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Multi-criteria Decision Making Methods and sustainable Appliations in the Digital Age

Chandarani Sutar[1], Dr. Deependra Singh[2], Dr. K. S. Verma[3]
[1]Department of Electrical Engg., RRSIMT Amethi, UP, India
[2, 3]Department of Electrical Engg., KNIT, Sultanpur, UP, India

Abstract: Designing a sustainable electrification system for remote places in developing countries is very complex while considering various factors such as technical, economic, environmental and social (TEES). Development of an efficient, rational, coherent and a translucent framework is required to address issues related to the requirement of energy needs based on the end user. The main goal of this research is to design a methodological framework based on decision analysis and optimized model with locally available energy sources. The new optimal renewable energy options are required to be used to minimize the fossil fuel dependency of electrical generation. Initially, suitable energy alternatives are selected by considering different criterion with multiple scenarios for decision analysis. The further optimal combination of energy sources evaluated for different possibilities. The new methodology of hybrid renewable optimization is applied to a rural place, Himachal Pradesh to illustrate its effectiveness based on metrological data.

The case study result shows that new methodology gives a real-time optimized system with multiple system combinations and configuration with the use of multitasking decision algorithm. This optimized system found very impactful on its technical feasibility, environment, economy and social factors (TEES) for the considered location.

Keywords: Renewable Energy Soucres,Demand side managment , Energy consumption, Wind energy, Battery, Hydro, Hybrid system, Optimization.

I. INTRODUCTION

According to the survey of international energy agency (IEA), the energy sector is facing many challenges that have obstructed the growth and full utilization of the crucial energy resources. The cost of high upfront installation and implementation of advanced control equipment with limited financing supports for project developers. The task to establish energy solution becomes very challenging due to lack of business maturity, less purchasing power at consumers level, small and remote dispersed consumers with a low density of population of local and remote locations. Communities low-income levels adversely affect agriculture conditions due to little employability[3].

Approximately 40% population of India are living in remote villages. The comprehensive growth of villages can create a positive impact on development and GDP growth. The proposed case study is considered for remote community of Himachal Pradesh, which is not connected to the grid network and road transport accessibility is also not available throughout the year due to the adverse environmental condition. The electricity of remote community totally depends upon diesel generators. Diesel generator contributes highest cost electricity consumption, which is 10 times more than on the average cost of hybrid renewable generation. Therefore a hybrid renewable generation can be utilized to ensure a power supply of quality, reliability, affordability. It can also provide increased sustainability assessment of advanced energy technology and further helps to reduce greenhouse gas emission and global warming effects[4]. The invariant nature of renewable energy sources creates power quality problems, therefore, the option of utilization of energy storage devices with new beneficial services provides new market space by reducing the cost of the battery. Advancement of new manufacturing technologies provides compactness and large-scale storage property. Most preferred batteries with their specific merits are sodium - sulpher (Na_S), having highest energy density and longest life with the use of nickel-cadmium (Ni_Cd), Lead acid batteries for cheapest cost and lithium-ion batteries for its best properties.

Battery charging status with maximum and minimum settings will depend upon the rate of self-discharging and its current ratings.

Most of the research literature emphasize towards optimization of a combined generation with consideration of its design criteria, specific location, planning and implementation, cost minimization, providing reliability for solving the economic problem.

The proposed multi-decision algorithm provides a better solution to regulate power outage and reduces dependency on fossil fuels which involves saving of high oil expenditure. It also provides reduced greenhouse gases emission, climate resilience, advance development, optimum renewable priorities with cost reduction.

II. RENEWABLES IN INDIA

In the county total renewable power generation capacity has reached the level of 310 GW. The power generation includes a combination of 13.9% of Hydro, 69.4% of Thermal, 1.9 % of Nuclear energy and Renewable energy of 14.8 %. The renewable generation has achieved IInd level after thermal energy and further expanding its range at the very high rate.

The target of renewable power capacity has increased by the government of India to 175 GW which consist of wind, solar, bio and small hydro of 60 GW, 100 GW, 10 GW, and 5 GW respectively. The set target is to be accomplished by the year 2022. Wind energy capacity generated till 31 March 2018 was 34,046 MW and it took India to the fourth position in the world.

