Optimal Line Flow in Conventional Power System using Euclidean Affine Flower Pollination Algorithm

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Abstract- In electric power market, electric power must be offered to the customer with high quality and least cost. In a deregulated power system, this is a difficult task because of several complicated problems. With increase in electricity cost of raw materials and its growing demand, an optimal solution is required for operation and design of an efficient power system. Conventional energy resource like solar system can be opted for generating electric energy using Photovoltaic (PV) cells. To address the power flow problems using PV cells, Optimal Line Flow (OLF) solution is used for solving and obtaining an optimal operating result for all the generators in distributed power systems. We proposed an Euclidean affine flower pollination algorithm (eFPA) to addresses the line flow OLF constraint for minimizing the fuel cost, loss, emission and voltage stability index. A multi-objective function for all the above constraints is used in eFPA to solve the OLF constraint. Results proved that the eFPA optimization for OLF constraint proved to be efficient because of its minimization of cost, loss, emission and voltage stability index. The analysis is performed on IEEE 30 bus system and IEEE 57 bus system.

Keywords OLF; security constraint; FPA; multi objective; Emission.

1. Introduction

Dommel and Tinney extended Newton’s power flow and introduced OPF [1]. This OPF provides solution for reducing electricity production cost and transmission line losses. The control and dependent variables limits the real and reactive power balance that is ensured for the optimization. Alsac and Stott extend this OPF solution for steady state contingency analysis [2]. Further, line outage contingency is considered and the OPF solutions which compromise constraints on dependent and control variables are verified with 30 bus test case system. IEEE 30 bus test case system became a standard and dominates the literatures so far and in the future. In power system economic load dispatch (ELD) is commonly used to find generation or fuel cost. To ensure the social welfare and air pollution act, emission of thermal power plants is optimized for economic emission dispatch (EED). But for the operation of power system both fuel cost and emission are most important issue and hence both ELD and EED combined together for the optimization called combined economic emission dispatch (CEED). In this CEED the bi-objective is converted into single objective using price penalty factor [3]. Another method of solving CEED is using multi-objective intelligent algorithm, which optimizes multiple objectives simultaneously and provide pareto-solutions.

This CEED laid the path for the formulation of multi-objective OPF problem. The most commonly used multi-objectives of OPF are generating cost, emission, loss and voltage improvement. Numerous optimization techniques have been used for solving OPF is summarized by Ming, Can and Zhao [7]. Conventional optimizations techniques for solving multi-objective OPF is done through inferiority and superiority of intelligent algorithms like genetic algorithm (GA) [13], differential evolution (DE) [12], evolutionary algorithm [4], particle swarm optimization (PSO) [10] and Evolutionary programming (EP). Niknam used improved particle swarm optimization (IPSO) to solve multi-objective OPF and fuzzy technique to extract best solution from pareto-solutions [5].

The main stability constraint of OPF is voltage limit that is considered in all literatures but very few literatures actually implements practical line flow limit constraint [6]. Line flow constraint or security constraint for the practical power system operation particularly plays a vital role in deregulated power system [18,19]. Ramesh Kumar and Premalatha lead the OPF into deregulated power system [8] where the multi-objectives are converted into single objective by using penalty factors. In the deregulated system power transaction form one area to another area through the transmission lines are vital. The line flows in various transmission lines are not focused and discussed in literatures.

This paper addresses the line flow in various transmission lines and enforces the security constraint. A non-linear complex multi-objective OLF requires a powerful intelligent optimization algorithm for optimizing results in its search space. In 2012, a new intelligent algorithm had been proposed based on the pollination process of flowers in the tree or plant [9] and named as Euclidean affine flower pollination algorithm (eFPA). The plants and trees survived billions of years using the process of pollination. eFPA is a new meta-heuristic algorithm well suited to solve real world problems [11]. This efficient eFPA application is extended in this paper to solve the multi-objective function including PV generation.

