

The Efficiency Evaluation of Sun Tracking Algorithms

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ABSTRACT: One of the most important renewable energies sources, photovoltaic energy has the highest growth potential and the increase rate of the domestic photovoltaic energy generation is increasing quickly. However, photovoltaic energy inherently has setbacks to be actively utilized such as low energy efficiency and high installation costs. Solar tracking systems are important to enhance the energy efficiency. This research aims to evaluate several existing solar tracking algorithms and to develop the solar tracking program which is suitable for Korea's climatic conditions. For the purpose, various existing solar tracking algorithms have been analyzed, and the most suitable algorithm for Korea has been proposed. And then, a solar tracking program has been developed, and its validity has been verified by comparing it with the data of the Korea Astronomy.

Keywords: energy, energy efficiency, solar tracking, algorithms

1. INTRODUCTION

The world is currently pouring its utmost efforts to secure continuous and stable energy sources amid various uncertainties including the oil price hike whose reserves are no doubt limited and the chaotic political situations in the Middle East. In the case of Korea, myriads of policies are underway to expand new renewable energies as clean alternatives sources of energy. Photovoltaic energy is the one with the highest growth potential among new renewable energies, and the increase rate of the domestic photovoltaic energy generation is increasing quickly, climbing to 38.4(%) from 2000 to 2005 (from Ministry of Knowledge Economy, 2007).

However, photovoltaic energy inherently has setbacks to be actively utilized such as low energy efficiency and high installation costs. According to research findings,

adoption of a solar tracking system can enhance the energy efficiency of solar energy by over 20 percent (C. F. Gray, etc. 1998). Accordingly, advanced countries are leading the efforts to develop solar light collecting systems in various methods, which are in turn applied to a variety of systems including photovoltaic systems, solar systems, and sunlightung systems.

This research aims to develop a solar tracking program which is suitable for Korea's climatic conditions. For this purpose, various existing solar tracking algorithms have been analyzed, and the most suitable algorithm for Korea has been proposed. Using the proposed method, a solar tracking program has been developed, and its validity has been verified by comparing it with the data of the Korea Astronomy. Based on the outcome, a solar tracking module has been developed and the tracking system model is being modulated.

2. SOLAR ENERGY BUSINESS IN KOREA

Korea's photovoltaic industry has been developed along with the growth of photovoltaic energy, and nominated as an industry with next-generation growth potential following the semiconductor and IT industries. Currently, various government policies are being conducted (from the Ministry of Knowledge Economy and the New & Renewable Energy Centre) including the (2004~2012) ten thousand photovoltaic house construction plan and feed-in tariffs in a bid to further develop the photovoltaic industry. Moreover, driven by the active participation of local governments and large enterprises, such an endeavour is leading to the development of enabling technologies including solar cells and poly silicon.

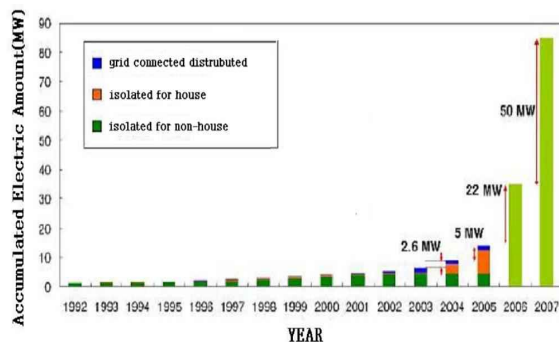


Figure 1: Verification of the solar azimuth

3. DEVELOPING SOLAR TRACKING ALGORITHMS

Analyzing the existed algorithms, the solar tracking algorithms are developed for Korean weather. The equations of Joseph J. Michalsky, Robert Walraven and Jean Meeus are investigated. The developed algorithms are followed.

