Modified Jaya Optimization Algorithm for Combined Economic Emission Dispatch Solution

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***Abstract*—The Combined Economic Emission Dispatch (CEED) problem focuses on the short-term determination of optimal generation from a number of power generating units in a way such that both generation costs and emission levels become minimum simultaneously, while satisfying all operational constraints and the load demand. The CEED problem considers the environmental impacts from the gaseous emission of pollutants at fossil-fueled power generating plants. This paper presents the formulation of the CEED problem as a multi-objective problem which in turn has been converted into a single objective function considering price penalty factor. This article proposes a new optimization algorithm, Modified Jaya Optimization Algorithm (MJOA), for CEED problem solution. The existing Jaya Optimization Algorithm (JOA) has been slightly modified to formulate the MJOA for faster convergence and robustness. Later the modified algorithm has been implemented in two test systems to investigate and ensure the effectiveness. The simulation results of the modified algorithm have been compared with other exiting algorithms, present in literature and MJOA has proved to be the best and most powerful amongst them.**

***Index Terms*—jaya optimization algorithm, economic load dispatch, constrained minimization, multi objective, valve-point effect, environmental dispatch**

I. Introduction

Emission control plays a vital role in energy planning in the field of power system operation and control. Determining optimal generation considering emission and cost constrains simultaneously along with some other system constraints such as valve-point constraint, Prohibited Operating Zone (POZ) etc. is an important practice for Economic Load Dispatch (ELD) problem solution. 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. 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, Modified 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.

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II. Problem Formulation

The combined environmental economic dispatch problem is to minimize two objective functions, fuel cost and emission, simultaneously while satisfying all equality and inequality constraints. The mathematical formulation of the problem is described as follows.

A. Economic Dispatch Formulation with Valve Point Effect

The cost function of economic load dispatch problem is defined as follows where P_G is the total generation:

$$F_C(P_G) = \sum_{i=1}^{N_g}\left(a_iP_i^2 + b_iP_i + c_i\right) + \left|d_i \sin\left(e_i * \left(P_i^{min} - P_i\right)\right)\right| \tag{1}$$

where N_g is the number of generating units. a_i, b_i, c_i, d_i and e_i are the cost coefficients of the i^{th} generating unit. P_i is the real power output of the i^{th} generator.

B. Emission Dispatch Formulation

The emission function of economic load dispatch problem is defined as follows:

$$E(P_g) = \sum_{i=1}^{n} 10^{-2}\left(\alpha_i + \beta_i P_{g_i} + \gamma_i P_{g_i}^2\right) + \xi_i exp\left(\lambda_i P_{g_i}\right) \tag{2}$$

where α_i, β_i, γ_i, ξ_i and λ_i are coefficients of the i^{th} generator emission characteristics.

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C. Minimization of Fuel Cost and Emission

The multi-objective combined economic and emission problem with its constraints can be mathematically formulated as a nonlinear constrained problem as follows:

$$OF = \omega \sum_{i=1}^{n} F(P_{gi}) + (1-\omega) \sum_{i=1}^{n} E(P_{gi}) \quad (3)$$

The solution of the problem is achieved by minimizing the objective function (*OF*), the fuel cost rate (*$/h*) is shown with *F(Pg)* and *NOx* emission rate (*ton/h*) with *E(Pgi).*

D. Power Balance Constraint

Generation should cover the total demand and the active power losses that occur in the transmission system.

$$\sum_{j=1}^{N_g} P_i = P_d + P_{loss} \quad (4)$$

where P_d is the total demand load and P_{loss} is the total transmission losses computed using quadratic approximation.

$$P_{loss} = \sum_{i=1}^{Ng} \sum_{j=1}^{Ng} P_i B_{ij} P_j \quad (5)$$

where B_{ij} is the loss coefficient matrix. This paper assumes *B-matrix* as constant.

Power generation limits. Each unit should generate power within its minimum and maximum limits.

$$P_i^{min} \le P_i \le P_i^{max} \quad (6)$$

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.$j = 1, 2, \dots, m$) and 'n' number of candidate solutions which gives the population size, $k = 1, 2, \dots, n$. 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):

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i} \times (X_{j,best,i} - |X_{j,k,i}|) - r_{2,j,i} \times (X_{j,worst,i} - |X_{j,k,i}|) \quad (7)$$

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 j^{th} 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 taken into account if it gives better function value. Finally, after iteration, all the accepted function values become the input to the next iteration.

