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Comparative Analysis of SPSO and PSO to Optimal Power Flow Solutions

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Abstract: In this paper two optimization techniques Particle Swarm Optimization (PSO) and Sliced Particle Swarm Optimization (SPSO) are used for solving Optimal Power Flow (OPF) problem for steady state analysis. The objectives that are taken in this paper are to minimize the total generation cost and active power loss of the power system. The effectiveness of the proposed methods was tested on the IEEE-30 bus system.
Keywords: Optimal Power Flow (OPF), Particle Swarm Optimization (PSO), Sliced-particle Swarm Optimization (SPSO).

I. INTRODUCTION

Optimal power flow considered to be the backbone tool in the complex power system. The expanding in demands lead to increasing in generation that requires increases the thermal capacity, for these reasons the problem of optimal power flow (OPF)[1-2] still under many studies in order to minimize the cost, losses, emission of harm gases, etc. The power flow or load flow analysis gives the voltages, phase angles, active and reactive power at each bus. Recently, the success of the appropriate by evolutionary algorithms for the solution of complex problems, and the improvement made in computation such as parallel computation have simulated the development of new algorithms like PSO [3-4] and SPSO [5] gives greater convergence characteristics and capability of determining global minima. The results are obtained for the IEEE-30 bus system [6].

II. OPTIMAL POWER FLOWS

OPF aims to optimize a certain objective, subject to the system power flow equations and equipment operating limits. The optimal condition is attained by adjusting the available controls to minimize an objective function subject to specified operating and security requirements [7].The PSO and the SPSO are applied to minimize the fuel cost of generation and to improve the system performance by maintaining thermal and voltage constraints. Mathematically

A. The Objective Functions Are

Minimization of generation fuel cost

$$F = \sum_{i=1}^{ng}(a_i P_{Gi}^2 + b_i P_{Gi} + c_i) \qquad \text{(1)}$$

The minimization of above objective function subjected to both equality and inequality constraints

B. Equality constraints

$$P_{Gi} - P_{Di} - \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\cos(\theta_{ij} - \delta_i + \delta_j) = 0 \ldots\ldots(2)$$

$$Q_{Gi} - Q_{Di} + \sum_{j=1}^{n} |V_i||V_j||Y_{ij}|\sin(\theta_{ij} - \delta_i + \delta_j) = 0 \ldots\ldots(3)$$

Where P_{Gi} and Q_{Gi} are the real and reactive power outputs injected at bus i respectively, the load demand at the same bus is represented by P_{Di} and QDi , and elements of the bus admittance matrix are represented by $|Y_{ij}|$ and θ_{ij}.

C. Inequality constraints are

1) Generators real and reactive power outputs

$$P_{Gi}^{\min} \le P_{Gi} \le P_{Gi}^{\max}, i = 1,\ldots, N \qquad (4)$$

$$Q_{Gi}^{\min} \le Q_{Gi} \le Q_{Gi}^{\max}, i = 1...N \quad (5)$$

2) Voltage magnitudes at each bus in the network

$$V_i^{\min} \le V_i \le V_i^{\max}, 1...NL \quad (6)$$

3) Transformer tap settings

$$T_i^{\min} \le T_i \le T_i^{\max}, i = 1...NT \quad (7)$$

4) Reactive power injections due to capacitor banks

$$Q_{Ci}^{\min} \le Q_{Ci} \le Q_{Ci}^{\max}, i = 1...CS \quad (8)$$

5) Transmission lines loading

$$S_i \le S_i^{\max}, i = 1...nl \quad (9)$$

6) Voltage stability index

$$Lj_i \le Lj_i^{\max}, i = 1...NL \quad (10)$$

Another objective function is to minimize the total active power loss is

$$\sum P_L = \sum P_G - \sum P_D \quad (11)$$

The equality constraints are satisfied by running the power flow program. The generator bus terminal voltages, transformer tap settings and the reactive power generation of capacitor banks are the control variables. The active power generation at the slack bus, load bus voltages and reactive power generation, voltage stability index are state variables.

III. PARTICLE SWARM OPTIMIZATION

Particle Swarm Optimization was originally developed by a social psychologist (James Kennedy) and an electrical engineer (Russell Eberhart) in 1995, and emerged from earlier experiments with algorithms that modelled the flocking behaviour seen in many species of birds. Particle Swarm Optimization (PSO) is an evolutionary algorithm that may be used to find to find optimal (or near optimal) solutions to numerical and qualitative problems.

