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Computer Simulation for Studying the Pattern of Solar Tract, Solar Radiation and Solar Angles at Both Equinoxes and Solstices Using Solar Position Algorithm

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Abstract

During the empirical or hypothetical work in the discipline of solar energy it is found that there is numerous parametric quantities need to be calculated or approximated. This paper introduces solar angles computer simulation and calculation using meteorological data to calculate the angle of these parametric quantities at any instant or position on the globe using SPA (Solar Position Algorithm). Specific case has been analyzed to study the pattern of solar tract, solar radiation and solar angles at both equinoxes and solstices, Hadejia town (and any location on $12°\ latitude$) selected for the simulation. The outcome indicated that the planned theoretical account can be profitably used to calculate approximately the tract of the sun during all the seasons of year for perusing the location, azimuth angle and solar radiation received at that particular position of the globe winter solstice ($1160 w/m^2$) and autumn equinox ($1027 w/m^2$) are recorded as the month received maximum solar radiation on the yearly orbital movement of the globe about the sun compare to that of spring ($905 w/m^2$) and winter solstice ($687 w/m^2$).

INTRODUCTION

Solar power is an unlimited source of energy; mankind has regarded the Sun as the copious source of renewable energy, with cipher emission (Abdurrahman et al., 2019) and plays more significant role in energy supply in present life. When solar radiation reaches the Globe's atmosphere, some of the incident energy will be absorbed or scattered by air aerosols, molecules and clouds. The accelerative exploitation of such systems and scientific advances result in an increasing demand for more precise knowledge of the placement of the Sun with respect to a system. The demand may be indirect, e.g., for computing radiation quantities by models and exploitation of satellite images (Espinar et al., 2009; Perez et al., 2002; Rigollier et al., 2004) or direct, e.g., for pointing a concentrating device or a measuring instrument (Blanco-Muriel et al., 2001; Stafford et al., 2009). Correct acquaintance of Earth-Sun geometry and of

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time is one of the results reached in astronomy (Bretagnon, Francou, 1988; Meeus, 1999). Algorithms applied ave been published and this acquaintance for solar radiation applications exist (Reda, Andreas, 2003, 2004). Their implementation is meant to calculate solar zenith and azimuth angles and other related parameters in the period from -2000 to 6000° with a standard deviation of 0.0003° (1''). In practice, time requested for computation may be excessive. Numerous articles have been published in the solar energy field, documenting algorithms for computing the solar location with regard to an observer at a given position on the globe (Blanco-Muriel et al., 2001; ESRA, 2000; Grena, 2008; Kambezidis, Tsangrassoulis, 1993; Michalsky, 1988; Pitman and Vant-Hull, 1978; Walraven, 1978). These algorithms differ in the earned exactness, in their period of validity: from a few years to repeated thousands of years, and in the calculation cost. Various strategies exist to decrease operations, such as reducing the period of validity still keeping a high accuracy (Blanco-Muriel et al., 2001; Grena, 2008; Kambezidis, Tsangrassoulis, 1993), or keeping a large epoch and shrink the accuracy (ESRA, 2000; Michalsky, 1988). Inflowing solar radiation (insolation), with a rhythmic input of 170 billion megawatts to the glove, is the prime driver for our planet's biological and physical processes (Geiger 1965, Gates 1980, Dubayah and Rich 1995, 1996). The amount of solar energy conquered by a collector is principally impressed by the installation azimuth and tilt angle. As we know, in the northern hemisphere, the optimal azimuth is due south (or maybe due north), but the tilt angle relative to the horizon altered with conditions such as the geographic latitude, climate, utilization period and atmospheric composition (Li, 2007, Yakub and Malik, 2001).

Global radiation at a location is roughly relative to direct solar radiation, and varies with the geometry of the receiving surface (Kondratyev 1965, Williams et al.1972). The flux of clear-sky diffuse radiation varies with slope orientation much the same way as the flux of direct solar radiation (Dubayah et al. 1989).

