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Application of Ant Colony Optimization Technique in Economic Load Dispatch of IEEE-26 Bus System with Valve Point Loading

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Abstract: ***Optimal System operation involves the Consideration of economy of operation, system security, emission of certain fossil-fuel plant. The main aim of this study is to minimize the fuel cost and to keep the power outputs of the generator within prescribed limit with the use of An Ant colony Optimization Techniques. It is based on the ideas of ant foraging by pheromone communication to make path. Ant Colony Optimization technique is a meta-heuristic approach for solving hard combinatorial optimization problems which can be applied for power system optimization. The work reported in this paper is carried out with the objective to make use of Ant colony Optimization for solving the economic load dispatch problem. IEEE-26 Bus 6 generator system is considered to test the Algorithm with cost functions. The proposed approach result has been compared to those which reported in the literature.***

Keywords: Ant Colony Optimization, Optimal power flow, meta-heuristic, IEEE Systems, power systems, optimization.

I. INTRODUCTION

Electric power grids are considered to be one of the most complex man-made systems mainly due to their wide geographical coverage, various transactions among different utilities, and diversity in individual electric power companies' layouts, size, and equipment used. Engineers need special tools to optimally analyze, monitor, and control different aspects of such sophisticated system. Some of these tools are economic dispatch, unit commitment, state estimation, automatic generation control, and optimal power flow. The main objective of electrical power utility is to ensure that electrical energy requirement from the consumer is delivered. However for doing so, the power utility has also to confirm that the electrical power is generated with reduced cost. So for economic operation of the system, the total demand must be equally shared among the generating units with an objective to minimize the total generation cost for the system. Economic Dispatch is a method to find the electrical power to be generated by the committed generating units in a power system so that the total generation cost of the system is minimized, with satisfying the load demand simultaneously. To show this problem, optimization is a necessary in solving the cost minimization problems. Power system optimization is an important area in the operation, planning and control of power systems. Many advanced heuristic techniques to the solution of complex power system optimization problems have been proposed, each differing in their procedure of representation, implementation and solution procedure:

Economic load dispatch is one of the basic problems in power system operation and planning.

It is defined as the process of giving generation levels to the generating units so that the system load is supplied fully and most economically.

It concerned on the reduction of an objective function, usually the total cost of generation, while considering both the equality and inequality constraints.

Load variation depends upon the output of generators has to be changed to meet the balance between loads and generation power to make the system efficient. There are a lot of conventional optimization techniques which are applied in solving the ELD problems that are briefly listed in literature reference [8] such as Newton-based techniques , Linear Programming, Non-Linear Programming , Quadratic Programming , Interior point methods , Parametric method , Sequential and unconstrained minimization technique . However, these methods usually suffer from some disadvantages such as convergence to local solutions instead of global ones if the initial guess is in the vicinity of a local solution, applicability to a specific ELD problem based on its mathematical nature and some inherent theoretical assumptions (such as convexity, differentiability, and continuity) which are inconsistent with the actual OPF formulations [8].

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Several stochastic search techniques are also listed and discussed briefly by the researchers of [8] such as genetic algorithms (GA), evolutionary programming (EP), particle swarm optimization (PSO), bacteria foraging (BF) algorithm [8] Ant colony optimization (ACO)[9] have been proposed to solve the OPF problem without any restriction on the shape of the cost curves. The results reported were promising and encouraging for further research in this direction. The remaining parts of the paper are organized as follows. In the second section, the formulation of ELD problem is briefly introduced. The ant colony optimization algorithm described in section three. The proposed ACO and its application for the solution of the ELD problem are presented in section four. Obtained numerical results from extensive testing of the proposed solution approach on different case studies are presented in section five and compared with the results of several other recently published methods. Section six concludes the paper.

II. ECONOMIC DISPATCH PROBLEM FORMULATION

Economic Dispatch problem can be solved by minimizing the cost of generation in the system. The solution gives the optimal generation output of the online generating units that satisfy the system's power balance equation under various system and operational constraints. The Economic Dispatch problem can be formulated mathematically as follows

A. *Objective Function is to Minimize the Cost*

$$F = \sum_{i=1}^{ng} F_i(P_{gi}) \quad (1)$$

Which is the sum of operating cost over all controllable power sources,Where Fi(Pgi) is the generation cost function for generation Pgi at bus i.

NG indicate the number of generation including the slack bus.

The individual costs of each generating units are consider being function, only, of active power generation and are showed by quadratic curves of second order. The objective function for the whole power system can be presented as the sum of the quadratic cost model at each generator.

