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Study of Sun Tracking Systems Considering Computer Modeled Results For Ghardaïa Algeria Site

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Abstract— **Solar energy is becoming more and more important these years, with an exponential growth in the installed capacity around the world. In addition to the standard fixed systems, solar tracking systems have been developed to increase the overall collected energy, maintaining the installed capacity, and are being used with a growing tendency. This paper presents the study of a tracking system prototype that helps the study of the different tracking strategy of one and two axis. The two axis tracking systems aim to that the sun's rays fall perpendicular with the solar collector panel, Whereas in one axis tracking systems the controller must search for the minimum angle between the sun's ray and the normal of the panel. Computer simulation models are also developed for several tracking systems. The results show that from the energetic point of view all the tracking systems evaluated are recommendable but some of them are more recommended then the other in some situation..**

Keywords— **Controller, solar tracking systems, solar panel, computer simulation.**

I. INTRODUCTION

Electrical energy from solar panels is derived by converting energy from the rays of the sun into other forms. The main challenge is to maximize the capture of the rays of the sun upon the solar panels. A practical way of achieving this is by positioning the panels such that the rays of the sun fall perpendicularly on the solar panels by tracking the movement of the sun [2].there for the tracking systems are one of the methods to reduce the power generation cost of costly systems like PV panels [1]. There are different tracking systems [3], tracking the sun by using two axes gives the maximum power but using one axis can reduces the cost of the tracking system. Making decision between two or one axis is the main subject of this paper.

In this paper we propose a SIMULINK model environment that helps a study of any new method of sun tracking system of one or two axes. The method of tracking is entered in a SIMULINK embedded MATLAB function block as an algorithm using MATLAB language coding. The output of is the cosine of the incidence angle and the direct or total energy captured by the panel.

II. THE SUN POSITION MODEL

This model is derived from the equation of elliptical motion of the earth around the sun and the rotational motion of the earth around its own polar axis. The model have as inputs the time, the date, the latitude and the longitude of the given site of interest and the model outputs as a result the coordinates of the sun in different reference frame systems(Azimuth/Zenith, site Cartesian system, …) and extraterrestrial solar irradiance. The model begins by calculating the sidereal time from the day angle (calculated from the day number), the local time, the GMT time zone, the correction given by the equation of time. The use of the sidereal time (not the solar time) is because the earth rotational axis is always points to the same point of the sky (Polaris star).

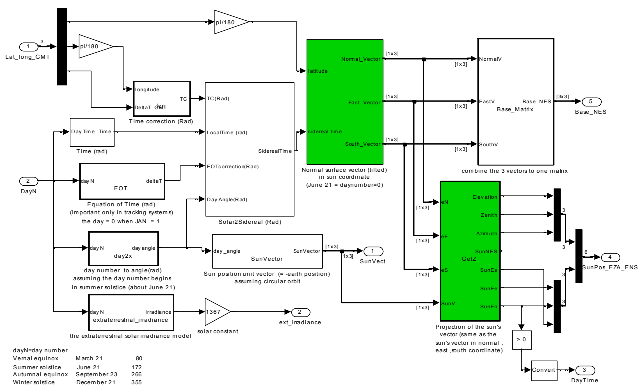


Fig.1: the SIMULINK sun position block model that calculates the suncoordinates, the East-Normal-South vectors and the extraterrestrial solar irradiance.

A. Calculation of the sun's vector in the solar system coordinate reference frame

the block of Fig.2 calculates the sun vector in the solar system coordinate where the z axis is the normal of the ecliptic plane and the x axis is the vector from the sun to the earth when the earth is in summer solstice and y axis axes is the remaining vector (orthogonal to x and y). If the day angle is day_angle then the sun's vector is calculated as:

$$SunVector = \begin{pmatrix} -\sin(day\_angle) \\ \cos(day\_angle) \\ 0 \end{pmatrix} \quad (1)$$

For example, this formula gives (0 1 0) when day_angle =0 (june 21).

