Flower pollination algorithm to solve dynamic economic loading of units with piecewise fuel options

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ABSTRACT

This paper presents a Flower Pollination Algorithm (FPA) to solve Dynamic Economic Load Dispatch (DELD) problem with valve-point effects and piecewise fuel options. DELD aims to find out optimum generation schedule of the committed generating units over a certain timing period, sustaining practical constraints and power demands in each interval. Due to the valve-point effect and piecewise fuel options DELD becomes as complex problem, hence in order to achieve the cost reduction and satisfying the dynamic behaviour of the generating units proposed algorithm presented. The practicality of the proposed method is evaluated by performing simulations on standard 10-unit and 19-unit Indian utility systems for a 24 h time schedule at various load patterns. The simulation results attained by the FPA are related with other previous published techniques of the biography. These results clearly show that the proficiency and robustness of the proposed FPA method for resolving the non-linear constrained DELD problem.

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1. INTRODUCTION

Power system is a large complex system, Economic Load Dispatch (ELD) and Unit Commitment (UC) plays major role in order to reduce the cost to the consumers based on required load demand. In general, the cost functions of generator model by a quadratic function and later were solving the quadratic form by different methods. The quadratic form defined for the generator can be solved by different method like lambda iteration method, gradient-based method, dynamic programming etc. [1]. Usually these methods offer only the local optimum point and also require derivatives of the cost function of the generator.

To overcome these shortcomings, a lot of nature based optimization techniques have been applied of which the famous technique is Particle Swarm Optimization (PSO) [2]. However other approaches like Firefly algorithm (FFA) [3], Cuckoo Search Algorithm (CSA) [4] and Grey wolf optimization (GWO) [5] are also used to solve ELD problem. However, we can observe the discontinuities in the turbine-generator set performance characteristics, and those owe to valve-point (non-convex) loading in plants [1]. Hybrid approaches as modified Sub-Gradient (MSG) and Harmony Search Algorithms MSG-HS [6] and hybrid GA-NSO [7] methods are used for solving ELD with valve point effect (ELDVPE) problem.

Besides, instabilities occurring in the generation at some particular levels of unit loading may be caused by physical limitations or faults. This problem can be resolved by using the model known as prohibited operating zones (POZ) [1] and changes in the unit's generation level between any two simultaneous periods has not to be exceeded its ramp rate limits [1]. Backtracking search algorithm (BSA)

[8], PSO [9] and Improved Random Drift PSO (RDPSO) [10] methods are used for solving ELD with ramp rate limits and POZs.

Present operating conditions of many thermal units, the generation cost functions for thermal plants be segmented as piecewise quadratic functions. Biogeography-based optimization (BBO) [11], Improved PSO [12], hybrid algorithm consisting of distributed sobol PSO, tabu search algorithm (DSPSO-TSA) [13], BSA [14] committed to the solve ELDVPE problem with multiple fuel options.

In practical power system Dynamic ELD (DELD) used to allocate the optimal generator outputs for a given various load demands in order to reduce the total operating cost over a given time period, imposed on practical constraints. DE algorithms have established attention in solving DELD problems [15, 16]. Other empirical search methods are Quantum GA (QGA) [17], Artificial Bee Colony (ABC) [18], PSO [19] and Multiple TS (MTS) [20] to solve DELD problems in the past decade. Hybrid methods such as hybrid AIS-SQP [21], and hybrid PSO-SQP [22] are found to be effective in solving complex DELD problem.

In this paper, to solve the DELD problem multiple fuel options proposed FPA method [23] implemented and simulation results are compared with refined DE algorithm [24]. FPA has shown good act in solving optimization problems in different areas, because only one key parameter p (switch probability) which makes the algorithm faster to reach global optimum solution. Moreover, this transferring switch between local and global pollination can guarantee escaping from local minimum solution. Results shown that FPA is capable to find better results comparing with other exploratory algorithms to solve DELD problem for test systems.

2. DELD PROBLEM FORMULATION

Explaining research chronological, including research design, research procedure (in the form of algorithms, Pseudocode or other), how to test and data acquisition [1-3]. The description of the course of research should be supported references, so the explanation can be accepted scientifically [2, 4].
The objectives function for DELD problem as follows:

$$\min TC = \sum_{t=1}^{T}\sum_{i=1}^{N} C_{it}(P_{it}) \tag{1}$$

Where C_{it} : Fuel cost of unit i at time t (in \$/h), N: Number of generation units, P_{it} : Power output of i^{th} unit at time t (in MW), T: Total number of hours.

