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A Review on Solar Radiation of the Photovoltaic System

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Abstract*: This paper is a mathematical study for finding the amount of solar radiation on the surface of the Photovoltaic (PV) system affected due to the variation in the slope (tilt angle) of the PV system along with the background theory of the attenuation of the solar radiation. The power density is maximum when the solar module-absorbing surface is perpendicular to the sun and in all other cases module power is always lesser than the incident power. Hence extra addition of panels with fixed tilt is no longer economical viable when electricity demand increases. Theoretical estimation of solar radiation on the slope of the PV surface from the radiation available on the horizontal surface is evaluated and the results are presented on the basis of the data available and proposed mathematical model for the calculation of the total amount of solar radiation on tilted surface.
Keywords:Solar Energy, Solar Radiation, Solar Photovoltaic, PV, Solar, solar tilt.

I. INTRODUCTION

World energy demand is projected to increase by up to 71% between 2003 and 2030 [1]. At present, most of the used energy is generated from the fossil fuels, and despite notable advances in renewable energy technology, it is questionable whether such a demand trajectory can be met in an environmentally sustainable manner [2]. It has been proposed, then, that the one way to reduce burden on fossil fuels is utilize the solar energy through photovoltaic route.

The power produced by the solar photovoltaic module is maximum when module surface is perpendicular to the incident radiation this means the power generated by the PV module not only depends on the intensity of solar radiation but also on slope of the surface i.e. the angle between module and the sun[3-14].

Therefore, set of empirical relation is required for evaluating the amount of solar radiation incident on a tilted surface if the solar radiation on horizontal surface is available. In this paper, a model based on the empirical relations is used for calculating the availability of solar radiation on tilted surface for power generation. A set of readings of the radiation available on horizontal surface is used for the further analysis.

II. MATHEMATICAL MODEL

Solar flux striking a collector will be a combination of direct beam radiation, scattered or diffused radiation and reflected radiation. Since measurements of solar radiation are often not available, attempts have been made by many investigators to establish relationships linking the values of radiation (global or diffuse) with meteorological parameters like number of sunshine hours, cloud cover and precipitation. These equations for solar radiation at a site can be estimated if the latitude, longitude and altitude of location is known. The main aim of this article is to estimate the radiation available on the tilted PV system for power generation. The amount of radiation falling on the tilted surface can be estimated by the following equation [3]:

$$I_t / I_g = \{1-(I_d / I_g)\} * r_b + (I_d / I_g) * r_d + \rho' r_r \quad (1)$$

Where, I_t is total radiation on the tilted surface, ρ' is reflectivity of ground surface and I_g, I_b, I_d are hourly global radiation, hourly beam radiation and hourly diffuse radiation respectively.

The radiation shape factor for a tilted surface with respect to sky r_d and radiation shape factor for the surface with respect to surrounding groundr_r can be expressed as follows[3]:

$$r_d = (1 + \cos\beta) / 2 \quad (2)$$

$$r_r = (1 - \cos\beta)/2 \quad (3)$$

where, β is tilt angle, r_b is the ratio of beam radiation flux falling on tilted surface to that falling on horizontal surface, also known tilt factor and it can be expressed by:

$$r_b = \cos\theta / \cos\theta_z \quad (4)$$

where, θ and θ_z are incident and zenith angles, as represented in Figure 1, of the sun ray with surfaces. These angles can be calculated by using the following relations:

$\cos\theta = \sin \emptyset \sin \delta \cos\beta + \cos\delta \cos\gamma \cos \omega \sin \emptyset \sin \beta + \cos\emptyset \cos\delta \cos \omega \cos\beta - \cos\emptyset \cos\gamma \sin \delta \sin \beta + \cos\delta \sin \gamma \sin \omega \sin \beta$ (5)

for surface facing south $\gamma = 0^\circ$

$\cos\theta = \sin \delta \sin (\emptyset - \beta)) + (\cos\delta \cos\omega \cos (\emptyset - \beta)$ (6)

for horizontal surface

$\cos\theta_z = \sin \emptyset \sin \delta + \cos\emptyset \cos\delta \cos\omega$ (7)

where, $\emptyset$, δ, γ and ω are latitude, declination, surface azimuth and hour angles.

γ = Azimuth or the orientation angle of the surface (i.e. the angle between the projection of the normal to the surface on the horizontal plane and the local medium; surface facing south $\gamma = 0^\circ$, east +, west -).

