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Modelling of An Optimal Slope Based Solar Collector for Solar Tower Plant

Abhishek Agarwal[1], Dr. Mohammad Israr[2]
[1]Research Scholar, Department of Mechanical Engineering, OPJS University, Churu, Rajasthan- India
[2]Principal, Dungarpur college of Engineering & Technology, Dungarpur, Rajasthan- India

Abstract*: There is an expanding interest for the solar collectors, particularly the flat plate fluid one. In this way, an examination inquire about has been done to show the operation to be prepared in a solar tower plant and to anticipate the execution of various sort's solar systems. The Solar radiation beams are to be constantly engaged onto the absorber plate. The upper surface must be pivoted by trackers, which is exorbitant framework so we can't utilize this for each system monetarily. Because of this reason the solar arrays and collectors are sloped either month to month, regularly or yearly example, in view of our prerequisites. By utilizing MATLAB programming, examination of various solar radiation models indicates comes about close to genuine experimental setup.

***Keywords*: Solar collector, optimal slope, declination, beam radiation.**

I. INTRODUCTION

Because of natural issues and restricted non-renewable energy source assets, more consideration is being given to sustainable power sources. Energy is viewed as a noteworthy specialist in the era of riches and a significant factor in monetary improvement. Therefore it is highly pertinent to ensure a sustainable energy supply for human kind so that the future generation will benefit from energy utilization. Energy plays the most essential role in the economic growth, progress, and development, as well as security and poverty eradication of any nation. Future economic growth crucially depends on the long-term availability of energy from sources that are affordable, accessible, and environmentally friendly [1]. Due to the fast increase in the world population, the need for the energy increases rapidly.the combustion of fossil fuels for energy has caused a significant increase in greenhouse gas emissions to the atmosphere, which is widely believed to be the primary cause of global warming. This has resulted in changes in sea levels, ecosystems and weather events, which have directly, affect people's health and way of life, as well as cause irreversible losses to plant and animal species [2].

Worldwide energy demand is escalated due to population and economic growth. As per the investigation done in energy outlook 2030 by bp global, the energy demand will increase by 36% between 2013 and 2030 provided there are continuous improvements in energy efficiency. Sustainable power sources have been essential for people since the start of human advancement. For a considerable length of time and from multiple points of view, biomass has been utilized for warming, cooking, steam rising, and power era, hydropower and twist vitality, for development and later for power generation. Sustainable power sources for the most part rely upon vitality courses through the earth's biological system from the insolation of the sun and the geothermal vitality of the earth.

According to world energy outlook 2014 report nuclear power is one of the options that can contribute to the reduction in carbon dioxide emissions into the atmosphere, but the safety aspect of this source of energy in terms of operating reactors, managing radioactive waste and preventing the spread of nuclear weapons remains a challenge [3]. As a result renewable energy has been taken as an alternative owing to the fact that it is inexhaustible and environmental friendly. Renewable sources of energy include; solar energy, wind power, hydro power, geothermal power, wave and tidal energy. Furthermore, many renewable technologies are suited to small off-grid applications, good for rural, remote areas, where energy is often crucial in human development. At the same time, such small energy systems can contribute to the local economy and create local jobs. The natural energy flows through the earth's ecosystem are immense, and the theoretical potential of what they can produce for human needs exceeds current energy consumption by many times. For example, solar power plants on one percent of the world's desert area would generate the world's entire electricity demand today [4]. Sun powered thermal systems look to store warm from the sun that can be utilized for an assortment of purposes. A wide range of methodologies can be utilized here, including dynamic frameworks, for example, sunlight based high temp water radiators, and latent frameworks, in which cautious designing plan brings about a building that naturally stores and uses sun oriented vitality. Nurseries are a prime possibility for detached sun oriented plan, in which they gather sun powered vitality on sunny days in winter and use it to keep the house warm around evening time.

II. SOLAR THERMAL COLLECTORS AND ARRAYS

The average power density of solar radiation is 100-300 watts a square meter. The amount of the sun's energy reaching the surface of the earth also depends on cloud cover, air pollution, location and the time of year. The net conversion efficiency of solar electric power systems (sunlight to electricity) is typically 10-15 percent. So substantial areas are required to capture and convert significant amounts of solar energy to fulfil energy needs (especially in industrialized countries, relative to today's energy consumption). The collector consists of a circular transparent roof and the ground under the collector floor surface. Solar radiation heats the ground, which in turn heats the air under the collector roof like in a greenhouse. For instance, at a plant efficiency of 10 percent, an area of 3-10 square kilometers is required to generate an average of 100 megawatts of electricity-0.9 terawatt-hours of electricity or 3.2 pet joules of electricity a year using a photovoltaic system. Attributable to the numerous parameters influencing the sun powered authority execution, endeavoring to make a definite investigation of a sunlight based gatherer is an extremely entangled issue. Luckily, a moderately basic investigation will yield extremely helpful outcomes [5].