Due to involvement of valve-point the fuel cost of a generation unit defined as:

$$C_{it}(P_{it}) = a_i P_{it}^2 + b_i P_{it} + c_i + \left| e_i \sin(f_i (P_i^{min} - P_{it})) \right| \tag{2}$$

Practically, the generating units are supplied with multiple fuels like oil, gas and coal. In general, the fuel cost represent as solitary quadratic function even though supplied with multiple fuels. For this purpose cost function represented as several piece-wise quadratic functions with valve-point effects,

$$F = F_C(P_{Gk}) = \begin{cases} a_{k1}P_{Gk}^2 + b_{k1}P_{Gk} + c_{k1} + \left| e_{ck1} \times \sin(f_{ck1} \times (P_{Gk}^{min} - P_{Gk})) \right| & P_{Gk}^{min} \le P_{Gk} \le P_{Gk1} \\ a_{k2}P_{Gk}^2 + b_{k2}P_{Gk} + c_{k2} + \left| e_{ck2} \times \sin(f_{ck2} \times (P_{Gk}^{min} - P_{Gk})) \right| & P_{Gk1} \le P_{Gk} \le P_{Gk2} \\ . & \\ a_{kn}P_{Gk}^2 + b_{kn}P_{Gk} + c_{kn} + \left| e_{ckn} \times \sin(f_{ckn} \times (P_{G}^{min} - P_{Gk})) \right| & P_{Gk(n-1)} \le P_{Gk} \le P_{Gk}^{max} \end{cases} \tag{3}$$

The DELD problem objective function maintain the following constraints should be minimized.

2.1. Real Power Balance

By considering network transmission losses, the equality constraint of the given network is written as:

$$\sum_{i=1}^{N} P_{it} = P_D(t) + P_{loss}(t) \qquad t = 1, 2, ..., T \tag{4}$$

Where $P_{loss}(t)$: Total transmission loss of the system (in MW), $P_D(t)$: Total power demand of the system at time t (MW). The power loss calculated using coefficients of the B matrix as follows:

$$P_{loss}(t) = \sum_{i=1}^{N}\sum_{j=1}^{N} P_{it} B_{ij} P_{jt} \quad t = 1, 2, 3, ..., T \tag{5}$$

2.2. Generation Limits of Units:

$$P_i^{min} \le P_{it} \le P_i^{max} \quad i = 1, ..., N, \ t = 1, 2, ..., T \tag{6}$$

Where P_i^{min} and P_i^{max} (in MW) are the minimum, maximum power outputs of ith unit.

2.3. Ramp Up and Ramp Down Constraints:

The generation unit ramp rate limits are stated as follows:

$$P_{it} - P_{it-1} \le UR_i \quad i = 1, ..., N, \ t = 1, 2, ..., T \tag{7}$$

$$P_{it-1} - P_{it} \le DR_i \quad i = 1, ..., N, \ t = 1, 2, ..., T \tag{8}$$

Where UR_i: Ramp up limit, DR_i: Ramp down limit of the i^{th} generator (MW/h). Due to involvement of ramp rate limits power limits can be modified as follows:

$$\max(P_i^{min}, P_{it-1} - DR_i) \le P_{it} \le \min(P_i^{max}, P_{it-1} + UR_i) \ i = 1, ..., N, \ t = 1, 2, ..., T \tag{9}$$

2.4. Prohibited Operation Zone Limits (POZ):

Due to stability concerns or limitations of machine components generating outputs have certain delimited operation zone. The generation unit acceptable operation zone canbe defined as:

$$P_{it} \in \begin{cases} P_i^{min} \le P_{it} \le P_{i,1}^{l} \\ P_{i,j-1}^{u} \le P_{it} \le P_{i,j}^{l} \\ P_{i,M_i}^{u} \le P_{it} \le P_i^{max} \end{cases} \quad j = 2, 3, ...M_i \quad i = 1, ..., N \quad t = 1, 2, ..., T \tag{10}$$

Where $P_{i,j}^{u}$ and $P_{i,j}^{l}$ are the upper and lower limits of the j^{th} POZs of unit i, respectively. M_i is the number of POZs of unit i.