The hour angle (i.e., each hour equal to 15˚ of latitude; solar noon is zero, morning +, afternoon -) and can be calculated as:

$\omega = (t - 12)*15$ (8)

where t = solar time

The declination angle can be estimated as follows:

$\delta = 23.45 \sin [(360/365)*(284+N)]$ (9)

where, N are No. of days

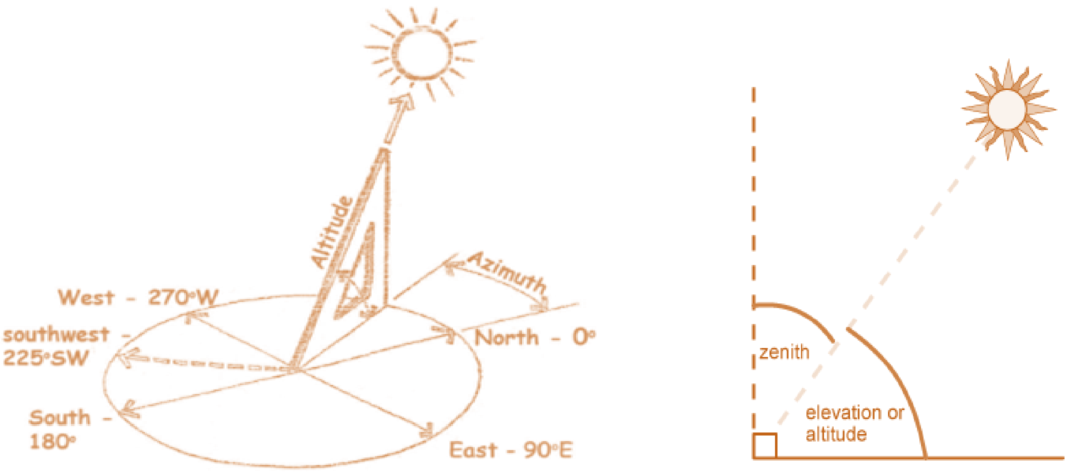

Figure 1. Representation of solar angles

The values of declination calculated by the above relation are shown in the Following figure

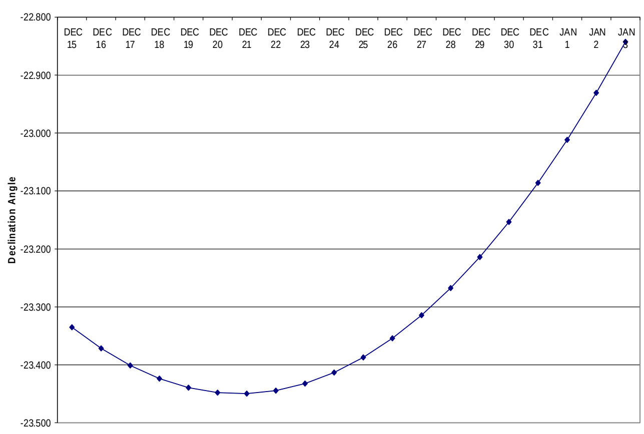

Figure2: Declination angle vs. date

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III. RESULTS AND DISCUSSION

The values of global and diffuse solar radiations and ambient temperature were measured experimentally for various days of the year. The measured values of these parameters are depicted in the Table 1.

The measured values of global and diffuse components of radiation were used to calculate the radiation values for different tilt angle. The model is used for calculating the radiation values for different tilt surfaces. The variation of solar radiation for different tilt angle are depicted in the Figures 3-10.

