

Date/Time Operated Two Axis Solar Radiation Tracking System for Baghdad City

Anas Lateef Mahmood*

Electronic and Communications Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq

Abstract

Finding energy sources is one of the challenges for the next years. The electricity generated from the solar cells is an important energy source. The sun trackers are used to increase the conversion efficiency of the PV panels. These trackers move the panels to keep the best orientation relative to the sun. In this paper a two axis sun tracker system is proposed to track the sun position for Baghdad city. The tracker system uses a pc or microcontroller to control two stepper motors rotation according to predefined functions in the algorithm. These functions calculates the angle of sunrise each day during the year, sunshine time, and the other functions calculates the azimuth and elevation angles of the sun during the day. These functions control the rotation of the stepper motors during the day and after the sunset it rotates the motors to the initial positions.

Keywords: Photovoltaic; Active tracker; Date/time tracking method; Sun position

Introduction

The power density received from the sun at sea level is about (1 kW/m²), therefore it is considered an important alternative source of energy. There are many advantageous of getting electrical energy directly from a solar energy directly such as it does not require fuel, operate silently, low cost maintenance, and there is no atmospheric pollution. The disadvantageous of the PV array is high capital cost. However, this kind of alternative source requires further research and development to maximize the conversion efficiency. One of the major problems of the PV system is the variation of the solar power due to the changes in weather conditions such as clouds, fog, dust, rainfall etc. therefore the PV systems requires special design considerations. Some tracking methods use date/time mode where the sun's position is calculates from formulae or algorithms with the aid of computer. The computer or microcontroller sends signals to the stepper motors to controls the movement of the PV panels according to these formulae. Many methods that uses the calculation of the solar position have been published, the error of these methods have been greater than $\pm 0.01^\circ$ in the calculations of the solar zenith and azimuth angle, some of these methods are only valid for a specific number of years [1]. For example, Michalsky's calculations with uncertainty of greater than $\pm 0.01^\circ$ [2]. Blanco-Muriel et al. with uncertainty greater than $\pm 0.01^\circ$ [1]. The best uncertainty achieved for a Solar Position Algorithm (SPA) to calculate the solar zenith and azimuth angle is described by Jean Meeus [3] with uncertainties equal to $\pm 0.0003^\circ$. It was developed by P Bretagnon in 1982 and modified by Bretagnon and Francou in 1987 [3]. A step by step procedure technical report for implementing Jean Meeus algorithm prepared by Ibrahim Reda and Afshin Andreas [4].

Sun-Tracking Methods

Sun-tracking systems are classified into two types: passive and active trackers. Passive solar trackers (mechanical) are based on thermal expansion of a matter, while active trackers (electrical) can be categorized as microcontroller-based electro-optical sensor, PC-based date/time controlled, auxiliary bifacial solar cell based and a combination of these two systems [5].

The date/time tracking method find the solar position by calculates a motion equation of the Earth. The best position for the PV array that

oriented to the sun is found by a real-time calculation. The position of the PV array can be controlled using devices consist of a microcontroller and motors. The control mechanism of this type of sun tracker is independent from weather parameters change and after the sunset the tracker move the PV panel a desired position. However, this method needs accurate azimuth settings and compensation (Figure 1) [6].

The two-axis tracking system was tilted from the horizontal equal to the latitude angle pointing to south ($\beta=32^\circ$) as shown in Figure 2.

Sun Tracking Equations

Figure 3 shows the sunrise angle variation during year 2014 for Baghdad city, the data are taken from tables found in timeanddate.com website. The data in this site match closely with those listed in the annual Astronomical Almanac published jointly by H.M. Nautical Almanac Office in the U.K. and the Naval Observatory in the U.S. [7].

The sunrise angle in this site is measured in degrees. The sunrise angle is counted in a clockwise direction (CW) with 360° in a full circle. The counting is start from the north direction, where the azimuth value has 0° ; east is 90° ; for the south it is 180° and for the west it is 270° .