3. FLOWER POLLINATION ALGORITHM

3.1. Introduction

In this section, new nature inspired optimization algorithm based on flower fertilization process has been proposed and implemented on DELD problem. Xin-She Yang developed FPA method in 2012. There are namely two types of fertilization processes known as biotic and abiotic. Majorly (90%) the transfer of pollen occurs due to the biotic pollination by using pollinators as bats, birds, insects and other animals. Wind and diffusion help in the abiotic fertilization (10% occur) rather than using pollinators.

Cross - fertilization or self - fertilization can achieve flower fertilization. First, one is due to the pollen fertilization of a different plant flower. Second, one occurs because one flower is fertilized from pollen of the same flower or other flowers of the same plant.

For FPA, the following four rules are used:

a) To find the global fittest, biotic and cross-fertilization considered, as pollen – carrying pollinators fly following Levy flights.
b) To find the local fittest, abiotic fertilization and Self-fertilization used.
c) Generally, insects can develop flower perseverance; this probability of reproduction is proportional to the similarity of the two flowers involved.

d) The switch probability of $P\varepsilon[0,1]$, is used to control interaction of local and global fertilization, which is slightly biased toward local pollinator.

3.2. Mathematical Representation of FPA

Global fittest (g_*) can be formulated using first rule, and it can be represented mathematically as (11),

$$X_i^{t+1} = X_i^t + L(X_i^t - g_*) \tag{11}$$

Where X_i^t the solution is vector X_i at iteration t, and g_* is the current iteration best solution. L is the strength of fertilization should be greater than zero.

Levy distribution can be represent as (12)

$$L \approx \frac{\lambda\Gamma(\lambda) * \sin(\pi\lambda / 2)}{\pi}\left(\frac{1}{S^{1+\lambda}}\right) \qquad (S >> S_0 > 0) \tag{12}$$

Where Γ (λ): Standard gamma function distribution is valid for large steps S > 0.

For the local fertilization, both Rules 2 and 3 can be signified as shown in (13).

$$X_i^{t+1} = X_i^t + \varepsilon(X_j^t - X_k^t) \tag{13}$$

Here X_j^t and X_k^t are pollens from the different flowers of the same plant species. Here ε is drawn from a uniform distribution as [0, 1]. In both local and global searches, flower pollination can occur. If there are two similar solutions, the search may be local; while there are two different solutions, the search will be global. The two parameters in this algorithm are population size n and probability switch (p [0, 1]). From our reproductions, found that probability switch= 0.75 for solving DELD problem. The flower pollination algorithm to the solve DELD problem discussed in below. Implementation of Flower Pollination Algorithm:

Step 1: The algorithm begins by setting the initial population size (n), the switch probability (p), the maximum number of iterations, the search variables dimension (dim), the cost of generation coefficients, the B - matrix, the upper & lower limit and the load demand for 24 hours.

Step2: Initialize the population or solutions of flower randomly.
Sol (i, :) =Lb+ (Ub-Lb).*rand (1, dim).

Step3: Find the current best solution g_* in the initial population. [F_{min}, I]=min (Fitness).

Step4: Start the iteration count i=1.

Step5: Check the limits that are simple. If random is larger than p, use (11) to draw a step vector that obeys a levy distribution. Use (12) to make the global pollination.

Step6: Draw a uniform distribution in [0, 1] randomly select j & k among all solutions if random is less than p. Use equation to do local pollination (13).

Step7: Check to see if all the restrictions are met if they are not met go to step 4. Assess new solutions (unit generation outputs, costs and losses).

Step8: Update the global fittest and its position.

Step9: Run the program up to meet the tolerance (0.00001). Display the results such as generation cost, power generations, transmission losses and total power generation for 24 hours.

4. SIMULATION RESULTS

The FPA method is examined on two test systems with ten and nineteen of units in this section. MATLAB programs are executed on a PC with 4 GB RAM using MATLAB R2014a to solve DELD issues with multiple fuel options. 30 Trails are considered in order to evaluate the robustness of the proposed FPA method for each system. The number of pollens in all test systems is 40. The stop criteria are defined in this paper as reaching the tolerance of 0.00001. DELD problem is solved for three different load patterns, taking into account valve-point effects, losses and POZs, resulting in a non-convex quadratic programming problem.

