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Comparative Analysis of Jaya Optimization Algorithm for Economic Dispatch Solution

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Abstract: The purpose of economic load dispatch problem is to minimize the power generating cost in a cost-effective way, while satisfying the load demand and all equality and inequality constraints of thermal units. This paper proposes the solution of economic load dispatch problem with valve-point loading effect through the application of a new optimization technique Jaya. Two representative systems, i.e. 13 and 40 thermal units have been considered for the investigations and to confirm the effectiveness of the algorithm. The Economic Load Dispatch (ELD) results using Jaya Optimization Algorithm (JOA) have been compared with other existing methods. The simulation results show the advantage of the proposed method for reducing the total cost of the system.

Keyword: Jaya Optimization Algorithm, Valve-point effect, Economic load dispatch, Optimization Technique, Constrained minimization.

I. INTRODUCTION

Economic Load Dispatch (ELD) is an optimization problem in power systems and a process to meet the continuous variation of power demand at minimum operating cost subject to operational constraints of the generators such as valve point loading effects, emission etc. Over the years, various mathematical methods and optimization techniques have been adapted to solve for ELD problems. Lambda-iteration method [1], Gradient method [2-3], Base-point participation factor method [4] are the conventional optimization methods which have been utilized for ELD problem in the past. These methods have some limitations of high computational time and have several local minima and oscillatory in nature [5]. Recently, some Stochastic Search Algorithms such as PSO [6-11], GA [12-14], Direct Search [15] and Differential Evolution [16-17], Simulated Annealing [18-19], Gravitational Search [20-21], Cuckoo Search [22-23], Binary successive approximation-based evolutionary search [24-25] have been utilized to solve the ELD problem. However, the above mentioned techniques are associated with its own limitations such as execution speed, executions of many repeated stages, local optimal solution and require common controlling parameters like population size, number of generations etc. Jaya optimization algorithm [26] is a class of relatively new proposed algorithm. In the present work, Jaya optimization technique has been applied. It has strong potential to solve the constrained optimization problem. This algorithm requires only the common control parameters and does not require any algorithm specific control parameter.

A. Formulation of Economic Load Dispatch Problem

The present study for Economic Load Dispatch is utilized to solve the operation and planning of a power system having objective function and constraints which have been introduced in the following sub section.

II. CONSTRAINTS

Equation (1) presents a power balance criteria and equation (2) is the generator limit criteria. The two equations are presented by-

$$\sum_{j=1}^{n} P_j - P_L - P_D = 0 \qquad \dots (1)$$

$$P_j^{min} \leq P_j \leq P_j^{max} \qquad \dots (2)$$

where, P_j is the power of the j^{th} generator (in MW), P_L is the total line loss, P_D is the system total load demand, P_j^{min} and P_j^{max} are the minimum and maximum operation of generating unit j respectively [4].

A. The Problem Objective Function

1) The Fuel Cost Function of a Power Plant: Let us assume, the overall fuel cost = C_{Total} , the output power of the j^{th} generating unit = P_j, the cost of the j^{th} generating unit = C_j and total number of generators = n.

Thus, C_{Total} is equal to the sum of the all unit fuel costs, which is given as below:

$$C_{Total} = C_1 + C_2 + C_3 + \dots + C_n = \sum_{j=1}^{n} C_j\,(P_j) \qquad \dots (3)$$

The generator cost curves are quadratic functions. The total $/hr. (dollar per hour) fuel cost C_{Total} is expressed as:

$$C_{Total} = \sum_{j=1}^{n} \left({}^{1}\!/_{2} \cdot a_j P_j^{2} + b_j P_j + c_j \right) \qquad \dots (4)$$

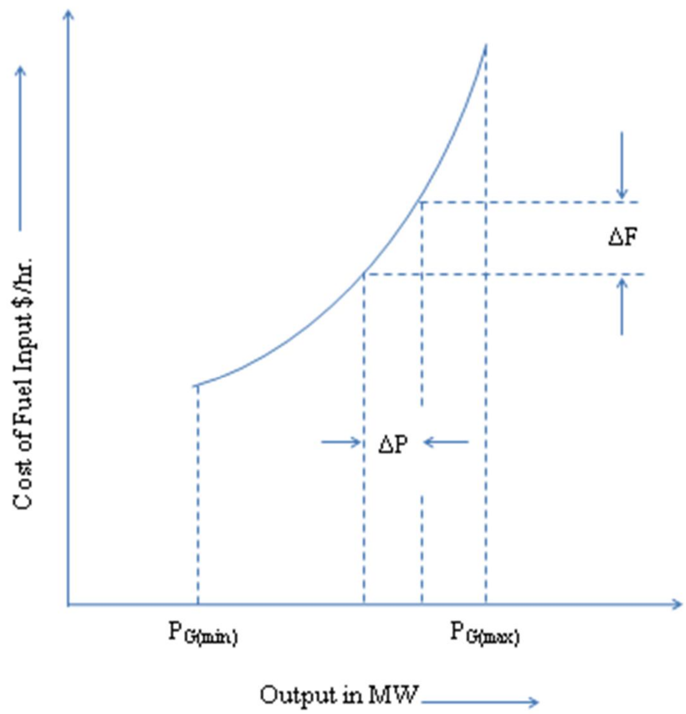

Figure 1. Incremental cost curve

where, a_j, b_j, c_j are the cost coefficients.Figure 1 shows the incremental cost curve. From the input-output curve a small change in input (ΔF) in terms of $/hr. and its corresponding change in output (ΔP_G) in terms of MW are taken. The Incremental Fuel Cost (IFC) is defined as the ratio of ΔInput (ΔF) to its corresponding ΔOutput (ΔP_G). Hence, $IFC = (\Delta\, Input) / (\Delta\, Output) = \Delta F / \Delta P_G$. Incremental Fuel Cost (IFC) should be same for all the generating units. Therefore, $(IFC)_1 = (IFC)_2 = (IFC)_3 = \dots \dots = (IFC)_N$, where N=Number of generating units [1, 4].

2) The Valve-Point Effect: The generating module with different valve-system turbine makes huge effects on the change in the fuel cost function. The cost-curve function is non-linear because of ripple effect due to opening of valve. The valve point effect can be mathematically presented by adding the absolute value of a sinusoidal function with a quadratic function [13, 16 and 18] of the cost curve.

