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Embedded System Based Open Loop Tracking System For Modified Solar Thermal Collector Using Sun Position Algorithm

Arun Kumar Ramasamy[1], Madhu Ganesh[2], R Venkatesh[3], SubaasiniMarudhamuthu Govindaraj[4]

[1,3,4]Department of Mechanical Engineering, PSG College of Technology, Coimbatore, India
[2]Department of Aerospace Engineering., Karunya Institute of Technology and Sciences

Email: [1]rak.mech@psgtech.ac.in

Abstract: In recent days, solar energy is one of the key sustainable power sources and is picking up its prominence rapidly. When the Sun's rays strike the solar system perpendicularly, the system gains the most energy. Solar energy can be made more feasible by amplifying its efficiency. Thus, solar tracking helps to track the sun and make the setup to receive the irradiation perpendicular at all time. In order to yield a real time solution and to maximize the energy efficiency, solar systems are continually tracked. In this paper solar tracking is designedfor a Parabolic Linear Fresnel Collector (PLFC) system. It is a modified solar collector which is a combination of Parabolic Trough Collector (PTC) and Linear Fresnel Collector (LFC). It combines the features of both PTC and LFC which is compact and efficient.Many individual Linear Fresnel mirrors are pivoted with their midpoints in a parabolic profile. The centre plate is employed with a geared stepper motor. All the discretised Fresnel mirrors are interlinked with a linkage mechanism and therefore rotating movements of the stepper motor make all the mirrors to pivot simultaneously. In this paper, a solar tracking system is designed for the PLFC system, the tracking is based on an embedded tracking design. MAT-lab software is used to calculate the tracking angle of the Fresnel mirrors with respect to Sun's position using Sun Position Algorithm. The Arduino microcontroller and a stepper motor are used to pivot the Fresnel mirrors according to the instant tracking angle. The objective of this paper is to track the discretised plates of modifiedPLFC solar system based on the sun's position. The proposed solar tracking helps to increase its efficiency by pivoting the mirrors to receive maximum solar irradiation.

Keywords – Embedded system, Tracking system, Parabolic, Linear Fresnel and Sun position Algorithm.

1. INTRODUCTION

Energy is the important requirement in our everyday life. It is a way of improving human development which leads to economic growth and productivity. Reliable and non-harmful energy supply is required in all economies. Returning to renewable energy is an excellent approach and helps to mitigate climate change but needs to be sustainable in order tomeet the future energy demand. Renewable energy replenishes them naturally without being depleted in the earth and thus it is interrelated and sustainable development. According to World Energy Council (2013), "The total energy from solar radiation falling on the earth was more than 7,500 times the World's total annual primary energy consumption of 450 EJ”[8]. The fuel for solar energy technology is solar irradiance to generate electricity using photovoltaic (PV) [2] and concentrating solar power (CSP), to produce thermal energy [3] This gives the evident solution for growing demand of energy.

In recent days, solar energy is one of key sustainable power source and is picking up its prominence rapidly. Solar energy technologies are those which employ directly the solar flux that reaches the solar system in three different ways to produce heat energy, chemical energy and electrical energy respectively in a collecting element (receiver). To increase the performance of the solar energy systems it is usual to previously concentrate the solar flux that reaches the solar system receiver to achieve higher peak temperatures and solar flux densities which improves thermodynamic efficiencies and reducing the heat loss area in relation to the receiver area. Two main types of solar concentration technologies can be found: concentrated solar thermal power (CSP) and concentrated photovoltaic (CPV). CSP produce high temperature heat that can be used directly in a process (process heat) or to produce steam to spin turbines and generate electricity. On the other hand, CPV uses concentrated solar radiation onto small photovoltaic cells to produce electricity. Recently, the research advances have achieved the combination of the two technologies, CPV with CSP, which is called concentrated photovoltaic thermal (CPVT). Studies show the very high potential of the CPVT technology due their unique features [4].

Solar energy can be made more feasible by amplifying the efficiency of solar thermal systems. Solar systems output is highest during the day when the sun’s rays are normal to the system, since it receives maximum input. Thus, solar tracking helps to track the sun and make the setup to receive the irradiation perpendicular at all time. The aim of solar tracking is to maximize the irradiation received by the solar thermal collector or PV panel. In order to yield a practical option and to increase the energy output, solar tracking is widely used in solar systems. The commonly used concentrators for thermal applications are Parabolic Trough Collector (PTC) and Linear Fresnel Collector (LFC). PTC offers high manufacturing and maintenance cost. LFC’s were developed as an alternative to counter the drawbacks of PTC but it either reduces the output power or increase the size.