The solar array consists of 14 + 4 parallel connected solar panels with the sections of 196 x 196 mm in size made on the basis of silicon solar cells. Six single-side panels are mounted on the facets of the sub satellite at the distance of 10 mm from metallic surface, 12 panels are to be deployed in space. After deploying their axes have 100 deg angle with respect to sub satellite axis directed toward Sun. The current of the panel being orthogonal to the Sun direction is about 0.2 A at the operation voltage of 14 Volt. The maximum total power of the solar array at the nominal solar orientation is 36 W. Solar arrays begin with a single solar energy cell known as a photovoltaic cell. "Photo" essentially means light, and "voltaic" refers to voltage, which is a unit of potential electrical energy. When you combine these two terms, the word photovoltaic encompasses the conversion of light energy to an electrical current. For the sake of simplicity, you can refer to photovoltaic cells as solar cells. To provide enough power to your home, you'll need many solar cells to convert the right amount of sunlight to electricity since a single solar cell only generates a relatively small electrical current. When you connect several solar cells together, you create a solar panel, sometimes called a solar module. According to information from the National Renewable Energy Laboratory (NREL), the typical solar panel consists of approximately 40 solar cells. A solar array is the totality of solar cells, modules and panels. However, a photovoltaic system is the totality of every component in the system, including what are known as balance-of-system components. Balance-of-system components are what safely converts DC power to AC power.[6]

III. LITERATURE STUDY

Hughes [7], explained that the geographic orientation and collector tilt can affect the amount of solar radiation the system receives. He further stated that for optimum performance, the collector must face the sun when the sun is at its highest and therefore strongest, this being 12 noon. To achieve this, the collector should be orientated to face the equator. So, in the southern hemisphere, solar collectors should face true north. There are various devices for absorbing the solar radiation. Mehleri E.D. et. al. [8] determined optimum slope angle and orientation for solar photovoltaic arrays in order to maximize incident solar irradiance exposed on the array, for a specific period of time. The method is extended, by introducing a second objective, i.e. minimization of variance of the produced power, in terms of hourly power generation throughout the given period of time. The proposed method uses both well-established models and data collected from the particular area where the photovoltaic panels will be installed and is built upon four steps. In the first step, the recorded data are used in order to select the most accurate, among several isotropic and anisotropic models that can be found in the literature, for predicting diffuse solar irradiance on inclined surfaces.

Bekker et al [9] explained the orientation and tilt of the panels directly relates to the annual energy yield of the panels. Computer modeling is used to determine the best possible position. The most important factor when considering the power output from a PV panel is the solar insolation at a site. Solar insolation differs from site to site, but PV panels are certified for insolation of 1000 W/m2.

Ahmad M. Jamil and Tiwari G.N. [10] analyzed the theoretical aspects of choosing a tilt angle for the solar flat-plate collectors used at ten different stations in the world and makes recommendations on how the collected energy can be increased by varying the tilt angle. The ratio of monthly average hourly diffuse radiation to monthly average hourly global radiation was correlated by UlgenKoray and Hepbasli Arif [11] with the monthly average hourly clearness index in the form of the polynomial relationships for the city of Izmir in the western part of Turkey.

KorayUlgen [11] found that the optimum tilt angle changes between 0◦ (June) and 61◦ (December) throughout the year. In winter (December, January, and February) the tilt should be 55.7◦, in spring (March, April, and May) 18.3◦, in summer (June, July, and August) 4.3◦, and in autumn (September, October, and November) 43◦. The yearly average of this value was found to be 30.3◦ and this would be the optimum fixed tilt throughout the year. Mubiru J. and Banda E.J.K.B. [12] explored the possibility of developing a prediction model using artificial neural networks (ANN), which could be used to estimate monthly average daily global solar irradiation on a horizontal surface for locations in Uganda based on weather station data: sunshine duration, maximum temperature, cloud cover and location parameters: latitude, longitude, altitude. Results have shown good agreement between the estimated and measured values of global solar irradiation. Sakonidou E.P. et. al. [13] developed a mathematical model to determine the tilt that maximizes natural air flow inside a solar chimney using daily solar irradiance data on a horizontal plane at a site.