The best energy utilization that comes from the sun will be successfully achieved when the sun path and position can be determined. The location of sun from celestial observation (from sky) can be stated based on its solar culmination and equations of time, solar altitude angle and solar azimuth angle (Abdurrahman et al., 2019). By appropriate reckoning and computer programs, the solar track for any topographical position can be traced. Consequently, a vibrant knowledge about the forecasts of alternative energy for any position can be acquired and accordingly determination and, measurement can be implemented for harnessing solar energy of that particular geographical location using Solar Azimuth/Altitude reckoner (Abdurrahman, 2019).

In this paper solar angles computer simulation and calculation using meteorological data to calculate the angle of these parametric quantities at any instant or position on the globe using SPA (Solar Position Algorithm).

Sun position in the sky

Solar monitoring systems play an important role in the development of solar energy applications, especially in systems with high solar concentrations that directly convert solar energy into heat or electricity (Luque et al., 2007), Observers require sensible, correct predictions where the sun will be located in the sky at any instant of time of a day and year. The sun location with regard to a perceiver on the globe can be fully delineated by means of two astronomical angles; the solar azimuth angle (z) and the solar altitude angle (α). The following is the associated formulation together with the description of each angle. Before the equations of azimuth angles, the solar declination, solar altitude and hour angle are defined. These are necessary in all other solar angle formulations.

1- Declination angle: Is the angle between the equatorial plane (is the plane of orbit of the earth around the sun) and the Sun's direction. Declination angle δ alter smoothly from +23.45^{o} at June solstice in the northern hemisphere, to -23.45 ^{o} at northern winter solstice, see Figure 1 below.

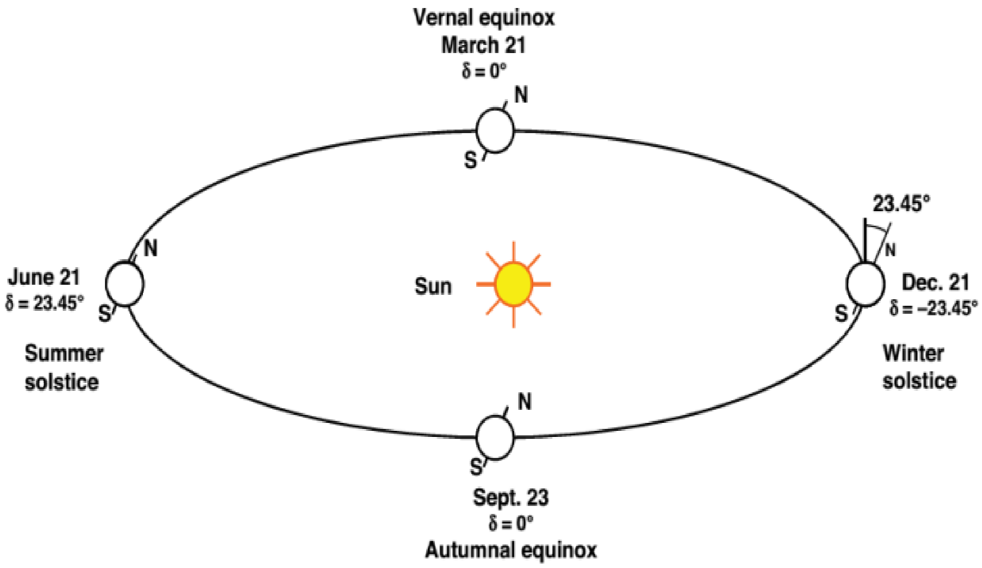

Figure 1. Yearly orbital movement of the globe about the sun (Haberlin, 2012)

Declination angle can be determined by (Duffie and Beckman, 2013)

$$\delta = 23.45° \sin\left[\frac{360}{365}(n + 284)\right] \qquad (3)$$

where n is the day in the year (n = 1 on 1^{st} January).