Basically, the PSO was developed through simulation of birds flocking in two-dimensional space. The position of each bird (called agent) is represented by a point in the X-Y coordinates, and the velocity is similarly defined. Bird flocking is assumed to optimize certain objective function. Each agent knows its best value so far (pbest) and its current position. This information is an analogy of personal experience of an agent. Each agent knows the best value so far in the group (gbest) among pbests of all agents. This information is an analogy of an agent knowing how other agents around it have performed.

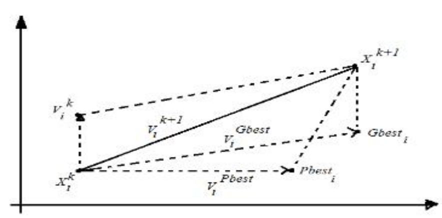

Figure1. Concept of modification of a searching point by PSO

Each agent tries to modify its position using the concept of velocity.

$$v_i^{k+1} = wv_i^k + c_1 rand_1 * (pbest_i - s_i^k) + c_2 rand_2 * (gbest - s_i^k) \quad (12)$$

Where v_i^k is velocity of agent i at iteration k. c_1 and c_2 are the acceleration constants, which changes the velocity of a particle towards pbest and gbest, $rand_1$ and $rand_2$ are random numbers between 0 and 1, s_i^k is current position of particle 'i' at iteration ' k' , $pbest_i$ is the best of agent i, and gbest value so far in the group among the pbests of all the agents. The following weighting function is usually used

$$w = w_{\max} - ((w_{\max} - w_{\min}) / (iter_{\max})) * iter \quad (13)$$

Where w_{max} is the final weight, w_{min} is the initial weight as these limits controls exploration and exploitation of the search space, $iter_{max}$ is the maximum iteration number and iter is the current iteration number.

The current position can be modified by the following equation:

$$s_i^{k+1} = s_i^k + v_i^{k+1} \tag{14}$$

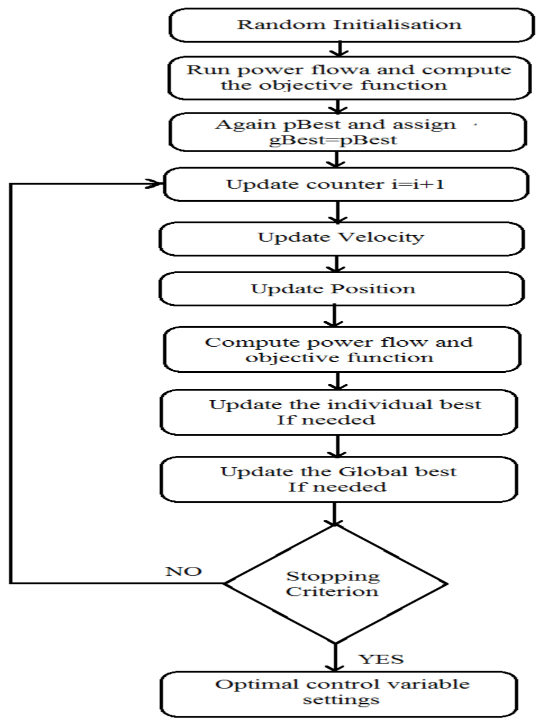

Figure2. Flow chart for PSO algorithm.

IV. SLICED PARTICLE SWARM OPTIMIZATION

A new optimization technique named as Sliced Particle Swarm Optimization (SPSO) introduces the slicing of search space into rectangular slices. It gives the complete solution in terms of reduction in the computational cost and tracking minutely each sliced search space.In SPSO, the algorithm divides the search space into no. of rectangular slotted sections i.e. from outer rectangular slot with high search space towards inner rectangular slot with less search space. Searching of the entire search space by slicing gives the complete solution. The comparison among all the slices gives S-best (pbest)and the comparison of S-best of each slices leads to the gbest.In this algorithm multiplication of momentum factor(mc) with position gives the convergence and for velocity, changes its velocity according position.