In this paper, solar tracking is incorporated to a Parabolic Linear Fresnel Collector (PLFC) system. It is a modified solar collector which is a combination of Parabolic Trough Collector (PTC) and Linear Fresnel Collector (LFC). It combines the features of both PTC and LFC which is compact and efficient. The objective of this paper is to position the discretised plates of modified solar thermal collector with respect to the sun’s position. The proposed solar tracking helps to increase itsefficiency by pivoting the mirrors to receive solar irradiation during whole day time.The formatter will need to create these components, incorporating the applicable criteria that follow.

SOLAR TRACKING

The Earth is in a constant rotation, so the relative position of the Sun in the sky continuously changes but can be defined by means of solar position algorithms or optically, with enough precision. Most of the solar concentrators demand a mechanism that controls the systems alignment with the Sun (solar tracker), being this a key issue for the general system efficiency.

A. Solar Tracking

The Earth is in a constant rotation, so the relative position of the Sun in the sky continuously changes but can be defined by means of solar position algorithms or optically, with enough precision. Most of the solar concentrators demand a mechanism that controls the systems alignment with the Sun (solar tracker), being this a key issue for the general system efficiency.

B. Solar Tracker

Trackers orient the solar systems to redirect the solar radiation. Tracking systems change the orientation of solar collectors throughout the day;sun's position is tracked and the energy capture thus maximized.

Solar trackers can be classified regarding the number and position of rotation axes. Systems with one rotation axis are employed with solar concentration systems like PTC or LFC. The tracking systems can be horizontal, vertical or tilted-axis. The main CSP applications of the single axis tracker are PTC and LFC. The main disadvantage of the single axis tracking system is that it can only track the sun during the daily movement and not the yearly movement, and during the cloudy days, the efficiency of the tracking system is reduced by a large amount due to the rotation around only one-axis. [6]

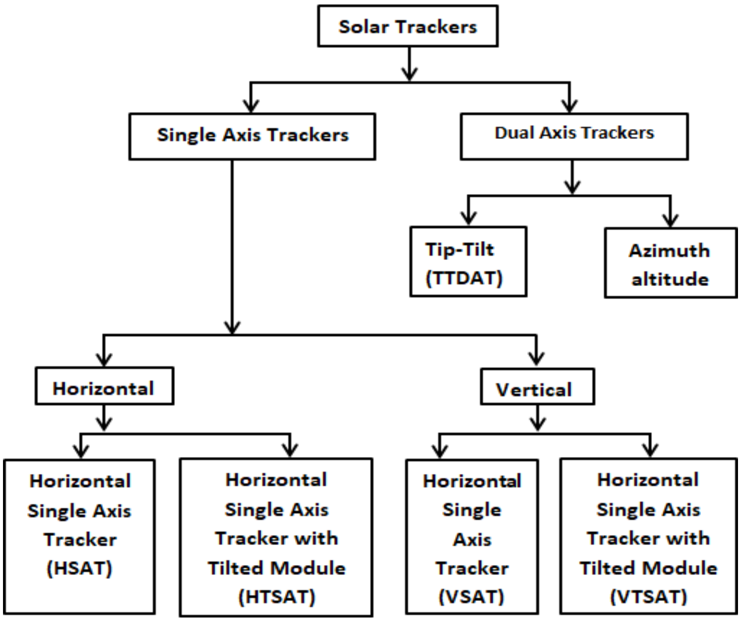

Fig. 1 Classification of solar trackers based on tilt axis

On the other hand, systems with two rotation axes, called point-focus systems, are employed with heliostats and dish modules. Azimuth-elevation, target aligned and polar trackers can be found as sub categories depending on the rotation axes position. One of the most important applications to dual axis tracker are CSP applications and especially solar dish and solar tower systems where the long distance between the heliostat reflectors and the receiver point concentration led to angle errors in the results.[6]

C. Driver Types

Sun tracking can eitherbe continuous or discrete depending on control method and the design of the rotary system. Most Sun tracker systems are developed for a specific solar technology. Solar tracker drive systems are classified based on the tracking technology.