2- Hour angle, h: Is the angle via which the Globe has revolved since solar noon. Since the Globe revolves at 360^{o}/24 hour = 15^{o}/ h. The hour angle is negative in the morning and is positive in the evening, the hour angle is given by (Duffie and Beckman, 2013):

$$h = (local\ time - 12)15°$$

$$H' = H - \Delta\alpha$$

3- Solar altitude angle, α: Is the angle of the sun comparative to the globes horizon and is calculated in degrees. Solar altitude altered based on the time of day, the latitude on the globe and the time of year.

4- Solar zenith angle, ϕ: Solar zenith angle of the sun is related to the directly over head or to the zenith (figure 2). Solar zenith angle and solar altitude angle are complementing each other ($\alpha + \phi = 90°$) and can be expressed as (Duffie and Beckman, 2013):

$$\sin\alpha = \cos\phi = \sin L \sin\delta + \cos L \cos\delta \cos h$$

where, L is the local latitude, values north of the equator are positive and those south are negative, $-90 < L < 90$.

5- Solar azimuth angle, z: Is the angle between the longitude meridian and the solar beam. For a surface facing due south azimuth angle (z = 0) in the northern hemisphere, 180° due north, $0\ to\ -180°$ for a surface facing eastward and $0\ to\ 180°$ for a surface facing westward.

$$\sin z = \cos\delta \sin h / \cos\alpha$$

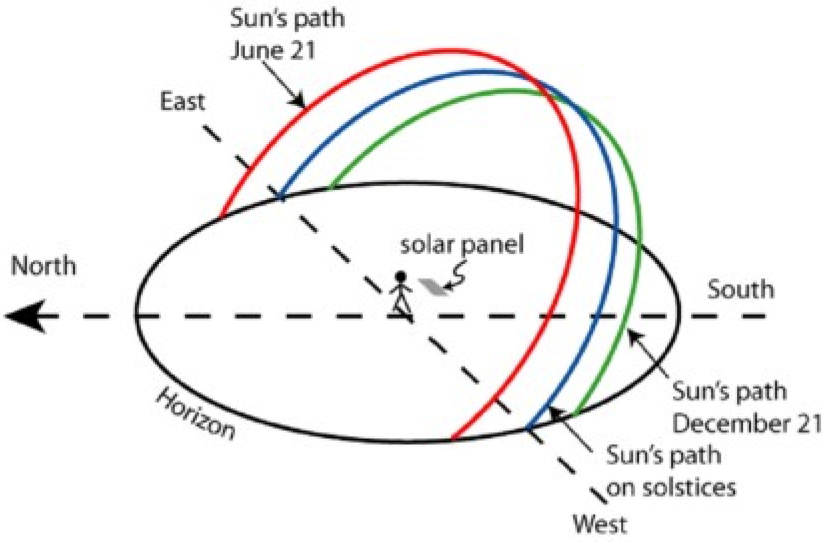

Figure 2. Annual changes in the sun's position in the sky (Li and Lam, 2007)

RIGHT ASCENSION AND DECLINATION

We can specify the positions of the solstices and equinoxes through the equatorial coordinate system. This system is used to discover star positions on the originating occurring outside globe or its atmosphere. Declination and right ascension (RA) are used as methods of measurement. With respect to the celestial equator the Declination measures the vertical position of the object in degrees. Right ascension measures the horizontal position of the object in time units and the March equinox (vernal equinox) is taken as the reference point, Summer solstice: RA= 6 hrs; declination= +23.5° in reference to the figure 3.

