Hybrid Particle Swarm Optimization Algorithm and Firefly Algorithm Based Combined Economic and Emission Dispatch Including Valve Point Effect

S. Arunachalam(✉), T. AgnesBhomila, and M. Ramesh Babu

Department of E.E.E, St. Joseph's College of Engineering, Chennai, India
{mailtoarunachalam, agnesbhomila}@gmail.com,
rameshbabum@stjosephs.ac.in

Abstract. For economic and efficient operation of power system optimal scheduling of generators to minimize fuel cost of generating units and its emission is a major consideration. This paper presents a new approach to Combined Economic and Emission Dispatch (CEED) problem having conflicting economic and emission objectives using a Hybrid Particle Swarm Optimization and Firefly (HPSOFF) algorithm. The CEED problem is therefore formulated as a multi-objective optimization problem with the valve point effect using a price based penalty factor method. The effectiveness of the proposed HPSOFF algorithm is demonstrated with ten bus generator systems, and the numerical results are compared and discussed with available algorithms. The numerical results indicate that the proposed algorithm is able to provide better solution with reasonable computational time.

Keywords: Economic dispatch · Emission dispatch · Power loss · Multi objective optimization

1 Introduction

The main objective of Economic Dispatch (ED) problem is to determine the optimal combination of power outputs for all generating units, which minimizes the total fuel cost of the thermal power plants, while satisfying system load demand and operating constraints of the generators [1]. This makes the ED problem a large-scale, non-linear constrained optimization problem.

In general, the only objective of the ED problem is to minimize the total fuel cost. It is also necessary to consider related societal issues because of the scale of the electric industry and its importance to modern life. One of these issues is the environmental impact of electricity generation. The environmental issues caused by the pollutant emissions produced by fossil-fuelled electric power plants, have become a matter of concern.After the 1990 Clean Air Act amendments [2], environmental considerations have regained considerable attention in the power system industry, modern utilities have been forced to simultaneously optimize both economic and emission objectives.

B.K. Panigrahi et al. (Eds.): SEMCCO 2014, LNCS 8947, pp. 647–660, 2015.
DOI: 10.1007/978-3-319-20294-5_56

Economic dispatch (ED) has become a fundamental function in operation and control of power systems [1, 2]. The ED problem can be stated as determining the least cost power generation schedule from a set of online generating units to satisfy the load demand at a given point of time [3, 4]. Though the core objective of the problem is to minimize the operating cost satisfying the load demand [5], several types of physical and operational constraints make ED highly nonlinear constrained optimization problem [6, 7], especially for larger systems [8–11]. After the 1990 Clean Air Act amendments, environmental considerations have regained considerable attention in the power system industry due to the significant amount of emission and other pollutants derived from fossil fuel based power generation [12, 13]. The most important emissions are sulphur dioxide (SO_2) and nitrogen oxides (NO_x) [14]. Considering only the minimum environmental impact is not practical which results in high production cost of the system. Conversely, to operate the system with minimum cost will result in higher emission. So a combined approach is the best to achieve an optimal solution. Evolutionary computing techniques when applied to multi-objective optimization have clear edge over traditional methods. On the other hand Pareto optimization based methods are also used to solve various types of economic dispatch problem and presented in [15–18].

Multi-objective optimization problem is formulated using Combined Economic Emission Dispatch (CEED) approach which merges the cost and emission objectives into one optimization function such that equal importance is assigned to both objectives [19–23]. One such approach is to use a combination of polynomial and exponential terms. The parameters are determined by curve fitting techniques based on realistic data. The CEED problem is solved using a PSO and FFA algorithm and also using hybrid HPSOFF algorithm for a 10 bus test system. A comparison of PSO and FFA and HPSOFF algorithm is presented as case studies and the results suggest HPSOFF technique give a better result than PSO or FFA algorithm.

2 Combined Economic and Emission Dispatch (CEED)

The multi-objective CEED problem is formulated by combining the economic dispatch problem and emission dispatch problem into a single objective using price penalty factor method.

