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Design and Development of Self-Sustainable Solar Energy Operated PV Assisted Sun Tracking Mechanism for Parabolic Trough Collector

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Abstract

Solar energy is available throughout the day which in scatter in nature, the concentrator is required to magnify this energy so we can used this for industrial process or power production. But in case of concentrator we required to track sun during whole day in such way that solar ray are always normal to aperture area of concentrator, this is made possible with help of sun tracking system. This solar tracing system consumed some amount of power so gross energy gained is somehow reduced. In our experimental setup we had prepared PV assisted Automatic Sun Tracking System mounted with parabolic trough collector to track sun from E to W during sunshine hours for increasing energy collection by PTC which leads to increasing energy efficiency of collector. The design mechanism holds the solar concentrator and allows the concentrator to perform an approximate hemispherical rotation to track the sun's movement during the day.

Keywords: Solar Energy, Parabolic Trough Collector, Automatic tracking mechanism, Sun tracking

INTRODUCTION

In today's climate of growing energy needs and increasing environmental concerns, alternative of non-renewable and fossil fuels have to be investigated. One such type of alternative is solar energy. Parabolic trough solar water heating is one of several well proven solar energy technologies. Despite the unlimited solar energy, harvesting of it is mainly challenged because of the inefficiency of the troughs/panels. Recent works shows that different types of methodology have been proposed to improve the efficiency of solar parabolic trough by sun tracking system. We had adopted our system to improve the efficiency for PTSC applications.

What is Solar Tracker**:** A solar tracker is a device for orienting a day lighting reflector, solar concentrating solar reflector or lens toward the sun. The sun's position in the sky varies both with the seasons (elevation) and time of day as the sun moves across the sky during whole year. But due to rotation of earth those concentrators can't maintain their position always in front of sun. This problem results in decrease of their efficiency, because the output of solar cells or collector depends on the intensity of sunlight and the angle of incidence. Thus to get a constant output, an automated system or near the sun, so a solar tracker can increase the effectiveness of such equipment over any fixed position, at the cost of additional system complexity.

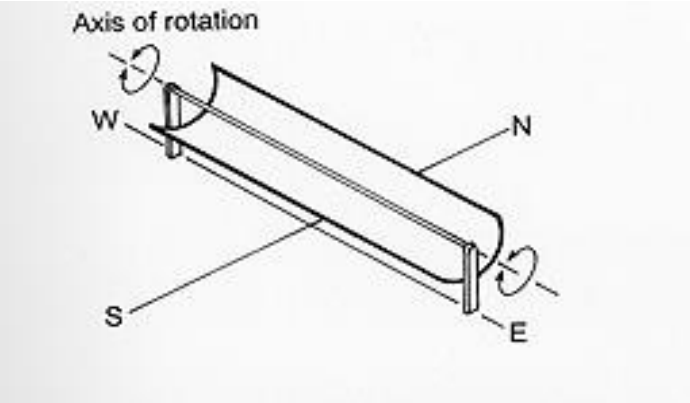

Figure 1. One-axis tracking parabolic trough with axis oriented east-west

Tracker Mount Types

Solar tracker may be active or passive and may be single axis or dual axis. Single axis tracker usually uses a polar mount for maximum solar efficiency. Single axis tracker will usually have a manual elevation adjustment on a second axis which is adjust on regular intervals throughout the year. Compare to a fixed mount, a single axis tracker increases annual output by approximately 25% and a dual axis tracker an additional 6%. There are two types of dual axis trackers, polar and altitude-azimuth.

Polar: Polar trackers have one axis aligned to be roughly parallel to the axis of rotation of the earth around the north and south poles-hence the name polar. Simple polar tracker with angle axis tracking may also have an adjustment along a second axis: the angle of declination.

Horizontal Axle: Several manufacturers can deliver single axis horizontal tracker which may be oriented by either passive or active mechanisms, depending upon manufacturer.

Vertical Axle: A single axis tracker may be constructed that pivots only about a vertical axle, with the panels either vertical, at a fixed. Such trackers with fixed or adjustable angles are

suitable for high latitudes, where the apparent solar path is not high, but which leads to long days in summer.

Altitude-Azimuth: A type of mounting that supports the weight of the solar tracker allows it to move in two directions to locate a specific target. One axis of support is horizontal (called the altitude) and allows the telescope to move up and down. The other axis is vertical (called the azimuth) and allows the telescope to swing in a circle parallel to the ground. This makes it easy to position the telescope: swing it around in a circle and then lift it to the target. However, tracking an object as the Earth turns is more complicated.

