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Firefly algorithm to solve non-convex economic dispatch problems with generator constraints and heuristic load patterns

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ABSTRACT

This paper presents a new algorithm called Firefly Algorithm (FA) to solve the well-known power system economic load dispatch (ELD) problem. FA is a novel nature-inspired algorithm inspired by social behavior of fireflies and the phenomenon of bioluminescent communication between them. The effectiveness of the proposed algorithm has been tested with the standard 6-bus, IEEE-14 bus and IEEE-30 bus system with several heuristic load patterns. The result of the proposed algorithm is compared with the results available in the literature. The numerical result reveals that the proposed algorithm can provide appreciably better solutions within reasonable time.

Introduction

The main objective of economic load dispatch problem of electric power generation is to schedule the output power of committed generating units so as to meet the required load demand at minimum operating cost while satisfying all units and system equality and inequality constraints. In the conventional methods, the input-output characteristics of the thermal generators are usually approximated by quadratic functions or piecewise quadratic functions. It can be solved by using mathematical based optimization programming techniques like Lambda-iteration, Gradient, Newton method, Base-point participation factor method and so on. Dynamic programming method is one of the approaches to solve the inherently non-linear and discontinuous ELD problem. However, it suffers from the "curse of dimensionality" or local optimality hence the conventional methods are not suitable for determining the global optimum solution of the ELD problem. The input-output characteristics of modern generators are non-linear and highly constrained because of the valve point loading effects, generating units ramp rate limits, etc. A unit with prohibited operating zones, its operating region [P_{min} to P_{max}] will be broken into several isolated sub-regions. These isolated sub-regions will form multiple decision spaces and result in very challenging task for determining the optimal economic dispatch.

Recently, power system engineers are inspired to apply different Artificial Intelligent (AI) techniques to a variety of optimization problems in power systems.

AI techniques including the genetic algorithm (GA), evolutionary programming (EP), simulated annealing (SA), differential evolution (DE), particle swarm optimization (PSO) [1–7] etc. appear to be very efficient in solving highly non-linear and discontinuous ELD problems without any restriction on the shape of cost curves due to their ability to seek the global optimal solution. Normally heuristic methods do not always guarantee the globally optimal solution but they generally provide a fast and acceptable solution, which is suboptimal and more or less equal to the global optimal. The FA was developed by Dr. Xin-She Yang at Cambridge University in 2009 [8]. Since its inception, FA has been successfully applied to solve many engineering optimization problems like standard pressure vessel design optimization [9], mixed variable structural optimization [10], flow shop scheduling problems [11], solving the economic emissions load dispatch problem [12] etc. In this article, this efficient FA is introduced to optimize the ELD problems with valve point loading effect, prohibited operating zones, ramp rate limits, spinning reserve constraints (only for IEEE-14 bus system) and with load patterns. The result obtained by the proposed FA is compared with IFEP and PSO methods, to validate the proposed method can produce very effective optimum generation schedule than others.

Economic load dispatch problem formulation

The objective function for the generation cost is minimized based on the simplified quadratic cost function which is subjected to various system constraints [13]. Mathematically, the problem is expressed as

$$\text{Minimize } F_T = \sum_{i=1}^{N} F_i\,(P_i) \qquad (1)$$

where

$F_i\,(P_i) = a_i + b_i P_i + c_i P_i^2$ without valve point loading effect and

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$F_i(P_i) = a_i + b_i P_i + c_i P_i^2 + |e_i \sin(f_i \times (P_{i,min} - P_i))|$ with valve point loading effect.

where F_T is the total fuel cost; F_i is the fuel cost of i^{th} generator; a_i, b_i and c_i are the fuel consumption cost coefficients of the i^{th} unit. e_i and f_i are the fuel cost coefficients of the i^{th} unit with valve point effects and P_i is the power output of the i^{th} generator in megawatts.

The minimization of the generation cost is subjected to the following equality and inequality constraints:

Real power balance constraint

$$\sum_{i=1}^{N}(P_i - P_D - P_L) = 0 \qquad (2)$$

where P_L is the total real power transmission losses, P_D is the total demand, and N is the total number of the online generators. The traditional B loss matrix formula is used to calculate transmission losses.

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

where B_{ij} is the ij^{th} element of the loss coefficient square matrix; B_{0i} is the i^{th} element of the loss coefficient vector; and B_{00} is the loss coefficient constant. Solving these equations for different load patterns by IFEP, PSO and FA method, a set of economic load scheduling solution has to be obtained.

