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Best Compromise Solution of Economic Emission Load Dispatch Using Ant Lion Optimization

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***Abstract*: This paper presents ant lion optimization method for solving multi-objective economic emission load dispatch (EELD) problem in diverse test power systems. NOX emission, power balance and generation limit constraints are considered here. Ant Lion Optimization (ALO) is a novel meta-heuristic motivated by hunting mechanism of ant lions in nature. The proposed technique is applied on different test systems having 3,6,10 and 40 generators have been considered for solving the EELD. Comparison of the obtained results is carried out with other techniques stated in literature which shows that ALO is effective to solveEELD.**

Keywords: Economic Emission Load Dispatch(EELD); ALO; best compromise solution(BCS)

I. INTRODUCTION

The main goal of economic emission load dispatch problem is to get optimum output of thermal generators in power system subjected to several constraints to minimize the operating cost. The thermal power plant operation is dependent upon combustion of fossil fuel which produces SOx, NOx and COx emissions. The increasing pollution is a matter of environmental concern worldwide which has led to formation of international standards for emissions from industries and power plants. Different acts have been made which forces the industries to modify their principles to follow the environment-emission standards strictly. Thus it becomes significant to do emission dispatch or consider emission constraints in economic emission load dispatch. The economic & emission scheduling are contradictory in character and both must be considered together to find optimal scheduling. The problem is put together as a multi objective economic emission load dispatch problem (EELD) problem in which both objectives (emission and economy) have to be minimized.

Earlier traditional methods like Newton's method, gradient approach and linear programming [1] were used for solving economic load scheduling problem. In the last years different techniques have been used for solving EELD. Nanda et al [2] applied goal programming techniques to solve economic emission load dispatch. Song et.al [3] solved environmental/economic dispatch with genetic algorithm controlled by fuzzy logic. Abido [4] used genetic algorithm for the economic emission load dispatch (EELD) to find out pareto-optimal solutions. Ah King [5, 6] applied improved non-dominated sorting genetic algorithm (NSGA-II) for creating pareto-optimal front for EELD. Then mozhi [7] solved EELD using hybrid genetic algorithm. Perez [8] solved environmental/economic dispatch using differential evolution. Hong [9] applied immune genetic algorithm for EELD. Hazra [10] proposed bacteria foraging algorithm for emission constrained economic dispatch. Hemamalini [11] solved non convex EELD by applying particle swarm optimization. Sudhakaran applied refined genetic algorithm[12] and hybrid genetic algorithm[13] for solving EELD problem. Bhattacharya.et.al [14] presented a BBO technique to solve EELD of thermal generators with different emission substances (SOx, NOx, &COx).Niknam [15]proposed teaching learning based algorithm for dynamic EED. Abedinia [16] applied firefly algorithm (FFA) for EELD.

Differential evolution hybridized with biogeography-based optimization [17]is applied to solve EELD problem. Rajasomashekaret al.[18]proposed a new method applying BBO algorithm for getting best compromised solution for EELD problem[18].Opposition based Harmony Search Algorithm [21] is used to solve EELD problems. Güvenç et al.[22]solved EELD using gravitational search algorithm (GSA). Shaw et al. [23]solved EELD by including the opposition based learning scheme of [21] within gravitational search algorithm. Basu [24] applied multi objective differential evolution for solving EELD. Bhattacharjee.et.al.[25] solved EELD using Real Coded Chemical Reaction algorithm.

Harinder.et.al [26] applied particle swarm optimization (PSO) algorithm for solving multi objective load dispatch. Hota et al. [27] proposed fuzzy based bacterial foraging algorithm (MBFA) for solving EELD problem. Similarly there are many other techniques like artificial neural networks [28], constraint handling PSO [29], artificial bee colony(ABC) algorithm[30],firefly optimization[31], NSGA [32] and SPEA [33]which have been successfully used to solve EELD problem.

Recently, a new optimization technique based on the concept of hunting mechanism of ant lions called antlion optimization (ALO)has been proposed by Seyedali Mirjalili[34].The proposed algorithm has been applied successfully to solve benchmark test functions , classical engineering problems(truss design, gear train design and cantilever beam design) and for optimizing shape of ship propellers. In this paper ALO is applied to find out best compromise solution for EELD problem using the normalized objective function proposed by Rajasomashekar[18].

II. PROBLEM FORMULATION

A. Economic load dispatch (ELD)

Objective for economic dispatch is to reduce the operating (fuel) cost of thermal generators satisfying some limits. The objective function is given by:

$$C = \sum_{i=1}^{NG}(a_i P_{gi}^2 + b_i P_{gi} + c_i) \quad (1)$$

Where a_i, b_i, & c_i are the fuel-cost coefficient sand P_{gi} is power output for the i^{th} generating unit among NG total committed generating units.

