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Economic Analysis of Hybrid PV-Biomass Energy System using Bat Algorithm

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Abstract: Optimal sizing methodology for a stand-alone and grid connected PV-biomass hybrid energy system that is serving the electricity demand for a complete village is discussed in this paper. The least levelised cost of energy while minimising annualised cost of system is done using BAT algorithm. This method is ascendable which can be used in any test system. It is proved from the results that grid connected hybrid PV-biomass energy system is cost effective and better choice when compared with stand-alone hybrid PV-biomass energy system. The proposed system is giving more reliable and affordable results for electrification of a village from its natural resources. The comparison of results for ABC algorithm with BAT algorithm is done in this paper. In this paper it is concluded that BAT algorithm is giving best results when compared with ABC algorithm alone.
Keywords: ACS (Annualised Cost of System), NPC (Net Present Cost), LCOE (Levelised Cost of Energy) ABC (Artificial Bee Colony) Algorithm, Bat Algorithm

I. INTRODUCTION

The National grid of India has an installed capacity of 331.11GW as on 31 October 2017[1]. In the total installed capacity around 31.7% is generated through the renewable resources. The average electricity usage is around 1,122KWh per capita for the year 2016-17. A total of 12288.83MW of solar power and 8182MW of biomass power is generated up to March 2017. Around 8846 remote villages were electrified using renewable energy systems by MNRE[2].Punjab shares only 1.4% of total geographical area of India but produces 17% of wheat, 11% of rice of India's total production. It also produces 12% of cereals produced in the country [3-7]. It can generate a total of 3172MW of biomass power through crop residues and 36.9MW through forest residue. This not only generates less pollution emitting biomass fuel and also reduces the air, soil pollutions along with human health hazards due to burning of crop residues in open farm lands[9,19].Power management, reliability and economic cost of energy are the three main issues while designing a renewable based hybrid system. For planning an effective and economic hybrid system the designed system should be optimal in terms of sizing and controllability. For rural electrification solar and biomass are having greater advantage when compared with other sources of energy. Various solar and biomass energy based systems are explored by various researchers. Off-grid renewable hybrid energy sources is one of the most adopted techniques. Because of the intermittent nature of the renewable energy sources integration to grid is a difficult task. But when connected it discards the usage of batteries and diesel generator [20].The authors [21-24] proposed different nature inspired algorithms for distributed generation placement. The mathematical modelling of the grid connected PV-biomass system is done in this paper and provides the cost analysis for the system. Bat inspired algorithm is a meta heuristic optimization algorithm developed by Xin-She Yang in 2010. This algorithm is based on the echolocation behaviour of micro bats with varying pulse emission and loudness. The main objectives of this paper are

A. To fulfil the electricity demand for a small area by using the locally available natural resources a mathematical model is developed for a grid connected PV-biomass hybrid energy system.
B. Performing comparative analysis between Bat algorithm [16] and swarm based ABC algorithm [15] for a grid connected and stand-alone hybrid PV-biomass energy systems.
C. By minimising the annualised cost of the system (ACS), the least levelised cost of energy (LCOE) is done by optimal sizing of the total system.

This paper is categorised into six sections, Section.2, explains the computational study of components in the system. Section.3 is cost analysis of the system and brief study of the algorithm. In Section.4 the results are displayed and Section.5 is for bibliography.

II. COMPUTATIONAL STUDY OF COMPONENTS IN THE SYSTEM

Solar PV panels, power inverter, biomass gasifier with generator and utility grid are present in the proposed grid connected hybrid renewable generation system as shown in the Fig.1. Back-up for the outages and overcast situations in this system is met by using

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diesel generator. It is assumed that for one hour the power generated by the solar PV panels and biomass gasifier are constant. For analysing the system performance mathematical modelling of different components is done as shown below.