The conventional quadratic fuel cost function of generating units is given by

$$Fi(Pgi)\sum_{i=1}^{ng} a_i P_i^2 + b_i P_i + c_i \quad (2)$$

Where Pgi is the generated active power at bus i.

a_i, b_i and c_i are the unit costs curve for generator i.

B. *Constraint Equations*

1) *Unit Operation Constraints can be Presented by*

$$P_{G_i}{}^{min} \leq P_{G_i} \leq P_{G_i}{}^{max} \quad (3)$$

where $P_{G_i}{}^{min}$and $P_{G_i}{}^{max}$: Lower and upper limit of active power generation at bus i.

2) *Power Balance Equation*

$$\sum_{i=1}^{ng} P_{G_i} = P_D + P_L \quad (4)$$

where P_D is the demand and P_L is transmission loss. The transmission loss calculated by the B-coefficients method.

B-coefficients applied in the power system by:

$$P_L = \sum_{i=1}^{NG}\sum_{j=1}^{NG} Pgi\ Bij\ Pgj \ \text{MW} \quad (5)$$

Where Pgi and Pgj are generation at i^{th} and j^{th} bus respectively.

B_{ij} is the Loss coefficient which is constant under certain assumed condition, NG no of generator bus.

III. ECONOMIC LOAD DISPATCH WITH VALVE POINT LOADING

Economic load dispatch (ELD) is considered one of the key functions in electric power system operation. The economic load dispatch problem is commonly formulated as an optimization problem, with the aim of minimizing the total generation cost of power system but still satisfying specified constrains. The input-output characteristics (or cost functions) of a generator are approximated using quadratic or piecewise quadratic function, under the assumption that the incremental cost curves of the units are monotonically increasing piecewise-linear functions. However, real input-output characteristics display higher-order nonlinearities and discontinuities due to valve-point loading in fossil fuel burning plant. The valve-point loading effect has been modeled in as a recurring rectified sinusoidal function, such as the one show in figure.1

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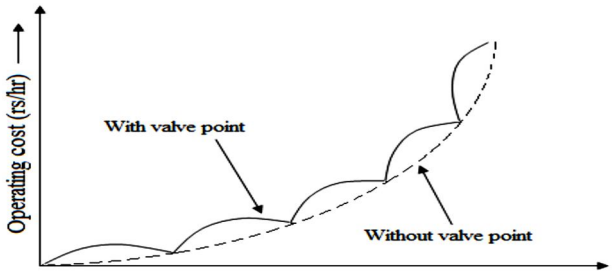

Fig.1 Operating cost characteristics with valve point loading

The generating units with multi-valve steam turbines exhibit a greater variation in the fuel cost functions [2]. The valve-point effects introduce ripples in the heat-rate curves. Mathematically, economic load dispatch problem considering valve point loading is defined as:
Minimize operating cost

$$F_i(P_i) = (a_i P_i^2 + b_i P_i + c_i) + |d_i . sin\{e_i(P_i^{min} - P_i)\}|$$

Where a_i, b_i, c_i, d_i, e_i are cost coefficients of the i th unit

ANT COLONY OPTIMIZATION ALGORITHM

A. Framework for Ant Colony System

Entomologists have studied the ability of ants to find the shortest path between their nest and a food source. From these studies, Ant Colony Optimization (ACO) has been developed by Dorigo et al. [1] and successfully employed to solve various optimization problems.ACO is a metaheuristic and evolutionary approach where several generations of artificial ants in a cooperative way search for good solutions. Initially artificial ants move randomly along paths and deposit chemical substance trails, called pheromone, on the ground when they move. And ants collect and store information in pheromone trails during their moving. This pheromone trails motivate them to follow the path with high intensity of pheromone. With time, the pheromone trail is reinforced or evaporated by the move of ants. Finally, all ants can choose the shortest path in their movement [25].

B. Ant Colony Optimization Algorithm

As shown in Fig. 2, the agents (i.e. ants) are guided by the intensity of pheromone trails. The path rich in pheromone becomes the best tour with time. This concept inspired the ACO algorithm. Initially, each agent is positioned on a starting node. Agents move to feasible neighbor nodes following the state transition rule. This rule indicates the preference of ants in choosing their paths that connect the current node to the next node. During the moving process, ants modify the level of pheromone on the paths they choose by applying the local updating rule. If the pheromone level on the chosen paths is lowered, these paths become less attractive to other agents. This property gives agents a higher probability to explore different paths and find an improved solution. Once all agents have reached the final node and have identified the best path which has the optimal value of the objective function, they update the pheromone level on the best path by applying a global pheromone updating rule. This is intended to allocate a higher level of pheromone on the best path. The rules to find the best path are detailed as below [13]:
State Transition Rule. This rule guides the agents' search toward neighbor nodes stochastically. The k-th agent at time t positioned on node r move to the next node u along the shorter path with higher intensity of pheromone $\tau_{ru}(t)$.

