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The Mathematical Model for Solar Angles Calculation in Automatic Solar Panel Tracker Using PLC and SCADA

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ABSTRACT
Solar energy is the main source of renewable energy in developing countries with power shortages. But because of their fixed panel configuration, solar panels are less effective at generating power. As a result, numerous tracking techniques have been created to track the sun, some of which are less accurate in control, some of which have complex control systems, and some of which are not able to track the sun in specific weather circumstances.
There are several environmental elements that affect the maximum power energy output. The impact of radiation intensity and panel location in improving output efficiency is examined in this work, and a useful dual-axis solar tracking mathematical model is suggested. This model watches the sun regardless of the weather and maximizes its production.
This paper's goal is to provide a new, straightforward mathematical model for the tracking mechanism, whose precision may be improved with the use of sensors. Using Delta PLC, the model's effectiveness was examined and validated.
This study uses a DELTA PLC-based automated solar tracking system since it follows the sun more accurately and reliably in all kinds of environmental situations.
Keywords*—Azimuth Angle, PLC, Solar Panel, Attitude Angle, Hour Angle, Declination Angle, Matlab.*

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I. INTRODUCTION

There are several environmental elements that affect the maximum power energy output. The impact of radiation intensity and panel location in improving output efficiency is examined in this work, and a useful dual-axis solar tracking mathematical model is suggested. This model watches the sun regardless of the weather and maximizes its production. This paper's goal is to provide a new, straightforward mathematical model for the tracking mechanism, whose precision may be improved with the use of sensors. Using Delta PLC, the model's effectiveness was examined and validated.

The previous several years have seen a marked growth in energy demand. The energy metrics predict a 50% increase in global energy use by 2030 [1]. The consumption has compelled researchers to look into and look for new ways to meet the demand for energy, according to the 2017 World Energy Statistics. Due to the straightforward energy conversion process, solar energy and other renewable energy sources outperform conventional energy sources. Solar Photo Voltaic (PV) panels are used to convert solar energy into electricity.

Due to their permanent nature, the majority of solar PV arrays used to harvest solar energy are not used to their maximum capacity. Tracking the sun throughout the day is crucial to maximizing energy output.

A solar tracker is a tool that monitors the sun's location. Additionally, a variety of single-axis and dual-axis methods have been put forth, with the dual-axis tracker being shown to be more effective since it could account for the whole range of the sun's motion [3]. In their article, S. Ozcelik and his colleagues proposed a two-axis solar tracker, and they created a control algorithm to spin the panel in azimuth and altitude directions. The complicated mathematical equations employed in this study required a lot of calculation time. Another dual axis tracker research project put out by Carlos Robles and his colleagues [5] claims to boost output energy by 9.87% where radiation sensors were used to orient the panel in the direction of the sun.

The fundamental barrier continues to be modeling complexity. This paper's work represents the Combination of the two previously suggested efforts. The paper aims to present a more efficient tracking system based on a substantially more accurate, simpler mathematical model raised even more by including radiation in the mechanism's sensors.

A photovoltaic effect-based p-n diode is what solar PVC essentially is [6,8]. The creation of this effect is described as charge carriers in a substance that absorbs light Whenever light radiation strikes it [6, 7]. The charge-generating process really occurs when the Sun's luminous energy, i.e, energy packets that have been compromised break off of a semiconductor material's free electrons (for instance, Si), and the electric field is produced. The electron in the produced electric field is propelled by the semiconductor in a systematic way, leading to the passage of electric current [7]. A power source series or parallel connection of the number of solar PVC is referred to as a solar module.

The term "solar PVC array" refers to the collection of solar modules. Theoretically, the efficiency of a 10 m2 Solar PVC array is equivalent to a 10 km2 array. This runs counter to the efficiency loss associated with scale decrease in other renewable resources including wind, hydro, and thermal generators [7]. Figure 1 depicts the electrical model of an ideal solar cell.