Two-Axis Mount: Restricted to active trackers, this mount is also becoming popular as a large telescope mount owing to its structural easiness and compact dimensions, one axis is a vertical pivot shaft that allows the device to be swung. The second axis is a horizontal elevation pivot mounted upon the azimuth platform. By using combination of the two axes, any location in the upward hemisphere can be pointed.

Drive Types

Active Tracker: Active tracker use motors and gear trains to direct the tracker as compared by a controller responding to the solar direction. Light sensing trackers typically have to photo sensors, such has photo diodes, configured differentially so that they output null when receiving the same sun light flux. Since the motors consume energy, one can want to use them only as necessary requirement.

Passive Tracker: It is used lower boiling point compressed gas fluid that is prevent to one side or the other (by solar heat creating gas pressure)to causes the tracker to move in response to an imbalance of panel. As this is known precision orientation its unsuitable for certain types of concentrating PV collectors but work fine for common PV panel types.

Chronological Tracker: A chronological counter act, the earth's rotation by turning and equal rate as the earth, but in opposite direction. The drive method may be as simple as a gear motor that rotates a very slow average rate of 1 revolution per day (15 degree/hour).

Types of Control System:

Closed system: Closed loop systems track the sun by relying on a set of lenses or sensors with a limited field of view, directed at the sun, and are fully illuminated by sunlight at all times. As the sun moves, it begins to shade one or more sensors, which the system detects and activates motors or actuators to move the device back into a position where all sensors are once again equally illuminated.

Open System: Open loop systems track the sun without physically following the sun via sensors (although sensors may be used for calibration). These systems typically employ electronic logic which controls device motors or actuators to follow the sun based on a mathematical formula.

Modes of Tracking:

There are two modes of tracking depending on the direction of rotation of the trough:

North-South tracking: In this case, the tracking axis is along the east-west direction

East-West tracking: In this mode, the tracking axis is along the north-south direction.

LITERATURE REVIEW

David H. Nelson experimented on a solar tracking mechanism which is used to orient a solar collector to directly face the rays of the sun using a hydraulic actuator and gear motor to both adjust the orientation of the collector and to stabilize it against spurious movement.

Saad D. Odeh & Hosni I. Abu-Mulawehfrom [1] which shows the design, development, testing and evaluation of an educational single-axis solar tracking parabolic trough collector that represents a standalone system to produce process heat at a moderate temperature for instructional and demonstrative purposes. The tracking system comprises electro-mechanical components such as a control box, a DC motor, a photo sensor and a gear box. A small power unit, which consists of a 12 V battery and two photovoltaic panels, is used to power the tracking systems. This apparatus is compact and portable.

Anand Mohan Sharan, did work on the solar tracking system maintains a solar collector with its responsive surface normal to the sun rays. It includes a shaft supported for rotation about an axis parallel to the north-south axis of the earth, a stepper motor for intermittent rotation of the shaft at a mean rate equal to the earth's rate of rotation. A solar collector securing assembly is located on one side of the shaft and includes a bracket, collars securing the bracket to the shaft, a support for fixing a solar collector pivoted to the bracket about a pivotal axis transverse to the shaft to vary the inclination of the support relative to the shaft and stays between the support and the bracket to maintain the support at an adjusted inclination.

Puramanathan Naidoo, **Theo I. van Niekerk** [5] shows the implementation of a mathematical computation – the PSA (Plataforma Solar de Almeria) computation developed at PSA (the European Test Centre for solar energy applications) – embedded in a control algorithm to locate the position of the sun.

James Sherman [6] has done work on an automated method causes a terrestrial solar cell array to track the sun. The solar cell system includes motors that adjust a position of the array along different respective axes with respect to the sun, wherein a first motor adjusts the inclination angle of the array relative to the surface of the earth and a second motor rotates the array about an axis substantially perpendicular to that surface.

DRIVING MECHANISM FOR AUTOMATIC SUN TRACKING SYSTEM

Here Worm and spur gear is used along with chain sprocket arrangement. It is made of mild steel. These arrangement is set with proper setting along with PTSC.

