Solution of Combined Economic and Emission Dispatch Problems by Using Flower Pollination Algorithm

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Abstract— This paper introduces another way to deal with Economic Load Dispatch (ELD) is the way toward distributing the required load between the accessible age units to such an extent that the expense of activity is limited. The ELD issue is detailed as a nonlinear constrained improvement issue with both uniformity and disparity constraints. The double target Combined Economic Emission Dispatch (CEED) issue is thinking about the natural effects that collected from emanation of vaporous poisons of fossil-fuelled power plants. In this paper, an execution of Flower Pollination Algorithm (FPA) to take care of ELD and CEED issues in power systems is talked about. Results gotten by the proposed FPA are contrasted and other improvement algorithms for different power systems. The outcomes presented in this paper demonstrate that the proposed FPA outlives different procedures notwithstanding for extensive scale power system considering valve point impact as far as complete expense and computational time.

Key words: Flower Pollination Algorithm, Economic Load Dispatch, Combined Economic Emission Dispatch, Emission Constraints, Valve Point Loading Effect, Swarm Intelligence

I. INTRODUCTION

Economic Dispatch (ED) issue has turned into a significant assignment in the task and arranging of power system. It is unpredictable to settle in light of a nonlinear target work and an expansive number of constraints. ED in power system manages the assurance of ideal generation schedule of accessible generators so the all out expense of generation is limited inside the system constraints. Surely understood since quite a while ago settled systems, for example, slope strategy, lambda emphasis strategy, straight programming, quadratic programming, Lagrangian multiplier technique, and established method dependent on co-appointment conditions are connected to tackle ELD issues. These ordinary techniques can't perform satisfactorily to take care of such issues as they are touchy to beginning evaluations and unite into nearby ideal arrangement notwithstanding its computational multifaceted nature.

Amid the keeps going decades numerous investigates and systems had managed ELD issues. An elective approach is to utilize Evolutionary Algorithm (EA) procedures. Because of its capacity to treat nonlinear target capacities, EA is accepted to be viable to manage ELD issue. Then again, FPA has just a single key parameter p (switch likelihood) which makes the algorithm simpler to actualize and quicker to achieve ideal arrangement. Also, this exchanging switch among neighborhood and worldwide pollination can ensure getting away from nearby least arrangement. Consequently, FPA is proposed in this paper to beat the past downsides. What's more, it is obvious from the writing overview that the utilization of FPA to tackle ELD and CEED issues has not been talked about. This urges us to receive FPA to manage these issues.

In this paper, another approach for taking care of ELD and CEED issues utilizing FPA strategy is talked about considering the power furthest reaches of the generator. The reason for CEED is to limit both the working fuel cost and outflow level at the same time while fulfilling load request and operational constraints. This multi-objective CEED issue is changed over into a solitary target work utilizing a modified price penalty factor approach. FPA is examined to decide the ideal loading of generators in power systems. Under MATLAB results for little and substantial scale power system considering the valve loading impact are actualized to show the strength of FPA.

II. PROBLEM FORMULATION

The CEED problem is to minimize two computing objective functions simultaneously, fuel cost and emission, while satisfying various equality and inequality constraints. Generally the problem is formulated as follows.

A. Objective function of ELD

For thermal generating units, the cost of the fuel per unit power output varies significantly with the output power of the unit. Fuel costs are usually represented as a quadratic function of output power, as shown in equation (1).

$$F(P) = \gamma P^2 + \beta P + \alpha \qquad (1)$$

Minimize,

$$F_t = \sum_{i=1}^{d} F_i\,(P_i) = \sum_{i=1}^{d} (\gamma_i P_i^2 + \beta_i P_i + \alpha_i) \qquad (2)$$

The minimization is performed subject to the equality constraint that the total generation must equal to the demand plus the loss thus:

$$\sum_{i=1}^{d} P_i = P_D + P_L \qquad (3)$$

The total transmission loss using Kron’s loss formula is given in equation (4)

$$P_L = \sum_{i=1}^{d} \sum_{j=1}^{d} (P_i B_{ij} P_j) + \sum_{i=1}^{d} B_{0i} P_i + B_{00} \qquad (4)$$

It is assumed with little error that these coefficients are constant (as long as operation is near the value where these coefficients are computed).

Based on the maximum and minimum power limits of generators the inequality constraint is

$$P_i^{mini} \leq P_i \leq P_i^{max} \quad i = 1, 2, \ldots \ldots, d \qquad (5)$$

B. *Impact of valve point on fuel cost objective*

To be increasingly down to earth, the valve point impact is considered in the cost capacity of generators. The sharp increment in misfortunes because of the wire drawing impacts which happen as steam affirmation valve opens prompts the nonlinear undulated input output curve as appeared in Fig.1 The got cost work dependent on the undulated curve is progressively precise demonstrating. Along these lines, the fuel cost capacity of every fossil fuel generator is given as the whole of a quadratic and sinusoidal capacity.

$$F_t = \sum_{i=1}^{d} F_i\,(P_i) = \sum_{i=1}^{d} (\gamma_i P_i^2 + \beta_i P_i + \alpha_i + e_i * \sin\left(f_i * \left(P_i^{min} - P_i\right)\right) \qquad (6)$$