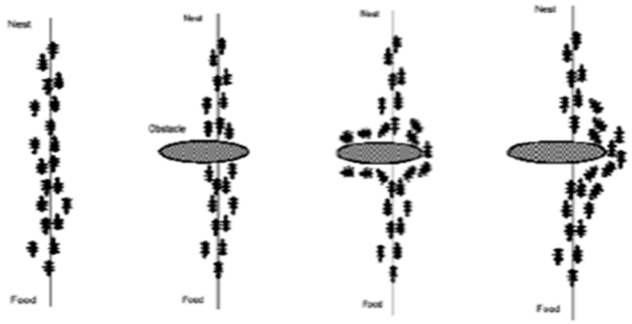

Fig. 2 An example of finding the shortest path

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This is achieved by a state transition rule (6) that utilizes both the inverse of the length of the path $\eta_{ru}(t)$ and the amount of pheromone $\tau_{ru}(t)$.

$$S=\begin{cases} \text{argmax} J_k(r)[\tau(r,u)]^{\alpha}\{[\eta(r,u)]^{\beta}\}, \text{if} q \le q0 (\text{exploitation}) \\ S, \text{otherwise} (\text{Bisedexploitation}) \end{cases} \quad (6)$$

Where,
$\tau_{ru}(t)$: The pheromone trail at time *t*.
$\eta_{ru}(t) = 1/ TrsC(t)$: the inverse of the transition cost.
TrsC(*t*) *with r-s* being the path from node *r* at the current stage to node *s* at the next stage.
α,β: parameters representing the relative importance
q: a random number uniformly distributed in [0,1].
*q*0: a pre-specified parameter ($0 \le q0 \le 1$).
allowed k (*t*) : the set of feasible nodes currently not assigned by the ant *k* at time *t*.
S: an index of node selected from *k(t) allowed* according to the probability distribution given by (7).

$$P_K(r,u) = \begin{cases} \frac{[\tau(r,u)^{\alpha}][\eta(r,u)^{\beta}]}{\sum_{u \in Jk(r)}[\tau(r,u)^{\alpha}][\eta(r,u)^{\beta}]} \text{if} s \in Jk(r) \\ 0, \text{otherwise} \end{cases} \quad (7)$$

$J_{k(}r)$*:* set of nodes that remain to be visited by ant *k* positioned on node (to make the solution feasible).
Local Updating Rule. An ant changes the pheromone level on the moved path (local updating) by applying the local updating rule (8). This rule has the effect of lowering the pheromone level on the search paths.

$$\tau(r,s) \leftarrow (1-\rho)\,\tau(r,s) + \rho.\,\tau_0 \quad (8)$$

Where,
ρ:evaporation coefficient (0<ρ<1).
τ_0: initial pheromone level, $\tau_0 = 1/J$ where *J* is a rough approximation of the optimum value of the cost function.
Global Updating Rule. The global pheromone updating is performed only after all ants have completed their moving. The global pheromone updating rule (9) is intended to provide a greater amount of pheromone to shorter path.

$$\tau(r,s) \leftarrow (1-\alpha).\tau(r,s) + \alpha.\Delta\tau(r,s) \quad (9)$$

Where,

$$\Delta\tau_{re} = \begin{cases} (J^*)^{-1}, \text{if } (r,s), \text{belongs to globle} - \text{path} \\ 0, \text{otherwise} \end{cases} \quad (10)$$

α: pheromone decay coefficient(0<α<1)
J^*: the best value of the objective function

The capability of finding the optimal path can be enhanced through this rule in the search process. The pseudo code of Conventional ACO algorithm can be described as [13]:

Initialize pheromone trails
Repeat until system convergence conditions satisfied
Generate agents ( );
Move according to the transition Rules ( );
Update Pheromone ( );
End

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IV. ACO APPLIED TO ECONOMICAL LOAD DISPATCH

A. *Description of Algorithm*

For every generator the area of its power limits is divided in discrete values. The division can be done in various ways. In this we can divide all fragments in equal number of sub-fragments. So far, every generator we have done did not have a continuous fragment of power but discrete definite set depending on the separation that has taken place.