Experimental Setup (N-S):

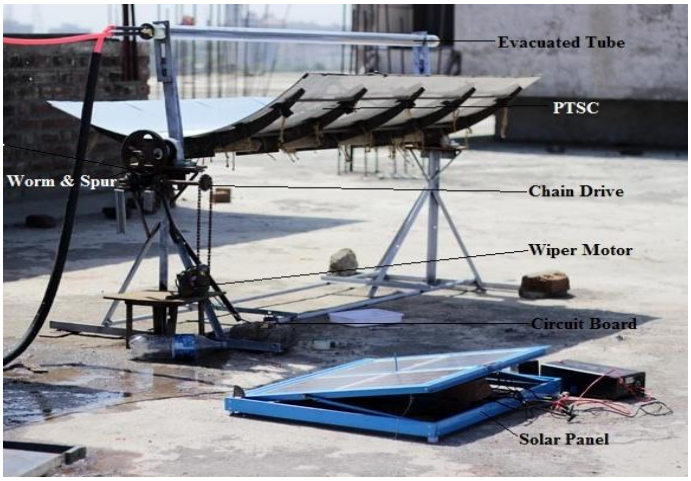

Figure 2: Experimental Setup of Tracking mechanism with Parabolic Through facing (N-S)

This setup is N-S direction. Here is the setup available in form of whole solar parabolic trough system. Various parts are assembled in this structure like parabolic trough, drive system, evacuated tube and thermal storage system; stand etc. By using this whole assembly the expected outcome can be generated. As above picture shown the whole system works in proper manner like first the Parabolic trough works as concentrator and concentrates sun rays on focal line at which absorber is kept. Through which cold water is running and hot water coming out for required various applications.

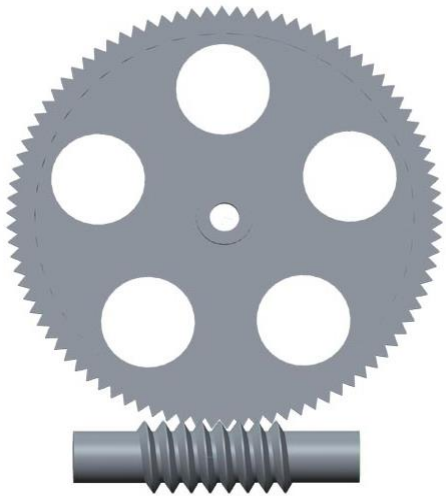

Figure 3. Worm and Spur

Mechanical Drive: In this, Worm and spur is used along with chain drive. Specifications are as below:

Lead (L)=12.34 mm, Diameter of worm (d_w) =38 mm, Diameter of gear (d_g) =200 mm,

No. of teeth on spur = 90. Module (m) = 2.2

Here, PV Module is attached with PTSC which can charge battery and thus there is no requirement of external source of energy to charge battery. Thus, this system is self-sustainable. As circuit drive which attached to PTSC setup which can drive wiper motor as per required rotation. It consist several components like Microcontroller, crystal, limit switch, LED, ULN2003, etc.

DESIGN & WORKING OF SETUP

Torque calculations:

Torque calculation done with Creo Parametric 2.0 software in which Geometric model of trough is drawn and finding C.G. of that model and also weight of that trough which want to be rotate by selecting material i.e. entering density of material. With this we simply get approximate torque of 150N.cm. Procedure for calculation is as below:

First Actual dimension geometric model of parabolic trough concentrator was drawn in Creo Parametric 2.0, after it through Analysis<Mass Properties option we select material (Mild Steel) density of material i.e. 7850 Kg/m³ and mass achieved is 18.26 Kg which we take around 20 Kg with evacuated tube arrangement. Again with Creo Parametric 2.0 CG of that geometry was found it is 10 cm up from bottom surface, for effective CG of parabolic trough just reducing 2.5 cm from bottom side for achieving CG from center axis of parabolic trough. Finally effective CG is 7.5 cm. For torque we just multiply weight of parabolic trough with CG and we got 150 Kg.cm torque. With considering factor of safety and other losses it may be approximate 400-500 Kg.cm. So, wiper motor is suitable as it has high torque and it is DC shunt motor, so that we can control motor speed with the help of coding.

Required Rotation for parabolic trough concentrator: The rotation of Parabolic trough in 24hrs is 360° (180° during day and another 180° during night to set trough at initial condition). Means variation of solar elevation angle is 15°/hour i.e. 0.25° per minute. But we take accuracy of 1° rotation for every 4 min of time. Thus, we achieve total 180° rotation of trough for 12 hours i.e. during sunshine hours of the day for achieve solar irradiation.