4.1. Ten Unit Test System

The 10-unit test system data are adapted from [24]. For this test system, valve-point loading, multiple fuel options and ramp rate limits are considered. The total time period of one day divided into 24 intervals, three various load patterns were considered. The peak demand for load pattern 1, pattern 2, and pattern 3 is 3208 MW, 2460 MW, and 3210 MW, respectively. The obtained simulation results for this test system by proposed FPA method are presented in Table 1 for load pattern 2. The fuel chosen by the units for all three load patterns is given in Table 2. The table format represents the fuel type chosen by a unit for pattern 1 and it is followed by fuel type for the same unit for patterns 2 and 3, respectively.

Table 1. Best Generation Dispatch Results Obtained by FPA for 10-Unit Test System for Load Pattern 2

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	142.6846	129.9651	200.0037	122.4141	190.0028	155.3210	200.0008	155.3207	257.2863	200.0008
2	141.9089	129.8627	200.0143	156.3134	190.0396	152.8515	200.0009	120.0872	247.8791	200.0423
3	140.3072	109.4027	200.0000	114.0102	190.0011	152.8468	200.0000	153.3417	250.0902	200.0000
4	141.0976	180.2711	200.0003	117.1524	190.0004	154.8269	200.0000	116.0061	250.6439	200.0013
5	163.2270	187.6980	213.1068	171.1580	190.2532	171.6529	200.0430	170.6631	282.1981	200.0000
6	175.8724	194.3822	233.2710	227.8148	218.7790	227.4117	223.7101	227.8148	298.2520	209.6919
7	168.7594	190.9163	218.1478	227.5460	194.2512	226.0680	216.4565	227.0086	292.7162	203.1300
8	162.4357	187.7028	212.1101	170.1688	190.2016	169.6733	202.8615	171.1741	281.6410	200.0311
9	137.9362	126.6959	200.0000	152.3520	190.0000	158.8366	200.0000	151.8571	247.3222	200.0000
10	138.7410	178.2908	200.0011	110.2796	190.0019	111.0260	200.0439	152.8471	246.7687	200.0000
11	164.8077	189.9261	215.1232	174.6222	190.0000	173.6324	204.7262	172.6426	285.5196	200.0000
12	139.5188	108.9494	200.0001	154.8262	190.01710	152.3519	200.0083	153.3418	248.9817	200.0047
13	166.3911	192.4020	219.1582	226.0683	193.8421	221.4993	204.8852	172.6440	284.9733	200.1365
14	179.8241	198.3433	238.3121	229.5616	225.8503	228.3523	237.8363	232.5178	306.5558	218.8465
15	201.1350	205.0275	263.5174	235.0708	247.8439	235.6083	259.2753	236.0114	325.9313	250.5791
16	177.4531	195.8676	233.2710	228.6210	218.3949	229.8303	228.4522	228.0835	303.2343	215.7920
17	166.3884	186.4602	215.1233	223.2462	190.4615	172.1477	204.7437	221.2306	282.1981	200.0003
18	137.1460	123.5203	200.0001	152.8471	190.0000	110.8124	200.0000	152.3520	247.3222	200.0000
19	154.5844	184.9748	205.0922	166.2073	190.1857	164.2556	200.0166	220.4241	272.2397	200.0198
20	144.2780	178.0443	200.0014	121.5471	190.0042	120.3964	200.0378	154.8259	252.8569	200.0080
21	144.2589	129.8678	200.0000	124.4969	190.0000	154.3315	200.0005	156.3112	256.7332	200.0000
22	149.7913	181.0137	200.0000	161.7550	190.0769	160.7652	200.0000	159.7754	262.8226	200.0000
23	141.0976	175.8149	200.0000	117.4415	190.0000	117.1274	200.0000	155.3213	251.1973	200.0000
24	165.5980	191.1639	220.1643	175.6120	193.5260	174.6222	207.1130	174.1273	286.0732	200.0000
								Total Cost	**$ 7880.0850**	

