Design, Fabrication and Experimental Study of a Novel Two-Axis Sun Tracker

M. R. I. Sarker, Md. Riaz Pervez, and R.A Beg

***Abstract*— This paper presents the design, construction and also investigates an experimental study of a two axis (azimuth and Polar) automatic control solar tracking system to track solar PV panel according to the direction of beam propagation of solar radiation. The designed tracking system consists of sensor and Microcontroller with built in ADC operated control circuits to drive motor with control software, and gear- bearing arrangements with supports and mountings. A digital program operates the designed Sun tracker in the control system. Two steeper motors are used to move the system panel, keeping the sun's beam at the center of the sensor. To investigate the effect of using two-axis sun tracking systems on the electrical generation of a flat photovoltaic system (FPVS) an experimental study is carried out to evaluate its performance under local climate. The measured variables are compared with the fixed axis. The results indicate that the energy surplus becomes about (30- 45%) with atmospheric influences. In case of seasonal changes of the sun's position there is no need to change in the hardware and software of the system. . Considering all above aspects of this tracking system it can be concluded that, it is a flexible tracking system with low cost electromechanical set-up, low maintenance requirements and ease on installation and operation.**

***Index Term*-- Microcontroller, Solar energy, Sensor, Stepper motor, Two-axis solar tracker.**

I. INTRODUCTION

The solar tracker, a device that keeps photovoltaic or photo thermal panels in an optimum position perpendicularly to the solar radiation during daylight hours, can increase the collected energy by up to 50%. Commercially; single-axis and two axis tracking mechanisms are available. Usually, the single axis tracker follows the Sun's East-West movement, while the two-axis tracker follows also the Sun's changing altitude angle. Sun tracking systems have been studied with different applications to improve the efficiency of solar systems by adding the tracking equipment to these systems through various methods [1]–[7]. A tracking system must be able to follow the sun with a certain degree of accuracy, return the collector to its original position at the end of the day and also track during periods of cloud over.

The aim of this work is to design a microcontroller operated two-axis Sun tracker which works efficiently in all weather conditions regardless of the presence of clouds for long period and also to investigate the effect of using two-axis sun tracking systems on the electrical generation of a flat photovoltaic system (FPVS), an experimental study is carried out to evaluate its performance under local climate.

Theoretical calculation of the energy surplus in the case of tracking collectors is as follows: Assume, the maximum radiation intensity is I=1100 W-m^{-2} falling on the area which is oriented perpendicularly to the direction of radiation. It is assumed, the day lengths t=12h=43000s as well as the daylight length and it is compared, the tracking collector which is all the time optimally oriented to the sun with the fixed collector which is oriented perpendicularly to the direction of radiation only at noon.

For fixed collector, The projection of the sun beam on the PV Cell, which is oriented perpendicularly to the radiation direction, is equal $S=S_0\cos\varphi$ and the angle φ is changing in the interval $[\pi/2,-\pi/2]$ during the day where S_0 is the collector area. The angular velocity of the sun moving cross the sky is equal $\omega=727\times10^{-5}s^{-1}$ and the differential of the falling energy is equal dW=IS dt. When it doesn't consider the atmosphere influence and can calculate the energy, which is fallen on the collector area $S_0=1m^2$ during one day.

$$w=\int_{-21600}^{+21600} IS_0\cos\omega t dt = IS_0\left[\frac{\sin\omega t}{\omega}\right]_{-21600}^{+21600}$$

$$=\frac{2IS_0}{\omega}=303\times10^7\, watt.s................(1)$$

For the tracking collector which is all the time optimally oriented to the sun: When it isn't considered the atmosphere influence, it can be calculated the energy, which is fallen on the collector area $S_0=1m^2$ during one day

$$W=IS_0t=475\times10^7\, watt.s\, ... (2) \quad (\text{Since}\ \varphi=0^o)$$

Comparison Equation 1 and Equation 2 shows the energy surplus 57% when it isn't considered the atmosphere influence. It would be really obtained this surplus for example on the Moon surface[1], [2], [10].