B. *Calculation of the sun's vector in the earth coordinate reference frame*

To calculate the sun vector coordinate in the earth reference frame we must calculate the unit vectors of the earth reference frame and then project the sun's vector in solar system coordinate Equation.1 onto those unit vectors (those vectors form the earth coordinate reference frame).

The unit vectors are calculated in two steps Fig.2: First we calculate those vectors in earth coordinate system Equation.2 and then rotate the results by 23.45° (the inclination angle of the polar axis in respect of ecliptic plane) to give those vectors in solar system coordinate.

$$NormalV = \begin{pmatrix} \cos(Latitude) * \cos(\varphi) \\ \cos(Latitude) * \sin(\varphi) \\ \sin(Latitude) \end{pmatrix}$$

$$EastV = \begin{pmatrix} -\sin() \\ \cos() \\ 0 \end{pmatrix} \quad (2)$$

$$SouthV = \begin{pmatrix} \sin(latitude) * \cos(\varphi) \\ \sin(latitude) * \sin(\varphi) \\ -\cos(latitudea) \end{pmatrix}$$

Where φ is the Sidereal time (radian).

The rotation axis by the tilt angle is the same as the x axis because when the earth is at summer solstice; all the earth vectors must be rotated by the tilt angle from Z axis down to Y axis Equation.3 [3].

$$Vrotated = \begin{pmatrix} 1 & 0 & 0 \\ 0 & \cos(Earth\_til) & \sin(Earth\_til \\ 0 & -\sin(Earth\_til) & \cos(Earth\_til \end{pmatrix} V \quad (3)$$

Where Erth_til is the tilt angle of 23.45°.

The SIMULINK implementation of those equations (2)and (3) are given in Fig.2.

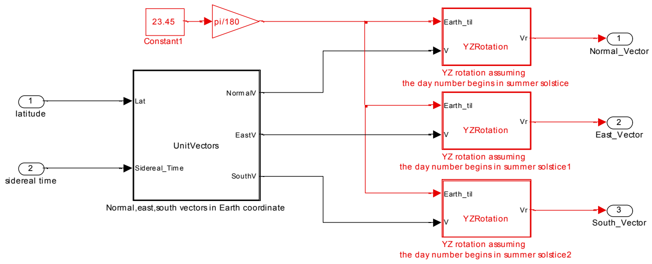


Fig.2: Earth unit vectors calculated in solar system coordinate reference frame.

Finally, we use the unit vectors and the sun's vector to produce azimuth and zenith angles in the final block of Fig.1.

III. THE RADIATION MODEL

The Extraterrestrial Radiation is modeled by the following equation [5]:

$$I = I_0\left(1 + 0.0335 * \cos\left(\frac{2\pi*(dayN-3)}{365.242}\right.\right. \quad (4)$$

Where ah is 0.14(above sea level/1000).*

The air mass at sea level is calculated as [5]:

$$AM = \frac{1}{\left(\sin(SEA) + (0.505.\left(SEA\frac{180}{\pi} + 6.09\right)^{-1.63}\right.} \quad (5)$$

Where SEA is the sun elevation angle (Radian).

The Equation.4 gives the irradiance when the surface is normal with the sun's ray and when the surface is above the atmosphere. Other surfaces must include a loss called cosine loss. We calculate this loss in our model by doing scalar product between the unit sun's vector and the unit normal vector of a given surface. The effects of the atmosphere and the altitude on different irradiance components are modeled by the following equations.