2.1 Formulation of CEED Problem

The objective of the CEED problem which has two conflicting objectives as economic and emission objective is to find the optimal schedules of the thermal generating units which minimizes the total fuel cost and emission from the thermal units subject to power balance equality constraint and bounds. The mathematical formulation of the CEED problem is given below

$$min[F_{TV}, E_T] \tag{1}$$

subject to power balance equation given in (2) and bounds given in (3)

$$\sum_{i=1}^{nb} P_i - P_D - P_L = 0 \tag{2}$$

$$P_{i,min} \leq P_i \leq P_{i,max} \tag{3}$$

where

F_{TV} Total fuel cost of Ng generating units with valve point effect

$$F_{TV} = \sum_{i=1}^{Ng} F(P_i) = \sum_{i=1}^{Ng} a_i P_i^2 + b_i P_i + c_i + d_i * \sin\left(e_i\left(P_{i,min} - P_i\right)\right) \$/h \tag{4}$$

E_T Total emission cost Ng generating units

$$E_T = \sum_{i=1}^{Ng} E(P_i) = \sum_{i=1}^{Ng} \alpha_i P_i^2 + \beta_i P_i + \gamma_i + \eta_i e^{\delta_i P_i} Kg/h \tag{5}$$

α_i, β_i, γ_i, η_i, δ_i Emission coefficients of thermal unit i
a_i, b_i, c_i Fuel cost coefficients of thermal unit i
e_i, f_i Coefficients to model the effect of valve point of thermal unit i
Ng Total number of thermal generating units
nb Number of buses
P_i Power generation of thermal unit i
P_D Total demand of the system
P_L Real Power transmission loss in the system
$P_{i,min}$ Minimum generation limit of thermal unit i
$P_{i,max}$Maximum generation limit of thermal unit i

In the above formulation the transmission loss in the system is calculated using B matrix coefficients calculated from load flow solution as given in [14] and incorporated into power balance equality constraint. These loss coefficients are independent of slack bus. The transmission loss in the system is expressed using B matrix coefficients as

$$P_L = \sum_{i=1}^{nb} \sum_{j=1}^{nb} P_i B_{ij} P_j + \sum_{i=1}^{nb} B_{i0} P_i + B_{00} \tag{6}$$

The above multi objective problem can be combined into a single objective problem using price penalty factor approach. The price penalty factor approach to combine this multi objective problem in to a single objective is given in the next section.

2.2 Penalty Factor Approach

As mentioned earlier Multi-objective CEED is converted into a single objective problem using penalty factor approach. The sequential steps involved in calculating penalty factor are listed below [23]

- Evaluate the maximum cost of each generator at its maximum output.

$$F\left(P_{i,max}\right) = a_i P_{i,max}^2 + b_i P_{i,max} + c_i + e_i * \sin\left(f_i\left(P_{i,min} - P_{i,max}\right)\right)^{\$}/_{h} \tag{7}$$

- Evaluate the maximum emission of each generator at its maximum output.

$$E\left(P_{i,max}\right) = \sum_{i=1}^{Ng} \alpha_i P_{i,max}^2 + \beta_i P_{i,max} + \gamma_i + \eta_i e^{\delta_i P_{i,max}} {}^{Kg}/_{h} \tag{8}$$

- Divide the maximum cost of each generator by its maximum emission

$$h_i = \frac{F\left(P_{i,max}\right)}{E\left(P_{i,max}\right)} \tag{9}$$

Arrange h_i in ascending order. Add $P_{i,max}$of each unit one at a time starting from the smallest h_i unit until it meets the total demand P_D

At this stage, h_i associated with the last unit in the process is the price penalty factor h in $^{\$}/_{Kg}$ for the given load.