The Government has set a target of 5 GW for SHP projects. Ministry of New and Renewable Energy has been assigned to develop SHP projects of capacities up to 25 MW. Currently, the number of sites for SHP is approx 7200 and power capacities up to 21188.69 MW are identified by Govt. agencies as well as Private developers[8].

III. FACTORS OF EVALUATION

Optimization of the renewable system is a very challenging task due to invariant performance characteristics of different renewable Sources. The presented research implements a multi-objective decision methodology to achieve the objective of research work. The main four prominent factors are considered here for the evaluation of proposed method efficiency for hybrid system considering its technical, economic, social, environmental and cultural impacts[33].

A. *Technology Criteria*

The technological criteria consist of system performance with technical efficiency and risk of system operation. The details are as follows:

1) *The efficiency of Power Sources*

It is the main parameter of generation components. Efficiency includes the proper utilization of renewable sources for fulfilling the desired limit of energy consumption. The efficiency of the hybrid renewable system depends upon factors such as solar radiations, wind speed variations, load demand and implemented control strategies.

$$\text{Efficiency}(\dot{\eta}) = \frac{\text{Real power output}(P_{\text{Real}})}{\text{Nominal Power output}(P_{\text{out}})} \qquad (1)$$

2) *Reliability of System*

It is a very crucial factor for designing of the hybrid renewable system. Hybrid renewable system reliability depends on the reliability of system component based on different operating modes while generated power must fulfill power demand or deficits caused by the unmet load. The reliability is measured by indices such as Loss of Power Supply Probability (LPSP), Probability of Unmet load (POUL), Loss of Load Hours (LOL), Level of system performance(LOSP), Average interruption of frequency Index (AIFI) and Average time of recovery.

The probability can be calculated as follows

Case 1: when all generator out of service

$$\text{Probability} = \Pi_{i=1}^{n} FOPi \qquad (2)$$

Case 2: when all generator are in service

$$\text{Probability} = \Pi_{i=1}^{n} (1 - FOPi) \qquad (3)$$

The calculation of these values is made by the exploring energy balances and the possible design of the electrical scheme.

3) *Installation Risk*

Installation risk may occur in case implemented technology does not work properly under prescribed conditions due to fake or wrong manufacturers information, design errors, damage of parts, down performance to meet expected values. The criteria can be calculated by the deterioration of equipment performance parameters.

The probabilistic approach includes a set of quantitative low, medium and high probability criteria of damage/deterioration.

$$\text{Probability P} = \{\text{Low,Medium,High}\} \qquad (3)$$

4) Security of Power Supply

The security of power supply depends on the probability of fuel reliability. Generation source is called secure or reliable when it is enough to maintain continuity of electricity. The fuel security issues may arise due to fluctuating fuel prices as per international business and also disruption may be caused by geopolitical disturbance. This criterion can be evaluated by the statical calculation of fuels with its low, medium and high probability by consultation of experts.

$$\text{Probability } P_{security} = \{\text{Low,Medium,High}\} \qquad (4)$$

B. Economical Criterion

Economic efficiency of the power system is the ratio of the effect of economic results to cost influences by this results. The cost of investment and its output results called higher economic efficiency. The factors considered to indicate economic efficiency are system investment, production cost, revenue obtained, low payback time and increased probability. Levelized cost (Lc_{ost}) and cost of energy are prime project indicators.

$$L_{cost} = \frac{\text{lifetime costs}}{\text{lifetime expected power output}} \qquad (5)$$

1) Services Access Time

It is the time required in case of breakdown for completion of repair. It calculates the number of hours to be required for complete repairing of unit and repairing of time includes from 0 to several hours leads to many days. It creates a database which can minimize repetitive work and can be taken for manufacturer guarantee in future repairing experiences.

$$P_{business} = \{< \text{one hour}, > \text{one hour, one day}, > \text{one day}\} \ (6)$$

2) Market business risk

It is a risk factor on market or business due to growing taxes, cancellation of subsidies, sudden growth in the price of components and not paid guarantees. Market risk can be measured by quantitative criteria of low, medium and high risk. It can be minimized by consulting with companies experts and project team leaders.

$$\text{Probability } P_{business} = \{\text{Low,Medium,High}\} \qquad (7)$$

3) Difficulties in administration

Issues concerned with the implementation of project and investment comes under administrative complexity criteria. It can be evaluated with low, medium and high quantitative complexity criteria and data can be taken for evaluation from federal, regional and local rules and regulations.

