Hybrid Artificial Bee Colony Algorithm and Simulated Annealing Algorithm for Combined Economic and Emission Dispatch Including Valve Point Effect

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Abstract. For economic and efficient operation of power system optimal scheduling of generators in order to minimize fuel cost of generating units and its emission is a major consideration. This paper presents hybrid approach of using Artificial Bee Colony (ABC) and Simulated Annealing (SA) algorithm to solve highly constrained non-linear multi–objective Combined Economic and Emission Dispatch (CEED) having conflicting economic and emission objective. The mathematical formulation of multi objective CEED problem with valve point is formulated and then converted into single objective problem using price penalty factor approach. Performance of proposed hybrid algorithm is validated with IEEE 30 bus six generator systems and a 10 generating unit system. Programming is developed using MATLAB. The results obtained and computational time of proposed method is compared with ABC and SA algorithm. Numerical results indicates 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 Economic Dispatch 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 [1]. Though the core objective of the problem is to minimize the operating cost satisfying the load demand, several types of physical and operational constraints make ED highly nonlinear constrained optimization problem, especially for larger systems [2]. In recent years, environmental considerations have regained considerable attention in the power system industry due to the significant amount of emissions like sulphur dioxide (SO_2) and nitrogen oxides (NOx).So along with economic dispatch environmental dispatch must also be carried out. Since economic and emission objectives are conflicting in nature, a combined approach is the best to achieve an optimal solution [3].

Power plants commonly have multiple valves that are used to control the power output of the units. When steam admission valves in thermal units are first opened, a

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sudden increase in losses is registered which results in ripples in the cost function. This effect is known as a valve point loading. Typically, the valve-point results in as each steam valve starts to open, the ripples like in to take account for the valve-point effects, sinusoidal functions are added to the quadratic cost function[4].This type of problem is extremely difficult to solve with conventional gradient based techniques due to the abrupt changes and discontinuities present in the incremental cost function. The CEED problem with valve point effect is a Multi-objective problem which can be solved by Multi-objective Optimization [5].

Traditional methods such as lambda iteration, base point participation factor, gradient method and Newton method may not converge to feasible solutions for complex problems whose objective function is not continuously differentiable and has a discontinuous nature. This method fails for non-convex problem except dynamic programming in which no restriction is imposed on the shape of cost curves, also this method suffer from dimensionality problem and excessive computation effort.

The 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 [6]. Several classical methods were proposed to solve economic dispatch problem such as lambda iteration method, Gradient method, base point and participation factor method [7]. Heuristic method for solving economic dispatch is presented in [8-20]. The formulation of multi objective CEED problem by weighting function method and priority ranking method using hybrid ABC-PSO method is presented in [21].

In this paper the CEED problem is first solved by ABC method and the optimal schedules are obtained. This schedule is given as starting point for Simulated Annealing and the optimal schedules are obtained. This approach combines the advantages of faster convergence of ABC method and robustness of SA method to find the global solution of highly non linear CEED problem with valve point effect.

The proposed method converts the multi –objective problem into a single objective problem by using a penalty factor approach. Methods which convert multi objective into single objective using weights generate the non dominated solution by varying the weights, thus requiring multiple runs to generate the desired Pareto set of solution. Various other approaches given in [23],[24] and [25] solves the conflicting objective functions simultaneously using multi objective evolutionary search strategies and find out compromise solution.

2 Formulation of 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 Multi Objective CEED problem

The objective of the multi-objective 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 multi objective CEED problem is given below

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

subject 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

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

$\alpha_i, \beta_i, \gamma_i, \eta_i, \delta_i$ 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

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

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

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

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

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

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

- 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 Conversion of Multi Objective CEED to Single Objective Formulation

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

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

subject to power balance equality constraint and bounds given below

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

$$P_{i,min} \leq P_i \leq P_{i,max} \qquad (12)$$

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 ABC-SA method. A Brief algorithm of ABC and SA is presented in the next section

3 Artificial Bee Colony Algorithm

ABC algorithm is one of the most promising methods for solving complex non-smooth optimization problems in power systems. It simulates the behavior of real bees for solving optimization problems. The colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. The first half of the colony consists of the employed artificial bees and the second half includes the onlookers. The number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source has been exhausted by the bees becomes a scout. Communication among bees related to the quality of food sources takes place in the dancing area. This dance is called a waggle dance. The four control parameters of ABC algorithm are

- NP – The number of colony size(employee bee+ onlookers)
- $Food\ number = \frac{NP}{2}$ The number of food sources equals the half of the colony size.
- $Limit$ – A food source which could not be improved through limit trials is abandoned by its employee bee.
- $Max\ cycle$ –The number of cycles for foraging (a stopping criterion).