A. Solar PV Panel

Geographical location, atmospheric conditions like temperature, dirt, shadow effects the power output P_{sol} of the solar photovoltaic cells [10,13]. Solar radiation and atmospheric temperature are the two main constraints in calculating the solar power

$$P_{sol}(t) = P_{rat}\, f_{loss} \frac{G_h}{G_s}[1+\alpha_p(T_c - T_s)] \text{-------(1)}$$

Where, P_{rat} = rated power output capacity of the solar PV panel,

f_{loss} =loss factor due to dirt, temperature, shadow etc.,

G_h= hourly solar radiation incident on panels,

G_s =standard solar radiation (1000 W/m^2),

α_p =temperature coefficient of power,

T_c = temperature in the present time step of PV cell,

T_s =temperature of cell under standard conditions.

B. Biomass Gasifier

The solid biomass residue [11,12] is converted into gaseous fuel i.e., producer gas by aerobic digestion procedure. For electricity generation, producer gas is used as the input fuel. Capacity utilization factor plays main role in calculating the annual output electricity, $E_{bg,}$ of the rated biomass gasifier system (P_{bg}). It is calculated by using the formula,

$$E_{bg} = P_{bg}(8760 * CUF) \text{-----(2)}$$

The maximum size of a biomass gasifier system, P_{bg}^{max}, that could be installed in a particular area can be calculated by using the below formula

$$P_{bg}^{\max} = \frac{M_{bg} * 1000 * CV_{bm} * \eta_{bg}}{365 * 860 * t_{bg}} \text{-----(3)}$$

Where, M_{bg} = total available biomass (Tons/year) for power generation,

CV_{bm} =calorific value of biomass available,

η_{bg} = efficiency of the gasifier,

t_{bg} =number of working hours of biomass gasifier [12].

C. Power Inverter

The DC power generate by solar PV panels is converted into AC at required frequency by using power inverter as the loads to be served are AC in general. Inverter rating (P_{inv}) is the main factor that decides the amount of maximum power conversion and is given by

$$P_{inv}(t) = P_{pv}(t)\eta_{inv} \qquad \text{----- (4)}$$

Where, η_{inv} is the efficiency of the inverter and P_{pv} is the total power generated by solar PV panels and can be calculated by the below formula

$$P_{pv}(t) = P_{sol}(t)N_{sol} \qquad \text{-----(5)}$$

Where, $P_{sol}(t)$ is the power generated by a single solar PV panel, N_{sol} is the number of solar PV panels.

In a grid connected system, grid sale capacity and load served plays a vital role in deciding the maximum size of inverter and is given below

$$P_{inv}^{\max}(t) = P_{L}^{\max}(t) + P_{gs}^{\max} \qquad \text{-----(6)}$$

Where, P_L^{max}(t) is the peak load demand at daytime (kW) and P_{gs}^{max} is the maximum capacity of power sold to the grid (kW).

D. Utility Grid

If the power is excessively generated from the renewable sources then the remaining power can be sold to the grid when it is a grid connected system and the excess energy supplied to the grid is calculated using the below formula

$$P_{gs}(t) = [P_{pv}(t)\eta_{inv} + P_{bg}(t)] - P_L(t) \qquad \text{-----(7)}$$

The maximum amount of power that can be supplied to the grid should not exceed the maximum grid sale capacity if it gets exceeded the excess amount of power can be supplied to the dump load.

The power can be supplied from the grid when the power generated by the renewable resources doesn't meet the load demand and is calculated using the formula

$$P_{gp}(t) = P_L(t) - [P_{PV}(t)\eta_{inv} + P_{bg}(t)] \qquad \text{-----(8)}$$

The maximum amount of power supplied by the grid should not exceed the maximum grid purchase capacity (P_{gp}^{max}).

III. COST ANALYSIS OF THE SYSTEM

Designing and modelling of a grid connected PV-biomass hybrid energy system as shown in fig1 is the main motive of this work. The cost effectiveness of the system is calculated with the optimal number of solar panels and size of the biomass gasifier system using ABC and BAT algorithms, by meeting the load demand LCOE of the system is achieved in this paper. The concept of ACS [17] is used for calculating the LCOE here.