B. Flowchart

Fig. 1 shows the flowchart of the Jaya algorithm [26].

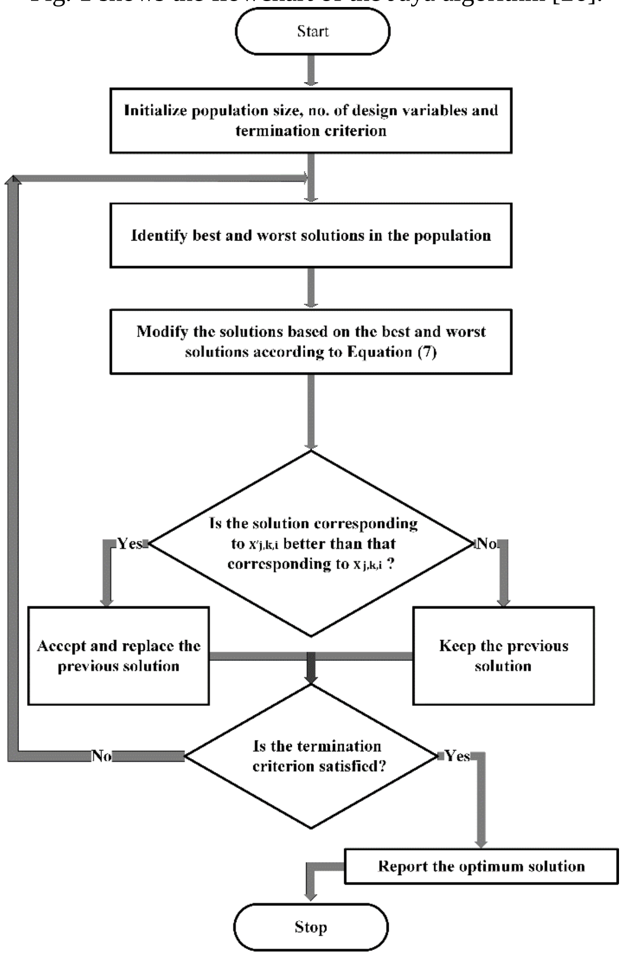

Figure 1. Flowchart of the Jaya algorithm

IV. Modifications in the Algorithm

Current context focusses on one modification in the original Jaya algorithm. The standard Jaya algorithm updates particle's position using the equation (7). This equation uses three terms out of which one term is the current position. In the process of position update, current position is updated to a new position by adding or subtracting a finite value. A minor modification is done in this finite value.

Auxiliary weighted position term: Instead of three terms in equation (7), it uses four terms. The fourth term calculates the fractional value of the mid-position between best and worst positions. This auxiliary weighted term will lead to accelerated convergence which in turn will take less number of iteration count. Less number of iteration count reflects to convergence time without compromising robustness in results. The modified position update equation can be written as-

$$X'_{j,k,i} = X_{j,k,i} + r_{1,j,i} \times (X_{j,best,i} - |X_{j,k,i}|) - r_{2,j,i} \times (X_{j,worst,i} - |X_{j,k,i}|) + r_{3,j,i} \times \{(X_{j,worst,i} + |X_{j,k,i}|)/2\} \quad (8)$$

where, the fourth term is the Auxiliary weighted position term.

V. Pseudo Code of Jaya Optimization

1. Set $i = 1$; $m = 1$; $n = 1$; j = no. of generators i.e. design variable; k = no. of candidates i.e. population size; P^j_{min}= Minimum generation of generators; P^j_{max}= Maximum generation of generators; P_D= Total load demand.

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

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

4. WHILE (the termination conditions are not met)

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

5. FOR $m \rightarrow k$

FOR $n \rightarrow j$

Modify solution based on best and worst solutions.

$$P'_{j,k,i} = P_{j,k,i} + r_{1,j,i} \times (P_{j,best,i} - |P_{j,k,i}|) - r_{2,j,i} \times (P_{j,worst,i} - |P_{j,k,i}|) + r_{3,j,i} \times \{(X_{j,worst,i} + |X_{j,k,i}|)/2\}$$

END FOR

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

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

7. Update solutions based on their contribution over total generation.

FOR $n \rightarrow j$

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

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

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

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

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

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

END

END IF

END FOR

END IF

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

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

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

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

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

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

END

END IF

END FOR

Set $i = i + 1$

END WHILE

VI. Results and Discussions

The practical applicability of MJOA has been applied for two case studies (10 and 40 thermal units) where the objective functions were non smooth due to the valve-point effects.