The attenuation of air mass is given by this factor [5]:

$$AM_{factor} = \left((1 - ah) * (0.7)^{(AM)^{0.678}}\right) + a \quad (6)$$

Where ah is 0.14(above sea level/1000).*

The diffuse irradiance on a horizontal surface is given by [5]:

$$I_{diffus\_h} = I_{beam\_normal} * (\quad (7)$$

Where $beam\_norm$ *is the beam normal irradiance.*

The total irradiance on a horizontal surface is given by[5]:

$$I_{total\_h} = I_{beam_{normal}} \cdot cos(Zenithangle) + I_{diffu} \quad (8)$$

The aperture (surface panel) beam irradiance includes a factor equal to the cosine of the incidence angle of the aperture [5].

$$I_{beam\_aperture} = I_{beam\_normal} \cdot cos(incidenceangle) \quad (9)$$

Finally, the total aperture irradiance is calculated by [1]:

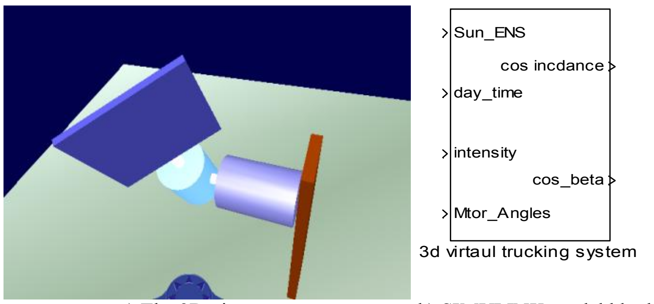
$$I_{total\_aperture} = I_{beam\_aperture} + I_{diffus\_h}\frac{1+cos\,(\beta)}{2} + \rho I_{total\_h}\frac{1-cos\,(\beta)}{2}$$

(10)

Where is the angle between the aperture and the horizontal plane and is the reflectance of surface of the earth.

IV. VIRTUAL TRACKING SYSTEM

To study the different tracking systems a virtual mechanical system is used. We choose this method to overcome the problem of hardware availability and as a test method before hardware realization. We use the VRML language to create the 3D mechanical system. The system is composed of two motors. The east/west direction is the axis of the first motor, the second motor case is mounted to the rotor of the first motor and its axis is perpendicular to the axis of the first motor as the Fig. 3 shows.



a) The 3D view b) SIMULINK model block

Fig.3: the two perpendicular motors virtual system.

The system is used by giving two angles (inner angle for the inner motor and outer angle for the outer motor) and other data (sun intensity and sun position). The two motors rotate by the two angles to give the panel (mounted in the axis of the second or inner motor) a definite orientation. Different tracking algorithms give different angles, for example in full tracking system the two angles must be calculated from the sun's position vector whereas is a east/west horizontal tracking system the outer angle is fixed. Finally, the SIMULINK block outputs the cosine of the incidence angle and the cosine of the inclination angle between the panel and the horizontal. These two cosines are used to calculate radiation components in the radiation model.

V. SIMULATION RESULTS

The following figure Fig. 4 gives the simulation results (direct irradiance profile) of the radiation model and the sun's position model for different altitude and for two different days of the year of Ghardaïa site.

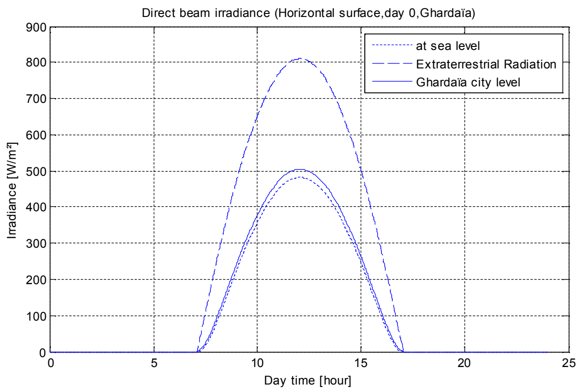


Fig. 4: The direct irradiance profile for different altitude

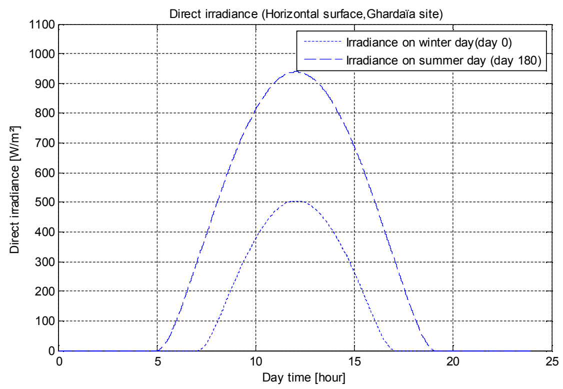


Fig. 5: the direct irradiance profile for two days of the year.