C. Environmental Impacts

Renewable power generation has large impacts on the environment such as greenhouse gases, change in climate, pollution index, depletion of resources and damage of localized ecosystem.

1) Green House Gases Emission

It includes the GHS like carbon dioxide CO_2, Methane CH_4, Nitrous oxide N_2O, Ozon O_3, chlorofluorocarbons CFCs and hydrofluorocarbon HCFCs. CO_2 emissions(E_{co2}) is annual produced electricity, W (kWh) by the average annual emissions ($E_{average}$) for the certain power system.

$$E_{co2} = W^* E_{average} \qquad (8)$$

2) Influence our Local Ecosystem

The local ecosystem includes influence during operation and construction for example:

- wind power- Loss due to the influence of birds and bats, noise, vibration, change in the landscape
- PV panel- The occupation of agriculture land, diesel include noise and vibration

$$\text{Probability } P_{influence} = \{\text{Zero,Low,Medium,High}\} \ (9)$$

3) Resource Depletion

The amount of Reservoir used during the operation or during the life of power generation.

$$\text{Probability } P_{depletion} = \{\text{Zero,Low,Medium,High}\} \ (10)$$

D. Social Criteria

Increased rate of employment or increase on welfare or increase of job opportunity to the local community in that region. The social criteria of welfare can be evaluated by no influence, low, medium and significant influence.

$$\text{Probability } P_{social} = \{\text{Zero,Low,Medium, significant}\} \quad (11)$$

1) Consistent with the local policy(LP)

Government is applying different measures in form of green certificate awards and allowances for low emission pollution. The quota system is influenced by the decision of power system designer's evaluation criteria which include zero, partly or fully consistency.

$$\text{Probability } P_{LP} = \{\text{Not,partially,fully}\} \quad (12)$$

2) Adoption of Technology by Public

It is the public willingness to adopt new technology by paying money for green energy. Number of ecological problems and consciousness about the sources depletion growth goes many years for acceptance of the project.

Decision task for a sustainable plant model is based on four factors and influenced by sub-criteria for development of the community and it needs to be related with the growth of the person living in remote areas in the terms of their experiences, motivation, and values. Any community is reliance on the health of every part of the community and its effective growth for all over development covering many regions. Impact of profit planning and ecosystem on human society and its biosphere parts generates a vibrant culture and emphasis should be given on tourism, arts, festival, history, economy, social development, traditional seasonal business market value employability and tourism in that region.

TABLE I. EVALUATION CRITERIA

Criteria	Parameters	Factor	Remark
Technical criteria	Power efficiency	C_1	MAX
	LOLP/SPL/SAIFI,	C_2	MIN
	Construction risk	C_3	MIN
	The probability of fuel undersupply	C_4	MIN
Economic criteria	Leverized costs or minimum electricity price	C_5	MIN
	Business risk	C_6	MIN
	The complexity of administrative issues	c_7	MIN
	Time to access the service,	C_8	MIN
Environmental criteria	The amount of GHG gases, kg/year	C_9	MIN
	The number of other air pollutants, kg/year	C_{10}	MIN
	Influence on the local ecosystems	C_{11}	MIN
	Resources depletion	C_{12}	MIN
Social criteria	Consistency with the local police	C_{13}	MAX
	The increase of welfare in the region	C_{14}	MAX
	Acceptance of new technologies by people	C_{15}	MAX

