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Effect of Valve Loading on the Thermal Power Economic Load Dispatch Using New Elephant Herding Optimization

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Abstract*—Economic load dispatch has used to evaluate minimum cost of power generated at the thermal plants. Economic load dispatch characteristic can be formulated in quadratic cost function, considered as linear function. The quadratic ELD cost function will be nonlinear in nature when involve the effect of valve loading. For optimization of linear as well as nonlinear cost function this work proposed a latest meta-heuristic swarm based technique known as Elephant herding optimization (EHO) and modified EHO (MEHO). The EHO technique stimulated by the behavior of herding of elephant organization. EHO has the fast convergence rate due to the use of clan updating as well as separator operators. In general elephants live together under the leadership of a matriarch. According to behavior of elephants consider two type of operators namely clan updating operators and separating operators for optimization of the linear and nonlinear problems. In the present work results of MEHO is compare with EHO, ACO and PSO. The outcomes show that MEHO can find the higher values on maximum benchmark issues than the ones three meta heuristic algorithms.

Keywords*—Economic load dispatch (ELD), Modified Elephant herding optimization (MEHO), ELD with valve loading effects, PSO, Constraints, Optimization.

I. INTRODUCTION

The goal of the economic load dispatch problem is to share the output power of the running generation sources so as to provide the load demand satisfying the generator restriction at the lowest cost. For obtaining the optimum solution of ELD plenty of methods implemented. Some of them incorporate the investment factor strategies, the inclination techniques, the straight strategies, and Newtonian strategies and so forth [1]. Electrical power systems are very large interconnected arrangement. It plays very significant role in the economy of any country. For the effective, economical and reliable operation of large interconnected power system, it requires a proper analysis of operation. Optimization of such large system can be easy obtained by using economic load dispatch. Study of economic load dispatch helps us to operate power systems economical and efficient manner, therefore improves supply of energy without any disturbances [2].

The characteristic of classical economic load dispatch (quadratic cost function) problem is linear in nature. Whereas if considered the valve loading effects the characteristic of cost function should be non-smooth [3]. Many classical and modern optimization techniques used to solve such nonlinear problem.

The feature of classical load dispatch problem is linear in nature. Whereas if considered the valve loading outcomes the feature of characteristic of ELD will be nonlinear [3]. Many classical and new optimization strategies used to evaluate solution of such nonlinear objective.

The parametric quadratic programming method was proposed by the authors of [4], for the solution of classical economic load dispatch problem. This method has the ability to increase the convergence rate, but it takes large memory space. Like article [5] proposed a QP method for solution of non-smooth cost function. Similarly the harmony search method proposed by the authors of [6] for the solution of 14 bus data system.

Since the classical optimization techniques has many drawbacks and unable to give the global solution of the problem. Many new approaches are presented in literature used for the solution of ELD. ELD with effect of valve loading effect is evaluated by using particle swarm optimization (PSO) is proposed by article [8].

The Simulated Annealing [13], Artificial Neural Network [14], also proposed to gets outcomes of ELD problem. Whereas article [16], suggested the ACO (Ant colony optimization) for handling the linear and nonlinear optimization problems.

This article proposed the EHO and modified EHO for the solution of linear and nonlinear ELD problems including the effect of valve loading in the generator. The effectiveness of the proposed algorithm is check for the data of 13& 15 generating units. The results of EHO and MEHO are compared by PSO and ACO.

II. MATHEMATICAL FORMULATION OF ELD

Linear Fuel Cost Function

Linear ELD fuel cost function is formulated as given in Eqn. (1) and eqn. (2).

$$F_T = \text{Min } f(FC) \tag{1}$$

$$f(FC) = \sum_{i=1}^{M} a_i P_i^2 + b_i P_i + c_i \tag{2}$$

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Where F_T is cost of plant, f(FC) function of cost function, a_i, b_i, & c_i are the generating units cost coefficients, P_i is the power of i^{th} generating units, M is the total generators.

Function of Fuel cost including valve point loading effects.

In the thermal power plants generators are provided valve system to control the speed of rotation. Due to presence of these valve ripples are arises at the time of operation. So that the characteristic of obtain fuel cost by ELD method is considered as nonlinear [3,9]. The operation of valves opening and closing to maintain the smooth speed of generator is shown in fig.1. The ELD function with valve effect is given as follows,

$$F_T(P_i) = f(FC) + \left|(e_i \sin(f_i(P_i^{min} - P_i)\right| \quad (3)$$

Where$F_T(P_i)$ shows the cost function including valve loading effect, e_i and f_i are the valve coefficients.