	15-Dec-08			**17-Dec-08**		
Time	Global	Diffused	Amb Temp.	Global	Diffused	Amb Temp.
08:22	102	101	18.2	173	86	26.7
10:22	388	337	24.2	443	167	27.6
12:22	577	405	26.5	622	161	27.3
14:22	570	321	27.7	526	180	24.8
16:22	141	129	26.2	200	66	19.3
		19 Dec 08			**23-Dec-08**	
Time	Global	Diffused	Temp	Global	Diffused	Temp
08:24	56	51	17.2	145	98	15.2
10:24	480	137	24	498	167	18.3
12:24	482	273	26.1	662	150	22.3
14:24	268	256	25.8	523	157	24.3
16:24	76	76	25.3	175	77	25.2
		24-Dec-08			**27-Dec-08**	
Time	Global	Diffused	Amb Temp.	Global	Diffused	Amb Temp.
08:26	174	62	14.1	260	44	16.6
10:26	529	100	23.1	564	64	23
12:26	592	156	25.7	702	63	27.5
14:26	509	148	27.6	566	151	28.9
16:26	193	69	27	217	51	27.4
		29-Dec-08			**30-Dec-08**	
Time	Global	Diffused	Amb Temp.	Global	Diffused	Amb Temp.
08:29	255	60	17.5	260	45	17.9
10:29	535	72	24.9	542	67	25
12:29	658	89	26.5	661	92	27
14:29	537	207	28	562	236	28
16:29	198	68	27.1	189	75	27
		31-Dec-08			**01-Jan-09**	
Time	Global	Diffused	Amb Temp.	Global	Diffused	Amb Temp.
08:29	200	60	14.3	200	75	14
10:29	502	95	21.1	507	109	20.7
12:29	633	123	23.4	600	133	22.8
14:29	522	278	25.1	523	324	26.7
16:29	189	85	24.9	158	94	24.1

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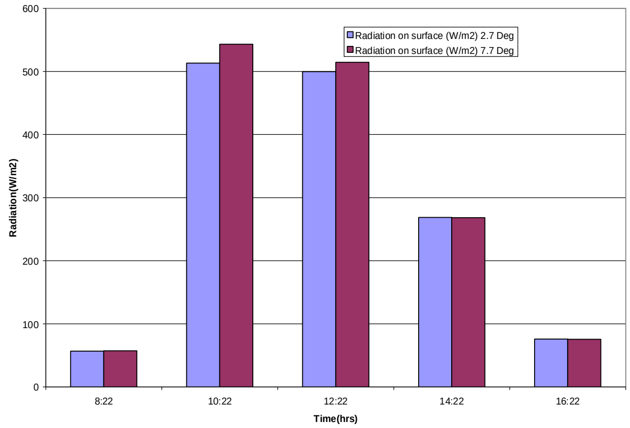

Figure3 . The amount of radiation incident on the surface of the PV system with 2.2 Deg and 7.7 Deg of tilt for the same horizontal radiation data on Dec 19, 2008.

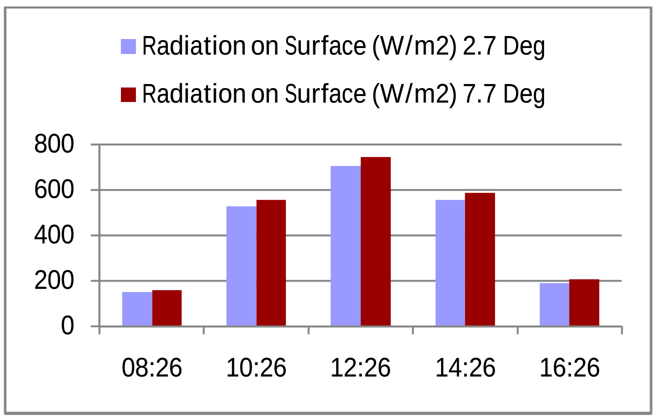

Figure 4. The amount of radiation incident on the surface of the PV system with 2.7 Deg and 7.7 Deg of tilt for the same horizontal radiation data on Dec 23, 2008.

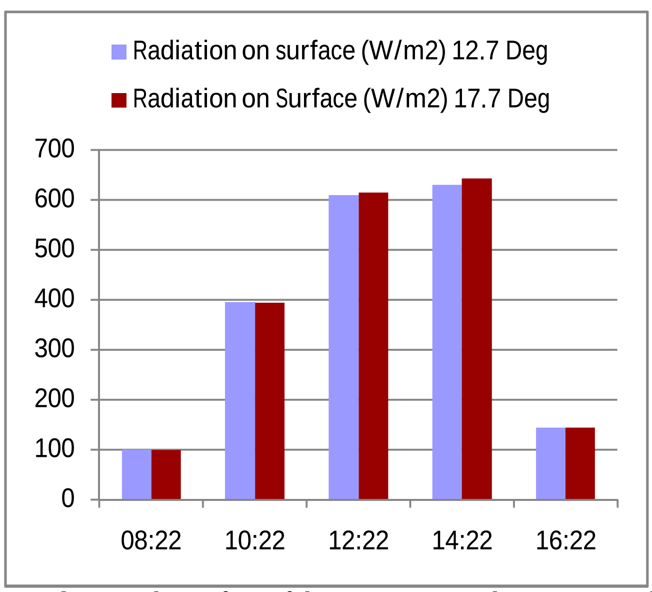

Figure 5. The amount of radiation incident on the surface of the PV system with 12.7 Deg and 17.7 Deg of tilt for the same horizontal radiation data on Dec 15, 2008.