The overall fuel cost has to be reduced with the following constraints:

1) *Power balance constraint:* The overall generation by the entire generators should be equal to the sum of whole power demand (P_D)& system's real power loss (P_L).

$$\sum_{i=1}^{NG} P_{gi} - P_D - P_L \quad (2)$$

The power loss is calculated by using B coefficients and unit power output:

$$P_L = \sum_{i=1}^{NG}\sum_{j=1}^{NG} P_i B_{ij} P_j + \sum_{i=1}^{NG} B_{0i} P_i + B_{00} \quad (3)$$

2) *Generator limit constraint*

Each generator's real power generation is to be controlled within its respective lower operating limits P_{gi}^{min} and upper operating limits P_{gi}^{max}.

$$P_{gi}^{min} \le P_{gi} \le P_{gi}^{max} \quad , i=1, 2\ldots NG \qquad (4)$$

B. Economic Emission dispatch(EED)

The objective is to reduce the entire pollution discharge from combustion of coal or gas for producing electricity. The problem of optimum emission dispatch for NOx emission can be defined by as:

$$E_N = \sum_{i=1}^{NG}(d_{iN} P_{gi}^2 + e_{iN} P_{gi} + f_{iN}) \quad (5)$$

Where E_N are the total amount of NOx emission from the power plant in kg/hr. d_{iN},e_{iN}, f_{iN} are the NOx emission coefficients of i^{th} generating unit. The power balance & generator limit restrictions are given by Eq. (2 & 4) respectively.

C. Multiobjective Economic emission load dispatch (EELD) problem

The emission and economic dispatch are contradictory in character and they both have to be considered together to find optimal dispatch. The problem is expressed as a multi objective economic emission load dispatch (EELD) problem in which both the objectives (emission and economy) have to be minimized. The objective function is given by:

$$FC\ (C, E_N) \qquad (6)$$

Where 'C'denotes fuel cost objective and 'E_N' denote emission objective.

The multi-objective optimization could be solved using Fuzzy set theory along with any conventional optimization techniques [19], weighted sum method and many other techniques. Again, the multi-objective problem mentioned above could be solved after converting EELD problem to a solo objective optimization problem using cost penalty factors (CPF) [20].The whole objective function may be put together by using PPF and given as:

$$\text{Minimize } FC = \sum_{i=1}^{NG}\{wC_i(P_{gi}) + (1-w)jE_i(P_{gi})\} \qquad (7)$$

Here 'j' is the cost penalty factor that combines the emission costs with the usual fuel costs and 'w' is the bargaining parameter varying between [0, 1]. The above equation is reduced subject to power balance and generating limits constraints as mentioned in

(2) and (4). When the value of w is 1 the objective function represents fuel cost of generation function and when w is equal to 0, the objective function represents emission function only. It is very difficult to make a solution that will give the best compromising solution (BCS) which lie nearer to both of the best solution. The fuel cost rises and emission price reduces when w is decreased in steps from 1 to 0. When w is equal to 0,objective function becomes purely EED that curtail only the emissions.

Pareto front based on the non-dominated solution could be founded by resolving the problem a number of times with dissimilar w values. However it might not give the best compromising result, which can be described as the one with equal percent difference from the best solutions resultant to ELD and EED.

Rajasomashekar et al. [18] proposed a method to find the best compromising solution. The drawbacks of the existing approaches is overcome, after expressing bi-objective function of Eq.(7) in a modified way after normalizing the fuel cost and emission components with a view to provide relatively equal significance to both the objectives. The modified overall objective function may be represented as:

$$Minimize\ FC = w\left[\frac{\sum_{i=1}^{NG} C_i(P_{gi}) - C_{min}}{C_{max} - C_{min}}\right] + (1-w)\left[\frac{\sum_{i=1}^{NG} E_i(P_{gi}) - E_{min}}{E_{max} - E_{min}}\right] \qquad (8)$$

The required values for C_{min}, C_{max}, E_{min} and E_{max}, canbe obtained through solving Eq.(7)for both economic dispatch and emission dispatch.

The customized normalized depiction of objective function for EELD problem offers best compromising solution (BCS) when w is set to 0.5 [18] and the overall solution process involves only three runs for solution of ELD, EED and EELD problems. But, fuzzy based strategies require several solution runs with different w values. The current methods provide a result in which fuel cost is extremely near to the best fuel cost while restraining the emission far-off from the best emission point and contrariwise. This indicates that the relative importance given to both objectives are unequal. But according to [18], the new problem formulation (8) based optimization process gives approximately the same significance to the fuel cost and emission and get their values to lie in the similar range.

The amount by which best compromising solutions deviate from the global best fuel cost and emissions are calculated using the following indices:

1) Fuel Cost Performance Index(FCPI)

$$= \left[\frac{\sum_{i=1}^{NG} C_i(P_{gi}) - C_{min}}{C_{max} - C_{min}}\right] \times 100 \qquad (9)$$

2) Emission Cost Performance Index(ECPI)

$$= \left[\frac{\sum_{i=1}^{NG} E_i(P_{gi}) - E_{min}}{E_{max} - E_{min}}\right] \times 100 \qquad (10)$$

However, the relative significance between fuel cost and emissions can be varied by altering w in between 0 and 1 in the objective function of (8). It permits the operator of system to choose on diverse desires for the objectives according to operating conditions of system.

