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Calculation of Sun Position and Tracking the Path of Sun for a Particular Geographical Location

Saheli Ray[1]

[1] *Department of Electrical Engineering, National Institute of Technology, Agartala*

***Abstract*— Solar energy is one of the freely available renewable sources of energy and abundant in almost every part of the world. It is the most fundamental among the alternative sources of energy. With a view to collect energy from the sun, it is necessary to predict the sun position relative to the collection device. In this paper, an attempt has been taken to track the exact location of the sun for any geographical location of the earth. MATLAB software has been used to track the sun path and corresponding information such as sunrise and sunset. Here, the location of Silchar in the state of Assam of north-eastern India has been considered**

***Keywords*— Altitude angle, azimuth angle, latitude, solar energy, solar time, standard meridian.**

I. Introduction

Solar energy has the greatest potential of all the sources of renewable energy [1]. Human life and all other forms of life on our planet are completely dependent on the daily flow of solar energy. For ages, man has been trying to harness the sun as an important source of energy. The best utilization of the solar energy will be when the path of the sun can be tracked.

II. Basic Earth-Sun Angles

The position of a point P on the earth's surface with respect to the sun's rays is known at any instant if the latitude, l, and hour angle, h, for the point, and the sun's declination angle, d, are known. It is explained in Figure 1 [2].

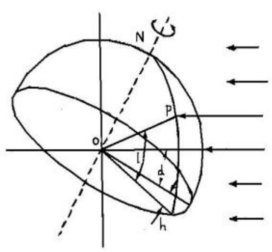

Fig.1 Latitude, hour angle and Sun's declination angles

A. Latitude

Latitude, l, is the angular distance of the point P north (or south) of the equator. It is the angle between OP and the projection of OP on the equatorial plane [2]. The centre of the earth is denoted by O. North latitudes are considered positive and south latitudes are considered negative.

B. Hour Angle

The hour angle, h, is the angle measured in the earth's equatorial plane between the projection of OP and the projection of a line from the centre of the sun to the centre of the earth. It is measure from local solar noon, being positive in the morning and negative in the afternoon [1]. One hour of time is represented by 360/24=15 degrees of hour angle.

C. Delination Angle

The plane that includes the earth's equator is called the equatorial plane. If a line is drawn between the center of the earth and the sun, the angle between this line and the earth's equatorial plane is called the declination.[3].The declination is positive when the sun's rays are north of the equator and negative when they are south of the equator. At the time of winter solstice, the sun's rays are 23.5 degrees south of the earth's equator and the sun's rays are 23.5 degrees north of the earth's equator At the time of the summer solstice. The sun's declination is zero at the two equinoxes. The declination angle is given by

$$d = 23.45 \sin [360/365(284+n)] \quad \text{(degrees)}$$

where n is the day of the year.

III. Relation Between Clock Time And Solar Time

Calculation of sun position must be made in terms of solar time. In order to know sun position, we are to convert local clock time into solar time. The conversion between solar time and clock time requires knowledge of the location, the day of the year, and the standards to which local clocks are set [4]. Time of Greenwich meridian (zero longitude) is known as Greenwich Civil Time or Universal Time.

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Such time is expressed on an hour scale from zero to 24. Local Civil Time is found from the precise longitude of the observer. On any particular meridian, Local Civil time is more advanced at the same instant than on any meridian further west and less advanced than on any meridian further east. [2] The difference amounts to 1/15 hour (4 minutes) of time for each degree difference in longitude.

Clocks are generally set to give the same reading throughout an entire area with a span of about 15 degrees of longitude. The time kept in each such area or zone is the Local Civil Time of a meridian near the centre of the area. Such time is called Standard Time. The Standard time of India is the local civil time of Allahabad. In many parts of the world, clocks are advanced beyond Standard time in summer and such time is called Daylight saving time.

Time measured with respect to the apparent diurnal motion of the sun is called Apparent Solar time, Local Solar Time, or simply Solar time. A solar day is slightly different from a 24 hours civil day due to irregularities of the earth’s rotation, obliquity of the earth’s orbit and some other factors. The difference between Local Solar Time, LST and Local Civil Time, LCT is known as the equation of time.