2.3 Problem Formulation Using Price Penalty Factor Approach

The multi objective CEED is converted into single objective optimization using price penalty factor and the respective formulation is given below

$$min \sum_{i=1}^{Ng} F_{TV}(P_i) + h \sum_{i=1}^{Ng} E(P_i) \tag{10}$$

subject to power balance equality constraint and bounds given below

$$\sum_{i=1}^{nb} P_i - P_D - P_L = 0 \tag{11}$$

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

In (10) the $F_{TV}(P_i)$ can also be replaced by $F_T(P_i)$ if the valve point effect has to be neglected. $F_T = \sum_{i=1}^{Ng} F(P_i) = \sum_{i=1}^{Ng} a_i P_i^2 + b_i P_i + c_i$. In this paper the above formulation is solved using hybrid (HPSOFF) algorithm. A Brief algorithm of PSO and FFA is presented in the next section.

3 Particle Swarm Optimization Algorithm

PSO is one of the modern heuristic algorithms developed by Kennedy and Eberhart in 1995. The flock of birds that have no leaders will find food randomly, following one of the members of the group that has the closest position to a food source. The flock achieves the best condition simultaneously through communication among members who already have better solution. This would happen repeatedly until the best solution or food source is discovered. The control parameters of PSO algorithm are Initial Position of Particles, Maximum particle velocity, Maximum Iteration, Acceleration constant for local Best influence, Acceleration constant for global Best influence, Initial Inertia weight, Final Inertia Weight and Error gradient.

4 Firefly Algorithm

A Firefly Algorithm (FA) is a meta heuristic algorithm inspired by the flashing behavior of fireflies. This algorithm is based on the natural behavior of fireflies which is based on the bioluminescence phenomenon. The firefly algorithm has basic idealized rules that are followed while movement of one firefly to other.

- All fireflies are unisex and they will move towards more attractive and brighter ones regardless of their sex.
- The degree of attractiveness of a firefly is proportional to its brightness.
- Also the brightness may decrease as the distance from the other fire flies increases due to the fact that the air absorbs light.
- If there is not a brighter or more attractive fire fly than a particular one it will then move randomly.
- The brightness or light intensity of a fire fly is determined by the value of the objective function of a given problem.

By using the above rules it is possible to achieve the optimum value of the objective function.

5 HPSOFF Algorithm

In this paper, a hybrid PSO-FFA algorithm is proposed for solving CEED problem. The proposed PSO-FFA is a method of combining the advantages of faster computation of Particle Swarm Optimization with robustness of Firefly Algorithm (FFA) so as to increase the global search capability. The PSO algorithm starts with a set of solutions and based upon the survival of fittest principle, only the best solution moves from one phase to another. This process is repeated until the any of the convergence criteria is met. At the end of the iterations the optimal solution is the one with the minimum total cost out of the set of solutions. The time of convergence of PSO depends upon the values of the randomly set control parameters. FFA algorithm starts with an initial operating solution and every iteration improves the solution until the convergence criteria is met. The optimal solution obtained from FFA algorithm depends upon the quality of the initial solution provided. In this paper the initial solution provided to FFA is the optimal solution obtained from PSO algorithm. Since a best initial solution from PSO is given to FFA algorithm the optimal solution obtained from this Hybrid approach is better than the solution obtained from PSO or FFA algorithms.

The sequential steps involved in the proposed HPSOFF algorithm is given below

1. The cost data, emission data and valve point data of each generating unit are read and system load is also specified. The operating limits of the thermal plants are specified.
2. The penalty factor to combine the multi objective problem into a single objective problem is obtained from the algorithm given in Sect. 2.2.
3. Using this penalty factor a lossless dispatch is carried out using PSO algorithm for the formulation given by Eqs. (10) to (12).
4. With the obtained solution an AC power flow is carried out and the B-loss coefficients are obtained [22]. These coefficients are used for calculation of real power loss in the subsequent iterations.
5. The various control parameters of the PSO algorithm are initialized. Formulation given by Eqs. (10) to (12) is solved using the PSO algorithm developed in MATLAB.
6. PSO runs till its stopping criterion (the maximum number of iterations) is met,
7. In order to obtain the optimal control parameters, the steps 7 to 10 is run many times with one control parameter fixed and all other control parameters are varied. This step is repeated to find the best control parameter for PSO algorithm.
8. With the best control parameters set, the PSO algorithm is carried and the optimal solution is obtained. With this optimal schedule an AC load flow is carried out and using the solutions of AC load flow the new loss Coefficients are obtained and considered for the subsequent iteration.
9. The optimal solution of PSO is given as the starting point (Initial guess vector) to the FFA algorithm and the control parameters of FFA are set.
10. Then, the FFA algorithm starts its search process and it is run until its stopping criterion is met.
11. With this optimal solution the total fuel cost of the thermal generating units and its emission cost are calculated.