2. Problem formulation

OLF is a power system optimization problem and has an objective function to be optimized that is subjected to certain constraints. This paper addresses both equality and inequality constraints in deregulated power systems in PV solar system for solving OLF. This complex and non linear OLF problem has multi-objectives of minimizing cost or generation cost, minimization of emission, minimization of loss and improvement voltage stability and improvement of security for power transmission between two areas. The mathematical model of the multi-objective functions is given below. Minimization of fuel cost or generation cost is the prime objective function stated mathematically,

$$f_1(P_g) = \sum_{i=1}^{NG} x_i + y_i * P_{gi} + z_i * P_{gi}^2 \quad \text{\$/hr} \tag{1}$$

Minimization of emission improves social welfare and stated mathematically,

$$f_2(P_g) = \sum_{i=1}^{NG} (a_i P_{gi}^2 + b_i P_{gi} + c_i) + \left| d_i \sin(e_i (P_{gi\_\min} - P_{gi}) \right| \quad \text{\$/hr} \tag{2}$$

Minimization of loss is stated as,

$$f_3(V,\theta) = \sum_{k=1}^{NBR} g_k (V_s^2 - V_r^2 - 2V_s V_r \cos(\theta_s - \theta_r)) \quad \text{MW} \tag{3}$$

Voltage security is measured by L_{index}, which should be as low as possible and stated as,

$$f_4(V) = \left| 1 - \sum_{n=1}^{NG} F_{jn} \frac{V_n}{V_j} \right| j = NG+1,\ldots,NB \tag{4}$$

Practical consideration in deregulated power system is the power transfer from one area to another area through the transmission line. This has to be secured and stated that the power flow should less than the maximum capacity of the transmission line,

$$f_5(V,\theta) = MVA_k^{\max} - MVA_k, \quad for\, k = 1,\ldots NBR \tag{5}$$

Where, P_{gi} is real power generation of i^{th} generator, NG is number of generator, x_i, y_i, z_i are co-efficient of quadratic fuel cost function, a_i, b_i, c_i, d_i, e_i are co-efficient of emission function, g_k is conductance of k^{th} transmission line, NBR is number of branch, V_s, V_r are sending and receiving end voltage magnitude, Θ_s, Θ_r are sending and receiving end voltage angle, F_{jn} is a special admittance matrix formulated using load to load and load to generator bus admittance sub matrices, V_n, V_j are generator bus and load bus voltage magnitude, and NB is number of bus. These multi objective functions from equation (1) to (5) are combined to form single objective function as given by equation (6),

$$f = \min(\lambda_c f_1 + \lambda_e f_2 + \lambda_l f_3 + \lambda_v f_4 + \lambda_m f_5) \tag{6}$$

Where λ_c, λ_e, λ_l, λ_v, λ_m are penalty factors for the respective fuel or generating cost function, emission function, transmission line loss, voltage security and line flow security functions.

Consider m solar power plants, the scheduled solar power are given as:

$$S_{share} = \sum_{i=1}^{m} P_i U_i \tag{7}$$

Where, P_i is the power available from i^{th} plant and U_i represent the status of the plant (ON or OFF).

The cost due to solar power plant is represented using:

$$S_{\text{Cos}t} = \sum_{i=1}^{m} P_i U_i \times PU_i \tag{8}$$

Where, PU_i represents per unit cost of i^{th} solar plant. Along with multi objective cost function, we need to minimize the constraints due to PV power plants, thus multi-objective OLF could be extended to:

$$f = \min(\lambda_c f_1 + \lambda_e f_2 + \lambda_l f_3 + \lambda_v f_4 + \lambda_m f_5 + \tag{9}$$

Where,

$$f_6 = \sum_{i=1}^{m} P_i \times U_i \times PU_i + ks\left(\sum_{i=1}^{m} P_i - \sum_{i=1}^{m} P_i \times U \right) \tag{10}$$

This is subjected to following constraints:

$$P_d + P_L - \left(\sum_{i=1}^{m} P_i - \sum_{i=1}^{m} P_i \times U_i \right) = 0 \tag{11}$$

$$P_{i\min} \le P_i \le P_{i\max} \tag{12}$$

$$\left(\sum_{i=1}^{m} P_i \times U_i \right) \le 0.3 \times P_d \tag{13}$$

U_i = [0,1], ks is the constant that is used that makes the last term of Eq. 10.

The units on and off status depends on the unit price of the particular plant to be operated.