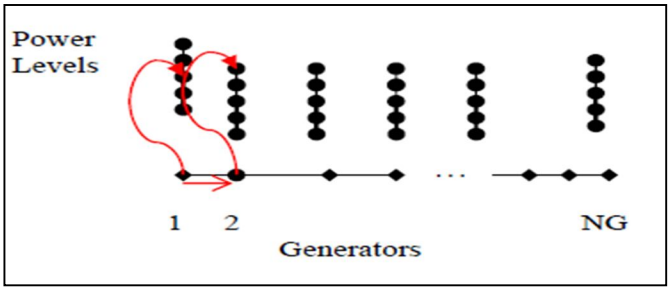

Figure: 3: Movement of an ant between machines and power levels

The algorithm works like this: each one ant starts from the first generator and selects a power level then, it goes to the next and chooses another power level for that generator and this is repeated until it reaches the last generator (Fig.3). At the end of this the total cost is calculated in séance to decide whether the solution is satisfactory or not.

B. *Mathematical Model*

1) *Transition Rule:* lets an ant k be in generator i and it must choose a power level j for it, according to the probability distribution, called a random-proportional rule:

$$p_{ij}^{k}(t)=\frac{\left[\tau_{ij}(t)\right]^{\alpha}\cdot\left[n_{ij}\right]^{\beta}}{\sum_{l\in J_i^k}\left[\tau_{il}(t)\right]^{\alpha}\cdot\left[n_{il}\right]^{\beta}} \quad \text{if j } \epsilon \ J_i^k \qquad (10)$$

Where J_i^k : is the list of the power levels that corresponds to generator i

n_{ij} : is the visibility. In the classical problem TSP this is defined as the inverse of the distance between two cities, $n_{ij}=\frac{1}{d_{ij}}$

α and β: are parameters that control the relative importance of pheromone intensity versus visibility

So, it could be also used here the inverse of the cost for the particular power level:

$$n_{ij}(t)=\frac{1}{F_i(P_{ij})} \qquad \tau_{ij}(t) \qquad (11)$$

2) *Pheromone Update Rule:* is the pheromone quantity that is found in edge that connects every generator with power level. Pheromone updated by the rule:

$$\tau_{ij}(t)=(1-\rho)\tau_{ij}(t)+\Delta\tau_{ij}(t) \qquad (12)$$

Where ρ is the coefficient representing pheromone persistence ($0 \le \rho < 1$), and $\Delta\tau_{ij}$, is a function of the solutions found at iteration t, and it is algorithm specific.

$\Delta\tau_{ij}$, is a function of the solutions found at iteration t, given by:

$$\Delta\tau_{ij}=\sum_{k=1}^{n}\Delta\tau_{ij}^{k}(t) \qquad (13)$$

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n: number of ants

$\Delta\tau_{ij}^{k}$: is the quantity per unit of length of pheromone addition laid on edge (i,j) by the k^{th} ant at the end of iteration t, is given by:

$$\Delta\tau_{ij}^{k}(t)=\begin{cases} Q/L^{k}(t), & \text{if } (i,j)\in T^{k}(t) \\ 0, & \text{if } (i,j)\notin T^{k}(t) \end{cases} \qquad (14)$$

Where $T^{k}(t)$ is the tour done by ant k at iteration t

$L^{k}(t)$, is its length and

Q is a constant parameter, used for defining to be of high quality solutions with low cost.

a) The Algorithm for Solution

- *Step 1:* Define (discrete) power for every generator. For every generator and for every power level we calculate the visibility $n_{ij}(t)=\frac{1}{F_i(P_{ij})}$.
  Define the pheromone, giving it a large value, in all edges that connect every generator with the power level respectively.Define the total number of ants and the number of iterations.
- *Step 2:* For every ant and for every generator select a power level based on random-proportional transition rule as according to equation (10).
- *Step 3:* Calculate the cost for all ants based on the division of power levels which is the based on objective functions and a_i,b_i and c_i are the unit costs curve and save the best.
- *Step 4:* Renew pheromone using pheromone update rule according to specified ant algorithm and the equation (12, 13 and 14).
- *Step 5:* Repeat the procedure from step 2 until a specific number of iterations are completed or all the ants preceding the same path.

V. SIMULATION RESULT AND DISCUSSION

A. Test System: IEEE 26-bus system [6]

The Proposed algorithm is tested on the standard IEEE 26 bus test system. This system is having 26 buses and 6 generators. Total demand is 1263 MW. Fig 4 shows the Line Diagram of IEEE-26 bus system.