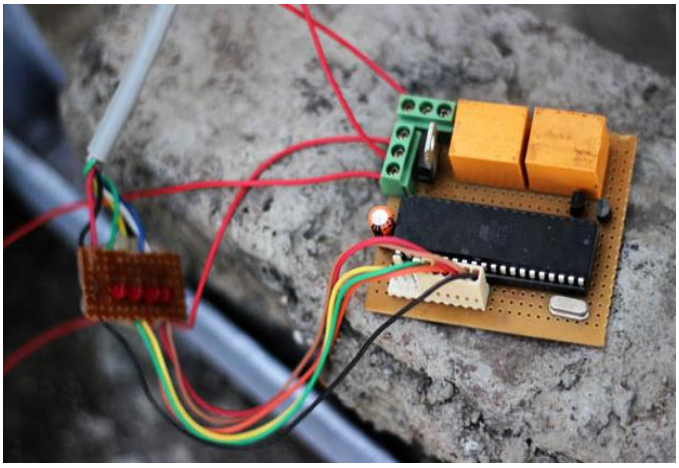

Figure 4. Circuit Board

Instruments& Parts used in Driving Mechanism:

AT89S52 Microcontroller: A microcontroller is a small computer on a single integrated circuit containing a processor core, memory and programmable input/output peripherals. Program memory in the form of NOR flash or OTP ROM is also often included on chip, as well as a typically small amount of RAM also included. Microcontrollers are designed for embedded applications.

The first one is to perform input/output operations and the second one is used to implement special features of the microcontroller like counting external pulses, interrupting the execution of the program according to external events, performing serial data transfer or connecting the chip to a computer to update the software. Each port has 8 pins, and will be treated from the software point of view as an 8-bit variable called 'register', each bit being connected to a different Input/output pin.

The 89C51 has an RISC structural design and holds fewer no of codes which makes it easy for programming through SPI as compared with a micro controller such as the 8051. However as compared to other micro controllers they have very few differences.

ULN2003: The ULN2003 is a monolithic IC consists of seven NPN darlington transistor pairs with high voltage and current capability. ULN2003 is used where the current rating and voltage rating of a motor or any load which is to handle by microcontroller is more than the current handling and voltage handling capacity of that microcontroller. A pin of ULN2003 can handle 600 mA current. It can withstand voltage up to 50 volt. A pin of any microcontroller can handle current up to 200 mA and controller voltage is around 5 volt. So we use ULN2003 in parallel to any microcontroller to drive heavy load devices. ULN2003 accepts TTL from MCU which may be 5v or 0v and depending on this value ULN2003 turns on the heavy load or turn it off respectively.

Limit Switch: A limit switch is used to limit the activation of an electrical circuit. When a circuit is "closed," it allows the flow of electrical current through the switch to pass to the device being powered. When the switch is "open," the switch is disengaged and no electrical power will pass through it. Whether the limit switch is open or closed is generally determined either by the position of a device being powered or by a set amount of time a device requires completing a specific task.

Figure 5. Limit Switch

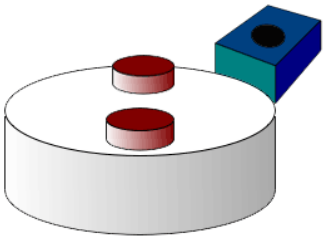

Figure 6. Hall Effect

Hall Effect sensor: A Hall Effect sensor is a transducer that varies its output voltage in response to a magnetic field. Hall Effect sensors are used for proximity switching, positioning, speed detection, and current sensing applications.

Capacitor: Capacitor is an electronic component that stores electric charge. The capacitor is made of 2 close conductors (usually plates) that are separated by a dielectric material. The plates accumulate electric charge when connected to power source. One plate accumulates positive charge and the other plate accumulates negative charge.

Resistor: A resistor is an electrical component that limits or regulates the flow of electrical current in an electronic circuit. Resistors can also be used to provide a specific voltage for an active device such as a transistor.