3. Euclidean affine Flower Pollination Algorithm (eFPA)

New meta-heuristic algorithm eFPA mimics the natural phenomena of flower germination. The flower is pollinated by its own pollen or from pollen of some other flower. This pollen is transferred to flower by means of air or insects or birds or animals. If the flower gets pollen of the same flower then it is called local pollination and if the flower gets pollen from another flower then it is called global pollination. In this algorithm pollens are nothing but control variables of the problem under consideration. Pollination of flower is the process of exchange of characteristic in nature, and in the eFPA it is the exchange of control variables. This process of pollination yields better values of control variables of the problem under consideration.

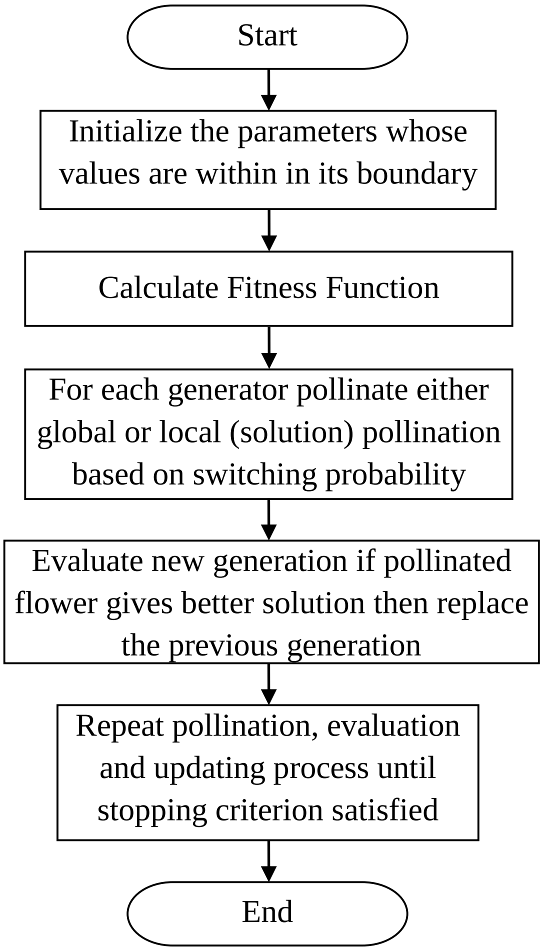

Fig. 1 eFPA flowchart for OLF problem

The processes involved in eFPA are initialization, pollination (either local or global), evaluation and selection [11,14,15].

Step 1: Initialization

Number of control variables in the problem under consideration is taken as a flower.

The values of these control variables are selected within its boundary condition and this process is called initialization of flowers [14].

Step 2: Pollination

Pollination is the process of exchange information or control variable values from one flower to flower. There are two type of pollination namely local and global pollination. In nature for the local pollination, pollen grains from the anther are fused into stigma of the same flower. But in the eFPA control variables of three flowers including pollen flower are participating to get pollination as given in the equation (14)

$$X_a^{i+1} = X_a^i + \varepsilon(X_b^i - X_c^i) \tag{14}$$

Where X_a^{i+1} is next or $(i+1)^{th}$ iteration pollinated flower, X_a^i is current or i^{th} iteration flower considered for the pollination, X_b^i and X_c^i are two different flowers in the current or i^{th} iteration of the same population, ε is a small constant.

In nature for global pollination, anther of one flower is fused into stigma of another flower by the action of insects or any other biotic. But in the eFPA control variable of best flower is used to update the pollinating flower as given in the equation (15)

$$X_a^{i+1} = X_a^i + \gamma L(X_a^i - X_g) \tag{15}$$

Where X_a^{i+1} is next or $(i+1)^{th}$ iteration pollinated flower, X_a^i is current or i^{th} iteration flower considered for the pollination, X_g is the global flower which given best solution, γ is scaling factor, and L is levy flight constant [14,16].

Step 3: Evaluation

Evaluation is the process of finding objective function value for the pollinated flowers, and to confirm the control variables in the pollinated flower are within in its lower and upper limits [14].