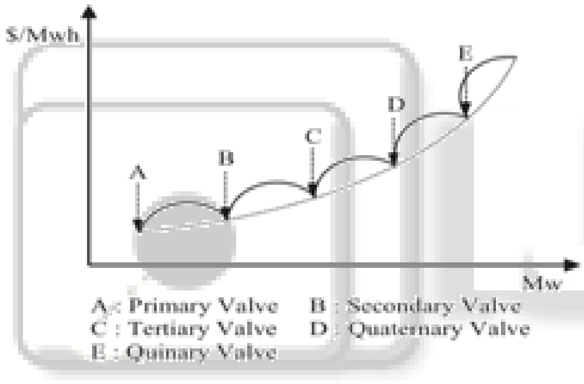

Fig. 1: Nonlinear undulated input output curve as appeared

C. *Objective function of CEED*

The barometrical poisons, for example, sulfur oxides, nitrogen oxides, and carbon dioxide brought about by fossil fuel terminated generator can be displayed independently. Be that as it may, for examination purposes, the all out emanation of these poisons which is the aggregate of a quadratic and an exponential capacity can be communicated as:

$$E_t = \sum_{i=1}^{d} E_i(P_i) = \sum_{i=1}^{d} (a_i P_i^2 + b_i P_i + c_i + \eta_i * \exp(\delta_i * P_i)) \qquad (7)$$

Optimization of generation cost has been formulated based on classical ELD with emission and line flow constraints. The detailed problem is given as follows:

Minimize $F = \sum_{i=1}^{d} \{F_i(P_i, E_i(P_i))\}$ (8)

The minimum value of the above objective function has to be found out subject to equality and inequality constraints given by equations (3) and (5). The dual-objective CEED problem is converted into single optimization problem by introducing a price penalty factor ‘h’ as follows:

Minimize $F = F_t + h * E_t$ (9)

Subject to constraints given by equations (3) and (5), the price penalty factor ‘h’, which is the ratio between the maximum fuel cost and maximum emission of corresponding generator in $/Kg, blends the emission with fuel cost, then F is the total operating cost in $.

$$h_i = \frac{F_t\,(P_i^{max})}{E_t\,(P_i^{max})}, \qquad i = 1,2, \ldots \ldots \ldots, d \qquad (10)$$

The following steps are used to find the price penalty factor for a particular load demand:

1) Find the ratio between maximum fuel cost and maximum emission of each generator.
2) Arrange the values of price penalty factor in ascending order.
3) Add the maximum capacity of each unit (P_i^{max}) one at a time, starting from the smallest h_i, until $\sum P_i^{max} \geq P_D$.
4) At this point, h_i which associated with the last unit in this process is the approximate price penalty factor value (h) for the given load.

Hence, a modified price penalty factor (h) is used to give the exact value for the particular load demand by interpolating the values of (h), corresponding to their load demand values.

III. OVERVIEW OF FLOWER POLLINATION ALGORITHM

FPA was created by Yang in 2012. It is enlivened by the pollination procedure of flowering plants. Genuine plan issues in building and industry are normally multi-objective. These different destinations frequently struggle with each other. Likewise, they have extra difficult issues, for example, time multifaceted nature, inhomogeneity and dimensionality. They are normally additional tedious. FPA has been embraced in this paper to take care of ELD and CEED issues.

A. *Characteristics of flower pollination*

The principle motivation behind a flower is at last proliferation by means of pollination. Flower pollination is normally corresponding with the exchange of dust, which frequently connected with pollinators, for example, winged creatures and creepy crawlies. Without a doubt, some flowers and bugs have an exceptionally particular flower-pollinator association, as some flowers can just draw in a specific types of bug or fowl for powerful pollination. Pollination shows up in two noteworthy structures: abiotic and biotic. About 90% of flowering plants rely upon the biotic pollination process, in which the dust is exchanged by pollinators. .About10%of pollination pursues abiotic structure that does not require any pollinators. Wind and dispersion help in the pollination procedure of such flowering plants.

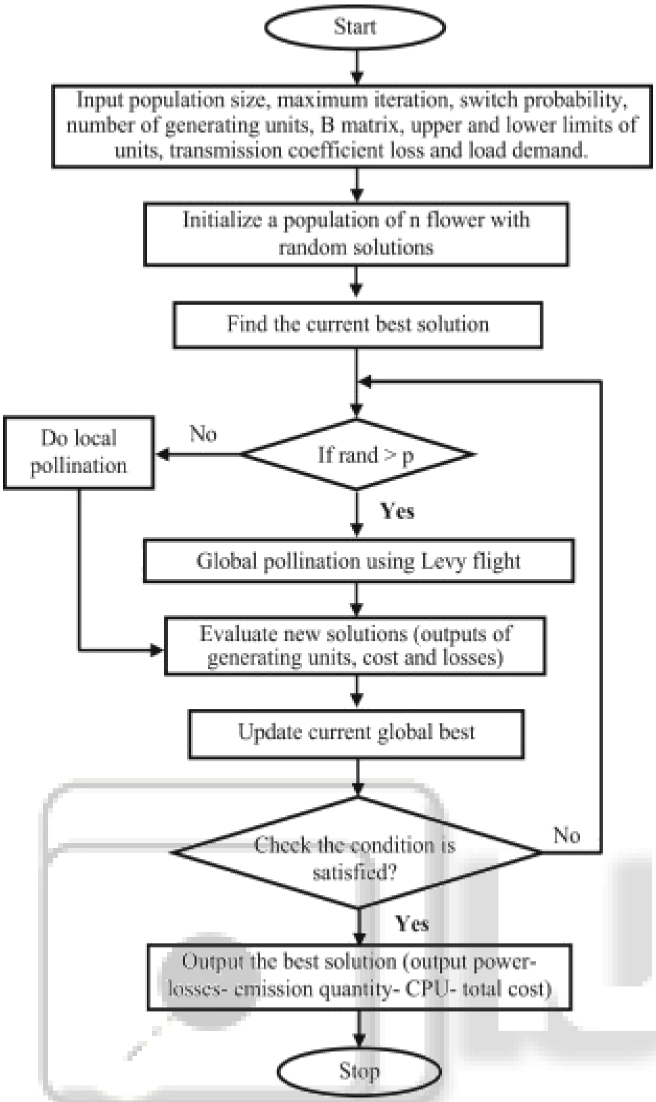

Fig.2: Flowchart of Flower Pollination Algorithm

Pollination can be accomplished independent from anyone else pollination or cross-pollination. Self-pollination is the pollination of one flower from dust of the equivalent flower. Cross-pollination is the pollination from dust of a flower of various plants. The goal of flower pollination is the survival of the fittest and the ideal proliferation of plants as far as numbers just as the fittest. This can be considered as an enhancement procedure of plant species. These factors and procedures of flower pollination made ideal proliferation of the flowering plants.

