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# A Novel Active Sun Tracking Controller for Photovoltaic Panels

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**Abstract:** This study presents a novel electromechanical controller that tracks the sun direction in order to maximize the solar system output and therefore reduces the cost of the KWh produced by PV systems. The electrical part of this controller consists of a stepper motor driven by a PIC and motor driving circuit. This controller is based on an open loop tracking algorithm that depends on a mathematical module to calculate the optimum tilt angle at which the installed collector should be slanted to collect the maximum radiation. A gear system has been attached to the stepper motor shaft to step up the motor torque in order to move the collector along the desired direction. Malaysia, a tropical country, which usually faces a lot of cloudy days has been considered as the case study. A MATLAB simulation has been developed and a PIC positioning controller has been implemented to compare the real sun angle with the proposed controller in order to estimate the system feasibility.

**Key words:** Solar energy, sun tracker, solar collector, tilt angle

## INTRODUCTION

Solar energy systems have emerged as a viable source of renewable energy over the past two or three decades and are now widely used for a variety of industrial, domestic and commercial applications. Such systems are based on a solar collector, designed to collect the sun's energy and to convert it into either electrical power or thermal energy. In general, the power developed in such applications depends fundamentally upon the amount of solar energy captured by the collector (Lee and Chou, 2009).

The most important factor of the solar modules is the peak watt (Wp), which rates the power by a solar module illuminated under the standard conditions: 1000 W m$^{-2}$ of solar intensity, 25°C of ambient temperature and a spectrum related to sunlight passing through the atmosphere when the sun is at a elevation from the horizon (defined as air mass 1.5; i.e., when the path through the atmosphere is 1.5 times than that when the sun is at high noon). Because of day/night and time-of-day variations in insulation and cloud cover, the average electrical power produced by a solar cell over a year is about 20% of its Wp rating. Ultimately, the Wp depends on the collected radiation and the collected radiation depends on the tilt angle (the angle between the collector and the ground line) and many schemes have been proposed so far for optimizing the tilt angle and orientation of solar collectors designed for different geographical latitudes or possible utilization periods (Mousazadeh *et al*., 2009; Yakup and Malik, 2001; Bari, 2000).

If a PV system tracks the sun, the energy yield increases. On days with high irradiation and large proportion of direct radiation, relatively high radiation gains can be obtained by tracking mechanism. In summer, these gains can reach about 50% on clear days and in winter, 300% as compared with systems with a static horizontal PV array. The predominant part of the increase in yield due to tracking can be obtained in summer. The absolute gains are larger than in winter, where the proportion of hazy days is significantly greater in winter as shown in Fig. 1 (German Solar Energy Society, 2005).

Mousazadeh *et al*.(2009) has compared between a collector installed in horizontal mode and a tracking collector. The comparing condition was 1100 W m$^{-2}$ for a period of 12 solar h. The fixed collector collects 8.41 Kwh m$^{-1}$day and the tracking collector collected 13.2 Kwh m$^{-1}$ day. Bione *et al*. (2004) also compared the pumping systems driven by fixed, tracking and tracking with concentration PVs. The results showed that for a given irradiance, the pumped water flow rate was significantly different than the other ones. They proved that the benefit ratios obtained for water volume were