This work was supported in part by the Department of Mechanical Engineering, RUET, Bangladesh.

Md. Rabiul Islam Sarker is with the Rajshahi University of Engineering & Technology (RUET), Boulder, Rajshahi 6204, Bangladesh. (Email: islamrabiul@yahoo.com)
Md. Riaz Pervez is with the Rajshahi University of Engineering & Technology (RUET), Boulder, Rajshahi 6204, Bangladesh. (Email: pie_parvez@yahoo.com)
Mohd. Rafiqul Alam Beg is with the Rajshahi University of Engineering & Technology (RUET), Boulder, Rajshahi 6204, Bangladesh. (Email: rabeg.meruet@yahoo.com)

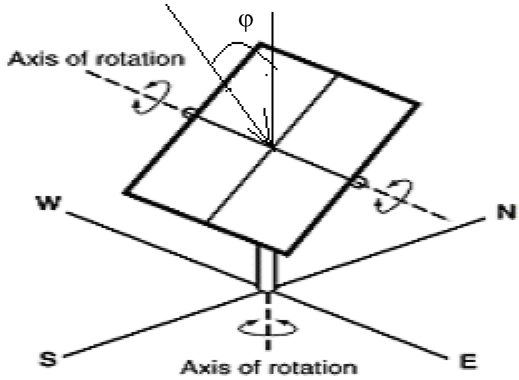

Fig. 1. Two axis tracking PV array.

II. DESIGN OF TWO AXIS SOLAR TRACKING SYSTEM

A. Electromechanical System

The designed tracking system consists of a software based online tracking method as shown in Fig. 2. The main components of the designed system are LDR (light dependent resistor) as sun sensor Microcontroller with built in ADC (AT89C51), stepper motor driver circuit (ULN2003), two stepper motor and PV cell supporting metallic structure with mechanical gear mechanism.

The electromechanical system consists of two drivers with two steeper motor of 0.1° per step: the first for the joint rotating about the vertical axis and the second for the E-W tracking as shown in Fig. 2 The sun position sensors (Photocell) give an mV voltage proportional to the radiation beam position inside the sensor. This sensor is intended to keep the radiation beam normal with collector. Sun sensor's detector determines system misalignment (position error of solar radiation collecting unit) and then sends a signal to the controller (Microcontroller's software). The controller (Microcontroller's software) uses the sun's rate and sun sensor information as inputs to generate proper motor commands to slew the collector. The Microcontroller contains database program based on sun's position for every time of a definite day. When the stepper motor gets the commands from the controller, the motor starts to rotate at a definite angle according to the controller command that slew the collector.

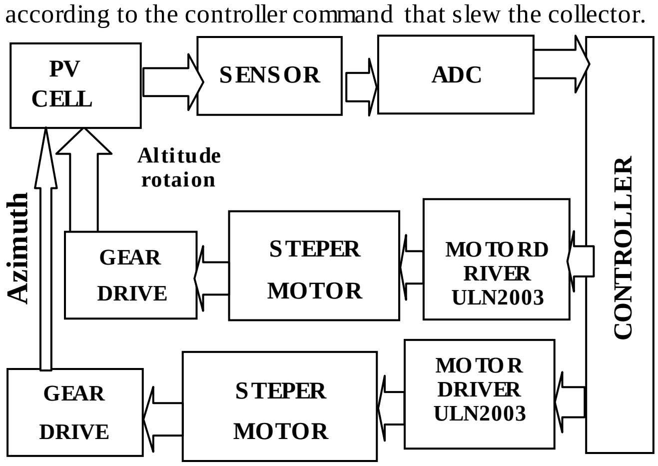

Fig. 2. Block diagram of two-axis tracker

Several functions (depending on solar irradiation and control status) are to be realized by the mechanism. After finding the sun, the system starts working in ‘‘CLOSED LOOP’’ mode.

