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Multi-Objective Dispatch of Thermal System using Dragonfly Algorithm

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Abstract—Two-third of electricity is produced from thermal power plants and indeed major sources of environment pollution in electricity generation sector. Serious concern towards environmental protection has turned economic dispatch to economic dispatch optimization. In economic emission dispatch, both objectives i.e economy and emission reduction are satisfied at the same time. Multi-objective is the complex optimization task of achieving generation schedule with economy and reduced emissions. This paper presents the solution of multi-objective dispatch problem of thermal system using Dragonfly Algorithm. Dragonfly Algorithm is a new population based meta-heuristic algorithm mimic the swarm behavior of dragonflies. The algorithm is tested in 10-unit system on MATLAB 2010b platform. In this paper, weighted sum method has been used to get the best combination of optimum values of both objectives. Valve point effect has been considered to reflect the realities of thermal units. In the first case simple economic load dispatch has been solved on 10 unit system with Dragonfly Algorithm and results are compared with Differential Evolution algorithm. In second case Dragonfly Algorithm was implemented to solve non-convex multi-objective dispatch problem for 10 unit system and the simulation results are compared with other algorithm including DE, MODE, PDE and found effective in achieving global optimal solution. The demand is set to 2000MW for both the cases. A result shows that Dragonfly Algorithm has good convergence for calculating global optimal solution and avoided local minima problem.

Keywords—Combined Economic Emission Dispatch, Dragonfly Algorithm(DA); Differential Evolution(DE), Multi-objective Differential Evolution(MODE).

I. Introduction

Generation of electricity from thermal power plants produces oxides of Carbon, Sulphur, Nitrogen (NO_x, SO_x, NO_x) which degrade the environment badly. Consequently the global carbon footprint is increasing which badly affect the human health and vegetation across the world. The issue was addressed globally and countries were made to modify their energy policies to reduce emissions from thermal power plants.

Multi-objective load dispatch is the complex optimization task in which conventional economic load dispatch problem along with emission reduction is considered so as to achieve environmental protection goal. Traditionally Thermal Units are dispatched in such a way that maximum fuel cost economy is gained while satisfying the load demand and other constrains. Fuel cost minimization is given high priority while emissions are not minimized in ELD. Also, when the generators are scheduled as per ELD, there will be more emissions.

Conversely when we dispatch the generators for minimizing the emissions, the fuel cost will be more. Therefore these both objectives are contradictory to each other. The objective of the multi-objective optimization is to find the best suited solution such that fuel cost along with emissions is globally minimum while satisfying various equality and inequality constrains.

Various traditional optimization techniques were employed in past to solve CEED problem. But these algorithms are time consuming and are not capable of handling non-linear constrains of objective function. To overcome these problems Meta heuristic algorithm were developed and are capable of solving multi-objective optimization problems efficiently. Meta-heuristic algorithms are nature inspired and handle constrains efficiently. The objective of each swarm/species is to survive. These algorithm mimics the foraging behavior of spices. These techniques are capable of avoiding local optima problem.

Several Meta-heuristic algorithms has been applied to combined economic emission dispatch of thermal system which includes Multi-Objective Differential Evolution(MODE)[1], Differential Evolution (DE) [2] , Multi-Objective Evolutionary Programming (MOEP)[3], Non Dominated Sorting Genetic Algorithm(NSGA) [4], Strength Pareto Evolutionary Algorithm-2(SPEA-2) [5]. P.Venkatesh converts a multi-objective optimization problem into single objective problem with the use of weight sum in MOEP algorithm to get a set of non-inferior solution. By varying the value of weights, the priority of objective function can be fixed. M.Basu presented MODE for solving multi-objective problems. MODE uses pareto-based approach to rank the non-dominated solutions. MODE algorithm was applied on six and ten generating unit system and shows superior performance as compared to other techniques.

Dragonfly Algorithm is new stochastic optimization technique proposed by Mirjaili in 2015[6]. It is population based meta-heuristic successfully tested on uni-modal and multi-modal benchmark test function. The algorithm has been implemented on areas of engineering and proved efficient.

