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"Boosting Photovoltaic Solar Panel Efficiency with Advanced Backings and Optical Concentrators"

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***Abstract:** Integrating copper and aluminum backings with advanced optical concentrators into photovoltaic (PV) solar panels can significantly increase efficiency. Copper's excellent thermal and electrical conductivity helps in reducing resistive losses and maintaining optimal temperatures, thereby minimizing thermal degradation. Its reflective properties also enhance light absorption. Aluminum, known for its lightweight and cost-effective nature, offers good thermal conductivity and reflective properties, making it suitable for extensive installations.*

Optical concentrators, such as Fresnel lenses and parabolic mirrors, play a crucial role in this enhancement. Fresnel lenses, being lightweight and economical, focus sunlight efficiently to boost panel output. Parabolic mirrors provide precise light focusing, significantly increasing light intensity and energy capture.

The combination of these backings with optical concentrators offers maximum benefits. Copper backings paired with parabolic mirrors can achieve up to 40% efficiency gains, while aluminum-backed panels with Fresnel lenses present a scalable and cost-effective improvement. These enhanced PV systems promise substantial energy savings, high ROI, and shorter payback periods. Improved thermal management and increased light absorption lead to higher energy yields and reduced maintenance costs, ensuring long-term economic viability.

Keywords: Photovoltaic Efficiency, Copper Backing, Aluminum Backing, Optical Concentrators, Fresnel Lenses, Parabolic Mirrors, Thermal Management.

I. INTRODUCTION

Solar energy plays a crucial role in our pursuit of sustainable and eco-friendly power sources. Its importance is derived from being a clean and renewable form of energy, which helps reduce the negative impacts on the planet. One of its primary advantages is its reliable availability, providing a steady and dependable energy supply daily.

In contrast to traditional energy sources like fossil fuels, solar energy generation does not cause pollution. The lack of harmful emissions makes it an environmentally friendly alternative, addressing the urgent environmental concerns of today. This feature is particularly important in the modern world, where environmental sustainability is a high priority.

Solar panel systems represent low-maintenance and unobtrusive energy solutions. These systems usually come with a 5–10-year warranty, offering users a sense of reliability and security. The low maintenance needs make solar energy a practical and efficient choice for long-term energy solutions.

Besides its environmental benefits, solar energy also offers economic advantages. By utilizing solar power for activities such as cooking and heating, both individuals and businesses can significantly lower their energy expenses. This cost-saving aspect is especially beneficial given the rising energy prices and the growing demand for sustainable practices.

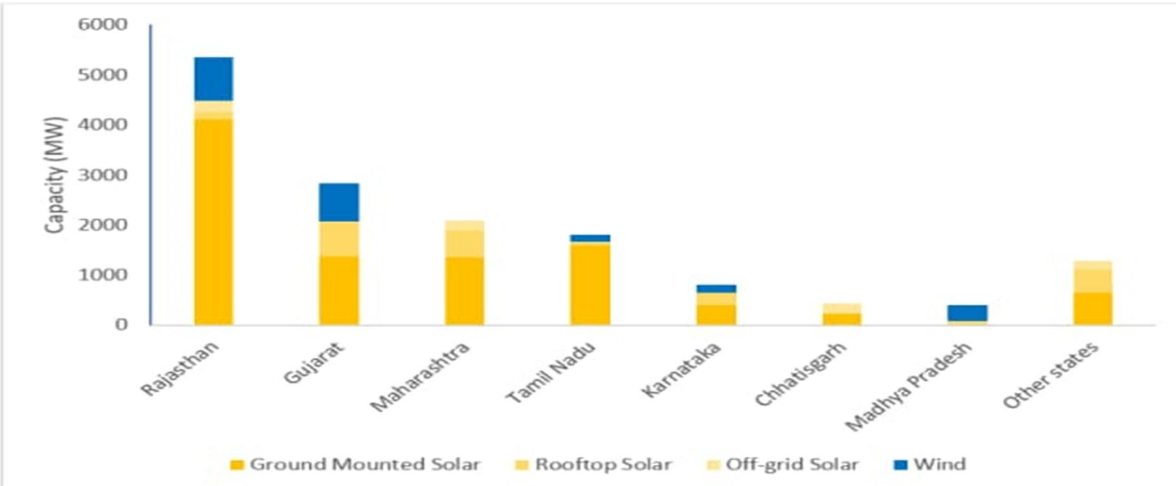
Furthermore, the versatility of solar energy is evident in its wide range of applications. From powering residential homes to supporting large-scale industrial operations, solar energy systems are used across various sectors. In countries like India, which enjoys abundant sunlight due to its geographic location between the equator and the Tropic of Cancer, the potential for solar energy is enormous.