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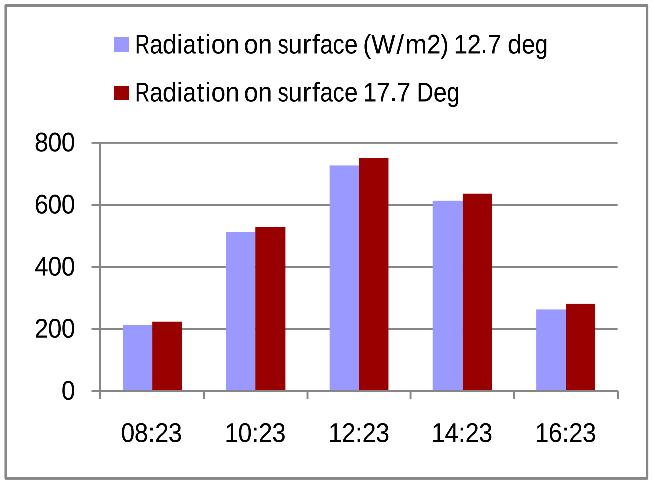

Figure 6. The amount of radiation incident on the surface of the PV system with 12.7 Deg and 17.7 Deg of tilt for the same horizontal radiation data on Dec 17, 2008.

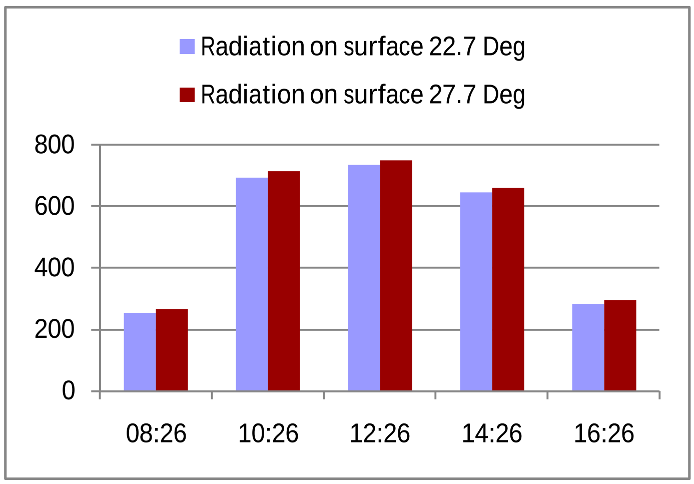

Figure 7. The amount of radiation incident on the surface of the PV system with 22.7 Deg and 27.7 Deg of tilt for the same horizontal radiation data on Dec 24, 2008.

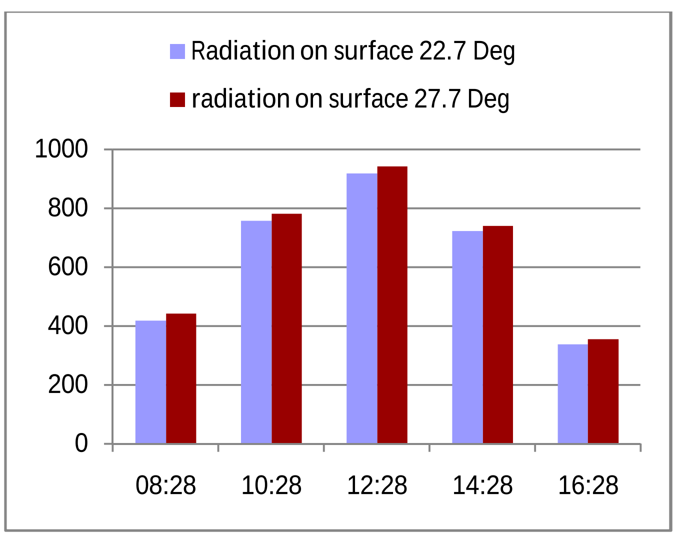

Figure 8. The amount of radiation incident on the surface of the PV system with 22.7 Deg and 27.7 Deg of tilt for the same horizontal radiation data on Dec 27, 2008.