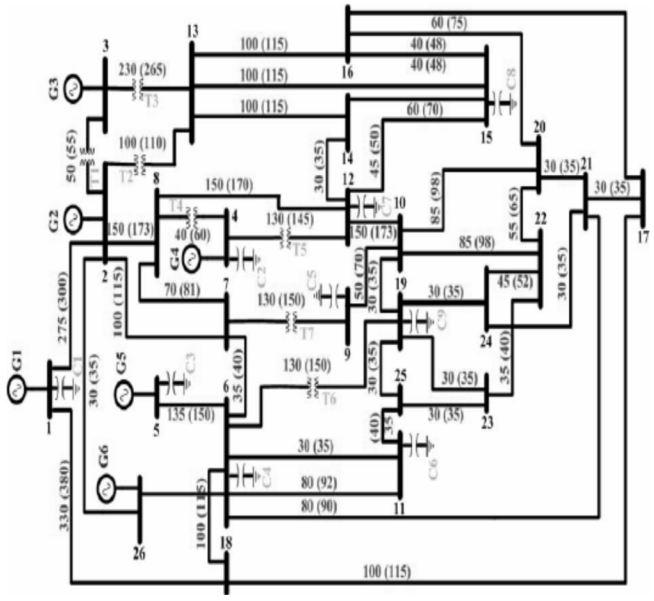

FIG.4 Single Line Diagram of IEEE-26 Bus system Test System

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Four parameters of the colony of ants α *β*, *ρ* and *q0* is extensively independent of the problem of optimization to solve, developed algorithm is tested on the network IEEE 26 buses while using the 10 better combinations of the three parameters *β*, *ρ* and *q0* and that give the best results for commercial traveler problem for the case of 30 cities [9].

TABLE 1: Cost Coefficients and Generator Limits [6]

Generator No	Cost Coefficient			MW Limit	
	a	b	c	Min	Max
1	0.0070	7.0	240	100	500
2	0.0095	10.0	200	50	200
3	0.0090	8.5	200	80	300
4	0.0090	11.0	200	50	150
5	0.0080	10.5	220	50	200
6	0.0075	12.0	190	50	120

Table 2 .The transmission loss co efficient matrix are given as

$$B = \begin{bmatrix} 0.0017 & 0.0012 & 0.0007 & -0.0001 & -0.0005 & -0.0002 \\ 0.0012 & 0.0014 & 0.0009 & 0.0001 & -0.0006 & -0.0001 \\ 0.0007 & 0.0009 & 0.0031 & 0.0000 & -0.0010 & -0.0006 \\ -0.0001 & 0.0001 & 0.0000 & 0.0024 & -0.0006 & -0.0008 \\ -0.0005 & -0.0006 & -0.0010 & -0.0006 & 0.0129 & -0.0002 \\ -0.0002 & -0.0001 & -0.0006 & -0.0008 & -0.0002 & 0.0150 \end{bmatrix} \text{MW-1}$$

B. Results for Test system

Various combinations of four parameters α β, ρ and q0 and that give the best results for commercial traveler problem for the case of 30 cities.

The economic value of the cost is 15444.0 $/h corresponds a (α=8,β=12,ρ= 0.8,q0=1) with losses of powers 12.35MW.

Result with considering the Valve Point Loading Effect the economic value of the cost is 15583 $/h corresponds a (α=4,β=11,ρ=0.5,q0=5) with loss of power 12.154 MW

The obtained minimum cost results are compared with those results which are there in literature.

Table 3 Comparison in Minimum cost and Losses

Methods	Proposed ACO Method with Valve Point Loading Effect	ACO Method without Valve Point Loading Effect	GA [16]	PSO [15]
Pg1(MW)	438.45	437.5	474.81	447.50
Pg2(MW)	169.15	172.7	178.64	173.32
Pg3(MW)	262.90	265.7	262.21	263.48
Pg4(MW)	153.15	145.9	134.28	139.06
Pg5(MW)	163.65	170.4	151.90	165.48
Pg26(MW)	87.85	83.15	74.18	87.13
∑Pgi(MW)	1275.15	1275.35	1276.03	1276.01
$Loss P_L$(MW)	12.154	12.350	13.02	12.96
Error	0	0	0.0083	0.0516
cost($/hr)	15583.0	15444	15459	15450

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VI. CONCLUSION

In this paper, an Ant Colony Optimization approach to the Economical Load Dispatch problem is introduced and tested. As a study case, the IEEE 26 Bus system with three generating units has been selected with smooth cost functions and Valve Point Loading Effect, the simulation results show that for medium-scale system an ant colony optimization method can give a better results. The developed algorithm is able to minimize the generation cost while meeting the demand requirement. Obtained results are also compared with established algorithms like GA, PSO etc. which are reported in literature comparison shows that developed technique is efficient compared to others but with considering the valve point loading effect the generation cost is higher. Further development in technique may help to solve dispatch problems with prohibiting operating zones as well as environmental constraints and unit commitment problems.