III. ANT LION OPTIMIZATION

Ant Lion Optimizer (ALO) [34] is a novel nature-inspired algorithm proposed in 2015 by Seyedali Mirjalili. The ALO algorithm imitates hunting behavior of ant lions in nature. Five major steps of prey hunting such as the arbitrary walk of ants, trap constructing, entrapping of ants in traps, prey grabbing, and trap rebuilding are implemented.

There are two main phases in ant lions lifecycle: larvae and adult. A normal entire lifespan (shown in Fig.1) could be of 3 years, which typically occurs in larvae (maturity period only for 3 to 5 weeks). Ant lions undergo metamorphosis in a cocoon to become adult. They generally hunt in larvae and the adulthood phase is for reproduction. An ant lion larva digs a cone-shaped pit in soil by moving along a round path and flinging out soil with its colossal jaw as shown in Fig. 2(a). After digging the trap, larvae hide at the bottom of the cone and wait for insect (ant) to be trapped in the pit. The verge of the cone is sufficiently sharp for insects to drop to the bottom of the trap easily as illustrated in Fig. 2(d). Once the ant lion realizes that a prey is in the trap, it tries to catch it [34].The steps for ALO algorithm are given Fig.3.

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Fig. 1. Lifecycle of Antlion

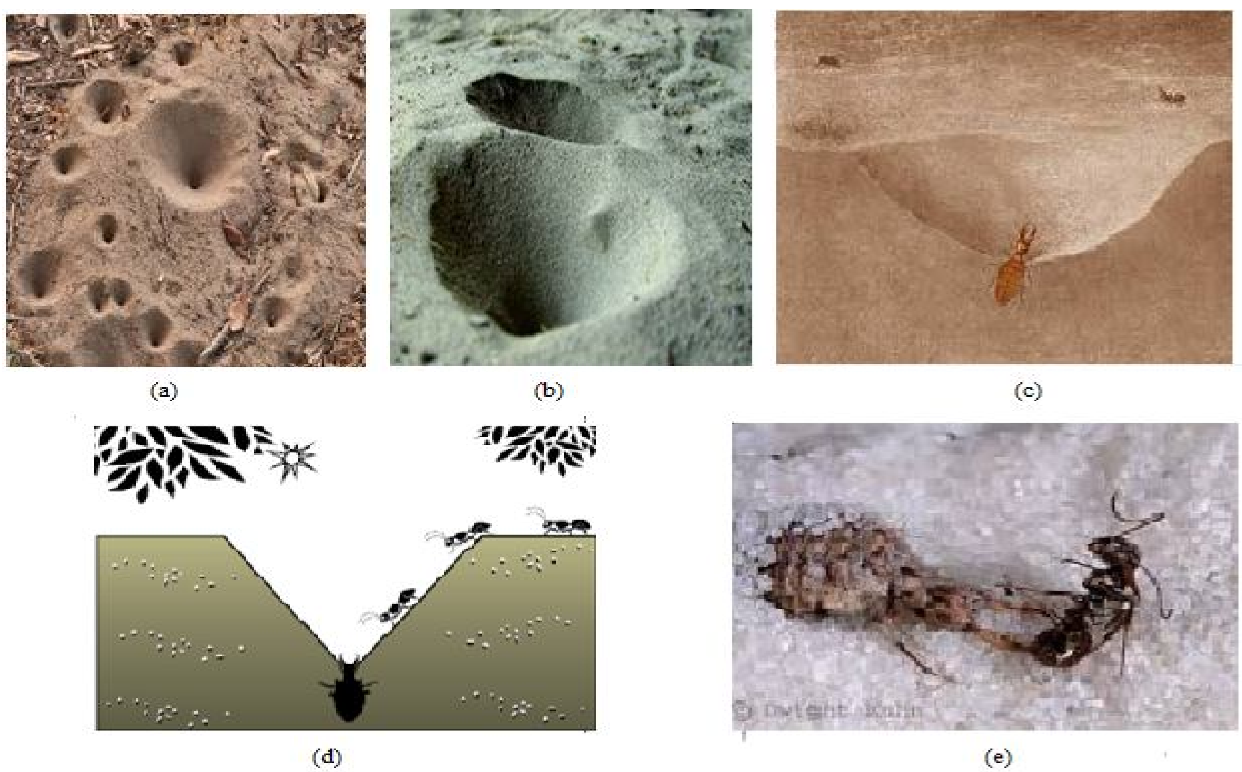

Fig. 2.a–c Trap building of antlions ; d–e prey catching and trap rebuilding [34]

A. Random Walks of Ants

Random walks are all based on the equation below:

$$X(t) = [0, cumsum(2r(t_1) - 1), cumsum(2r(t_2) - 1), \ldots\ldots, cumsum(2r(t_n) - 1)] \quad (11)$$

Where *cumsum* computes the cumulative sum, *n*denotes maximum iterations, *t* shows the arbitrary walk step and *r(t)* is an assumed function stated as :

$$r(t) = \begin{cases} 1 & if\ rand > 0.5 \\ 0 & if\ rand \leq 0.5 \end{cases} \quad (12)$$

To keep the arbitrary walks within the search space, they are normalized using the succeeding equation:

$$X_i^t = \frac{(X_i^t - a_i) \times (d_i - c_i^t)}{(d_i^t - a_i)} + c_i \quad (13)$$

Where $a_i$is the minimum of arbitrary walk of i^{th} variable, b_i is the maximum of arbitrary walk in i^{th} variable, c_i^t is the minima of i^{th} variable att^{th} iteration, and d_i^tindicates the upper limit of i^{th} variable at t^{th} iteration.