6 Case Study

This case study consists of a standard test system with 10 generating units. The complexity to the solution process has significantly increased since the valve point effect is considered. In this system with higher non-linearity, it has more local minima and thus it is difficult to attain the global solution. The load demand of this test system is 2000 MW. The fuel cost coefficients with valve point co-efficient and emission function coefficients to minimize sulphur oxides(SOx) and Nitrogen oxides(NOx) caused by thermal plant along with generator capacity limits of each generator are given in appendix Tables 5 and 6. Here the losses in the system are also considered. The B matrix of the test system is tabulated in appendix Table 7. As mentioned earlier economic and emission objectives are combined using Penalty factor approach. The penalty factor obtained from the procedure described in Sect. 2.2 is $h = 51.99\$ /kg$

For this system the optimal dispatches is obtained using PSO, FFA, and HPSOFF algorithm and are compared in the subsequent sections. The simulations are all carried

Table 1. Solution of CEED problem obtained using ABC algorithm

P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)	Fuel Cost ($/hr)	Emission (kg/hr)	Total Cost ($/hr)	TIME (sec)
54.99	78.16	79.94	75.00	159.99	239.99	269.53	287.08	409.81	423.77	111261	3934.5	320593	8.01
54.99	77.47	79.63	79.18	159.99	239.99	255.02	296.15	410.94	429.07	111272	3948.9	321069	6.01
54.99	77.77	78.91	80.04	159.99	239.95	255.02	296.15	410.94	429.07	111228	3942.1	321003	6.17
54.93	76.04	78.15	78.20	159.92	232.11	262.55	287.51	419.28	434.10	111229	3957.5	321456	6.29
54.99	**78.82**	**78.90**	**79.58**	**159.99**	**239.99**	**290.19**	**302.99**	**398.40**	**397.85**	**111263**	**3922.0**	**320069**	**5.98**
54.99	76.96	80.44	79.71	159.99	235.2	287.53	293.05	381.94	432.28	111269	3940.2	320781	6.03
54.99	76.87	78.53	78.30	159.99	228.58	271.94	286.15	418.33	428.93	111262	3954.4	321176	6.92
54.99	77.86	79.55	78.86	159.99	239.99	262.63	296.63	433.66	397.75	111265	3940.1	320914	6.90
54.99	78.25	79.61	78.98	159.99	239.99	273.23	289.12	410.62	417.44	111266	3934.1	320411	6.69
54.99	78.35	78.59	78.42	159.99	239.8	269.63	271.00	426.58	425.27	111266	3945.9	321164	6.92
54.99	78.62	79.30	78.56	159.99	239.93	281.35	273.33	435.63	400.50	111261	3939.5	320890	6.85
54.98	78.27	79.03	79.09	159.99	239.87	268.47	285.36	414.72	422.5	111262	3936.2	320672	6.55
54.99	76.88	79.25	78.11	159.99	235.57	276.54	289.88	419.86	411.10	111264	3936.3	320565	6.13
54.99	77.65	79.87	78.98	159.99	235.59	285.04	284.03	433.94	390.94	111252	3940.7	320817	6.75
54.99	78.61	78.35	78.78	160.00	239.99	266.24	284.33	420.07	421.06	111262	3935.5	320792	6.95
54.99	77.06	78.62	78.39	159.99	226.1	283.14	271.56	430.83	422.07	111263	3961.0	321447	6.90
54.99	77.43	79.20	78.46	159.99	239.99	282.47	271.92	403.9	434.05	111253	3940.0	320900	6.79
54.99	77.98	78.70	79.32	159.99	239.97	266.01	282.39	420.47	422.62	111254	3939.7	320848	6.72
54.99	78.20	79.00	79.49	159.99	238.18	264.01	291.08	422.59	414.84	111226	3939.3	320768	6.68
54.99	77.90	79.00	79.83	159.99	239.99	278.67	268.58	423.36	420.14	111224	3939.7	320876	6.32

Table 2. Optimal Schedule of CEED problem obtained using Firefly algorithm.