B. *Flower pollination algorithm*

For FPA, the following four steps are used:

Step 1: Global pollination represented in biotic and crosspollination processes, as pollen-carrying pollinators fly following Lévy flight.

Step2: Local pollination represented in abiotic and self-pollination as the process does not require any pollinators.

Step 3: Flower constancy which can be developed by insects, which is on a par with a reproduction probability that is proportional to the similarity of two flowers involved.

Step 4: The interaction of local pollination and global pollination is controlled by a switch probability p ∈ [0, 1], lightly biased toward local pollination.

To produce the refreshing recipes, the above principles must be changed over into appropriate refreshing conditions. For instance at the worldwide pollination step, the pollinators, for example, creepy crawlies convey the flower pollen gametes, so the pollen can go over a long separation on account of the capacity of these bugs to fly and move in any longer ranges. Subsequently, worldwide pollination step and flower steadiness step can be spoken to by:

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

In fact, L (λ) is the Lévy flights based step size that corresponds to the strength of the pollination. Since long distances can be covered by insects using various distance steps, a Lévy flight can be used to mimic this behavior efficiently. That is, L > 0 from a Lévy distribution.

$$L \sim \frac{\lambda\Gamma(\lambda)\sin(\pi\lambda/2)}{\pi}\left(\frac{1}{S^{1+\lambda}}\right)(s \gg s_0 > 0) \tag{12}$$

This distribution is valid for large steps s>0. For the local pollination, both Step 2 and Step 3 can be represented as

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

Where X_j^t *and* X_k^t are pollen from different flowers of the same plant species mimicking the flower constancy in a limited neighborhood? For a local random walk, X_j^t *and* X_k^t come from the same species, then ε is drawn from a uniform distribution as [0, 1].

In principle, flower pollination activities can occur at all scales. But in reality, adjacent flower patches are more likely to be pollinated by local flower pollen than those far away. In order to mimic this, one can effectively use a switch probability (Step 4) to switch between common global pollination to intensive local pollination. To start with, one can use a native value of p=0.5. A preliminary parametric showed that p=0.8 might work better for most applications. The flow chart of FPA is given in Fig. 2. The data of FPA are shown in Appendix A.

IV. RESULTS AND DISCUSSION

FPA is employed to solve ELD and CEED problems for different cases to assure its optimization efficiency, where the objective function is limited by the output limits of generation units and transmission losses. The performance of FPA is compared with various optimization algorithms. Simulations were done under the MATLAB environment.

A. *Case study 1*

This situation deliberates 40 generators as per a large scale power system to confirm the dominance of FPA over further procedures in reaching optimal solution. The records of this system are specified in Appendix B.

Table 1 summaries the productions of every one unit for 10,500 MW load demand in addition the cost for all algorithm. This one can be observed that the proposed FPA reaches lower cost equated with additional algorithms whereas succeeding the constraints of generations. Thus, Projected FPA achieves better than these procedures in expressions of fuel cost level for large scale control system through valve loading effect.

Outputs	PSO	APPSO	ARCGA	PPSO	MPSO	Proposed FPA
P1 (MW)	113.116	112.579	110.8252	110.601	113.9971	86.6949
P2 (MW)	113.010	111.553	113.9112	111.781	112.6517	114.0000
P3 (MW)	119.702	98.751	97.4000	118.613	119.4255	118.4648
P4 (MW)	108.647	180.384	179.7331	179.819	189.0000	187.5227
P5 (MW)	95.062	94.389	88.6454	92.443	96.8711	47.3617
P6 (MW)	139.209	139.943	140.0000	139.846	139.2798	139.6756
P7 (MW)	299.127	298.937	259.6000	296.703	223.5924	291.6567
P8 (MW)	287.491	285.827	284.6000	284.566	284.5803	135.4799
P9 (MW)	292.316	298.381	284.6000	285.164	216.4333	282.0293
P10 (MW)	279.273	130.212	130.0000	203.859	239.3357	153.2281
P11 (MW)	169.766	94.385	168.7985	94.283	314.8734	94.0321
P12 (MW)	94.344	169.583	168.7994	94.090	305.0565	94.0540
P13 (MW)	214.871	214.617	214.7600	304.830	365.5429	312.6804
P14 (MW)	304.790	304.886	394.2800	304.173	493.3729	484.9770
P15 (MW)	304.563	304.547	304.5200	304.467	280.4326	499.8137
P16 (MW)	304.302	304.584	394.2800	304.177	432.0717	478.8050
P17 (MW)	489.173	498.452	489.2798	489.544	435.2428	473.5511
P18 (MW)	491.336	497.472	489.2800	489.773	417.6958	496.6359
P19 (MW)	510.880	512.816	511.2806	511.280	532.1877	513.2533
P20 (MW)	511.474	548.992	511.2800	510.904	409.2053	549.9741
P21 (MW)	524.814	524.652	523.2803	524.092	534.0629	548.0959
P22 (MW)	524.775	523.399	523.2800	523.121	457.0962	526.1131
P23 (MW)	525.563	548.895	523.2800	523.242	441.3634	542.4401
P24 (MW)	522.712	525.871	523.2800	524.260	397.3617	540.9974
P25 (MW)	503.211	523.814	523.2800	523.283	446.4181	549.5248
P26 (MW)	524.199	523.565	523.2801	523.074	442.1164	523.5615
P27 (MW)	10.082	10.575	10.0000	10.800	74.8622	17.4973
P28 (MW)	10.663	11.177	10.0000	10.742	27.5430	10.4278
P29 (MW)	10.418	11.210	10.0000	10.799	76.8314	18.9260
P30 (MW)	94.244	96.178	88.7611	94.475	97.0000	96.8811
P31 (MW)	189.377	189.999	190.0000	189.245	118.3775	169.7219
P32 (MW)	189.796	189.924	190.0000	189.995	188.7517	186.3745
P33 (MW)	189.813	189.714	190.0000	188.081	190.0000	186.7114
P34 (MW)	199.797	199.284	164.8000	198.475	120.7029	102.2795
P35 (MW)	199.284	199.599	164.8000	197.528	170.2403	97.1927
P36 (MW)	198.165	199.751	164.8054	196.971	198.9897	92.2629
P37 (MW)	109.291	109.973	110.0000	109.161	110.0000	41.0009
P38 (MW)	109.087	109.506	110.0000	109.900	109.3405	92.8854
P39 (MW)	109.909	109.363	110.0000	109.855	109.9243	109.9837
P40 (MW)	512.348	511.261	511.2800	510.984	468.1694	493.4339
Fuel Cost* 10^5\$	1.22578	1.22238	1.21415	1.31790	1.34930	1.27058