2. OBJECTIVE FUNCTION

In this paper multi objective optimization is implemented to minimize two objectives simultaneously. These objectives include fuel cost minimization and emission reduction. The optimization is subjected to various equality and inequality constrains. Multi-objective optimization can be mathematically expressed as [7]:-

Minimize $F(x) = [\ f_1(x), f_2(x) \ldots\ldots\ldots\ldots f_{Nobj}(x)\ ]$ (1)

Subject to $g_k(x) \le 0, k = 1, \ldots\ldots N_c$

Where $x=[x_1,x_2,x_3\ldots\ldots x]^T$

Fuel Cost

The fuel cost of each thermal generator unit is expressed as sum of quadratic equation and sinusoidal function. To reflect realities of thermal plants, valve point effect has been considered. The total fuel cost is expressed in term of active power generation as[8]:-

$f_1(x)= a_i + b_i p_i + c_i p_i^2 + |\ d_i \sin(e_i\ (P_{i\ min} - P_i))\ |$ Rs/hr (2)

a_i,b_i,c_i are fuel cost coefficients and d_i,e_i are valve point coefficients.

Emissions

Thermal power plants cause emissions in form of oxides of NO_x, CO_x, SO_x. These all three emissions can be generalized using single equation. Emissions from thermal generators can also be expressed in form of active power generation. The emissions follow quadratic function with addition of exponential function and can be expressed mathematically as:-

$f_2(x) = (\alpha_i+\beta_i P_i + \gamma_i P_i^2 + \eta_i \exp(\delta_i P_i)$ Kg/hr (3)

Consequently mathematical expression for multi-objective optimization for economic emission dispatch is[9]:

Min $F(x) = [f_1(x), f_2(x)]$

System Constrains:

The economic dispatch is thermal system is subjected to following constrains:

Equality Constrains: - Equality constrains represent demand supply relationship of thermal system. Active power generated must be equal to meet the load demand. It can be mathematically expressed as:

$$\sum_{i=1}^{N} P_i = P_d + P_{loss}$$

Inequality constrains: - These constrains include active power generation limits of individual generator. While dispatching active power, active power generation limits plays significant role. Power generation is stricted to upper and lower limits, if during iteration calculated is more than maximum generating limits then it will be fixed at max. active power generation limit of corresponding generator.

$$P_{i,min} \le P_i \le P_{i,max} \quad (4)$$

Weighted Sum Method[10]

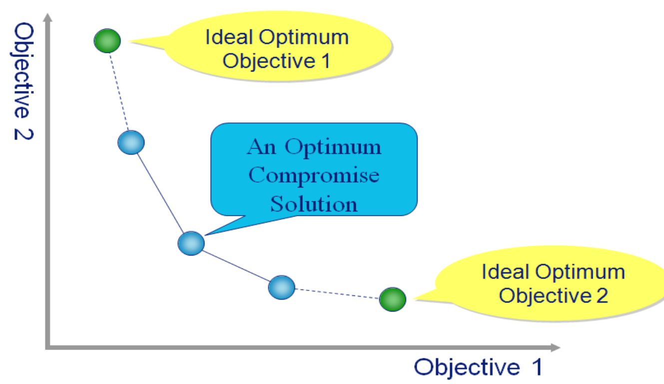
Weighted sum method is a simple method for finding the best solution between various combinations of solution. In this work, weighted sum method has been used to trade-off the best compromise between two objectives. In this method different weights are assigned to objectives relative to their significance. Multi-objective optimization is converted into single objective optimization. Then two weighted functions are added together to produce the objective function as:

$$\text{Min } f = \omega F_1 + (1-\omega)\ F_2 \quad (5)$$

Subjected to:-

$$\sum^{n=2} \omega = 1$$

Where F1 represent the fuel cost function and F2 represents emission function of generating units. The value of ω ranges from 0 to 1[11]. While the value 0 assigned to weight of objective function indicates that respective function is not considered and only other function is selected for optimization i.e emission function. When ω=1 only fuel cost function is considered and no emissions are considered. By varying the value of ω, non-dominated set of solutions can be calculated.



3. DRAGONFLY ALGORITHM

Dragonfly Algorithm is swarm intelligence based optimization technique mimic the swarming behavior of Dragonflies. Dragonflies are one of the best species survived over the centuries. They follow a set pattern of steps for hunting almost every small insect. Their hunting pattern is the main inspiration for the development of this algorithm. Dragonfly Algorithm simulates the problem as food source and search agent as artificial dragonflies. Dragonfly swarm for two purposes as hunting and migration. The former is called static (feeding) and

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latter is called dynamic (migration) swarm. The activity followed by actual dragonfly is simulated by artificial dragonfly as follow:

1. Separation: While attacking a food source, firstly the dragonflies got separated from each other with a safer distance. They maintained certain distance from nearby dragonfly and this distance are defined by vector namely S as defined by:-

(6)

Where X is the position of the current individual, X_j shows the position of j-th neighbourhood individual, and N is the number of neighbouring individuals.