The next figure gives the Air mass profile for two days of the year. This figure shows that the air mass in the summer is below that of the winter because the sun in summer is close to the zenith.

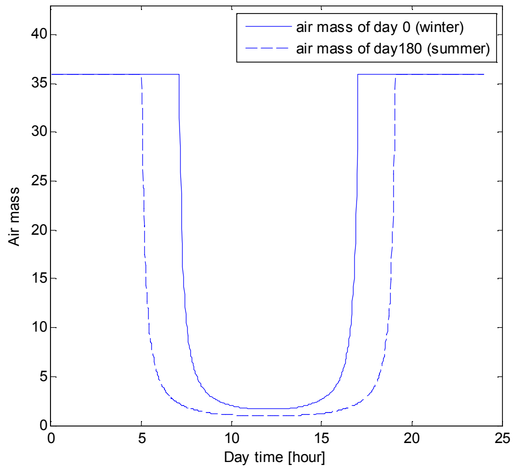


Fig. 6: the air mass for two days of the year.

Finally the last figure gives the direct irradiance profile for different panel inclination angles.

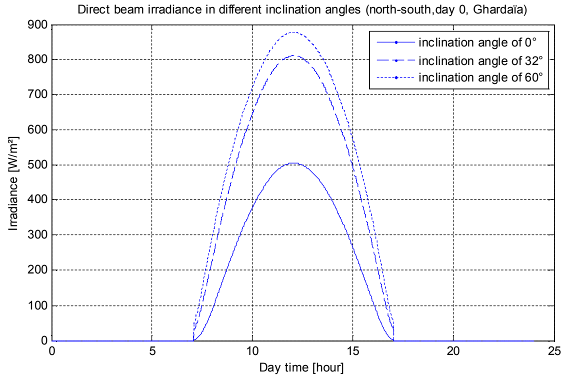


Fig. 7: Direct irradiance profile for different panel inclination angle and for two days of the year.

VI. Incidence angle for different tracking systems

Different tracking systems are studied in this section where the mean value of the cosine of the incidence angle (throughout the year), the mean value of the direct irradiance and the mean value of the global irradiance are used as a measure of how the system is good in tracking the sun.

To calculate those measures we begin by selecting the tracking algorithm (full tracker, horizontal tracker...); this algorithm must calculate two angles that the two motors must rotate Fig 8. The inputs to the algorithm are the sun vector, the base unit vectors and the surface tilt angle. Any new tracking algorithm can be defined or entered in the SIMULINK block *'tracking system'* and the rest of the model remains as it is.

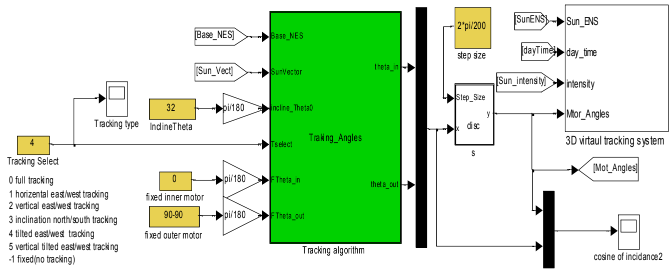


Fig.8: Tracking algorithms calculate the two angles theta_in and theta_out, the middle block (disc) defines the step size of used stepper motor.

Then from the two motors angles we calculate the aperture normal vector by using the two following equation:

$$Normal1 = SouthV * \cos(theta_{out}) + NormalV * \sin(theta_{out})$$
$$Normal = Normal1 * \cos(theta_{in}) + EastV * \sin(theta_{in}) \quad (11)$$

The two formulas represent two rotations by theta and theta respectefly.where SouthV is the south unit vector and EastV is the east unit vector and NormalV is the Zenith unit vector.