Table: 1 ELD comparison for 40 generators at load of 10,500 MW

Correspondingly, Table 2 lists the arithmetical comparison amongst FPA and distinct algorithms conveyed in relations of the *best*, *mean*, *worst cost and computational time* through 40 trials.

The situation is flawless that the fuel cost achieved by the projected FPA is enhanced than further algorithms.

P_D	h	Power outputs	GA	PSO	Proposed FPA
400 (MW)	43.1703	P1 (MW)	102.617	102.612	102.4268
		P2 (MW)	153.825	153.809	153.8289
		P3 (MW)	151.011	150.991	151.1655
		P_L (MW)	7.41324	7.41173	7.4212
		Fuel Cost (\$)	20840.0982	20838.311	20838.344
		Emission (Kg)	200.2575	200.2208	200.2345
		Total Cost (\$)	29563.2642	29559.8915	29482.5
		CPU (Sec)	0.282	0.235	NA

Table: 2 Statistical comparisons between FPA and different algorithms.

Fig.3 demonstrations the total cost intended for every single algorithm. On the other hand, a display for $convergence$ rate of the unprejudiced function is certain in Fig.4 This one can be understood that the objective function is become constant after 18 iterations. Moreover, the mean CPU interval of FPA be present the shortest one.

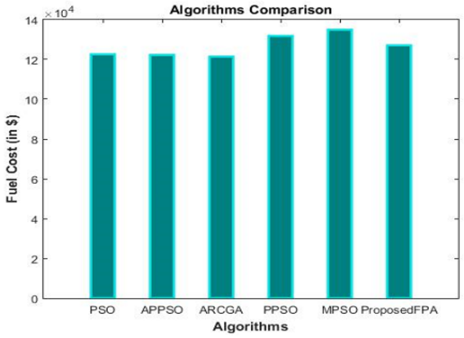

Fig.3 Fuel cost for various algorithms for case study-1

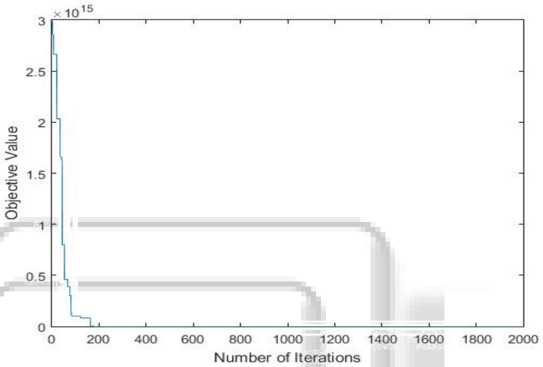

Fig.4 Objective function for forty unit system.

B. Case study 2

This circumstance studies an 3-unit generating thermal system considering emission impact. The generator cost coefficients, emission coefficients, generation limits and the transmission loss coefficient matrix are specified in Appendix B. Fig. 5.4 demonstrations the over-all cost connected with FPA on behalf of 400 MW demand. The dominance of the projected procedure in declining the overall cost can be certified as shown in fig. 5.5.

Table 3 summarizes the results of solving CEED using the proposed FPA compared with GA and PSO. As shown from Table 3, FPA provides greater result in relations of fuel cost, total cost and CPU associated with other procedures. Furthermore, the equality plus inequality constraints are proficient. The projected FPA provides improved results in relations of least total cost and lesser CPU time than additional algorithms.

P_D	h	$Power\ outputs$	GA	PSO	$Proposed\ FPA$
400 (MW)	43.1703	$P1\ (MW)$	102.617	102.612	102.4268
		$P2\ (MW)$	153.825	153.809	153.8289
		$P3\ (MW)$	151.011	150.991	151.1655
		$P_L\ (MW)$	7.41324	7.41173	7.4212
		$Fuel\ Cost\ (\$)$	20840.0982	20838.311	20838.344
		$Emission\ (Kg)$	200.2575	200.2208	200.2345
		$Total\ Cost\ (\$)$	29563.2642	29559.8915	29482.5
		$CPU\ (Sec)$	0.282	0.235	NA

Table: 3 Results for the best simulations with 3-unit system considering emission

Fig.5 Shows the total cost associated with FPA for 400 MW demand. The superiority of the proposed algorithm in decreasing the total cost can be verified as shown in fig.6.