4 Simulated Annealing

Simulated Annealing (SA) is a stochastic optimization technique and it can be used to solve our CEED problem since our objective is to find an optimal solution. Simulated Annealing is a random search technique which exploits an analogy between the way in which a metal cools and freezes into a minimum energy perfect crystalline structure with minimum defects (the annealing process) and the search for a minimum in a more general system. There are four control parameters that are directly associated with its convergence (to an optimized solution) and its efficiency. They are Initial temperature, Final temperature, Rate of temperature decrement, Iteration at each temperature.

5 Hybrid ABC-SA Algorithm

In this paper, a hybrid ABC-SA algorithm is proposed for solving CEED problem. The proposed ABC-SA is a method of combining the advantages of faster computation of Artificial Bee colony Algorithm with robustness of Simulated Annealing (SA) so as to increase the global search capability. The ABC 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 ABC depends upon the values of the randomly set control parameters. SA algorithm starts with an initial operating solution and every iteration improves the solution until the convergence criteria is met. The optimal solution obtained from SA algorithm depends upon the quality of the initial solution provided. In this paper the initial solution provided to SA is the optimal solution obtained from ABC algorithm. Since a best initial solution is given to SA algorithm the optimal solution obtained from this Hybrid approach is better than the solution obtained from ABC or SA algorithms.

The sequential steps involved in the proposed algorithm ABC-SA 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.
2. The minimum and maximum operating limits of the generating units are specified.
3. The penalty factor to combine the multi objective problem into a single objective problem is obtained from the algorithm given in section 2.2.
4. Using this penalty factor a lossless dispatch is carried out using ABC algorithm for the formulation given by equation (10) to (12) with $P_L = 0$.
5. With the solution obtained an AC power flow is carried out and the B-loss coefficients are obtained [14]. These coefficients are used for calculation of real power loss in the subsequent iterations.
6. The various control parameters of the ABC algorithm are initialized. Formulation given by equation (10) to (12) is solved using the ABC algorithm developed in MATLAB.
7. ABC runs till its stopping criterion (the maximum number of iterations) is met,
8. 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 ABC algorithm.
9. With the best control parameters set, the ABC 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 B Coefficients are obtained and considered for the subsequent iteration.
10. The optimal solution of ABC is given as the starting point (Initial guess vector) to the SA algorithm and the control parameters of SA are set.
11. Then, the SA algorithm starts its search process and it is run until its stopping criterion is met.
12. With this optimal solution the total fuel cost of the thermal generating units and its emission cost are calculated.

6 CASE STUDY – IEEE 30 Bus System

In order to validate the proposed algorithm a case study with IEEE 30 bus test system consisting of 6 generating units and 41 transmission lines is carried out. The valve point effect is not considered. The load demand of this test system is $500\ MW$. The total load in the IEEE 30 bus system is $283.4MW$. Each of the real power demand is scaled to increase the total demand to $500\ MW$. The fuel cost coefficients 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 table A1. With the schedules obtained from lossless dispatch a load flow is carried out and the B-co-efficient matrix computed from the load flow analysis is given in appendix table A2. The penalty factor to combine the multi objective problem into single objective problem is calculated as given in section 2.2 and is found to be $h = 43.15\ \$/kg$

For this system the optimal dispatch is obtained using ABC, SA and Hybrid ABC-SA algorithm and are compared in the subsequent sections

6.1 Solution of CEED Problem Using ABC Method

Since evolutionary algorithm is used to solve CEED, certain parameters of the algorithm have to be randomly adjusted. The optimal control parameters for ABC algorithm are found by varying each parameter and setting one parameter constant at a time and this process is repeated to find the optimal control parameters. The optimal control parameter for this test system is found as $NP = 30$, limit $= 300$, $maxcycle = 500$. With these parameters ABC 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.