The position and velocity updating equations for each particle are

$$v_i^{k+1} = w.v_i^k + c_1 rand_1 * (pbest_i - s_i^k) + c_2 rand_2 * (gbest - s_i^k) \tag{15}$$

$$w = \frac{(w_{final} - w_{initial})(T_{iter} - iter)}{T_{iter}} + w_{initial} \tag{16}$$

W_{final} and $w_{initial}$ are the predetermined maximum and minimum inertia weight values, respectively. A large inertia weight facilitates a global search while a small inertia weight facilitates a local search.

The current position can be modified by using the following equation:

$$s_i^{k+1} = (1 - mc)s_i^k + mc.v_i^{k+1} \tag{17}$$

mc=momentum factor (o<mc<1)

$$V_{min} = X_{min} \tag{18}$$

$$V_{max} = X_{max} \tag{19}$$

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A. SPSO Algorithm

1) Split the search space and divide the particles in each sliced search space.
2) Initialize the population of particles in search space of one slice
3) For trials = 1:30for iterations = 1: total iterations for I= 1:No.of particles for J= 1:No.of dimensions
4) Evaluate the objective function &fitness of each particle
5) Update the pbest position.
6) Update the gbest position.
7) Update theposition according to formula (17).
8) Bound the position of particle with in boundaries of the slice.
9) Update the velocity according to formula (15).
10) Bound the velocity of particles with in slice according to equations (18) and (19).
11) Find S-best fitness.
12) Initialization of each slice is completed, if No do steps 2-11 otherwise, end.
13) Find g-best fitness, if yes go to 14, otherwise go to step 4.
14) End.

The selected mean S1, S2, S3, S4 represents the S-best value of each slice and the selected mean ‘S’ represents the g-best value of each slice. i.e. S-best. The mean value of fitness of SPSO for each slice is much better than PSO.

V. SIMULATION RESULTS

The proposed PSO &SPSO algorithms are used to solve optimal power flow is tested on the standard IEEE-30bus system. The parameters and their values are used in both PSO and SPSO are shown below.

Table1. Optimal parameter settings for PSO

Parameter	PSO
Population size	20
Number of iteration	200
Cognitive constant ,c1	2
Social constant ,c2	2
Inertia weight , w	0.3-0.9

Table2. Optimal parameter settings for SPSO

Parameter	SPSO
Population size	40
Number of iteration	150
Cognitive constant ,c1	2
Social constant ,c2	2
Inertia weight , w	0.3-0.9
momentum factor(mc)	0.3

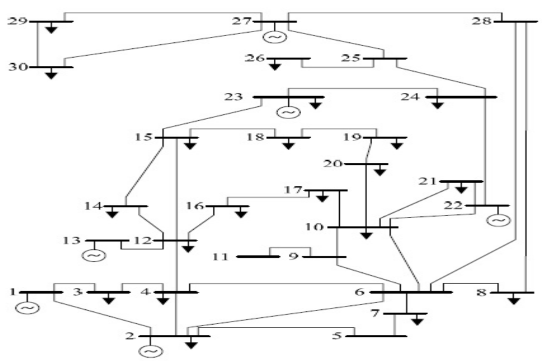

Figure3. IEEE-30 bus system

The active power and reactive power flows are calculated for the IEEE-30 bus system using both PSO and SPSO are shown in below tables 3 & 4.

Table: 3 OPF solutions for IEEE-30 using PSO

Bus From-To	Active power (p.u)	Reactive power (p.u)	Bus From-To	Active power (p.u)	Reactive power (p.u)
1-2	0.1847	0.0037	10-20	0.0326	-0.0088
1-8	0.1305	0.0044	10-17	0.0429	-0.0208
2-11	0.3265	0.0120	10-21	0.0205	-0.0101
8-11	0.1742	0.0057	10-22	-0.0420	0.0211
2-5	1.1231	-0.3640	21-22	0.0610	-0.0268
2-13	0.5630	-0.1483	15-23	0.0297	-0.0113
11-13	0.2686	-0.1004	22-24	0.0953	-0.0438
5-7	0.5093	-0.1758	23-24	0.0460	-0.0221
13-7	0.5897	-0.1268	24-25	0.0055	0.0027
13-3	0.3787	-0.1301	25-26	0.0330	-0.0162
9-4	0.4770	-0.1363	25-27	0.0328	-0.0209
9-10	-0.1360	0.0450	27-29	0.0317	-0.0067
12-6	0.3167	-0.1068	27-30	-0.0073	0.0042
12-14	0.1041	-0.0341	29-30	0.0136	-0.0090
12-15	-0.1225	0.0014	3-28	-0.0254	0.0134
12-16	0.3072	0.0048	13-28	0.0417	-0.0215
14-15	0.1200	0.0009	15-1	0.0483	-0.0248
16-17	0.0555	-0.0261	17-2	0.0265	-0.0138
15-18	0.1192	-0.0592	24-3	0.0179	-0.0274
18-19	0.0483	-0.0226	21-4	0.1338	-0.0437
19-20	0.0047	-0.0052			