Generation limit constraint

$$P_{i,min} \le P_i \le P_{i,max} \text{ , for } i = 1, 2, 3 \ldots\ldots N \qquad (4)$$

where $P_{i,\min}$ and $P_{i,\max}$ are the minimum and maximum active power limits on the loading of the i^{th} generator.

Prohibited operating zones

A generating unit with prohibited operating zones has a discontinuous input-output power generation characteristic which gives rise to additional constraints on the unit operating range.

$$P_i = \begin{bmatrix} P_{i,min} \le P_i \le P_{i,1}^L & \text{or} \\ P_{i,k-1}^U \le P_i \le P_{i,k}^L & \text{or} \\ P_{i,n_i}^U \le P_i \le P_{i,max}, & k = 2,3,\ldots,n_i \end{bmatrix} \qquad (5)$$

where n_i is the number of prohibited operating zones in the i^{th} generating unit. k is the index of the prohibited operating zones of the i^{th} generating unit. $p^L_{i,k}$ and $p^U_{i,k}$ are the lower and upper bounds of k^{th} prohibited operating zones of unit i.

Ramp rate constraint

The ramp rate constraint restricts the operating range of the physical lower and upper limit to the effective lower limit $p_{i,min}$ and upper limit $p_{i,max}$ respectively.

This constraint can be formulated as follows:

$$\max(p_{i,min}, p_i^o - DR_i) \le p_i \le \min(p_{i,max}, p_i^o + UR_i) \qquad (6)$$

where p_i^o is the power generation of unit i at previous hour and UR_i and DR_i are the ramp rate limits of unit i as generation increases and decreases respectively.

System spinning reserve constraint

The spinning reserve constraint for securing power system is as follows:

$$\sum_{i\in\Omega}^{n} S_i \ge S_R \qquad (7)$$

where S_i: spinning reserve contribution of unit i in MW

S_R: system spinning reserve requirement in MW

$$S_i = \min[(P_{i,max} - P_i), S_{i,max}] \quad \forall\ i \in (\Omega - \Delta) \qquad (8)$$

where Ω : set of all on-line units.

$P_{i,max}$: maximum generation limit of unit i.

$S_{i,max}$: maximum spinning reserve contribution of unit i

Δ : set of all on-line units that have prohibited operating zones.

$S_i = 0, \quad \forall\ i \in \Delta$

The spinning reserve constraint restricts only the physical upper generation limit in generators that do not have prohibited operating zones. The effective upper generation limit can be determined by the following equations (9) & (10) [14].

$$\sum_{i\in(\Omega-\Delta)} \bar{P}_i = \left[\sum_{i\in(\Omega-\Delta)} \bar{P}_{i,max}\right] - S_R \quad \forall\ i \in (\Omega-\Delta) \qquad (9)$$

$$\max\left|(P_{i,max} - S_{i,max}), P_{i,min}\right| \le \bar{P}_i \le P_{i,max} \qquad (10)$$

Firefly algorithm

Recently, Yang 2009 [8, 9] has developed a new meta-heuristic algorithm, called as Firefly Algorithm. The flashing characteristics of the fireflies are used to develop firefly algorithm, based on the following three idealized rules:

(1) all fireflies are considered as unisex, one firefly gets attracted to the other fireflies regardless of their sex.

(2) The landscape of the objective function to be optimized determines or affects the brightness or light intensity of a firefly at a particular location.

(3) Attractiveness of two flashing fireflies is proportional to their brightness, thus for any two flashing fireflies, the less bright one will move towards the brighter one. Even though the attractiveness of a firefly is proportional to the brightness, it will decreases as distance between the fireflies increases this is due to the fact that the air absorbs light. If there is no brighter or more attractive firefly, than a particular firefly, it will move randomly in the space.

For a maximization problem, the brightness can simply be proportional to the objective function. Other forms of brightness can be defined in a similar way to the fitness function in genetic algorithms or bacterial foraging algorithm (BFA) [15].The firefly algorithm and the bacteria foraging algorithm have certain conceptual similarity. However, they slightly differ from each other. First, in the case of BFA, the attraction among bacteria depends partly on their distance and partly on their fitness value. On the other hand, in FA, the attractiveness is linked to its fitness function and decays monotonically with distance between fireflies. Second, the agents in FA has adjustable visibility and more versatile attractiveness variations loading to higher mobility makes the solution space to explore more efficiently. Third, FA has two important limit cases. So properly combining the advantages of both limit cases, the searching capacity of the FA can be enhanced.