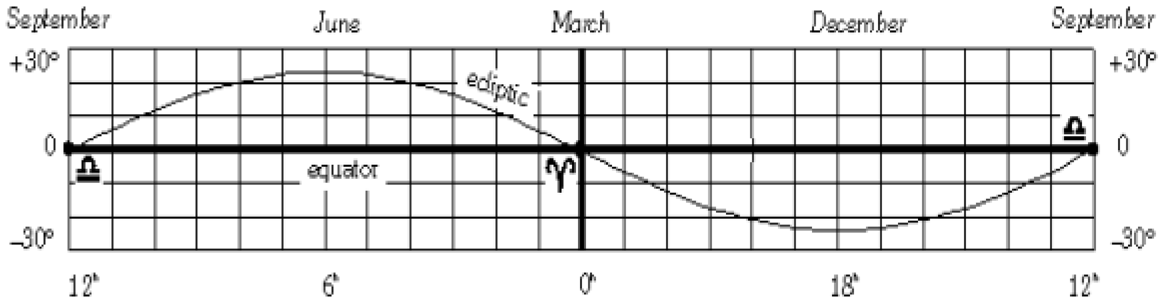

Fig 3: Right ascension and declination angle

Equinoxes and Solstices

Globe's rotational axis is inclined about 23.5° from the perpendicular with respect to Globe's orbit around the Sun. As a result, the amount that Globe's axis inclined away or towards the Sun is altered during the year. June Solstice occurs at the instant the tilt of Globe's axis towards the Sun is at a maximum. The Sun then seems at its highest distance above sea level at noon for perceivers in the Northern Hemisphere than in the Southern hemisphere. June Solstice marks shortest night and the longest day of the year in the Northern Hemisphere (Astro, 2018). On the other hand, the northern hemisphere is further from the sun than the southern hemisphere throughout the astronomic winter, which starts on 21-22 December, a date known as the winter solstice.

December Solstice occurs at the instant the tilt of globe's axis away from the Sun is at a maximum. The Sun then seems at its lowest distance above sea level at noon for perceivers in the Northern Hemisphere. December Solstice marks the longest night and shortest day of the year in the Northern Hemisphere.

There are two times a year when Globe's axis neither tilt away or towards the Sun. In detail, the axis is then at right angles to the Sun giving a nearly equal length of day and night at all latitudes. These instances are referred to as equinoxes (derived from two Latin words: aequus (equal) and nox (night)). The two equinoxes are almost six (6) month apart and are known as the Spring Equinox and Fall Equinox (Astro, 2018).

MATERIALS AND METHODS

First circumstantial position must be selected by finding its angular distance above the horizon, latitude followed by longitude using a portable GPS receiver. Latitude of 12.4481N, longitude 10.0436E and altitude of 337m is the geographical location of Hadejia LGA in Jigawa State, Nigeria. Secondly the remaining stimulant includes; observer time zone, annual average local pressure in millibars and annual average local temperature in degree Celsius are also entered in the SPA.

The Solar Position algorithm

The workflow in figure 4 shows in details the calculation of azimuth angle, hour angle, declination angle, elevation angle using Solar Position Algorithm in order to track the location of the sun during the solstices and equinoxes. The program prompts entering the start date and end date, year, day as well as the time interval to be used. Obviously if calculations are for one day only the day number for the start and end of calculation will be the same and the program will integrate the values of that particular day. Accordingly, by simply altering the day number, solar azimuth angle, hour angle, elevation angle and right ascension for any length of time can be deduced or calculated. The observer must ascertain latitude as southern values are negative and northern values are positive. Solar Position Algorithm (SPA) is to enforce an algorithmic program to compute the solar azimuth angle and solar zenith angle in the period from the year -2000° to 6000°, with precariousness of $\pm 0.0003°$. The modification include changing the direction of evaluating azimuth angles to measure from north and eastward rather of being measured from south and eastward and the direction of measuring the perceivers geographical longitude to be measured as positive eastward from Greenwich meridian instead of negative.