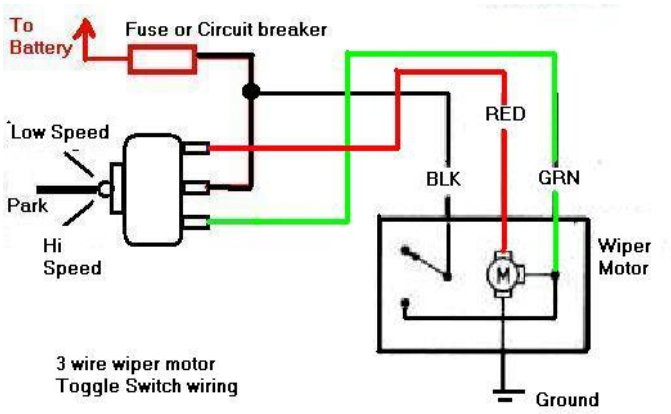

Figure 7. Wiper Motor with diagram

LED: A light-emitting diode (LED) is a two-lead semiconductor light source that resembles a basic PN-junction diode, except that an LED also emits light in some cases. When an LED's anode lead has a voltage that is more positive than its cathode lead by at least the LED's forward voltage drop, current flows. Electrons are able to recombine with holes within the device, releasing energy in the form of photons. This effect is called electroluminescence, and color of the light (corresponding to the energy of that photon) is determined by the energy band gap of the semiconductor.

Wiper Motor: A DC motor is a mechanically commutated electric motor powered from direct current (DC). The stator is stationary in space by definition and therefore the current in the rotor is switched by the commutator also be stationary in space. This is how the relative angle between the stator and rotor magnetic flux is maintained near 90 degrees, which generates the maximum torque.

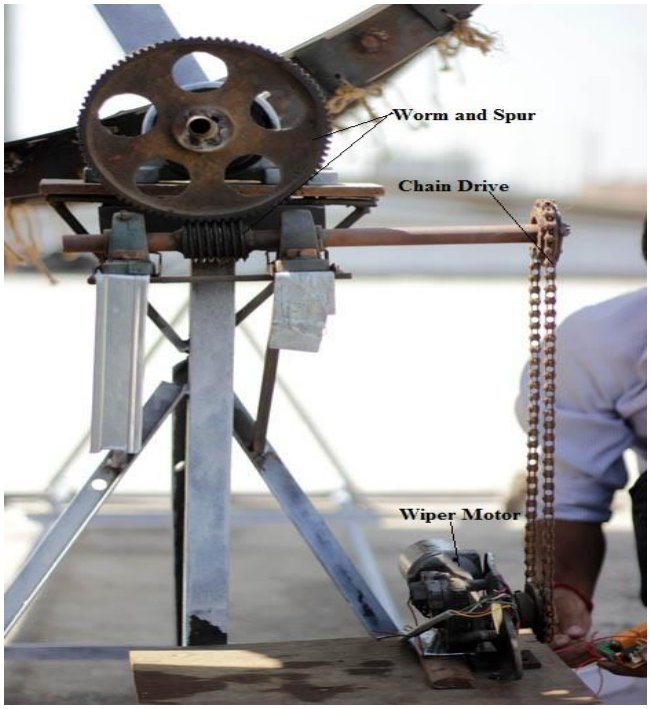

Figure 8. Worm and Spur & Chain Drive

Crystal Oscillator: A crystal oscillator is an electronic oscillator circuit that uses the mechanical resonance of a vibrating crystal of piezoelectric material to create an electrical signal with a very precise frequency. This frequency is commonly used to keep track of time (as in quartz wristwatches), to provide table clock signal for digital integrated circuits also to stabilize frequencies for radio transmitters and receivers.

Power Supply: For running the motor and other equipment the external power supply is require. For this DC supply is used and the DC battery is used for that. Also use solar PV module is used for charging of Battery. Thus, the charging cost can be eliminated.

Worm and Spur& Chain drive: Worm and spur has gear reduction ratio of 90:1 i.e. with rotation of 90 times of worm the spur only rotates one time. This worm and spur is made by casting method. Worm gear with chain sprocket arrangement attached with motor via micro controller. Worm and worm gear is selected due to following reason:

There are few reasons why one would choose a worm gear over a standard gear. The first one is the high reduction ratio. A worm gear can have a massive reduction ratio with little effort - all one must do is add circumference to the wheel. Thus we can use it to either greatly increase torque or greatly reduce speed. It will typically take multiple reductions of a conventional gear set to achieve the same reduction level of a single worm gear, i.e. by using worm gears which have fewer moving parts and fewer places for failure

Figure 9. PV Module

A second reason to use a worm gear is the inability to reverse the direction of power. Because of the friction between the worm and the wheel, it is virtually impossible for a wheel with

force applied to it to start the worm moving. On a standard gear, the input and output can be turned independently once enough force is applied. This necessitates adding a backstop to a standard gearbox, further increasing the complication of the gear set.