B. Trapping in Antlion's Pits

Antlions' traps influence the arbitrary walks of ants. To model this assumption mathematically, the equations proposed are:

$c_i^t = Antlion_j^t + c^t$(14)

$d_i^t = Antlion_j^t + d^t$ (15)

where c^t is minima of entire variables at t^{th} iteration, d^t denotes the vector having the maxima of entire variables at t^{th} iteration, c_j^t is the minima of entire variables for i^{th} ant, d_j^t is the maxima of entire variables for i^{th} ant, and $Antlion^t_j$ indicates the location of the chosen j^{th} antlion at t^{th} iteration

C. Constructing Trap

To model the hunting ability of antlion, a roulette wheel is used. ALO algorithm needs to use a roulette wheel operator for picking ant lions according to their fitness during optimization [34]. This method gives better probabilities to the fitter ant lions to catch ants.

D. Sliding ants towards ant lion

With the method proposed so far, ant lions are capable of constructing traps relative to their fitness and ants are required to move arbitrarily. However, ant lions shoot soil outward the mid of the pit once they understand that an ant is in trap. This conduct slides down the trapped ant that is attempting to escape [34]. To model this mathematically following equations are proposed in this regard:

$$c^t = \frac{c^t}{I} \& d^t = \frac{d^t}{I} \quad (16)$$

Where c^t is the minima of entire variables at t^{th} iteration, and d^t indicates the vector having the maxima of entire variables at t^{th} iteration and 'I' is a fraction given by:

$I = 10^w \frac{t}{T}$ (17)

Where t is the iteration in progress, T is the maximum number of iterations, and w is a constant defined based on the current iteration [23].

E. Catching prey and re-building the pit

Thelast phase of hunting is when an ant reaches the bottommost of pit and is trapped in the antlion's jaw. After this phase, the antlion jerks the ant inside the soil and eats its body. For imitating this procedure, it is supposed that prey catching occur when ants turn out to be fitter (go inside soil) than its analogous antlion [34]. Then it is essential for antlion to update its position to the newest position of frightened ant

to improve its gamble of catching novel prey. The following equation is offered in this regard:

$$Antlion_j^t = Ant_i^t \ \ if\ f(Ant_i^t) > f(Antlion_j^t) \quad (18)$$

Where t shows the current iteration, $Antlion_j^t$ shows the location of selected j^{th} antlion at t^{th} iteration, and Ant_i^t indicates the location of i^{th} ant at t^{th} iteration.

F. Elitism

It is supposed that each ant arbitrarily walks around a particular antlion by roulette wheel and the elite concurrently as follows:

$Ant_i^t = \frac{R_A^t + R_E^t}{2}$ (19)

Where R_A^t is the arbitrary walk in the region of the antlion nominated through roulette wheel at t^{th} iteration, R_E^t is the arbitrary walk in the region of the elite at t^{th} iteration, and Ant_i^t indicates the location of i^{th} ant at t^{th} iteration.