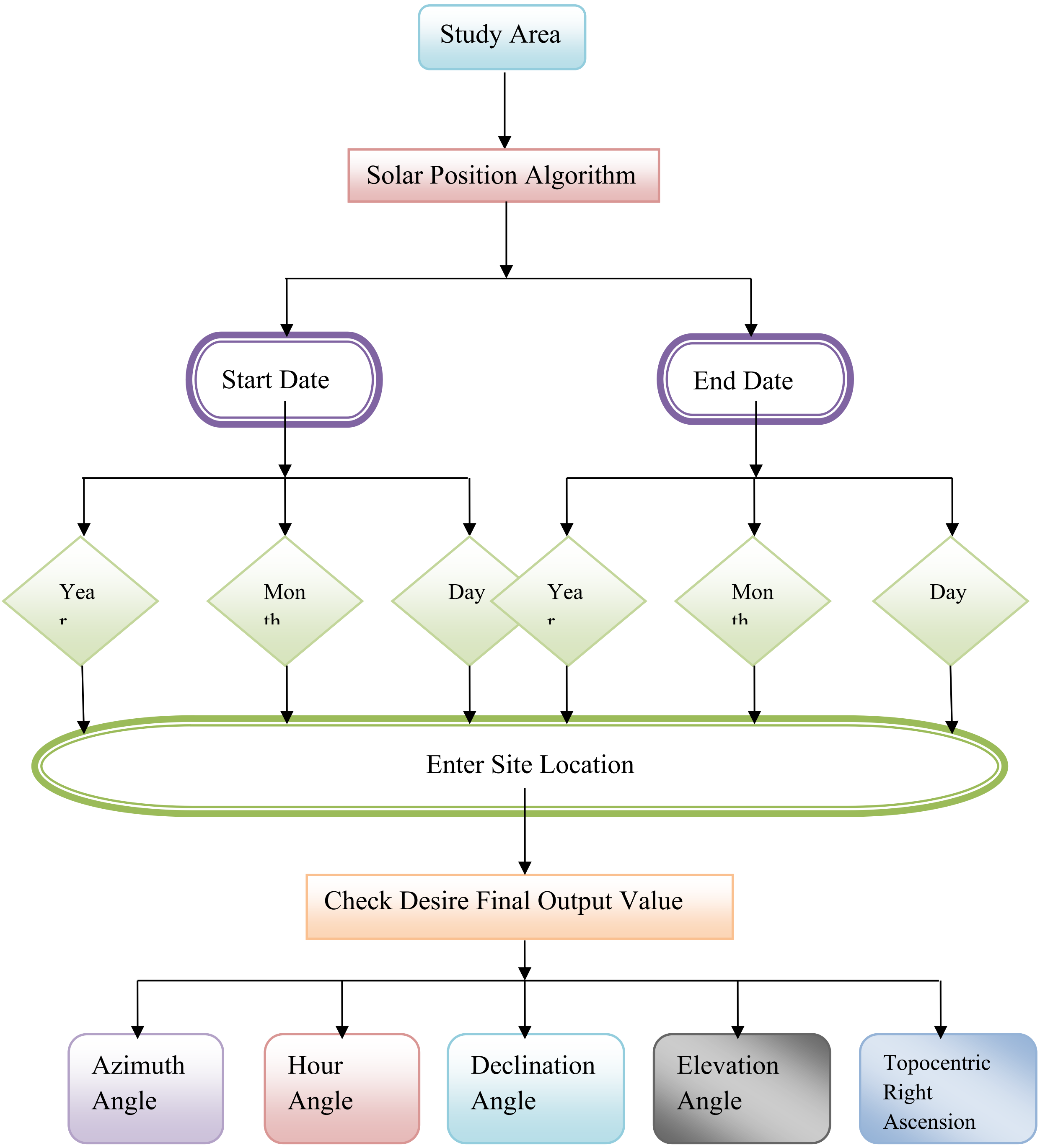

Fig 4: workflow of azimuth angle, hour angle, declination angle, elevation angle using Solar Position Algorithm

RESULTS AND DISCUSSION

Results

The data of the diffuse and global solar radiation have been measured in (W/m^2) by the meteorological station of Binyaminu Usman Polytechnic, Hadejia Jigawa state. The data collected for the period of January –December 2016, and 2017. The time of transcription is 60 min. A program called weather link has been installed to allow the import of measured data solar energy and high solar radiation values was considered. The result was explained graphically in Fig 5, 6, 7 and 8 for the Azimuth angle, Declination angle, Observer hour angle and High solar radiation of Spring equinox, June solstice, Autumn equinox and Winter solstice of the year 2016 and 2017 respectively.