India has adopted solar energy on a large scale, ranking fourth globally in solar energy production as of 2021. The creation of the "INTERNATIONAL SOLAR ALLIANCE" (ISA) highlights India's commitment to global cooperation in advancing solar energy technologies and practices.

As of June 30, 2023, India's solar energy installation capacity has reached an impressive 70.01 GW, marking significant progress in this rapidly growing sector. The country's proactive approach to solar energy aligns with the global trend, as solar power becomes one of the fastest-growing sources of renewable energy worldwide.

II. HEADQUARTER

Gurugram (Haryana) introduced the concept of "one sun, one world, one grid" and the World Solar Bank to harness abundant solar power on a global scale. Solar energy, which is the radiation from the Sun, can produce heat, trigger chemical reactions, or generate electricity.



Graph 1: The above pictograph represents the distribution of solar & wind energy in different regions of our country

Rajasthan, Gujarat, Maharashtra, and Tamil Nadu are major producers of ground and rooftop-mounted solar energy and wind energy. These states are pivotal in achieving the nation's target of reaching 455 gigawatts of renewable energy by 2030.

A. *Types of Energy*

Energy can be categorized into two main types:

1) *Renewable Energy*
   a) Wind
   b) Solar
   c) Hydrothermal
   d) Geothermal
   e) Biogas

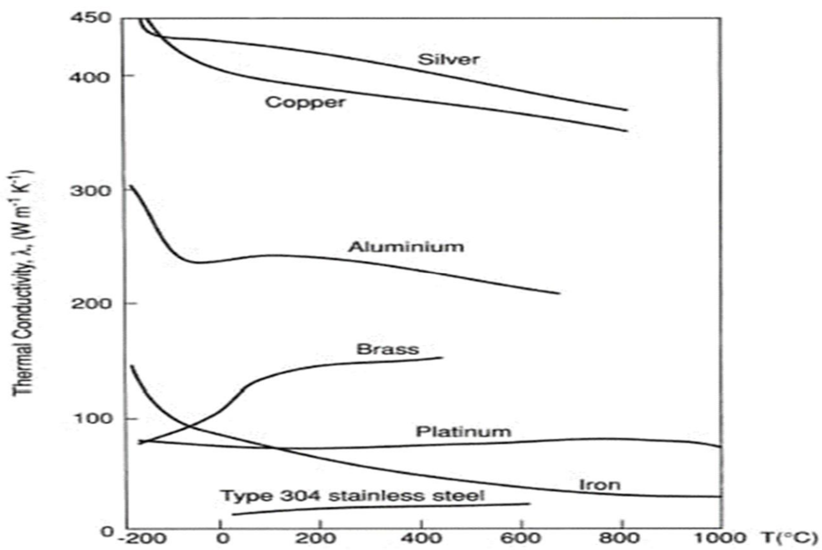
2) *Non-Renewable Energy*
   a) Fuel & Coal
   b) Natural Gas
   c) Fossil Fuel
   d) Nuclear Energy

Solar energy is both free and widely accessible, with sunlight being its primary source. This energy controls climate and weather patterns and supports almost all life on Earth. Solar energy is the main source of energy on our planet, delivering about 15,000 times more energy annually than the world's current usage. It can be used for heating, cooling, lighting structures, and generating electricity and hot water. However, solar energy is intermittent and dispersed, requiring capture or conversion for effective use, particularly outside its optimal spectral range for visible light and near-infrared rays (7000 to 1100 Å). With advancements in science, it may become possible to convert solar energy across various spectral bands into usable energy efficiently.

