

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

Dr. Anas Lateef Mahmood

Ph.D in Electronic and Communications Engineering from Al-Nahrain University, Baghdad, Iraq in 2007
Al-Nahrain University, College of Engineering, Electronic and Communications Engineering Department

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/m^2), 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.'s 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 shows the movement of the sun in the sky during the year in the Northern Hemisphere [6].

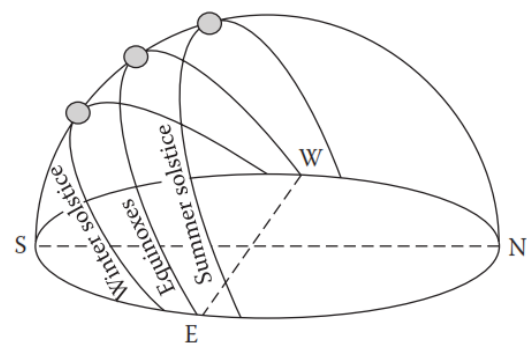


Figure 1. Sun movement during the year.

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.

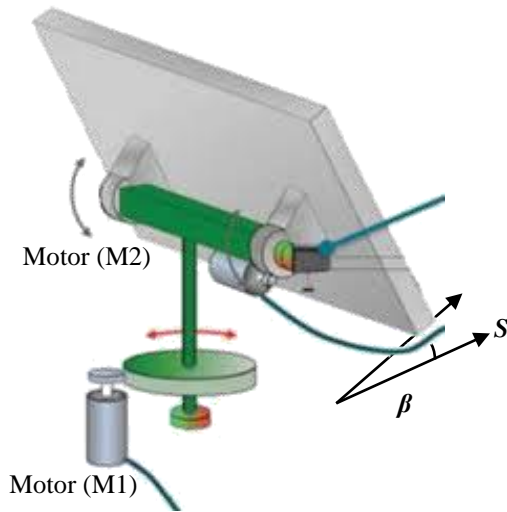


Figure 2. Two-axis sun-tracking system.

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 degrees; east is 90 degrees; for the south it is 180 degree and for the west it is 270 degree.

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

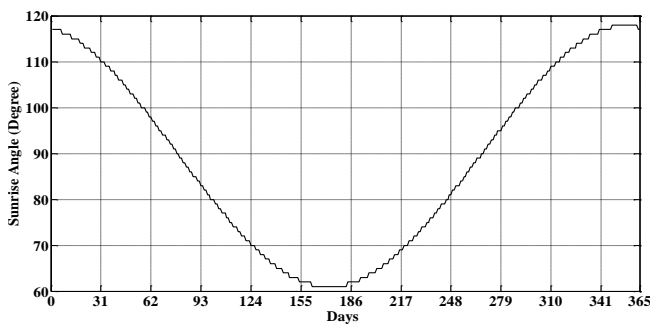


Figure 3. Sunrise angle for Baghdad in 2014.

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

Where

θ_r is the sunrise angle in degree

D is the day of year ($D = 1, 2, \dots 365$ 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 .

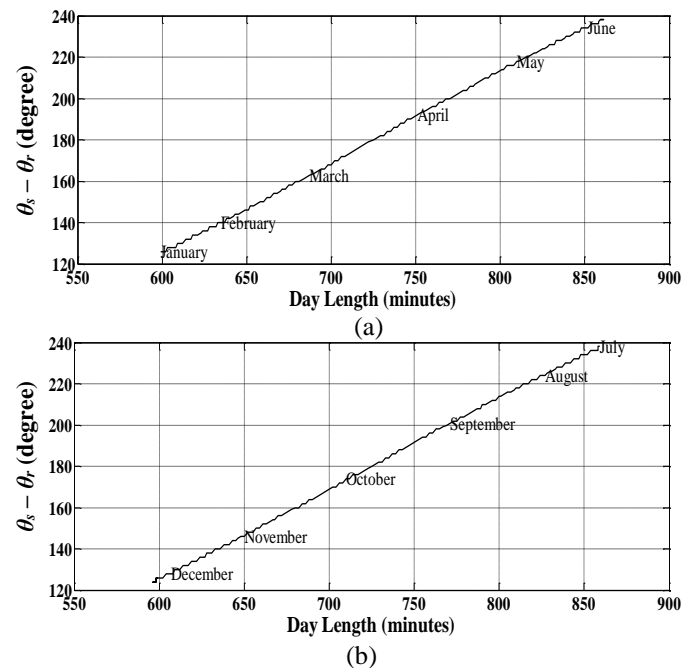


Figure 4 Difference between sunrise and sunset angles against day length (a) from 1/1 to 30/6 (b) from 1/7 to 31/12.

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

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

The day length (D_L) variation during the year (2014) is shown in Figure 5 and it can be expressed using the 4th order polynomial shown in Eq. (3) below.