Getting the transfer function is rather complicated, but it can be derive from the block diagram of fig..3:

$$\varphi_s = (\varphi_{s,h,} \varphi_{s,e}) \quad (1)$$

$$\varphi_m = (\varphi_{m,h,} \varphi_{m.e)} \quad (2)$$

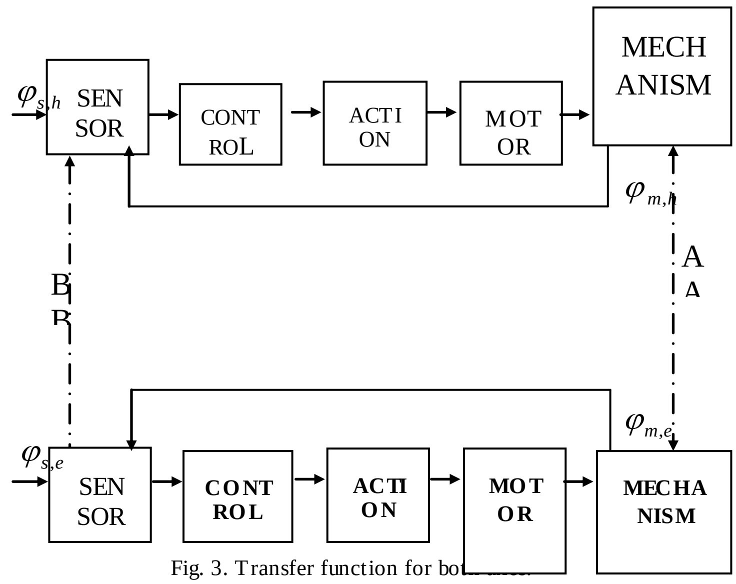

Fig. 3. Transfer function for bo

Where φ_s is the angle of the sun, φ_m is the direction to which the mechanism moves, subscriph h is for axis HH and subscript E is for axis EE.

The cross-coupling of AA and BB (fig.-3) is nearly zero because of the orthogonal dispo-sition of the axes and the parallel mounting of the sensor. The angles in (1) and (2) are measured respective to and arbitrary reference.

Microcontroller software is developed to determine the different solar angles and the optimal positions of the tracking surfaces during daylight hours. Microcontroller programming is performed based on solar angles and motor speed calculations. The program of the horizontal and vertical axis tracking system consists of two parts related to the forward and backward motions. According to sensor recoreded value microcontroller controls the intermittent position adjustmentsmade by the steeper motors. The two steeper motors will be idle for 30 min and work only for few seconds. This stepwise tracking simplifies the work of the electromechanical system without great loss in power. The motors works only for few minutes during the whole day. The estimated consumed power by the electric motor and control system is less than 2% of the collected energy.

Fig. 4. Photographic of Experimental set-up of the tracker

Fig. 5. Photographic of Experimental set-up of the Fixed Panel

Fig. 6. Photographic of Experimental set-up of the entire system

B. Control Software

Control software has been developed to determine the optimum position of the panel during day light i.e. how much deviated from maximum power point. The calculated values taking from the sensor is a function of voltage which is converted to digital form is fed to the microcontroller program to control the actuator of the sun tracker. In this research the programming method of control works efficiently in all weather conditions regardless of the presence of clouds. The software for the solar tracker is written in Bascom AVR version-11.1.8.7. Fig. 7 shows the flow chart of the control software.