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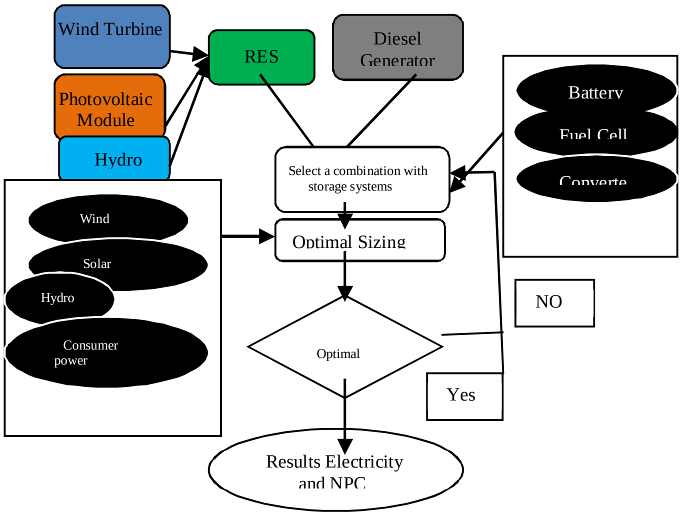

Fig.1. Flowchart for Optimal combination

IV. MODELING OF COMPONENTS

Modeling of components in hybrid energy system

A. Wind System

The wind system power output (P_{WT}) expression given by the following equation[17,18].

$$P_{WT}=\begin{cases} 0, & V_{(t)} \le V_{(cut\ in)} or\ V_{(t)} \ge V_{(cut\ out)} \\ Pr\,\frac{V^k - V^k_{(cut\ out)}}{V^k_{(cut\ out)} - V^k_r}, & V_{(Cut\ in)} < V_{(t)} < V_r \\ Pr, & V_r < V_t < V_{(cut\ out)} \end{cases} \quad (13)$$

Where v is wind speed, rated power is Pr (wind turbine), a Wind speed, cut_ in, cut_ out, rated speed of wind turbine and the number of a wind turbine are denoted by $V_{\_cut\ in}$, V_cut-out, Vr, N_{wind} respectively.

The overall power is given by

$$P_{wt}(t) = N_{wind} * P_{wt}(t) \quad (14)$$

B. Photovoltaic System

PV system power output is given by

$$P_{PV}(t) = I(t) * A * \dot{\eta}_{PV} \quad (15)$$

Where I, A, and $\dot{\eta}_{pv}$ represents radiation of solar, PV area, PV panels and DC to DC converter overall efficiency. It is supposed that PV panels are having MPPT system. Npv is number of PV systems[24].

The overall output power of PV is

$$P_{PV}(t) = N_{PV} * P_{PV}(t) \quad (16)$$

The consumption of fuel in diesel generator set (ConsD (L/h)) is given by,

$$ConsD = BD * PDN + AD * PD \quad (17)$$

Hourly diesel fuel cost is given by

$$C_f = P_{fuel} * ConsD \quad (18)$$

where the rated power PDN , power output of diesel generator PD, BD =0.0845 (litter/Kwh)and AD =0.246(litter/kWh) are consumption coefficients.Fuel Price is denoted as Pfuel.

C. Battery Model

The battery bank charging capacity at time t can be expressed as:

$E_{Battery(t)}=E_{Battery(t\_1)}*(1\_\acute{\alpha})+[(E_{PV(t)}+E_{wt(t)}\_E_{Load(t)}/\dot{\eta}_{inv}]*\dot{\eta}_{Battery}$ (19)

where symbol $E_{Battery(t)}$ and $E_{Battery(t\_1)}$, $\acute{\alpha}$, $\dot{\eta}$ inv, E_{Load}, $\dot{\eta}_{Batt}$ are battery bank charge capacities at time t and t_1, discharge rate hourly, inverter efficiency, demand, charge efficiency respectively [13].

$$E_{Battery(t)} = E_{Battery(t_1)} * (1_{\acute{\alpha}})[\frac{E_{Load(t)}}{\eta_{inv}.\eta_{PV}} + E_{wt(t)}] \quad (20)$$

$$CB = \frac{EL.AD}{DOD.\eta_{inv}.\eta_{b}.} \quad (21)$$

Where EL,AD,DOD, η_{inv} and η_b are load ,autonomy days (3-5 days), depth of discharge 80%, Inverter efficiency 95% and battery efficiency 85% respectively.

