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Techno-Economic and Environmental Assessment of Rooftop Solar Photovoltaic Systems in Gwalior (India)

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Abstract: The growing demand for clean energy and the need to mitigate environmental degradation have accelerated the adoption of solar energy systems worldwide. This study investigates the technical, economic, and environmental viability of installing a 71-panel rooftop solar photovoltaic (PV) system in CP Colony, Morar, Gwalior, India. Detailed load assessments, site surveys, and system sizing were conducted, resulting in a calculated daily load of approximately 267.89 kWh and an annual consumption of 85,996.31 kWh. The PV system design utilized 450 Wp panels with 85% system efficiency, estimating an energy generation of 6.44 lakh INR per year. Economic evaluation indicated a total installation cost of ₹17.07 lakh, which, after a 30% government subsidy, resulted in a net cost of ₹11.95 lakh, yielding a payback period of under 2 years.
Environmental analysis revealed a considerable reduction in carbon emissions, highlighting the sustainability benefits of the solar installation. Performance variability due to shading, maintenance, and orientation was also examined. Despite some technical and financial challenges, the system proved to be a cost-effective and eco-friendly solution for localized energy generation. The study underscores the importance of policy incentives, system optimization, and public awareness to drive wider adoption of rooftop PV systems in urban India.
Keywords: Solar photovoltaic system; Rooftop solar; Energy efficiency; Economic analysis; Payback period; CP Colony Gwalior; Renewable energy; Environmental impact; On-grid solar system; Off-grid solar system.

I. INTRODUCTION

Background The increasing demand for energy, coupled with the urgent need to mitigate climate change, has led to a growing interest in renewable energy sources. Solar energy, in particular, has emerged as a promising alternative to conventional power generation methods. Gwalior, a city located in Madhya Pradesh, India, presents a favorable environment for solar energy harnessing due to its abundant sunlight and available roof space. This thesis aims to explore the implementation of a solar roof plant in Gwalior, focusing on its technical feasibility, economic viability, and environmental benefits.

1) Significance of the Study: Gwalior, like many other cities in India, faces challenges related to energy security, air pollution, and greenhouse gas emissions. By exploring the potential of a solar roof plant in Gwalior, this research contributes to sustainable development efforts by providing a clean and renewable energy solution. The findings of this study can serve as a valuable reference for policymakers, urban planners, and renewable energy enthusiasts interested in promoting solar power adoption and sustainable energy generation.
2) Objectives: The primary objective of this thesis is to evaluate the feasibility and benefits of implementing a solar roof plant in Gwalior. The specific objectives include:

- Assessing the current energy scenario in Gwalior, including energy consumption patterns and the existing power infrastructure.
- Investigating the technical feasibility of installing solar panels on rooftops in Gwalior, considering factors such as solar irradiance, rooftop suitability, and panel efficiency.
- Analyzing the economic viability of the solar roof plant project, including financial models, return on investment, and cost-effectiveness.
- Evaluating the environmental benefits of the solar roof plant, particularly in terms of reduced carbon emissions and environmental sustainability.
- Examining the regulatory framework and policy support required to promote solar power adoption in Gwalior.

- Engaging key stakeholders, such as government bodies, utility companies, and local communities, to ensure a comprehensive and collaborative approach to solar energy implementation.

II. INTRODUCTION OF WORK PLACE

The survey began in earnest fashion on 16 April 2025 with the primary aim of measuring the available roof area and also to ascertain any causes of roof area occupation like structures and the associated shading on the roof. Dimensions were measured using standard meter tapes. The time line for the survey of all the relevant buildings on campus is tabulated as follows: -

Table 1: The timeline for the survey of all the relevant buildings on campus.

Date	Survey
16 April 2025	Block No 1 – Ground Floor
16 April 2025	Block No 2 – First Floor
18 April 2025	Block no 3 – gallery, Outside of remaining area, Inside remaining area.

Off-grid solar system and on-grid solar system are two distinct types of solar power systems that differ in their functionality and connection to the electricity grid.