Step 4: Selection

Selection is the process of selecting either pollinated flower or old flower based on its objective value. The selection process in eFPA obeys elitism, which gives opportunity for best flower to participate in the next iteration [14]. Euclidean affine vector in the solution space is used to find the best convex combination of nearest node with best flower or solution. This solution is obtained after the evaluation of the best flower at the pollination stage. Thus to retrieve best solution from the vector space we use convex combination from Euclidean affine components updated over solution or vector space.

The Euclidean affine vector space with distance between the particles is defined in equation (16):

$$d(A,B) = |\overrightarrow{AB}| \tag{16}$$

The solutions have to be mapped with the solution vectors using:

$$d : \mathrm{A} \times \mathrm{A} \rightarrow \mathrm{T} \tag{17}$$

Where A is the Euclidean affine space and $d(A,B)$ is the distance between the points A and B that belongs to A.

Thus the mapping of the best variables in the solution space could be defined as:

$$A, B \mapsto \min(d(A, B)) \tag{18}$$

This can improve the speed of finding the particle at the faster than the normal vector space. The aim of using this is to obtain the solution vector at much faster time than what it actually was.

Step 5: Stopping criterion

Stopping criterion in eFPA may take as maximum number of iteration or when the problem is converged. In this paper maximum number of iteration is considered as stopping criterion [11]. This eFPA flowchart is given in the fig. 1 [14]. Using this eFPA, the best part is that the solution retrieved from particle space seems to be good than previous approaches.

4. Implementation of eFPA to solve OLF

To implement the multi-objective eFPA [17] formulation, number of control variables in the problem has to be identified. The control variables of OLF are real power generation P_g except slack generator, generator bus voltage magnitude V_g, transformers tap position T, and shunt connected reactive power sources Q_c. All these control variables form a flower as given in the equation (19),

$$F(P_g, V_g, T, Q_c) = \min(\lambda_c f_1 + \lambda_e f_2 + \lambda_l f_3) \tag{19}$$

Group of these flowers form the population. As like other intelligent algorithms 20 flowers or more than that constitute a population. Flowers in the population are subjected to the process of pollination, evaluation and selection or replacement repeatedly till the stopping criterion satisfied [15].

The OLF problem is subjected to power balance equality constraints as given in equation (20) and (21)

$$\sum_{i=1}^{NG} P_{gi} = \sum_{j=1}^{NB} P_{dj} + \sum_{k=1}^{NBR} P_{lk} \tag{20}$$

$$\sum_{i=1}^{NG} Q_{gi} = \sum_{j=1}^{NB} Q_{dj} + \sum_{k=1}^{NBR} Q_{lk} \tag{21}$$

Where P_{gi}, P_{dj}, P_{lk} are real power generation, real power demand and real power loss, and Q_{gi}, Q_{dj}, Q_{lk} are reactive power generation, reactive power demand and reactive power loss.

4.1 Generator constraints

Real and reactive power generation bounded between minimum and maximum limit, and similarly control variable of generator bus voltage magnitude,

$$P_{gi}^{\min} \le P_{gi} \le P_{gi}^{\max} \quad \text{, for } i=1 \text{ to } NG \tag{22}$$

$$Q_{gi}^{\min} \le Q_{gi} \le Q_{gi}^{\max} \quad \text{, for } i=1 \text{ to } NG \tag{23}$$

$$V_{gi}^{\min} \le V_{gi} \le V_{gi}^{\max} \quad \text{, for } i=1 \text{ to } NG \tag{24}$$

4.2 Transformer constraint

Transformer tap position may control the voltage magnitude and there by reactive power in the power system and becomes the control variable but bounded on its minimum and maximum tap position.

$$T_i^{\min} \le T_i \le T_i^{\max} \quad \text{, for } i=1 \text{ to } NTrans \tag{25}$$

4.3 VAR injection constraint

Power system has capacitor or reactive power source used to inject reactive or VAR power and becomes the control variable which is bounded by the limits

$$Q_{ci}^{\min} \le Q_{ci} \le Q_{ci}^{\max} \quad \text{, for } i=1 \text{ to } NCap \tag{26}$$

4.4 Security constraints

OLF solution should ensure secure operation of power system which includes voltage stability and line flow security given in the equation (27) and (28).

$$V_{Li}^{\min} \le V_{Li} \le V_{Li}^{\max} \quad \text{, for } i=1 \text{ to } NLoad \tag{27}$$

$$0 \le MVA_i \le MVA_i^{\max} \quad \text{, for } i=1 \text{ to } NBR \tag{28}$$

These load bus voltage and MVA flow in the transmission line are depended variables of the OLF. This minimization objective of OLF subjected to equality and inequality constraints is solved by the powerful eFPA which is explained in the following section.