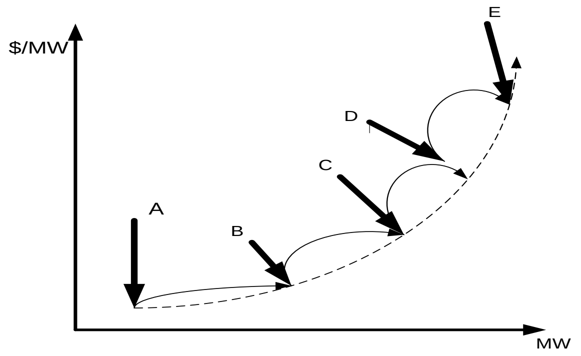

Figure.1.Characteristic of fuel cost curve including valve effect

Various Constraints

Power Generation Limits

The generated power at plant should be lies in the limits of maximum and minimum,

$$P_i^{min} \le P_i \le P_i^{max} \quad (4)$$

Where P_i is power generated between the limits of maximum and minimum. P_i^{max} and P_i^{min} is the maximum to minimum limit of i^{th} generator respectively.

Condition of ELD will be fulfill if the condition given in eqn. (5) is satisfy,

$$\sum_{i=1}^{n} P_i = P_D + P_L \quad (5)$$

Where

$$P_L = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j \quad (6)$$

Where P_D &P_L is the total system demand & line loss respectively, B_{ij} is the line loss elements.

III. ELEPHANT HERDING OPTIMIZATION

In the natural environment an elephant herd is comprised of some clans of elephant individuals under the headship of a matriarch. In this group, the female elephants intend to stay with the family group. But the male elephants will stay alone and they left their group as they are mature enough. The elephant herding behavior can be considered as two special operators that are used to create a best global optimization technique [15].

To implement the elephant herding behavior for global optimization problems. This algorithm considers the following assumptions:

1. The complete populace of elephants carries some constant wide variety of subgroups referred to as clans and every clan incorporates constant number of elephants.
2. A constant wide variety of elephants departs their extended family and lives alone.
3. Each extended family moves below the management of a matriarch. In widespread a matriarch within the every group is the oldest one and it's miles considered because the best elephant person inside the group for optimization.

Operator for updating the clan

The best solution of the problem is depending on the position of matriarch in the clan. Let us assume that we have C clans of elephants and each clan have R elephants. The position of elephant, i=1,2….R, in jth clan, j=1,2…..C is represented as Xij. The current position of all elephants is updated as given below,

$$X_{i,jNew} = H_{i,j\,initial} + \alpha(X_{best,j} - X_{i,j,initial})^{*}\ \text{rand} \quad (7)$$

Where $X_{i,jNew}$ is new position after update the initial position $X_{i,j,initial}$). α is a coefficients and its values increases from 0 to 1. $X_{best,j}$ Shows the best position of j^{th} clan. $X_{i,j,initial}$ Position of all elephant at starting. Rand shows the random value between 0 & 1.

The position of the matriarch movement updated as follows

$$X_{best,j} = \beta^{*} X_{center,j} \quad (8)$$

Where β is number between 0 to 1 and

$$X_{center,j} = \frac{1}{R}\sum_{j=1}^{R} X_{i,j} \quad (9)$$

Where R is total elephants in clan.

Separating operator of clan

In general in the group of clan the male elephants left the group as they grow up enough. The leaving of group is considered as separation and hence considers an operator called separating operator.

The worst position of the clans is updated as follows, So as to additionally enhance the pursuit capacity of EHO technique, let us expect that the elephant people with the most noticeably bad wellness will actualize the isolating administrator. The most exceedingly terrible position of every group indicates the male elephant leaving the tribe.

$$X_{worst,j} = 1 + X_{i,min} + [\text{rand} * (X_{i,max} - X_{i,min}) \quad (10)$$

Where $X_{worst,j}$ the worst positions of elephant. Xi,max and Xi,min are upper and lower bound of the position of elephant individuals.

Modified EHO

In MEHO, the equation to update the fittest elephant is modified as shown

$$X_{best,j} = \beta^{*} X_{center,j} + X_{best,fittest,j} \quad (11)$$

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According to eqn.(11) it's far proposed in MEHO to add the influence of center of clan of extended family to the previous role of the fittest elephant to discover new role rather than immediately replacing the position of the fittest elephant with the have an effect on of center of the extended family.

Algorithm used for the MEHO

1. Initialization
2. Generates the herd of elephants with in the number of clans an number of populations.
3. Set the limits of violations.
4. Setting the iteration counter = 1,
5. Take a set of elephants according to their fitness from all the clans.
6. Updates the position of elephants.
7. Separates the worse elephants using the separator operators.
8. Insert the linear cost function.
9. Insert the cost function included valve loading effects.
10. Set the objective function for minimization.
11. Check the violation limits
12. Find out the optimum values.
13. Iterations=initial ireration+1
14. Apply stopping criteria.