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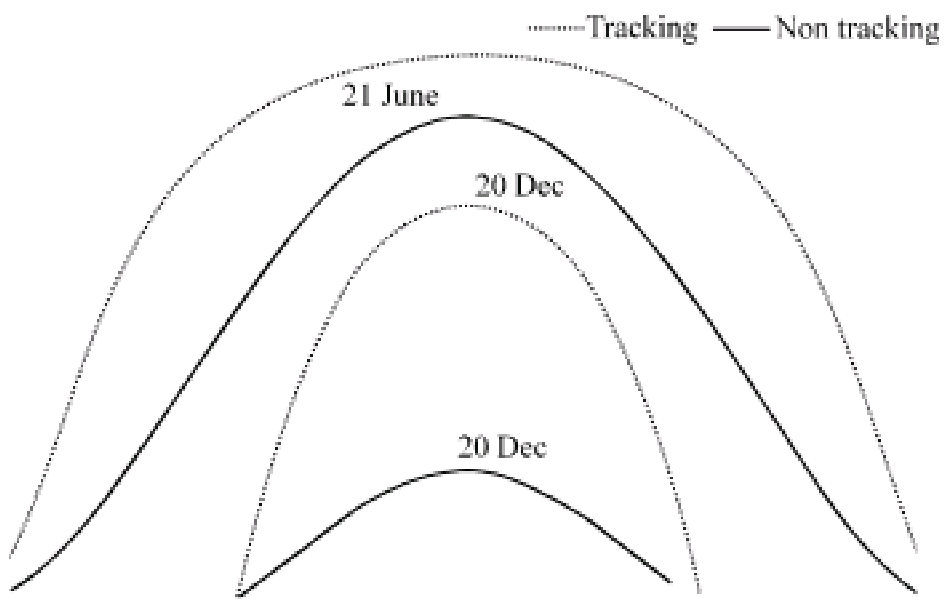


Fig. 1: Comparison of the tracking system with the non tracking systems

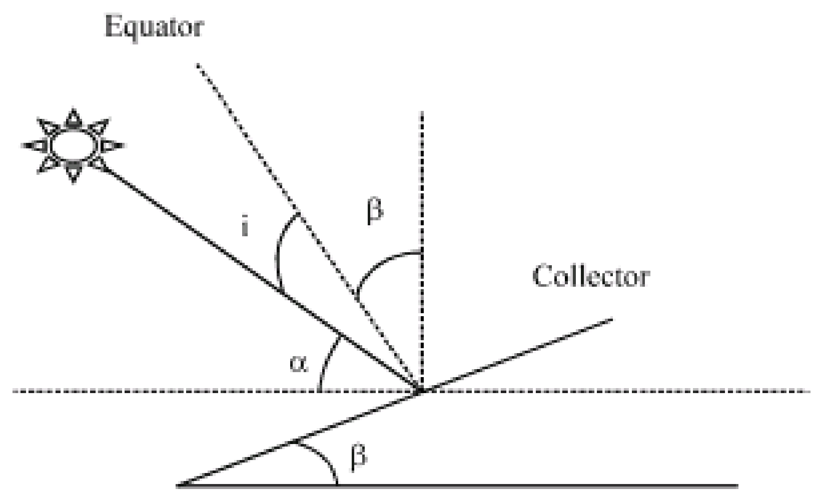


Fig. 2: Geometrical angles of sun's projection

higher than collected solar energy. The fixed PV, the PV with tracker and the concentrating-tracking systems pumped 4.9, 7.4 and 12.6 $m^3$ $day^{-1}$, respectively (Mousazadeh *et al*., 2009; Bione *et al*., 2004).

In general, there are two types of tracking devices; dual axis and single axis. The dual axis system is much better than the single axis since it can focus on the optimum point although it is more complicated than the single axis system. In central Europe, systems using dual axis increase the achieved yield by 30-40% compared with one axis with the yield by 20% (Patel, 1999).

Figure 2 shows the geometrical angles of the projected line from the sun. The perpendicular path between the sun projection and the collector is called the equator. The angle between the collector and the reference line is called tilt angle (β) and the angle between the sun projection and the collector is called altitude angle (α). The incident angle (i) is the angle between the sun projection and the equator (Gunerhan and Hepbasli, 2007; Saraf and Hamad, 1988; Chang, 2008).

Sun is moving across the sky during the day. In the case of fixed solar collectors, the projection of the collector area on the plane, which is perpendicular to the radiation direction, is given by cosine function of the angle of incidence. The higher the angle of incidence (i), the lower is the power (Gunerhan and Hepbasli, 2007; Saraf and Hamad, 1988; Chang, 2008).

## PROPOSED DESIGN

A schematic diagram of the proposed sun tracker is shown in Fig. 3. It consists of two parts; stepper motor driven by a PIC controller and a gear system in order to step up the motor torque to drive the collector. Most of the tacking systems, whatever open loop or closed loop systems depend on light sensors, light resistors, photo transistors, the voltage and the current of the I-V curve and the mathematical formula of the altitude angle of the sun. All mentioned methods are used to track a DC motor driven by electronic circuits or PLCs. The main problem of the tracking methods was represented in the error of determined angle i.e., the deviation from the accurate sun angle (Lee and Chou, 2009; Mousazadeh *et al*., 2009).