The sunrise angle variation during the year can be expressed using Eq. (1)

$$\theta_r = -5.9656 \times 10^{-8} D^4 + 4.1406 \times 10^{-5} D^3 - 7.1372 \times 10^{-3} D^2 - 0.013818D + 116.82 \quad (1)$$

Where, θ_r is the sunrise angle in degree. D is the day of year ($D = 1$,

***Corresponding author:** Anas Lateef Mahmood, Electronic and Communications Engineering, College of Engineering, Al-Nahrain University, Baghdad, Iraq, Tel: +964 770 716 0860; E-mail: anas.lateef@eng.nahrainuniv.edu.iq, anaslatif78@gmail.com

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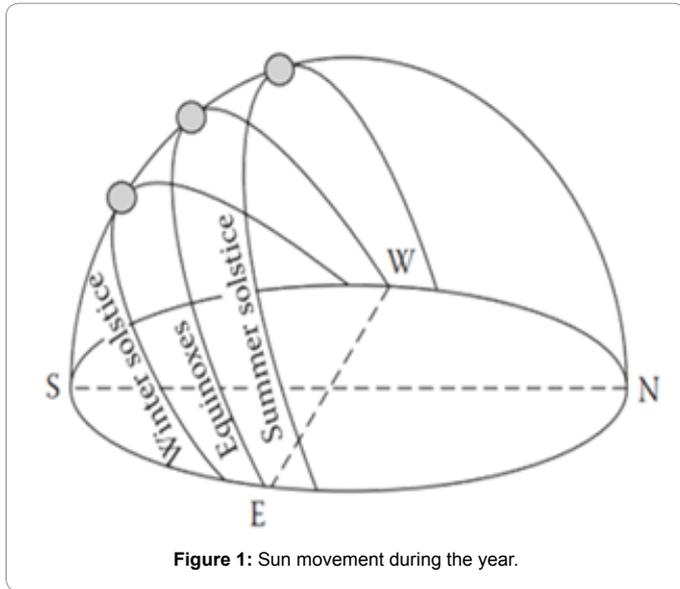


Figure 1: Sun movement during the year.

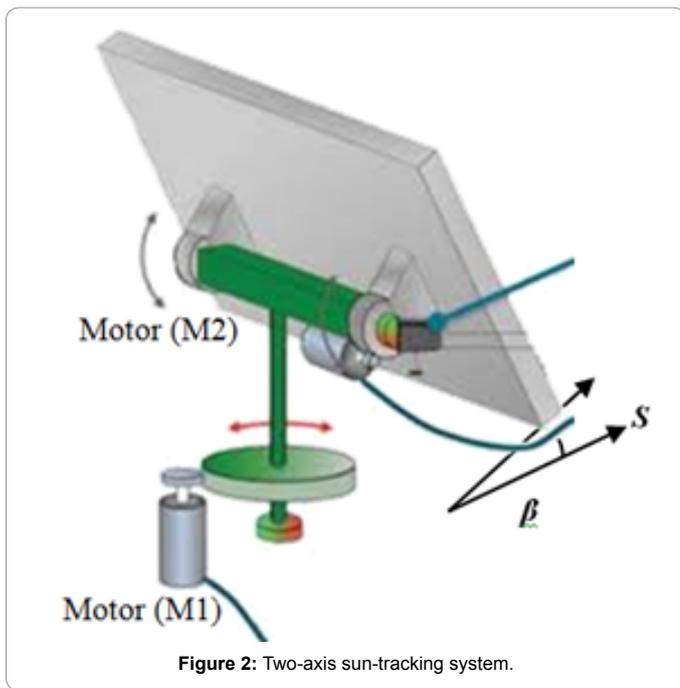


Figure 2: Two-axis sun-tracking system.

2, ... 365 or 366 for leap year).

The difference between the sunrise angle calculated from Eq. (1) above and that found in the tables in [7] is $<1.3^\circ$. This difference can be reduced to $<0.7^\circ$ if the sunrise angle variation expressed using 7th degree polynomial. However, Figure 4 shows the difference between the sunset angle (θ_s) and the sunrise angle (θ_r) ($\omega = \theta_s - \theta_r$) against the day length D_L .