Table 2. Fuel Switching for Three Different Load Patterns to 10-unit Test System

HOUR	UNIT (MW)									
	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	2,1,1	1,2,1	1,1,1	3,2,3	1,1,1	3,1,1	1,1,1	3,2,2	1,1,1	1,1,1
2	2,1,1	1,3,1	1,1,1	3,2,2	1,1,1	3,1,3	1,1,1	3,1,2	1,1,1	1,1,1
3	1,1,1	1,3,1	1,1,1	2,2,2	1,1,1	1,2,1	1,1,1	2,2,2	1,1,1	1,1,1
4	1,1,1	1,1,1	1,1,1	2,2,2	1,1,1	2,1,3	1,1,1	2,2,2	1,1,1	1,1,1
5	1,1,1	1,1,1	1,1,1	2,2,2	1,1,1	1,1,3	1,1,1	2,3,3	1,1,1	1,1,1
6	1,1,2	1,1,1	1,1,1	2,3,3	1,1,1	1,3,3	1,1,1	2,3,3	1,1,3	1,1,1
7	1,1,2	1,1,1	1,1,2	2,3,3	1,1,1	3,3,3	1,1,1	3,2,3	1,1,3	1,1,1
8	1,1,2	1,1,1	1,1,2	3,3,3	1,1,1	1,1,3	1,1,2	3,2,3	1,1,3	1,1,1
9	1,1,2	1,3,1	1,1,2	3,2,3	1,1,1	3,1,3	1,1,3	3,2,3	1,1,3	1,1,1
10	1,1,2	1,3,1	1,1,2	3,2,3	1,1,1	3,2,3	1,1,1	3,2,3	3,1,3	1,1,1
11	1,1,2	1,1,1	1,1,1	3,2,3	1,1,1	3,3,3	1,1,1	3,2,3	1,1,3	1,1,1
12	1,1,2	1,1,1	1,1,1	3,2,3	1,1,1	3,2,3	1,1,1	3,1,3	1,1,3	1,1,1
13	2,2,2	1,1,1	1,1,1	3,3,3	1,1,1	3,3,3	1,2,	3,3,3	3,3,1	1,1,1
14	2,2,1	1,1,1	1,2,1	3,3,2	1,1,1	3,3,1	1,1,1	3,3,2	3,3,1	1,1,1
15	2,2,1	1,1,1	1,1,1	3,3,2	1,1,1	3,3,1	1,1,1	3,3,2	3,1,1	1,1,1
16	2,2,1	1,1,1	1,1,1	3,3,2	1,1,1	3,3,3	1,1,1	3,3,3	3,3,1	1,1,1
17	2,2,1	1,1,1	2,1,1	3,3,3	1,1,1	3,3,3	2,1,1	3,3,3	3,3,1	1,1,1
18	2,1,1	1,3,1	2,1,1	3,2,3	1,1,1	3,1,3	3,1,1	3,1,3	3,1,1	1,1,1
19	2,1,2	1,1,1	1,1,1	3,2,3	1,1,1	3,1,3	1,1,1	3,2,3	3,1,3	1,1,1
20	2,1,1	1,3,1	1,1,1	3,2,3	1,1,1	3,1,3	1,1,1	3,1,3	3,1,1	1,1,1
21	2,1,2	1,1,1	1,1,1	3,1,3	1,1,1	3,2,3	1,1,1	3,2,3	3,1,1	1,1,1
22	1,1,2	1,1,1	1,1,1	3,2,3	1,1,1	1,1,3	1,1,1	3,2,3	1,1,1	1,1,1
23	1,1,1	1,3,1	1,1,1	2,2,3	1,1,1	1,1,3	1,1,1	2,3,3	1,1,1	1,1,1
24	1,1,1	1,1,1	1,1,1	1,2,2	1,1,1	2,1,3	1,1,1	2,2,2	1,1,1	1,1,1

The best cost obtained by the FPA method for pattern 1, 2, and 3 is $9526.2580, 7788.1972, and $10276.8797, respectively. The worst cost for pattern 1 is $9550.6938, pattern 2 is $7821.2645, and pattern 3 is $10311.2545. The average cost for pattern1 is 9535.9478, pattern 2 is $7821.2645, and pattern 3 is $10311.2545. These results are compared with DE-NM [24] method presented in recent literature in terms of minimum cost, mean cost, and maximum cost over 30 runs those are presented in Table 3. By investigating the results presented in Table 3, it can be observed that the obtained results outperform the DE-NM method for 10-unit test system.