A. Objective Function

Minimising the total system cost for the given hybrid system is the main objective function. Combining the total capital cost, replacement cost, maintenance cost, salvage cost of the solar, biomass gasifier, power inverter and diesel generator along with the grid sale and purchase costs forms the total system cost[8]. Satisfying the other constraints of the system with minimum LCOE is considered as the optimal system. The objective function that has to be minimised is given below

$$min(ACS) = [N_{sol}C_{sol} + P_{bg}C_{bg} + P_{inv}C_{inv} - C_{gs} + C_{gp}] \text{------(9)}$$

Where the annualised total cost of the solar PV panel (per kW), biomass gasifier (per kW), power inverter (per kW), are C_{sol}, C_{bg}, C_{inv} respectively. C_{gs} *and* C_{gp} are the annualised grid sale and grid purchase costs in $/yr. The annualised capital cost, annualised operational and maintenance costs, salvage cost along with the fuel cost combining forms the annual cost of each of the component. Biomass gasifier system contains all the five annualised costs and is given below

$$C_{bg} = C_{acap}^{bg} + C_{arep}^{bg} + C_{m}^{bg} + C_{f}^{bg} + C_{sal}^{bg} \qquad \text{------(10)}$$

Where, $C_{acap}^{bg}, C_{arep}^{bg}, C_{m}^{bg}, C_{f}^{bg}, C_{sal}^{bg}$, are the annualised capital cost, annualised replacement cost, annual maintenance cost, fuel cost and salvage costs of the biomass gasifier respectively.

1) *Annualised capital cost:* Combination of the costs for installing and purchasing the components gives the capital cost of the components. Capacity recovery factor (CRF), is the main factor for calculating the annualised cost of solar PV panels, biomass gasifier, power inverter. For biomass gasifier the annualised capital cost is calculated using the formula

$$C_{acap}^{bg} = C_{cap}^{bg} CRF(r,n) \qquad \text{-----(11)}$$

Here, C_{cap}^{bg} represents the initial cost of the biomass gasifier system. Capital recovery factor (CRF), the ratio for calculating the present value of money for n years lifetime and r interest rate is given below

$$CRF(r,n) = \frac{r(1+r)^n}{(1+r)^{n-1}} \qquad \text{-----(12)}$$

2) *Annualised replacement cost:* The cost of replacement of components at the end of its lifetime gives the annualised replacement cost. The annualised replacement cost of the biomass gasifier, C_{arep}^{bg}, can be calculated using the formula

$$C_{arep}^{bg} = C_{rep}^{bg} CRF(r,n) \frac{1}{(1+r)^y} \qquad \text{------(13)}$$

Where, C_{rep}^{bg} represents the replacement cost of the component and y represents the lifetime of biomass gasifier in years. Replacement cost comes into existence when the component lifetime is less than the system lifetime. Lifetime (number of years) for biomass gasifier and is given below

$$y = \frac{N_{bg,h}}{N_{bg}} \qquad \text{------(14)}$$

Where, $N_{bg,h}$ represents the generator lifetime in hours and N_{bg} is the operating hours during an year.

3) *Maintenance cost:* For power generating systems the labour costs, repairing cost and other charges together constitutes the maintenance cost of that particular system. For a biomass gasifier it is calculated using

$$C_m^{bg} = N_{bg} C_m^h \qquad \text{------(15)}$$

Here, N_{bg} is the operating hours during an year and C_m^h represents the hourly maintenance cost of the biomass gasifier.

4) *Fuel cost:* Fuel cost is nothing but the cost incurred for buying of fuels like biomass feedstock for biomass gasifierand diesel for diesel generator. For biomass gasifier fuel cost is given by the formula

$$C_f^{bg} = E_{bg} C_b q(t) \text{ ------(16)}$$

Here, C_b indicates the price of biomass per kg, E_{bg} represents the total energy generated by the biomass gasifier in kWh/yr and q(t) is the rate of biomass consumed in kg/kWh for biomass gasifier system.