Where ω is measured in degree and D_L is measured in minutes. It is shown from Figure 4 that there is a linear relationship between ω and D_L and can be expressed using the following equation:

$$\omega = \begin{cases} 0.5074D_L - 162.177 & \text{from 1/1 to 30/6} \\ 0.4652D_L - 146.8035 & \text{from 1/7 to 31/12} \end{cases} \quad (2)$$

The day length (D_L) variation during the year (2014) is shown

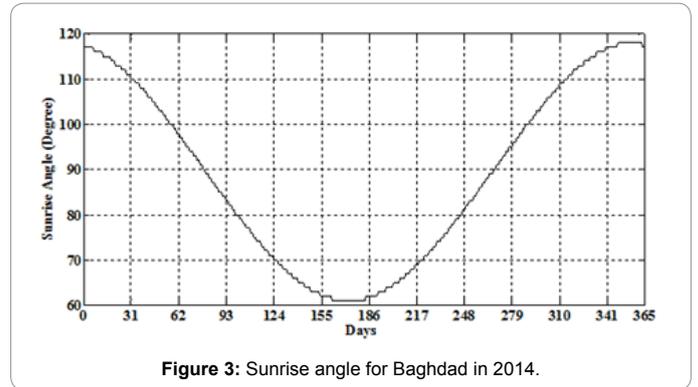


Figure 3: Sunrise angle for Baghdad in 2014.

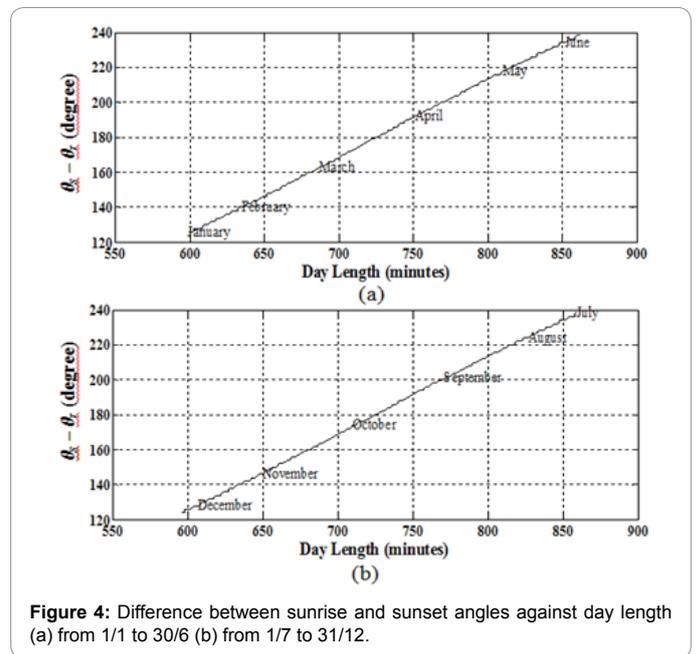


Figure 4: Difference between sunrise and sunset angles against day length (a) from 1/1 to 30/6 (b) from 1/7 to 31/12.

in Figure 5 and it can be expressed using the 4th order polynomial shown in Eq. (3) below:

$$D_L = 2.7169 \times 10^{-7} D^4 - 1.8829 \times 10^{-4} D^3 + 0.032297 D^2 + 0.099972 D + 602.19 \quad (3)$$

The difference between the day length calculated from Eq. (3) above and that found in the tables is <7 minutes and it can be reduced to <2.5 minutes when using 7th degree polynomial. The variation of the ω/D_L in terms of D is found in Eq. (4) below:

$$\frac{\omega}{D_L} = 5.1777 \times 10^{-11} D^4 - 3.5463 \times 10^{-8} D^3 + 5.2397 \times 10^{-6} D^2 + 2.9193 \times 10^{-4} D + 0.20778 \quad (4)$$

The sunrise time (T_r) in the year is found in Eq. (5), where (T_r) is measured in minutes.