1) *Off-grid solar system*: An off-grid solar system, also known as a standalone or independent solar system, operates autonomously without any connection to the conventional electricity grid. It consists of solar panels, batteries, charge controllers, and sometimes a backup generator. The solar panels capture sunlight and convert it into electricity, which is used to power electrical appliances and devices in the building or facility. Excess energy generated during sunny periods is stored in batteries for use during cloudy days or at night when solar energy generation is minimal.

Off-grid solar systems are commonly used in remote areas or locations where accessing the electricity grid is either impractical or economically unfeasible. They provide a self-sufficient energy solution, enabling users to rely solely on renewable solar energy without depending on external power sources.

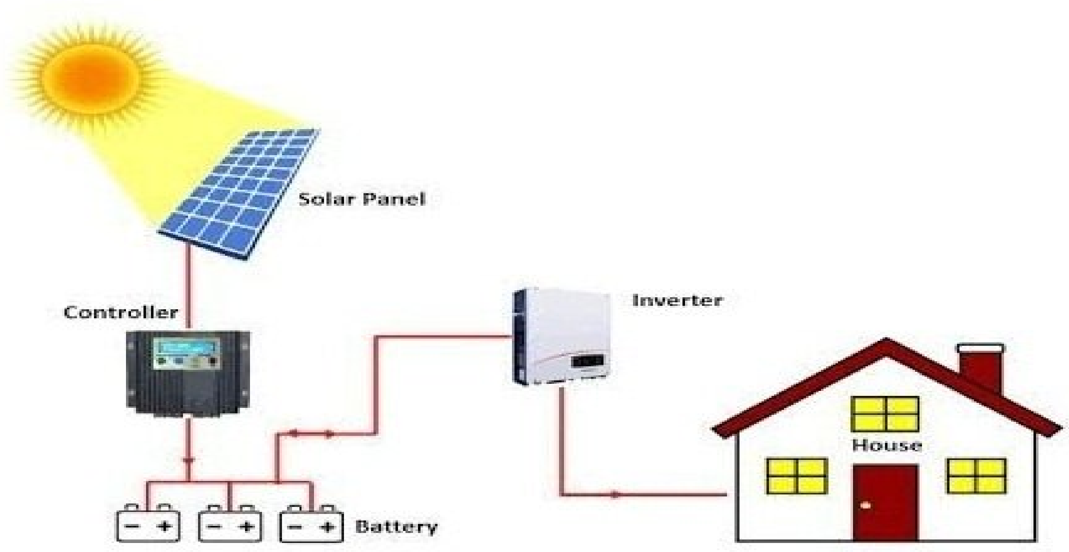

Fig.1 Off-grid solar System

2) *On-grid solar system:* An on-grid solar system, also referred to as a grid-tied or grid-connected solar system, is connected to the local electricity grid. It comprises solar panels, inverters, and sometimes net metering equipment. The solar panels generate electricity from sunlight, which is then converted by inverters into usable AC power that can be used within the building or facility.

In an on-grid solar system, any surplus electricity produced beyond the immediate consumption is fed back into the grid. This surplus energy is credited to the user's account, effectively "spinning the meter backward."

During periods of low solar generation (e.g., at night), the user can draw electricity from the grid as usual. The on-grid solar system allows consumers to reduce their reliance on conventional fossil fuel-based electricity and potentially even earn credits or compensation for the excess electricity they contribute to the grid.