Thus, the modified cost function is as follows:

$$\overline{C_{Total}} = \sum_{j=1}^{n} \left({}^{1}\!/_{2} \cdot a_j P_j^{2} + b_j P_j + c_j \right) + \left| e_j \times \sin\left(f_j \left(P_{j,min} - P_j \right) \right) \right| \qquad \dots (5)$$

where, e_j and f_j are the coefficients of the j^{th} unit valve-point effect.

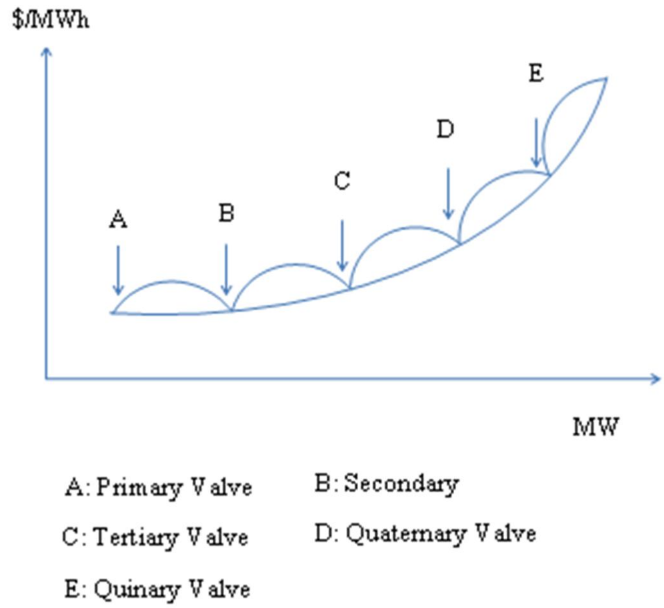

Figure 2. Valve-point effects

Figure 2 illustrates the valve-point effect over the actual cost curve of thermal generating station. Due to this effect the actual cost curve becomes non-continual and prone to be more non-linear in nature. This brings sudden turbulence in the cost curve and also reflects on the smooth operation of the system [22 and 27].

III. JAYA OPTIMIZATION TECHNIQUE

A. Algorithm and Flowchart

$f(x)$ is assumed as the required objective function which is to be minimized (or maximized). For i^{th} iteration, the design variables are 'm' numbers (i.e.$j = 1, 2, \ldots, m$) and 'n' number of candidate solutions which gives the population size, $k = 1, 2, \ldots, n$. Amongst entire candidate solutions, the best candidate obtains the best value of $f(x)$ (i.e.say $f(x)_{best}$) and the worst candidateobtains the worst value of $f(x)$ (i.e. say $f(x)_{worst}$). If $X_{j,k,i}$ is the value of the j^{th} variable for the k^{th}member of a set of possible solution during the i^{th} iteration, then this value is modified as per the following Equation (6):

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i} \times (X_{j,best,i} - |X_{j,k,i}|) - r_{2,j,i} \times (X_{j,worst,i} - |X_{j,k,i}|) \quad \ldots (6)$$

where, $X_{j,best,i}$is the value of the variable $j$for the best candidate and $X_{j,worst,i}$is the value of the variable $j$for the worst member of a set of possible solution. $X'_{j,k,i}$ is the updated value of $X_{j,k,i}$. For the i^{th} iteration in the range of [0, 1], $r_{1,j,i}$and $r_{2,j,i}$are the two random numbers for the jth variable. The term "$r_{1,j,i} \times (X_{j,best,i} - |X_{j,k,i}|)$" shows the affinity of solution to move nearer to the best solution and the term "$r_{2,j,i} \times (X_{j,worst,i} - |X_{j,k,i}|)$" shows the tendency of the solution to avoid the worst solution. $X'_{j,k,i}$ is