The stepper motor and PIC controller technologies can be combined to form an accurate controller that can tilt the solar collectors as close as possible to the sun angle.

**Proposed algorithm:** As shown in Fig. 2 the maximum power can be achieved at a tilt angle which investigates a zero incidence angel. The relationship the tilt, altitude and incidence angles are given below (Gunerhan and Hepbasli, 2007; Saraf and Hamad, 1988; Chang, 2008).

$$\text{At AM time: } \beta + \alpha - i = 90 \tag{1}$$

$$\text{At PM time: } \beta + \alpha + i = 90 \tag{2}$$

To achieve the maximum radiation by the collector, the incidence angle (i) must be zero and so the optimum tilt angle can be determined as follows:

$$\beta = 90-\alpha \tag{3}$$

The altitude angle (α) can be calculated using Eq. 4. It is a function of the latitude (L), longitude (LOD), the time, the date, the angle of declination ($б_s$) and the hour б angle ($H_s$).

$$\sin\alpha = \sin L \sin б_s + \cos L \cos б_s \cos H_s \tag{4}$$

The angle of declination ($б_s$) which shown in Fig. 4 can be defined as the angle between the sun projection and the line from the center of the earth to the point where the collector is located. It can be calculated using Eq. 5.

$$б_s = 23.45 \sin\left[\frac{360(284+N)}{365}\right] \tag{5}$$

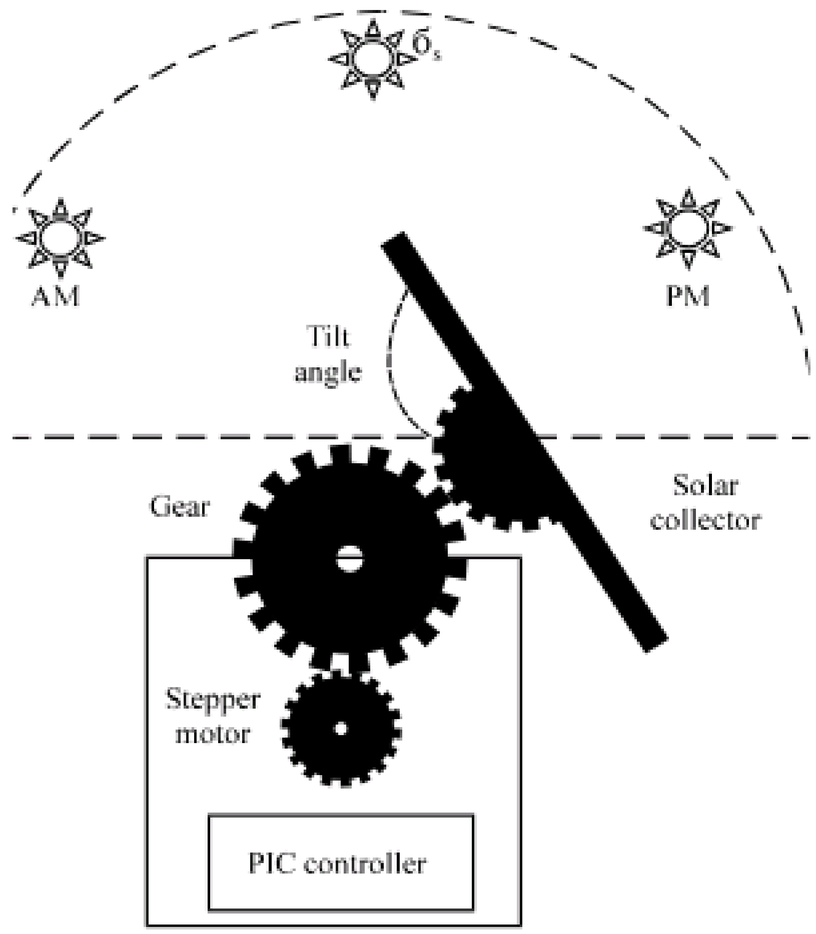


Fig. 3: Proposed design

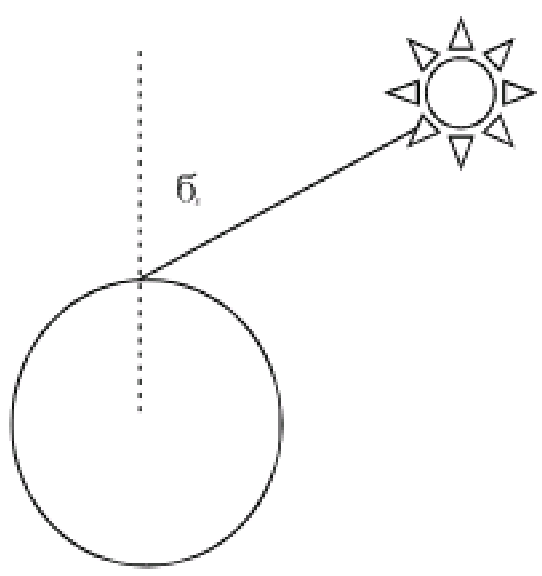

Fig. 4: Angle of declination

where, N is the number of days passed since the beginning of the year and until the moment of calculating the angle. The hour angle ($H_s$) is the angular displacement of the sun from the local point. It can be calculated using Eq. 6. It is clear that the hour angle has a positive value at AM and a negative value at PM.

$$H_s = 15\,(t_s - 12\,h) \tag{6}$$

$t_s$ is the solar time, which is the time measured with respect to the sun. $t_s$ can be calculated using Eq. 7.

$$t_s = LMT + EOT + \frac{4}{0}(L_{zt} - LOD) \tag{7}$$

where, LMT is the time at the moment of calculation , EOT is the equation of time and $L_{zt}$ is local standard meridian. The local standard meridian ($L_{zt}$) can be calculated using Eq. 8:

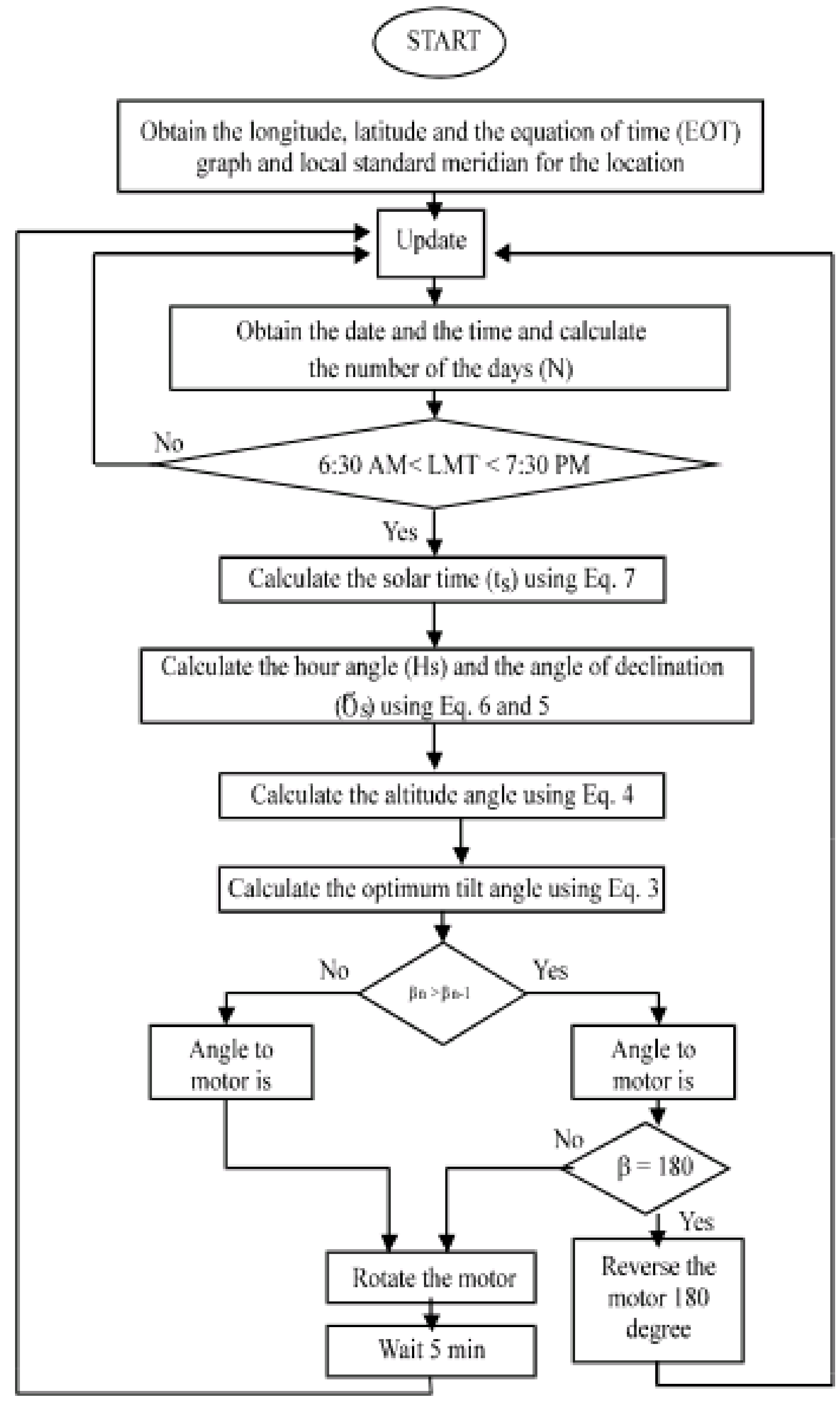


Fig. 5: Tracking algorithm

$$L_{zt} = \text{time zone in GMT}\times 15 \tag{8}$$

The value of ($L_{zt}$) should negative for Eastern countries.

These equations have been implemented in a PIC controller in order to calculate the optimum tilt angle and to rotate the collector to investigate the zero incidences. Figure 5 shows tracking algorithm of the proposed controller which has been developed using (C++, PIC/C converter).

## RESULTS AND DISCUSSION

Most of sun trackers are evaluated by the error in the position of tilt angle and energy gain i.e., how much the collected energy is increased by applying the tracker. The proposed controller has been implemented to evaluate the feasibility of the controller. Two evaluating factors (the error in tilt angel and the energy gain) have been taken into consideration.

**Tracking error:** The tracking error can be defined as the difference between the real altitude angle and the calculated altitude angle by the used method (Lee and Chou, 2009). To evaluate the proposed mathematical model, a schedule of solar angles for the 2nd of July 2009 in Malaysia/Kuala Lumpur (L = 3.1667, LOD = 101.7, Lzt = 120) was obtained using NASA sun position calculator and compared with the angles obtained using the proposed mathematical model. A MATLAB simulation has been developed for the proposed mathematical model in order to calculate the altitude and tilt angles for the chosen day. In Fig. 6, a comparison between the altitude angle by the NASA calculator and the proposed model has been shown. The two angles were almost identical. The error in determining the altitude angle was around 0.014.

In Fig. 7, the optimum tilt angle during the solar day on the 2nd of July is shown. The collectors should be tilted at 90 degree facing the east at the sun rise at 7:11 AM, then the tilt angel should decreased as far as the sun's altitude angle increases. At the solar noon (1:15 PM) the tilt angle should be around 19.9 degree then the tilt angle should be increased as far as the sun's altitude angle decreases. At sunset the tilt angle should be 90 degree facing the west. The stepper motor should be driven until solar noon the in forward mode and after the solar noon until sunset the positioning should be in reverse mode. At sunset, the motor should be reversed back by 180 degrees.