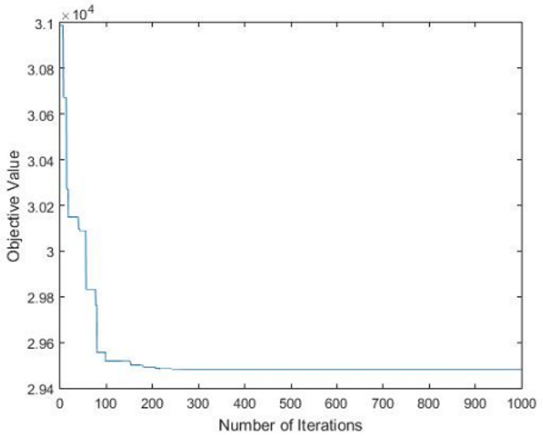

Fig.5 Objective function for 3-unit system with demand = 400MW.

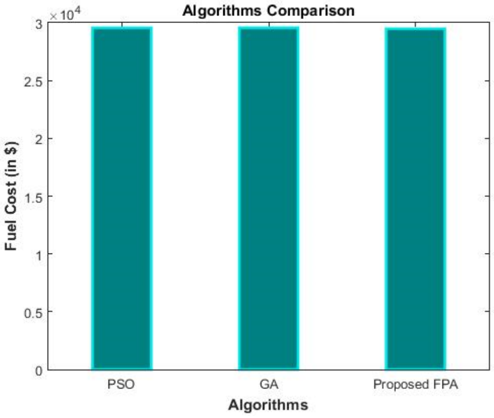

Fig.6 Total cost for various algorithms with demand = 400MW

C. Case study 3

This situation involves a $ten\ unit\ generating\ thermal\ system$ $with\ valve$

point effects. The fuel cost quantities, generators restraint, emission quantities and transmission loss coefficient matrix are displayed in Appendix B.

Table 4 summaries the effects of solving *CEED* for 2000 MW load demand by means of FPA as well as associating with additional algorithms. The result of the proposed algorithm is emphasized here. The suggested FPA produces a worse cost than GSA, MODE, PDE and NSGA-II respectively although attaining the constraints of the system. Moreover, its emission is also inferior to PDE, GSA, MODE and NSGA-II. Thus, FPA succeeds in reaching the over-all minimum solution. Furthermore, the CPU interval is slighter than additional algorithm. From now, FPA outperforms as well carry on other procedures in dropping the remaining cost with least time.

Outputs	*MODE*	*NSGAII*	*GSA*	*PDE*	*Proposed FPA*
$P1\ (MW)$	54.9487	51.9515	54.9992	54.9853	55.0000
$P2\ (MW)$	74.5821	67.2584	79.9586	79.3803	77.2084
$P3\ (MW)$	79.4294	73.6879	79.4341	83.9842	89.3635
$P4\ (MW)$	80.6875	91.3554	85.0000	86.5942	85.8728
$P5\ (MW)$	136.8551	134.0522	142.1063	144.4386	158.0335
$P6\ (MW)$	172.6393	174.9504	166.5670	165.7756	237.5622
$P7\ (MW)$	283.8233	289.4350	292.8749	283.2122	281.5300
$P8\ (MW)$	316.3407	314.0556	313.2387	312.7709	298.9178
$P9\ (MW)$	448.5923	455.6978	441.1775	440.1135	392.8715
$P10\ (MW)$	436.4287	431.8054	428.6306	432.6783	405.2473
$Fuel\ cost * 10^5\$$	1.13252	1.13319	1.13266	1.13280	1.16051
$Emission(lb)$	4124.86	4150.983	4111.4175	4111.38	3946.224
$Losses(MW)$	84.3271	84.2495	83.9869	83.9331	81.5754
$Total\ cost * 10^5\$$	3.27819	3.29245	3.27134	3.27146	3.21326
$CPU\ (Sec)$	3.82	6.02	NA	4.23	NA

Table: 4 CEED comparison for ten unit system at demand of 2000 MW

In addition, the cost *convergence* for this demand is given in Fig.7. The objective function is convergent after 15 iterations. In conclusion, the total cost for each algorithm is specified in Fig.8.

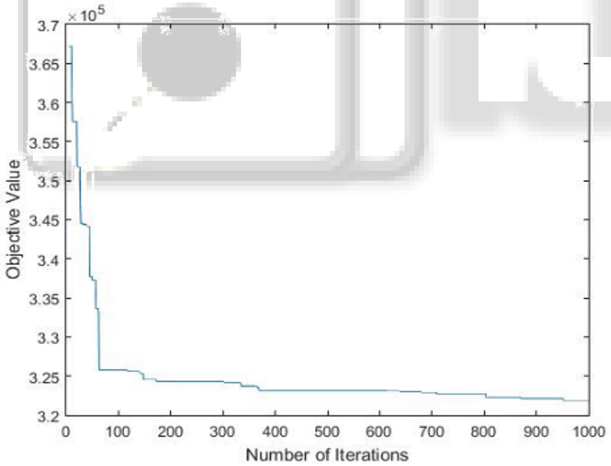

Fig.7 Change of objective function with iteration for ten units.

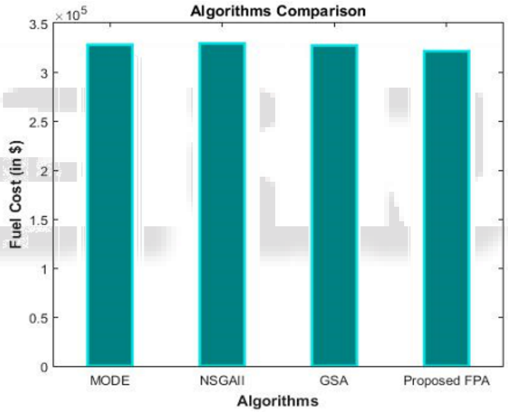

Fig.8 Total cost for various algorithms for case 3.