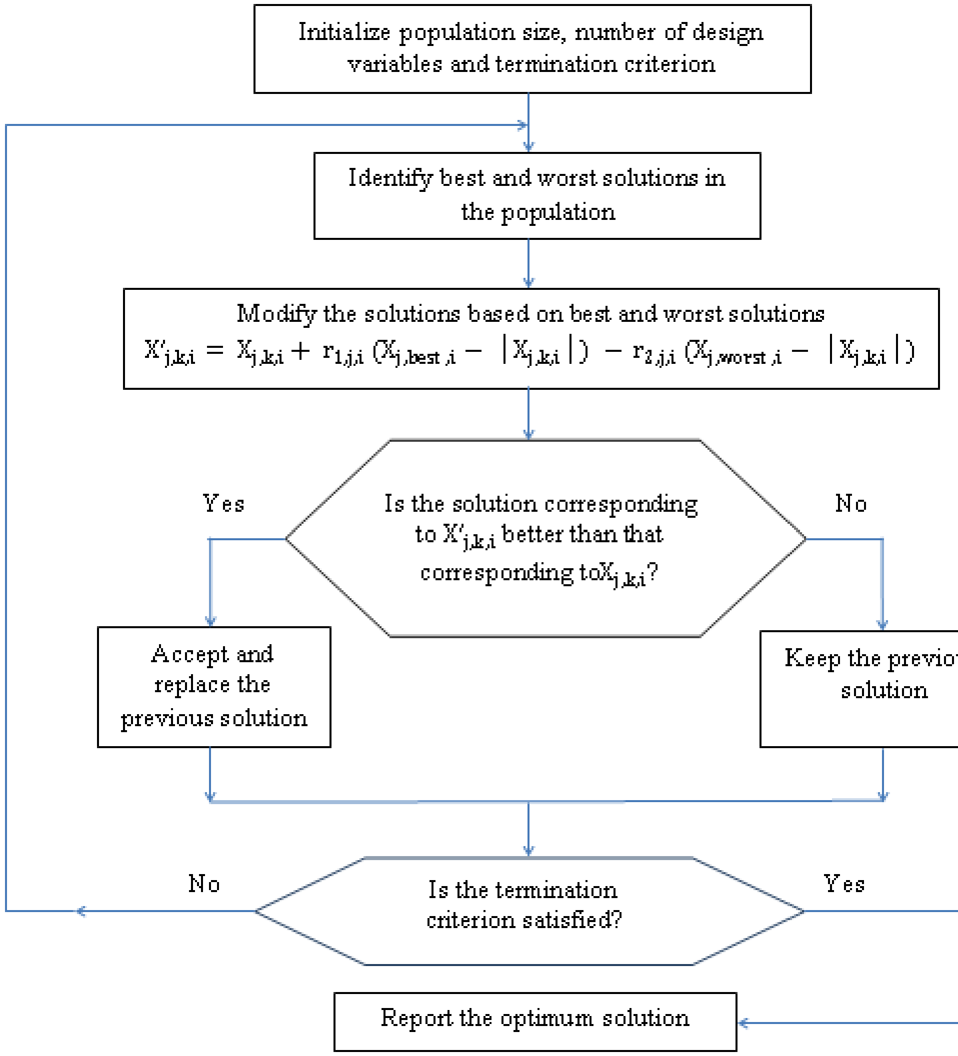

Figure 3. Flowchart of the Jaya algorithm

taken into account if it gives better function value. Finally, after iteration all the accepted function values become the input to the next iteration. Figure 3 shows the flowchart of the Jaya algorithm [26].

B. Mathematical Illustration of JOA for Eld

For the sake of simplicity of understanding, initially the algorithm has been utilized for two generating systems where their maximum and minimum generation limits (in MWs) are (250, 700) and (0, 350) respectively and the total load demand (P_D, Without considering transmission losses) is 700 MW. The stepwise mathematical analysis has been shown in the current section. Being a constrained minimization problem, this ELD problem must satisfy all the constraints. Therefore, initial population is distributed in such a way that randomization of starting point does not violate any of the constraints, considered. Table 1 shows the initial population. For the two design variables (Power Generation) P1 and P2, candidate solution and termination criterion have been set as 7 and one iteration respectively. The objective function is same as equation number (5) and the corresponding data of cost co-efficients and valve point effect co-efficients have been taken from [27], TABLE I for first two generators.

Table 1 shows the best (minimum $/hr.) and worst (maximum $/hr.) solutions. The best solution corresponds to the fifth candidate and the worst solution corresponds to the first candidate. Assuming random numbers as r1=0.63, r2=0.59 for P1 and r1=0.47,

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r2=0.61 for P2 the new values are calculated using equation number (6). For example, the new values of the third candidate during the first iteration will be:

$$X'_{1,3,1} = X_{1,3,1} + r_{1,1,1}(X_{1,5,1} - |X_{1,3,1}|) - r_{2,1,1}(X_{1,1,1} - |X_{1,3,1}|)$$

$$= 400 + 0.63 * (550 - |400|) - 0.59 * (500 - |400|) = 435.5$$

$$X'_{2,3,1} = X_{2,3,1} + r_{1,2,1}(X_{2,5,1} - |X_{2,3,1}|) - r_{2,2,1}(X_{2,1,1} - |X_{2,3,1}|)$$

$$= 300 + 0.47 * (150 - |300|) - 0.61 * (200 - |300|) = 290.5$$

Table 1. Power output for two generator system at initial population and without considering transmission losses ($P_D = 700$MW)

Candidate	P_1 (MW)	P_2 (MW)	Total Load (MW)	$\sum_{i=1}^{2} C_i$ (Total Cost in $/hr.)	Status
1	500	200	700	7085.0	*Worst*
2	600	100	700	7060.7	
3	400	300	700	6928.1	
4	450	250	700	6809.2	
5	550	150	700	6746.6	*Best*
6	650	50	700	7027.8	
7	350	350	700	6894.4	

Similarly, other values are also calculated. Table 2 shows the new values of the initial population during first iteration. From Table 2, it is seen that inequality constraints are not at all violated but almost in

Table 2. New values of initial population during first iteration

Candidate	Updated Value of P1 (MW) (Random Number r1=0.63, r2=0.59)	Updated Value of P2 (MW) (Random Number r1=0.47, r2=0.61)	Load
1	531.5	176.5	708
2	627.5	62.5	690
3	435.5	290.5	726
4	483.5	233.5	717
5	579.5	119.5	699
6	675.5	5.5	681
7	387.5	347.5	735

all cases total load has changed which was initially fixed at 700 MW. This violates the equality constraint. To overcome equality constraint violation, each new value from Table 2 is again updated by its own weight that reflects its contribution over total generation. If P_{g1} and P_{g2} are the generator outputs, G_T is the total generation then updated values of generations (P'_{g1}, P'_{g2}) will be:

$$\begin{Bmatrix} P'_{g1} = P_{g1} - \left(P_{g1}/G_T\right) * (G_T - P_D) \\ P'_{g2} = P_{g2} - \left(P_{g2}/G_T\right) * (G_T - P_D) \end{Bmatrix} \quad \ldots (7)$$

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This data updates may bring chances of inequality constraint violation. If so, data will again be updated following the equation (8).

$$\begin{Bmatrix} P'_{g1} = P_1^{min} & \text{if} & P'_{g1} < P_1^{min} & \text{or} & P'_{g1} = P_1^{max} & \text{if} & P'_{g1} > P_1^{max} \\ P'_{g2} = P_2^{min} & \text{if} & P'_{g2} < P_2^{min} & \text{or} & P'_{g2} = P_2^{max} & \text{if} & P'_{g2} > P_2^{max} \end{Bmatrix} \quad \ldots (8)$$

1) Where P_1^{min} and P_1^{max} are the minimum generated power and maximum generated power of generator
2) Where P_2^{min} and P_2^{max} are the minimum generated power and maximum generated power of generator

These data updates, following the equation (8), may regain equality constraint violation. Hence, the execution of equation (7) and (8) will be continued until all constraints are satisfied. Table 3 shows the updated values of power output satisfying all constraints after the first iteration and the corresponding costs for each candidate solution. Costs at initial population and after the first iteration are compared in

Table 3. Updated values (Effective power output) during first iteration

P1'' (Updated Value of P1satisfying the constraints)	P2'' (Updated Value of P2satisfying the constraints)	Load'' (Unchanged Load ≈ 700 MW)	$\sum_{i=1}^{2} C_i$
525.4944	174.4885	699.9829	6928.70
636.5942	63.3940	699.9882	6822.50
419.9036	279.8680	699.7716	7019.80
472.0363	227.8738	699.9101	6866.80
580.3290	119.6708	699.9998	7119.80
680.0000	19.9959	699.9959	7099.10
369.0476	330.5263	699.5739	6921.30