Chang Ying-Pin [14] maximized the output electrical energy of the modules. In this study, seven Taiwanese cities were selected for analysis. First, the position of the Sun at any time and location was predicted by the mathematical procedure of Julian dating; then, the solar irradiation was obtained at each site under a clear sky. SahinAhmet Z. et. al. [15] investigated based on measurements of a complete year of data at a coastal location near Dhahran.

Global solar radiation and sunshine duration for various stations in Turkey are presented based on measurements of a complete year's data. Consumption and demand projections of solar energy in Turkey were also introduced by Ogulata R. Tugrul and Ogulata S. Noyan [16]. Hourly global and diffuse radiation measurements on a horizontal surface were performed in the Solar-Meteorological Station of the Solar Energy Institute in Ege University over a 5 year period from 1994 to 1998.

IV. METHODOLOGY

An empirical method for the estimation of the monthly average daily total radiation incident on a tilted surface was developed by Liu B.Y.H. and Jordan R.C. [17]. In their correlation, the diffuse to total radiation ratio for a horizontal surface is expressed in terms of the monthly clearness index, K_t with the following equation:

$$\frac{H_{diff}}{H} = 1.390 - 4.027Kt + 5.5312.5557Kt^2 - 3.108Kt^3$$

Collares P. and M. Rabl A. [18] expressed the same parameter by also considering the sunset hour angle:

$$\frac{H_{diff}}{H} = 0.775 + 0.00653(\omega - 90) - \left(0.505 + 0.00455(\omega - 90)\right)\cos(115K_t - 103)$$

Knowing the value of the clearness index; one can calculate the diffuse component, H_{diff} as follows [19].

For $\omega \leq 81.4^{c}$

$$\frac{H_{diff}}{H} = \begin{cases} 1 - 0.2727K_t + 2.4495K_t^2 - 11.9514K_t^3 + 9.3879K_t^4, & K_t < 0.715 \\ 0.143, & K_t \geq 0.715 \end{cases}$$

Whereas $\omega > 81.4°$

$$\frac{H_{diff}}{H} = \begin{cases} 1 + 0.2832K_t - 2.5557K_t^2 + 0.8448K_t^3, & K_t < 0.722 \\ 0.143, & K_t \geq 0.722 \end{cases}$$

For a surface tilted at a slope angle from the horizontal, the incident total radiation is given by

$H_t = H_{dir\ on\ a\ tilted\ surface} + H_{diff\ on\ a\ tilted\ surface} + H_{ref\ on\ a\ tilted\ surface}$

Several models have been proposed by various investigators to calculate global radiation on tilted surfaces from the available data on a horizontal surface. The only difference among the models appears in the assessment of sky-diffuse component. Based on the assumptions made, the estimation models can be classified into isotropic Liu, B.Y.H. and Jordan R. C. [17] and anisotropic Hay, J.E. [20] ones. The daily beam radiation received on an inclined surface can be expressed as-

H_{dir} on a tilted surface= $(H - H_{diff}) R_b$

where H and H_d are the monthly mean daily global and diffuse radiation on a horizontal surface, and R_b is the ratio of the average daily beam radiation on a tilted surface to that on a horizontal surface. The daily ground reflected radiation can be written as

$$H_{ref\ on\ a\ tilted\ surface} = H\rho\ (1 - \cos\beta)/2$$

Liu, B.Y.H. and Jordan R. C. [17] have suggested that R_b can be estimated by assuming that it has the value which would be obtained if there were no atmosphere. For surfaces in the northern hemisphere, sloped towards the equator, the equation for R_b is given as below Miguel A. et. al. [21] and is used in the present study.

$$R_b = \frac{\cos(\emptyset - \beta)cos\delta sin\omega + (\pi/180)\omega \sin(\emptyset - \beta)sin\delta}{cos\emptyset cos\delta sin\omega + (\pi/180)\omega sin\emptyset sin\delta}$$

Where,

ω = min

ω is the sunset hour angle for the tilted surface for the mean day of the month. ''min'' means the smaller of the two terms in the bracket.

For surfaces in the southern hemisphere, sloped towards the equator, the equation for R_b is given as below Liu, B.Y.H. and Jordan R. C. [17].

$$R_b = \frac{\cos(\emptyset + \beta)\, cos\delta sin\omega + (\pi/180)\,\omega \sin(\emptyset + \beta)sin\delta}{\cos\emptyset cos\delta sin\omega + (\pi/180)\omega sin\emptyset\, sin\delta}$$

Where

$$\omega' = \min\begin{bmatrix}\omega = \arccos(-\tan\phi\tan\delta) \\ \arccos(-\tan(\phi-\beta)\tan\delta)\end{bmatrix}$$