D. Case study 4

This assessment system contains of forty generating units with non-smooth fuel cost and emission functions. Unit records and loss coefficients have been initiated in Appendix B.

Table 5 summarizes the results of solving CEED for 10,500 MW load demand via FPA. The consequence of the proposed algorithm produces to a minor fuel cost than others as displayed in Table 5. Consequently, these algorithms have confined in local least possible solutions.

Outputs	*MODE*	*NSGAII*	*GSA*	*PDE*	*Proposed FPA*
$P1\ (MW)$	113.5295	113.8685	113.9989	112.1549	50.7979
$P2\ (MW)$	114	113.6381	113.9896	113.9431	102.2685
$P3\ (MW)$	120	120	119.9995	120	103.3391
$P4\ (MW)$	179.8015	180.7887	179.7857	180.2647	140.2540
$P5\ (MW)$	96.7716	97	97	97	81.6417
$P6\ (MW)$	139.2760	140	139.0128	140	133.0165
$P7\ (MW)$	300	300	299.9885	299.8829	258.1700
$P8\ (MW)$	298.9193	299.0084	300	300	295.0135

$P9\ (MW)$	290.7737	288.8890	296.2025	289.8915	292.1970
$P10\ (MW)$	130.9025	131.6132	130.3850	130.5725	176.5917
$P11\ (MW)$	244.7349	246.5128	245.4775	244.1003	285.6475
$P12\ (MW)$	317.8218	318.8748	318.2101	318.2840	301.7452
$P13\ (MW)$	395.3846	395.7224	394.6257	394.7833	491.5834
$P14\ (MW)$	394.4692	394.1369	395.2016	394.2187	472.7456
$P15\ (MW)$	305.8104	305.5781	306.0014	305.9616	419.6869
$P16\ (MW)$	394.8229	394.6968	395.1005	394.1321	399.5794
$P17\ (MW)$	487.9872	489.4234	489.2569	489.3040	452.4989
$P18\ (MW)$	489.1751	488.2701	488.7598	489.6419	468.9487
$P19\ (MW)$	500.5265	500.8	499.2320	499.9835	453.3730
$P20\ (MW)$	457.0072	455.2006	455.2821	455.4160	463.9356
$P21\ (MW)$	434.6068	434.6639	433.4520	435.2845	463.9356
$P22\ (MW)$	434.5310	434.15	433.8125	433.7311	463.1785
$P23\ (MW)$	444.6732	445.8385	445.5136	446.2496	465.0215
$P24\ (MW)$	452.0332	450.7509	452.0547	451.8828	455.1291
$P25\ (MW)$	492.7831	491.2745	492.8864	493.2259	480.8097
$P26\ (MW)$	436.3347	436.3418	433.3695	434.7492	453.8503
$P27\ (MW)$	10	11.2457	10.0026	11.8064	453.8503
$P28\ (MW)$	10.3901	10	10.0246	10.7536	10.0000
$P29\ (MW)$	12.3149	12.0714	10.0125	10.3053	13.5955
$P30\ (MW)$	96.9050	97	96.9125	97	89.2439
$P31\ (MW)$	189.7727	189.4826	189.9689	190.0000	190.0000
$P32\ (MW)$	174.2324	174.7971	175	175.3065	167.1119
$P33\ (MW)$	190	189.2845	189.0181	190	120.5611
$P34\ (MW)$	199.6506	200	200	200	173.2768
$P35\ (MW)$	199.8662	199.9138	200	200	189.9298
$P36\ (MW)$	200	199.5066	199.9978	200	192.2955
$P37\ (MW)$	110	108.3061	109.9969	109.9412	96.8547
$P38\ (MW)$	109.9454	110	109.0126	109.8823	100.7522
$P39\ (MW)$	108.1786	109.7899	109.4560	108.9686	68.1648
$P40\ (MW)$	422.0628	421.5609	421.9987	421.3778	452.9532
$Total\ cost\ *\ 10^5\$$	4.84456	1.92802	1.92761	1.93436	1.97551
$Emission\ *\ 10^5 ton$	2.11284	2.11048	2.11027	2.11862	2.16933
$CPU\ (Sec)$	5.39	7.32	NA	4.92	NA

Table: 5 CEED comparisons for 40 generators at load of 10,500 MW.

Instead, the $objective\ function$ on behalf of the overall cost drops gradually and congregates after 18 iterations as given in Fig.9. Furthermore, the average CPU interval of the projected FPA is the minimum one associated with additional algorithms. The dominance of the projected FPA in realization the global slightest cost is noticed by observing Fig.10.

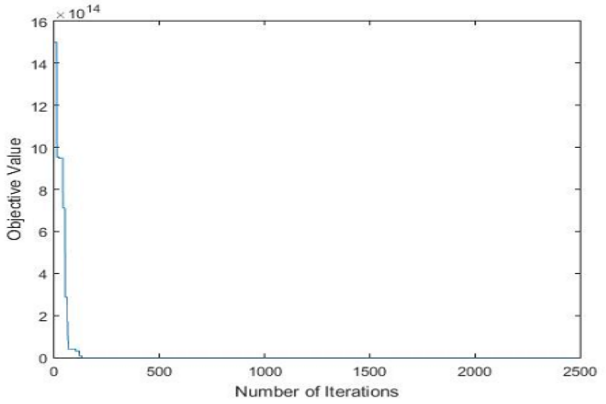

Fig.9 Change of objective function with iterations for forty units.