Table 3. Comparison Results of Different Load Patterns for 10-Unit Test System

Load demand	Method	Minimum Cost ($)	Average Cost ($)	Maximum Cost ($)
Pattern 1	DE-NM [24]	10649.68	11451.82	11952.07
	Proposed **FPA**	**9526.2580**	9535.9478	9550.6938
Pattern 2	DE-NM [24]	8103.326	9711.448	9163.973
	Proposed **FPA**	**7788.1972**	7800.8958	7821.2645
Pattern 3	DE-NM [24]	11054.83	11497.85	12036.89
	Proposed **FPA**	**10276.8797**	10293.2937	10311.2545

4.2. 19-unit Indian Utility Test System

This system involves a standard Indian utility system with 19 units. All the 19 units include nonlinear characteristics such as valve point effect, ramp rate limit, multiple fuels, prohibited operating zones and spinning reserve constraint. This system is applied for three different load patterns. The maximum demand for pattern 1 is 4400 MW, for pattern 2 is 4186 MW, and for pattern 3 is 4173 MW. Table 4 gives the best generation schedule obtained by the FPA method for pattern 2. Few units in the system are provided with multiple fuel option. The fuel types include 1, 2, 3, 4, 5and 6. Table 5 shows the fuel switching for units 3, 5, 7, 13, and 19 and all the remaining units utilize fuel 1 for every hour of time interval.

Table 4. Best Generation Dispatch Results Obtained by FPA for 19-unit Indian Utility System for Load Pattern 2

	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10
1	100.0000	120.0327	100.9887	20.76666	82.2480	161.8143	175.9278	100.0009	200.1628	33.3400
2	100.0002	123.2428	100.6766	17.0406	176.5358	150.1571	176.5470	100.1397	200.7483	30.3581
3	112.4216	121.6729	249.9994	15.3482	174.3989	230.7346	171.0398	100.3583	212.7103	31.4505
4	100.0118	371.7785	345.5735	8.3328	176.1724	217.9259	175.7711	112.1717	202.8636	39.9983
5	100.0015	432.6571	378.4861	10.3150	175.0199	294.9874	176.5728	100.0164	204.5333	39.9479
6	139.2736	433.5937	399.9891	25.0000	176.1002	398.4731	169.8704	233.0472	200.0488	39.9888
7	240.9011	435.9810	396.2001	23.9839	176.5697	299.9995	176.5505	427.6827	353.8093	27.3263
8	248.3570	437.9769	399.9811	22.2722	176.5247	395.1113	176.5009	402.1547	389.2728	39.8374
9	100.0028	120.0428	356.4301	10.3553	174.8167	220.9792	176.6223	100.0000	200.1354	32.2547
10	100.0035	245.8055	249.9997	23.7589	175.2543	184.3788	176.3841	124.1856	204.9449	17.3496
11	110.0156	179.5462	249.9990	20.6745	168.9997	151.6498	81.9179	100.5506	201.8712	20.8552
12	100.0752	182.5495	251.9955	8.0030	172.7171	166.7121	175.7966	100.0467	200.0000	38.7754
13	100.0022	120.4559	110.1985	12.0364	80.6498	150.0289	176.5759	100.0413	200.2619	17.5664
14	100.0002	120.3974	150.9720	24.5498	82.8460	150.0019	82.8728	100.0004	200.3569	35.3499
15	100.0008	120.4163	137.5633	21.2887	175.5058	160.0827	175.5111	100.0010	200.3982	39.9262
16	101.4075	307.0646	249.9996	24.9200	175.5223	342.2286	169.6239	100.7939	205.7584	19.8109
17	108.7141	308.5629	386.2323	24.9878	170.3976	246.2583	173.5649	100.2903	200.0000	39.9939
18	100.0207	183.1580	320.3185	12.2250	176.1875	155.0934	176.2270	130.1912	200.0448	33.9815
19	100.0054	244.7331	249.9994	24.9671	176.5464	166.0365	176.4829	100.0276	200.6785	16.0514
20	100.0000	183.1689	170.9149	23.7713	174.9614	190.8759	168.4022	100.0141	230.4055	18.3130
21	100.0003	120.0003	100.1160	24.9015	176.6244	150.9495	176.6234	100.0025	200.0613	15.5214
22	100.0000	120.0082	100.0068	19.1080	168.3374	150.0045	176.6190	100.0028	200.0003	15.3447
23	100.0000	120.0377	100.0003	24.7610	176.3491	150.1893	74.5563	100.0037	200.6072	32.2142
24	100.0009	120.0838	120.0493	23.1896	175.7491	150.2228	82.2767	100.0029	200.0077	15.0114

