variation of angle for different values of, viz., 25, 35, 45, 55 and 65 . The other details of the calculation of angle can be found in [8]. The plot is approximately linear, i.e., voltage difference is directly proportional to when is chosen as 25.

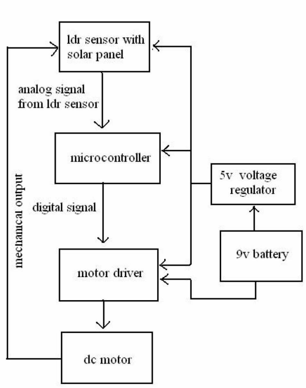

Fig. 4: Block Diagram of Complete System

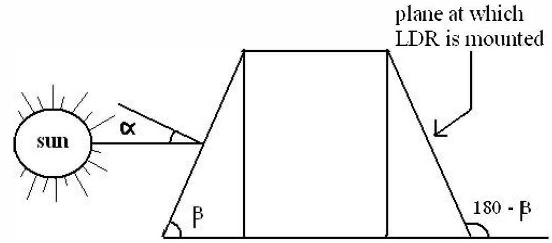

Fig. 5: Calculation of Tilt Angle of LDR

Figure 6 shows the complete design of LDR sensor, which shows the position of LDR on the surface of LDR sensor panel which is tilted at an angle 25 with respect to the horizontal plane. This sensor is mounted on the rotating surface on which the solar panel is mounted.

Fig. 6: LDR Sensor Tilted at an Angle= 25

D. *Working of Control Circuit*

1. The sensor consist of two LDRs positioned at = 25 and connected across a 5 volt supply with a potentiometer connected in series.
2. The LDR have the characteristic that the resistance of LDR decreases as the light intensity falling on it increases.
3. We measure the output voltage across the potentiome-ter, which varies according to the resistance of LDR.
4. As the light intensity on LDR increases, resistance of LDR decreases, hence the output voltage measured across the potentiometer increases. Similarly, when light intensity decreases the output voltage also de-creases.
5. When the sun is at middle of the sensor panel, the light falling on both sensors are same, hence the output voltage from both sensor will be same.
6. When the sun moves towards any side of a sensor (when the sun rotates from east to west), the angle of incidence of light changes for both sensors, hence light intensities on both sensors differ and there is a continuous voltage difference between the sensor output voltages
7. The output voltages across the LDRs are converted into digital value in the microcontroller with the help of inbuilt analog to digital converter.
8. The microcontroller compares the two digital values of LDR sensors. When the difference become more then 20 (equivalent to 0.0977volts), the microcon-troller sends the digital signal to the motor driver to rotate the motor fixed to the solar panel, such that the difference between two values of LDR sensors become less than 20. After the panel takes its new position the difference between the two digital values become less than 20, hence the motor stops rotating.
9. The process continues and in this way this solar tracker tracks the movement of sun from east to west.

III. Design and Working of Azimuth-Altitude Dual Axis Tracker

The sun's position in the sky not only changes from east to west, but the latitude of the sun's path also varies throughout the year. The AADAT starts tracking the sun at morning and ends tracking at evening and automatically comes to its initial position for tracking the sun next day. The whole movement of the system is driven by two DC geared motors controlled by the control circuit and LDR sensors. The whole system is powered by the 9 volts rechargeable batteries which can be charged by the solar panel itself that makes the whole system independent of any external power supply.