Movement:

The movement of a firefly *a* towards another more attractive (brighter one) firefly *b* is determined by equation (11)

$$x_a^{t+1} = x_a^t + \beta_0 * \exp(-\gamma d_{a,b}^2) * (x_b^t - x_a^t) + \alpha * (rand - 1/2)^t \qquad (11)$$

where t, γ and β_0 are number of generation, absorption coefficient which controls the light intensity and attractiveness at d = 0, respectively. The first term denotes the current position of a firefly, the second term denotes the attractiveness between the fireflies and the third term is to generate the random movement among the fireflies in case there are no brighter ones. The distance between any two fireflies *a* and *b*, at the positions x_a and x_b can be expressed in Cartesian distance as shown in (12).

$$d_{ab} = \|x_a - x_b\|_2 = \sqrt{\sum_{k=1}^{n}(x_{a,k} - x_{b,k})^2} \qquad (12)$$

where $x_{a,k}$ is the k^{th} component of the spatial coordinate x_a of the a^{th} firefly and n is the number of dimensions. The coefficient α is a randomization parameter which is problem dependent, while *rand* is a random number generator uniformly distributed in the space [0, 1]. From the equation (11), it's inferred that there exist two limit cases when γ is very large or very small, respectively. When γ tends to zero, the attractiveness and brightness are constant. Therefore, a firefly can be viewed by all other fireflies. Conversely, when γ is very large, the attractiveness and thus brightness is almost zero, and as a result, the fireflies cannot see each other, and they move completely in random fashion, which corresponds to a random search method. Normally, FA performs occurs between these two limits cases, thus by properly tuning these parameters, FA can be made to outperform both standard PSO and random search algorithm. In general, γ should be related to the scales of each variable.

The pseudo-code of firefly algorithm is as follows:

Begin of algorithm

Generate initial population of firefly $X_{j,i}$, using equation

$X_{j,i} = X^L_{j,i} + \text{rand}\ (X^U_{j,i} - X^L_{j,i})$

(where j = 1, 2 ,…, n , i = 1, 2 ,…, N and N is number of decision variables)

Calculate objective function f(X), $X = (x_1 ,..., x_N)^T$

Define algorithm parameters

(γ - light absorption coefficient, α - randomization parameter and β_0 - attractiveness)

While (t < max generation)

for j = 1 : n all n firefly

for k = 1 : j all n firefly

Light intensity I_a at x_a is decided by $f(X_a)$

if ($I_a < I_b$)

Move firefly *a* towards firefly *b* (move towards brighter one)

Attractiveness varies with distance $d_{a,b}$ via exp $[-\gamma\, d^2_{a,b}]$

Generate and evaluate new solutions and update light intensity

end for k loop

end for j loop

Check equality and inequality constraints violations

Rank the fireflies and find the current best

end while

% post process results

Display the firefly with the highest light intensity among all the fireflies, that is the optimal solution

Plot the light intensity versus time/iterations

end of algorithm

Case Study and Simulation Results

The standard 6-bus system [13], IEEE-14 bus system [16] and IEEE-30 bus system [17] were taken as test systems to demonstrate the effectiveness of the proposed FA algorithm. Two different cases were considered along with different load patterns:

Case-1: Cost function with prohibited operating zones, ramp rate limits and without valve point loading effect. &

Case-2: Cost function with prohibited operating zones, ramp rate limits, spinning reserve constrains (only for IEEE-14 bus system) and with valve point loading effect.