5. Simulation results and discussion

eFPA is written in Matlab to solve multi-objective OLF problem. This eFPA is applied over power systems to solve the line flow constraint and OLF constraints. This multi-objective function is tested over two test cases of 30 bus and 57 bus systems with defined multi-objective minimization function to prove the ability of the proposed Line Flow and OLF formulation.

5.1 IEEE 30 bus system:

IEEE 30 bus system is used here for the study. It consists of 41 transmission lines, 6 generators, 4 transformers, and 2 shunt reactive power supports. It gives 5 real powers (P_g) except slack bus, 6 generators bus voltage magnitude (V_g), 4 transformers tap position, and 2 shunt reactive power support of total 17 control variables. These 17 control variables form a flower. 20 such flowers used to form a population, and 200 iterations considered as stopping criterion.

eFPA parameters are switching probability (p) is taken as 0.6, gamma (γ) is taken as 0.01, epsilon (ε) is taken as 0.3, and levy flight constant (L) is taken as 0.034. Maximum number of iterations is taken to be 200; total pollens is 100; The results obtained by eFPA for the test case IEEE 30 bus system for multi-objectives are given and discussed in the following sections.

Case 1: Generating cost minimization

Generating cost is calculated by the quadratic cost function given in the equation (1). This is the function of real power and generating cost depends on the real power generation, which is subjected to its minimum and maximum limit of generation. The result of eFPA is compared to other literatures in Table 1.

Table 1. Generating cost comparison for case 1

Real Power (MW)	PSO [5]	IPSO [5]	ARCBBO [8]	eFPA
Pg1	178.4	177.04	177.16	176.36
Pg2	46.27	49.21	48.56	49.21
Pg3	21.46	21.51	21.43	21.51
Pg4	21.45	22.65	21.29	22.65
Pg5	13.21	10.41	11.98	10.41
Pg6	12.01	12.00	12.00	12 .00
Cost ($/hr)	802.2	801.97	800.516	**799.70**

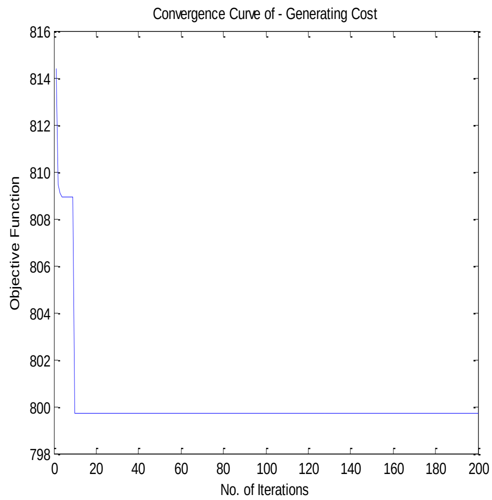

Fig 2: Convergence curve of eFPA for cost minimization objective

Proposed eFPA result is better than Particle Swarm Optimization (PSO), Improved PSO (IPSO), and Adaptive real coded biogeography-based optimization (ARCBBO). The convergence curve for cost minimization is given in Fig 2.

Case 2: Emission minimization

Emission has to be minimized using eFPA using the equation (2). The result is compared with other algorithm as given in Table 2. eFPA result is compared with other intelligent algorithm and it gives better result. The emission observed wrt iterations is plotted in Fig 3.