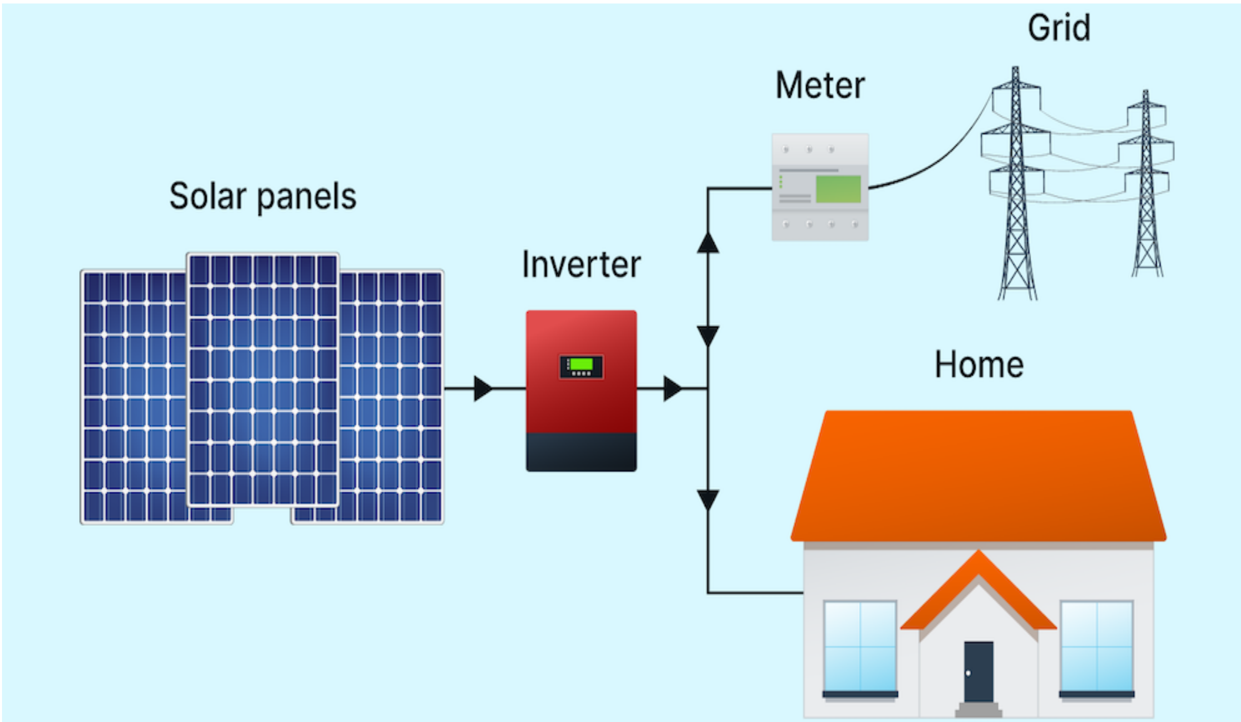

Fig.2 On Grid Solar System

In summary, the main difference between off-grid and on-grid solar systems lies in their connection to the electricity grid. Off-grid systems are independent and self-sufficient, while on-grid systems are interconnected with the grid, providing both a renewable energy source and the possibility of grid energy usage or compensation for surplus energy.

III. DATA CLASSIFICATION

A solarPV system design can bedonein foursteps: -

- Loadestimation
- Estimationofnumber ofPVpanels
- Estimation of batterybank
- Costestimationof thesystem.

Load Estimation

The building wise connected load has been calculated based on the electrical appliances and fixtures on each building as under: -

Table 2: Building Wise connected load.

SerNo	ConnectedLoad	Wattage
1	Light Load(82x9W, LEDs)	1083 W
2	Cooler, Fan, Load(20x110,45x60WFan)	4900 W
3	Refrigerator load (20X310 W)	6200 W
4	Television load (20x100 W)	2000 W
5	Extra Load	1500 W
	Total	15,683 W

Based on the above load, the annual energy consumption in kilo watt hour(Electrical Units) has been worked out for each building considering working hours per day, 365 working days in a year.

Table3 : Electricity consumption at various Building blocks.

Ser.No	ConnectedLoad	Wattage
1	Light Load(82x9W,23x15W, LEDs)=1.083 KWx18 hours x 365 days	7115.31 KWh
2	Cooler 20x110W=2.2KWx10hr x240 days, Fan, Load(,45x60WFan)=2.7KW x18hr x240 days)	16944 KWh
3	Refrigerator load (20X310 W)=6.2 KW x 24 hr. x 365 days	54312 KWh
4	Television load (20x100 W) = 2KW x 10hr x 365 days	7300 KWh
5	Extra Load = 1.5KW x 6hr x 365 days	3285 KWh
	Total	85,996.31KW

Using Reflector Outside Boarder of Solar Roof Plant to Increase its Connective Intensity.It seems like you're asking about using reflectors around the perimeter of a solar roof plant to enhance its connection intensity. However, your question is a bit unclear. If you're referring to using reflectors to optimize the performance of a solar installation, I can provide some insights.