Table 4. Updated values of the cost function based on fitness comparison

Candidate	$\sum_{i=1}^{2} C_i$ (Cost at initial population)	$\sum_{i=1}^{2} C_i$ (First Iteration Cost Values)	$\sum_{i=1}^{2} C_i$ (Updated Cost Values after first iteration)	Status
1	7085.0	6928.70	6928.70	
2	7060.7	6822.50	6822.50	
3	6928.1	7019.80	6928.10	
4	6809.2	6866.80	6809.20	
5	6746.6	7119.80	6746.60	Best
6	7027.8	7099.10	7027.80	Worst
7	6894.4	6921.30	6894.40	

Table 4 and that cost, which gives lesser $/hr. value, is counted for. Column 3 shows lesser costs for all candidates and it is found that candidate 5 still gives better result whereas candidate 6 gives worst output. It is also seen that after the first iteration the value of the cost function (i.e. objective function, best candidate) remains unchanged but the worst value has come down to 7027.80 $/hr. from its previous value 7085 $/hr. and that clearly foretells about the system convergence with the increment in iteration count. The calculation stops here as the termination criterion is previously set as one iteration.

C. Pseudo Code Of Jaya Optimization

Set $i = 1$; $m = 1$; $n = 1$; j = no. of generators i.e. design variable; k = no. of candidates i.e. population size; P_{min}^{j}= Minimum generation of generators; P_{max}^{j}= Maximum generation of generators; P_D= Total load demand without considering transmission losses.

Generate initial population i.e. generation of all generators randomly, satisfying all constraints.

Calculate objective function (cost in $/hr.)$C_{T_{k,i}}$ $\left(= \sum_{j=1}^{j} C_{j,k,i}\right)$ for each candidate.

WHILE (the termination conditions are not met)

Identify the best solution $P_{j,best,i}$ and worst solution $P_{j,worst,i}$

FOR $m \rightarrow k$

FOR $n \rightarrow j$

Modify solution based on best and worst solutions.

$$P'_{j,k,i} = P_{j,k,i} + r_{1,j,i} \times (P_{j,best,i} - |P_{j,k,i}|) - r_{2,j,i} \times (P_{j,worst,i} - |P_{j,k,i}|)$$

END FOR

Check whether total generation $\sum_{j=1}^{j} P'_{j,k,i}$ and demand P_D are same.

IF $\sum_{j=1}^{j} P'_{j,k,i} \neq P_D$

Update solutions based on their contribution over total generation.

FOR $n \rightarrow j$

$$P''_{j,k,i} = P'_{j,k,i} - \left({P'_{j,k,i}} \Big/ {\sum_{j=1}^{j} P'_{j,k,i}} \right) \times \left(\sum_{j=1}^{j} P'_{j,k,i} - P_D \right)$$

Check whether $P''_{j,k,i}$ is within limits.

IF $P''_{j,k,i} < P_{min}^{j}$

$$P''_{j,k,i} = P_{min}^{j}$$

ELSE IF $P''_{j,k,i} > P_{max}^{j}$

$$P''_{j,k,i} = P_{max}^{j}$$

END

END IF

END FOR

END IF

Calculate objective function (cost in $/hr.) $C'_{T_{k,i}}$ $\left(= \sum_{j=1}^{j} C'_{j,k,i}\right)$ for each candidate.

Check whether $C'_{T_{k,i}}$ gives better result.

IF $C'_{T_{k,i}}$ is better than $C_{T_{k,i}}$ i.e. $\sum_{j=1}^{j} C'_{j,k,i} < \sum_{j=1}^{j} C_{j,k,i}$

$$C_{T_{k,i}}^{new} = C'_{T_{k,i}}$$

ELSE IF $C'_{T_{k,i}}$ is worse than $C_{T_{k,i}}$ i.e. $\sum_{j=1}^{j} C'_{j,k,i} > \sum_{j=1}^{j} C_{j,k,i}$

$$C_{T_{k,i}}^{new} = C_{T_{k,i}}$$

END
END IF
END FOR
Set i = i + 1
END WHILE

IV. RESULTS AND DISCUSSIONS

The practical applicability of JOA has been applied for two case studies (13 and 40 thermal units) where the objective functions were non smooth due to the valve-point effects.

The JOA has been applied through coding in MATLAB 7.9.0 (MathWorks, Inc.) whereas the results of GA and PSA have been logged using the MATLAB Optimization Toolbox (fmincon routine). All the simulations have been worked out on a 2.2-GHz Intel Pentium processor with 4 GB of RAM.

A. Ase-Study – 1 For 13 Generating Systems

This case study has been performed for a test system of 13 thermal units considering the effects of valve-point loading. The relevant data for this system have been shown in Table 5 [27]. In the present study, the load demand was PD=1800 MW (without considering transmission losses).The results for Case Study-1applying JOA are shown in Table 6 and the program, *ELD_Solution_Jaya_Algo_13_gen.m*, has been written in an m-file. Here the termination criterion has been set as 100 iterations. The m-file has been loaded in the current MATLAB folder. The lower and upper bounds, linear equalities have been set as per the data given in Table 5. The default initial size for Pattern Search Algorithm (PSA) is 1. Changing its value up to 5 in small steps different results were noted and analyzed. For greater value of initial size, the convergence time became prolonged which was quite inappropriate where immediate decision making was required. From successive runs the best results were logged using Genetic Algorithm (GA) and all the best outputs were written in a tabular form (shown in Table 6) for their comparative analysis.

B. Case-Study – 2 For 40 Generating Systems

A case of 40 thermal units was also carried out to check the effectiveness of the present algorithm. The required data is shown in the Table 7 [27]. The load demand to be satisfied was PD = 10500MW (without considering transmission losses). To find the optimal generation of power for 40 generator units, the proposed technique has been utilized using Jaya algorithm. The population size, maximum and minimum generation limits and iteration count for the present study has been fixed. The same procedure was followed as in previous case except the range of maximum function evolution for PSA. It has been set from its default value 100×number of variable (100×40 = 4000) to 8000.