II. METHODOLOGY

1. SOLAR CELL EQUIVALENT MODEL

The total output current (I) under illumination can be given by equation(1)

$I = ID - IL$ (1)

Figure 2 depicts the analogous circuit with series and shunt resistances Rs and RSH

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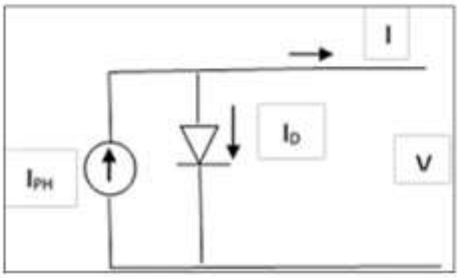

Figure 1: Equivalent Circuit of Ideal Solar Cell

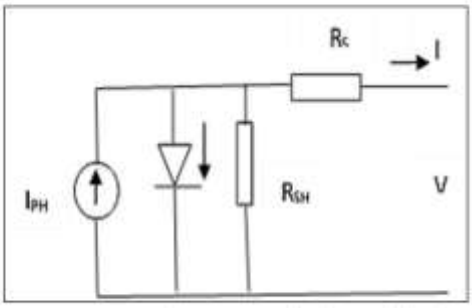

Figure 2. Equivalent Circuit of Solar Cell with Series and Shunt Resistance

Table 1 lists the electrical factors that go into solar cells.

I_D	Diode Current	I_{sc}	Short-Circuit Current
I_{ph}	Photovoltaic current	V_{oc}	Open-Circuit Voltage
I_{sh}	Shunt Resistor Current	V_D	Diode Voltage
I_{ref}	Reference current	G	Amount of Solar Radiation
R_s	Series Resistance	I_o	Diode Saturation current
R_{sh}	Shunt Resistance	V_M	Maximum Power Point Voltage
η	Ideality Factor	I_M	Maximum Power Point Current
Q	Electron Charge		
K	Boltzmann Constant	E_g	Diodes Bandwidth
T	Temperature	K_i	Current Temperature Coefficient
P_M	Maximum Power	K_v	Voltage Temperature Coefficient
N_{pc}	Number of Parallel	I_{pv}	PV Battery Output Current
Nsc	Number of Serial	G_{ref}	Amount of Solar Radiation
C_o	Temperature Coefficient	I_e	Electron Current
B	Constant Semiconductor	I_h	Hole Current

III. FACTORS AFFECTING THE PANEL'S EFFICIENCY

1. ATMOSPHERE

Electromagnetic radiation is a sort of energy that the sun emits. This effect of the atmosphere on radiation intensity is described by air mass (AM), which is the secant of angle between the zenith and sun and defined in eq. (20), as shown in figure 3. The radiation intensity is attenuated when it interacts with the atmosphere [9] primarily due to absorption and scattering phenomena.

Figure 5 depicts solar spectral irradiance curves for various AM; these curves explain how the atmosphere affects solar radiation intensity for various wavelengths.

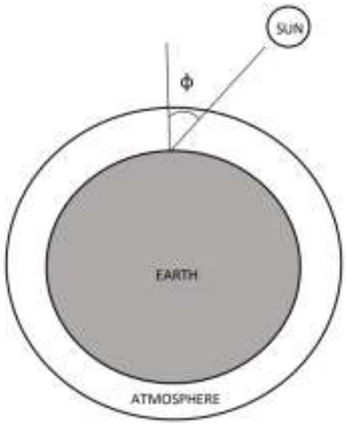

Figure 3. Schematic Showing Air Mass.

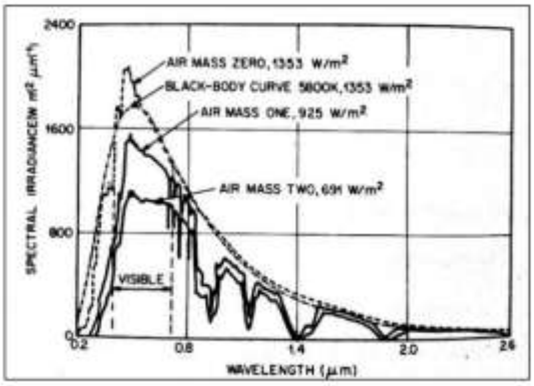

Figure 4. Spectral Irradiance Curve for Different AM (after Thekaekara) [10].