Table 1. Optimal Schedules of CEED problem obtained using ABC algorithm

RUNS	P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	LOSS (MW)	Fuel COST ($/hr)	Emission (kg/hr)	Total COST ($/hr)	TIME (sec)
1	10.02	23.96	94.56	119.11	134.22	127.99	9.89	27671	273.91	39491	5.50
2	**10.01**	**18.40**	**108.26**	**99.22**	**131.72**	**141.52**	**9.17**	**27583**	**271.90**	**39316**	**5.9**
3	10.00	12.13	109.93	89.08	130.91	157.46	9.53	27556	276.34	39480	5.90
4	10.03	10.00	96.851	104.87	161.80	125.71	9.27	27499	277.11	39457	5.65
5	10.06	11.85	94.82	72.35	194.52	125.79	9.41	27485	291.81	40076	5.63
6	10.00	10.67	125.98	84.97	138.11	138.17	7.93	27519	279.03	39559	3.49
7	10.01	11.62	91,69	78.40	191.13	126.76	9.63	27484	288.68	39941	3.43
8	10.01	10.07	118.68	108.28	130.46	130.64	8.17	27552	277.58	39530	3.51
9	10.03	10.46	116.08	65.82	171.25	134.61	8.27	27473	286.37	39830	3.43
10	10.02	10.00	120.56	74.49	163.23	129.56	7.88	27471	282.72	39670	3.49
11	10.02	10.30	93.12	59.36	202.65	134.30	9.77	27502	301.87	40528	3.47
12	10.00	10.03	111.93	102,75	147.25	126.35	8.33	27504	275.67	39400	3.42
13	10.02	11.70	122.89	35.00	186.99	141.78	8.39	27563	313.29	41082	3.46
14	10.15	10.13	108.59	106.17	140.35	133.37	8.79	27525	274.78	39382	3.42
15	10.04	10.02	40.08	88.23	200.25	167.03	15.68	27728	312.28	41592	3.45
16	10.06	10.99	143.16	77.66	138.85	126.19	6.93	27553	289.35	40039	3.46
17	10.00	10.41	123.95	95.43	130.03	138.23	8.08	27541	277.93	39534	3.43
18	10.13	35.81	88.20	90.35	158.36	127.65	10.53	27704	270.87	39392	3.50
19	10.02	14.65	97.57	121.73	140.04	125.40	9.44	27598	277.23	39560	3.45
20	10.00	10.07	115.74	76.17	158.14	138.24	8.37	27474	279.73	39545	3.48

At the end of several trial runs the best optimal fuel cost is found to be 27583 $/hr and the emission is found to be 271.90 kg/hr. The total cost of the system is obtained as 39316 $/kg. These results are obtained within a computation time of 5.65 seconds.

6.2 Solution of CEED Problem Using SA Method

Similar to ABC method, the parameters of SA method is also tuned to certain trial values like (i.e. cool schedule=0.5T and 0.8T, Temp (T) =200 and 300, Max tries=8000 and 10000).Among the several results the best optimal solution is obtained with cool schedule=0.8T, T=100 and Max tries=8000 and is shown in table 2.
At the end of several trial runs the best optimal fuel cost is found to be 27498 $/hr and the emission is found to be 275.60 kg/hr. The total cost of the system is obtained as 39391 $/kg. These results are obtained within a computation time of 58.44 seconds.

6.3 Solution of CEED Problem Using Hybrid ABC-SA Method

In this method the best schedule obtained in ABC method is given as initial start to SA algorithm and the parameters of the SA are set as T= 100, cool schedule= 0.8T and Max tries= 5000. The optimal schedule obtained from the hybrid method is shown in table 2.The optimal fuel cost is found to be 27588 $/hr and the emission is found to be 271.71 kg/hr. The total cost of the system is obtained as 39313 $/kg which is better than the ABC method and the SA method as shown by the comparison table 2. These results are obtained within a computation time of 18.57 seconds. The computational time is more than ABC method but the optimal cost is further reduced than the ABC method. The results are better than the hybrid approach used in [22] and this is mainly due to the computation of loss using B loss coefficients obtained from lossless dispatch in hybrid ABC-SA method which is very reasonable when compared to the B loss matrix used in [22].

Table 2. Comparison of the optimal schedules obtained by ABC, SA and Hybrid ABC-SA method and Hybrid ABC-PSO method used in [22]

Optimal Schedules	ABC	SA	ABC-SA	Ref [22]
P1(MW)	10.01	10.00	10.90	54.6
P2(MW)	18.40	10.00	18.37	32.484
P3(MW)	108.26	94.53	108.41	48.548
P4(MW)	99.22	93.12	99.29	77.517
P5(MW)	131.72	155.81	131.68	167.28
P6(MW)	141.52	146.49	140.62	137.29
LOSS(MW)	9.17	9.97	9.31	17.718
FUEL OST($/hr)	27583	27498	27588	28157
EMISSION (lb/hr)	271.90	275.60	271.71	288.01
TOTAL COST ($/hr)	39316	39391	**39313**	40584.6
TIME (sec)	**5.9**	58.44	18.57	-