The solar time and the clock time can be related as [2]

$$LST=CT+ (1/15) (L_{STD} - L_{loc}) +E-DT \quad [hr]$$

Where, LST= Local solar time [hr]

CT= Clock Time [hr]

L_{STD} = Standard meridian of the local time zone.

L_{loc} = Longitude of actual location [degrees west]

E= Equation of time [hrs].

DT= Daylight Savings Time correction, (DT=0 if not on Daylight savings time, otherwise DT is equal to the number of hours that the time is advanced for daylight savings time, usually 1hr).

Values of the Equation of Time, E, are calculated as [2] -

$$E=0.165 \sin 2B - 0.126 \cos B - 0.025 \sin B \ [hrs]$$

Where, $B=\dfrac{360(n-81)}{364}$ and n is the day of the year.

Thus, in order to relate local solar time with clock time, we are to consider two correction factors apart from daylight saving time, which are longitude correction and equation of time.

After calculating Local Solar Time, the solar hour angle, h can be calculated. As hour angle varies by 15 degrees per hour and as it is zero at solar noon, and negative before solar noon, the equation for the hour angle can be given by [2]-

$$h = 15(LST - 12) \quad [degrees].$$

Longitude Correction

At a certain moment the Sun passes over the meridian for all places situated on the same meridian. If two places are not located on the same meridian then they will have a different local solar time, varying by 4 minutes for each degree difference in longitude. In order to calculate the Longitude correction, the longitude of the time zone meridian is to be subtracted from the local meridian of the location being considered.

Equation of Time

The Equation of Time is the amount by which true solar time differs from mean (clock) time [5]. It is the difference, over the course of a year, between time as read from a sundial and a clock, in an ideal situation, which would be at the centre of a time zone, in an area that does not use daylight saving time. The sundial can be ahead (fast) by as much as 16 min 33 s (around November 3) or fall behind by as much as 14 min 6 s (around February 12). It is because of the irregularity in the path of the Sun across the sky, due to a combination of the obliquity of the Earth's rotation axis and the eccentricity of its orbit. Apparently by general convention a negative value for the equation of time means that the sun-dial time is behind the clock (mean) time and a positive value means sun-dial time is ahead of clock time.

IV. Azimuth Angle And Altitude Angle

The azimuth angle is the angle in the horizontal plane measured from true south to the horizontal projection of the sun’s rays [2].

The solar altitude angle is defined as the angle between the horizontal plane of the area and at a point on the earth’s surface a default line connecting the point on the earth and the sun [6].

The zenith angle is the angle between the local vertical and the sun’s ray.

Figure 2 shows the shows the solar azimuth angle, altitude angle and zenith angle denoted by Φ, β and θ_H respectively.

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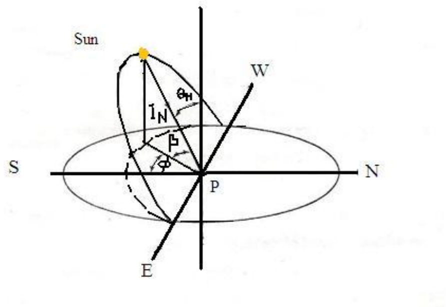

Fig. 2 Sun's Azimuth, Altitude and Zenith angles

The sign convention used for azimuth angle is positive in the west direction of south and negative in the east direction of south. This results in the hour angle and the sun's azimuth angle always having the same sign.

V. RESULTS AND DISCUSSION

The sun's position in the sky can be expressed in terms of azimuth angle and altitude angle. A program has been formulated which takes date and time as input and executes the solar altitude angle and azimuth angle as output for a particular geographical location. The program takes into consideration the daily as well as seasonal variation of the solar path. Thus for a given date, we can know the path that the sun follows at a particular location.

Fig. 3 shows the sun position in terms of Azimuth angle, altitude angle for 26th may for the location of Silchar, Assam.