After reviewing the existing research and data, I decided to modify the back supporting stand or panel of solar plates using materials with higher thermal conductivity. This change aims to enhance heat dissipation from the panel, thereby improving efficiency. Currently, back panels are typically made of iron or steel, which, while economical, offer lower efficiency. Replacing these with aluminum or copper could significantly boost efficiency as they act like fins. Fins are extensions on the exterior surface of objects that increase the rate of heat transfer. The thermal conductivity of different materials is listed in the chart below:

Table1: Thermal conductivity of Different metals

Materials	Thermal conductivity(k)
Diamond	2000-2210 w/mk
Silver	432 w/mk
Copper	397 w/mk
Gold	318 w/mk
Aluminum	239 w/mk
Iron	52-73 w/mk
Steel	15 w/mk



Graph 2: Thermal conductivity Different metals v/s Temp.

B. Comparison of the performance of different generations of solar panels.

Table 2: Different types of solar panel

Generation	Types of Panel	Panel efficiency (%)	uses
First	Monocrystalline type	14-17.5	Used in conventional surroundings
	Polycrystalline type	12-14	
Second	Thin film solar cells	16-17	Used in smaller power systems
	Amorphous silicon	4-8	
Third	Nanocrystal	7-8	Best suited for areas with normal irradiation
	Polymer	3-10	

Monocrystalline solar panels perform better than polycrystalline ones due to their uniform structure and high purity. Most crystalline solar cells absorb 90% of radiation in the 400 to 1200 nm range but achieve only 18% conversion efficiency, with the rest converted to heat. After installing the solar panels, data was collected throughout the day. This data was recorded two days each month from April to July. The average data for these months is presented for both conditions: without the aluminum plate on the rear side and with the aluminum plate on the rear side to observe changes in efficiency.

Table 3: Average data collection of PV panel with iron plate in April 2024

Time	current	voltage	Panel surface temperature	Solar radiation (G) (w/m^2)	
	(Amp)	(V)	(°c)	Direct radiation	Diffuse radiation
08:00AM	3.39	11.9	38.5	620	288
10:00 AM	4.56	12.3	45.1	715	490
12:00 PM	5.15	12.8	48.9	909	585
02:00 PM	4.91	11.7	46.3	850	472
04:00 PM	3.17	10.6	37.2	845	471
AVERAGE VALUE	4.236	11.86			

Dimension =153cmx72cmx3.5cm

Solar panel efficiency % *

$$\text{Efficiency (\%)} = \frac{\text{Pmax}}{(\text{Area} \times 1000 W/m^2)} \times 100$$

* at STC = Irradiance $1000 W/m^2$
- Pmax = Max panel power (W)
- Area = Panel area (m^2)

This efficiency is obtained under STC condition but in real life result varies from given data
Now we find original efficiency under my observation,

Given data average current= 4.236amp
Average voltage=11.86 volt
Dimension =153cmx72cm