The MJOA has been applied through coding in MATLAB 7.9.0 (MathWorks, Inc.) and compared with other optimization methods available in literature. All the simulations have been worked out on a 2.2-GHz Intel Pentium processor with 4 GB of RAM.

A. Case-Study – 1 for 10 Generating Systems

This case study has been performed for a test system of 10 thermal units considering the effects of valve-point loading. The relevant data for this system has been shown in Table I [27]. In the present study, the load demand is $P_D = 2000$ MW (considering transmission losses). The results for Case Study-1applying MJOA are shown in Table II and the program, ELD_Solution_Jaya_Algo_10_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 I. From successive runs the best results were logged and all the best outputs were written in a tabular form (shown in Table II) 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 III [27]. The load demand to be satisfied was P_D = 10,500MW (without considering transmission losses). To find the optimal generation of power for 40 generating units, the proposed technique has been utilized. 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.

The program for MJOA, 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 IV shows most feasible results for 40 generating units using different methods. The comparative analysis, out of the results in Table IV, puts forth MJOA to be one of the reliable techniques while valve-point effect is considered.

To investigate the effectiveness of this approach, it is seen that in both the two cases the results obtained from MJOA are almost same with the results of other existing methods. From Table II and IV it is seen that MJOA gives viable results in both the cases. For 10 thermal units (Case-study – 1), MJOA decreased the fuel cost as well as total transmission loss. The B-matrix for test system-1 is shown in Box I.

TABLE I. DATA FOR THE 10 THERMAL UNITS [27]

Unit	$P_i^{min}(MW)$	$P_i^{max}(MW)$	a_i (\$/h)	b_i (\$/MWh)	c_i (\$/(MW)^{2}h)	d_i (\$/h)	e_i (rad/MW)	$\alpha_i(lb/h)$	$\beta_i(lb/MWh)$	$\gamma_i(lb/(MW)^2h)$	$\xi_i(lb/h)$	λ_i (1/MW)
1	10	55	1000.403	40.5407	0.12951	33	0.0174	360.0012	-3.9864	0.04702	0.25475	0.01234
2	20	80	950.606	39.5804	0.10908	25	0.0178	350.0056	-3.9524	0.04652	0.25475	0.01234
3	47	120	900.705	36.5104	0.12511	32	0.0162	330.0056	-3.9023	0.04652	0.25163	0.01215
4	20	130	800.705	39.5104	0.12111	30	0.0168	330.0056	-3.9023	0.04652	0.25163	0.01215
5	50	160	756.799	38.539	0.15247	30	0.0148	13.8593	0.3277	0.0042	0.2497	0.012
6	70	240	451.325	46.1592	0.10587	20	0.0163	13.8593	0.3277	0.0042	0.2497	0.012
7	60	300	1243.531	38.3055	0.03546	20	0.0152	40.2669	-0.5455	0.0068	0.248	0.0129
8	70	340	1049.998	40.3965	0.02803	30	0.0128	40.2669	-0.5455	0.0068	0.2499	0.01203
9	135	470	1658.569	36.3278	0.02111	60	0.0136	42.8955	-0.5112	0.0046	0.2547	0.01234
10	150	470	1356.659	38.2704	0.01799	40	0.0141	42.8955	-0.5112	0.0046	0.2547	0.01234

$$B = \begin{bmatrix} 0.000049 & 0.000014 & 0.000015 & 0.000015 & 0.000016 & 0.000017 & 0.000017 & 0.000018 & 0.000019 & 0.000020 \\ 0.000014 & 0.000045 & 0.000016 & 0.000016 & 0.000017 & 0.000015 & 0.000015 & 0.000016 & 0.000018 & 0.000018 \\ 0.000015 & 0.000016 & 0.000039 & 0.000010 & 0.000012 & 0.000012 & 0.000014 & 0.000014 & 0.000016 & 0.000016 \\ 0.000015 & 0.000016 & 0.000010 & 0.000040 & 0.000014 & 0.000010 & 0.000011 & 0.000012 & 0.000014 & 0.000015 \\ 0.000016 & 0.000017 & 0.000012 & 0.000014 & 0.000035 & 0.000011 & 0.000013 & 0.000013 & 0.000015 & 0.000016 \\ 0.000017 & 0.000015 & 0.000012 & 0.000010 & 0.000011 & 0.000036 & 0.000012 & 0.000012 & 0.000014 & 0.000015 \\ 0.000017 & 0.000015 & 0.000014 & 0.000011 & 0.000013 & 0.000012 & 0.000038 & 0.000016 & 0.000016 & 0.000018 \\ 0.000018 & 0.000016 & 0.000014 & 0.000012 & 0.000013 & 0.000012 & 0.000016 & 0.000040 & 0.000015 & 0.000016 \\ 0.000019 & 0.000018 & 0.000016 & 0.000014 & 0.000015 & 0.000014 & 0.000016 & 0.000015 & 0.000042 & 0.000019 \\ 0.000020 & 0.000018 & 0.000016 & 0.000015 & 0.000016 & 0.000015 & 0.000018 & 0.000016 & 0.000019 & 0.000044 \end{bmatrix}$$