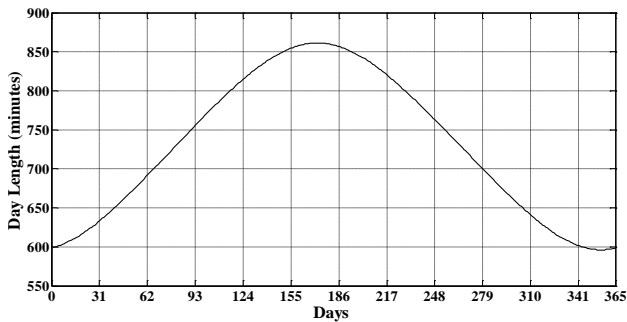


Figure 5. Day length variation during the year 2014.

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

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:

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

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

$$T_r = -3.4227 \times 10^{-14} D^7 + 4.4086 \times 10^{-11} D^6 - 2.18 \times 10^{-8} D^5 + 5.0203 \times 10^{-6} D^4 - 4.9246 \times 10^{-4} D^3 + 0.011169 D^2 - 0.35194 D + 429.14 \quad \dots (5)$$

PROPOSED TRACKING METHOD

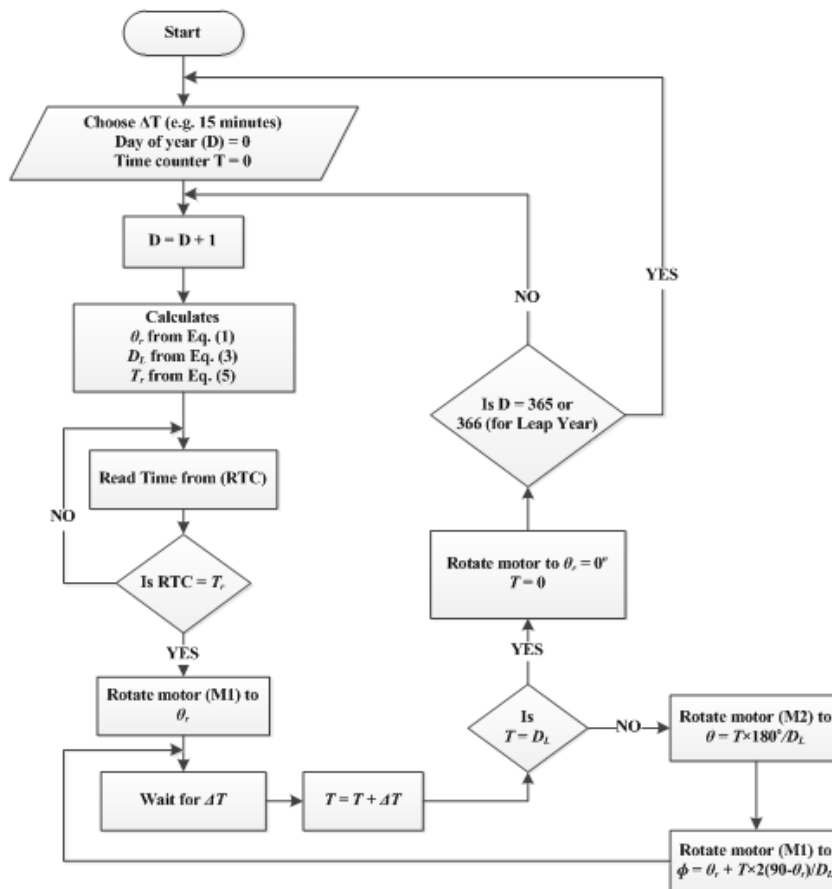


Figure 6 Suggested tracking method for solar position.

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 these values and the values found in [7].

Table 1

	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	$< 1 \times 10^{-4}$	$< 3 \times 10^{-4}$

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

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

$$\theta = T \times 180 / D_L \quad (7)$$

CONCLUSIONS

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)

REFERENCES

- [1] Blanco-Muriel, M., et al. "Computing the Solar Vector". *Solar Energy*. Vol. 70, No. 5, 2001; pp. 431-441, 2001, Great Britain.
- [2] Michalsky, J. J. "The Astronomical Almanac's Algorithm for Approximate Solar Position (1950-2050)". *Solar Energy*. Vol. 40, No. 3, 1988; pp. 227-235, USA.
- [3] Meeus, J. "Astronomical Algorithms". Second edition 1998, Willmann-Bell, Inc., Richmond, Virginia, USA.
- [4] Ibrahim Reda and Afshin Anderas "Solar Position Algorithm for Solar Radiation Applications". NREL/TP-560-34302, January 2008.

- [5] Hossein Mousazadeh, et al. "A review of principle and sun-tracking methods for maximizing solar systems output". *ELSEVIER Renewable and Sustainable Energy Reviews*. Vol. 13; pp. 1800-1818, 2009.
- [6] Robert Foster, Majid Ghassemi, and Alma Cota, "Solar Energy: Renewable Energy and the Environment", CRC Press, 2010.
- [7] <http://timeanddate.com>.