Majorly, solar trackers can also be classified to five types,based on control methods passive and active solar trackers are the common trackers. Passive solar trackers are made up of two actuators that work against each other and are powered by thermal expansion.Microprocessor and electro-optical sensor-based active trackers, PC-controlled date and time-based active trackers, auxiliary bi-facial solar cell-based active trackers, and a combination of these three systems are all available[7].

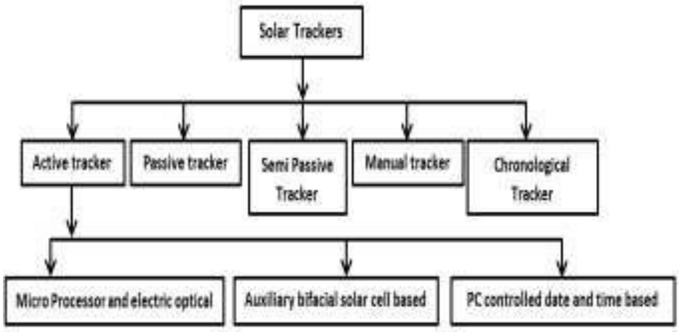

Fig. 2 Classification of solar trackers based on driver

Regarding control for active solar trackers, both closed-loop and open-loop controllers can be found. To evaluate if its inputs have achieved the desired goal without needing feedback, an open-loop controller estimates its inputs using only the current state and a computer algorithm.The sun position is computed using solar equations that require time and place as inputs and is computer controlled based on date and time. When compared to the other two forms of closed loop controllers for solar trackers that are dependent on feedback from sensors, the accuracy of this system is heavily influenced by continual aberrations.This one is simpler than the closed-loop controller, but it is unable to remedy any system disturbances [5].

In case ofmodified collector, active solar tracker with open loop controller is been incorporated as the system cannot be easily disturbed by external act. So, feedback circuit is not necessary.

PROPOSED TRACKING SYSTEM

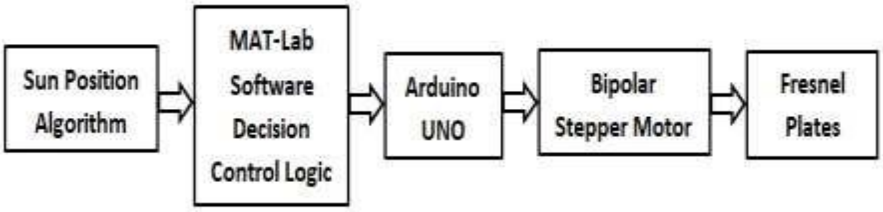

Fig. 3 Proposed Tracking System Framework

In this paper, solar tracking is incorporated to a Parabolic Linear Fresnel Collector (PLFC) system. It is a modified solar collector which is a combination of Parabolic Trough Collector (PTC) and Linear Fresnel Collector (LFC). It combines the features of both PTC and LFC which is compact and efficient. Many individual Linear Fresnel mirrors are pivoted with their midpoints in a parabolic profile. The centre plate is employed with a geared stepper motor. All the discretised mirrors are interlinked with a linkage mechanism and therefore rotating movements of the stepper motor make all the mirrors to pivot simultaneously. A single axis sun tracking mechanism for PLFC systems is proposed in this paper using an embedded based approach. MAT-lab software is used to calculate the tracking angle of the Fresnel mirrors with respect to Sun's position by using Sun Position Algorithm. The arduino microcontroller and a stepper motor are used to pivot the Fresnel mirrors according to the instant tracking angle. The objective of this paper is to position the discretised plates of modified solar thermal collectorbased on suns position. The proposed solar tracking helps to increase its efficiency by pivoting the mirrors to receive solar irradiation during whole day time.

A. Methodology

- Software - MAT-Lab (Decision Control Logic)
- Hardware - Arduino Uno, Stepper Motor, Driver circuit
  - Mat-lab acts as a decision control logic. Sun Position Algorithm is interfaced with Mat-lab.
  - Mat-lab does the main calculation process.
  - Arduino gets the command (tracking angle) from Mat-lab.
  - Arduino gives the command to driver circuit of stepper motor.
  - The stepper motor responds to its driver circuit signal.
  - Fresnel plates are made to rotate in order to track the sun.

ELEMENTS OF TRACKING SYSTEM

The vital elements of any tracking system include,

• **Sun tracking algorithm**: This algorithm calculates the Sun's azimuth and zenith angles, which are used to align the solar panel or reflector with the sun. The tracking method would be based on either mathematical astronomical references or real-time light intensity sensors.