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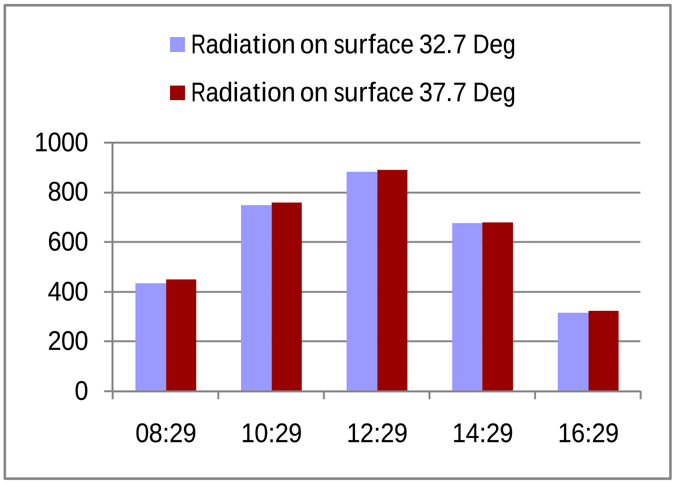

Figure 9. The amount of radiation incident on the surface of the PV system with 32.7 Deg and 37.7 Deg of tilt for the same horizontal radiation data on Dec 29, 2008.

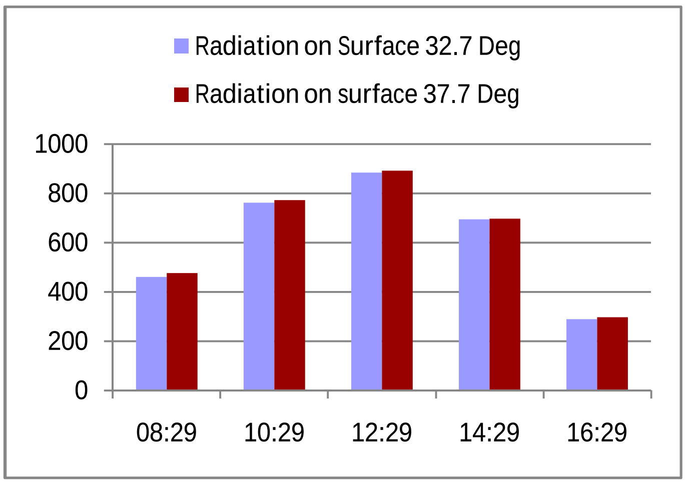

Figure 10. The amount of radiation incident on the surface of the PV system with 32.7 Deg and 37.7 Deg of tilt for the same horizontal radiation data on Dec 30, 2008.

Table2. showing the conversion efficiency of the PV system with the amount of Short circuit current generated with the solar radiation falling on the tilted PV surface

Tilt Angle	Amount of Total Radiation Incident (W/m^2)	Amount of Total Short Circuit Current Generated (A)	Conversion Efficiency
Latitude -20	4806	25.25	$5.25 * 10^{-3}$
Latitude - 15	4806	27.66	$5.75* 10^{-3}$
Latitude - 10	5760	36.56	$6.35 * 10^{-3}$
Latitude - 5	6330	41.29	$6.52 * 10^{-3}$
Latitude	8612	59.88	$6.95 * 10^{-3}$

Latitude + 5	8612	62.87	$7.3 * 10^{-3}$
Latitude + 10	7764	56.2	$7.24 * 10^{-3}$
Latitude + 15	6680	49.27	$7.38 * 10^{-3}$
Latitude + 20	8068	59.01	$7.31 * 10^{-3}$

The proposed model is quite successful in finding the incident solar radiation on tilted surface when horizontal data for radiation is available. Also the graphical representation shows the amount of variation in solar radiation incident on the surface of PV system i.e. variation in solar radiation intensity with the slope of the PV system with respect of horizontal. The mathematical model is useful in order to evaluate the total amount of solar radiation on tilted surface when the radiations on horizontal surfaces are known. The calculated results obtained here are used for finding the optimization of tilt angle for Photovoltaic system and presented.[13]and is represented in above Table2 hence it verify Results are evaluated and verified by the comparison in the graph for different tilt angle on the same day and location.