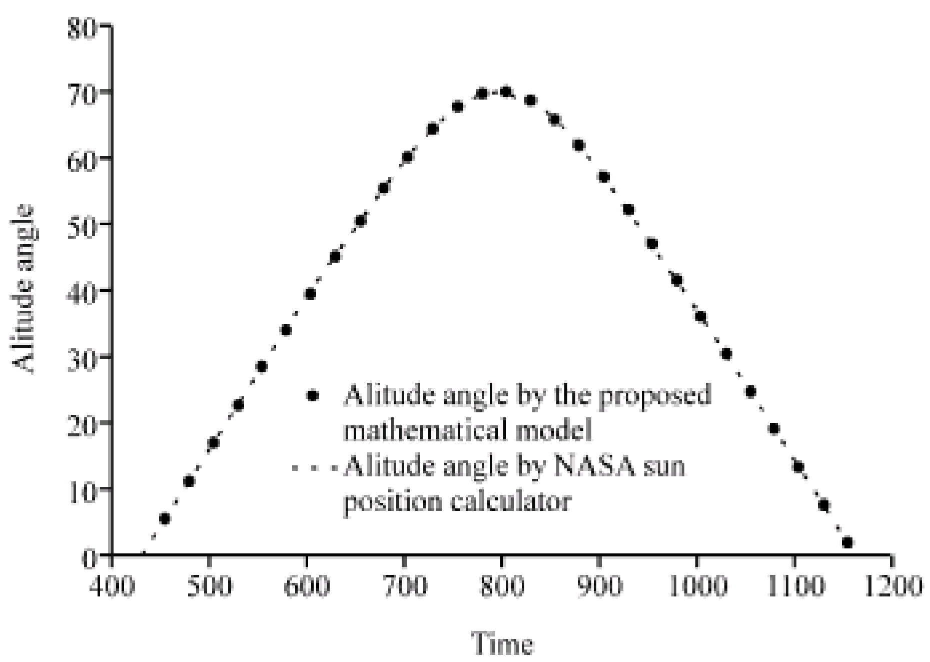


Fig. 6: Comparison between altitude angles. Time scale: Reading/60 = (Hour. Mintures)

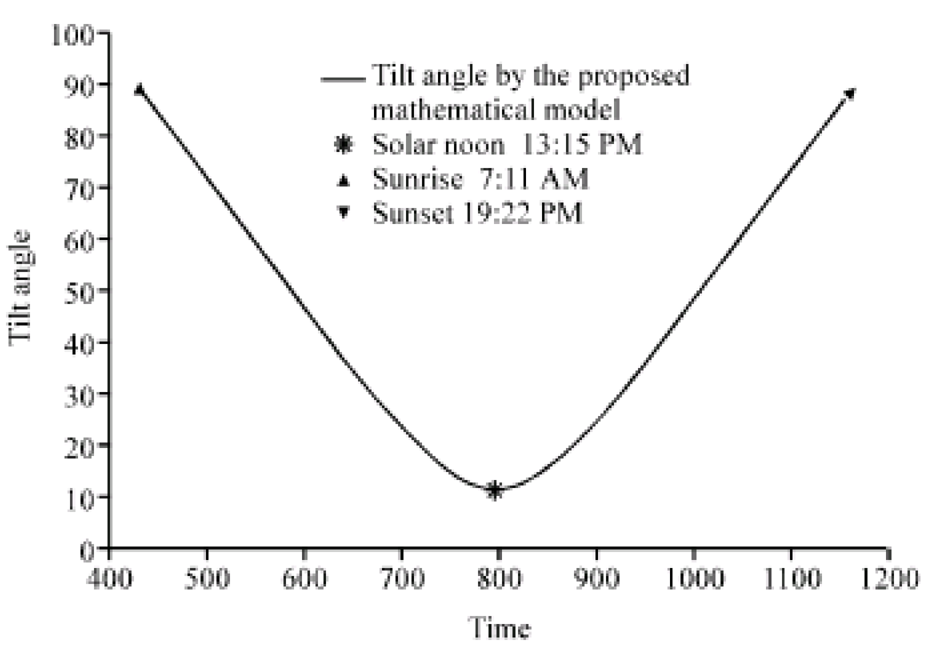


Fig. 7: Optimum tilt angles for 2.07.09 Kuala Lumpur. Time scale: Reading/60 = (Hour. Mintures)