There are four important control parameters in the FA. They are α, β_0, γ and population size n. In order to obtain right parameters, a detailed parametric study was conducted by varying these parameters. Finally, the best values for the parameters of the proposed FA, PSO and IFEP method are as follows:

FA	PSO	IFEP
Population size(n) = 20	Population size = 20	Population size = 20
Max_ iteration(t) = 300	Max_ iteration = 300	Max_ iteration = 300
Alpha (α) = 0.6	Inertia weight: W_{max}= 0.9, W_{min} = 0.4	Mutation operator = 0.01
Beta(β_0) = 1 Gamma(γ) = 1	Acceleration coefficients: C1 = C2 = 2	Selection operator= 0.08

The optimal solutions obtained by PSO and IFEP methods using their best parameters values were already reported in [18]. To validate the result of proposed FA method; the simulation result of FA is compared with the result of IFEP and PSO in [18] for all the test cases under consideration. The convergence characteristics of FA, PSO and IFEP for case-2 of 30-bus system (P_D=283.4MW) are shown in Fig.1

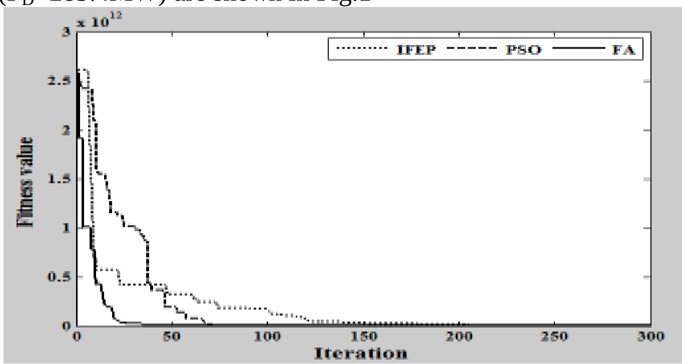

Fig.1 : Convergence characteristic of 30 bus system for case 2 (P_D=283.4MW)

In this paper, the best production cost and mean execution time presented are obtained after conducting 30 trial runs for all the test cases. Equality constraint is satisfied by taking one of the generators as dependent, in the case of standard 6-bus system, out of three generators, the third generator (P_{G3}) is assumed as dependent and its value is calculated as follows:

$$P_{G3} = (P_D+P_L) - (P_{G1}+P_{G2}) \quad (13)$$

where P_D is the total demand, P_L is the total real power transmission losses and P_{G1}, P_{G2} are randomly generated values within the limits of first and second generators. Penalty function method is used to penalize the dependent generator value, if it violates the limits. The same penalty function method is used to penalize generation value, if it falls between the limits of prohibited operating zones. The software was written in MATLAB-7 language and executed in a 1.6 GHz, Pentium-IV, 128 MB RAM, personal computer.

Test System 1

The proposed FA method was tested in the standard 6-bus system which composed of three thermal generating units and three load buses. The line parameters and cost curve data's are given in [13, 19]. Heuristically taken load demands with their load patterns are given in the Table.2 of [19]. The ramp rate limits and prohibited operating zones of on-line units are given in Table.1of [18]. The minimum production costs obtained for all load patterns of case-1 and case-2 are shown in the Table.1 & 2. The computational efficiency of the FA is demonstrated using the production cost distribution curves in Fig.2 for the load demand of 195MW of case-2. From the Fig.2, the maximum production cost obtained by IFEP=$5853.63, PSO=$4648.68 and FA=$3668.62. The mean production cost obtained by IFEP=$4828.47, PSO=$4011.61 and FA=$3231.88. The minimum production cost obtained by IFEP=$3041.46, PSO =$3040.54 and FA=$3034.32. In the case of FA, out of 30 trials, the frequency of achieving production cost better than the mean production cost is 19, which is higher compared to IFEP and PSO. The production cost in FA at different trials varies in a smaller range when compared to IFEP and PSO method. This shows that the proposed FA has the capacity to generate better quality solution. The result obtained by the proposed FA method is better than IFEP and PSO methods reported in [18], in saving the cost of generation significantly, reducing line loss and also reduces execution time. It can be observed from the table 1 and 2, that the production cost of case-2 is higher than case-1 due to the presence of valve point loading effect.

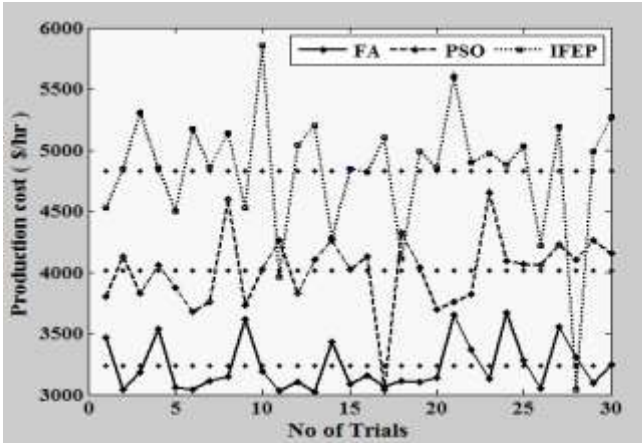

Fig. 2 : Distribution of production cost for 30 trials runs of 6-bus system case-2 (Load demand of 195MW).