D. Hydro Power Output

$$P_{hydro}=\frac{\eta hdro.\rho water.g.hnet.Qturbine}{1000} \quad (22)$$

P_{hydro}, $\dot{\eta}_{hydro}$,ρ_{water},g ,h_{net} and Q_{turbin} denote power output of hydro (kW), Power turbine efficiency (85%),density of water (Kg/m^3),acceleration due to gravity (9.8m/s^2),effective head(meter) and hydro turbine flow rate (m^3/s) respectively.

f) *Analysis of cost:* COE is the total electricity price per unit of energy and calculated by the following equation.

$$\text{COE}\left(\frac{\$}{\text{KWh}}\right) = \frac{\text{Total Net Present Cost(\$)}}{\sum_{h=1}^{h=8760}\text{Pload(h)(Kwh)}} \quad (23)$$

CRF is the ratio of the present value system component in a system for a provided time period taking its interest rate into an account called as CRF.

It is given by the following expression :

$$\text{CRF} = \frac{(1+i)^n}{(1+i)^n-1} \quad (24)$$

Where i and n denote real interest rate and life period of the system.

E. Analysis of system reliability

The power supply, loss of probability (LPSP) is a static parameter, which indicates the failure of probability either due to less renewable output or unable to fulfill the load demand by a technical failure[11].

$$\text{LPSP} = \frac{\sum P_{Load}-P_{PV}-P_{wind}+P_{BCS}+P_{Diesel}}{\sum P_{Load}} \quad (25)$$

F. Factor of Renewable

Factor of Renewable

The renewable factor is diesel generated produced energy as compared to renewable energy. The 100% renewable factor means the ideal system which uses renewable energy sources only. However 0% renewable factor refers that diesel generator power supplied is equal to power from renewable energy resources.

$$\text{Renewable Factor (\%)} = (1-\frac{\sum P_{Diesel}}{\sum P_{PV}+\sum P_{Wind}}) \times 100 \quad (26)$$

V. THE PROPOSED HYBRID OPTIMISATION ALGORITHM

A. Analysis of criteria and objective function

Based on a broad discussion, a total of 15 numbers of different criteria are determined for the system to be taken into account. For different technologies, different values of each criterion can be set (example in Table 1).

Method of global criterion has been chosen for the most suitable structure for the given task [19]. Maximum and minimum values for each criterion have been calculated and used for converting the absolute values to the relative ones. Minimization criteria are obtained by dividing the value of criterion with optimal value (in most cases it is the minimum possible value of this criterion among all other alternatives) and maximization criteria obtained by dividing the optimal value (maximum) by value of considered criterion. The weights assigned to each criterion (from 0 to 100%) are set depending on the importance of the criterion.
The optimization process is finding minimum, maximum or optimum value of each decision variable criteria of TET criteria as per optimization function. A higher percentage of possible decision variable decides the size of Engineering, size of the wind turbine, hydro generation, size of generator and number of batteries. Strategy related to set of rules govern system operation and optimization process. It is a very useful tool to find a system with configuration out of various option and useful in the hybrid renewable power generation. Power management strategy along with energy storage devices, state of battery charging will depend upon total load demand and power output of wind and hydroelectric hybrid combination.

The objective function in the method of global criterion is

$$F = \sum_{N=1}^{15} \frac{C_N}{C_{N\max}} . W_n + \frac{C_{N\min}}{C_N} . W_N \rightarrow \text{Min} \qquad (27)$$

C_N- The value of criterion C_N
W_N %- the weight for the criterion C_N
$C_{N\,MAX}$- Maximum value for the criterion C_N (for minimizing criteria)
$C_{N\,MIN}$- minimum value for the criterion C_N (for maximizing criteria)

VI. CASE STUDY OF SELECTED SITE

A remote village of Himachal Pradesh with population approx 4600 data taken in the designing of the proposed model of the different combination of hybrid generation. A hybrid renewable optimization model considering input data daily, hourly, monthly and yearly of load profile. It also takes solar radiation per months per watt per meter square, a variation of wind speed meter per second and water flow meter per second for the PV system, wind turbine, and hydroelectric system. The first state of the problem of taking the load profile consisting of the load for Residential, Public Administration Building, agriculture, transportation conventional, industrial and others. The pool of the hybrid renewable energy sources including solar wind hydropower and diesel as a backup is used to minimize fuel consumption and a battery energy storage device is used to store surplus energy.