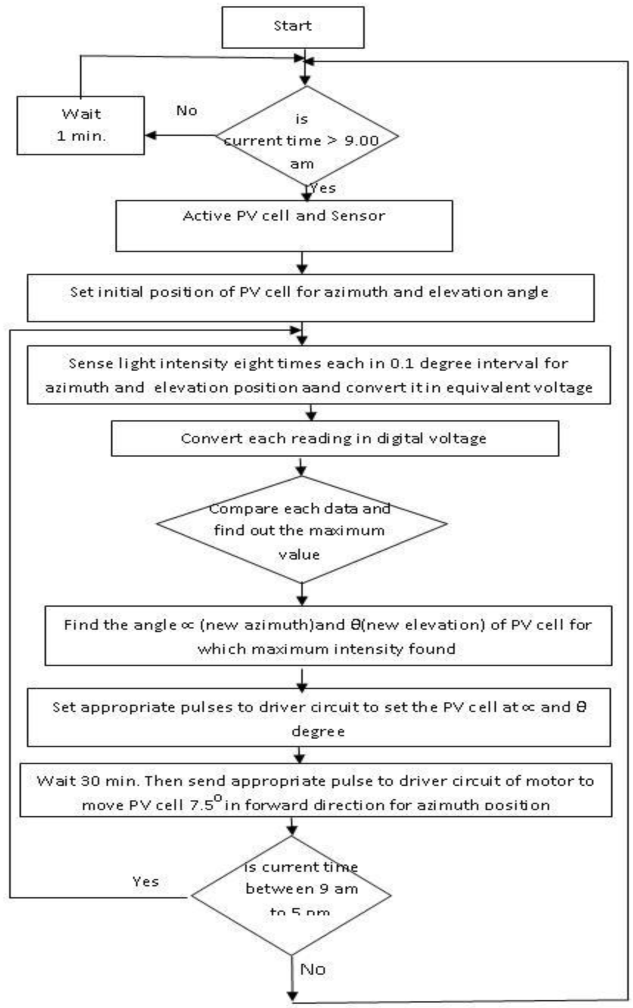

Fig. 7. Flow chart of the Control Software

III. EXPERIMENTAL PROCEDURE

Software based online tracking method has been used inthe designed tracking system. GL-418-TF, model solar panel of 6.5 watt were used to obtain the tracker performance of the tracking module where one system was kept in fixed mode and other one was kept in tracking mode. The simplest method to obtain an I-V characteristic is to load the module with a variable resistor, and measure the voltage and current through digital Multimeters (fig. 8) [8], [9]. Fixed panel was kept tilted at an angle of 40° where the tracking panel is tracked through changing the azimuth and elevation position so that it was always remained perpendicular to the solar beam radiation. . The measured value of voltage and current was the open circuit voltage and short circuit current of the PV cell. Also there was a digital arrangement with the PV panel that could give the solar irradiation in W/m^2, cell temperature etc and power could be obtained from measured voltage and current. Also surplus energy of tracking module with respect to fixed module of PV panel was obtained by the following equation:

Energy Gain (%)= {(power obtained by tracking mode – power obtained by fixed mode) / power obtained by fixed mode} *100%

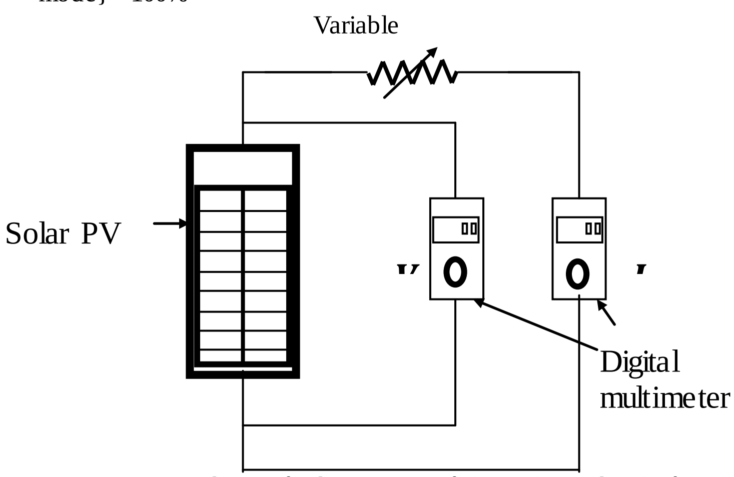

Fig. 8. Connection diagram for determination of I(current)-V(voltage) of PV panel