Table: 4 OPF solutions for IEEE-30 using SPSO

Bus From-To	Active Power(p.u)	Reactive Power(p.u)	Bus From-To	Active Power(p.u)	Reactive Power(p.u)
1-2	0.9181	-0.2840	10-20	0.0721	-0.0315
1-8	0.5183	-0.1213	10-17	0.0524	-0.0199
2-11	0.2879	-0.0926	10-21	0.1039	-0.0476
8-11	0.4854	-0.1654	10-22	0.0515	-0.0247
2-5	0.5816	-0.1099	21-22	0.0026	-0.0013
2-13	0.3816	-0.1166	15-23	0.0244	-0.0210
11-13	0.4077	-0.1146	22-24	0.0426	-0.0270
5-7	-0.1161	0.0422	23-24	0.0052	-0.0026
13-7	0.2740	-0.0890	24-25	-0.0036	0.0020
13-3	0.1863	-0.0543	25-26	0.0136	0.0090
9-4	-0.2712	0.0820	25-27	-0.0196	0.0104
9-10	0.3618	0.0078	27-29	0.0418	-0.0214
12-6	-0.1300	0.0011	27-30	0.0490	-0.0246
12-14	0.0532	-0.0250	29-30	0.0266	-0.0137
12-15	0.1012	-0.0503	3-28	0.0002	-0.0095
12-16	0.0236	-0.0111	13-28	0.1309	-0.0390
14-15	-0.0001	0.0001	15-1	0.0905	0.0010
16-17	0.0128	-0.0035	17-2	0.1163	0.0037
15-18	0.0314	-0.0512	24-3	0.3144	0.0129
18-19	0.0090	0.0044	21-4	0.1420	0.0049
19-20	-0.0535	0.0269			

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A. *Cost convergence characteristics*

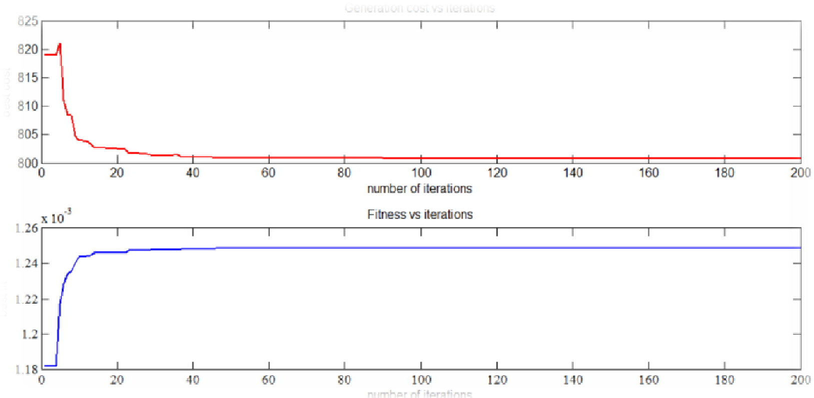

Figure4. Cost convergence characteristics of IEEE-30 using PSO algorithm.

The above graph shows the cost convergence characteristics of the IEEE-30 bus system by taking number of iterations on X-axis and total generation cost on Y-axis for the first graph. Second graph is the fitness of the cost function is obtained by taking inverse of the generation cost.