	P11	P12	P13	P14	P15	P16	P17	P18	P19	COST ($/h)
1	132.3604	73.1954	176.5942	74.1227	20.0078	78.0941	78.1721	75.1541	400.0176	10609.8946
2	87.2892	65.6923	67.4513	87.6610	20.0000	73.2831	26.8840	87.2291	400.0640	10418.9046
3	139.2190	56.6975	62.5055	90.0000	49.2406	79.9796	78.9417	227.2816	400.0000	11687.5017
4	149.6111	74.8889	176.1803	89.5715	74.4076	77.6175	79.9984	228.9912	400.1341	14987.5124
5	149.8977	74.8782	176.6218	89.8920	212.6962	78.1103	80.0000	229.3269	400.0394	17174.8152
6	149.9886	74.9744	176.3482	89.9768	212.7035	78.2667	79.9569	229.63	400.7634	19939.2191
7	149.7958	67.6665	176.6001	89.9991	216.9499	78.9131	79.9998	224.9247	467.1469	22687.3545
8	149.9985	74.9136	176.5884	89.9880	216.8708	79.9707	79.8060	229.8747	400.0000	25033.9678

	P11	P12	P13	P14	P15	P16	P17	P18	P19	COST ($/h)
9	149.6243	71.8199	169.7801	90.0000	158.2310	77.6133	79.9546	229.9224	400.4152	13756.5375
10	140.3102	74.7562	175.9684	86.4321	28.4338	74.5815	79.9455	228.3214	400.1859	11697.5801
11	150.0000	25.0000	175.9665	89.4232	49.3258	80.0000	80.0000	229.9464	400.2582	10962.9719
12	67.1626	72.5701	173.8985	90.0000	20.0000	24.9347	79.4158	170.8804	400.4669	11748.6299
13	83.2022	65.3406	176.1549	12.5828	53.5100	79.5802	77.6139	229.1548	400.0435	10864.6588
14	149.9959	71.1066	176.5922	89.9758	20.0033	79.9925	79.8423	229.9849	400.1594	11380.2207
15	149.7868	74.9990	172.3164	88.3079	166.6085	79.9998	80.0000	229.6210	401.6666	12276.2114
16	124.7012	69.4550	176.0328	54.4291	193.7624	72.8755	79.6993	216.6866	406.2283	14492.9218
17	149.9914	75.0000	174.9108	88.9011	166.6066	73.9374	79.8305	229.8168	400.0033	15564.6556
18	149.8850	72.0212	175.9815	89.3313	200.1121	79.9347	79.9764	211.4989	400.8112	13903.0686
19	149.9887	72.7335	176.6089	89.9573	57.7103	80.0000	79.9946	229.3496	400.1288	11544.5647
20	50.1422	73.8478	173.9423	75.2285	103.7723	31.5194	78.7547	154.9686	400.0000	12138.0264
21	70.3626	74.9741	175.5616	61.8712	20.0027	72.0377	79.8549	85.5340	400.0006	10275.9358
22	79.1162	48.0748	176.4270	8.6713	20.0001	79.9986	50.8617	165.4000	400.0186	10327.0054
23	131.1185	42.8497	176.5582	71.4559	20.0012	79.8770	31.4897	72.9299	401.0009	10422.7257
24	101.3351	38.7833	176.5711	87.1548	24.1851	75.8279	79.2886	148.1634	400.0965	10529.4970
								Total Cost		**$ 324424.3813**

Table 5. Fuel Switching for Three Different Load Patterns to 19-unit Indian Utility System