Test System 2

The proposed FA method was also tested in the IEEE-14 bus system with five thermal generating units. The cost curve data is presented in [19] in this, P_{max} value of units 4 and 5 is taken as 76 MW each instead of 45 MW and all other necessary information is presented in [16]. Two heuristically taken load patterns of 260.01MW and 289 MW are given in Table.4 of [18]. The ramp-rate limits and prohibited operating zones of on-line units 1, 2 and 3 are given in Table.5 of [18]. The total spinning reserve requirement is 60 MW. Based on equations 7 to 10, the effective upper generation limits computed for units 4 and 5 are 46 MW each and so that the units 4 and 5 will have reserve capacity of 30 MW each. The comparative simulation results of the proposed FA, IFEP and PSO are given in Table.3 for the load demands of 260.01MW and 289MW.The production cost distribution for 30 different trial runs is shown in Fig.3 for the load demand of 260.01MW of case-1. From the Fig.3, the maximum production cost obtained by IFEP=$3494.84, PSO=$1987.54 and FA=$1585.67. The mean production cost obtained by IFEP=$2604.09, PSO=$1624.17 and FA=$1044.44. The minimum production cost obtained by IFEP=$781.44, PSO =$780.72 and FA=$770.69. In the case of FA, out of 30 trials, the frequency of achieving production cost better than the mean production cost is 17, which is higher compared to IFEP and PSO. Once again it is proved, that the proposed FA has the capacity to generate better quality solution. The result obtained by the proposed FA method is better than the result of IFEP and PSO methods reported in [18], in saving the cost of generation, reducing line losses and also reducing execution time. In this case also, the production cost of case-2 is higher than case-1 due to the presence of valve point loading effect.

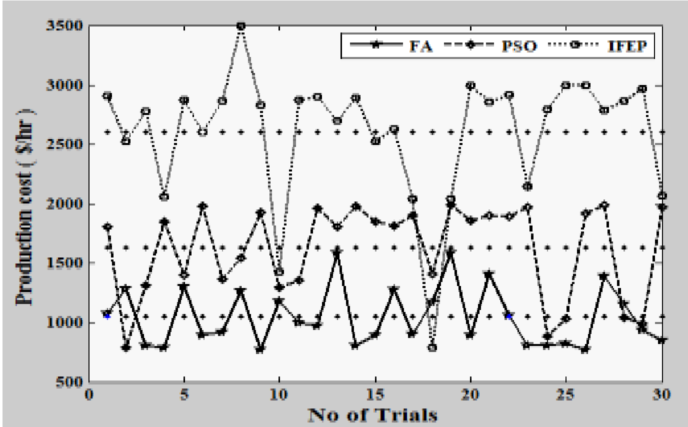

Fig. 3 : Distribution of production cost for 30 trials runs of 14-bus system case-1 (Load demand of 260.01MW)

Test System 3

The effectiveness of the proposed FA method was also further tested by applying it to the IEEE-30 bus system, which composed of six thermal generating units. The cost curve data and all other necessary information are presented in [17, 19]. Two load patterns used for the simulation are given in Table.7 of [18]. The ramp rate limits and prohibited operating zones of all on-line units are given in Table.8 of [18]. The comparative simulation results of IFEP, PSO and the proposed FA method are given in Table.4 for the load demands of 283.4MW and 360MW. The production cost distribution for 30 different trial runs is shown in Fig.4 for the load demand of 283.4MW of case-2. The maximum production cost obtained by IFEP=$1672.56, PSO=$1474.93 and FA=$1328.32. The mean production cost obtained by IFEP=$1326.17, PSO=$1173.08 and FA=$955.78. The minimum production cost obtained by IFEP=$830.39, PSO =$828.15 and FA=$812.53 is shown in Fig.4. Out of 30 trials, the frequency of achieving production cost better than the mean production cost in FA method is 18, which is higher compared to IFEP and PSO. This shows that the proposed FA has the capacity to generate better quality solution than others. The result obtained by the proposed FA method is better than the result of IFEP and PSO methods reported in [18], in saving the cost of generation, reducing line losses and also reducing execution time. In this case also, it is noticed that the production cost of case-2 is higher than case-1 due to the presence of valve point loading effect.