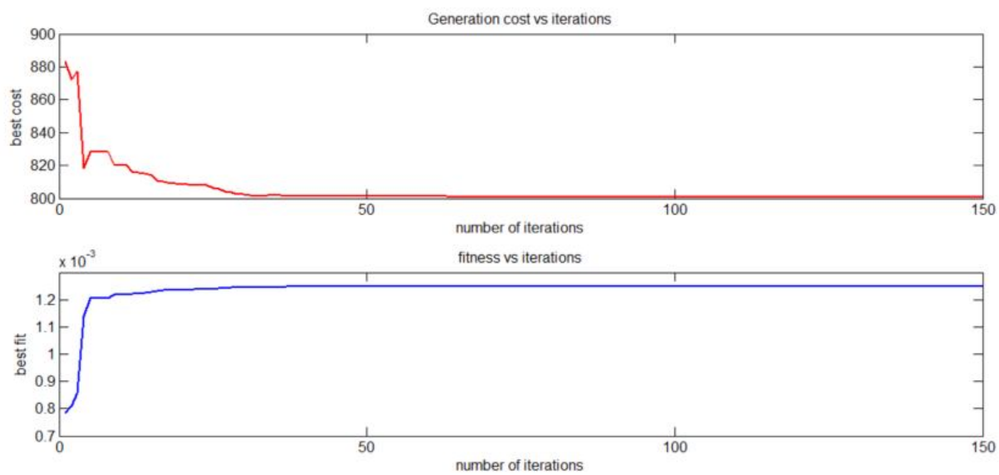

Figure5. Cost convergence characteristics of IEEE-30 using SPSO algorithm.

The above graph shows the cost convergence characteristics of the IEEE-30 bus system by taking number of iterations on X-axis and total generation cost on Y-axis for the first graph. Second graph is the fitness of the cost function is obtained by taking inverse of the generation cost.

B. *Comparison Between PSO and SPSO:*

Table5. Comparison of PSO and SPSO for the IEEE-30 bus.

Objective Function	PSO algorithm	SPSO algorithm
Total cost ($/hr)	800.77	800.30
Active power loss(p.u)	0.0972	0.0895

The total generation cost and active power loss of IEEE-30 bus system are minimized by using SPSO when compared to PSO. The total cost of the plant using PSO is 800.77($/hr) and by using SPSO is 800.30($/hr). Similarly the active power loss using PSO is 0.0972 (p.u) and by using SPSO is 0.0895(p.u).

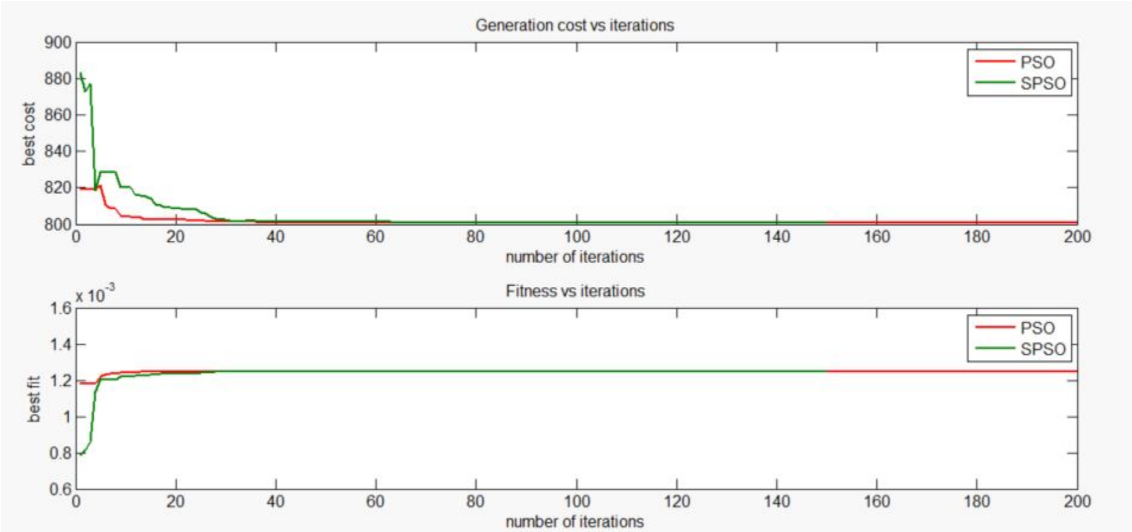

Figure6. Comparison of Cost convergence characteristics for IEEE-30 bus system

C. Using SPSO and PSO

The above characteristics shows that combined characteristics of SPSO and PSO optimization methods. It is clear that SPSO gives better results when compared to PSO method.