So, efficiency = (4.236x11.86/153x72x1000)100%
=4.560%

Radiation coming to solar panel in these way

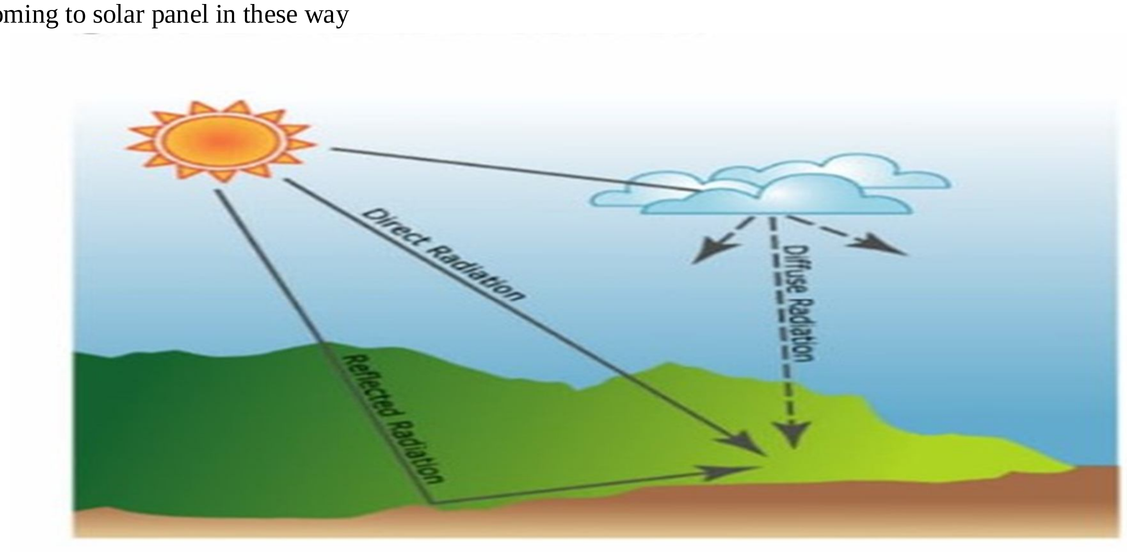


Figure 4.2 Radiation coming to solar panel

Table 4 Average data collection of PV panel with rear side aluminum plate in April 2024

Time	current	voltage	Panel surface temperature	Solar radiation (G) (w/m²)	
	(Amp)	(V)	(°c)	Direct radiation	Diffuse radiation
08:00AM	4.12	11.12	35.2	620	288
10:00 AM	4.68	12.8	39.1	715	490
12:00 PM	5.27	12.7	44.12	909	585
02:00 PM	4.98	11.10	43.23	850	472
04:00 PM	3.20	10.8	34.16	845	471
AVERAGE VALUE	4.45	11.704			

C. Average data collection of PV panel with rear side aluminum plate in April 2024

Now we find original efficiency under my observation when aluminum plate is installed in backside of panel which help in heat dissipation as result surface temperature decreases, which gives better efficiency

Given data average current= 4.45 amp

Average voltage=11.704 volt

Dimension =153cmx72cm

So, efficiency = (4.45x11.704/153x72x1000)100%

=4.727%

Net increase in efficiency after installation on aluminum panel is

= (4.727-4.560) % =0.167%

Due to installation of aluminum panel which as very high thermal conductivity as compare to iron heat dissipation rate increases that why surface temperature of panel is maintain at lower value due to uniform heat dissipation.

Table 5 Average data collection of PV panel with iron plate in May 2024

Time	current	voltage	Panel surface temperature	Solar radiation (G) (w/m²)	
	(Amp)	(V)	(°c)	Direct radiation	Diffuse radiation
08:00AM	4.15	11.15	36.9	642	298
10:00 AM	5.03	12.10	41.11	824	526
12:00 PM	5.06	12.4	50.23	929	559
02:00 PM	5.02	11.13	50.17	922	585
04:00 PM	3.42	10.02	43.2	787	438
AVERAGE VALUE	4.536	11.36			

D. Average data collection of PV panel with iron plate in May 2024

Now we find original efficiency under my observation,

Given data average current= 4.536 amp

Average voltage=11.536 volt

Dimension =153cmx72cm

So, efficiency = (4.536x11.36/153x72x1000)100%=04.6776%

Table 6 Average data collection of PV panel with Aluminum plate in May 2024					
Time	current	voltage	Panel surface temperature	Solar radiation (G) (w/m²)	
	(Amp)	(V)	(°c)	Direct radiation	Diffuse radiation
08:00AM	4.18	11.25	34.2	642	298
10:00 AM	5.13	13.01	39.7	824	526
12:00 PM	5.40	13.22	47.8	929	559
02:00 PM	5.32	12.01	46.4	922	585
04:00 PM	4.29	10.32	41.9	787	438
AVERAGE VALUE	4.864	11.962			

E. Average data collection of PV panel with Aluminum plate in May 2023

Now we find original efficiency under my observation,
Given data average current= 4.864 amp
Average voltage=11.962 volt
Dimension =153cmx72cm
So, efficiency = (4.864x11.962/153x72x1000)100%
=05.1624%
Net increase in efficiency after installation on aluminum panel is = (5.1624 - 4.6776) =0.4848%
Due to installation of aluminum panel which has very high thermal conductivity as compare to iron, heat dissipation rate increases.