5) *Salvage value:* The cost of the remaining components at the end of the lifetime of the whole system is considered as the salvage cost. For biomass gasifier the salvage cost is calculated using the below equation

$$C_{sal}^{bg} = C_{rep}^{bg} \frac{R_{rem}}{y} \text{ ------(17)}$$

Where, C_{rep}^{bg} indicates the component replacement cost, R_{rem} represents the biomass gasifier remaining life and y is the lifespan of the biomass gasifier.

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Levelised cost of electricity is the major economic parameter for the proposed hybrid energy system cost effectiveness. The ratio of the annualised cost of the system to the effective electricity produced by the system gives the levelised cost of electricity. Total electrical load served is 152,421kWh/yr.

$$LCOE = \frac{ACS(\$/yr)}{Totalelectricalloadserved(kW/yr)} \quad \text{------(18)}$$

Following constraints are to be followed in order to minimise the objective function

$$N_{sol}^{\min} \le N_{sol} \le N_{sol}^{\max}$$

$$P_{bg}^{\min} \le P_{bg} \le P_{bg}^{\max}$$

$$P_{gp} \le P_{gp}^{\max}$$

$$P_{gs} \le P_{gs}^{\max}$$

Where, $N_{sol}^{\min}$ and $N_{sol}^{\max}$ are the minimum and maximum number of solar PV panels. $P_{bg}^{\min}$ and $P_{bg}^{\max}$ are the minimum and maximum ratings of biomass gasifier. $P_{gs}^{\max}$ and $P_{gp}^{\max}$ are the grid selling and purchasing capacities.

B. Operational Strategy

As the biomass gasifier has more environmental hazards, solar PV panels are preferred for generation of electricity. For the proposed grid connected hybrid system the operational strategies opted are given below.

1) When the power generated from solar PV panels is greater than the load demand then the excess power generated is sold to the grid and is given by the formula

$$P_{gs}(t) = P_{pv}(t)\eta_{inv} - P_L(t)$$

2) If the amount of power generated is greater than the maximum grid sale capacity, then the excess amount is dumped and is calculated using the formula

$$P_d(t) = (P_{PV}(t)\eta_{inv}) - P_L(t) - P_{gp}^{\max}$$

3) If the power from solar power panels is not adequate then biomass gasifier, diesel generator and grid provides the required amount of power.

4) If the load demand is high but $P_L(t) \le P_{gp}^{\max}$, the excess load is supplied by grid alone.

5) If the load demand is high but $P_L(t) \ge P_{gp}^{\max}$, then excess amount is supplied by solar PV panels, biomass gasifier, grid.

C. Bat Algorithm

Bats are the only mammals on earth with wings and have the advanced capability of echolocation. A type of sonar is used by micro bats called echolocation for detecting the prey, avoiding obstacles and locating their roosting crevices in the dark.By emitting a very loud sound pulse bats wait for the echo to bounce back from the surrounding objects. The pulse has a constant frequency in a range of 25kHz to 150kHz even though it lasts for a few thousandths of a second (up to about 8 to 10ms). The loudness of the pulses changes from loudest while searching for a prey to the quietest while approaching the pray.

Bat algorithm is found by idealizing some of the echolocation characteristics of microbats. Some of them are given below:

1) For sensing the distance, all the bats use echolocation and they know the difference between food/prey and background barriers.

2) For searching the prey bats fly randomly with velocity v_i at position x_i with a fixed frequency $f_{\min}$, varying wavelength λ and loudness A_0 to search for prey. The wavelength of emitted pulses and the rate of pulse emission $r \in [0,1]$ of the bats are automatically adjusted depending on the target.

3) Even though the loudness can vary in different ways, we assume that it differs from a large (positive) A_0 to a minimum constant value $A_{\min}$.