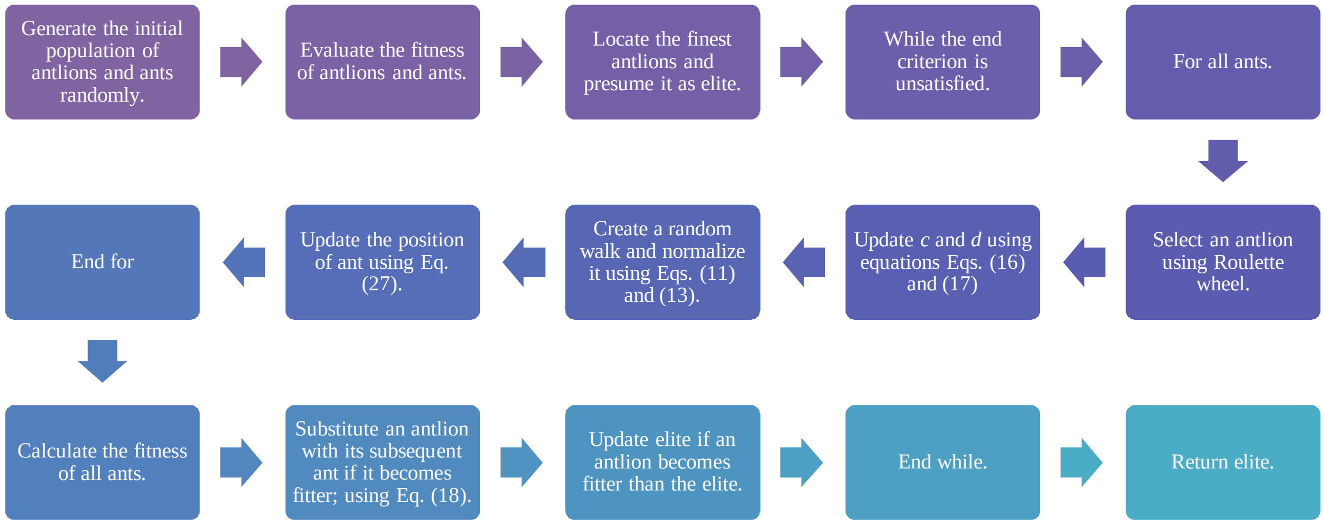

Fig.3. Steps of ALO algorithm [34]

IV. SIMULATION TESTS & RESULTS

In this paper multi-objective economic emission load dispatch has been solved for three different test systems. In all cases, the constraints of operating limit and power balance are considered. The program was written in MATLAB (R2009b).The population taken in each case was 30 and maximum numbers of iterations performed were 500.

A. Test system I

In this case system having 3 generating units considering NOx emissions is tested with power demand of 700 MW. The inputdata, such as cost & emission coefficients, loss data, generation restrictions, is taken from [30]. The best compromise results achieved from ALO are shown in table 1 and their comparison with conventional method [12], simple genetic algorithm (SGA) [12], refined genetic algorithm (RGA)[12] and FFA[31] is shown in table 2.FCPI and ECPI indices were calculated with respect to ELD and EED results for ALO and small difference of 2.86 between the two indices promises the validity of ALO for finding best compromising solution.

B. Test system II

In this case system having 6 generating units considering NOx emissions is tested with power demand of 1200MW. The input data, such as cost & emission coefficients, loss data, generation restrictions, is taken from [24]. The best compromise results achieved from ALO are shown in table 3 and their comparison with MODE [24], PDE [24], NSGA-II [24], SPEA-2 [24] and PSO [26] is shown in table 4. FCPI and ECPI indices were calculated with respect to ELD and EED results for ALO and small difference of 0.331 between the two indices promises the validity of ALO for finding best compromising solution.

TABLE I. OBTAINED BY ALO FOR TEST SYSTEM I (P_D=700 MW)

Units	Power output (MW)		
	ELD	EED	BCS for EELD
1	154.725	185.818	169.764
2	284.518	268.748	276.879
3	284.516	268.725	276.872
Power loss (MW)	23.760	23.292	23.516

Fuel Cost (Rs)	35424.174	35472.112	35435.510
Emission (kg)	660.408	651.416	653.800
FCPI	0	100	23.6456
ECPI	100	0	26.5079
Difference	100	100	2.86

TABLE II. COMPARISO OF BEST COMPROMISING SOLUTION FOR TEST SYSTEM I (P_D=700 MW)

Method	Cost ($/h)	Emission (lb)
CONVENTIONAL METHOD [12]	35485.05	652.55
SGA [12]	35478.44	652.04
RGA [12]	35471.4	651.60
FFA[31]	35464	651.5
ALO	35435.510	653.800

C. *Test system III*

In this case system having 10 generating units considering valve point effects and NOx emissions is tested with power demand of 2000 MW. The input data, such as cost & emission coefficients, loss data, generation restrictions, is taken from [22]. The best compromise results achieved from ALO are shown in table 5 and their comparison with MODE [24], PDE [24], NSGA-II [22],SPEA 2,[22],GSA [22],RCCRO[25] is shown in table 6. FCPI and ECPI indices were calculated with respect to ELD and EED results for ALO and small difference of 2.209 between the two indices promises the validity of ALO for finding best compromising solution. The pictorial comparison of difference between FCPI and ECPI indices obtained by various methods is shown in fig.4.

TABLE III. RESULTS OBTAINED BY ALO FOR TEST SYSTEM II (P_D=1200 MW)

Units	Power output (MW)		
	ELD	EED	BCS for EELD
1	80.695	124.931	104.461
2	87.566	150	118.094
3	225	205.652	210.234
4	210	201.789	203.9678
5	325	283.770	308.998
6	325	283.840	305.872
Power loss (MW)	53.26	49.98	51.629
Fuel Cost (Rs)	63964.041	66004.790	64783.992
Emission (kg)	1359.879	1241.000	1288.366
FCPI	0	100	40.1789
ECPI	100	0	39.8457
Difference	100	100	0.3331

TABLE IV. COMPARISO OF BEST COMPROMISING SOLUTION FOR TEST SYSTEM II (P_D=1200 MW)

Method	Cost ($/h)	Emission (lb)
MODE[24]	64843.00	1286.00
PDE[24]	64920.00	1281.00
NSGA-II[24]	64962.00	1281.00
SPEA-II[24]	64884.00	1285.00
PSO [26]	64887.88	1283.40
ALO	64783.99	1288.366

D. *Test system IV*

In this case system having 40 generating units considering valve point effects and NOx emissions is tested with power demand of 10500 MW. The input data, such as cost & emission coefficients is taken from [22]. The best compromise results achieved from ALO are shown in table 7 and their comparison with MBFA [27] is shown in table 8. FCPI and ECPI indices were calculated with respect to ELD and EED results for ALO and small difference of 4.30078 between the two indices promises the validity of ALO for finding best compromising solution. The pictorial comparison of difference between FCPI and ECPI indices obtained by ALO and MFBA [27] is shown in fig.5.