BOX I. TRANSMISSION LOSS MATRIX FOR TEST SYSTEM

TABLE II. COMPARISON OF BEST RESULTS OF DIFFERENT OPTIMIZATION TECHNIQUES FOR CASE STUDY-1, PD = 2000 MW

Comparison of the results for test system-1 (P_D = 2000 MW)								
Unit	MODE [27]	PDE [27]	NSGA-II [27]	SPEA [27]	GSA [28]	TLBO	JOA	MJOA
P1(MW)	54.9487	54.9853	51.9515	52.9761	54.9992	54.4285	55.0000	54.9441
P2(MW)	74.5821	79.3803	67.2584	72.8130	79.9586	78.9558	78.4112	79.7300
P3(MW)	79.4294	83.9842	73.6879	78.1128	79.4341	79.5993	80.3464	80.1338
P4(MW)	80.6875	86.5942	91.3554	83.6088	85.0000	85.4390	84.6690	86.2269
P5(MW)	136.8551	144.4386	134.0522	137.2432	142.1063	143.7134	143.8600	143.5906
P6(MW)	172.6393	165.7756	174.9504	172.9188	166.5670	166.9796	167.4608	165.9426
P7(MW)	283.8233	283.2122	289.4350	287.2023	292.8749	293.3021	292.4104	292.7701
P8(MW)	316.3407	312.7709	314.0556	326.4023	313.2387	312.9163	313.2630	312.4573
P9(MW)	448.5923	440.1135	455.6978	448.8814	441.1775	440.4352	440.4677	440.3041
P10(MW)	436.4287	432.6783	431.8054	423.9025	428.6306	428.1624	428.0384	427.8155
Cost (x 10^5 \$)	1.1348	1.1351	1.1354	1.1352	1.1349	1.1333	1.1333	1.1330
Emission (lb)	4124.9	4111.4	4130.2	4109.1	4111.4000	4108.1000	4105.3000	4108.8000
Loss (MW)	84.3271	83.9331	84.2496	84.0612	83.9869	83.9317	83.9270	83.9150

TABLE III. DATA FOR THE 40 THERMAL UNITS [27]

Unit	$P_i^{min}(MW)$	$P_i^{max}(MW)$	a_i (\$/h)	b_i (\$/MWh)	c_i (\$/(MW)^{2}h)	d_i (\$/h)	e_i (rad/MW)	$\alpha_i(ton/h)$	$\beta_i(ton/MWh)$	$\gamma_i(ton/(MW)^2h)$	$\xi_i(ton/h)$	λ_i (1/MW)
1	36	114	94.705	6.73	0.0069	100	0.084	60	-2.22	0.048	1.31	0.0569
2	36	114	94.705	6.73	0.0069	100	0.084	60	-2.22	0.048	1.31	0.0569
3	60	120	309.54	7.07	0.02028	100	0.084	100	-2.36	0.0762	1.31	0.0569
4	80	190	369.03	8.18	0.00942	150	0.063	120	-3.14	0.054	0.9142	0.0454
5	47	97	148.89	5.35	0.0114	120	0.077	50	-1.89	0.085	0.9936	0.0406
6	68	140	222.33	8.05	0.01142	100	0.084	80	-3.08	0.0854	1.31	0.0569
7	110	300	287.71	8.03	0.00357	200	0.042	100	-3.06	0.0242	0.655	0.02846
8	135	300	391.98	6.99	0.00492	200	0.042	130	-2.32	0.031	0.655	0.02846
9	135	300	455.76	6.6	0.00573	200	0.042	150	-2.11	0.0335	0.655	0.02846
10	130	300	722.82	12.9	0.00605	200	0.042	280	-4.34	0.425	0.655	0.02846
11	94	375	635.2	12.9	0.00515	200	0.042	220	-4.34	0.0322	0.655	0.02846
12	94	375	654.69	12.8	0.00569	200	0.042	225	-4.28	0.0338	0.655	0.02846
13	125	500	913.4	12.5	0.00421	300	0.035	300	-4.18	0.0296	0.5035	0.02075
14	125	500	1760.4	8.84	0.00752	300	0.035	520	-3.34	0.0512	0.5035	0.02075
15	125	500	1760.4	8.84	0.00752	300	0.035	510	-3.55	0.0496	0.5035	0.02075
16	125	500	1760.4	8.84	0.00752	300	0.035	510	-3.55	0.0496	0.5035	0.02075
17	220	500	647.85	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075
18	220	500	649.69	7.95	0.00313	300	0.035	222	-2.66	0.0151	0.5035	0.02075
19	242	550	647.83	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075
20	242	550	647.81	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075