Table 2. Emission comparison for case 2

Real Power (MW)	PSO [5]	IPSO [5]	ARCBBO [8]	eFPA
Pg1	67.13	67.04	63.6625	47.97
Pg2	68.94	68.14	68	52.86
Pg3	49.73	50	50	67.12
Pg4	34.42	35	35	53.17
Pg5	29.67	30	30	12.57
Pg6	39.29	40	40	53.01
Emission (ton/hr)	0.2063	0.2058	0.2048	**0.2047**

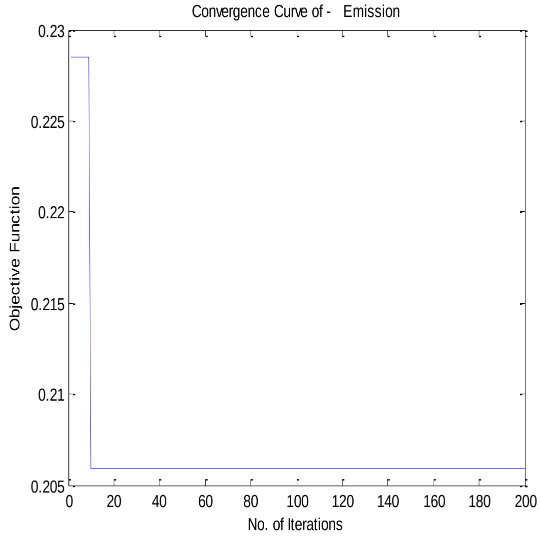

Fig.3 Convergence curve for Emission optimization

Case 3: Loss minimization

Transmission loss has to be minimized by economic scheduling of the committed generators using the equation (3). eFPA gives better result as compared to other algorithms except ARCBBO but eFPA overall multi objective result is better than this compared algorithm. The comparison is given in Table 3 and the convergence of power loss is shown in Fig 4.

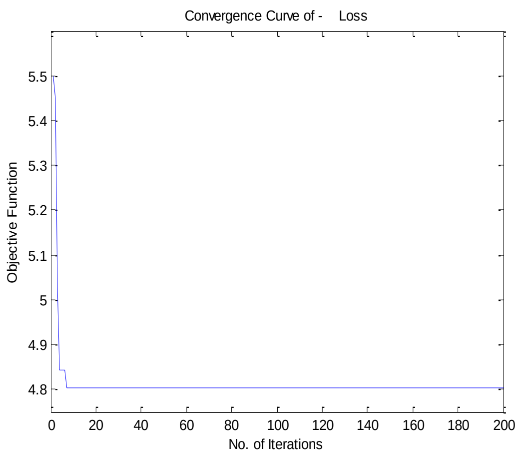

Fig. 4 Convergence curve for Loss optimization

Table 3. Comparison of Voltage Profile and Power Loss for Case 3

Voltage (pu)	PSO [5]	IPSO [5]	ARCBBO [8]	eFPA
Vg1	1.045	1.047	1.0618	0.97707
Vg2	1.043	1.044	1.0577	0.96062
Vg3	0.998	0.976	1.0381	0.95965
Vg4	1.009	1.035	1.0447	1.00159
Vg5	1.014	0.984	1.0854	1.07081
Vg6	1.047	1.042	1.0523	0.96976
Loss (MW)	5.2105	5.0732	3.1009	**4.80363**

Case 4: VSI minimization

Voltage stability index is the measure of voltage security. The power system stability in terms of voltage limit is found using the equation (4) and the comparison is given in Table 4. eFPA gives better result as compared to other algorithms. The convergence curve for VSI is given in Fig 5. It is observed that the value is converged in less than 10 iterations.

Table 4. VSI comparison calculated for case 4

Voltage (pu)	PSO [5]	IPSO [5]	ARCBBO [8]	eFPA
Vg1	1.0493	1.05	1.0694	1.005
Vg2	1.0485	1.047	1.0504	0.998
Vg3	1.049	1.049	1.0274	1.016
Vg4	1.026	1.021	1.0388	0.997
Vg5	1.025	1.023	1.0982	1.055
Vg6	1.031	1.043	1.0999	1.010
VSI	0.1042	0.1037	0.1369	**0.1012**

Case 5: multi-objective optimization

All the objectives are optimized simultaneously and the best optimal result by compromising all the objectives of eFPA given in the Table 5. Last column gives multi objective solution and first four columns gives four cases of single objective.