TABLE V. RESULTS OBTAINED BY ALO FOR TEST SYSTEM III (P_D=2000 MW)

Units	Power output (MW)		
	ELD	EED	BCS for EELD
1	54.980	54.966	54.986
2	79.956	79.042	79.942
3	105.265	80.630	82.355
4	100.306	82.613	84.021
5	82.915	160	135.191
6	83.624	240	156.177
7	299.982	297.052	298.707
8	340	299.305	316.477
9	470	391.990	437.905
10	470	395.928	438.608
Power loss (MW)	87.030	81.529	84.375
Fuel Cost ($/h)	111498.783	116432.038	113099.329
Emission (lb)	4562.541	3932.814	4151.034
FCPI	0	100	32.444
ECPI	100	0	34.653
Difference	100	100	2.209

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TABLE VI. COMPARISO OF BEST COMPROMISING SOLUTION FOR TEST SYSTEM III (P_D=2000 MW)

Units	MODE [24]	PDE [24]	NSGA-II [22]	SPEA 2 [22]	GSA [22]	RCCRO[25]	ALO
P1 (MW)	54.9487	54.9853	51.9515	52.9761	54.9992	55.0000	54.986
P2 (MW)	74.5821	79.3803	67.2584	72.8130	79.9586	80.0000	79.942
P3 (MW)	79.4294	83.9842	73.6879	78.1128	79.4341	85.6453	82.355
P4 (MW)	80.6875	86.5942	91.3554	83.6088	85.0000	84.1259	84.021
P5 (MW)	136.8551	144.4386	134.0522	137.2432	142.1063	136.5034	135.191
P6 (MW)	172.6393	165.7756	174.9504	172.9188	166.5670	155.5801	156.177
P7 (MW)	283.8233	283.2122	289.4350	287.2023	292.8749	300.0000	298.707
P8 (MW)	316.3407	312.7709	314.0556	326.4023	313.2387	316.6746	316.477
P9 (MW)	448.5923	440.1135	455.6978	448.8814	441.1775	434.1252	437.905
P10 (MW)	436.4287	432.6783	431.8054	423.9025	428.6306	436.5724	438.608
Cost ($/h)	11.348 * 10^5	1.1351 * 10^5	1.1354 * 10^5	1.1352 * 10^5	1.1349 * 10^5	113355.7454	113099.329
Emission (lb)	4124.9	4111.4	4130.2	4109.1	4111.4	4121.0684	4151.034
FCPI	40.33	40.94	41.56	41.15	40.54	37.81	32.444
ECPI	30.12	28.01	30.94	27.65	28.01	29.52	34.653
Difference	10.21	12.93	10.62	13.50	12.53	08.29	2.209

TABLE VII. RESULTS OBTAINED BY ALO FOR TEST SYSTEM IV (PD = 10500 MW).

Units	ELD		EED		BCS for EELD	
	MBFA [27]	ALO	MBFA [27]	ALO	MBFA [27]	ALO
1	114.0000	112.3215159	114.0000	113.7901571	–	113.6650901
2	110.8035	113.4247916	114.0000	113.8942034	–	111.3219521
3	97.4002	100.5697446	120.0000	119.7159511	–	99.41236768
4	179.7333	131.5182381	169.3671	175.7333282	–	180.7215271
5	87.8072	89.35228422	97.0000	96.93064366	–	87.36721866
6	140.0000	114.7613699	124.2630	122.6306849	–	106.94894
7	259.6004	297.2870638	299.6931	294.2575497	–	275.1213922
8	284.6002	299.9440429	297.9093	293.6042562	–	293.1532851
9	284.6006	287.0497722	297.2578	287.639498	–	288.9386537
10	130.0000	139.0494733	130.0007	153.7915638	–	132.4513295
11	168.7999	98.24985186	298.4210	296.0180853	–	244.6069906
12	168.7998	168.8810585	298.0264	299.6681256	–	243.9528083
13	214.7598	304.629644	433.5590	433.5063754	–	394.355992
14	304.5195	394.3024487	421.7360	421.5400279	–	394.7416178
15	394.2794	304.534581	422.7884	423.6487236	–	394.1624837
16	394.2794	305.2867349	422.7841	423.3030886	–	394.3357374
17	489.2794	490.3691148	439.4078	438.3566651	–	487.9795599
18	489.2794	489.5036818	439.4132	439.7283053	–	489.2258923
19	511.2795	511.7451751	439.4111	441.3131258	–	509.5198803
20	511.2795	511.3866797	439.4155	440.9302873	–	424.3372814
21	523.2794	523.7526806	439.4421	432.7498843	–	444.6752248
22	523.2794	546.4490405	439.4587	437.9981222	–	498.1749219
23	523.2796	524.5335111	439.7822	436.3860074	–	518.8884704
24	523.2794	524.3520391	439.7697	438.764263	–	461.4264655