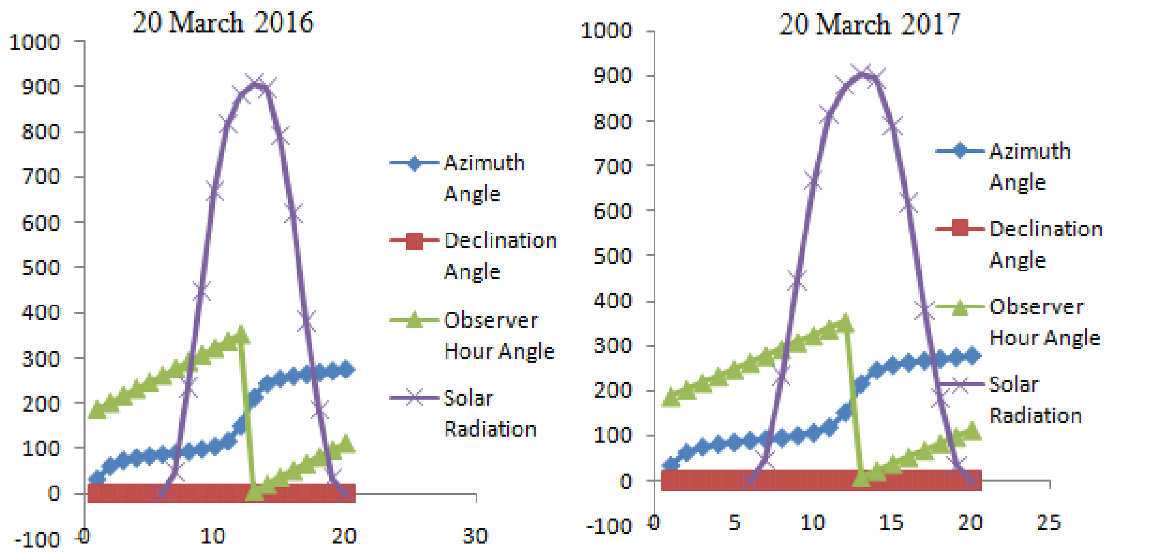

Fig 5: Azimuth angle, Declination angle, Observer hour angle and High solar radiation of spring equinoxes of the year 2016 and 2017