HOUR	UNIT (MW)					
	P3	P5	P6	P7	P13	P19
1	1,1,2	6,5,6	2,2,1	6,6,6	6,6.6	1,1,1
2	1,1,2	5,6,6	2,2,2	6,6,6	6,5,6	1,1,1
3	1,1,2	6,6,6	2,2,2	6,6,6	6,3,6	1,1,1
4	1,2,2	6,6,5	2,2,2	6,6,6	6,6,6	1,1,1
5	2,2,2	5,6,6	2,2,2	6,6,6	6,6,6	1,1,1
6	2,2,2	6,6,6	2,1,6	6,6,6	6,6,6	1,1,1
7	2,2,2	6,6,6	2,6,1	6,1,6	6,6,6	1,1,1
8	2,2,2	6,6,6	6,1,2	1,6,6	6,6,6	1,1,1
9	2,2,2	6,6,6	2,2,2	6,6,6	6,6,6	1,1,1
10	2,1,2	6,6,6	6,2,2	1,6,5	6,6,6	1,1,1
11	2,1,2	6,6,6	1,2,2	6,5,6	6,6,6	2,1,1
12	2,2,2	6,6,6	1,2,2	6,6,6	6,6,6	1,1,1
13	2,1,1	6,5,6	6,2,2	1,6,6	6,6,6	1,1,1
14	2,1,1	6,5,6	6,2,2	1,5,6	6,6,6	1,1,1
15	2,1,1	6,6,6	2,2,2	6,6,6	6,6,5	1,1,1
16	2,1,1	6,6,6	2,1,2	6,6,5	6,6,5	1,1,1
17	2,2,1	6,6,6	6,2,2	1,6,6	6,6,6	1,1,1
18	2,2,1	6,6,6	6,2,2	1,6,6	6,6,6	1,1,1
19	2,1,2	6,6,6	6,2,2	1,6,6	6,6,6	1,1,1
20	1,1,2	6,2,6	2,6,2	6,6,6	6,6,6	1,1,1
21	2,1,2	6,6,6	2,2,2	6,6,6	6,6,6	1,1,1
22	1,1,2	6,6,6	2,2,6	6,6,1	6,6,6	1,1,1
23	2,1,2	6,6,6	2,2,2	5,5,6	6,6,6	1,1,1
24	1,1,2	6,6,6	2,2,6	5,5,1	6,6,6	1,1,1

The best cost obtained by the FPA method for pattern 1, 2, and 3 is $379594.8892, 324424.3813, and $358242.0471, respectively. Te worst cost for pattern 1 is $386008.3299, pattern 2 is $330761.8204, and pattern 3 is $367925.4131. The average cost for pattern1 is 383482.8741, pattern 2 is $326958.9964, and pattern 3 is $364261.6592. These results are compared with DE-NM method presented in recent literature in terms of minimum cost, mean cost, and maximum cost over 30 runs those are presented in Table 6. By investigating the results presented in Table 6, it can be observed that the obtained results outperform the DE-NM method for 19-unit test system.

Table 6. Comparison Results of Different Load Patterns for 19-unit Indian Utility Test System

Load demand	Method	Minimum Cost ($)	Average Cost ($)	Maximum Cost ($)
Pattern 1	DE-NM [24]	404122.623	405515.7524	405665.6592
	Proposed **FPA**	**379594.8892**	383482.8741	386008.3299
Pattern 2	DE-NM [24]	324962.343	334321.1071	341440.818
	Proposed **FPA**	**324424.3813**	326958.9964	330761.8204
Pattern 3	DE-NM [24]	372140.528	33109.9977	374405.694
	Proposed **FPA**	**358242.0471**	364261.6592	367925.4131

5. CONCLUSION

In this paper, the Flower Pollination Algorithm (FPA) is used to solve the DELD problem, including ramp rate effects, prohibited operating zones and multiple fuel options within a single frame. With ten and19-unit Indian utility test systems for different load patterns for 24-hour time interval, the feasibility of the proposed method was demonstrated. The test results show that the optimal dispatch solution obtained by the proposed FPA method is superior to other methods presented in the literature to determine the optimal solution to solve the DELD problem. The proposed approach outperforms the method used by DE - NM to solve DELD problems with better performance in terms of solution quality.

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