Table 2. SOLAR RADIATION

Month	Jan	Feb	Mar	April
Kwh/m^2 /day	5.33	5.56	6.61	6.40
Month	May	June	July	Aug
Kwh/m^2 /day	6.53	4.66	3.17	2.97
Month	Sept	Oct	Nov	Dec
Kwh/m^2 /day	5.09	7.86	7.16	6.32

The data of monthly average wind speed data at a 10m anemometer height of 50m above the surface of the earth is measured with average wind speed data of 10 years based on metrological and solar energy database and according to the data, annual average wind speed is 6.15 meter per second.

Table 3. WIND SPEED DATA

Month	Jan	Feb	Mar	April
Wind speed m/s	6.8	6.7	6.9	6.4
Month	May	June	July	Aug
wind speed m/s	5.9	5.57	5.00	5.05
Month	Sept	Oct	Nov	Dec
wind speed m/s	5.6	6.10	6.7	7.22

The proposed system hydropower is runoff river type which requires the determination of available head and flow rate of water with an annual average of 6.258 liters per second the data of hydro from Institute of water resources.

Table 4. DATA OF HYDRO RESOURCES

Month	Jan	Feb	Mar	April
water stream flow (l/s)	250	160	285	6.4
Month	May	June	July	Aug
water stream flow (l/s)	458	1698	24,300	30,500
Month	Sept	Oct	Nov	Dec
water stream flow (l/s)	6505	5800	950	740

Table 5. LOAD ESTIMATION OF SELECTED SITE

Type	Electricity total demand in kWh		
	category	*Energy consumption %*	*Electricity consumption, kWh*
Community & Residential Load Demand	Residential	40%	3000 kwh
	Public Buildings	5%	295.3 kWh
	Transport	2.5%	25 kwh
	Agricultural	2.0%	200.9 kwh
Industrial & commercial Load	Commercial	25%	2500 kwh
	Industrial	10%	2000 kWh
	Tourists	15%	1500 kwh
	others	1.5%	80.5 kwh
			10000.8 Kwh

Table.5 shows community load, which includes residential industrial and a commercial load of Himachal Pradesh. A capacity of 25 MW peak load is required to support and expand fully access of power consumption to the community.

VII. RESULTS

Hybrid renewable system configuration for a community of 4600 population of Himachal Pradesh is analyzed and demonstrated with the use of multi-decision optimization evaluation methodology. This decision variable includes criteria of technical, environmental, economic and social (TEES) impact on the system . Presented case study shows the impact of diesel generation is minimized by use of energy storage devices. The result provides the most optimal configuration with a comparison on basis of total net present cost, operating cost of the system, cost of energy and a renewable factor of the system.

A. Optimized Result

Table 5. OPTIMIZED RESULT

System configuration	Total NPC	Operating cost	COE (Rs/Kwh)	Renewable fraction
PV, wind,hydo, battery	670 M	7250.750	4.425	91%
PV, hydro,battery	715 M	8505.420	4.875	90%

B. Conclusion

The proposed method provides the solution with a comparison of different configuration and gives the most optimized configuration with PV, wind, hydro and batteries. This project configuration simulated for the site of Himachal Pradesh for increasing its qualitative value of Environment and tourism and impress more positive impact on reduction in CO_2 and GHS gases emission which helps to reduce global warming effect. This optimized configuration is very much useful for the industrial development of the woolen market and improves culture and heritage to increase revenue to add economic benefits. This multi-decision Optimization is helpful to take decision for environmental, technical and economic benefits with improved structure of government policies and awareness to the community. This system configuration making the availability of electricity helps to improve living standard by providing education economics help and job opportunities. Therefore proposed hybrid system minimizes COE and improve renewable factor further reduces operating cost by minimizing fuel consumption.