P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)	Fuel Cost ($/hr)	Emission (kg/hr)	Total Cost ($/hr)	TIME (sec)
30.99	60.39	99.24	83.72	122.05	206.57	240.14	309.69	458.33	449.06	114518	4172.8	331490	1.94

out using algorithms developed in MATLAB (V2009a) software installed in HP Compaq Presario V3000 Laptop with Windows XP operating system, AMD Turion processor, 1.61 GHz and 960 MB of RAM.

6.1 Solution of CEED Problem Using PSO Algorithm

Since the evolutionary algorithm is used to solve CEED, certain parameters of the algorithm have to be randomly adjusted. The control parameters of PSO algorithm are set as follows

- Initial Position:Random
- Maximum particle velocity: 1
- Maximum Iteration: 500
- Acceleration constant for local Best influence: 2
- Acceleration constant for global Best influence: 2
- Initial Inertia weight: 0.9
- Final Inertia Weight: 0.4
- Error gradient: $1e^{-6}$

The optimal particle size for this case study after testing with various values is found to be 50. With these parameters PSO algorithm is run for twenty times and the schedules are shown in Table 1.

The optimal schedules from the ABC algorithm is shown in bold in Table 1. At the end of several trial runs the best optimal fuel cost is found to be 111263 $/hr and the emission is found to be 3922 kg/hr. The transmission loss for the optimal schedule showed in bold in Table 1 is 81.704 MW. The total cost is obtained as 320069 $/hr. These results are obtained within a computation time of 5.98 s.

6.2 Solution of CEED Problem Using Firefly Method

Similar to PSO method, the parameters of FIREFLY method is set by trial and error technique and the parameters are set at

- Number of Fireflies: 40
- Maximum Iterations: 500
- Alpha: 0.5
- Beta: 0.2
- Absorption Coefficient gamma:0.1

With these parameters Firefly algorithm is run for twenty times and the optimal schedule is shown in Table 1.

At the end of several trails the best optimal fuel cost is found to be 114518 $\$/hr$ and the emission is found to be 4172.8 kg/hr. The total cost is obtained as 331490. in 1.94 s. Even though the optimal schedules obtained by the firefly algorithm is inferior to PSO algorithm it converges faster than PSO algorithm.