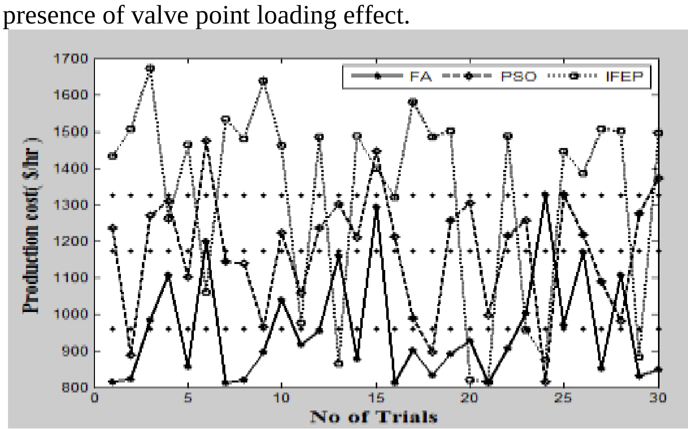

Fig. 4 : Distribution of production cost for 30 trials runs of 30-bus system Case-2 (Load demand of 283.4MW)

Conclusion

The application feasibility of the proposed FA for solving economic load dispatch by taking into account of load pattern problem with various systems constraints like valve point loadings, prohibited operating zones, ramp rate limits, spinning reserve requirements have been investigated successfully. The simulation result shows that the proposed FA method can give competitively cheaper generation cost and at the same time the transmission line losses also reduced considerably. Furthermore, the execution time of FA for all the test systems under consideration is almost constant and less compared to the IFEP and PSO methods reported in the literature. Hence, the performance of the proposed FA appears to be an efficient and powerful tool to solve highly nonlinear discontinuous cost functions of ELD problem and to obtain globally better optimum solution. In the future work, the proposed FA technique will be applied to solve optimal power flow problem to further investigate its performance.

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Table. 1 : Comparative result of 6-bus system for Case-1

S. No	P_D (MW)	Method	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_L (MW)	Cost ($/hr)	Average time(Sec)
1	195	IFEP	65.00	77.30	59.00	6.30	2950.91	0.61
		PSO	60.22	81.13	59.90	6.25	2949.27	0.56
		FA	**61.95**	**80.56**	**58.77**	**6.28**	**2949.18**	**0.40**
2	225	IFEP	60.78	111.94	59.90	7.62	3325.59	0.61
		PSO	62.59	85.37	84.56	7.52	3321.48	0.56
		FA	**60.72**	**90.61**	**81.18**	**7.51**	**3318.82**	**0.41**
3	235	IFEP	65.00	102.50	75.61	8.11	3448.05	0.60
		PSO	60.00	102.20	80.89	8.09	3446.09	0.57
		FA	**60.00**	**104.00**	**79.07**	**8.07**	**3446.06**	**0.42**
4	265	IFEP	65.00	122.00	87.43	9.43	3830.78	0.61
		PSO	63.50	111.05	99.85	9.40	3828.23	0.56
		FA	**65.23**	**109.22**	**99.93**	**9.38**	**3828.11**	**0.41**
5	285	IFEP	66.12	125.00	103.97	10.09	4084.86	0.60
		PSO	70.51	117.41	107.12	10.04	4083.61	0.56
		FA	**70.50**	**117.41**	**107.12**	**10.03**	**4083.51**	**0.41**

Bold values indicate the results of proposed FA method. IFEP and PSO results taken from [18]

Table. 2 : Comparative result of 6-bus system for Case-2.