**Energy gain:** Energy gain is the most important factor in evaluating tracking systems. The energy gain means how much the tracking system increases the energy collected compared with non-tracking systems. A MATLAB simulation has been done using the weather file from the Solar Energy Research Institute (SERI) at Universiti Kebangsaan Malaysia (UKM). The simulation was done for the 17th, 19th and 20th of July in Kuala Lumpur. Figure 8 shows the comparison between the horizontal collectors and proposed tracking collector for the 17th of July. During this day there was a cloudy period between (12- 14 PM). Despite the low efficiency tracking during the cloudy condition, the proposed tracker increased the energy collected by 60%. Figure 9 and 10 show the results for the 19th and 20th of July. The proposed tracker increased the collected energy by 50 and 52%,

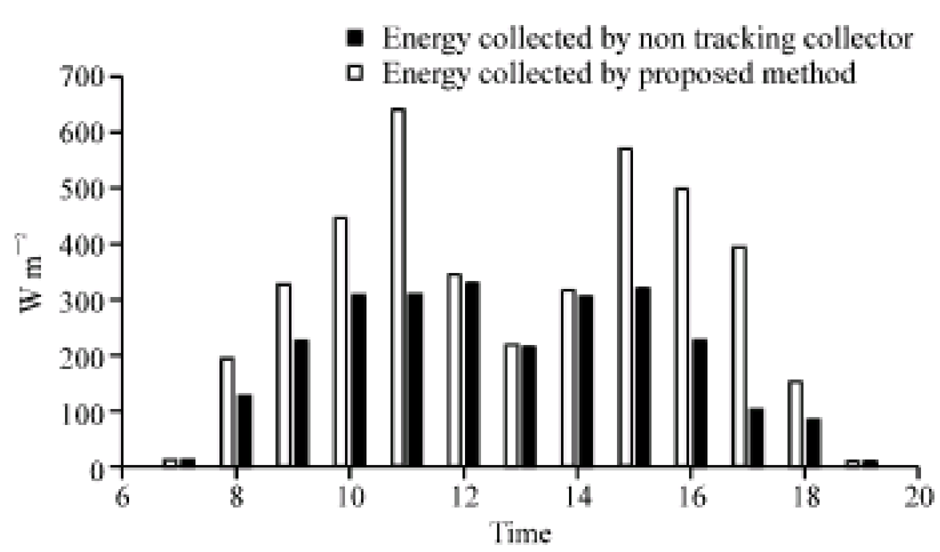


Fig. 8: Energy comparison between tracking and non tracking systems for 17.7.09, Kuala Lumpur

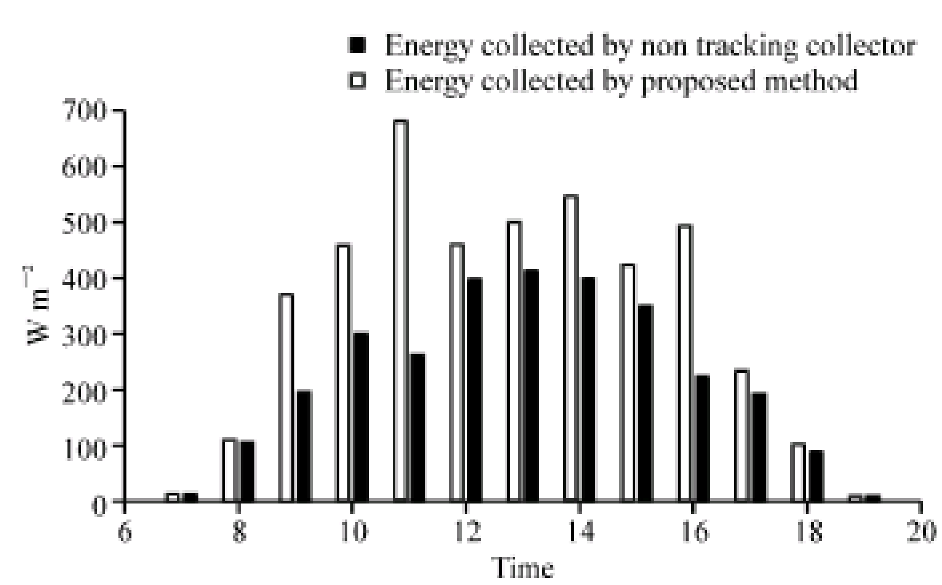


Fig. 9: Energy comparison between tracking and non tracking systems for 19.7.09, Kuala Lumpur