• **Control unit**:The Sun tracking algorithm can be implemented, and the positioning system must be moved in relation to the Sun.The calculation is done by MATLAB, which sends commands to the Arduino UNO, a microprocessor board that is attached to control motor mechanism.

• **Positioning system**:To adjust the array of reflectors so that the Sun is focused at the correct angle.Hydraulic or electrical positioning mechanisms are available.To monitor the present position and change the position defined by the control unit, electrical positioning systems use encoders, linear actuators, or variable frequency motors.

• **Drive mechanism / transmission**: Linear drives, swivel drives, hydraulic cylinders, worm gears, planetary gears, linear actuators, and threaded spindles may be used to power the positioning system.

• **Hybrid Stepper Motor** is used due to its high torque and low power consumption. Planetary gears are coupled with it to increase the torque ratio.

• **Driver Circuit**: Hybrid Stepper motor requires a micro-step driver circuit. A stepper motor driver is a device that supplies the necessary current and voltage to a stepper motor to ensure smooth operation. It is a circuit that converts pulse signals from a controller into stepper motor motion.

• **Power supply unit**: Power Unit is a transformer for supplying suitable voltage and current to the driver circuit.

• **Modified Collector:** Parabolic Linear Fresnel Collector (PLFC)

A. Parabolic Linear Fresnel Collector(PLFC)

An experimental setup has been developed for testing of modified collector. The modified collector of solar concentrator was to use semi-spherical surface covered with many small sections of mirror to form a segmented, spherical concentrator. Linear Fresnel mirrors having a structure of rectangular plate are mounted on the parabolic curves as in PTC. The midpoint of each mirror edge lies on a parabolic curve. Here the absorber tube will be fixed non movable. It concentrates beam radiation to a stationary receiver. It consists of glass absorber tubes and 17 mirrors. Each receiver has a secondary CPC reflector that directs the beam radiation on to the absorber tube. The entire optical system is enclosed by a sealed glazed casing.The bipolar stepper motor coupled with planetary gear is attached to the centre mirror of the PLFC collector. The mirrors are interlinked through a linkage mechanism hence mirrors are rotated uniformly. Therefore, all the mirrors in parabolic curve are made to track the sun uniformly.

B. Bipolar Stepper Motor

A stepper motor is a brushless DC electric motor that divides one rotation into an equal number of steps.The microcontroller can be used to control the motor's position.The size of the motor is carefully chosen in relation to the given application, taking torque and speed into account.In a two-phase stepper motor, an electromagnetic coil can be wound in either a unipolar or bipolar configuration. Each phase of a unipolar motor has two windings.The magnetic pole arrangement can be switched without changing the current direction.Bipolar motors have a single winding for each phase.To reverse the magnetic pole, the winding current should be reversed. When compared to unipolar stepper motors, the windings in bipolar stepper motors are better utilised, and thus bipolar is more powerful than unipolar motors of the same weight.The complexities of driving a bipolar stepper motor can be mitigated by the abundance of driver circuits available.

Hybrid Bipolar stepper motor of (planetary gear box stepper motor – BH86SH156-6204PL-10 high torque hybrid)is being selected according to the torque requirement. This hybrid bipolar stepping motor has a maximum 1.8° step angle (200 steps/revolution). Each phase draws 1 A at 2.4 V, allowing for a holding torque of 4.2 kg-cm (51 oz-in). The motor has four color-coded wires terminated with bare leads: black and green connect to one coil; red and blue connect to the other.

The commonly used driving circuit is H-bridge arrangement and the circuit is considered to be complicated.

Fig.4Bipolar Stepper Motor- Planetary Gear Box

Since, it is a bipolar stepper motor it has 4 wires. Bipolar stepper motors have two windings, which are not connected to each other, wired internally like this:

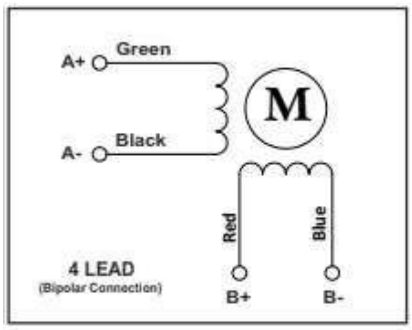

Fig. 5 Wiring Diagram

C.Micro Step Driver

Step motors are commonly driven by microstepping drives. A Microstep Driver applies power to the appropriate step motor winding to produce torque. Smaller step angle is achieved by dividing the current between the motor phases. It provides higher resolution but with less torque. It does not increase step accuracy, but will allow a motor to run with less noise, minimize low speed resonance effects and produce smooth rotation over a wide speed range. It is a dual H-bridge motor driver interfacing circuit which accepts a low-current control signal and outputs a higher-current signal to drive the stepper motor.