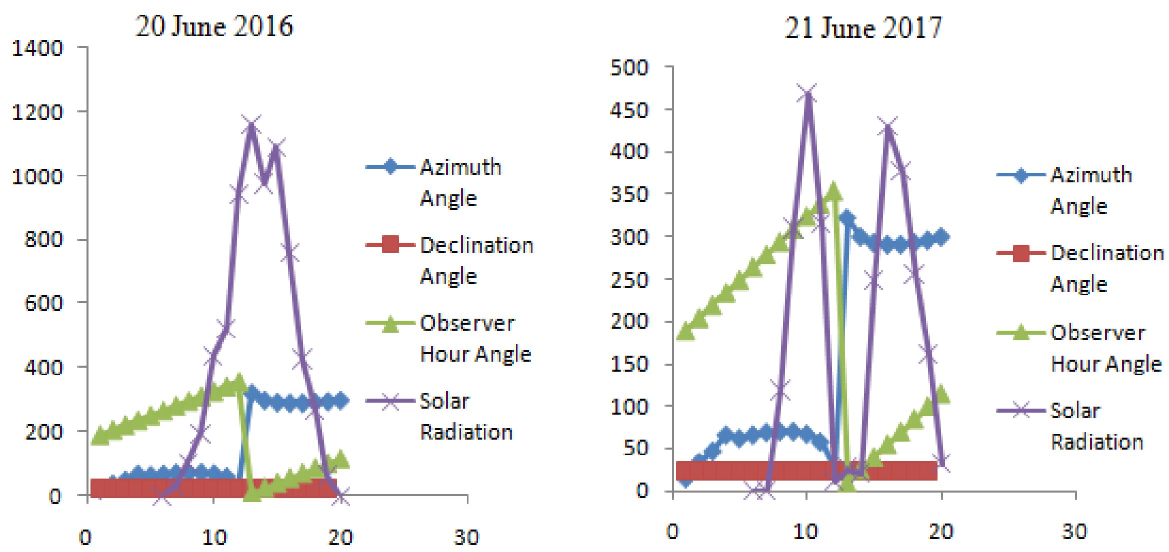

Fig 6: Azimuth angle, Declination angle, Observer hour angle and High solar radiation of June solstices of the year 2016 and 2017

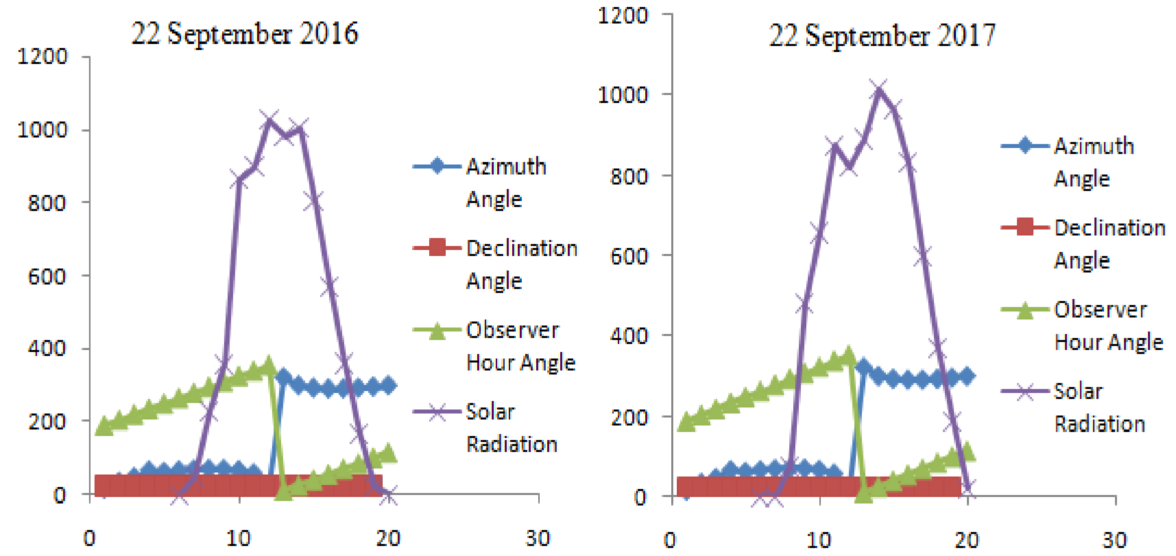

Fig 7: Azimuth angle, Declination angle, Observer hour angle and High solar radiation of autumn equinoxes of the year 2016 and 2017