Table 5. Data for 13 Thermal Units [27]

G	P_i^{min}	P_i^{max}	*a*	*b*	*c*	*e*	*f*
1	0	680	0.00028	8.10	550	300	0.035
2	0	360	0.00056	8.10	309	200	0.042
3	0	360	0.00056	8.10	307	150	0.042
4	60	180	0.00324	7.74	240	150	0.063
5	60	180	0.00324	7.74	240	150	0.063
6	60	180	0.00324	7.74	240	150	0.063
7	60	180	0.00324	7.74	240	150	0.063
8	60	180	0.00324	7.74	240	150	0.063
9	60	180	0.00324	7.74	240	150	0.063
10	40	120	0.00284	8.60	126	100	0.084
11	40	120	0.00284	8.60	126	100	0.084
12	55	120	0.00284	8.60	126	100	0.084
13	55	120	0.00284	8.60	126	100	0.084

Table 6. Comparison of best results of different Optimization Techniques for Case Study-1, P_D = 1800 MW

Power	*Generation from 50 different runs using different Optimization Techniques*		
	Genetic Algorithm (51 Iterations)	*Pattern Search Algorithm(470 Iterations)*	*Jaya Optimization Algorithm(99 Iterations)*
P_1	452.0062	179.5196	627.673115
P_2	292.9286	149.5997	299.164293
P_3	83.0481	170.2147	223.436139
P_4	107.4441	159.7331	159.725577
P_5	109.6404	109.8665	60.000000
P_6	109.9520	159.7331	60.000000
P_7	109.2165	159.7331	60.000000
P_8	110.9403	109.8665	60.000000
P_9	106.8282	159.7331	60.000000
P_{10}	75.5199	114.7998	40.000000
P_{11}	81.5795	114.7998	40.000000
P_{12}	81.3565	92.3999	55.000000
P_{13}	79.5391	120.0000	55.000876
Fuel Cost ($/h)	18451.07	18376.12	17988.35

The program for JOA, *ELD_Solution_Jaya_Algo_40_gen.m*, has been written in an MATLAB m-file and kept in the current MATLAB directory. The termination criterion has been set as 2000 iterations. Table 8 shows most feasible results for 40 generating units using GA, PSA and JOA. The comparative analysis, out of the results in Table 8, puts forth JOA to be one of the reliable techniques while valve-point effect is considered.

C. Discussion

To investigate the effectiveness of this approach two more existing methods, Genetic Algorithm (GA) and Pattern Search Algorithm (PSA), have been considered for comparison purpose. The outputs using all the three algorithms have been shown in the Table 6 (for 13 units) and Table 8 (for 40 units). It is seen that in both the two cases the results obtained from JOA are almost same with the results of other two existing methods. From Table 6 and 8 it is seen that JOA gives viable results in both the cases. For 13 thermal units (*Case-study – 1*), JOA decreased the fuel cost by an amount of (18451.07 - 17988.35 = 462.72) 462.72 $/h in just (99-51=) 48 extra iterations while compared with GA and decreased both the fuel cost by an amount of (18376.12 - 17988.35 = 387.77) 387.77 $/h and number of iterations by (470 - 99 = 371) 371 while compared with PSA. For 40 thermal units (*Case-study – 2*), JOA gives better result than GA with decreased fuel cost by an amount

Table 7. Data for the 40 Thermal Units [27]

G	P_i^{min}	P_i^{max}	*a*	*b*	*c*	*e*	*f*
1	36	114	0.00690	6.73	94.705	100	0.084
2	36	114	0.00690	6.73	94.705	100	0.084
3	60	120	0.02028	7.07	309.54	100	0.084
4	80	190	0.00942	8.18	369.03	150	0.063

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5	47	97	0.01140	5.35	148.89	120	0.077
6	68	140	0.01142	8.05	222.33	100	0.084
7	110	300	0.00357	8.03	278.71	200	0.042
8	135	300	0.00492	6.99	391.98	200	0.042
9	135	300	0.00573	6.60	455.76	200	0.042
10	130	300	0.00605	12.90	722.82	200	0.042
11	94	375	0.00515	12.90	635.20	200	0.042
12	94	375	0.00569	12.80	654.69	200	0.042
13	125	500	0.00421	12.50	913.40	300	0.035
14	125	500	0.00752	8.84	1760.4	300	0.035
15	125	500	0.00708	9.15	1728.3	300	0.035
16	125	500	0.00708	9.15	1728.3	300	0.035
17	220	500	0.00313	7.97	647.85	300	0.035
18	220	500	0.00313	7.95	649.69	300	0.035
19	242	550	0.00313	7.97	647.83	300	0.035
20	242	550	0.00313	7.97	647.81	300	0.035
21	254	550	0.00298	6.63	785.96	300	0.035
22	254	550	0.00298	6.63	785.96	300	0.035
23	254	550	0.00284	6.66	794.53	300	0.035
24	254	550	0.00284	6.66	794.53	300	0.035
25	254	550	0.00277	7.10	801.32	300	0.035
26	254	550	0.00277	7.10	801.32	300	0.035
27	10	150	0.52124	3.33	1055.1	120	0.077
28	10	150	0.52124	3.33	1055.1	120	0.077
29	10	150	0.52124	3.33	1055.1	120	0.077
30	47	97	0.01140	5.35	148.89	120	0.077
31	60	190	0.00160	6.43	222.92	150	0.063
32	60	190	0.00160	6.43	222.92	150	0.063
33	60	190	0.00160	6.43	222.92	150	0.063
34	90	200	0.00010	8.95	107.87	200	0.042
35	90	200	0.00010	8.62	116.58	200	0.042
36	90	200	0.00010	8.62	116.58	200	0.042
37	25	110	0.01610	5.88	307.45	80	0.098
38	25	110	0.01610	5.88	307.45	80	0.098
39	25	110	0.01610	5.88	307.45	80	0.098
40	242	550	0.00313	7.97	647.83	300	0.035

of (146897.13 - 123262.67 =23,634.46) 23,634.46 $/h in (1532 – 54 =1478) 1478 extra iterations. PSA gives further reduced fuel cost by an amount of (123262.67- 121469.86 = 1792.81) 1792.81 $/h in 1855 iterations whereas JOA took 1532 iterations to reach the optimal value of 123262.67 $/h. The results obtained using JOA for optimal generation of each of the 13 and 40 unit systems have been shown in Figure 4 and Figure 5 respectively