For implementation of Bat algorithm in solving the optimisation problem the below steps are followed.

a) *Initialise the bat population* $\mathrm{x}_i \ (i = 1, 2, ..., n)$*, and* v_i
b) *Define pulse frequency* f_i *at* x_i *,*
c) *Initialise no. of generations* N_{gen} *, pulse rates* r_i *and the loudness* A_i

for i=1 to population size

forj=1 to dimension size

Generate new solutions by adjusting frequency, and updating velocities and locations/solutions

end

calculate fitness value

end

- for t=1 to number of generations

if $(rand > r_i)$
Select a solution among the best solutions
Generate a local solution around the selected best solution
end if
generate a new solution by flying randomly
if$_S$
accept the new solutions
increase r_i and reduce A_i
end if

if $(f(\mathrm{x}_i) < f_{\min})$

update the current best solution

end if

end

Rank the bats and find the current best x_*

end for

D. Post process results and visualisation.

IV. AVAILABLE DATA FOR COMPONENT SELECTION

The case study is for a typical village located at a coordinate of $30^0\ 26^{'}$N latitude and 76^0 26'E longitudes near Patiala, India. The average daily load demand of the village is 131kW/yr [16]. 5.14kWh/m^2 is the average solar radiation of the village. For producing 1kWh of electricity we require 1.3-1.5 kg of biomass and costs around 0.025$/kg including transportation and labour charges. Lifespan of the system is considered as 20 years at an annual interest rate of 6%. The CRF is found to be 0.08714 at an interest rate of 6% for a life span of 20 years. In Punjab state the purchasing cost of electricity from grid is 0.1$/kWh whereas the selling price is

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0.15$/kWh [9]. 5 kW and 50kW are considered as the maximum grid purchase and sale capacities respectively. Table I gives various costs of different components used in the system.

TABLE I
COST OF COMPONENTS OF THE SYSTEM

Component	Initial cost per kW, $	Replacement cost per kW,$	Maintenance cost per Kw	Lifetime
Photovoltaic module [10]	1200	1200	4 $/yr	20 years
Biomass gasifier [11,12]	1834	1834	0.3$/h upto 20kW 0.5 $/h above 20kW	15,000 h
Inverter [13]	127	127	1.34 $/yr	15 years
Diesel generator [14]	278	278	0.02 $/h	15,000 h

TABLE II
CONTROL PARAMETERS FOR BAT ALGORITHM

Population size, n	20
Number of generations, N	1000
Frequency limit, Q	2
Dimension of the problem, D	2

V. RESULTS

Total electricity demand of the village is 131 kW/yr. The Bat algorithm is simulated using MATLAB 2013 program. In this paper, the results obtained from the Bat algorithm is compared with that of the ABC algorithm. The control parameters of the Bat algorithm are given in Table II. The configurations that are considered for cost analysis in this paper are stand-alone and grid connected systems. The range for rate of pulse emission is [0, 1] where 0 represents no pulse emission at all and 1 represents maximum rate of pulse emission. When the bat reaches its prey loudness A usually decreases and rate of pulse emissionr increases accordingly.

A. Standalone System

Stand-alone system consists of solar PV panels and biomass gasifier system. The analysis is done using ABC and Bat algorithms. According to peak load demand, $P_L^{\max}(t)$, the size of PV and inverter are designed. The minimum load ratio for biomass gasifier and diesel generator is taken as 30%. Stand-alone system is determined for two scenarios in this paper. They are Scenario A (without back-up) and Scenario B (with back-up)

TABLE III
COST ANALYSIS OBTAINED FOR CASE-2 OF TABLE 5 USING BAT ALGORITHM

Components	Capital cost $/yr	Replacement Cost, $/yr	Maintenance Cost,$/yr	Fuel Cost, $/yr	Salvage cost , $/yr	Total cost, $/yr
Solar PV	7533.3	0	288	0	0	7821.3
Biomass gas	6552.41	24432.72	2658	7110.81	-1026.95	39726.99
Grid	0	0	-36879.60	0	0	-36879.60
Inverter	973.88	406.36	117.92	0	202.46	1295.70

1) *Scenario A (Without Back-Up):* In this scenario only renewable energy sources will provide electricity to meet the load demand. Storage or back-up or grid connectivity is not considered in this study. A total of 131 kWh/yr of load demand is not

met by this case. But however it is observed that Bat algorithm provides best results when compared with ABC algorithm. The results for ABC and Bat algorithms for this scenario is given in table- III as case-1 and case-2 respectively.