2. Alignment: After maintaining the certain distance from nearby dragonfly, they tend to align in a particular direction. This alignment is presented by vector A and can be calculated as:

(7)

Where V_j is the velocity of j-th neighbouring individual.

3. Cohesion:- In process to attack the food source, the next step followed by dragonflies is move towards the centre of mass of the neighborhood. The vector cohesion is indicated as C and can be calculated as:

(8)

4. Attraction towards food source:- After getting cohesive toward food source, all the dragonflies start flying towards food source in order to hunt it. Attraction toward food source is given by A and can be calculated as:

$$F_i = X^+ - X \quad (9)$$

Where X^+ shows the position of food source.

5. Distraction outward the enemy: - In case there is a enemy in place of food source, then all the dragonflies will be distracted outward in order to save themselves. This vector is indicated by E and can be calculated as:

$$E_i = X^+ - X \quad (10)$$

Where X^- shows the position of enemy.

For hunting or surviving, dragonflies generally follow these all five steps. Two vectors are defined to simulate the movement of artificial dragonflies in search space. These two vectors are:-

Step Vector (Δ X): Step vector shows the direction of movement of dragonflies. It is analogous to velocity vector in PSO.

$$\Delta X_{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta X_t \quad (11)$$

Where s, a, c, f, e and w are weights specified to Separation, Alignment, Cohesion, Food Attraction, Enemy distraction, step vector respectively.

If there is only one artificial dragonfly considered, then Levy Flight function is used to compute Step vector as:

$$\Delta X_{t+1} = X_t + \text{Levy}(d) \, . \, X_t \quad (12)$$

Where Levy(x) = $Levy(x) = 0.01 \times \frac{(r_1}{|r}$

Where r_1, r_2 are random numbers in range [0,1], β is a constant whose value is considered 1.5 in this work. Levy flight reduces the arbitrary movement of artificial dragonfly and guides its movement according to equation.

$$\sigma = \left(\frac{\Gamma(1+\beta) \times Sin\left(\frac{\pi\beta}{2}\right)}{\Gamma\left(\frac{1+\beta}{2}\right) \times \beta \times 2^{\left(\frac{\beta-1}{2}\right)}} \right)$$

Where $\Gamma(x) = (x -$

Position vector (X_{t+1}): Position vector shows the change in position of artificial dragonflies as per step vector value. The new position of dragonfly is given by adding the step vector to initial position of artificial dragonfly. Position vector is calculated as follow:

$$X_{t+1} = X_t + \Delta X_{t+1} \quad (13)$$

After calculating separation, alignment, cohesion, food pos and enemy position, different explorative and exploitative behaviours can be achieved during optimization.

In each iteration, the position and step of each dragonfly is updated using equation. The position updating process is continued until the end criterion is satisfied. The weights i.e w,s,a,c,f and e assigned with Separation,Alignment,Cohesion, Attraction to food and distraction from enemy are so tuned that search agent explore the search space adequate and then converge them.

The best feature of this algorithm is that its weights are adaptive and are designed such that they first explore the search space completely and then converge to get the optimal solution. Thereby achieving global optimal solution and avoids local optima problem. Initially dragonflies start exploring and with the increase in iteration they start exploiting the solution.

The DA algorithm starts optimization process by creating a set of random solutions for a given ELD problem. Lower and upper generating limits define the area of search space. Also, the position and step vectors of dragonflies are initialized by random values. To apply Dragonfly Algorithm to CEED problem the following steps should be followed:-

Step 1: Read Input Data:

1. Nos. of search agents,
2. Max no. iteration
3. Nos. of Generating units i.e N
4. Define the generation capacity of thermal and wind generator i.e Upper limit and lower limit.
5. Enter cost co-efficients of thermal and wind generator

Step 2: Initiate the population (randomly selected) and should cover the whole search space defined by operating limits of generators. Initially it is a null matrix.