Table 8. Comparison of best results of different Optimization Techniques for Case Study-2, P_D=10500 MW

Power	Generation from 50 different runs using different Optimization Techniques		
	Genetic Algorithm (54 Iterations)	Pattern Search Algorithm(1855 Iterations)	Jaya Optimization Algorithm(1532 Iterations)
P_1	110.0137	114	110.866356

P_2	110.6269	113.5162	112.296284
P_3	116.7311	97.3999	119.99666
P_4	183.0596	179.7331	179.741569
P_5	94.6652	97	96.917292
P_6	137.4385	140	105.458032
P_7	296.8879	259.5997	260.859511
P_8	294.8997	284.5997	284.615102
P_9	295.0147	284.5997	294.171983
P_{10}	295.7493	130	130.006046
P_{11}	369.6644	168.7998	94.009726
P_{12}	331.7766	168.7998	373.953022
P_{13}	384.572	214.7598	214.764338
P_{14}	382.0324	304.5196	125.003494
P_{15}	388.4051	304.5196	484.049873
P_{16}	476.9804	394.2794	304.528507
P_{17}	404.2148	489.2794	489.291637
P_{18}	380.3977	489.2794	489.286203
P_{19}	421.2156	511.2794	549.427526
P_{20}	380.8611	511.2794	511.289849
P_{21}	431.53	523.2794	523.301206
P_{22}	379.583	523.2794	523.289504
P_{23}	384.2445	523.2794	523.294690
P_{24}	381.6215	523.2794	433.530414
P_{25}	381.5228	523.2794	523.290281
P_{26}	451.4409	523.2794	523.287491
P_{27}	51.2562	10	10.052375
P_{28}	121.7068	10	10.000920
P_{29}	135.9145	10	10.050860
P_{30}	93.4065	97	96.985888
P_{31}	186.8245	190	190.000000
P_{32}	185.2257	190	189.986600
P_{33}	185.6589	190	189.999854
P_{34}	194.7441	200	199.997149
P_{35}	193.7228	200	199.992336
P_{36}	194.5296	164.7998	200.000000
P_{37}	106.0757	110	110.000000
P_{38}	101.6185	110	91.109474
P_{39}	105.1237	110	110.000000
P_{40}	379.0433	511.2794	511.297946
Fuel Cost ($/h)	146897.13	121469.86	123262.67

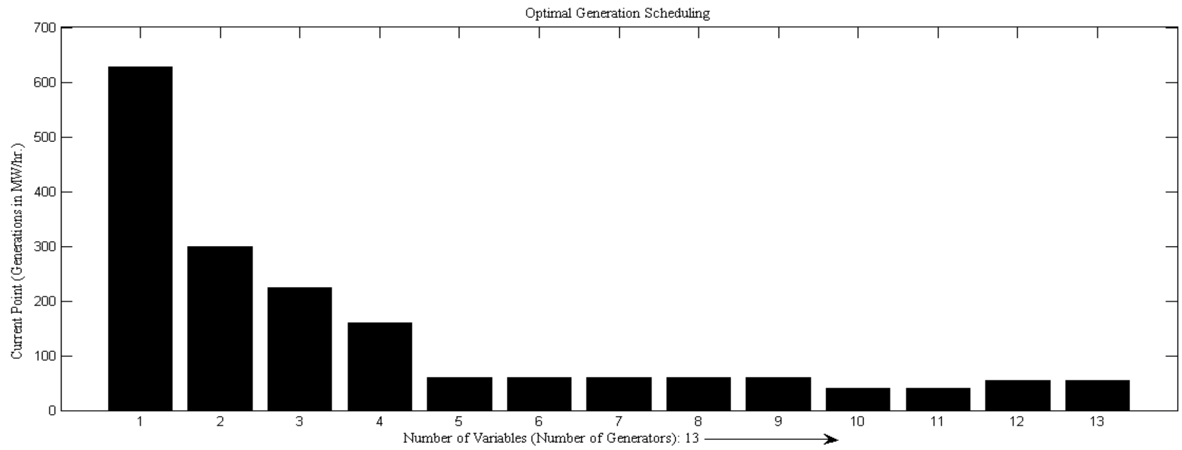

Figure 4. Optimal Generation: 13 units

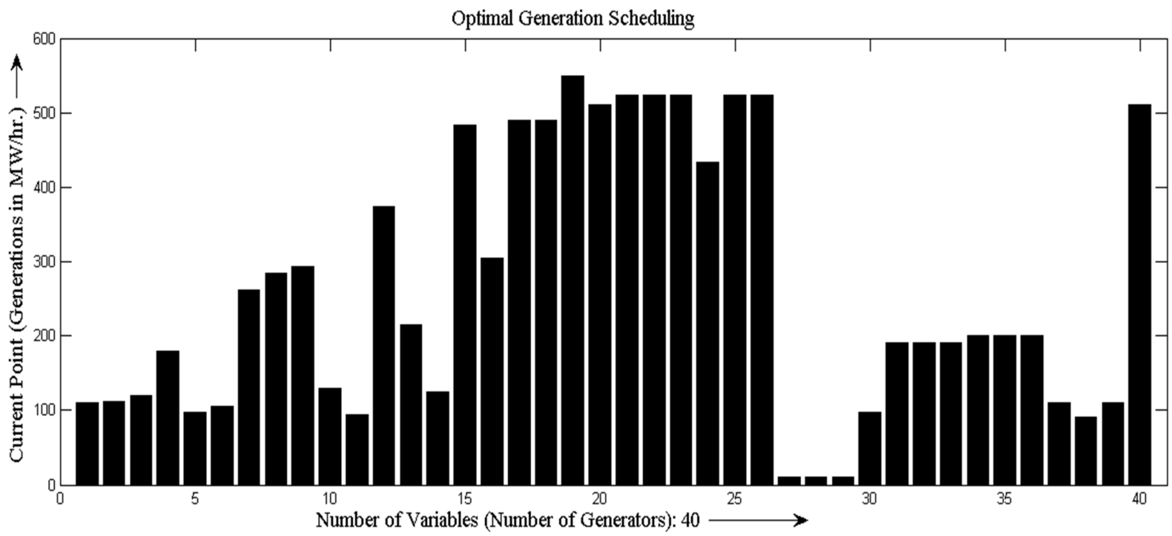

Figure 5. Optimal Generation: 40 units

1) *Convergence and Robustness Analysis:* The convergence characteristics for minimizing the fuel cost have been shown in Figure 6 (Case Study- 1) and Figure 7 (Case Study- 2). It shows that JOA converges at the best solution. It is clearly shown from Figure 8 (Case Study- 1) and Figure 9 (Case Study- 2) that there is no constraint violation at different iterations. Therefore, it reflects the feature of robustness of the proposed algorithm.