D. Arduino Uno

The Arduino Uno is an open-source microcontroller board. It is based on the Microchip ATmega328P microcontroller. It was developed by Arduino.cc. The board has sets of digital and analog input/output (I/O) pins that may be interfaced to various expansion boards (shields) and other circuits. The board has 14 Digital and 6 Analog pins. It is programmable with the Arduino IDE (Integrated Development Environment) software via a type B USBcable. It can be powered by the USB cable or by an external 9-volt battery.

In our proposed work, Arduino Uno is interfaced with the Mat-lab. It is programmed using Mat-lab. It couples the Mat-lab and Stepper motor. The micro-step driver circuit acts as a bridge between stepper motor and Arduino.

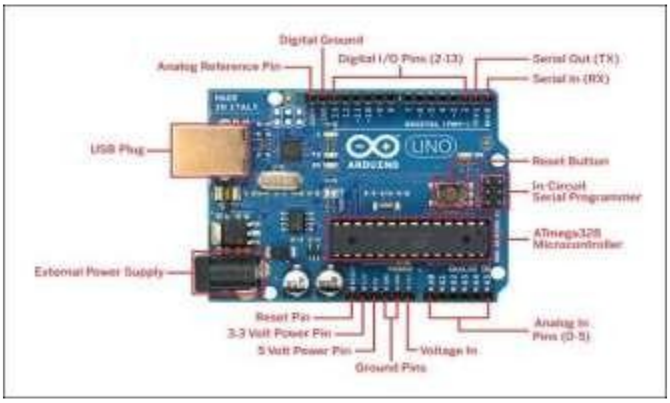

Fig. 6Pin Mapping of Arduino UNO

E. Mat-Lab Decision Control Logic

MATLAB is known as matrix laboratory. It is a multi-paradigm numerical computing environment. It is proprietary programming language. It was developed by Math Works. MATLAB is a high-performance technical-computing language. It combines calculation, visualization, and programming into an easy-to-use environment where familiar mathematical notations are used to represent problems and solutions. Typical applications include: Math and computing. MATLAB allows to manipulate the matrixes, to plot functions and data, to implementalgorithms, to construct user interfaces and to communicate with programs written in other languages.

In this proposed tracking mechanism, MAT-Lab is used as the decision control logic. Tracking angle for the time instant is calculated using sun position algorithm in the excel sheet. MAT-Lab gets the pre calculated time stamp and its corresponding tracking angle data from excel sheet. Its time stamp is compared with the current system time stamp for the execution of motor operation. It is clearly explained in followed flowchart and algorithm.

Step 1: *Get the updated Sun Position Algorithm from the Excel sheet. (Time stamp and tracking angles)*

Step 2: *Get the system time stamp (Current time).*

Step 3: *First time stamp in excel sheet and current system time stamp is compared.*

Step 4: *If, first time stamp <= Current system time Calculation process will be executed*

Step 5: *During calculation process,*
Tracking angle is added to meet the range fixed in order to match with step angle of stepper motor

Step 6: *Once it is matched, get that time stamp A and tracking angle from the excel sheet*

Step 7: *If, time stamp A = Current system time stamp*
Run the motor

Step 8: *If, time stamp A > Current system time stamp*
Wait process will be executed

Step 9: *During wait process,*
if, Time stamp A = Current system time, go to step 7 to proceed.

Step 10: *Repeat from the third step for time stamp B*

Step 11: *If, Last time stamp = Current system time stamp*
Motor rotation stops.