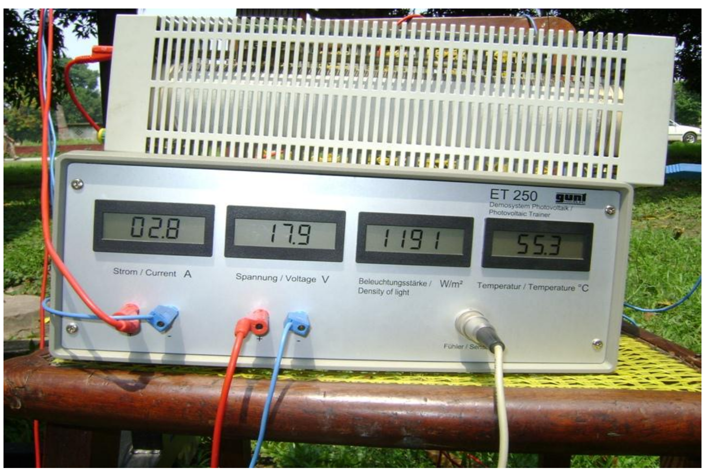

Fig. 9. Digital meter of Intensity measurement system

TABLE I
SPECIFICATION OF INTENSITY MEASURING INSTRUMENT

	Model	ET 250
Current Measurement	Shunt	0.01 Ohm
	Measuring Range	0-20A DC
Voltage Measurement	Voltage Divider	0.11/100 kOhm
	Measuring Range	0-20 V DC
Iluminance Sensor	Measuring Range	0-2000 W/m2
	Output Signal	0-5V DC
	Transducer	photodiode

IV. EXPERIMENTAL RESULTS AND DISCUSSION

Measurements on the PV system with and without sun tracking at various local climatic conditions are shown in Fig. The experiment is carried out through the months February, march and April, 2008 and April ,May 2009.