Then the cosine of the incidence angle is calculated as scalar product between the sun vector and the calculated normal vector, and the cosine of the beta (beta the angle between the aperture and the horizontal plane) is calculated as the scalar product between the normal aperture vector and the Zenith unit vector. Those calculations are implemented in SIMULINK as in Fig. 9.

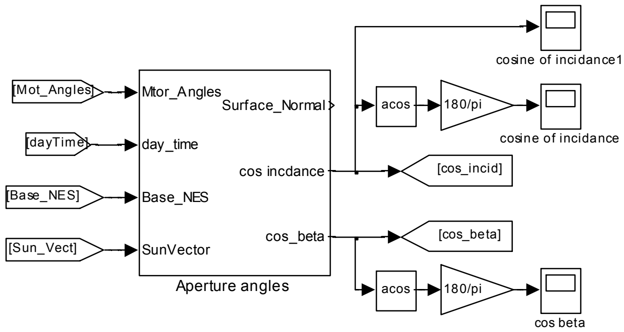


Fig.9: calculation of the incidence and the beta angles from the motors angles theta_in and theta_out.

Finally we integrate the different radiations (beam normal and total) and cosine of the incidence angle and divide the results by the corresponding value of the full tracker as in Fig.10.

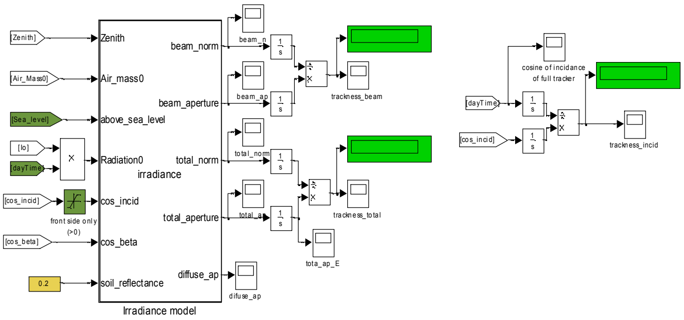


Fig.10:.The radiation model (finals value after simulation are displayed in green blocks)

The following figures (12),(13),(14) and (15) compare the cosine of the incidence angle the direct beam irradiance between the full tracker and the east/west horizontal tracker.