Step 12: *Repeat from step 1 for next day.*

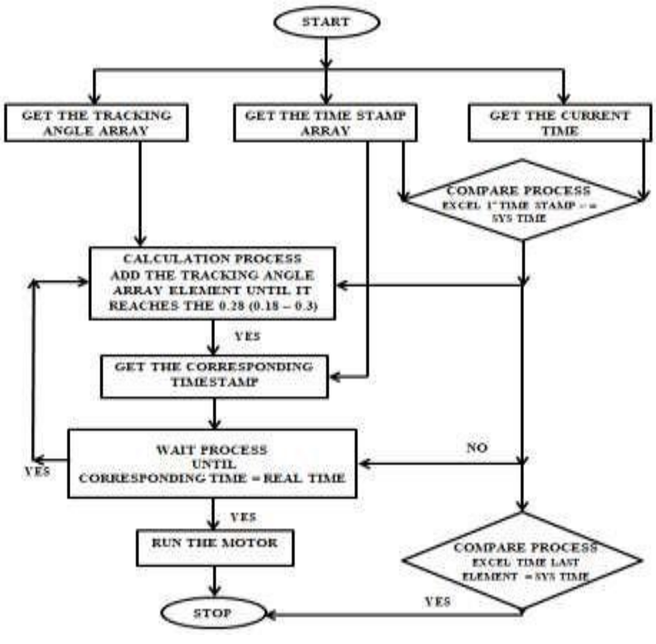

Fig.7Flowchart of Decision Control Logic

F. Sun Position Algorithm

The Sun Position Algorithm is used to find the tracking angles for the corresponding time for the modified collector. Sun Position Algorithm is based on Astronomical Algorithms by Jean Meeus. This Sun Position Calculations are referred in the NOAA Sunrise/Sunset and Solar Position Calculators. The sunrise and sunset results for the specified location are theoretically accurate within a minute for the locations between +/- 72° latitude, and within 10 minutes outside of those latitudes. However, due to some variations in atmospheric composition, temperature, pressure and conditions, observed values may vary from calculations.The Sun Position is calculated by the four basic inputs Latitude, Longitude, Date and Time.

2. RESULTS AND DISCUSSION

Manual tracking for the modified collector setup is been carried out. The efficiency was obtained by calculating the mass flow rate of the hot fluid in the absorber tube. This sample work was carried out on a peak hour between 10.00am to 3.00pm. It was achieved utmost 75% efficiency. The experimental data are shown in fig.8. Thus, in order to increase its efficiency embedded based automation is designed for automatic tracking. Mat-lab is core of the tracking system. It is used as the programming software for Arduino thus, Arduino is interfaced with the Mat-lab. The Arduino Uno acts as a coupler for stepper motor and Mat-lab. Micro step driver is used as a bridge to amplify the low pulse signal to high pulse signal according to stepper motor. The micro step driver is powered by the appropriate power supply. The detailed hardware connection is shown in fig.9

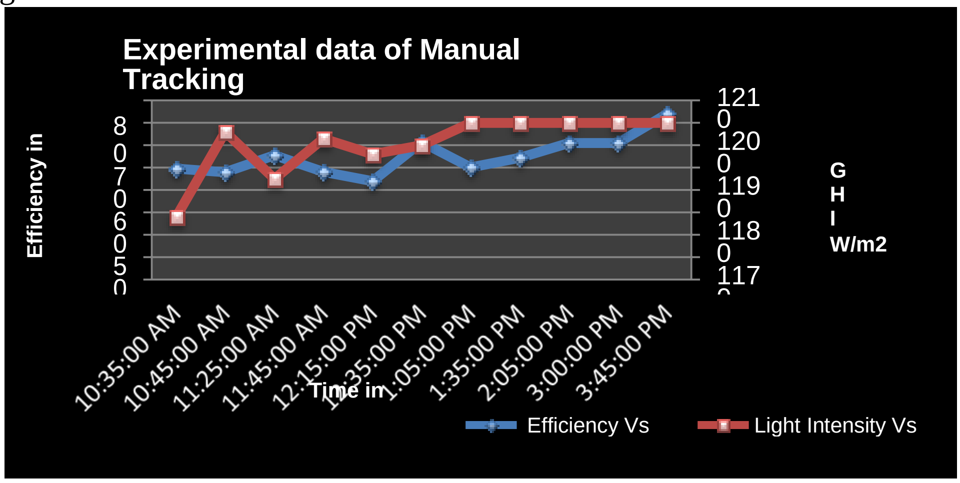

Fig. 8Experimental data

It is the open loop tracking system which does not require any sensors. The Fresnel mirrors of PLFC system cannot be disturbed easily. Thus, sensors are not required to detect the errors. Mathematical Code is enough to track the Fresnel mirrors of PLFC system.