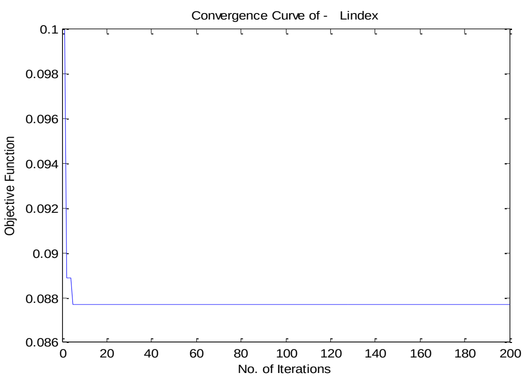

Fig. 5 Convergence curve for VSI optimization

Table 5. Control variables for different cases

Variables	**Case 1**	**Case 2**	**Case 3**	**Case 4**	**Multi Obj.**
Pg1	176.357	63.8795	75.5083	112.964	132.119
Pg2	49.209	68.1400	73.8144	38.526	56.1214
Pg3	21.5135	50.0000	40.9928	41.581	24.5562
Pg4	22.648	35.0000	42.3504	40.629	36.1271
Pg5	10.4146	30.0000	27.8329	22.476	25.8022
Pg6	12	40.0000	27.7048	33.128	16.0072
Vg1	0.972887	1.035	0.927072	1.005	1.026
Vg2	0.955911	1.027	0.960628	0.991	1.002
Vg3	0.937041	1.022	0.959655	1.016	0.978
Vg4	0.938297	1.025	1.00159	0.992	0.981
Vg5	1.00891	1.032	1.07081	1.055	0.992
Vg6	0.929429	1.021	0.969761	1.010	1.005
T1	1.01	1.06	0.952339	0.923	1.0187
T2	0.98	1.03	1.03402	1.028	1.0203
T3	1.01	1.01	0.959757	0.998	1.0416
T4	1.02	0.99	1.07622	1.007	1.0529
Qc1	27.270	12.53	28.316	22.818	16.320
Qc2	22.430	8.741	12.626	17.795	21.063
Cost ($/hr)	**799.70**	946.227	900.635	869.447	**821.996**
Emission (Ton/hr)	0.36559	**0.2047**	0.216357	0.2397	**0.2711**
Loss (MW)	8.74277	3.6224	**4.80363**	5.916	**7.3365**
VSI	0.12102	0.0877	0.09253	**0.1012**	**0.1104**
Mean (FPA)	1.06E+01	2.12E+01	2.06E+01	1.46E+00	1.29E+00
Standard Deviation (FPA)	8.95E+00	1.08E+01	4.17E+00	5.96E−01	5.35E+01
Mean	0.95 E+01	2.03E+01	2.06E+01	1.46E+00	1.29E+00
Standard Deviation (eFPA)	8.84 E+00	0.95E+01	3.88E+00	5.22E−01	5.08E+01

5.2 IEEE 57 Bus test system:

IEEE 57 bus system is has 7 generators including slack generator, 17 transformers and 3 shunt reactive power support. This system has total load of 1250.8MW and 336.4 MVAR. eFPA is applied to the system for finding the OLF solution for cost minimization objective and is compared with a recent method and are given in table 6 and 7. From Table 6 it is observed that eFPA gives better results in terms of cost. It is also observed that the voltages at the generator buses are in desirable limits.

Table 6. OLF solution of our proposed eFPA algorithm tested over IEEE 57 bus

Control Variables	**ARCBBO [8]**	**eFPA**
Pg1 (MW)	142.5804	141.59

Pg2 (MW)	89.8965	89.79
Pg3 (MW)	44.6317	43.91
Pg4 (MW)	75.3757	76.27
Pg5 (MW)	495.0765	456.97
Pg6 (MW)	96.2061	96.56
Pg7 (MW)	358.4099	359.92
Vg1 (p.u)	1.080	1.040
Vg2 (p.u)	1.077	1.010
Vg3 (p.u)	1.064	0.985
Vg4 (p.u)	1.080	0.980
Vg5 (p.u)	1.054	1.005
Vg6 (p.u)	1.049	0.980
Vg7 (p.u)	0.901	1.015
T1 (p.u)	1.099	0.97
T2 (p.u)	1.001	0.978
T3 (p.u)	1.072	1.043
T4 (p.u)	1.000	1.000
T5 (p.u)	1.067	1.000
T6 (p.u)	1.000	1.043
T7 (p.u)	0.992	0.967
T8 (p.u)	0.976	0.975
T9 (p.u)	0.992	0.955
T10 (p.u)	0.955	0.955
T11 (p.u)	0.997	0.900
T12 (p.u)	1.000	0.930
T13 (p.u)	0.994	0.895
T14 (p.u)	1.068	0.958
T15 (p.u)	0.994	0.958
T16 (p.u)	1.000	0.980
T17 (p.u)	1.000	0.940
Qc1 (Mvar)	8.771	45.0
Qc2 (Mvar)	13.995	25.9
Qc3 (Mvar)	9.942	26.3
Cost ($/hr)	**41686.54**	**41641.15**