2) *Scenario B (With Back-Up):* Reliability of power to the consumer is the main drawback for stand-alone system. The total system collapses, if one of the renewable energy goes off. To improve the reliability and meet the shortage of load demand a 48 kW diesel generator is included in the system along with grid connection. The current diesel price is 0.8 $/l. As diesel generator emits harmful gases it is considered as the least priority for generation of electricity. By adding diesel generator, the NPC of the system increases which in turn increases the LCOE of the system. As the system LCOE for stand-alone system is higher than the grid purchase cost it is suitable for remote villages or off-grid located areas. AC load served by the system is around 1,52,421 kWh/yr. The results for ABC and Bat algorithms for this scenario is given in table- III as case-3 and case-4 respectively.

TABLE IV

OPTIMAL SIZING FOR STAND-ALONE HYBRID PV-BIOMASS ENERGY SYSTEM

		Algorithm	PV, Units	Biomass gasifier, kW	DG, kW	Inverter, kW	Gasifier running, h	ACS, $/yr	NPC, $	LCOE, $/kWh
Scenario A Without (Back-Up)	CASE 1	ABC [16]	72	48	-	37	-	47,388	543,814	0.310
	CASE 2	Bat	71	47	-	37	-	46,510	533,740	0.305
Scenario B (With Back-Up)	CASE 3	ABC [16]	72	48	48	37	306	54,891	629,592	0.360
	CASE 4	Bat	72	47	48	37	306	53959	619,220	0.354

B. Grid Connected System

High LCOE and dependency of weather conditions for generating power through renewable sources are the two main drawbacks of the stand-alone system. To overcome this the system is connected to grid. The results obtained for ABC and Bat algorithms are shown in Table-V. Excess or dump energy is the main drawback for case-1 and case-2 of ABC and Bat algorithms as reduced LCOE is considered as the highest priority. For the next two cases the excess energy given to dump load is minimised by the optimisation algorithm by imposing high penalty on excess energy in the objective function. In this system it is observed that the energy sold to the grid is higher when compared with the energy purchased from the grid.

TABLE V

OPTIMAL SIZING RESULT FOR GRID CONNECTED HYBRID PV-BIOMASS ENERGY SYSTEM

	Algorithm	PVUnits	Biomass gasifier, kW	Inverter, kW	Grid sale capacity, kW	Grid purchase capacity, kW	Biomass running, h	ACS, $/yr	NPC $	LCOE $/kWh
CASE 1	ABC [16]	128	43	88	50	5	4915	16,748	192,162	0.11
CASE 2	Bat	126	41	88	50	5	4915	14,792	169,750	0.097
CASE 3	ABC [16]	73	43	88	50	5	5316	21,655	248,014	0.141
CASE 4	Bat	72	41	88	50	5	5316	19710	226,180	0.129

The replacement cost of the biomass gasifier is having a great impact on the LCOE of the system. As the total running hours of biomass gasifier is considered as 4915 hours [16] in a year, the operational life is around 3.05 years. Hence, the biomass gasifier has to be six times replaced during the lifetime of the system. It is observed that as the grid sale capacity increases the LCOE of the system decreases.

V. CONCLUSIONS

The main findings of the paper can be summarised as

A. The LCOE is 0.305 $/kWhfor a stand-alone PV-biomass system without back-up,0.354 with back-up whereas for a grid connected PV-biomass system LCOE is found to be 0.097 $/kWh by Bat algorithm [Tables III and IV].

B. For generation of power through biomass gasifier system in grid connected system around 263 tons of biomass feedstock is used.