4.1 Time Coordinates

$Jd = 2432916.5 - \delta y \times 365 + \text{leap} + \text{day} + \text{hour}/24$ ---- eq. 1

Here, $\delta y = \text{year} - 1949$

$\text{leap} = \text{integer portion of } (\delta y/4)$

$\text{day} = \text{day of the year (exam Fed. 1=32)}$

$\text{hour} = \text{UT in hour (exam 9:10:10)}$

$\text{KSP} = 0.16944 \text{ UT}$

4.2 Ecliptic Coordinates

① mean longitude, $L(\text{degree})$

$$L = 280.460 + 0.9856474 \times n \text{ ---- eq. 2}$$

② mean anomaly, $G(\text{degree})$

$$G = 357.528 + 0.9856003 \times n \text{ ---- eq. 3}$$

③ ecliptic longitude, $I(\text{degree})$

$$I = L + 1.9 \times \sin(G) + 0.02 \times \sin(2G) \text{ ---- eq. 4}$$

④ obliquity of ecliptic, $ep(\text{degree})$

$$ep = 23.439 - 0.0000004 \times n \text{ ---- eq. 5}$$

4.3 Celestial Coordinates

① right ascension, $ra(\text{degree})$

$$\tan(ra) = \cos(ep) \sin(I) / \cos(I) \text{ ---- eq. 6}$$

② declination, $dec(\text{degree})$

$$\sin(dec) = \sin(ep) \sin(I) \quad (-90^\circ \leq dec \leq 90^\circ)$$

4.4 Solar Altitude & Azimuth

① solar altitude, $el(\text{degree})$

$$\sin(el) = \sin(dec) \sin(lat) + \cos(dec) \cos(lat) \cos(ha) \quad (lat: \text{latitude}) \text{ ---- eq. 8}$$

② solar azimuth, $az(\text{degree})$

$$\sin(az) = -\cos(dec) \sin(ha) / \cos(el)$$

Here, if $\sin(el) \geq \sin(dec) \sin(lat)$ then $az =$

$$180^\circ - az$$

if $\sin(el) \leq \sin(dec) \sin(lat)$ and $ha > 0$

$$\text{then } az = 360^\circ + az$$

③ sunrise = $720 + 4 \times (\text{Long.} - ha \times 180/\pi) -$

$$\text{eqtime} + (\text{timezone} - 17) \times 60 \text{ ---- eq. 9}$$

④ sunset = $720 + 4 \times (\text{Longitude} - ha \times 180/\pi) -$

$$\text{eqtime} + (\text{timezone} - 17) \times 60 \text{ ---- eq. 10}$$

Here, $\text{acos}(\cos(90.933\pi/180)/\cos(\text{Latitude}))/\cos(\text{decl}) - \tan(\text{Latitude}) \times \tan(\text{decl})$

Table 1: Comparison of existed algorithms

	Michalsky	Walraven	Jean Meeus
Time	O	O	O
Declination	O	O	O
Right Ascension	O	O	
Sidereal Time	O	O	
Azimuth	O	O	O
Altitude	O	O	
Sun rise/set		O	O
Scattering Error Correct	O		

4. EVALUATION OF DEVELOPED ALGORITHMS

The evaluation standards were based on the data provided by Korea Astronomy and Space Science Institute. The developed algorithms have been verified using the value calculated therein and the standard value of the margin of error.

4.1 Verification of the solar azimuth

The projected value and the standard value are compared in the (Fig. 2). The margin of error of the developed algorithms, according to the analyses, falls in the range of 0.01° ~ 2.82° . The day with the highest margin of error was analyzed to be March 22, 12:00 am. The projected value was 164.20° vis-à-vis 167.02° , whose margin of error of 2.28 was the highest. The margin on March 27 and April 1 was analyzed to be the smallest with 0.01° .