25	523.2795	526.0300827	440.1191	440.5317634	–	433.7498497
26	523.2796	523.6386784	440.1219	440.2191136	–	503.3093562
27	10.0001	10.53824559	28.9738	24.16349618	–	11.00102962
28	10.0002	10.3420627	29.0007	48.41126024	–	16.56165106
29	10.0002	10.92134498	28.9828	30.7785289	–	13.95256909
30	89.5070	94.02741173	97.0000	95.82240167	–	96.3499386
31	190.0000	189.4857853	172.3348	172.5764043	–	188.984363
32	190.0000	190	172.3327	170.1042776	–	189.0600581
33	190.0000	188.8414191	172.3262	173.2868247	–	172.3326822
34	164.8026	168.7137325	200.0000	199.8494977	–	199.2972466
35	164.8035	190.3635298	200.0000	200	–	169.5882049
36	164.8292	199.1141077	200.0000	200	–	199.9560462
37	110.0000	89.15280064	100.8441	96.57168146	–	96.01766374
38	110.0000	103.4431437	100.8346	105.9796775	–	108.4345129
39	110.0000	109.9597579	100.8362	82.96801795	–	89.737272
40	511.2795	512.1733591	439.3868	442.8381317	–	422.1824737
Total generation	10500.00	10500.00	10500.00	10500.00	10500.00	10500.00
Fuel cost ($/h)	121415.653	122310.1012	129995.000	130503.4665	123638.00	125084.5385
Emission (Ton/h)	356424.497	368903.5705	176682.269	179062.812	188963.00	235182.0535
FCPI	0	0	100	100	25.9034	33.862
ECPI	100	100	0	0	6.8324	29.5612
Difference	100	100	100	100	19.0710	4.30078