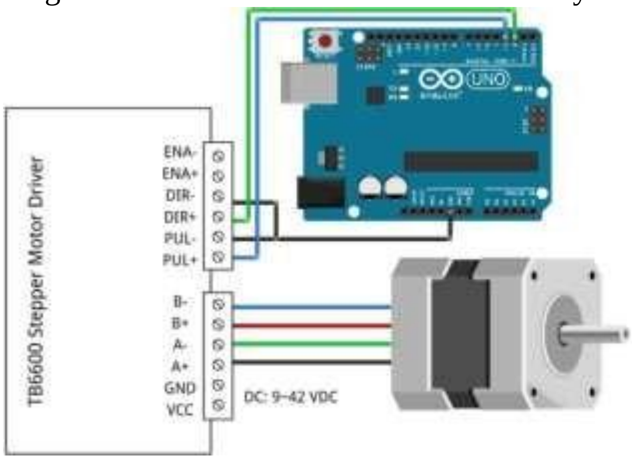

Fig. 9Hardware Connection

3. CONCLUSION AND FUTURE WORK

The suggested study proposes an embedded-based tracking mechanism for PLFC systems in order to achieve optimum efficiency by setting the Fresnel mirrors at an optimal angle to the sun. The proposed tracker comprises of a geared stepper motor and its driver circuit. The Arduino microcontroller used to couple the hardware and software. The MAT-Lab software lies at the core of the proposed frame work. It uses the Sun position algorithm for its computation process. The MAT-Lab computations are used as the decision control logic to decide when the Fresnel mirrors should be pivoted through stepper motor. The tracking system based on embedded method can be considered a cost effective and accurate forPLFC systems.The complete mechanical design should be developed and accuracy should be tested in future.

4. REFERENCES

[1] Urban F & Mitchell T, (2011), “Climate change, disasters and electricity generation”. Current opinion in Environmental sustainability 3 (3), 164-168,2011 [Google Scholar]

[2] Asumadu-Sarkodie S, Owusu P A, (2016d), “The potential and economic viability of solar photovoltaic in Ghana”. Energy Sources, Part A: Recovery, Utilization and Environmental Effects. doi: 10.1080/15567036.2015.1122682 [Google Scholar]

[3] Edenhofer O, Pichs-Madruga R, Sokona Y, Seyboth K, Matschoss P, Kadner S von, Stechow C (2011). “Renewable Energy Sources and Climate Change Mitigation”: Cambridge University.
Press.10.1017/CBO9781139151153 [Google Scholar]

[4] TP Kitching, “Development of a tracking compound parabolic collector for a solar-driven diffusion absorption cycle”, Thesis report of Master of Engineering in Mechanical Engineering at the North-West University- 2018. North West University.

[5] Jose A. Carballo, Javier Bonilla, Lidia Roca, Manuel Berenguel 2018. “New low-cost solar tracking system based on open source hardware for educational purposes”. Solar Energy 174 (2018) 86-836

[6] Hafez AZ, Yousef AM, Harag NM. “Solar tracking systems: Technologies and trackers drive types - A review”, Renewable and Sustainable Energy Reviews 91 (2018) 754-782

[7] Mousazadeh H, Keyhani A, Javadi A, Mobli H, Abrinia K, Sharifi A, 2009. “A review of principle and sun-tracking methods for maximizing solar systems output”. Renew. Sustain. Energy Rev. 13 (8), 1800–1818. https://doi.org/10.1016/j.rser. 2009.01.022

[8] Phebe AsantewaaOwusu, Samuel Asumadu-Sarkodie, 2016. “A review of renewable energy sources, sustainability issues and climate change mitigation”. Civil and Environmental Engineering. https://doi.org/10.1080/23311916.2016.1167990

[9] Babu M,ValanArasu A, Jennifer Ranjani J, (2016), “A Arduino based Sun Positioning for Linear Fresnel Solar Concentrating System with Horizontal Absorber and Varying Width Reflectors”. IJCTA 9(31)2016,pp.377-388

[10] William B. Stine, Michael Geyer. (2001). Power From the Sun

[11] Selvam, S.; Kannan, S. T. Analysis of the major issues in Cloud Computing Environments. IARS’ International Research Journal, Vic. Australia, v. 5, n. 2, 2015. DOI: 10.51611/iars.irj.v5i2.2015.50.