C. The LCOE and grid sale capacity are observed to be inversely proportional to each other in this system.

D. Reliability of power is high in case of grid connected system when compared with the stand-alone system.

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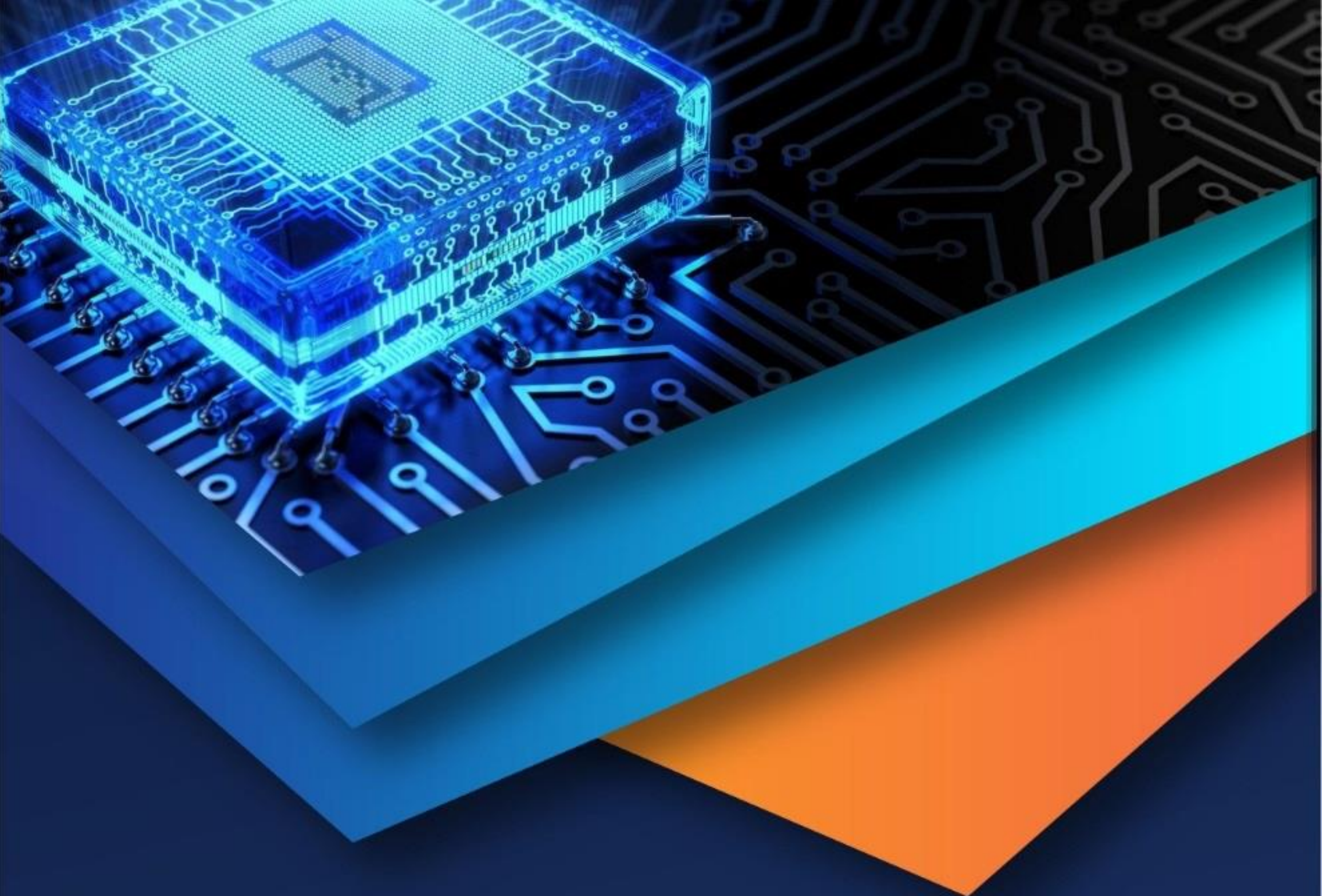

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