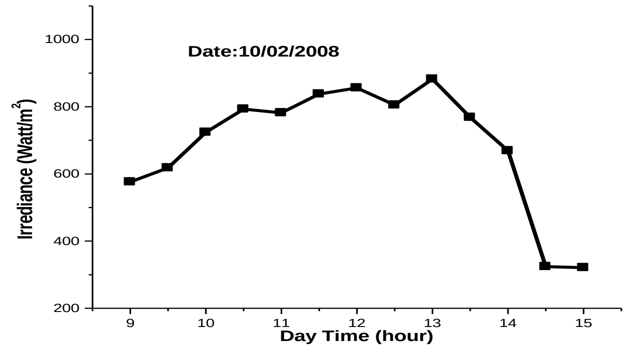

Fig 10 Variation of Intensity with day time

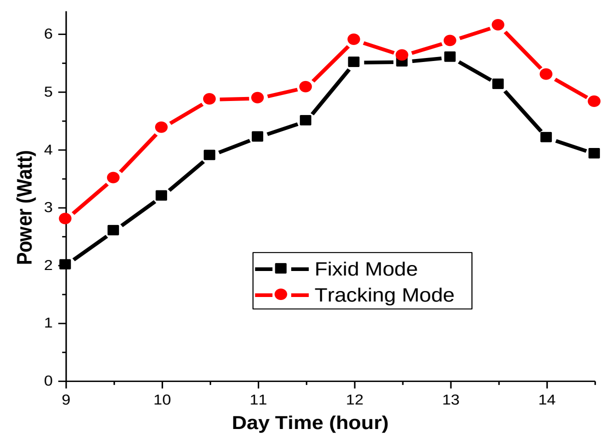

Fig 11 Variation of cell power with day time

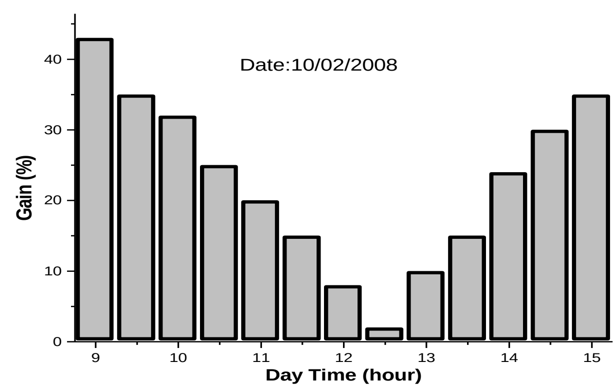

Fig 12 Variation of Surplus Energy with day time

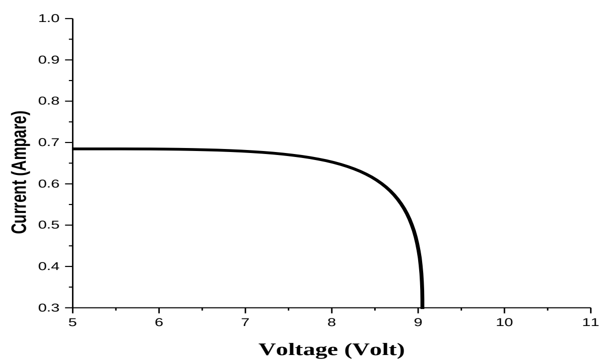

Figure 13 I-V Charecteristics of solar cell (cell temperature is constant)

From the experimental results of variation of intensity with day time characteristic (Fig. 10) it is seen that solar intensity increases with day time up to 13 PM and then decreases but there is some fluctuation of intensity due to flow of some cloudy sky and abnormal atmospheric condition. As a result there is some fluctuation on solar cell characteristic. Also there is shown I-V (Fig. 13) and power characteristics where maximum power is obtained from I-V plot which meet approximately meet with the with ideal curve. The experimental measured variables are compared with that at fixed axis. The results (fig. 11 and 12) indicate that there is an overall increase of output power about 30-45% for the two-axis Sun-tracking system compared to the fixed PV system.

The tracking mechanism is capable of tracking the Sun according to the direction of beam propagation of solar radiation and there has a provision in the software for adjustment of the system in case of seasonal variation if necessary. The power consumption by the system is very low because of low energy consumption devices are used like as COMS digital IC's and other low power consuming solid-state electronic components. Moreover the motor (operate by only 12V DC) also consumes a small amount of energy because it rotates only for a fraction of a minute at every interval of time. The software control circuit faces the panel always perpendicular to the Sun's incident rays with grater accuracy. The tracker is able to withstand available wind load and temperature and aims at the sun with greater than ±0.1 degree of accuracy. It is possible to face the panel always perpendicular to the Sun's incident rays by the software control circuit. So, it has greater flexibility and accuracy.

V. CONCLUSION

In this project work a sun tracker has been developed to increase the amount of power generated by the solar panel through tracking the sun and also an experimental study has been performed to investigate the effect of using two-axis tracking system on the PV power output. The system was designed, as automatic system such that energy generated by the solar panel would be maximum. The tracking mechanism is capable of tracking the sun automatically so that the direction of beam propagation of solar radiation is perpendiculer to the PV panel.

From the results of the performance test of designed system the following conclusions can be drawn.

- A mechanical set-up characterizes the tracker and Micro controller operated control system. During its relatively short time of operation, it proved to be fairly precise and reliable, even in adverse weather conditions;
- The designed solar tracker automatically follows the sun path according to the direction of beam propagation of solar radiation;
- The maximum power output of the tracking solar panel has been found as 6.2 Watt (rated of 6.5 Watt) at average solar intensity of 1100 W/m^2;
- The excess output-power of the tracking solar panel with respect to fixed panel was 30-45% at average solar intensity of 1100 W/m^2;
- The result obtained has a good agreement with that found in the results of George C. Bakos (2004).
- I-V characteristics also tested from PV cell outputs, which approximately meet with the ideal characteristics curve. It was observed that at high temperature PV cell performance becomes low.
- The use of software outside the mechanical part makes the tracker flexible for future development.
- Design simplicity, Low cost and material availability will make the designed tracking system more effective and competitive to other designed system.
- The developed tracking mechanism can be used efficiently to orient other concentrating collectors such as parabolic dish collectors.

Considering all above aspects of this tracking system it can be concluded that, it is a flexible tracking system with low cost electromechanical set-up, low maintenance requirements and ease on installation and operation.

REFERENCES LIST

[1] M.R. I. Sarker, M. R.A Beg, M.Z. Hossain, M. T. Islam and M. R. Zaman. 2005. Design of a Software Controlled Two axis Automatic Solar tracking system. Mechanical Engineering Research Journal. Vol. 5.