A. *Mechanical Design*

The complete Mechanical Design of Azimuth Altitude Dual Axis Tracker is shown in Fig. 7 and Fig. 8 below,

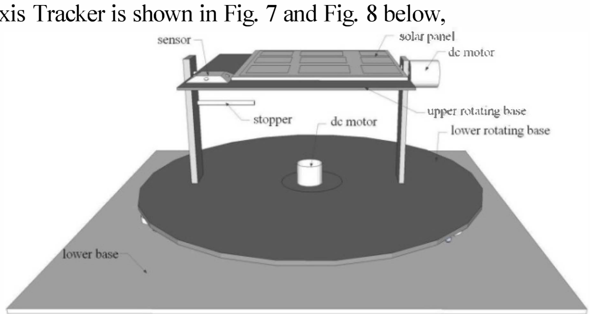

Fig. 7: Mechanical Design of Azimuth Altitude Dual Axis Solar Tracker

The dimension of the lower base is about 15in 15in. The circular rotating base is of 12 inches diameter supported by three caster wheels and a DC motor is mounted with the upper rotating base and shaft of this motor is rigidly coupled with the lower base so when the motor shaft rotates, the whole upper base rotates with the motor because the shaft of the motor is coupled with the fixed lower base.

On the circular rotating base, two columns are made to support the upper rotating base on which solar panel and sensors are mounted. The axis of rotation of upper rotating base is perpendicular to the axis of rotation of lower rotating base.

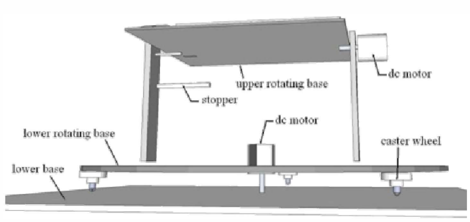

Fig. 8: Complete Angular view of Azimuth Altitude Dual Axis Solar Tracker

In this design of AADAT we have three stoppers stopper1, stopper2 and stopper3, one for the upper rotating base and other two for the lower rotating base respectively. Stopper1 shown in Fig. 9 stops the rotation of motor when the metal contact touches stopper by sending the signal to the control circuit. Hence, it stops the rotation of upper base and it comes to its initial tracking position at evening to start tracking on next morning. Stopper2 and Stopper3 shown in Fig. 10 and Fig. 11 respectively are used to stop the rotation of lower base at final position at evening and at the time of resetting the position for tracking at next day.

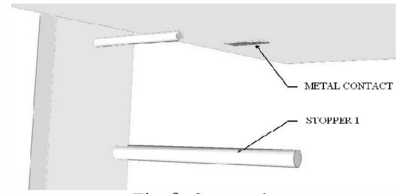

Fig. 9: Stopper1

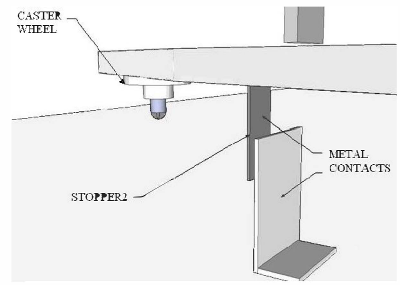

Fig. 10: Stopper 2

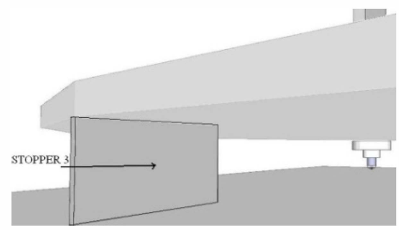

Fig. 11: Stopper 3

The same mechanism is used for Stopper1, three metallic contacts are used, one is fixed on one column and other two are on the lower rotating base.

B. *Tracking Controller Circuit*

The Fig. 12 shows the complete circuit diagram of control circuit and the sensor. The components used in control circuit are same as those used in TSAT. The changes only are enlisted below:

1. Four LDR sensors are connected in series with the four potentiometers of resistance 10 Kohm each to form four potential divider circuits.
2. R1 to R4 are pull down resistors and R6 is pull up resistor. R5 is used for current limiting for LED.
3. Four tact switches SW 1 to SW 4 are used for the stoppers.
4. Two DC motors are used, Motor1 for moving the lower rotating base and Motor2 for the upper rotating base.