VI. CONCLUSION

In this paper, we implemented PSO and SPSO optimization techniques to solve the optimal power flow in steady state condition. The performance of the IEEE 30-bus test system is analysed and obtained fuel cost minimization and minimization of active power loss and with real power generation and bus voltages as control variables. The PSO and SPSO algorithms give reliable and accurate optimal power flow solutions.

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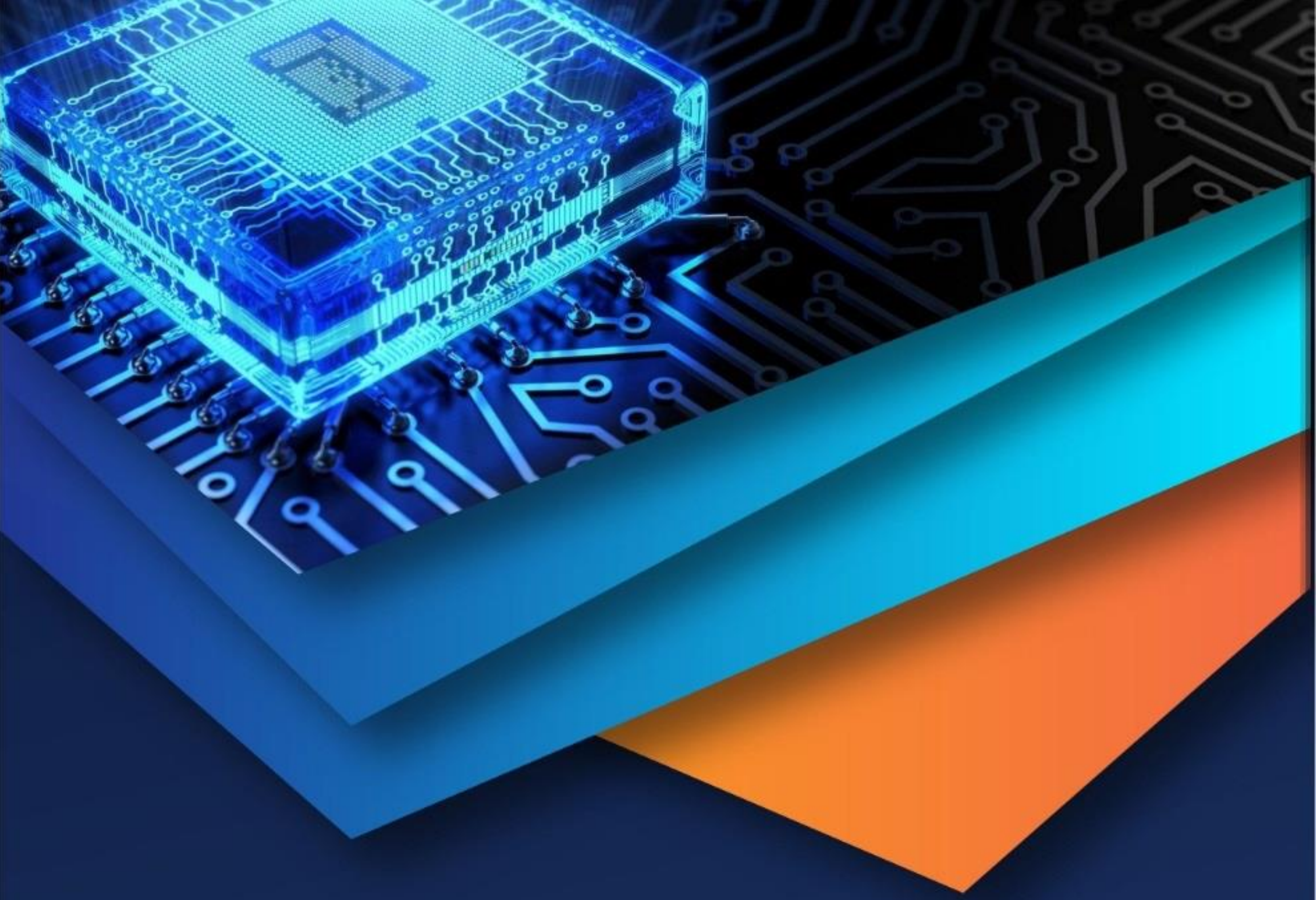

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