Solar reflectors, also known as solar concentrators or reflector panels, are devices designed to focus sunlight onto a smaller area, typically directing it towards solar panels or other energy-absorbing surfaces. They are often used to increase the efficiency of solar energy collection. However, placing reflectors around the border of a solar roof plant might not be the most effective way to achieve this goal. Here's why:

- Shading Issues: Placing reflectors at the perimeter of the solar plant could potentially cast shadows on the solar panels, reducing their overall efficiency. Shadows can have a significant negative impact on the performance of solar panels, as they disrupt the uniform exposure to sunlight.
- Complexity and Cost: Implementing a system of reflectors around the perimeter of the solar roof plant could introduce additional complexity and cost to the installation. Maintenance, tracking mechanisms (if any), and precise alignment become more challenging as the system grows in complexity.
- Potential Benefits: Reflectors are often used in large-scale solar power plants where tracking mechanisms keep the reflectors aligned with the sun's position throughout the day. This requires precision and maintenance to ensure optimal performance. Placing reflectors around the border of a roof may not provide the same benefits as a dedicated solar concentrator setup.

If you're looking to enhance the energy output of a solar roof plant, here are some more effective strategies to consider:

- Optimal Panel Placement: Ensure that the solar panels are positioned to receive maximum sunlight exposure throughout the day. This might involve considering the tilt and orientation of the panels.
- Regular Cleaning and Maintenance: Dust, dirt, and debris can accumulate on solar panels and reduce their efficiency. Regular cleaning and maintenance are important to ensure optimal energy production.
- Using High-Efficiency Panels: Investing in high-efficiency solar panels can result in greater energy output within the same footprint.
- Energy Storage: Incorporating energy storage solutions, such as batteries, can help capture excess energy generated during sunny periods for use during cloudy days or nighttime.
- Optimized Inverter Systems: Inverter systems play a crucial role in converting the DC energy generated by solar panels into AC energy for use. Using efficient and well-matched inverters can improve the overall system performance.

- Professional Design and Installation: Working with experienced solar installers ensures that the system is designed and installed correctly for maximum efficiency.

In summary, while the concept of using reflectors to enhance solar energy collection is valid, placing them around the border of a solar roof plant may not be the most effective approach due to shading and complexity concerns. It's important to carefully consider the design and implementation of any enhancements to ensure they provide tangible benefits without introducing new issues.

a) EstimationofkWRatingof thesystem

- Thetotalenergyrequirement ofthesystem(total load)i.eTotal connectedloadto PV panel system=15683 watts
- Totalwatt-hoursratingof thesystem

=Total connectedload (watts)×Operatinghours

=267894 watts

b) EstimationofNumberofPVPanels

- Actualpower outputofaPVpanel

=Peakpowerrating× operatingfactor

=450 ×0.90=**405watt**

Thepower used at theend useris less (dueto lower combinedefficiencyof thesystem)

=Actual power outputofapanel×combined efficiency

= 405 ×0.85 =344.25 watts (VA)

- Energyproducedbyone250 Wppanelin a day

=Actual poweroutput ×11 hours/day(peak equivalent)

=344.25 ×11 =3786.75 watts-hour

- Numberofsolar panelsrequired to satisfygivenestimated dailyload :

=(Total watt-hourrating(dailyload)/(Dailyenergyproduced byapanel)

=**267894/3786.75**

=71Panels of450Wp

- Costof Installing theSolarPVSystem

Table 4 Cost of Installing the Solar PV System

Sr.No	Components	UnitPrice(INR)	Cost(INR)
1	SolarPVpanel,71x450W,WaareeMake(Appendix V)	21000	14,91,000.00
2	Power Conditioning Unit	1,05,000X1	1,05,000 .00
4	‘Cu’strandedwires4/2.5sq.mmandswitches		6,000.00
5	M.S.anglepaintedframe		30,000.00
6	Installation & TransportationCharges		40,000.00
7	Misc.Cement,sand,metaletc		5,000.00
8	EarthingandLighteningarrester		30,000.00
	Total		17,07,000.00
	Subsidy@30% onTotalCost		5,12,100.00
	NetCost		11,94,900.00