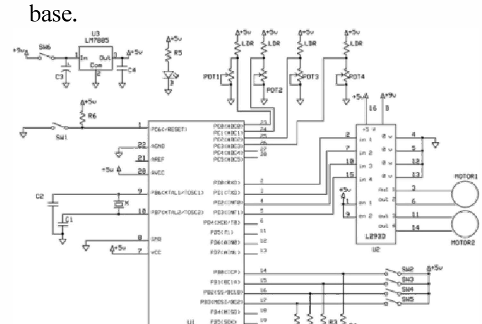

Fig. 12: Schematic Diagram of Azimuth-Altitude Dual Axis Solar Tracker

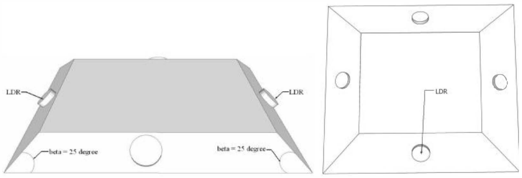

Fig. 13: Sensor Design

The geometrical construction of the LDR sensors for AADAT shown in Fig. 13 is same as the LDR sensor of TSAT. At first, the four analog voltage coming from four LDR sensor's are applied to the microcontroller. The inbuilt ADC of microcontroller converts these analog voltages to four 10 bit digital value. These digital values are then analyzed and compared and an appropriate command is given to the motor driver to drive the two DC motors in such a manner that the solar panel remain perpendicular to the sun rays. The value of output voltage can be adjusted by the potentiometer by rotating its trimer by screw driver.

IV. Programming and Fabrication

The programming codes of the microcontroller for TSAT and AADAT are written in C language. AVR Studio 4:0 is the editor and compiler which is used to write C code and then compile the C code to generate hex file for the microcontroller. Robokits Avr USB Programmer is the software which is used for burning the hex file generated by the AVR Studio 4.0 into microcontroller using usb programmer.

The frame consisting of the bases and the columns are made of plywood. After fitting all the mechanical parts, the control circuit is designed on the PCB. The design of PCBs depends on circuit requirements like noise immunity, working frequency and voltage levels etc. The fabrication process of the printed circuit board determines to a large extent the price and reliability of the equipment. The layout of the PCB incorporates all the information of the board.

The following steps were taken while preparing the circuit:

1. PCB Designing:
2. Layout Design:
3. Etching Process:
4. Component Assembly:
5. Soldering:

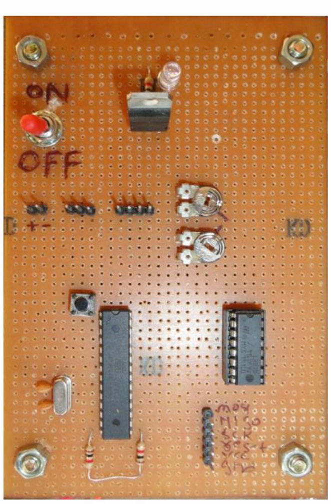

Fig. 14: Complete Control Circuit of the TSAT

After following the above described process, firstly the PCBs for TSAT and AADAT were designed on the basis of Fig. 3 and Fig. 12. Lastly all the required components were mounted on the PCBs. The final PCBs of the control circuits of TSAT and AADAT are shown in Fig. 14 and Fig. 15 respectively. These PCBs are fixed at the base of both the tracking systems. The complete assembled views of TSAT and AADAT are shown in Fig. 16 and Fig. 17.