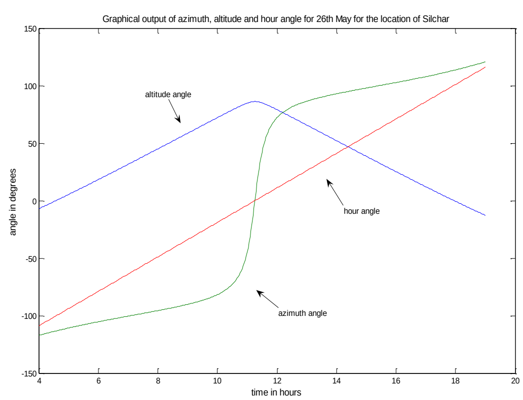

Fig. 3 Sun position for 26th May

The values of the output of the program for 26th May are shown in Table I.

TABLE I
SOLAR PATH FOR 26TH MAY FOR SILCHAR

Clock Time (hr)	Solar Time (hr)	Azimuth Angle (degree)	Altitude Angle (degree)
4.00	4.7380	-7.1060	-117.2024
5.00	5.7380	5.3354	-110.7910
6.00	6.7380	18.2783	-105.3521
7.00	7.7380	31.5470	-100.4440
8.00	8.7380	45.0238	-95.6272
9.00	9.7380	58.6148	-90.1828
10.00	10.7380	72.1917	-81.7585
11.00	11.7380	84.8056	-44.9281
12.00	12.7380	79.1505	72.1392
13.00	13.7380	65.7439	86.4868
14.00	14.7380	52.1361	92.9282
15.00	15.7380	38.5879	97.9422
16.00	16.7380	25.1978	102.7404
17.00	17.7380	12.0668	107.8499
18.00	18.7380	-0.6643	113.6913
19.00	19.7380	-12.7771	120.7539

The curves of azimuth angle, altitude angle and hour angle for 21st June and 22nd December are shown in Fig.4. and Fig.5 respectively. 21st June corresponds to the longest day and 22nd December corresponds to the shortest day. At all other days of the year, the solar azimuth and altitude angles will have values in between the values of these two days.

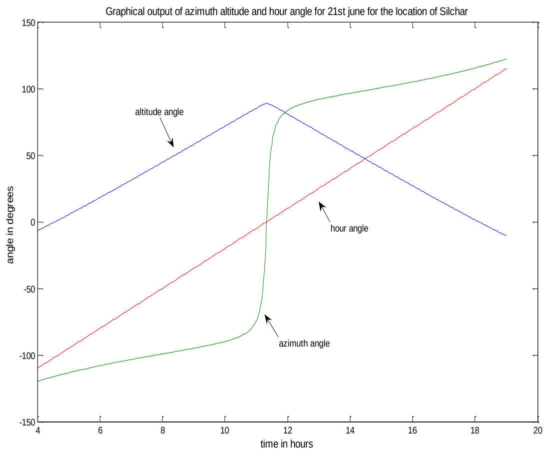

Fig. 4 Sun Positin for 21st June for Silchar

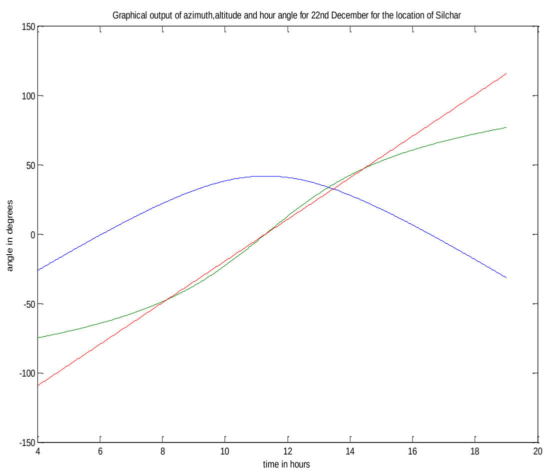

Fig.5 Sun Position for 22nd December

The results show that there is a considerable variation of the sun path at different date and time of the year. By knowing the geographical location in terms of latitude and longitude, the path followed by the sun can be tracked for any location of the earth.

VI. Conclusion

Solar energy if properly utilized can be used as an effective alternative source of energy. The maximum utilization of solar energy depends upon determining the exact location of the sun position. By proper calculation and computer programs, the solar path for any geographical location can be tracked. Thus, a clear idea about the prospects of solar energy for any location can be obtained and accordingly decisions and, measures can be adopted for harnessing solar energy in that area.

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