$P_i = [P_{i,1}, P_{i,2}, P_{i,3}, P_{i,4}, P_{i,5} \ldots\ldots P_{i,m}]$

Step 3: Initiate the step vector ΔP. It is also initially filled with null value.

$$\Delta P = \begin{bmatrix} \Delta x^1 \\ \Delta x^2 \\ \Delta x^3 \\ \vdots \\ \Delta x^N \end{bmatrix} = \begin{bmatrix} \Delta P_1^{\ 1} & \Delta P_1^{\ 2} & \Delta P_1^{\ 3} & \cdots & \Delta P_1^{\ n} \\ \Delta P_2^{\ 1} & \Delta P_2^{\ 2} & \Delta P_2^{\ 3} & \cdots & \Delta P_2^{\ n} \\ \Delta P_3^{\ 1} & \Delta P_3^{\ 2} & \Delta P_3^{\ 3} & \cdots & \Delta P_3^{\ n} \\ \vdots & \vdots & \vdots & \cdots & \vdots \\ \Delta P_N^{\ 1} & \Delta P_N^{\ 2} & \Delta P_N^{\ 3} & \cdots & \Delta P_N^{\ n} \end{bmatrix}$$

Step 4: Calculate the value of objective function given as in equation 8.1 as follow:-

$$F = \omega_1(a_i + b_i p_i + c_i p_i^2 + |\ d_i \sin(e_i\ (P_{i\ min} - P_i))\ |) + \omega_2(\alpha_i + \beta_i P_i + \gamma_i P_i^2 + \eta_i \exp(\delta_i P_i))$$

This objective value is calculated for all generators.

Step 5: Update the value of power generated output in Matrix of step 1

Step 6: For each iteration calculate and update r,s,a,c,f,e. As the nos. of iteration increases, c increases and s decreases which results in first exploration the search space and then exploit the best solution.

Step 7: Calculate S,A,C,F & E with the help of equation (6),(7),(8),(9).

Step 8: Update Velocity Vector for complete Generators using equation.

$$\Delta P_{t+1} = (sS_i + aA_i + cC_i + fF_i + eE_i) + w\Delta P_t$$

Step 9: Update Position Vector (Generation Level) using following equation. The generator output is revised w.r.t previous stored matrix using equation:

$$P_{t+1} = P_t + \Delta P_{t+1}$$

Step 10: Check and update the generator output by considering the constrains as follows:

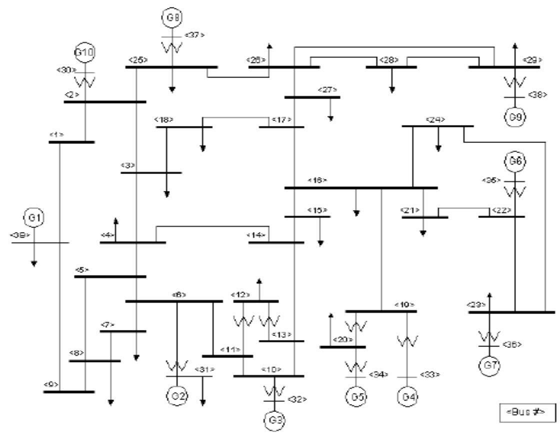
$$\sum_{i=1}^{N} P_i = P_d + P_{loss} \qquad 4.$$

$$P_{i,min} \le P_i \le P_{i,max}$$

CASE STUDY

The Dragonfly Algorithm is implemented on IEEE-39 bus system having 10 thermal units. The fuel cost coefficients, fuel emission coefficients are taken from M.Basu [1] as shown in table I, II.

The Algorithm is implemented in MATLAB 2010a programming language. In this simulation, total numbers of iterations are 500. Total nos. of search agents considered is 50. Load demand is considered as 2000MW. The best cost obtained in a single run is shown in table II.



To check the performance of Dragonfly Algorithm, result are compared with other stochastic algorithms like Multi-objective Differential Evolution (MODE)[1], Differential Evolution (DE) [2], Non Dominated Sorting Genetic Algorithm (NSGA) [3], Strength Pareto Evolutionary Algorithm-2(SPEA-2) [4].