2. Orientation of the solar panel

Knowing the irradiance impact on a horizontal surface can help you understand how the panel orientation affects the power generated.

Irradiance on a horizontal surface depends on the source tilt angle (θ) [11]. As the tilt angle increases, the effective area for the radiant flux drops, which is comparable to Acosθ, as shown in Figure 2. As a result, the radiant power (Rp) stated in equation (2) on the surface decreases.

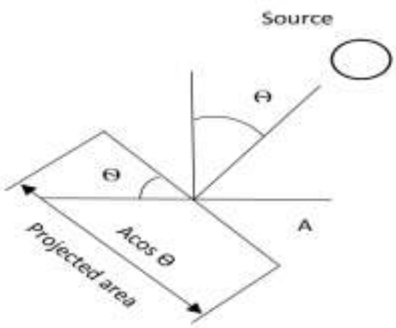

Figure 5. Irradiance on a Horizontal Surface.

$Rp = Acos\Theta * Ee$
Rp stands for radiant power, A for surface area, and Ee for radiant flux density (W m-2).
Cosθ should be 1 to increase power output. This may be achieved by following the sun's motion throughout the day.
An approximate mathematical model that can compute the azimuth and altitude angles needed for tracking is provided in this study. The calculation is predicated on the following hypotheses:
1. The earth's precession is ignored
2. Atmospheric refraction is not taken into account.
3. The Earth is regarded as perfectly spherical.

IV. PROPOSEDMATHEMATICAL MODEL

During the earth's rotation around the sun, the solar declination angle (δ) varies between +23.50 and -23.50 (see Figures 6 and 7). A mathematical equation (eq.) (3) [12]
$\delta = 23.45\sin(0.9863(284 + n))$
For n=1 at the beginning of the year, n is the day number (Jan 1st). Altitude angle (α) at solar noon can be obtained if δ is known by eq.(4).
$\alpha = 90 - L + \delta$ (4)
L stands for latitude angle.

Equation(4) is derived from equation(17) when ω=0.

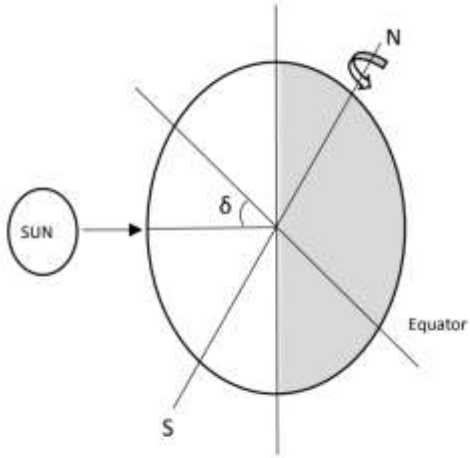

Fig. 6: Declination Angle

Sunrise(ωs+) and Sunset(ωs-) Angle
The sunrise and sunset angles are shown in figure5. These angles depend on δ and latitude which can be proved mathematically as follows
$R\sin L = x\cos\delta$ (5)
$\sin\omega s+ = -\tan\delta\tan L$ (6)
negative sign indicates the orientation of the angle as shown in Figure 8.
$\omega s- = 180 - \omega s +$ (7)

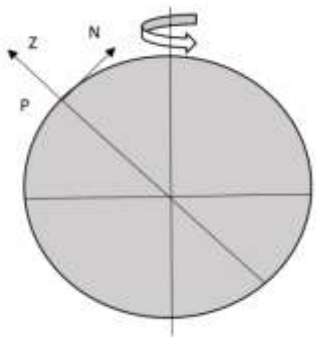

Fig. 7: Schematic Diagram Showing Observer Latitude.