Table 7. Average data collection of PV panel with iron plate in June 2024					
Time	current	voltage	Panel surface temperature	Solar radiation (G) (w/m²)	
	(Amp)	(V)	(°c)	Direct radiation	Diffuse radiation
08:00AM	3.27	10.17	36.7	527	196
10:00 AM	4.67	11.15	43.8	732	399
12:00 PM	5.11	12.13	53.6	842	412
02:00 PM	5.09	12.31	54.2	833	418
04:00 PM	3.36	9.45	39.8	685	440
AVERAGE VALUE	4.3	11.042			

F. Average Data Collection of PV panel with iron plate in June 2024

Now we find original efficiency under my observation,
Given data average current= 4.3 amp
Average voltage=11.042 volt
Dimension =153cmx72cm
So, efficiency = (4.3x11.042/153x72x1000)100%
=04.31%

After observation it is seen that reason for lower efficiency is the surface temperature of solar panel which crosses 50°c during proper sunlight that why most of sunlight energy is converted in heat due to this its efficiency decreases so different method is used to decrease the surface temperature in such a way that is economical as well as no extra electricity is consumed in cooling the surface of solar panel.

Table 8. Average data collection of PV panel with Aluminum plate in June 2024

Time	current	voltage	Panel surface temperature	Solar radiation (G) (w/m²)	
	(Amp)	(V)	(°c)	Direct radiation	Diffuse radiation
08:00AM	3.28	10.8	36.5	527	196
10:00 AM	5.10	11.5	43.6	732	399
12:00 PM	6.11	12.6	53.1	842	412
02:00 PM	6.71	12.4	54.4	833	418
04:00 PM	4.89	9.86	39.2	685	440
AVERAGE VALUE	5.218	11.432			

G. Average data collection of PV panel with Aluminum plate in June 2024

Now we find original efficiency under my observation,
Given data average current= 5.218 amp
Average voltage=11.432 volt
Dimension =153cmx72cm
So, efficiency = (5.218x11.432/153x72x1000)100%
=05.415%
Net increase in efficiency after installation on aluminum panel is = (5.415 - 4.310) =1.105%
Due to installation of aluminum panel which has very high thermal conductivity as compare to iron, heat dissipation rate increases.

III. DATA ANALYSIS AND RESULTS

Data collected from the solar panel system, using both iron and aluminum plates, shows that efficiency improves when using aluminum due to better thermal conductivity and heat dissipation, thus reducing surface temperature. This results in increased electrical output, validating the hypothesis that thermal management impacts solar panel efficiency. This research highlights the importance of material choice in solar panel mounting structures for maximizing energy conversion and efficiency.

IV. CONCLUSION

This study examined the performance of an off-grid solar energy system enhanced by mounting aluminum panels behind the solar panels. The primary objective was to design an efficient, economical, and environmentally friendly system. According to previous studies, this design increases solar panel efficiency by 1-2% in each analysis. The efficiency improvements were determined by analyzing the voltage, current, temperature, and solar radiation data. This method does not require additional space for mounting aluminum panels, making it a practical solution. Therefore, this approach can be recommended for any PV solar panel installation, offering a permanent, cost-effective, and eco-friendly solution.

A. Scope of Improving Solar Panel Efficiency in the Future

There are several avenues for further enhancing solar panel efficiency, and identifying research gaps can guide future improvements:

1) *Material Selection:* Utilizing materials with higher thermal conductivity, such as copper, on the back of the solar panels can enhance heat dissipation and improve overall performance.
2) *Advanced Cooling Systems:* Implementing a condenser heat exchanger made of copper with a liquid refrigerant, such as water, can provide better cooling for the solar panels. This setup would further reduce the operating temperature, thereby increasing efficiency.