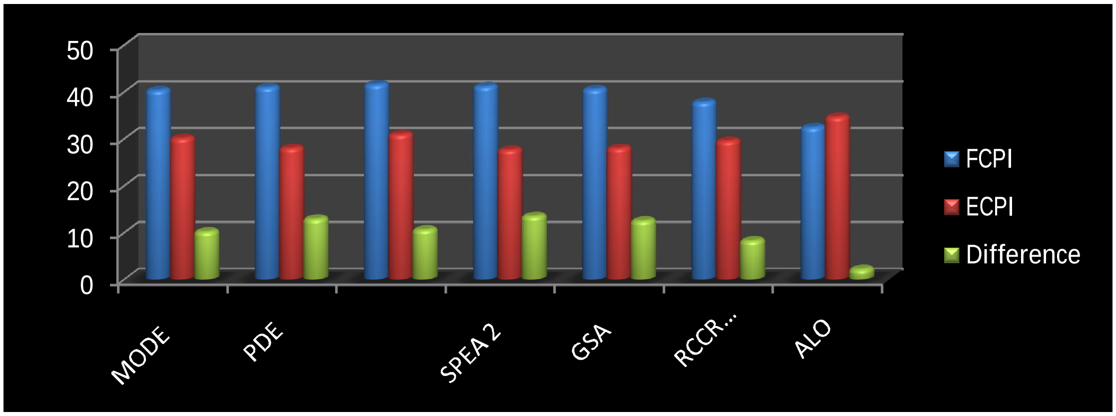

Fig.4. Comparison of the performances for Test case III

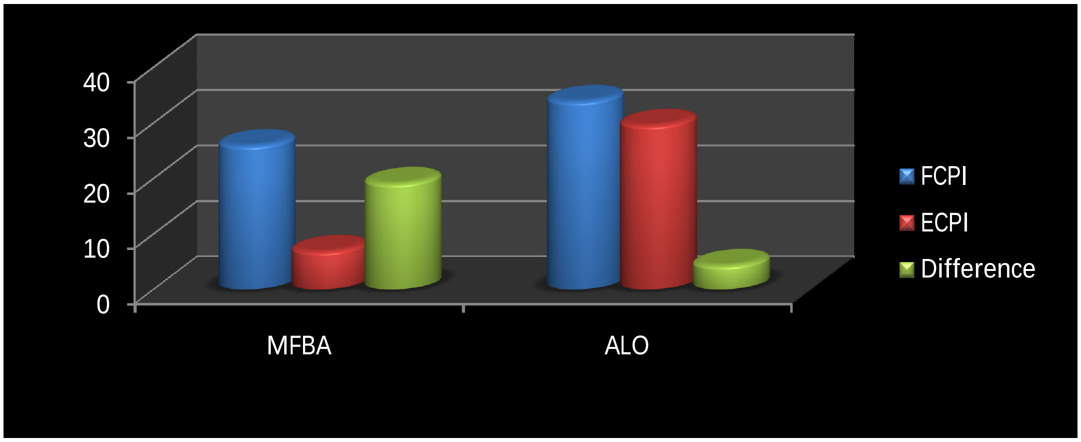

Fig.5. Comparison of the performances for Test case IV

IV. CONCLUSION

The ALO algorithm is efficiently applied for solving multi-objective EELD problem. The obtained results shows that the proposed ALO algorithm can evade the deficiency of early convergence of the genetic algorithm and particle swarm optimization methods to get superior solutions. The results confirmed that ALO was able to give competitive results in comparison to GA, hybrid GA, PSO, FFA, MFBA, MODE, NSGA-II, GSA and RCCRO. The novel probabilistic model of trap constructing, entrapping of ants in traps, prey grabbing, and trap rebuilding handle the trouble of early convergence. Because of simplicity and effectiveness of the ALO method, it can be useful for searching better results in difficult power system problems in future.

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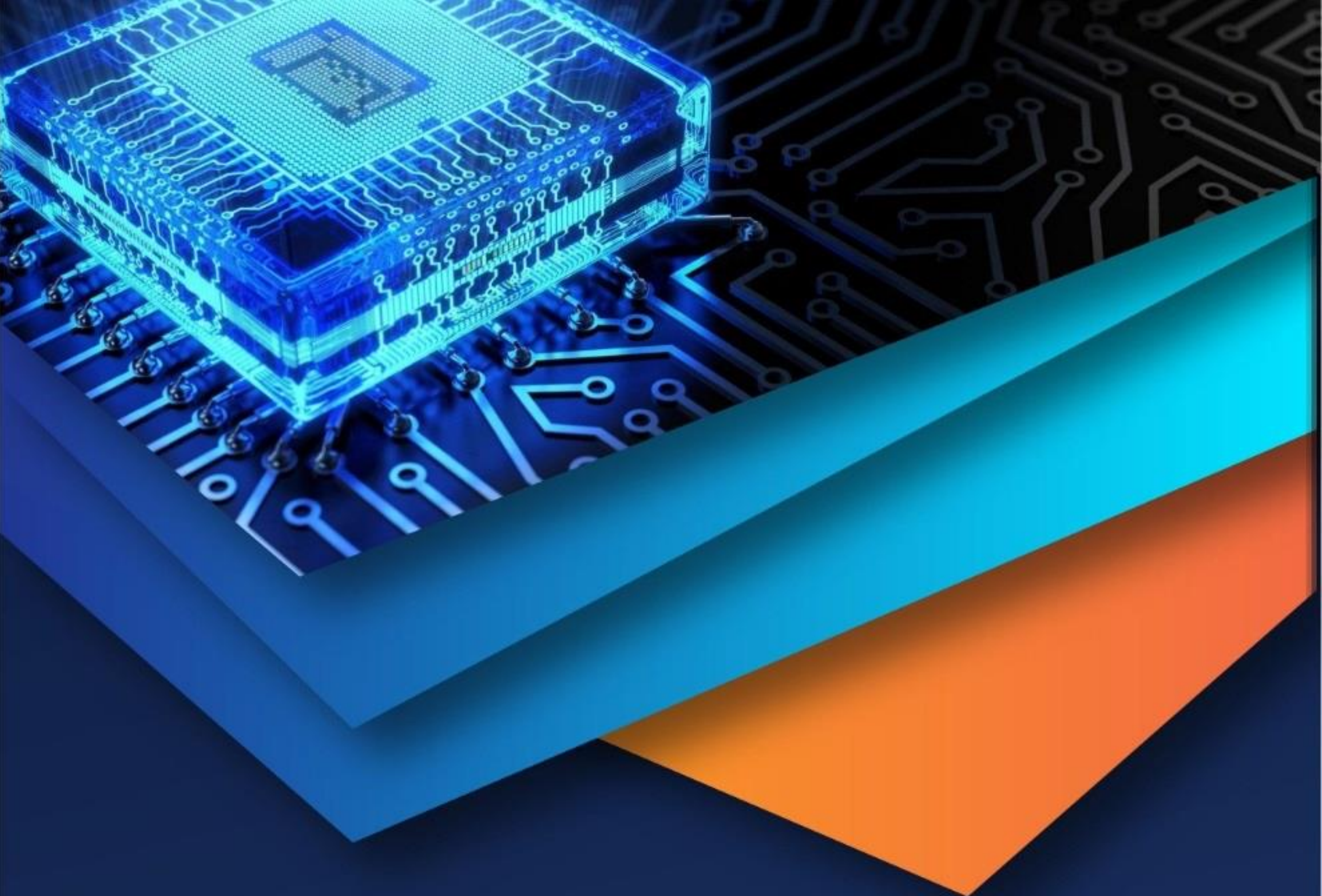

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