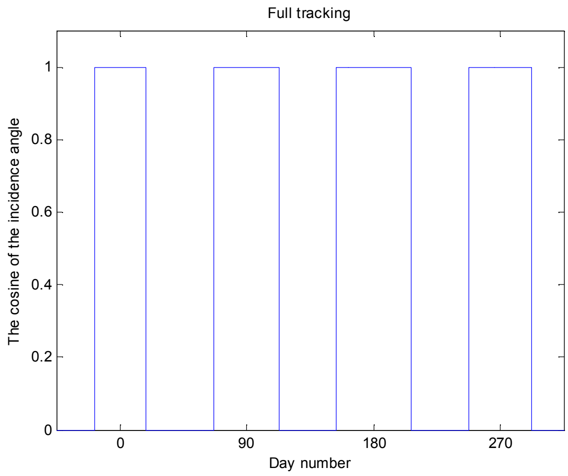


Fig. 11:. The cosine of the incidence angle of the full tracker

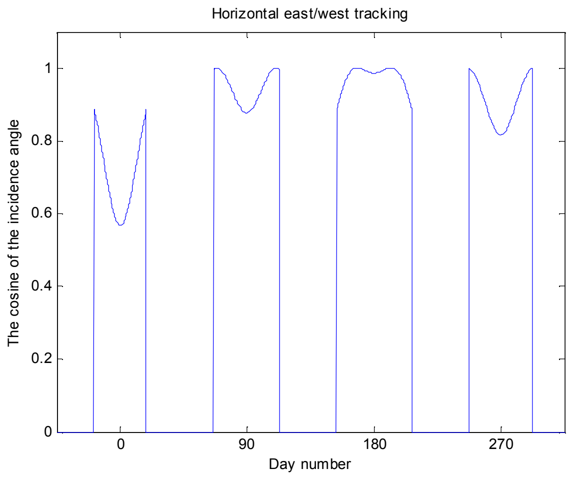


Fig. 12:.The cosine of the incidence angle of horizontal east/west tracker

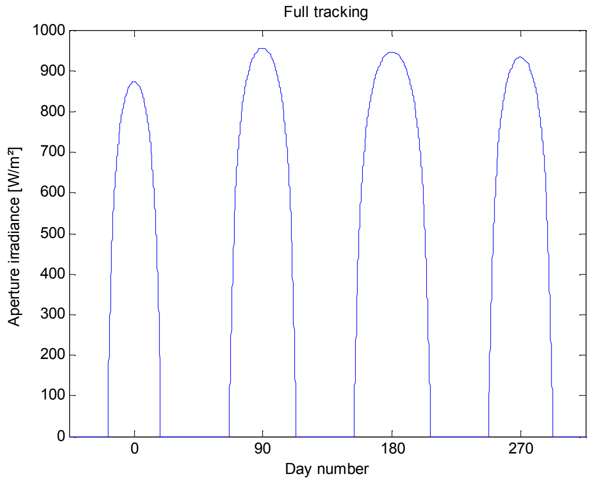


Fig. 13. The direct irradiance of the full tracker

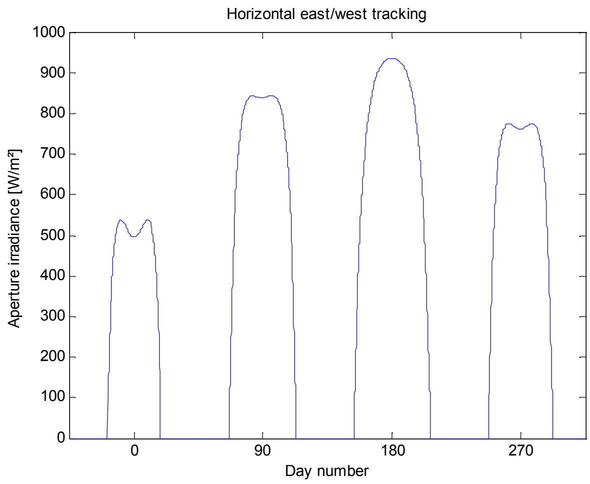


Fig. 14:.The direct irradiance of horizontal east/west tracker

The following table gives those measures (the three outputs of Fig. 10) of different tracking methods or algorithms (different orientation of the tracking axes and the number of those axes).the numbers in the table are calculated with respect to the full tracker that is where a two axis tracker is used (full tracker equal. 1).

We can see from the table that the vertical tracker is best then the inclination tracker in minimizing the cosine of the incidence angle, this tracker minimizes the angle in the beginning and the end of the day (0°) where the sun is in the lowest of its power (because of the air mass), but the inclination tracker minimize the incidence angle at noon and this explain why this tracker is best in the direct irradiance measure and it is not good in the cosine of incidence measure.

TABLE 1 :DIFFERENT MEASURES FOR DIFFERENT TRACKING SYSTEMS

Tracking type	Mean value of the Cosine of the incidence angle	Mean value of direct irradiation (%)	Mean value of global irradiation (%)
Full tracker	1	100	100
tilted east/west (32.5°) tracker	0.96	96	97
horizontal East/west tracker	0.89	89	90
Tilted (32.5°) vertical tracker	0.86	89	91
Vertical East/west tracker	0.78	73	77
Inclination tracker	0.69	75	77
Fixed tilted (32.5°)	0.60	68	71
Fixed horizontal	0.53	60	63

VII. CONCLUSION

In this paper we propose a SIMULINK model that helps the study of any tracking system by entering it as an algorithm (MATLAB language) in SIMULINK block. We test the model in the last section and it gives a reasonable results. The results show that the tilted east/west tracker is the best single axis tracker and it is only 4% (96% efficient) below that of the full tracker with two axes.

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