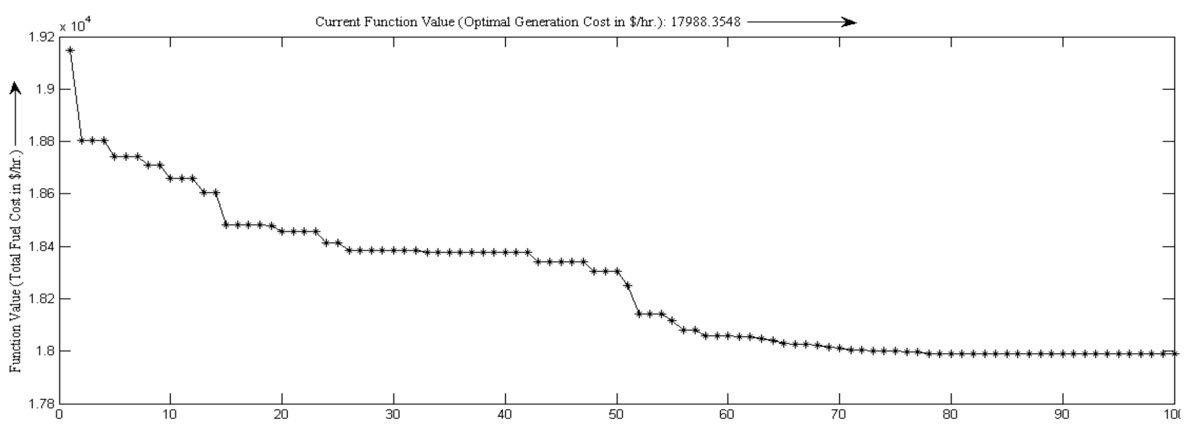

Figure 6. Convergence characteristic: (Case Study -1)

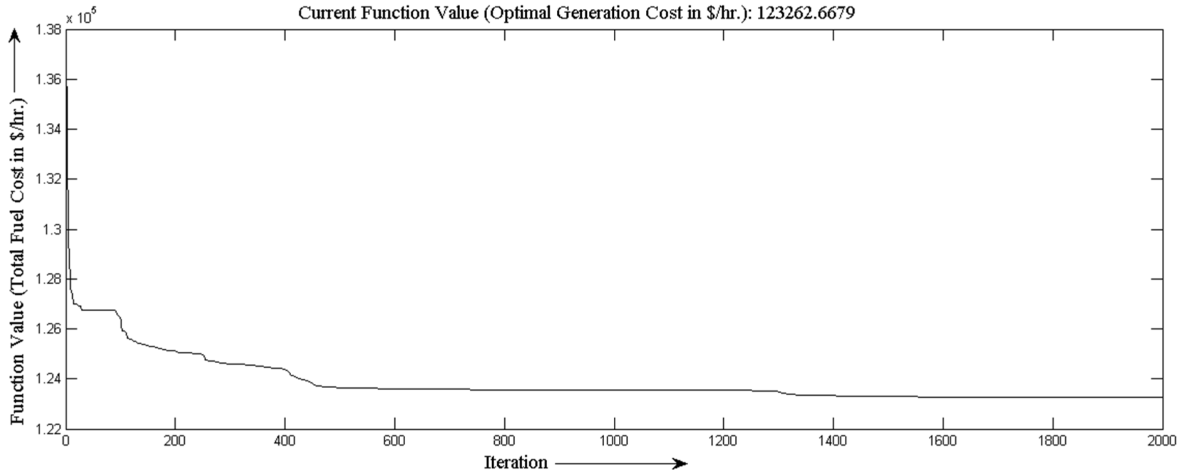

Figure 7. Convergence characteristic: (Case Study -2)