6.4 Case Study on 10 Generating Units with Valve Point Effect

This case study consists of a standard test system with 10 generating units. The valve point effect is considered. The complexity to the solution process has significantly increased. In as much as this is a larger 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 table A3& table A4. Here the losses in the system are also considered. The B matrix of the test system is tabulated in appendix table A5. As mentioned earlier economic and emission objectives are combined using Penalty factor approach. The penalty factor obtained from the procedure described in section 2.2. is $h = 51.99\$/kg$

In this method the best optimal schedule obtained in ABC method is given as initial start to SA algorithm and the SA method. The best optimal is obtained at T= 100, cool schedule= 0.8T and Max tries= 8000. The optimal power schedule of the 10 generating units and the loss of the system is tabulated in table 3. At the end of several trial runs the best optimal fuel cost is found to be 113510 \$/hr and the emission is found to be 4169 kg/hr. The total cost of the system is obtained as 330210 \$/kg. These results are obtained with a computation time of 22.35 seconds.

Table 3. Optimal Schedules obtained using Hybrid ABC-SA Method

P1 (MW)	P2 (MW)	P3 (MW)	P4 (MW)	P5 (MW)	P6 (MW)	P7 (MW)	P8 (MW)	P9 (MW)	P10 (MW)	LOSS (MW)
55.00	70.32	81.18	96.47	159.72	155.92	229.31	337.57	431.34	467.57	84.45

7 Conclusion

This paper has implemented a hybrid ABC and SA algorithm for solving the combined economic and emission dispatch problem including valve point effect. Results obtained from the proposed method are compared with ABC, SA and Hybrid ABC-PSO method. 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.

References

1. Wood, A.J., Wollenberg, B.F.: Power Generation, Operation and control. John Wiley and Sons, New York (1996)
2. Jeyakumar, A.E., Victorie, T.A.A.: Hybrid PSO-SQP for economic dispatch with valve-point effect. Electr. Power Syst. Res. 71(1), 51–59 (2004)
3. Wang, W.S., Chen, Y.M.: A Particle Swarm approach to solve environmental/economic dispatch problem. International Journal of Engineering Computations 1, 157–172 (2010)
4. Chiang, C.-L.: Improved Genetic Algorithm for Power Economic Dispatch of units with Valve-Point Effects and Multi Fuels. IEEE Transactions on Power Systems 20(4) (2005)

5. Hemamalini, S., Simon, S.P.: Economic/Emission Load Dispatch using Artificial Bee colony Algorithm. In: Proc. of Int. Conf. on Control, Communication and Power Engineering (2010)
6. Dinu, S., Odagescu, L., Moise, M.: Environmental Economic Dispatch Optimization using a Modified Genetic Algorithm. International Journal of Computer Applications (0975-8887) 20(2) (2011)
7. Saadat, H.: Power System Analysis. TATA MCGraw Hill Edition
8. Altun, H., Uzam, M., Yalcinoz, T.: Economic Dispatch Solution using a Genetic Algorithm based on Arithmetic Crossover. In: IEEE Porto Power Tech. Conference, September 10-12, Porto, Portugal (2001)
9. Senthil, K.: Combined Economic and Emission Dispatch using Evolutionary Programming Techniques. IJCA Special Issue on "Evolutionary Computation for Optimization Techniques" ECOT (2010)
10. Niu, Q., Wang, X., Zhou, Z.: An efficient cultural Particle Swarm Optimization for Economic Load Dispatch with Valve-Point Effect. Sciverse Science Direct, Procedia Engineering 23, 828–834 (2011)
11. Manikandan, K., Senthil, K.: Economic Thermal Power Dispatch with Emission constraint and Valve Point Effect Loading using Improved Tabu Search Algorithm. IJCA (0975-8887) 3(9) (2010)
12. Coelho, L.D.S., Mariani, V.C.: An Improved Harmony Search Algorithm for Power Economic Load Dispatch. Science Direct, Energy Conversion and Management 50, 2522–2526 (2009)
13. Hassan, E.E., Rahman, T.K.A., Zakria, Z.: Improved Adaptive Tumbling Bacterial Foraging Algorithm for Emission constrained Economic Dispatch Problem. In: Proceedings of the World Congress on Engineering, vol. 2 (2012)
14. John, J., Grainer William, D., Stevenson, J.: Power system Analysis. TATA McGraw-Hill Edition
15. Karaboga, D.: AN Idea Based On Honey Bee Swarm for Numerical Optimization. Technical Report-TR06, Erciyes University, Engineering Faculty, Computer Engineering Department (2005)
16. Dixit, G.P., Dubey, H.M., Pandit, M., Panigrahi, B.K.: Economic Load Dispatch using Artificial Bee Colony Optimization. International Journal of Advance in Electronics Engineering 1, ISSN 2278-215X
17. Hemamalini, S., Simon, S.P.: Economic Load Dispatch With Valve Point Effect Using Artificial Bee Colony algorithm. In: XXXII National Systems Conference, NSC, December 17-19 (2008)
18. Ramaswamy, M., Sasikala: Optimal based Economic Emission Dispatch using Simulated Annealing. International Journal of Computer Applications(0975-8887) 1(10)
19. Dubey, H.M., Vishwakarma, K.K., Pandit, M., Panigrahi, B.K.: Simulated annealing approach for solving economic load dispatch problems with valve point loading effects. International Journal of Engineering, Science and Technology 4(4), 60–72 (2012)
20. Vlachos, A.: Simulated Annealing Algorithm for Environmental/Economic Dispatch Problem. Journal of Information and Computing Science 6(1), 64–72 (2011) ISSN 1746-7659
21. Manteau, E.D., Odero, N.A.: Combined economic emission dispatch using hybrid ABC-PSO algorithm with valve point loading effect. International Journal of Scientific and Research Publications 2(12) (December 2012) ISSN 2250-3153
22. Manteau, E.D., Odero, N.A.: Multi Objective Environmental/economic Dispatch Solution using ABC_PSO Hybrid Algorithm. International Journal of Scientific and Research Publications 2(12) (December 2012) ISSN 2250-3153