Table 7. Fuel cost comparison of various algorithms tested over 57 bus system

Methods	Fuel Cost ($/hr)
GSA [8]	41695.872
ABC [8]	41693.959
ARCBBO [8]	41686.545
eFPA	**41641.15**

5.3 OLF of Combined Solar Thermal system:

This test is conducted over duration of 4 hours from 10.00am to 1.00pm. The total solar power generation is limited to 30 percent on the total demand. A total of 10 solar units with different cost functions are considered. The solar units are operated only if the minimum generation constraint is fulfilled. The data related to solar farm is given in Appendix. The results of which is shown in Table 9. The optimized costs were reliably less when compared with normal cost. Depending upon the availability of the solar generation, solar share gets increased or decreased due to eFPA.

Table 8. Comparison of OLF incorporating solar

		10 am	11 am	12 pm	1 pm
Total Demand (MW)		1244	1088	1240	1135
Thermal generation	**P1 (MW)**	121.24	11.05	11.00	11.01
	P2 (MW)	93.64	94.38	94.61	119.02
	P3 (MW)	156.87	100.45	195.60	148.04
	P4 (MW)	77.56	169.67	178.17	187.65
	P5 (MW)	258.48	236.26	225.62	151.56
	P6 (MW)	303.02	247.04	304.25	222.64
	PT(MW)	1010.81	775.85	926.25	839.92
Solar generation	**U1**	37.92	39.79	41.65	38.41
	U2	37.92	39.79	41.65	38.41
	U3	37.92	39.79	41.65	38.41
	U4	37.92	39.79	41.65	38.41
	U5	37.92	39.79	41.65	38.41
	U6	37.92	39.79	41.65	38.41
	U7	37.92	33.83	41.65	38.41
	U8	37.92	33.83	41.65	38.41
	U9	34.92	10	19.4	16.61
	U10	34.92	10	19.4	16.61
Solar power share (MW)		373.2	326.4	372	340.5
Cost	**Fuel ($/h)**	8262.4	5938.4	8652.2	5836.1
	Solar ($/h)	894.48	770.25	883.9	808.41
	Total ($/h)	9156.88	6708.65	9536.1	6644.51

6. Conclusion

Thus eFPA is applied over power systems by, solving multi-objective OLF problem. The variables are calculated using eFPA that proved to be efficient than previous works that includes Newton method, PSO, IPSO and ARCBBO. The calculations with eFPA variables proved to provide a better result in terms of its generation cost, emission, losses and voltage stability index. When comparing cost with existing techniques, it is found that the optimal results had reduced the total cost of the system. Similarly, emission has reduced to a certain extent than the previous techniques. Likewise, total loss with voltage variable has reduced using eFPA approach than the previous techniques. Voltage stability index results were promising when the eFPA is applied over the system. Thus eFPA, OLF minimization constraints are proved to be effective and provided nominal results when compared with previous approaches. This model can further be applied over other standard buses for reducing the optimal cost in conventional generating resources. Furthermore, the technique could be applied over other renewable resources also to solve the OLF problems.

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Appendix

Solar farm data considered for the analysis

Solar Unit	Ps min	Ps max	Cost/MW($/hr)
U1	10	60	2.2
U2	10	60	2.2
U3	10	60	2.3
U4	10	60	2.3
U5	10	60	2.4
U6	10	60	2.4
U7	10	60	2.5
U8	10	60	2.5
U9	10	60	2.6
U10	10	60	2.6