21	254	550	785.96	6.63	0.00298	300	0.035	290	-2.22	0.0145	0.5035	0.02075
22	254	550	785.96	6.63	0.00298	300	0.035	285	-2.22	0.0145	0.5035	0.02075
23	254	550	794.53	6.66	0.00284	300	0.035	295	-2.26	0.0138	0.5035	0.02075
24	254	550	794.53	6.66	0.00284	300	0.035	295	-2.26	0.0138	0.5035	0.02075
25	254	550	801.32	7.1	0.00277	300	0.035	310	-2.42	0.0132	0.5035	0.02075
26	254	550	801.32	7.1	0.00277	300	0.035	310	-2.42	0.0132	0.5035	0.02075
27	10	150	1055.1	3.33	0.52124	120	0.077	360	-1.11	1.842	0.9936	0.0406
28	10	150	1055.1	3.33	0.52124	120	0.077	360	-1.11	1.842	0.9936	0.0406
29	10	150	1055.1	3.33	0.52124	120	0.077	360	-1.11	1.842	0.9936	0.0406
30	47	97	148.89	5.35	0.0114	120	0.077	50	-1.89	0.085	0.9936	0.0406
31	60	190	222.92	6.43	0.0016	150	0.063	80	-2.08	0.0121	0.9142	0.0454
32	60	190	222.92	6.43	0.0016	150	0.063	80	-2.08	0.0121	0.9142	0.0454
33	60	190	222.92	6.43	0.0016	150	0.063	80	-2.08	0.0121	0.9142	0.0454
34	90	200	107.87	8.95	0.0001	200	0.042	65	-3.48	0.0012	0.655	0.02846
35	90	200	116.58	8.62	0.0001	200	0.042	70	-3.24	0.0012	0.655	0.02846
36	90	200	116.58	8.62	0.0001	200	0.042	70	-3.24	0.0012	0.655	0.02846
37	25	110	307.45	5.88	0.0161	80	0.098	100	-1.98	0.095	1.42	0.0677
38	25	110	307.45	5.88	0.0161	80	0.098	100	-1.98	0.095	1.42	0.0677
39	25	110	307.45	5.88	0.0161	80	0.098	100	-1.98	0.095	1.42	0.0677
40	242	550	647.83	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075