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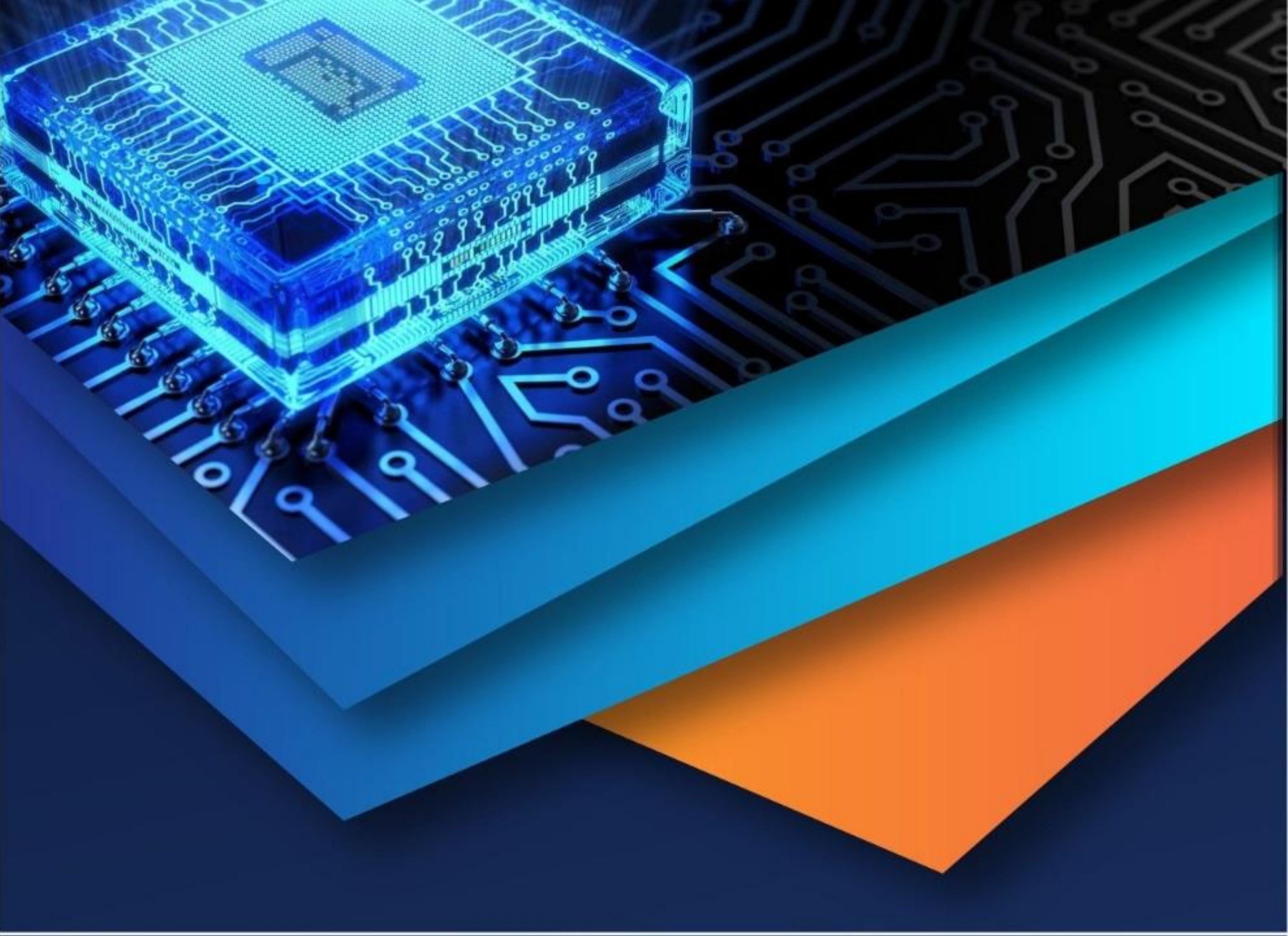

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