[2] M.R. I. Sarker, R.A. Beg, M.Z. Hossain and M.T.Islam. 2006. Design of a New Beneficial Single Axis Automatic Controlled Solar Tracker. Proceedings of the 11th APM, 25-26 December, Dhaka, Bangladesh.

[3] [3] Abdallah S. 2004. The effect of using Sun tracking systems on the voltage current characteristics and power generation of a flat plate photovoltaics. Energy Convers Manage 45 (11-12): 1671-1679.

[4] [4] Kalogirou SA. 1996. Design and construction of a one axis Sun-tracking system. Solar Energy 57(6):465-9.

[5] [5] Khalifa A, Al-Mutawalli S. 1998. Effect of two axis Sun tracking on the performance of compound parabolic concentrators. . Energy Converse Manage 39(10):1073-9.

[6] [6] Al-Mohammad A. 2004. Efficiency improvements of phot-voltaic panels using a sun tracking system. Appied Energy 79(3):345-354.

[7] [7] Abdullah A , Nijmih S. 2004. Two axis Sun tracking system with PLC control. Energy converse Manage 45(11-12):1931-1939.

[8] [8] Rai G.D. 1987. Solar Energy Utilisation .Third Edition,

Khanna Publishers Delhi-110006.
[9] [9] D.G. Infield, A.K.M. Sadrul Islam. 2001. Photovoltaic Technology for Bangladesh. Department of Mechanical Engineering, BUET, Dhaka, Bangladesh.
[10] [10]. Dr. M. R.A Beg, M.R. I. Sarker and Md. Riaz Pervez .An Experimental Investigation on Photovoltaic Power output through Single Axis Automatic Controlled Sun-tracker. Proceedings of the 4th BSME-ASME, 27-28 December2008, Dhaka, Bangladesh.

Md. Rabiul Islam Sarker was born at Jaipurhat, Bangladesh in 20/02/1982. He obtained M.Sc Engineering in Mechanical Engineering from RUET, Bangladesh in the field of Automatic Control System.
Now he is a Lecturer of the Department of ME, RUET. He is now supervising some B.Sc Engineering thesis & project in the field of automatic control system. He published some journal & conference paper in the field of Control Engineering.
Mr. Sarker is a member of Institute of Engineers, Bangladesh.

Md. Riaz Pervez was born at Tangail, in 20th June 1985, Bangladesh. He received his Bachelor of Science degree in Mechanical Engineering in 2008 from RUET, Bangladesh in the field of Solar Energy with Automatic Control System.
He, Lecturer of Mechanical Engineering, RUET supervised thesis & project work related to the Robotics, Control System & Renewable Energy. He is also interested on Mechatronics & Machine Vision.
Md. Pervez is a member of Bangladesh Society of Mechanical Engineering (BSME) & Institute of Engineers (IEB), Bangladesh.

Prof. Dr. Mohd. Rafiqul Alam Beg was born in 07/01/1959 at Rajshahi, Bangladesh. He obtained PhD in Mechanical Engineering from Jadavpur University of India in the field of Applied Thermodynamics in 1996.
Now he is working as a dean of faculty of Mechanical Engineering of RUET, Bangladesh. He also worked as a Treasurer, Head of the Dept. of the IPE, ME, Director Research & Extansion, Register, Provost of the student Halls.He supervised one PhD student as a home supervisor under JSPS-RONPAKU program in 2008, and also supervised M.Sc thesis in 2009 and a co-supervisor in 20002. He also worked in the various research projects at IIT Khargpur and Jadavpur University as titles (i) Development of Ceramic Coated Diesel Engin using Methanal/ Vegetable oils as alternative fuels (ii) Use of Vegetable oil as a fuel in Diesel Engine (iii) Experimantal Investigation on the performance & Exhaust Emissions of a low heat rejection Engine in 1996 etc.
Mr. Beg as a Fellow of Institute of Engineers, Bangladesh.