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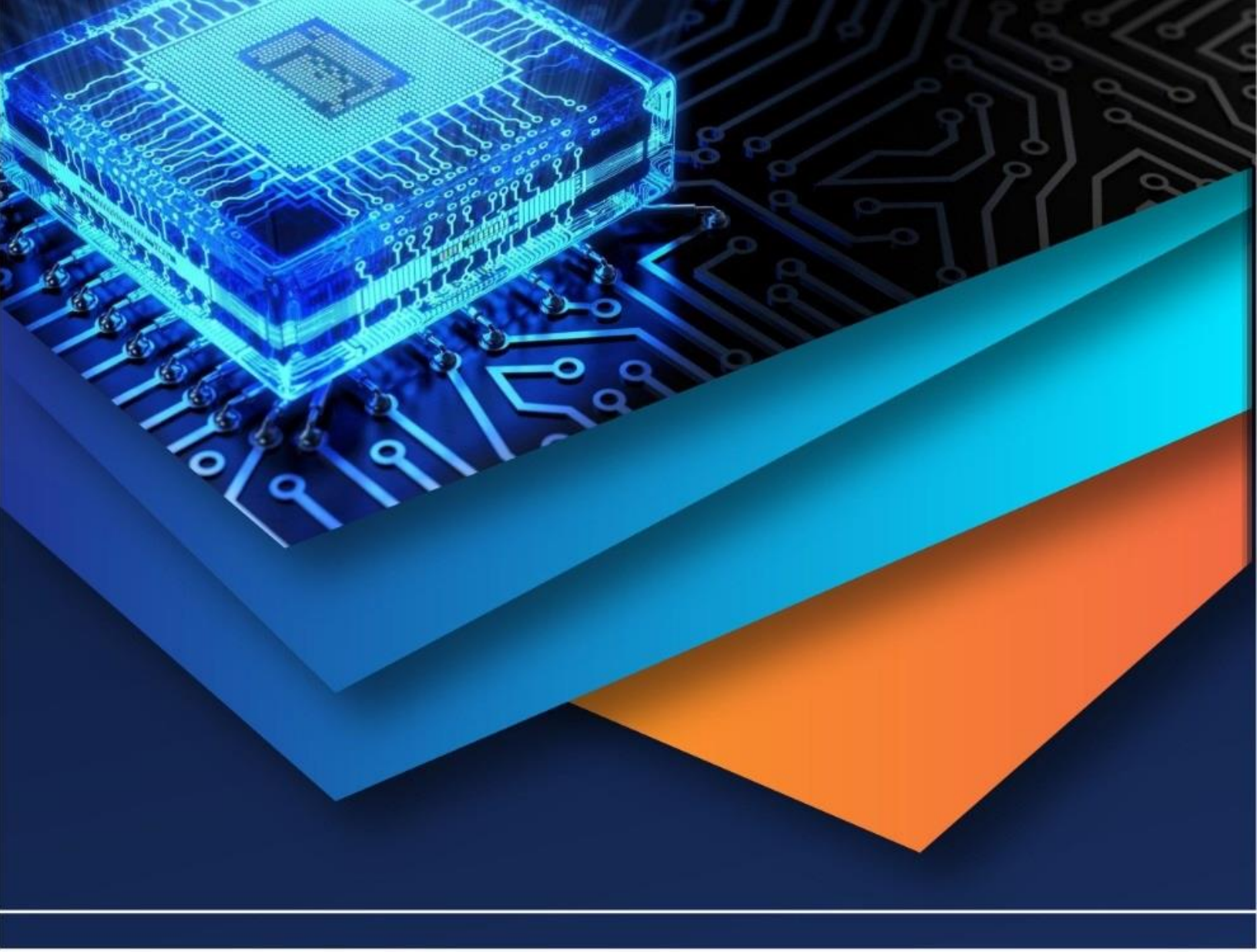

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