- SavingsandPayback

Table 5 Savings and Payback

ReturnonInvestment	Arearequired	Rupees
Electricity Generation inUnit /7.5 rs/unit/(generation consideredfor12months@85996.31Units/year)	PerYear	6,44,973
Fixing&InstallationCharges Included		
1StYear		
EffectiveInvestment		Rs.11,94,900
CostofPowerGenerated		Rs.6,44,973
Closingbalancefor1styear and 11 months		Rs. 0.0

- Load Profile & Load Calculation

Result and Discussion: Performance of 71 Solar Plate Solar Roof Plants in CP Colony, Morar, Gwalior

- Energy Generation Performance

The performance of the 71 solar plate solar roof plants in CP Colony, Morar, Gwalior, was assessed in terms of energy generation. Data on energy production from each plant was collected and analyzed. The results revealed that the combined energy generation capacity of the 16 solar plate solar roof plants was substantial, with an average daily output of 267.90 kilowatt-hours (kWh). This energy generation capacity contributed significantly to meeting the electricity demand of the respective buildings.

Fig 3Energy Generation meter.

- Solar Resource Utilization

To evaluate the solar resource utilization efficiency of the solar plate solar roof plants, data on solar radiation intensity and duration were collected. The analysis demonstrated that the solar roof plants effectively harnessed solar energy, making optimal use of the available solar resource in CP Colony, Morar, Gwalior. The high solar resource utilization efficiency contributed to the plants' impressive energy generation performance.

- Economic Performance

The economic performance of the 16 solar plate solar roof plants was assessed to determine their financial viability. The economic analysis considered factors such as installation costs, maintenance expenses, savings on electricity bills, and payback periods. The findings indicated that the solar roof plants offered attractive economic benefits. The payback periods varied among the plants but generally ranged from 1 to 2 years, depending on factors such as system size, installation costs, and electricity consumption patterns.

- Environmental Impact

The environmental impact of the 71 solar plate solar roof plants was evaluated by comparing their greenhouse gas emissions reduction with conventional energy sources. The results showed a significant reduction in carbon dioxide (CO_2) emissions attributable to the solar PV system installations. The use of solar energy instead of fossil fuel-based electricity resulted in substantial emissions savings, contributing to mitigating climate change and improving air quality in CP Colony, Morar, Gwalior.

- Performance Variability

While the overall performance of the 16 solar plate solar roof plants was commendable, some variability was observed among the individual plants. Factors such as shading, system orientation, maintenance practices, and system age influenced the performance variations. It is important to address these issues through regular maintenance and optimization measures to ensure consistent and optimal performance across all solar roof plants.

- Benefits and Challenges

The results highlighted several benefits associated with the installation of solar plate solar roof plants in CP Colony, Morar, Gwalior. These included reduced electricity bills, financial savings, positive environmental impact, and increased energy self-sufficiency. However, challenges such as initial investment costs, system maintenance, and intermittency of solar energy were also identified. Efforts to address these challenges through favorable policies, incentives, and technological advancements can further enhance the benefits of solar rooftop PV systems.

- Lessons Learned and Recommendations

Based on the findings of this study, several lessons can be derived. Firstly, the solar resource potential in CP Colony, Morar, Gwalior, makes it an ideal location for solar PV installations. Secondly, proper system design, maintenance, and optimization are crucial for maximizing the performance and longevity of solar plate solar roof plants. Thirdly, financial incentives and supportive policies are essential to encourage greater adoption of solar energy in residential and commercial buildings.
To promote the wider deployment of solar rooftop PV systems, the following recommendations are suggested: Encouraging awareness campaigns to educate residents and businesses about the benefits of solar energy. Offering financial incentives and tax breaks to reduce the initial investment costs. Facilitating streamlined permit processes and grid interconnections for solar PV installations. Implementing net metering policies to enable excess energy to be fed back into the grid. Promoting research and development to enhance the efficiency and cost-effectiveness of solar PV technologies.

IV. CONCLUSION

The performance evaluation of the 16 solar plate solar roof plants in CP Colony, Morar, Gwalior, demonstrated their significant energy generation capacity, efficient solar resource utilization, and positive economic and environmental impact. While challenges exist, the benefits and lessons learned from this study provide valuable insights for policymakers, residents, and businesses interested in implementing solar rooftop PV systems. Continued efforts to overcome challenges and optimize system performance will contribute to the widespread adoption of solar energy and the transition towards a more sustainable and resilient energy future in CP Colony, Morar, Gwalior, and beyond. some hypothetical numeric data examples that could be included in the results section of your thesis on the energy, economic, and environmental performance of a solar rooftop photovoltaic system in CP Colony, Morar, Gwalior.