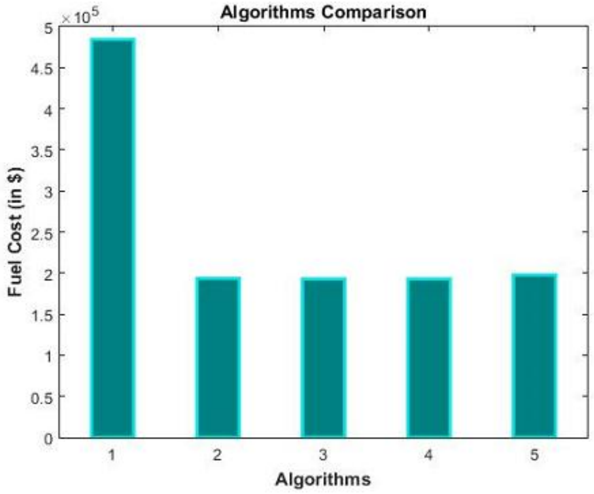

Fig.10 Total cost for various algorithms for case 4.

V. COMPARISONS AND DISCUSSION

The superiority of the proposed FPA is investigated here by comparison with other optimization algorithms in terms of economic effects and computation efficiency.

A. *Economic effects*

By means of Fig. 3, 6, 8, and 10, the suggested FPA be able to get the best result between other algorithms in the fictions. From Table 2, it is clear that the mean cost price attained by the proposed FPA is moderately rarer paralleled with further algorithms. As a result, the planned FPA can outcome in well economic special effects than new algorithms. Furthermore, it leads to advanced quality result than further algorithms.

B. *Convergence property and computation efficiency*

From Fig. 4, 5, 7 and 9, one can get that the descending speeds at the beginning are high; this indicates the high convergence of the proposed algorithm based on evolution search. FPA can be convergent quickly and get the optimum results in very small iteration numbers. It is confirmed to have a good convergence property. As seen in Table 1-5, CPU times of the proposed FPA are smaller than other algorithms since FPA has only one key parameter. Thus, it can get better computation efficiency than other algorithms.

VI. CONCLUSION

In this paper, FPA has been developed to solve ELD and CEED problems in power systems. The performance of the FPA was tested for various test cases and compared with the reported cases in recent literatures. The superiority of FPA over other algorithms for settling ELD and CEED problem seven for large scale power system with valve point effect is confirmed. Moreover, the economic effect, computation efficiency and convergence property of FPA are demonstrated. Therefore FPA optimization is a promising technique for solving complicated problems in power systems. Applications of the proposed algorithm to multi are a power system integrated with wind farms and PV system are the future scope of this work.

- Appendix A: Parameters of FPA
  - For case A:
    Maximum number of iterations = 2000;
    Probability switch = 0.87;
    Population size = 25.
  - For case B:
    Maximum number of iterations = 1000;
    Probability switch = 0.8;
    Population size = 25.
  - For case C:
    Maximum number of iterations = 1000;
    Probability switch = 0.85;
    Population size = 50.
  - For case D:
    Maximum number of iterations = 2000;
    Probability switch = 0.823;
    Population size = 50.
- Appendix – B: See Tables B1-B3 and the transmission line losses coefficient.

Unit	γ \$/MW^2h	β \$/MWh	α \$/h	a (Kg/MW^2h)	b (Kg/MWh)	c (Kg/h)	P^{min} (MW)	P^{max} (MW)
1	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.2669	35	210
2	0.02111	36.32782	1658.5696	0.00461	-0.5116	42.89553	130	325
3	0.01799	38.27041	1356.6592	0.00461	-0.5116	42.89553	125	315

Table B1: Generator cost coefficients for the three unit system considering emission:

The transmission line losses coefficient of three units system.

$$B_{ij} = 0.0001 * \begin{bmatrix} 0.71 & 0.3 & 0.25 \\ 0.3 & 0.69 & 0.32 \\ 0.255 & 0.32 & 0.8 \end{bmatrix}$$

Unit	γ \$/M W^2h	β \$ $/MWh$	α \$/h	e \$ $/h$	f rad $/MW$	P^{min} MW	P^{max} MW	a lb $/MW^2h$	b lb $/MWh$	c lb/h	η lb/h	δ $1/MW$
P1	0.12951	40.540	1000.40	33	0.017	10	55	0.04702	-	360.001	0.2547	0.0123
P2	0.10908	39.580	950.606	25	0.017	20	80	0.04652	-	350.005	0.2547	0.0123
P3	0.12511	36.510	900.705	32	0.016	47	120	0.04652	-	330.005	0.2516	0.0121
P4	0.12111	39.510	800.705	30	0.016	20	130	0.04652	-	330.005	0.2516	0.0121
P5	0.15247	38.539	756.799	30	0.014	50	160	0.0042	0.3277	13.8593	0.2497	0.012
P6	0.10587	46.159	451.325	20	0.016	70	240	0.0042	0.3277	13.8593	0.2497	0.012
P7	0.03546	38.305	1243.53	20	0.015	60	300	0.0068	-	40.2669	0.248	0.0129
P8	0.02803	40.396	1049.99	30	0.012	70	340	0.0068	-	40.2669	0.2499	0.0120
P9	0.02111	36.327	1658.56	60	0.013	135	470	0.0046	-	42.8955	0.2547	0.0123
P10	0.01799	38.270	1356.65	40	0.014	150	470	0.0046	-	42.8955	0.2547	0.0123

Table B2: Ten unit generator characteristics:

The transmission line losses coefficient of ten units system

$$\begin{bmatrix} 0.49 & 0.14 & 0.15 & 0.15 & 0.16 & 0.17 & 0.17 & 0.18 & 0.19 & 0.20 \\ 0.14 & 0.45 & 0.16 & 0.16 & 0.17 & 0.15 & 0.15 & 0.16 & 0.18 & 0.18 \\ 0.15 & 0.16 & 0.39 & 0.10 & 0.12 & 0.12 & 0.14 & 0.14 & 0.16 & 0.16 \\ 0.15 & 0.16 & 0.10 & 0.40 & 0.14 & 0.10 & 0.11 & 0.12 & 0.14 & 0.15 \\ 0.16 & 0.17 & 0.12 & 0.14 & 0.35 & 0.11 & 0.13 & 0.13 & 0.15 & 0.16 \\ 0.17 & 0.15 & 0.12 & 0.10 & 0.11 & 0.36 & 0.12 & 0.12 & 0.14 & 0.15 \\ 0.17 & 0.15 & 0.14 & 0.11 & 0.13 & 0.12 & 0.38 & 0.16 & 0.16 & 0.18 \\ 0.18 & 0.16 & 0.14 & 0.12 & 0.13 & 0.12 & 0.16 & 0.40 & 0.15 & 0.16 \\ 0.19 & 0.18 & 0.16 & 0.14 & 0.15 & 0.14 & 0.16 & 0.15 & 0.42 & 0.19 \\ 0.20 & 0.18 & 0.16 & 0.15 & 0.16 & 0.15 & 0.18 & 0.16 & 0.19 & 0.44 \end{bmatrix}$$

Unit	P^{min} MW	P^{max} MW	α \$/h	β \$ $/MWh$	γ \$ $/MW^2h$	e \$ $/h$	f rad $/MW$	c lb $/h$	b lb $/MWh$	a lb $/MW^2h$	η lb/h	δ $1/MW$
P1	36	114	94.705	6.73	0.00690	100	0.084	60	-2.22	0.0480	1.3100	0.05690
P2	36	114	94.705	6.73	0.00690	100	0.084	60	-2.22	0.0480	1.3100	0.05690
P3	60	120	309.54	7.07	0.02028	100	0.084	100	-2.36	0.0762	1.3100	0.05690
P4	80	190	369.03	8.18	0.00942	150	0.063	120	-3.14	0.0540	0.9142	0.04540
P5	47	97	148.89	5.35	0.01140	120	0.077	50	-1.89	0.0850	0.9936	0.04060
P6	68	140	222.33	8.05	0.01142	100	0.084	80	-3.08	0.0854	1.3100	0.05690
P7	110	300	287.71	8.03	0.00357	200	0.042	100	-3.06	0.0242	0.6550	0.02846
P8	135	300	391.98	6.99	0.00492	200	0.042	130	-2.32	0.0310	0.6550	0.02846
P9	135	300	455.76	6.60	0.00573	200	0.042	150	-2.11	0.0335	0.6550	0.02846
P10	130	300	722.82	12.9	0.00605	200	0.042	280	-4.34	0.4250	0.6550	0.02846
P11	94	375	635.20	12.9	0.00515	200	0.042	220	-4.34	0.0322	0.6550	0.02846
P12	94	375	654.69	12.8	0.00569	200	0.042	225	-4.28	0.0338	0.6550	0.02846
P13	125	500	913.40	12.5	0.00421	300	0.035	300	-4.18	0.0296	0.5035	0.02075
P14	125	500	1760.4	8.84	0.00752	300	0.035	520	-3.34	0.0512	0.5035	0.02075
P15	125	500	1728.3	9.15	0.00708	300	0.035	510	-3.55	0.0496	0.5035	0.02075
P16	125	500	1728.3	9.15	0.00708	300	0.035	510	-3.55	0.0496	0.5035	0.02075
P17	220	500	647.85	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075
P18	220	500	649.69	7.95	0.00313	300	0.035	222	-2.66	0.0151	0.5035	0.02075
P19	242	550	647.83	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075
P20	242	550	647.81	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075
P21	254	550	785.96	6.63	0.00298	300	0.035	290	-2.22	0.0145	0.5035	0.02075
P22	254	550	785.96	6.63	0.00298	300	0.035	285	-2.22	0.0145	0.5035	0.02075
P23	254	550	794.53	6.66	0.00284	300	0.035	295	-2.26	0.0138	0.5035	0.02075
P24	254	550	794.53	6.66	0.00284	300	0.035	295	-2.26	0.0138	0.5035	0.02075
P25	254	550	801.32	7.10	0.00277	300	0.035	310	-2.42	0.0132	0.5035	0.02075
P26	254	550	801.32	7.10	0.00277	300	0.035	310	-2.42	0.0132	0.5035	0.02075
P27	10	150	1055.1	3.33	0.52124	120	0.077	360	-1.11	1.8420	0.9936	0.04060
P28	10	150	1055.1	3.33	0.52124	120	0.077	360	-1.11	1.8420	0.9936	0.04060
P29	10	150	1055.1	3.33	0.52124	120	0.077	360	-1.11	1.8420	0.9936	0.04060
P30	47	97	148.89	5.35	0.01140	120	0.077	50	-1.89	0.0850	0.9936	0.04060
P31	60	190	222.92	6.43	0.00160	150	0.063	80	-2.08	0.0121	0.9142	0.04540
P32	60	190	222.92	6.43	0.00160	150	0.063	80	-2.08	0.0121	0.9142	0.04540
P33	60	190	222.92	6.43	0.00160	150	0.063	80	-2.08	0.0121	0.9142	0.04540
P34	90	200	107.87	8.95	0.00010	200	0.042	65	-3.48	0.0012	0.6550	0.02846
P35	90	200	116.58	8.62	0.00010	200	0.042	70	-3.24	0.0012	0.6550	0.02846
P36	90	200	116.58	8.62	0.00010	200	0.042	70	-3.24	0.0012	0.6550	0.02846+
P37	25	110	307.45	5.88	0.01610	80	0.098	100	-1.98	0.0950	1.4200	0.06770

P38	25	110	307.45	5.88	0.01610	80	0.098	100	-1.98	0.0950	1.4200	0.06770
P39	25	110	307.45	5.88	0.01610	80	0.098	100	-1.98	0.0950	1.4200	0.06770
P40	242	550	647.83	7.97	0.00313	300	0.035	220	-2.68	0.0151	0.5035	0.02075

Table B3: Forty unit generator characteristics.

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