Table 3. Solution of CEED problem obtained using HPSOFF algorithm

P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)	Fuel Cost ($/hr)	Emission (kg/hr)	Total Cost ($/hr)	TIME (sec)
41.21	73.54	86.56	78.17	153.44	235.19	286.31	304.22	399.49	410.06	114989	3938.9	331361	14.21
37.21	68.67	83.97	82.88	160.00	238.01	291.41	299.73	403.43	397.61	115186	3929.7	319187	14.39
34.64	73.10	93.79	81.03	159.31	233.87	275.63	294.50	404.34	411.30	114893	3950.4	319541	17.07
34.83	75.90	90.64	93.99	159.69	236.69	290.20	299.56	391.14	388.14	115035	3930.5	319405	15.97
38.09	68.28	95.45	82.15	159.92	236.49	283.35	306.34	391.74	402.80	115130	3935.4	319761	15.53
34.84	69.39	91.74	78.04	159.88	231.87	293.65	301.23	391.86	409.14	114779	3938.8	315921	14.96
22.95	74.19	91.22	84.81	159.98	236.96	278.16	305.41	401.05	394.67	114484	3951.8	319402	15.62
34.80	72.15	85.80	83.13	159.99	232.12	287.73	297.28	402.29	406.36	114749	3931.1	319154	15.33
26.17	68.70	90.60	85.82	158.49	236.50	278.57	301.62	391.29	415.14	114466	3947.9	319750	16.24
33.51	77.30	84.82	90.07	159.99	235.84	285.17	305.04	399.11	388.80	114922	3937.5	319062	15.19
29.52	58.75	87.36	96.74	160.00	238.78	278.69	300.87	409.38	395.90	114949	3976.0	320664	13.32
40.17	68.78	94.26	88.55	158.21	234.33	284.58	291.06	412.82	293.97	115081	3941.3	320016	16.39
32.09	73.09	85.26	86.32	159.99	232.63	280.64	297.80	403.32	407.81	114621	3933.7	319167	16.52
35.41	70.23	79.15	89.58	158.02	235.73	278.02	296.52	419.70	399.99	114860	3945.9	319647	14.99
22.76	74.67	86.81	84.62	160.00	238.56	280.53	301.47	399.70	400.22	114437	3945.0	319157	16.30
31.72	74.94	91.85	87.82	159.99	238.24	281.59	286.65	393.01	412.73	114945	3936.5	319257	13.59
37.59	71.84	86.66	84.56	160.00	231.85	277.55	301.94	407.77	404.75	114924	3937.1	319360	16.37
36.15	**76.03**	**88.35**	**84.23**	**160.00**	**237.0**	**280.85**	**297.7**	**410.36**	**391.93**	**115012**	**3923.3**	**319038**	**16.08**
37.22	69.77	88.84	96.39	159.99	236.44	282.53	297.56	397.71	397.23	115103	3943.0	319757	15.05
35.41	68.46	89.18	88.07	151.87	238.59	294.62	294.62	295.32	396.22	114876	3953.4	319934	17.74

Table 4. Comparison of the optimal schedules obtained by PSO, FFA, HPSOFF method.and Hybrid ABC-SA method used in [29]

SCHEDULES	PSO	FFA	HPSOFF	Ref [29]
P1(MW)	54.99	30.99	36.15	55.00
P2(MW)	78.82	60.39	76.03	70.32
P3(MW)	78.90	99.24	88.35	81.18
P4(MW)	79.58	83.72	84.23	96.47
P5(MW)	159.99	122.05	160.00	159.72
P6(MW)	239.99	206.57	237.05	155.92
P7(MW)	290.19	240.14	280.85	229.31
P8(MW)	302.91	309.69	297.77	337.57
P9(MW)	398.40	458.33	410.36	431.34
P10(MW)	397.85	449.06	391.93	467.57
TOTAL COST ($/hr)	320069	331490	**319038**	330210
TIME (sec)	5.98	1.94	**16.08**	22.35

Table 5. Fuel cost coefficients of 10 generating units

UNIT	a $(\$/\text{MW}^{2})$hr	b $/(MW)hr	c $/hr	d ($/hr)	e rad/MW
1	0.12951	40.5407	1000.40	33	0.0174
2	0.10908	39.5804	950.606	25	0.0178
3	0.12511	36.5104	900.705	32	0.0162
4	0.12111	39.5104	800.705	30	0.0168
5	0.15247	38.539	756.799	30	0.0148
6	0.10587	46.1592	451.325	20	0.0163
7	0.03546	38.3055	1243.53	20	0.0152
8	0.02803	40.3965	1049.99	30	0.0128
9	0.02111	36.3278	1658.56	60	0.0136
10	0.01799	38.2704	1356.65	40	0.0141

Table 6. Emission coefficients of 10 generating units

A (lb/MW)$^{2\ h}$	β (lb/MWhr)	γ lb/hr	eta lb/hr	Lambda (1/MW)	$P_{Max\ (MW)}$	$P_{Min\ (MW)}$
0.04702	-3.9864	360.0012	0.25475	0.01234	55	10
0.04652	-3.9524	350.0012	0.25473	0.01234	80	20
0.04652	-3.9023	330.0056	0.25163	0.01215	120	47
0.04652	-3.9023	330.0056	0.25163	0.01215	130	20
0.0042	0.3277	13.8593	0.2497	0.012	160	50
0.0042	0.3277	13.8593	0.2497	0.012	240	70
0.0068	-0.5455	40.2699	0.248	0.0129	300	60
0.0068	-0.5455	40.2699	0.2499	0.01203	340	70
0.0046	-0.5112	42.8955	0.2547	0.01234	470	135
0.0046	-0.5112	42.8955	0.2547	0.01234	470	150