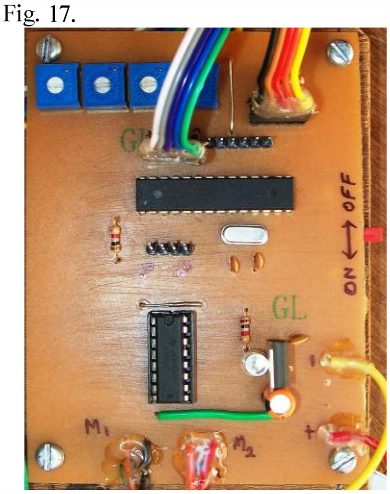

Fig. 15: Complete Control Circuit of the AADAT

V. Discussion

Generally two types of solar tracker systems are available in the market {single axis and dual axis trackers. Single axis trackers will track the sun from east to west on a single pivot point whereas dual axis trackers track east to west and tilt for north to south tracking using two pivot points. Dual axis trackers are more complex in design, as it uses additional motors and sensors to track the sun whereas single axis tracker are simple and effective in design. Dual axis trackers also use an eye sensor which visually follows the sun, while the single axis tracker tracks the sun using a predictable pattern based on the time of year. Less maintenance are required in single axis as compared to dual axis tracker. Single axis tracker have minimal points of failure as compared to dual axis trackers which requires additional point of failure. Cost is lower in single axis tracker as compared to dual axis tracker. On a cloudy day dual axis trackers are pointing all over the sky, while the single access tracker points directly only at the sun. This eliminates any unnecessary tracking movements which only result in additional wear and tear, and loss of power. Single axis tracker increase solar yields upto 34% whereas dual axis tracker increase solar yields upto 37%. With the added cost of equipment, higher maintenance costs, and high potential downtime, dual axis trackers may actually be less productive in the long run. In order to study the effects of the single axis and double axis trackers, in [9] the relations between the solar components are extracted according to its position in the sky. The results of the analysis show that the average value of the energy received by the panel with single axis tracker was 1.35 times greater than that of a fixed panel system, while the double axis tracker system receives only 1.04 times the received energy of a single axis one. Hence, low maintenance solar tracker, single axis trackers are the best way to go. However, [10] state that both single-axis and dual-axis are highly efficient in terms of the electrical energy output when compared to the fixed mount system an the efficiency of dual-axis tracker system is higher when compared with single-axis tracker system.

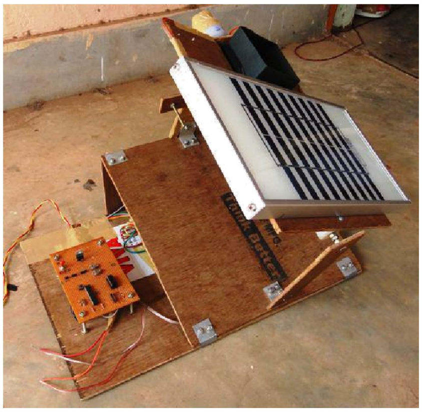

Fig. 16: Complete Side View of Tilted Single Axis Tracker

Fig. 17: Complete Side View of Azimuth-Altitude Dual Axis Tracker

VI. CONCLUSION

The completion of this work has led to several conclusions that can be made about this solar tracking system as well as solar tracking systems in general. The Tilted Single Axis tracking system designed and built in this project show a tracking efficiency of 2.5 degree and it increases the efficiency of solar panel upto 30%, whereas, the Azimuth Altitude Dual Axis Solar Tracking system also show a tracking efficiency of 2.5 degree but increases the efficiency of solar panel upto 40%. Furthermore, testing showed that the power used by the tracking system built was much less than the power gained by tracking the sun accurately. This means that if the tracking system were to charge its own batteries, it would be entirely self-sufficient except for the maintenance.

Perhaps the most important conclusion to be made from this project is that:

1. The cost for TSAT is Rs 1500 (approx), whereas, the cost for AADAT is Rs 2500 (approx).
2. The total cost for the both tracking systems is very low, that is, Rs 4000 (approx), this means that the system can be built for a very low cost and most importantly; this system would be within the financial reach of many communities if built in large size.
3. No running cost is required, however, replacements of components may be essential.
4. Since natural source is involved, it is perpetual.
5. No pollution of environment.

However, the control system has not been discussed that could aim to maximize the output power while minimizing the power consumption of the tracking system. This would be taken up as our future work, where the optimum sensitivity range of the controlling system would be evaluated to deter-mine when the solar tracker should operate to generate more power or stay stand-still to save energy.

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