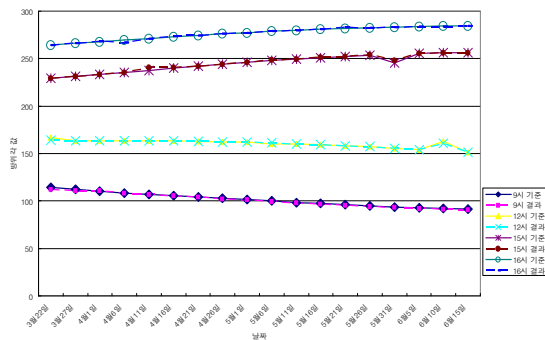


Figure 2: Verification of the solar azimuth

4.2 Verification of the solar altitude

The margin of error of the developed algorithms was analyzed to fall in the range of 0° ~ 3° . The day with the highest margin was April 6 09:00 am, and showed the highest margin of error of 3° between the standard value of 32.12° and the projected value of 29.6° . However, the projected outcome of over 70 percent was analyzed to have a small margin of error of 0.01° ~ 0.1° vis-à-vis the standard value.

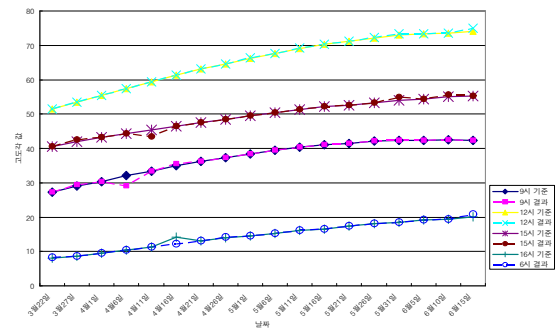


Figure 3: Verification of the solar altitude

4.3 Verification of the sidereal time

The margin of error of the developed algorithms, according to the analyses, falls in the range of 0.08~0.38. The day with the highest margin was March 22 and showed the highest margin of error of 0.38° between the standard value (11.56) and the projected value (11.94). However, June 10 was analyzed to have the lowest margin of error of 0.08.

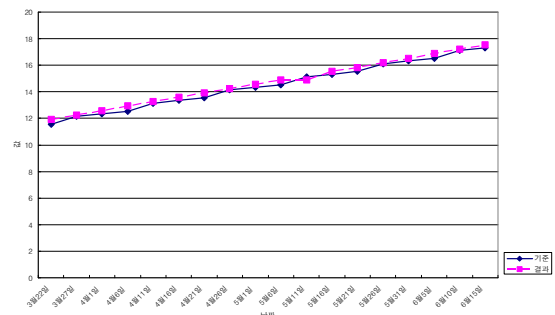


Figure 4: Verification of the sidereal time

4.4 Consequences

The set value and calculated value of the solar azimuth, the solar altitude, the value of sidereal time was compared to identify their margin of error. As a consequence, it was analyzed to be 0.01° ~ 2.82° for the solar azimuth angle, 0° ~ 3° for the solar altitude angle, and 0.08~0.38 for the sidereal time. Moreover, each value not only showed a small margin of error but also had the difference between the standard value and the calculated value

distributed in the small value bracket. Therefore, given that the three had a small margin of error, respectively, the system is judged to have a comparatively high accuracy.

5. CONCLUSIONS

The solar tracking system, one of the efficient methods of using solar energy, has its bottom line in reducing the margin of error by increasing the accuracy level. Accordingly, algorithms needed for tracking were made, which were in turn programmed. The conclusions can be derived as follows.

Research on the formula to predict the solar position have been conducted by Cooper, Spencer, Swift, Pitman, Walraven, Lamm, Michalsky, et al. Among them, the formulas of both Walraven and Michalsky further considered the channels, the solar azimuth and altitude, thereby guaranteeing high accuracy, so a prediction equation was proposed based on this.

The proposed prediction equation was compared with the data provided by the Korea Astronomy and Space Science Institute. Based on the outcome, the solar azimuth and altitude angle were analyzed to have the margin of error of about $0.01\sim 3^\circ$, and as a result of calculating the sunrise and sunset time, a maximum three-minute difference was found, proving the validity of the proposed algorithms.

It is expected the structure and hardware of the solar tracking system are judged to be utilized as the basic data for future research. Also, the developed solar tracking program can be variously applied to systems in order to effectively utilize the solar energy.

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