Table 7. B Loss coefficeints of 10 generating units

0.000049	0.000014	0.000015	0.000016	0.000016	0.000016	0.000016	0.000016	0.000016	0.000016
0.000014	0.000045	0.000016	0.000016	0.000017	0.000015	0.000015	0.000016	0.000018	0.000018
0.000015	0.000016	0.000039	0.00001	0.000012	0.000012	0.000014	0.000014	0.000016	0.000016
0.000015	0.000016	0.00001	0.00004	0.000014	0.00001	0.000011	0.000012	0.000014	0.000015
0.000016	0.000017	0.000012	0.000014	0.000035	0.000011	0.000013	0.000013	0.000015	0.000016
0.000017	0.000015	0.000012	0.00001	0.000011	0.000036	0.000012	0.000012	0.000014	0.000015
0.000017	0.000015	0.000014	0.000011	0.000013	0.000012	0.000038	0.000016	0.000016	0.000018
0.000018	0.000016	0.000014	0.000012	0.000013	0.000012	0.000016	0.00004	0.000015	0.000016
0.000019	0.000018	0.000016	0.000014	0.000015	0.000014	0.000016	0.000015	0.000042	0.000019
0.00002	0.000018	0.000016	0.000015	0.000016	0.000015	0.000018	0.000016	0.000019	0.000044

6.3 Solution of CEED Problem Using HPSOFF Algorithm

In this method the best schedule obtained in PSO method is given as initial start to Firefly algorithm and the parameters of the firefly algorithm are set as Number of Fireflies: 40, Maximum Iterations:500, Alpha:0.5, Beta:0.2 and Absorption Coefficient gamma:0.1. HPSOFF algorithm is run for 20 times and the schedules obtained from the hybrid method are shown in Table 3. The optimal schedule is shown in bold in Table 3.

The transmission loss for the optimal schedule shown in bold in Table 3 is 62.602 MW. The optimal cost obtained using HPSOFF is 319038 $/hr is better when compared to the optimal cost of 320069$/hr obtained using PSO algorithm shown in Table 1 and the optimal cost of 331490 $/hr obtained using firefly algorithm shown in Table 2. The comparison of the results obtained from the proposed method is shown in Table 4.

7 Conclusion

This paper has implemented a hybrid PSO and FF algorithm for solving the combined economic and emission dispatch problem including valve point effect. Results obtained from the proposed method are compared with PSO, FFA and HPSOFF. From the case studies carried out on the test systems and the results obtained indicate the proposed algorithm is able to find better optimal schedules in a reasonable computational time since it combines the advantages of faster computation of Particle Swarm Optimization with robustness of Firefly Algorithm (FFA) so as to increase the global search capability.

References

1. Wood, A.J., Wollenberg, B.F.: Power Generation, Operation and Control. Wiley, New York (1996)
2. Da-Kuo, H., Fu-li, W., M., Zhi-Zhong : Hybrid genetic algorithm for Economic Dispatch with Valve point effect, Electr. Power Syst. Res. **78**, 626–633 (2008)
3. Lu, Y., Zhou, J., Yinghaili, H.Q., Zhang, Y.: An adaptive hybrid differential evolution algorithm for dynamic economic dispatch with valve point effects. Electr. Power Syst. Res. **37**, 4842–4849 (2010)
4. Hota, P.K., Barisal, A.K., Chakrabarthi, R.: Economic Emission load dispatch through fuzzy based bacterial Foraging algorithm. Electr. Power Syst. Res. **32**, 794–803 (2010)
5. Zhang, P.X., Zhao, B., Cao, Y.J., Cheng, S.J.: A novel multi-objective genetic algorithm for economic power dispatch. In: 39th International Universities Power Engineering Conference, UPEC 2004, vol. 1, p. 422–6, 6–8 September 2004
6. Gong, D., Zhang, Y., Qi, C.: Environmental/economic power dispatch using a hybrid multi objective optimization algorithm. Int. J. Electr. Power Energy Syst. **32**(6), 607–614 (2010)
7. Han, X.S., Gooi, H.B., Kirschen, D.S.: Dynamic economic dispatch: feasible and optimal solutions. IEEE Trans. Power Syst. **16**(1), 8–22 (2001)