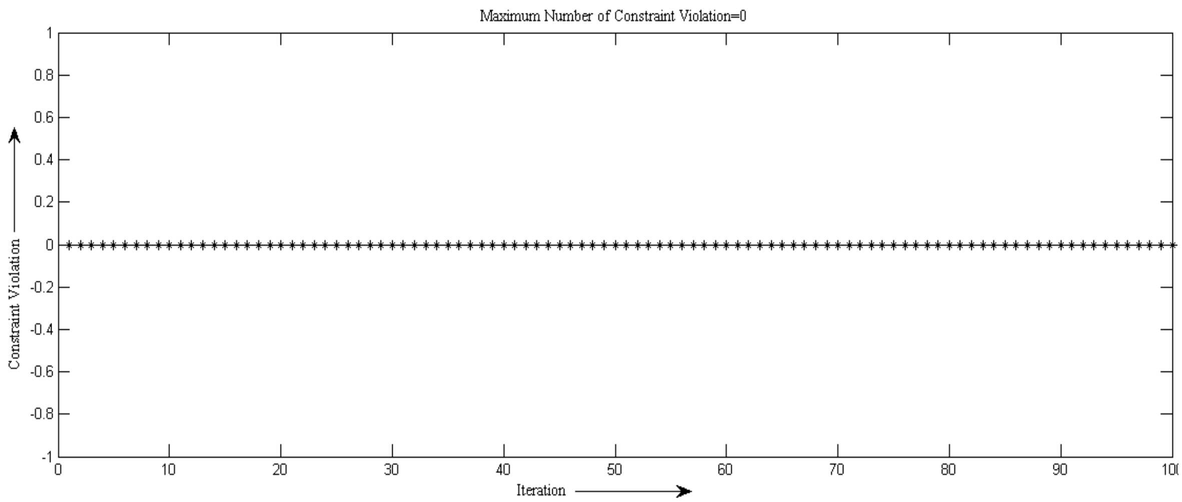

Figure 8. Robustness of case-study-1

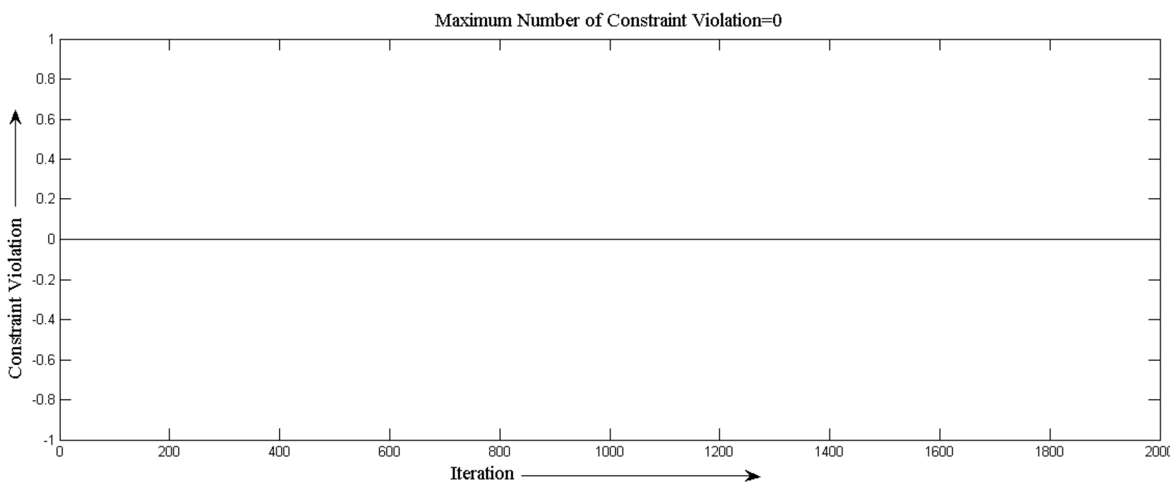

Figure 9. Robustness of case-study-2

V. CONCLUSION

The present work proposed a new approach of Jaya Optimization Algorithm for minimizing the generating cost considering the valve-point loading to solve ELD problem in electric power industry. The results, associated with two different systems (13 thermal units and 40 thermal units), achieved with the application of JOA have been analyzed and compared with other existing methods reported in the literature for the same systems. The performance of JOA proved to be effective while satisfying the constraints with highly probable solutions in an acceptable computing time. JOA has therefore proved to be the very effective technique to solve ELD problem with valve-point consideration.

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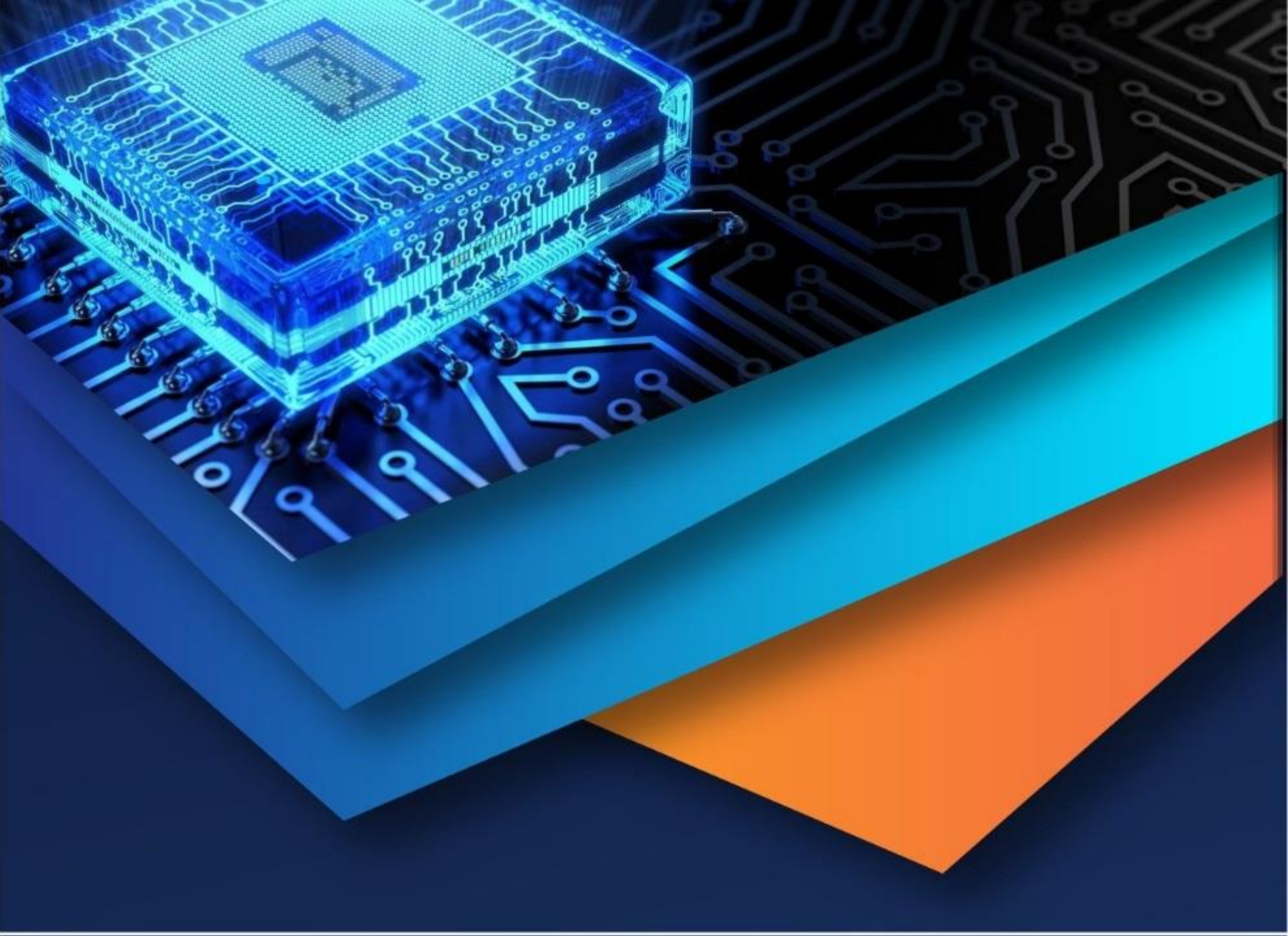

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