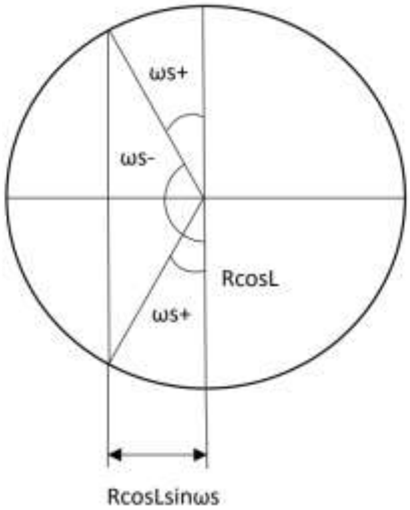

Fig. 8: Observer Latitude view from North Pole.

Calculating Altitude and Azimuth Angles

Let the z-axis be the direction of the earth's rotation. Now, the various vectors shown in figures 9 and 10 may be resolved along the x, y, and z axes.

$Z = \cos(L)cos(\omega)i + \cos(L)sin(\omega)j + \sin(L)k$ (9)

$Z = \cos(L)cos(\omega)i + \cos(L)sin(\omega)j + \sin(L)k$ (10)

$S = cos(\delta)i + \sin(\delta)k$ (11)

Since Z and N are unit vectors, S's projection on those vectors would result from the dot product of S and Z or N.

$S.N = \sin(\delta)\cos(L) - \sin(L)\cos(\delta)\cos(\omega)$ (12)

$S.Z = \cos(L)\, cos(\delta)cos(\omega) + \sin(L)\sin(\delta)$ (13)

The projection of S on N and Z in Figure 7 can alternatively be computed as shown below.

$Sn = cos(\alpha)\cos(Az)$ (14)

$Sz = \sin(\alpha)$ (15)

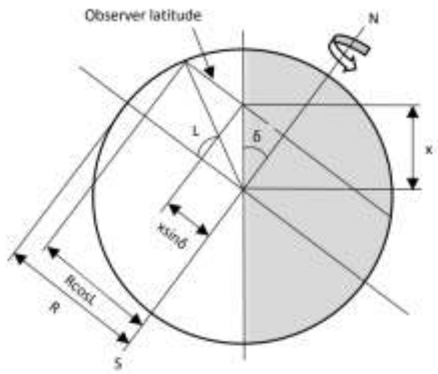

Figure 9. Schematic Showing Z and N Vector.

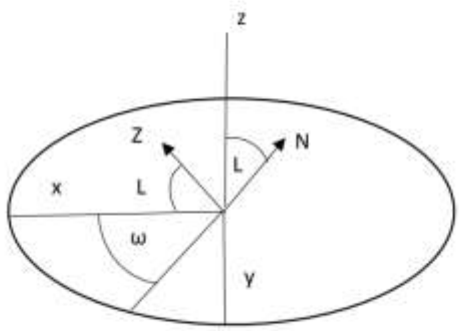

Figure 10. Schematic Showing Z and N Vectors and their Orientation with x, y, and z-axis.

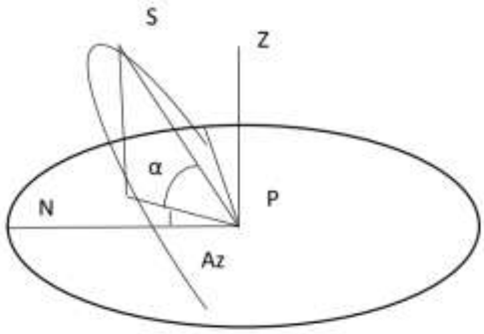

Fig. 11: Azimuth and Altitude Angles for Point P (Place where Panel is Azimuth and Altitude Angles for Point P (Place where Panel is Placed)).