8. Granelli, P., Marannino, P., Montagna, M., Silvestri, A.: Fast and efficient gradient projection algorithm for dynamic generation dispatching. Proc. Inst. Elect. Eng. Gener Trans. Distrib. **136**(5), 295–302 (1989)
9. Li, F., Morgan, R., Williams, D.: Hybrid genetic approaches to ramping rate constrained dynamic economic dispatch. Elect. Power Syst. Res. **43**(2), 97–103 (1997)
10. Aruldoss, A.V.T., Ebenezer, J.A.: Deterministically guided PSO for dynamic dispatch considering valve-point effect. Elect. Power Syst. Res. **73**(3), 313–322 (2005)
11. Abido, M.A.: Environmental/economic power dispatch using multi objective evolutionary algorithms. IEEE Trans. Power Syst. **18**(4), 1529–1537 (2003)
12. El-Keib, A.A., Ma, H., Hart, J.L.: Economic dispatch in view of the clean air act of 1990. IEEE Trans. Power Syst. **9**(2), 972–978 (1994)
13. IEEE Current Operating Problems Working Group, Potential impacts of clean air regulations on system operations, IEEE Trans. Power Syst. **10**(2), 647–653 (1995)
14. Abido, M.A.: A novel multi objective evolutionary algorithm for environmental/economic power dispatch. Electr. Power Syst. Res. **65**, 71–81 (2003)
15. Panigrahi, B.K., Ravikumar, V., Pandi, S.D., Swagatam, D.: Multi objective fuzzy dominance based bacterial foraging algorithm to solve economic emission dispatch problem. Energy **35**(12), 4761–4770 (2010)
16. Pandi, V.R., Panigrahi, B.K., Hong, W.C., Sharma, R.: A multiobjective bacterial foraging algorithm to solve the environmental economic dispatch problem. Energy Sources Part B **9** (3), 236–247 (2014)
17. Agrawal, S., Panigrahi, B.K., Tiwari, M.K.: Multiobjective particle swarm algorithm with fuzzy clustering for electrical power dispatch. IEEE Trans. Evol. Comput. **12**(5), 529–541
18. Panigrahi, B.K., Pandi, V.R., Das, S.: An adaptive particle swarm optimization approach for static and dynamic economic load dispatch. Int. J. Energy Convers. Manage. **49**, 1407–1415 (2008)
19. Yokoyama, R., Bae, S.H., Morita, T., Sasaki, H.: Multi objective generation dispatch based on probability security criteria. IEEE Trans. Power Syst. **3**(1), 24–317 (1988)
20. Abido, M.A.: Multi objective particle swarm optimization for environmental/economic dispatch problem. Electr. Power Res. **79**, 1105–1113 (2009)
21. Abido, M.A.: Multi objective evolutionary algorithms for electric power dispatch problem. IEEE Trans. Evol. Comput. **10**(3), 315–319 (2006)
22. John, J., Stevenson, G.W.D. Jr.: Power system Analysis. TATA McGraw-Hill Edition
23. Arunachalam, S., Saranya, R., Sangeetha, N.: Hybrid artificial bee colony algorithm and simulated annealing algorithm for combined economic and emission dispatch including valve point effect. In: Panigrahi, B.K., Suganthan, P.N., Das, S., Dash, S.S. (eds.) SEMCCO 2013, Part I. LNCS, vol. 8297, pp. 354–365. Springer, Heidelberg (2013)