Optimum tilt angle curve along the year, in winter, the tilt angle approaches to 55°, while in summer it approaches to 8°. Assuming all previous angles are random variables, so the expected values for those variables as follows:

$$E[\beta opt] = E[\delta] - E[\varphi]$$

Since the declination angle acts as sinusoidal wave, so its expected value equals Zero, which implies the average optimum tilt angle should equal the latitude of the location as follows:

$$E[\beta opt] = \varphi$$

Liu and Jordan model (1962) R_d= [1 + cos (β)] / 4

Badescu model (2002) R_d= [3+ cos 2β] /4

Hay model (1979)

$$R_d = \frac{H_b}{H_\circ} R_d + \left(1 - \frac{H_b}{H_\circ}\right)[(1 + cos\beta)/2]$$

Reindl *et al.* model (1990)

$$R_d = \frac{H_b}{H_\circ} R_b + \left(1 - \frac{H_b}{H_\circ}\right)[(1 + \cos\beta)/2][1 + \sqrt{H_b/H}\,\sin^3(\beta/2)]$$

V. RESULT

The daily variation of optimum slope has been extended to evaluate the yearly optimum tilt angle, ($\beta_{opt(y)}$) the yearly optimum tilt angle is a fixed value for any solar collector throughout the course of a year. It is 30.61 ^{c} for Nandha, Haryana and oriented towards the south. The amount of solar radiation received by the solar collector tilted at yearly optimum angle facing south was computed. Fig 4.8shows the yearly averages tilt angles for different locations considered in the study. It is maximum for North and then decreases as moves toward South. It is 30.61 ^{c} for Nandha, Haryana. The optimum seasonally tilt angle is maximum in winter ie.57.33° and minimum i.e. 2.67° in summer by Liu and Jordan model. Optimum seasonally tilt angle is maximum in winter ie.57.83° and minimum i.e. approximately zero in summer by Badescu model.

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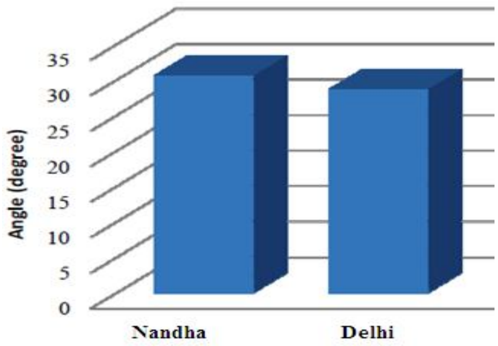

Figure 1 Yearly averages slope angles

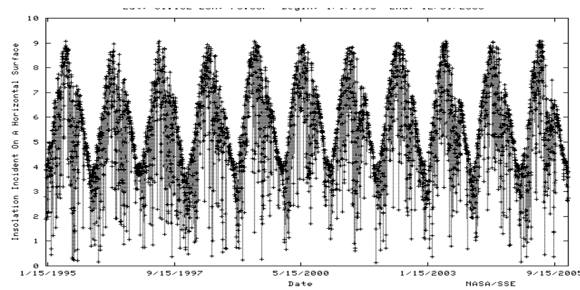

Figure 2 Daily Averaged Insolation Incident on a Horizontal Surface

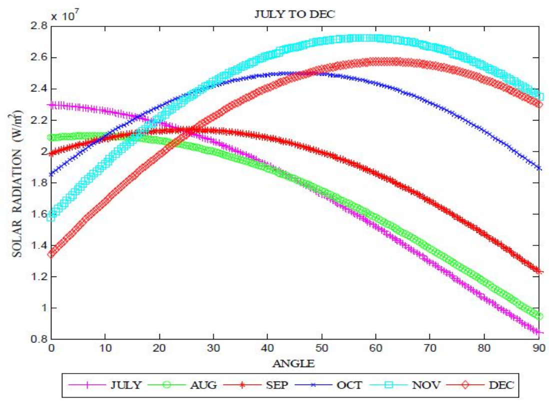

Figure 3 Monthly-average daily solar radiation availability

VI. CONCLUSION

In this study the solar radiation output of solar collector is investigated at various tilt between angles 0° to 90° for south facing to calculate daily and monthly optimum tilt angles, seasonal optimum tilt angles and yearly optimum tilt angle for particular locations in India. For Indian sites, the optimum tilt angle is generally between 10º and 35º, facing true south.The beam radiation dominates throughout the year where the maximum beam radiation reaches in the month of May whereas the least amount of beam radiation occurs in the month of December at Village Nandha, Haryana. The optimum tilt angle in June goes to a minimum zero degree as indicated by all the models. When the monthly optimum tilt angles were used, the yearly collected solar radiation was 2.500775×10^7 W/m^{2}day When the seasonal optimum tilt angles were used the yearly collected solar radiation was 2.3669×10^7 W/m^{2}day Finally, when the yearly optimum tilt angle was used, the yearly collected solar radiation was 2.27168×10^7 W/m^{2}day. The optimum tilt angles increases during the winter months and reaches a maximum of 62° in December by Liu & Jordan model whereas Hay model, Badescu model indicate the optimum tilt angle as 63.5°,62.5° resp. The P.V panel at Village Nandha, Haryana is installing at 30° the entire model shows that the yearly optimum tilt angle is close to 30° but Badescu model shows very closeness to the setup install at Village Nandha, Haryana it underestimate the angle just by 0.43%.