By addressing these areas, future research can continue to optimize solar panel performance, making solar energy an even more viable and sustainable option.

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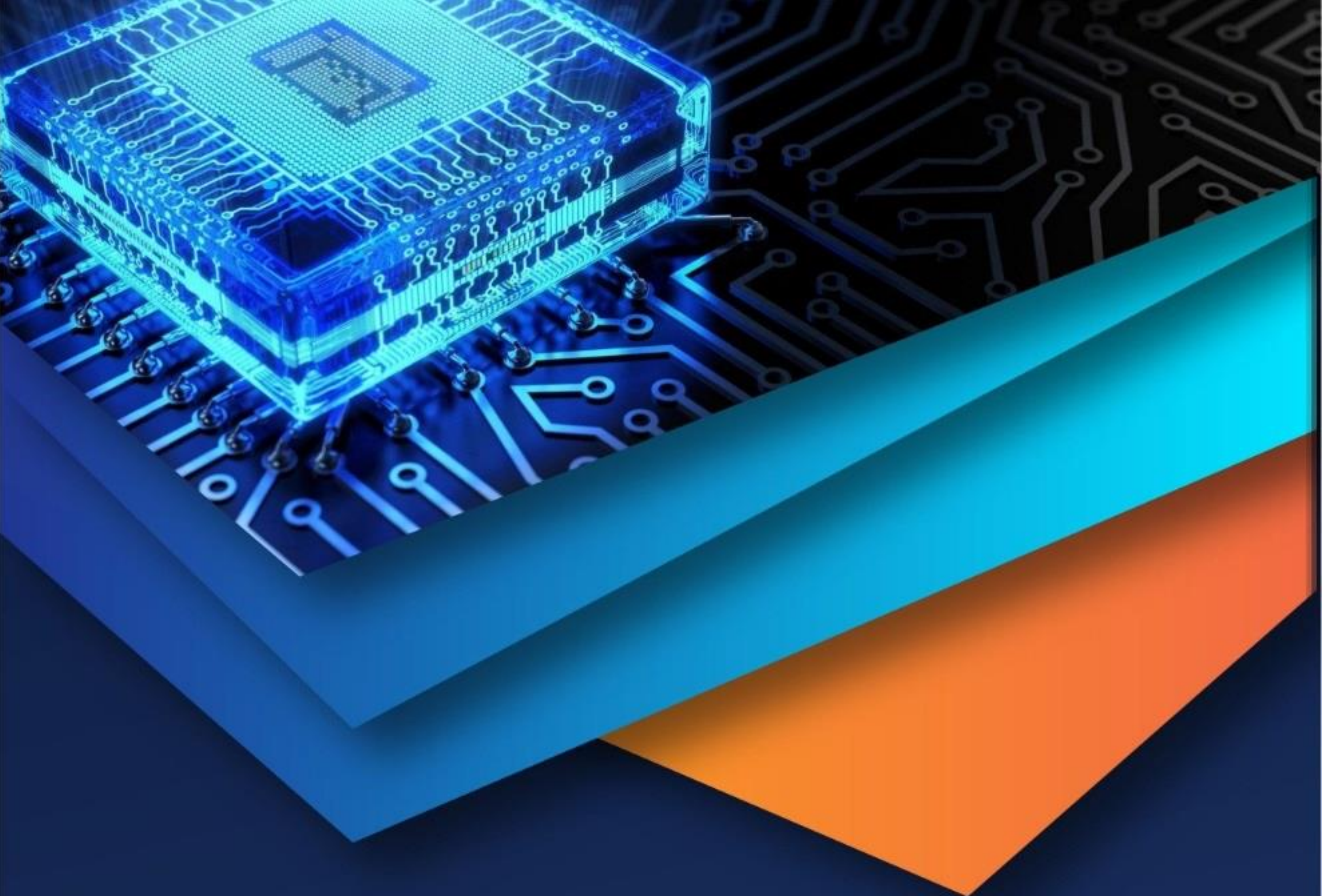

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