Assumptions Made

Following are the assumptions made in MEHO.

- ➢ The population is divided into clans.
- ➢ Each clan has fixed number of elephants.
- ➢ Let a finite number of male elephants exit the groups.
- ➢ Each group has a leader called matriarch.

IV. TEST CASES AND RESULTS

In this work considered four different cases. In the first study consider the case of three generating unit system [12]. In second case study considered the data of 6 generating unit systems [7]. In case of third and fourth data of 13 and 15 generating units are considered respectively [10].

In this part modified EHO results are comparing with EHO, PSO and ACO for different test data of ELD problem. For obtain the genuine results of the test data, all the implementations are conducted under the same conditions. All optimization methods consider in this work takes equal number of population size and maximum iteration. The parameters in EHO are considered shown in table 1:

Table 1: value of operator of MEHO

S.No.	Operator	Value taken
1	α	0.5
2	β	0.4
3	No. of Clan	50

In general, all the Meta heuristic methods are depended on certain stochastic distribution. Therefore, different runs will generate different results. To get the most representative statistical results each method is trail for 100 times (shown in table 3, 5, 7& 9).

Test Case 1

The proposed algorithms are tested for the data of three generator systems shown in table 2. Proposed algorithm of EHO, MEHO along with PSO and ACO applied for both smooth as well as non-smooth cost functions and its results listed in the table 2.

Table2 Cost and valve loading co-efficient for 3 generating units system, Load demand=850MW

Units	a_i	b_i	c_i	e_i	f_i	P_i^{min}	P_i^{max}
1	0.008	7	200	300	0.0315	50	200
2	0.009	6.3	180	150	0.0630	100	400
3	0.007	6.8	140	200	0.0420	100	600

Table 3 Results for the data of 3 generating unit

Generating units	MEHO	EHO	PSO	ACO
P1	189.25	187.42	185.44	183.62
P2	313.87	321.60	316.51	319.6
P3	347.12	341.45	348.05	346.8
Total Power (MW)	850	850	850	850
Total Cost($/h) without Valve Effect (Smooth Function)	8199.147	8207.846	8203.516	**8207.98**
Total Cost($/h) with Valve Effect (Non-Smooth Function)	9148.823	9151.574	9165.712	**9166.779**
Computation time (sec)	1.203	1.171	1.502	1.420

Test case 2

Proposed algorithm of EHO, MEHO along with PSO and ACO applied for both smooth as well as non-smooth cost functions and its results listed in the table 5 for the test data of six generating units.

Table 4: For the load demand of 1263MW, data of six generating units

Units	a_i	b_i	c_i	e_i	f_i	P_i^{min}	P_i^{max}
1	0.007	7	240	300	0.031	100	500
2	0.0095	10	200	150	0.063	50	200
3	0.009	8.5	220	200	0.042	80	300
4	0.009	11	200	100	0.08	50	150
5	0.008	10.5	220	150	0.063	50	200
6	0.0075	12	190	100	0.084	50	120

Table 5 Results of 6 Generating Units for the load demand of 1236 MW after 50 trials

Generating units	ACO	PSO	EHO	MEHO
P1(MW)	429.354	421.82	425.21	427.25
P2(MW)	133.466	136.62	137.04	141.45
P3(MW)	299.86	298.92	296.48	295.37
P4(MW)	144.34	146.409	148.51	142.66
P5(MW)	162.77	167.43	168.36	154.26
P6(MW)	93.304	91.81	87.48	102.01
Total Power Generation without Valve Effect ($/h)	15309.06	15307.42	15305.89	**15303.65**

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Total Power Generation with Valve Effect ($/h)	15939.96	15890.45	15900.88	**15877.058**
Computational Time(Sec)	1.54	1.59	1.68	1.63

Results for case of thirteen generating units

Proposed algorithm of EHO, MEHO along with PSO and ACO applied for both smooth as well as non-smooth cost functions and its results listed in the table 7.

Table 6 Data of thirteen generating units (load demand of 2630MW)

Gen. Units	P_i^{max} (MW)	P_i^{min} (MW)	e_i	f_i	a_i ($/MW)	b_i ($/MW)	c_i ($)
	Generated power limits		Valve loading coefficients		Fuel cost coefficients		
1	680	0	300	0.035	0.00028	8.10	550
2	360	0	200	0.042	0.00056	8.10	309
3	360	0	150	0.042	0.00056	8.10	307
4	180	60	150	0.063	0.00324	7.74	240
5	180	60	150	0.063	0.00324	7.74	240
6	180	60	150	0.063	0.00324	7.74	240
7	180	60	150	0.063	0.00324	7.74	240
8	180	60	150	0.063	0.00324	7.74	240
9	180	60	150	0.063	0.00324	7.74	240
10	120	40	100	0.084	0.00284	8.60	126
11	120	40	100	0.084	0.00284	8.60	126
12	120	55	100	0.084	0.00284	8.60	126
13	120	55	100	0.084	0.00284	8.60	126