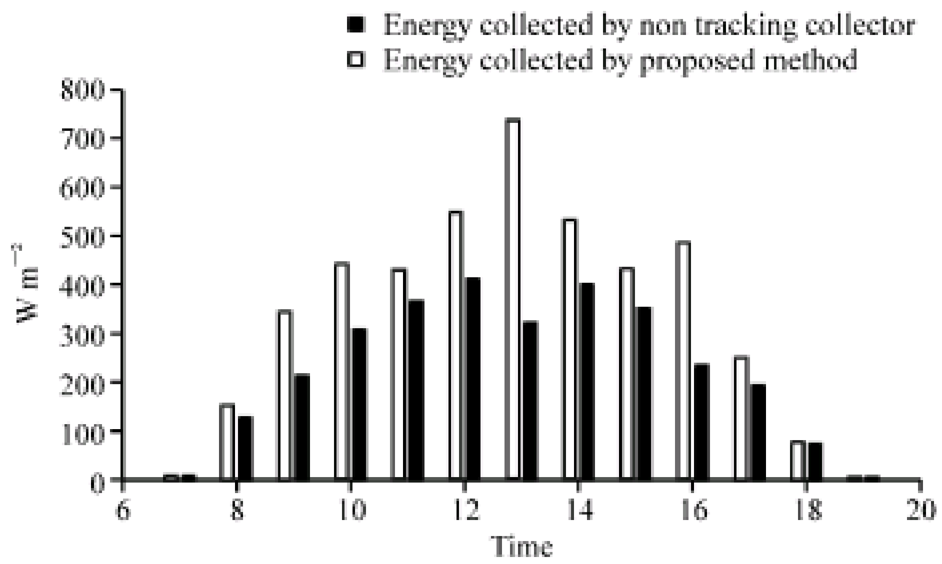


Fig. 10: Energy comparison between tracking and non tracking systems for 20.7.09, Kuala Lumpur

Table 1: Tracking methods comparison

| References | Error | Energy gain (%) |
|---|---|---|
| Akhmedyarov *et al*. (1986) | - | 40 |
| Maish (1990) | 1° | - |
| Enslin (1992) | - | 10-15 |
| Brown and Stone (1993) | <0.01° | - |
| Kalogirou (1996) | - | |
| Khalifa and Al-Mutwalli (1998) | - | 75 |
| Falbel *et al*. (2002) | 0.05-0.2° | - |
| Al-Mohamad (2004) | 0.05°- | 20 |
| Abdullah (2004) | - | 15-44 |
| Aiuchi *et al*. (2004) | 0.1° | - |
| McFee (1975) | 0.5-0.1° | - |
| Muriel *et al*. (2001) | 0.08? | - |
| Abdullah and Nijmeh (2004) | - | 41 |
| Reda and Andreas (2004) | 0.0003° | - |
| Chen *et al*. (2006) | 0.02° | - |
| Chen and Feng (2007) | 0.2° | - |
| Grena (2008) | 0.0027° | - |
| Proposed method | 0.14° | 50-60 |

respectively. The tracker did not increase the energy at constant gain because the energy gain strongly depends on the weather condition at the tracking moment and also the geographical region, i.e., the efficiency of the tracker may vary with the longitudes and latitudes.

**Comparison of solar tracking methods:** Lee and Chou (2009) classified the tracking methods. This classification was based on the control configuration (open loop or closed loop), tracking error and energy gain. Table 1 shows a comparison between the classified methods and the proposed method. The proposed method ranked the 4th in minimum tracking error among tracking methods and the 2nd in the maximum energy gain among the tracking methods.

## CONCLUSION

In this study, a cost effective single axis sun tracker has been developed. The PIC controller successfully calculated the tilt angle of the solar collectors in order to investigate the accurate sun altitude angle. The positioning technique which has been investigated by the stepper motor reduced the error in locating the altitude angle to 0.014°. The proposed tracker has increased the energy collected by (50-60)%. Energy saving was taken into consideration by applying a gear system in order to increase the speed of rotation and decrease the power to drive the motor.

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