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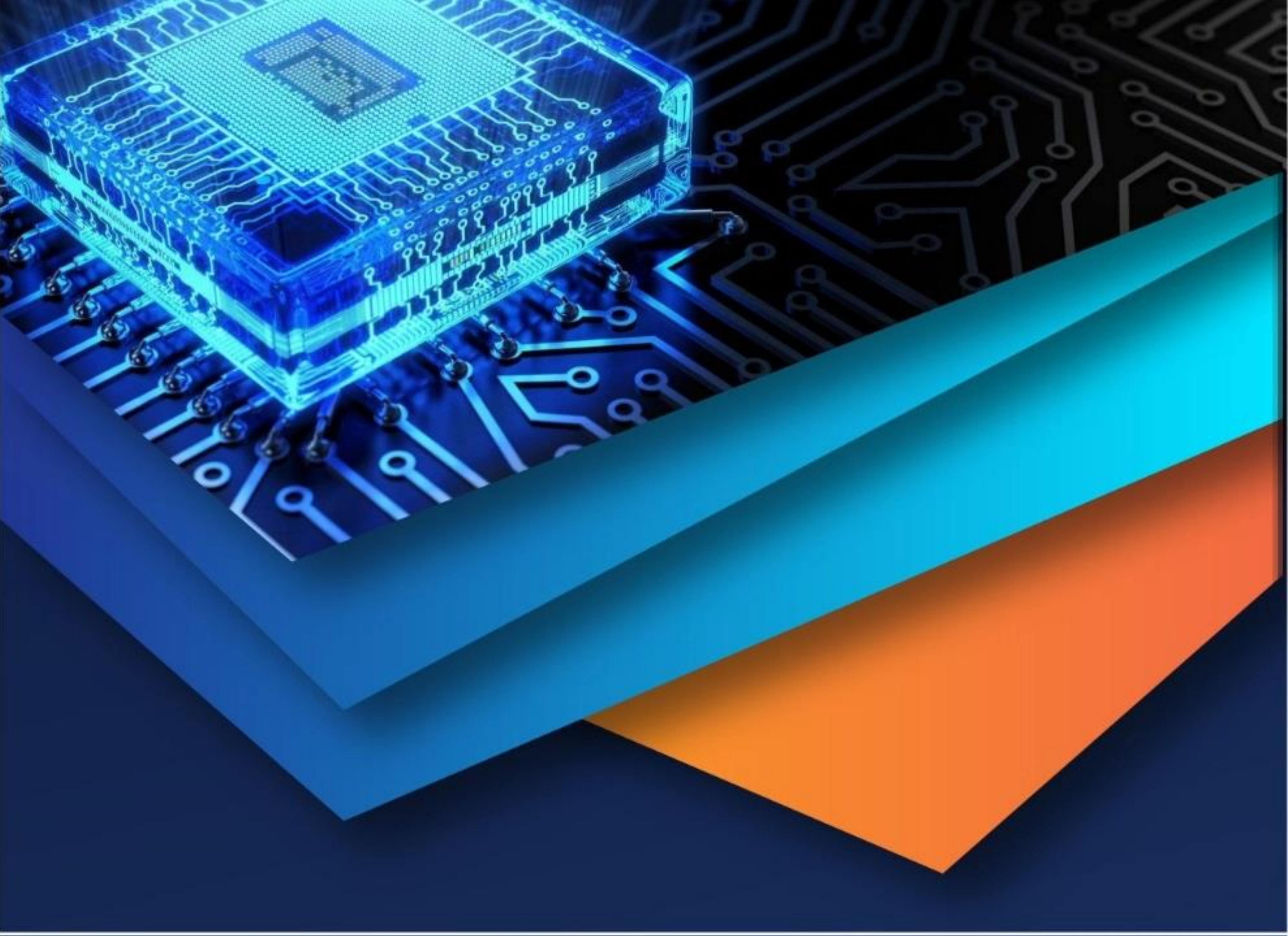

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