Table 7. Results of data of thirteen generating unit (demand of 1800MW)

Generating units	PSO	ACO	MEHO	EHO
P1(MW)	530.81	445.06	460.21	472.45
P2(MW)	228.24	142.12	230.45	182.72
P3(MW)	112.17	223.07	155.4	167.35
P4(MW)	94.94	94.56	111.61	84.62
P5(MW)	121.94	92.75	90.43	97.35
P6(MW)	115.11	154.03	135.46	108.07
P7(MW)	63.77	160.67	147.15	156.81
P8(MW)	144.93	87.18	110.53	117.94
P9(MW)	85.78	151.52	136.77	149.64
P10(MW)	59.19	81.89	56.23	63.52
P11(MW)	92.46	59.92	43.15	73.79
P12(MW)	71.13	56.08	59.53	58.87
P13(MW)	79.45	51.13	63.16	66.88
Power Output (MW)	1800	1800	1800	1800
Total Cost without Valve Effect ($/h)	18022.64	18004.76	**17973.06**	17999.797
Total Cost with Valve Effect ($/h)	19245.58	18830.95	**18969.99**	19219.913
Computation time (sec)	1.803	1.712	1.704	1.97

Results of case 4

In this test case considered the data of 15 generating unit systems, shown in table 8. Proposed algorithm of EHO, MEHO along with PSO and ACO applied for both smooth as well as non-smooth cost functions and its results listed in the table 9.

Table 8 Data of fifteen generating units for the load demand of 2630MW

Units	c_i($)	b_i($/Mw)	a_i(Mw^2)	e_i	f_i	P_i^{min}	P_i^{max}
1	671.03	10.07	0.000299	100	0.084	150	455
2	574.54	10.22	0.000183	100	0.084	150	455
3	374.59	8.80	0.001126	100	0.084	20	130
4	374.59	8.80	0.001126	150	0.063	20	130
5	461.37	10.40	0.000205	120	0.074	150	470
6	630.14	10.10	0.000301	100	0.084	135	460
7	548.20	9.87	0.000364	200	0.042	135	465
8	227.09	11.50	0.000338	200	0.042	60	300
9	173.72	11.21	0.000807	200	0.042	25	162
10	175.95	10.72	0.001203	200	0.042	20	160
11	186.86	11.21	0.003586	200	0.042	20	80
12	230.27	9.90	0.005513	200	0.042	20	80
13	225.28	13.12	0.000371	300	0.035	25	85
14	309.03	12.12	0.001929	300	0.035	15	55
15	323.79	12.41	0.004447	300	0.035	15	55

As seen above the proposed methods are tested for different type of data for different generating units and it is found that the results given by MEHO is better than other methods included in this work.

V. CONCLUSIONS

This paper demonstrates four test cases of ELD problem are considered. The proposed MEHO, basic EHO, PSO and ACO are applied for four different cases of linear and nonlinear test cases. The quantitative results obtained by proposed techniques show that the total operating cost obtained by MEHO for the assumed cases is less than that of EHO, PSO and ACO algorithms. Hence, the method proposed in this work has potential to solve the linear as well as nonlinear optimization problems.

Table 9 Results for 15 generating for the demand load of 2630MW

Generating units	PSO	EHO	MEHO	ACO
P1(MW)	451.7	405.345	422.45	435.46
P2(MW)	410.06	415.341	435.82	431.62
P3(MW)	52.08	102.484	82.61	87.04
P4(MW)	125.02	127.421	122.43	129.31
P5(MW)	287.437	354.79	386.15	368.53
P6(MW)	452.63	459.98	437.25	427.29
P7(MW)	363.98	376.508	409.47	393.25
P8(MW)	76.816	64.35	55.26	52.14
P9(MW)	39.91	25.4005	31.14	28.16
P10(MW)	142.903	136.705	104.51	114.43
P11(MW)	72.71	40.7512	34.14	55.42

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P12(MW)	50.281	36.6468	42.36	32.47
P13(MW)	23.98	31.148	22.48	21.48
P14(MW)	47.12	22.4836	19.41	21.17
P15(MW)	33.4	30.656	24.57	32.31
Total power generation(MW)	2630	2630	2630	2630
Total cost without vale Effect($/hr)	32752.4	32584.16	**32538.71**	32566.976
Total cost with vale Effect($/hr)	34339.42	33888.57	**33747.42**	34019.445
Computation Time(Sec)	2.92	2.72	2.05	2.78

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