S. No	P_D (MW)	Method	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_L (MW)	Cost ($/hr)	Average time(Sec)
1	195	IFEP	109.84	47.88	45.02	7.74	3041.46	0.65
		PSO	109.87	47.83	45.00	7.70	3040.54	0.56
		FA	**108.00**	**49.03**	**45.59**	**7.62**	**3034.32**	**0.41**
2	225	IFEP	60.05	127.82	45.00	7.87	3342.27	0.65
		PSO	60.00	127.86	45.00	7.86	3341.90	0.55
		FA	**63.00**	**124.83**	**45.00**	**7.83**	**3341.36**	**0.40**
3	235	IFEP	60.00	63.53	119.80	8.33	3474.89	0.64
		PSO	60.00	65.00	118.32	8.32	3473.99	0.55
		FA	**62.00**	**65.91**	**115.34**	**8.25**	**3468.74**	**0.41**
4	265	IFEP	60.00	91.99	122.61	9.60	3850.95	0.66
		PSO	60.10	91.52	122.95	9.57	3847.36	0.56
		FA	**65.00**	**91.34**	**118.16**	**9.50**	**3841.94**	**0.41**
5	285	IFEP	60.02	114.34	120.79	10.15	4089.72	0.65
		PSO	60.00	115.34	119.80	10.14	4087.40	0.55
		FA	**80.00**	**115.05**	**100.01**	**10.06**	**4086.10**	**0.41**

Bold values indicate the results of proposed FA method. IFEP and PSO results taken from [18]

Table. 3 : Comparative result of 14-bus system for Case -1 and 2.

Method	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_L (MW)	Cost ($/hr)	Average time(Sec)
Case-1, P_D=260.01MW								
IFEP	100.00	46.00	38.00	45.00	36.13	5.12	781.44	0.95
PSO	99.11	45.87	34.24	44.69	41.00	4.90	780.72	0.84
FA	**99.78**	**44.39**	**32.10**	**43.11**	**43.01**	**2.38**	**770.69**	**0.62**
Case-2, P_D=260.01MW								
IFEP	96.07	46.00	37.00	45.00	40.73	4.79	793.10	0.98
PSO	96.08	46.00	37.38	44.91	40.42	4.78	791.51	0.82
FA	**96.72**	**43.90**	**36.50**	**43.05**	**42.22**	**2.38**	**781.06**	**0.62**
Case-1, P_D=289MW								
IFEP	100.00	46.00	58.50	44.89	43.41	3.80	961.46	0.96
PSO	99.97	46.00	58.29	44.90	43.63	3.79	960.83	0.81
FA	**99.79**	**46.00**	**57.10**	**44.98**	**44.54**	**3.41**	**956.17**	**0.61**
Case-2, P_D=289MW								
IFEP	96.62	46.00	60.00	45.00	44.99	3.61	984.83	0.92
PSO	96.28	46.00	62.00	44.81	43.51	3.60	982.69	0.88
FA	**96.50**	**46.00**	**58.99**	**45.96**	**44.96**	**3.41**	**970.78**	**0.62**

Bold values indicate the results of proposed FA method. IFEP and PSO results taken from [18]

Table. 4 : Comparative result of 30-bus system for Case -1 and 2.

Method	P_1 (MW)	P_2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	P_L (MW)	Cost ($/hr)	Average time(Sec)
Case-1, P_D=283.4MW									
IFEP	175.10	48.00	21.00	22.04	13.00	14.00	9.74	803.86	1.04
PSO	177.73	45.33	21.80	19.55	13.92	14.70	9.63	803.52	0.92
FA	**176.49**	**46.52**	**21.30**	**17.60**	**15.00**	**14.03**	**7.54**	**801.05**	**0.68**
Case-2, P_D=283.4MW									
IFEP	156.07	48.01	21.03	24.00	24.79	18.04	8.54	830.39	0.99
PSO	156.08	49.67	23.83	23.39	24.35	14.50	8.42	828.15	0.84
FA	**145.00**	**60.29**	**22.13**	**23.72**	**23.66**	**16.14**	**7.54**	**812.53**	**0.68**
Case-1, P_D=360MW									
IFEP	200.00	63.00	39.11	24.39	23.90	34.97	25.37	1170.13	1.03
PSO	199.66	62.96	38.65	24.67	24.65	34.77	25.36	1169.28	0.92
FA	**199.77**	**63.00**	**38.10**	**24.99**	**24.79**	**34.47**	**25.12**	**1168.09**	**0.67**
Case-2, P_D=360MW									
IFEP	199.12	62.94	40.17	24.06	24.00	34.99	25.28	1238.02	1.01
PSO	199.11	63.00	40.06	24.10	24.00	35.00	25.27	1237.74	0.93
FA	**199.11**	**63.00**	**38.85**	**24.49**	**24.81**	**34.86**	**25.12**	**1195.56**	**0.68**

Bold values indicate the results of proposed FA method. IFEP and PSO results taken from [18]