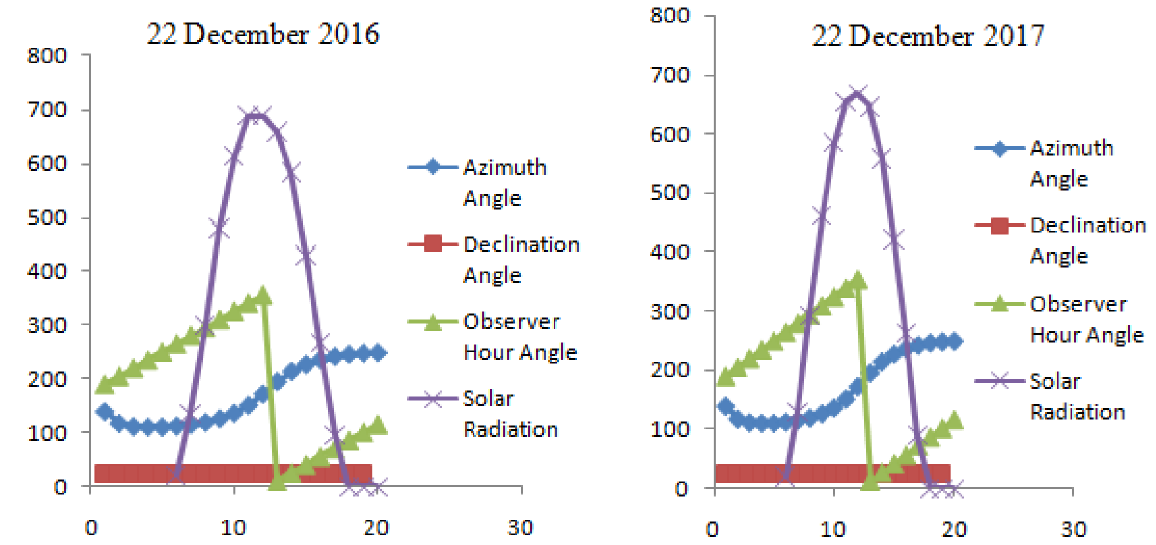

Fig 8: Azimuth angle, Declination angle, Observer hour angle and High solar radiation of winter solstices of the year 2016 and 2017

DISCUSSION

Daily and Annual pattern of the solar azimuth angle in Figures 5, 6, 7 and 8 displays the Azimuth angle, Declination angle, Observer hour angle and High solar radiation of the year 2016 and 2017 changes in for four different dates (21 March, 21 June, 21 Sep and 21 Dec). It was found that in midsummer; the longest day and the shortest night have a maximum value of solar radiation compare to the other three days of solstice and equinoxes with two different maximum values $1169w/m^2$, $758w/m^2$ (see Figure 6). In winter solstice to track the sun from the east to the west will allow you to capture solar radiation as much as accomplishable.

The nature of the graph in fig 5 and fig 8 are related but base on the annual orbital motion of the globe about the sun are two neighboring location. Even though the declination angle are not the same, but they have one maximum value of solar radiation. This show that the paths of the sun of these two days are similar since the nature of the curve of azimuth angle is the same. While fig 6 and fig 7 has the same nature of the azimuth angle and they experience more values of solar radiation than the other remaining two days.

Similarly, for the daily and annual pattern of the solar altitude angle altered for 4 different dates autumn equinox (21 Sep.), summer solstice (21 June), spring equinox (21 Mar.) and winter solstice (21 Dec.). Solar elevation angle is the altitude angle of the sun using the keisan reckoner we study the altitude angle of the sun in both the solstices and the equinoxes; June solstice seems to be the highest elevation angle pursued by the autumn equinox. While the spring equinox is the lowest followed by winter solstice. The higher the altitude angle the higher the solar radiation received at that particular location.

The algorithm computes the global coordinates of the sun (Right ascension a and declination d), and the local coordinates (Hour angle h, Zenith z and Azimuth C) corrected taking into account the atmospherical refraction of geographical location (Grena, 2008). While in this paper we used SPA to compute the solar angles at both solstices and equinoxes which allows one to reach a very good exactitude, adequate to all the desires of solar engineering.

CONCLUSION

The valuable characteristic of solar energy applications, is the solar radiation which run through free fuel. Unfortunately, the sun is moving continuously. The ultimate utilization of alternative energy depends upon determining the particular position of the sun location. By using the solar position algorithm (SPA) and meteorological data, the solar path for any topographical position can be traced and the study of solar radiation at winter solstice, summer solstice, autumn equinox and spring equinox was successful. Winter and autumn equinox has experiences more solar radiation than spring and winter solstice. The azimuth angle we use in tracking the location of the sun has more effect on the solar radiation compared to the declination angle which has less effect on the solar radiation falling on the surface of the globe. In addition there is similarity in curved nature of solar radiation and azimuth angle in both the solstice and equinoxes. The values of solar radiation are connected or depend on the azimuth angle; the higher the azimuth angle the higher the solar radiation experienced at the surface of the globes.

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