From eq(12 & 14) and eq(13 & 15) and figure 11

$\sin(\alpha) = \cos(L)\cos(\delta)\cos(\omega) + \sin(L)\sin(\delta)$ (16)

$\cos(Az)=(\sin(\delta)\cos(L)-\sin(L)\cos(\delta)\cos(\omega))/\cos(\alpha)$(17)

4. The Simulation of Solar angles in Matlab

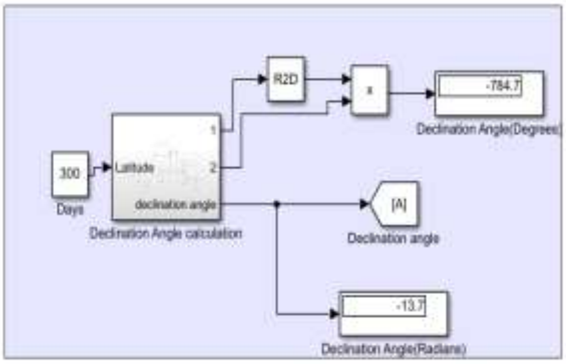

Figure.12 The Declination angle calculation Simulink model

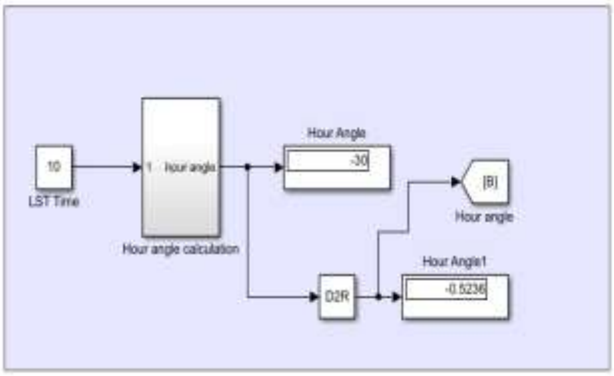

Figure.13 The Hour angle calculation Simulink model

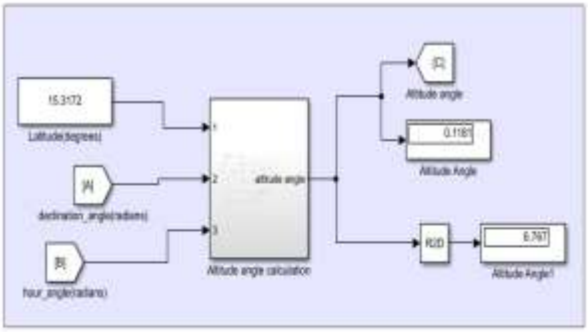

Figure.14 The Altitude angle calculation Simulink model

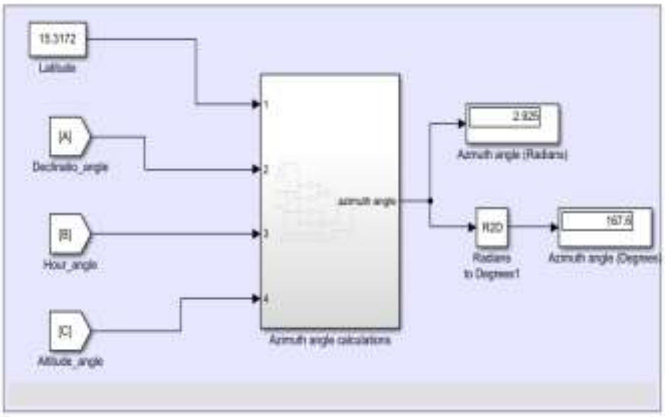

Figure.15 The Azimuth angle calculation Simulink model

Table.1 Solar angles over a year

Date	Elevation angle	Azimuth angle
Jan-01	22.64	122.03
Jan-31	22.83	115.46
Feb-05	23.25	113.94
Feb-25	25.86	107.01
Mar-02	26.68	105.1
Mar-27	31.01	94.88
Apr-01	31.81	92.76
Apr-26	34.79	82.46
May-01	35.13	80.58
May-31	35.38	72.19
Jun-05	35.19	71.41
Jun-30	34.01	70.63
Jul-05	33.79	71.08
Jul-30	33.18	76.17
Aug-04	33.16	77.69
Aug-29	33.45	87.21
Sep-03	33.52	89.43
Sep-28	33.36	101.18
Oct-03	33.16	103.54
Oct-28	31.07	114.18