23. Panigrahi, B.K., Ravikumar Pandi, V., Das, S., Das, S.: Multi objective fuzzy dominance based bacterial foraging algorithm to solve economic emission dispatch problem. In: The 3rd International Conference on Sustainable Energy and Environmental Protection, SEEP 2009, vol. 35(12), pp. 4761–4770 (December 2010)
24. Panigrahi, B.K., Ravikumar Pandi, V., Sharma, R., Das, S., Das, S.: Multi objective bacterial foraging algorithm for electrical load dispatch problem. Energy Conservation and Management 52(2), 1334–1342 (2011)
25. Agrawal, S., Panigrahi, B.K., Tiwari, M.: Multi objective particle swarm algorithm with fuzzy clustering for electrical power dispatch. IEEE Transaction on Evolutionary Computation 12(5), 529–541 (2008)

Table A1. Fuel and Emission Coefficients for IEEE 30 Bus System with 6 Generator Bus

UNIT	a ($/hr)	b ($/MWhr)	c ($/(MW)^{2}hr)	α (kg/MW)^2 hr	β (kg/MWhr)	γ (kg/hr)	P_{Max} (MW)	P_{Min} (MW)
1	0.15247	38.53973	756.79886	0.00419	0.32767	13.85932	125	10
2	0.10587	46.15916	451.32513	0.00419	0.32767	13.85932	150	10
3	0.02803	40.39655	1049.32513	0.00683	-0.54551	40.2669	250	40
4	0.03546	38.30553	1243.5311	0.00683	-0.54551	40.2667	210	35
5	0.02111	36.32782	1658.5696	0.00461	-0.51116	42.89553	325	130
6	0.01799	38.2704	13356.2704	0.00461	-0.51116	42.89553	315	125

Table A2. B-Loss Coefficient Matrix for IEEE 30 BUS System

0.8422	0.1411	-0.0069	0.0033	0.0009	0.0012	0.0304
0.0009	0.0019	0.1411	0.0677	-0.0023	0.0001	0.0077
-0.0069	-0.0023	0.0167	-0.0087	-0.0069	0.0069	-0.0009
0.0055	0.0037	-0.0033	0.0001	-0.0087	0.0164	0.0012
0.0009	0.0009	-0.0069	0.0055	0.0121	0.0005	-0.0001
0.0005	0.0258	0.0012	0.0019	-0.0069	0.0037	-0.0012
0.0304	0.0077	-0.0009	0.0012	-0.0001	-0.0012	0.0014

Table A3. Fuel Cost Coefficients of 10 Generating Units

UNIT	**a ($/MW)^{2}hr**	**b \$/(MW)^{2}hr**	**c \$/(MW)^{2}hr**	**d ($/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 A4. Emission Coefficients of 10 Generating Units

α (lb/MW)^2 hr	**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 A5. 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