Gear ratio calculation: For 1° rotation of trough with interval of 4 min, and with 90:1 spur-worm rotation of worm and worm wheel, (Rotation of trough) x (Worm gear ratio) = required rpm from motor

(1°/360°) * (90) = 0.25 rpm

Here consider 360° = one revolution of trough shaft.

For 0.25 rpm, motor must rotate 1 rpm (in four steps i.e. 90° of rotation of motor) with interval of 4 minutes, for that there are 4 sensors placed on motor with a magnet which can rotate motor 90° with hall sensor effect.

Worm-Spur Calculations:

Diameter of worm (Dw) = 38 mm

Diameter of gear (Dg) = 200 mm

Number of start (Z_w) =1

Lead (L) =12.34 mm

Number of teeth on gear=90

Ψ_w=helix angle of worm

Ψ_g=helix angle of gear

1. Module: m=Dg/Zg =200/90 =2.22
2. Lead angle of warm: ƛ =tan-1(L/πdw)
   =tan-1(12.34/π*38) =5.90
3. Diametral quotient:- $q=Z_w/\tan\lambda$ =1/0.1033 =9.676
4. Center to center distance a= m(q+Zg)/2
   =110.63mm
   ƛ = ψ_g=5.90,
   ψ_w = 90-ƛ =90-5.90 =84.1
5. Face width:- $b=2*m*\sqrt{q+1}$
   $=2*2.22*\sqrt{9.67+1}$ =14.50mm or
   b=0.73*dw =27.74mm

Chain drive: Chain drive is used for connecting trough shaft and motor shaft. Also transmitting power from motor to trough shaft of same value. It has 14 teeth for each sprocket.

PV Module: We use PV Cell for charging of 12V DC battery. It contains group of 4cell in which each cell can produce 16.4 V and 0.67A. With connecting parallel that all, we can collect 16.4 V and 2.4A which is enough to charging 12V, 2A dc battery.

The 'PV Module Kit' consists[9] of four PV Modules, arranged in such a way that angle of the PV Module kit can be easily changed and various connections can be made for easy rotation of the PV Kit making PV Modules perpendicular to the sun rays. It consist several parts as follow:

1. The kit consists of two mono-crystalline modules arranged diagonally.
2. The kit consists of two multi-crystalline modules arranged diagonally.
3. Angle indication – The degree protector makes it feasible to arrange the PV modules at certain latitude angle of a location.
4. Needle – It can be used for tracking the sun. By omitting the shadow of the needle, the sun can be tracked.
5. Terminals and connections – The positive and negative terminals of each of the PV Modules are provided with banana connectors, to connect the modules in series and or in parallel.
6. Handle, Locking arrangement, castor wheels and legs are also provided.

Working of Driving Mechanism:

Working of Circuit Drive and Mechanical Drive start when supply is given by DC battery to motor via microcontroller. First circuit sets first Hall sensor in front of magnet so that proper rotation of motor can be achieved. It is done with help of jumper and limit switch. As of coding is done, after detecting first hall sensor there is 240 sec i.e. 4 min timer set which stop motor for 4 min. With rotation of 90° i.e. ¼ rotation, worm and spur mechanism rotates PTSC 1° by chain drive. After that 4 min, supply is given to motor for rotation of motor again for 90° (As 4 sensors are arranged on motor i.e. sensors placed at 90°difference) which rotates PTSC 1 degree. This cycle is run continuously during all day and rotates PTSC 180°. In the Circuit drive, program is set in which initial value for all sensor is given '1', whenever magnet detect by sensor value becomes '0' and it will set 4 min delay in motor rotation. After this, motor start and another sensor detect magnet and this process last continuously. This rotation is enough to drive through 1° at every interval of 4 minutes.

CONCLUSION

Following points can be concluded from this experimental work carried out:

Minimum rotation of PTSC achieved is 1^0 with time elapsed of 4 minutes. And thus, total rotation of 180^0 can be achieved with 12hrs. We had mount this self-sustainable type of continuously automatic tracking system to track sun with our Solar Parabolic Through collector. We had found noticeable outcome in term of heat gain and efficiency increased by 25-30 % compare with fixed structure. Using of PV Modules to charge battery this system is become self-sustainable as there is no need of external supply to system.

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