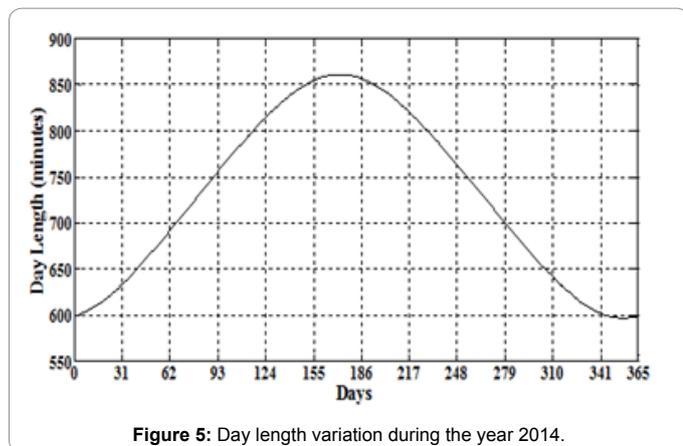


Figure 5: Day length variation during the year 2014.

	2015 Relative error	2016 Relative error
θ_r	$< 1 \times 10^{-3}$	$< 2.7 \times 10^{-3}$
D_L	$< 7 \times 10^{-4}$	$< 1.3 \times 10^{-3}$
T_r	$< 1 \times 10^{-4}$	$< 3 \times 10^{-4}$

Table 1: Relative errors between the values found in 2015 and the values found in 2016.

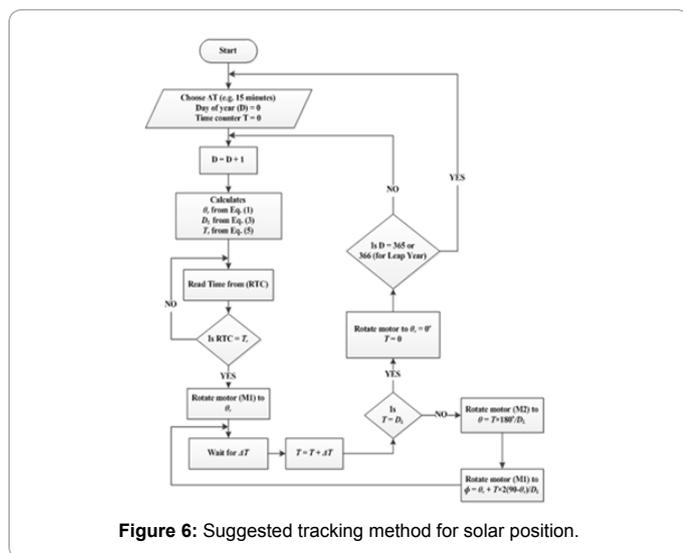


Figure 6: Suggested tracking method for solar position.

$$\begin{aligned}
 T_r = & -3.4227 \times 10^{-14} D^7 + 4.4086 \times 10^{-11} D^6 \\
 & -2.18 \times 10^{-8} D^5 + 5.0203 \times 10^{-6} D^4 - 4.9246 \\
 & \times 10^{-4} D^3 + 0.011169 D^2 - 0.35194 D + 429.14
 \end{aligned}
 \tag{5}$$

Proposed Tracking Method

Equations (1, 3, and 5) are used to calculate θ_r , D_L , and T_r respectively for the years 2015 and 2016 for Baghdad city. Table 1 shows the values of the relative errors between the values found in 2015 and the values found in 2016 [7].

From the results shown in Table 1 it is shown that the relative errors are small, therefore Equations (1, 3, and 5) can be used to calculate (θ_r , D_L , and T_r) for any year in Baghdad. In order to obtain a general sun tracking method for Baghdad city the steps explained in the flowchart shown in Figure 6 are followed. First a constant time delay ΔT which

represent the time to turn ON motor is chosen (e.g. 15 minutes). Starting from 1st January, the program calculates (θ_r , D_L , and T_r) from Equations (1, 3, and 5) respectively, then it reads the time from a real time clock (RTC). If the time equal T_r then it rotate the motor (M1) to an angle θ_r . The program start to rotate motors (M1) and (M2) with angles equal to ϕ and θ respectively where,

$$\phi = \theta_r + T \times 2 \times (90 - \theta_r) / D_L \tag{6}$$

$$\theta = T \times 180 / D_L \tag{7}$$

Conclusion

This paper proposes a two-axis control algorithm for a PV tracking system for Baghdad city. This algorithm uses the date/time mode. In this mode the computer calculates the sun's position from formulae to send signals to the motors. It eliminates the need of any sensor and this can reduce power loss. It also don't affect by changing weather conditions (e.g. clouds, fog, dust, rainfall etc.)

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