Nov-02	30.45	115.94
Nov-27	26.78	121.99
Nov-27	26.78	121.99
Dec-07	25.32	123.01
Dec-27	23.02	122.62

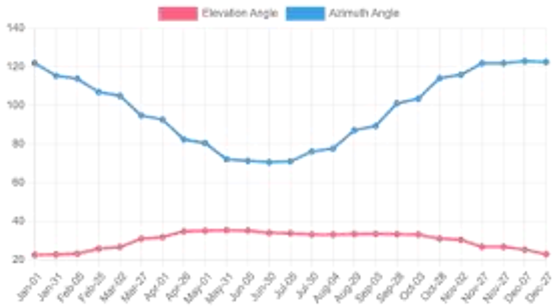

Figure 16. Solar angle variations over a Year in Bengaluru, India.

The Address of Bengaluru is
1. Latitude= 12.9716 N
2. Longitude= 77.9946 E
3. Time Zone = UTC-5.00 Indiana(East)

The Plot shows the solar angle variation in Bengaluru, India for different months in a year. The values are calculated using the Matlab Simulink model as shown in the above figures. it calculates more accurate values compared to manual calculations of solar angles.

V. CONCLUSION

The output power generated by a solar PV module is dependent on ambient radiation, atmospheric temperature, and weather conditions. The optimal altitude and azimuth for tilting a solar panel are different for each month of the year. An optimum panel tilt for each month is needed to harvest maximum solar energy. This Paper suggests simple mathematical expressions for elevation and azimuth angles. The results compared to the actual elevation and azimuth angles show a high correlation when simulated and compared in MATLAB.

REFERENCES

[1]. 1.Abdallah, Salah, Nijmeh, Salem, 2004. Two axes solar tracking system with PLC control. Energy Convers. Manage. 45 (11–12), 1931–1939.
[2]. Smith DD, Cousins P, Westerberg S, De Jesus-Tabajonda R, Aniero G, Shen Y-C. Toward the practical limits of silicon solar cells. Proc. Photovoltaic Spec. Conf. 2014, 1465–1469p.
[3]. Deepthi S, Ponni A, Ranjitha R, Dhanabal R. Comparison of Efficiencies of SingleAxis Tracking System and Dual-Axis Tracking System with Fixed Mount. International Journal of Engineering Science and Innovative Technology. 2013; 2 (2), 1925-1933p.
[4]. Ozcelik S, Prakash H, Challoo R. TwoAxis Solar Tracker Analysis and Control for Maximum Power Generation. Complex Adaptive System. 2011; vol.6,457-462p.
[5]. Algarin CR, Castro AO, Naranjo JC. Dual-Axis Solar Tracker for Using in photovoltaic Systems. International Journal of Renewable Energy Research. 2017; 7 (1), 137-145p.
[6]. Araújo GL, Martí A. Absolute limiting efficiencies for photovoltaic energy conversion. Sol. Energ. Mater. Sol. C. 1994; 33: 213–240p.
[7]. Bauer A, Hanisch J, Ahlswede E. An Effective Single Solar Cell Equivalent Circuit Model for Two or More Solar Cells Connected in Series. IEEE J. Photovolt. 2014; 4: 340–347p.
[8]. Yatimi H, Aroudam E. Mathematical Modeling and Simulation of Photovoltaic Power Source using Matlab/Simulink. Int. J. Innov. Appl. Stud. 2016; 16: 322–330p.
[9]. Mazouchi M, Jia J, Huo Y. Analysis of luminescent coupling effects in n series-connected multijunction solar cells. Phys. Status Solidi A. 2016; 213 (20): 941–946p. 10. Kasten F, Young AT. Revised Optical Air Mass Tables and Approximation Formula. 1989; 28 (22): 4735-4738p.
[10]. Thekaekara MP. Data on Incident Solar Energy. suppl. Proc. 20th Annu. Meet. Inst. Environ. Sci., 1974, p. 21.
[11]. Elachi C. Introduction to the Physics and Techniques of Remote Sensing. New York: Wiley; 1987.