IV. CONCLUSION

Mathematical model is quite helpful to illustrate and estimate the general trends of the distribution of solar energy which varies with geographical location, altitude, and the time of the year and also by local whether condition. It can be concluded from the results that the PV module should be optimally inclined to obtain the maximum power output. The inclination angle may vary location to location and day to day.

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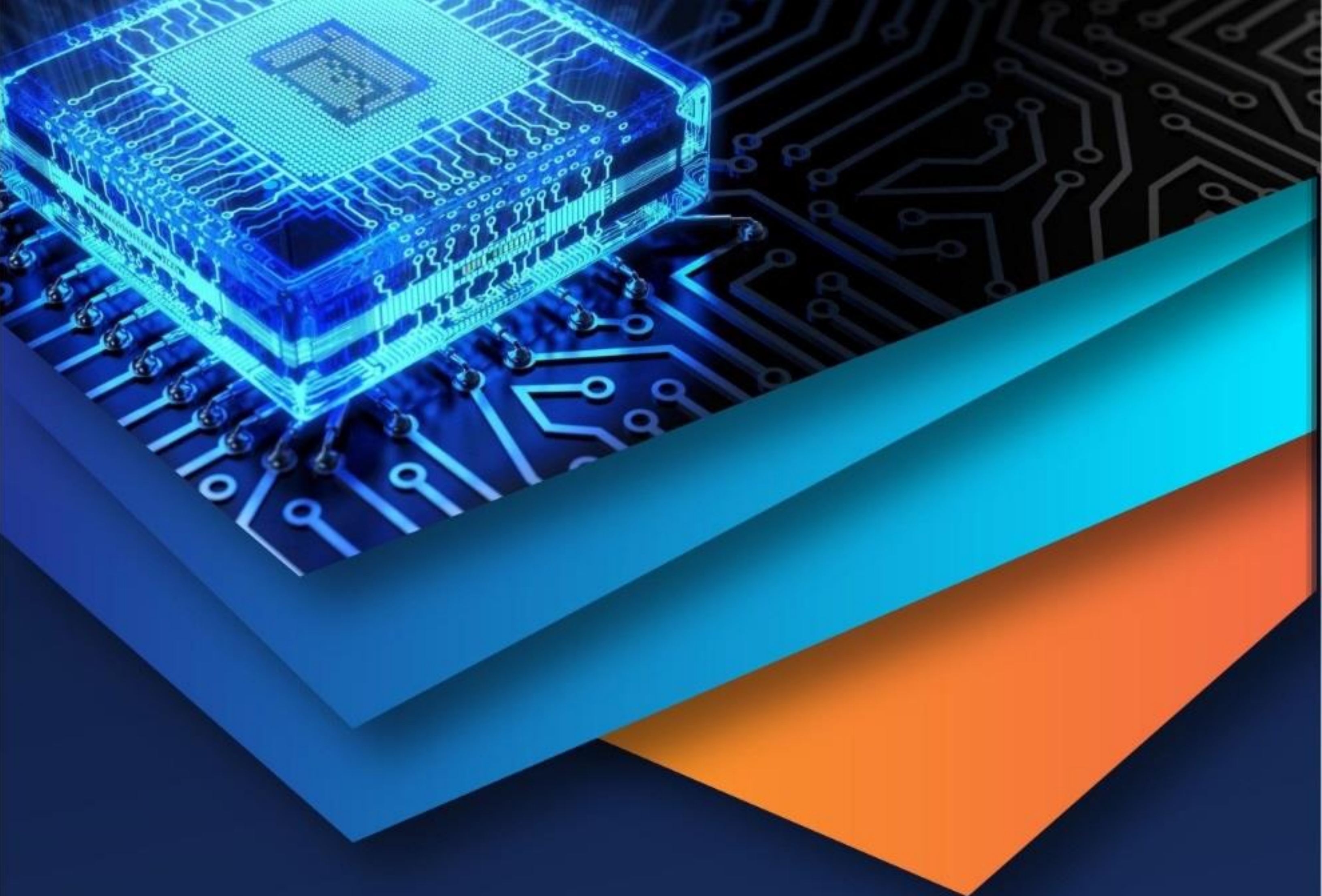

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