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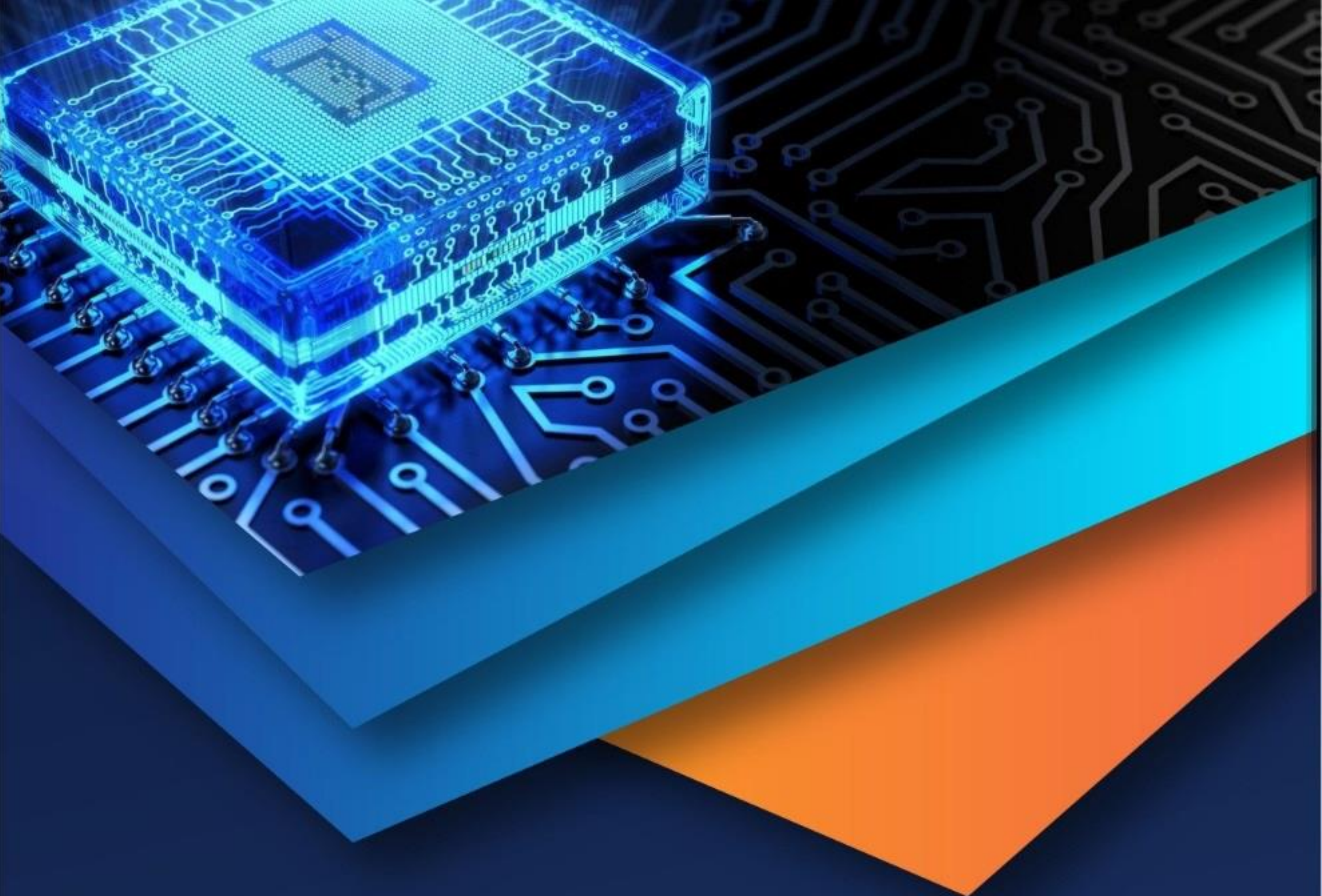

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