TABLE I. FUEL COST COEFFICIENTS

Unit	Fuel Cost Coefficients				
	a_i	b_i	c_i	d_i	e_i
G1	1000.403	40.5407	0.12951	33	0.0174
G2	950.606	39.5804	0.10908	25	0.0178
G3	900.705	36.5104	0.12511	32	0.0162
G4	800.705	39.5104	0.12111	30	0.0168
G5	756.799	38.5390	0.15247	30	0.0148
G6	451.325	46.1592	0.10587	20	0.0163
G7	1243.531	38.3055	0.03546	20	0.0152
G8	1049.998	40.3965	0.02803	30	0.0128
G9	1658.569	36.3278	0.02111	60	0.0136
G10	1356.659	38.2704	0.01799	40	0.0141

TABLE II. EMISSION COEFFICIENTS

Unit	Emission Coefficients				
	α_i	β_i	γ_i	η_i	δ_i
G1	360.0012	-3.9864	0.04702	0.25475	0.01234
G2	350.0056	-3.9864	0.04652	0.25475	0.01234
G3	330.0056	-3.9023	0.04652	0.25163	0.01215

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Unit	Emission Coefficients				
	α_i	β_i	γ_i	η_i	δ_i
G4	330.0056	-3.9023	0.04652	0.25163	0.01215
G5	13.8596	0.3277	0.00420	0.24970	0.01200
G6	13.8596	0.3277	0.00420	0.24970	0.01200
G7	40.2669	-0.5455	0.00680	0.24800	0.01290
G8	40.2669	-0.5455	0.00680	0.24990	0.01203
G9	42.8955	-0.5112	0.00460	0.25470	0.01234
G10	42.8955	-0.5112	0.00460	0.25470	0.01234

Case-1:-In this case ten thermal generating units are considered and load demand is set to 2000MW. Thermal unit cost coefficients are taken from table I & II. In this case simple economic load dispatch problem is solved using Dragonfly Algorithm and results are shown in Table III. Table IV demonstrates its comparison with Differential Evolution algorithm.

TABLE III. SOLUTION OF ELD WITH DA

Unit	Generation(MW)	Fuel Cost($)
G1	40.5326	2840.00
G2	45.8383	2983.00
G3	115.7578	6775.00
G4	104.3776	6215.00
G5	104.7259	6443.00
G6	112.6931	6985.00
G7	284.9527	15044.0
G8	251.1221	12943.0
G9	470.00	23455.0
G10	470.00	23357.0
Total	2000.00	107049.0

FIGURE-I COMPARISON OF DA WITH DE FOR ELD PROBLEM

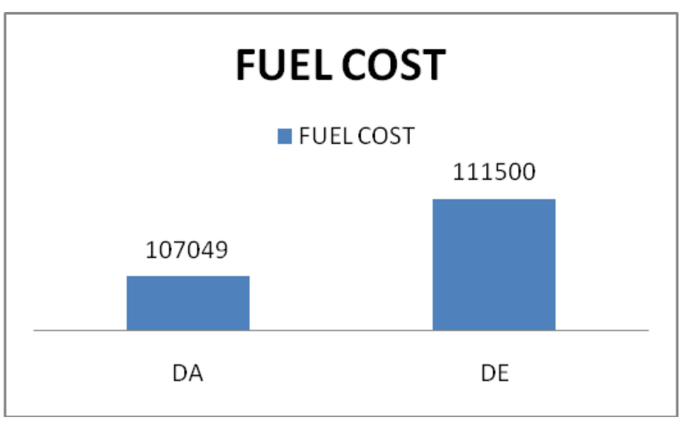


TABLE IV. COMPARISON OF DA FOR CEED SOLUTION

Unit	DA	DE
G1	40.5326	55.00
G2	45.8383	79.8063
G3	115.7578	106.8253
G4	104.3776	102.8307
G5	104.7259	82.2418
G6	112.6931	80.4352
G7	284.9527	300.00
G8	251.1221	340.00
G9	470.00	470.00
G10	470.00	469.8975
Total	107049.0	111500.0

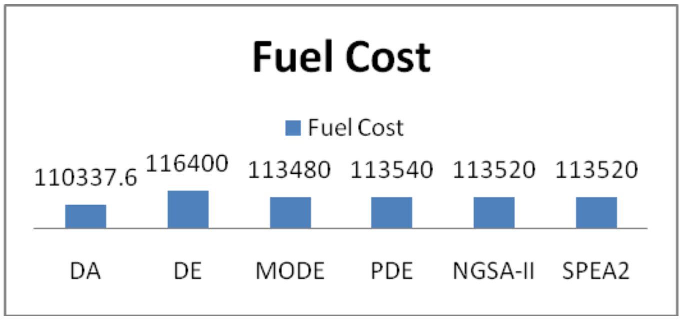
Case-II:-In this case, combined economic and emission problem is considered with valve point effect. Thermal unit coefficients are referred from table-I & II. Load demand is set to 2000MW. Multi-objective optimization is done to obtained best trade-off, the results are tabulated in table V. This algorithm is compared with several other meta-heuristic techniques and is tabulated in table-VI.