TABLE IV. COMPARISON OF BEST RESULTS OF DIFFERENT OPTIMIZATION TECHNIQUES FOR CASE STUDY-2, PD=10,500 MW

Comparison of the results for test system 2 (PD = 10, 500 MW)							
Unit	MODE [27]	PDE [27]	NSGA-II [27]	SPEA [27]	GSA [28]	TLBO	MJOT
P1(MW)	113.5295	112.1549	113.8685	113.9694	113.9989	113.9637	113.7032
P2(MW)	114	113.9431	113.6381	114	113.9896	114.0000	114.0000
P3(MW)	120	120	120	119.8719	119.9995	119.2759	119.9368
P4(MW)	179.8015	180.2647	180.7887	179.9284	179.7857	181.0562	180.5315
P5(MW)	96.7716	97	97	97	97	96.4756	97.0000
P6(MW)	139.276	140	140	139.2721	139.0128	137.7332	138.3124
P7(MW)	300	299.8829	300	300	299.9885	299.4274	300.0000
P8(MW)	298.9193	300	299.0084	298.2706	300	299.6958	300.0000
P9(MW)	290.7737	289.8915	288.889	290.5228	296.2025	298.0269	297.1393
P10(MW)	130.9025	130.5725	131.6132	131.4832	130.385	131.0000	130.9194
P11(MW)	244.7349	244.1003	246.5128	244.6704	245.4775	245.1809	245.2199
P12(MW)	317.8218	318.284	318.8748	317.2003	318.2101	319.6045	318.0639
P13(MW)	395.3846	394.7833	395.7224	394.7357	394.6257	394.8243	394.2374
P14(MW)	394.4692	394.2187	394.1369	394.6223	395.2016	395.6854	396.4756
P15(MW)	305.8104	305.9616	305.5781	304.7271	306.0014	306.6104	306.8609
P16(MW)	394.8229	394.1321	394.6968	394.7289	395.1005	393.7669	393.9455
P17(MW)	487.9872	489.304	489.4234	487.9857	489.2569	489.3632	489.8599
P18(MW)	489.1751	489.6419	488.2701	488.5321	488.7598	489.2599	488.5698
P19(MW)	500.5265	499.9835	500.8	501.1683	499.232	499.3462	497.9881
P20(MW)	457.0072	455.416	455.2006	456.4324	455.2821	455.8277	454.8535
P21(MW)	434.6068	435.2845	434.6639	434.7887	433.452	433.3401	432.5556
P22(MW)	434.531	433.7311	434.15	434.3937	433.8125	432.5457	434.2654
P23(MW)	444.6732	446.2496	445.8385	445.0772	445.5136	445.5808	444.7076
P24(MW)	452.0332	451.8828	450.7509	451.897	452.0547	453.4598	452.8684
P25(MW)	492.7831	493.2259	491.2745	492.3946	492.8864	493.0912	492.2676
P26(MW)	436.3347	434.7492	436.3418	436.9926	433.3695	434.2457	434.1368
P27(MW)	10	11.8064	11.2457	10.7784	10.0026	11.2841	10.7532
P28(MW)	10.3901	10.7536	10	10.2955	10.0246	10.6029	11.1086
P29(MW)	12.3149	10.3053	12.0714	13.7018	10.0125	10.9478	11.1915
P30(MW)	96.905	97	97	96.2431	96.9125	96.2683	97.0000
P31(MW)	189.7727	190	189.4826	190	189.9689	189.5610	189.2526
P32(MW)	174.2324	175.3065	174.7971	174.2163	175	174.3280	174.6346
P33(MW)	190	190	189.2845	190	189.0181	188.7028	188.8095
P34(MW)	199.6506	200	200	200	200	198.2413	200.0000
P35(MW)	199.8662	200	199.9138	200	200	198.3432	198.6563
P36(MW)	200	200	199.5066	200	199.9978	200.2483	200.4569
P37(MW)	110	109.9412	108.3061	110	109.9969	109.5386	109.4282
P38(MW)	109.9454	109.8823	110	109.6912	109.0126	108.7831	110.0000
P39(MW)	108.1786	108.9686	109.7899	108.556	109.456	110.0000	108.5079
P40(MW)	422.0682	421.3778	421.5609	421.8521	421.9987	420.7631	421.7822
Cost (X 10^5 $)	1.2579	1.2573	1.2583	1.2581	1.2578	1.2323	1.2322
Emission (lb) (X 10^5 ton)	2.1119	2.1177	2.1095	2.111	2.1093	2.114	2.103

In case study-2 (Test system-2) MJOA has worked effectively decreasing both generation cost and emission.

VII. CONCLUSION

Jaya Optimization Algorithm (JOA) is one of the recent powerful methods for solving constrained optimization problems. The present work proposed a new approach for minimizing the generating cost in electric power industry. The successful implementation of MJOA brings forth robust solutions for multi-objective problem solution. CEED problem consists of non-smooth cost function which has been successfully solved by MJOA considering two test systems. The results, associated with two different systems (10 thermal units and 40 thermal units), achieved with the application of MJOA have been compared and analyzed with other existing methods available in literature. The performance of MJOA proved to be effective while satisfying the constraints with highly probable solutions in an acceptable computing time. MJOA has therefore proved to be capable of providing better results when compared with other stochastic search algorithms and hence stands to be a very effective technique to solve ELD problems.

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