TABLE V SOLUTION OF MULTI-OBJECTIVE ELD WITH

Unit	Generation(MW)	Fuel Cost($)	Emission
G1	46.49749	3145.87	276.7538
G2	73.58246	4433.239	311.6824
G3	75.37136	4349.078	300.7854
G4	63.07534	3754.809	269.4879
G5	99.64559	6090.84	89.0415
G6	240.0000	17620.4	338.8755
G7	226.8554	11746.85	271.0991
G8	340.0090	18025.17	655.0991
G9	470.0000	23455.1	902.882
G10	364.9724	17116.24	492.0775
Total	2000.00	110337.605	3908.49

DA

GRAPH-II COMPARISON OF FUEL COST FOR MULTI-OBJECTIVE PROBLEM



GRAPH-III COMPARISON OF EMISSIONS FOR CEED PROBLEM

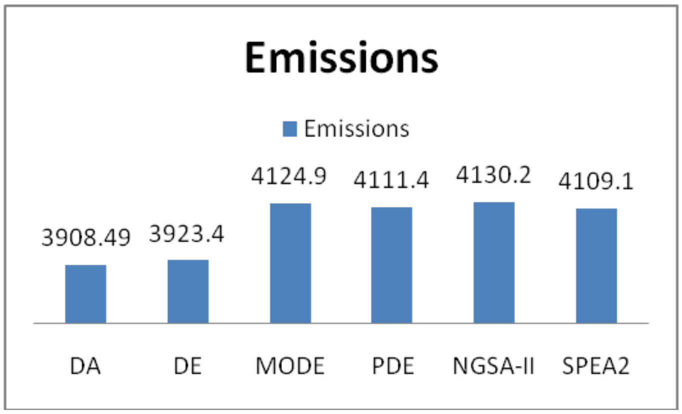


TABLE- VI COMAPRISON FOR DA FOR CEED PROBLEM

Unit	DA	DE	MODE	PDE	NGSA-2	SPEA2
G1	46.49	55.00	54.94	54.98	51.95	52.97
G2	73.58	80.00	74.58	79.38	67.25	72.81
G3	75.37	80.59	79.42	83.98	73.68	78.11
G4	63.07	81.023	80.68	86.59	91.35	83.60
G5	99.64	160.00	136.85	144.43	134.05	137.24
G6	240.00	240.00	172.63	165.77	174.05	172.91
G7	226.85	292.73	283.82	283.21	289.43	287.20
G8	340.00	299.12	316.34	312.77	314.05	326.40
G9	470.00	394.51	448.59	440.11	455.69	448.88
G10	364.97	398.63	436.42	432.67	431.80	423.90
Total	110337	116400	113480	113540	113520	113520
Emissions	3908.49	3923.4	4124.9	4111.4	4130.2	4109.1

Dragonfly Algorithm is compared with other Meta-heuristic technique viz DE and results are tabulated in table IV, VI. From results, it is indicated that highly economical units are loaded first and more costly units are loaded least.

6. *Conclusion*

In this paper IEEE-39 bus system having 10-generators are used for simulating the problem of Multi-objective Dispatch of thermal system. The Generator parameters are depicted in table-I, II. Dragonfly Algorithm has been used to solve ELD and Multi-objective ELD on MATLAB 2010a platform. Table III, IV shows the results of ELD and its comparison. Table V, VI demonstrates the results of Economic Emission Dispatch problem and its comparisons with various other techniques. Load demand in both cases is fixed on 2000MW.For getting better trade-off between both objectives, weighted sum method was used.

Hence Dragonfly Algorithm significantly achieves the environmental protection goal along with fuel economy considerations. Comparisons shows that it perform better than other meta-heuristic optimization techniques.

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