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Multi-objective based Adaptive Immune Algorithm for Solving the Economic and Environmental Dispatch Problem

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Abstract

This paper proposes a new multi-objective based adaptive immune algorithm for solving the combined economic and environmental dispatch problem. Economic dispatch problem deals with the minimization of fuel cost while satisfying a set of equality and inequality constraints. The fossil fuel plants pollute the environment by emitting some toxic gases. Therefore, the traditional minimization of cost objective cannot be the only basis for the generation dispatch, but the emission minimization must also be taken be taken into the account. The objective of combined economic and emission dispatch problem is to optimize simultaneously the generation cost and emission level while satisfying system load and operational constraints. The inequality constraints due to ramp rate limits are included by combining with generation limits constraints and hence converted in to single inequality constraint. For a prohibited operating zone, the unit is made only to operate above or below the zone. In this paper, a heuristic algorithm is developed to adjust the generation output of a unit to avoid unit operation in the prohibited zones. Finally, the proposed multi-objective based adaptive immune algorithm has been applied on a standard IEEE 30 bus system. The simulation results demonstrate the effectiveness of the proposed algorithm in solving the economic and emission dispatch problem.

Keywords: Utility grid, railroad power system, distributed generation, electrical smart grid, energy storage.

NOMENCLATURE

F	Total generation/fuel cost.
n	Total number of generators.
P_{Gi}	Active power output of ith generating unit (in MW).
$f_i(P_{Gi})$	Generation cost for P_{Gi} (in \$/h).
P_D	Total system load demand (in MW).
P_{loss}	Transmission losses (in MW).
$\mathbf{P_{Gi}^{min}}$	Minimum power output limit of ith generating unit in (MW).
$\mathbf{P_{Gi}^{max}}$	Maximum power output limit of ith generating unit (in MW).
a_i, b_i, c_i	Generator fuel cost coefficients of ith generating unit.
E	Total emission release (Kg/hr).
α_i, β_i, γ_i	Emission coefficients of ith generator.

INTRODUCTION

Nowadays, because of the increasing deterioration of environmental problem, the multi-objective combined Economic Emission Dispatch problem has become one of the important research areas. The main objective of conventional economic dispatch problem is to determine the most economical schedule for the generating units while satisfying load and other operational constraints. This involves the allocation of active power between the generating units, as the operating cost is insensitive to the reactive loading of a generator. Various solution methodologies for solving the combined economic and emission dispatch problems have been presented in the literature References [1-9]. All these approaches are proposed for determining the solution to the economic generation scheduling by iterative methods based on exact co-ordination equation for determining the optimum plant allocations, and equal incremental cost principle for determining the allocation of different generators in a generating station. The solution methodologies discussed above do not consider prohibited zone, ramp rate etc., therefore these solutions does not include actual operating conditions. The conventional lambda iteration method requires continuous incremental cost curve, hence it cannot be directly applied to the present economic dispatch problem.

In Reference [10], the Economic emission dispatch problem is solved considering the conflict between the objectives of economy and emission, valve-point effect, prohibited operation zones of generating units, and security constraints of transmission networks. A new global particle swarm optimization technique to solve the economic emission dispatch problems is proposed in Reference [11]. A Euclidean Affine Flower Pollination Algorithm (eFPA) and Binary Flower Pollination algorithm is used for solving the Combined Emission Economic Dispatch for Photo Voltaic (PV) plants and thermal power generation units are proposed in [12]. Reference [13] concerns using the multi-objective optimization by learning automata for economic emission dispatching in the environment where wind power and loads vary. A stochastic multi-objective optimization method for solving the Security-Constrained Optimal Power Flow problem with uncertain wind power and distributed load variations is proposed in [14]. In [15], a newly developed Multi-Objective Evolutionary Algorithm based on Decomposition has been applied to optimize the cost and emission of wind–thermal power system. A new parameter-less diversity preservation approach to solve the non-linear multi-objective economic emission load dispatch problem is envisaged in Reference [16] using Teacher-Learning Based Optimization algorithm.

A multi-objective electric model to integrate the generation of thermal units considering heat and power dispatch is proposed in [17]. Reference [18] describes the application of backtracking search algorithm for solving an economic/emission dispatch problem as a multi-objective optimization problem. A quasi-oppositional teaching learning based optimization algorithm for solving non-linear multi-objective economic emission dispatch problem of electric power generation with valve point loading is proposed in [19]. An improved multi-objective binary differential evolution to solve the EED problem is proposed in [20]. Reference [21] formulates the economic and environmental power dispatch as a probabilistic multi-objective problem considering the operation cost and green house gas emission functions as the sum of deterministic part and probabilistic one.

Recently, multi-objective based adaptive immune algorithm has been developed based on the partial affinity and global affinity to evaluate the antibody affinity to the multi-objective functions [22]. It also uses the adaptive mutation, crossover and clone rates for the antibodies to maintain the diversity. The proposed optimization method has been examined on standard IEEE 30 bus system.

PROPOSED PROBLEM FORMULATION

Economic Dispatch Problem

The thermal generating units scheduling involves the optimization of a problem with non-linear objective function considering the mixture of linear, non-linear and network constraints. The economic dispatch is a constrained optimization problem and it can be expressed as,

minimize,

$$F = \sum_{i=1}^{n} f_i(P_{Gi}) \tag{1}$$

Generally, the fuel cost function $f_i(P_{Gi})$ is represented as a quadratic polynomial and it is expressed as,

$$f_i(P_{Gi}) = a_i P_{Gi}^2 + b_i P_{Gi} + c_i \tag{2}$$

Subject to the following equality and inequality constraints.

System Active Power Balance Constraint

The total amount of power generation must balance the predicted load demand and system losses at each time interval over the scheduling period.

$$\sum_{i=1}^{n} P_{Gi} = P_D + P_{loss} \tag{3}$$

Generation Constraints

The maximum active power generation of a source is limited by thermal consideration. Unless a generator is off-line it is not desirable to reduce the power output below a certain minimum value (i.e., P_{Gi}^{min}). For example, in fossil fuel plant minimum boiler temperature must be maintained to prevent liquidation. Each generating unit's power generation is limited by,

$$P_{Gi}^{min} \le P_{Gi} \le P_{Gi}^{max} \tag{4}$$

Transmission Losses

Generally, the power stations are spread out geographically, the transmission losses must be taken into account to achieve the true economic dispatch. In the B coefficients approach, the system losses are represented as a quadratic function, and it is expressed as,

$$P_{loss} = \sum_{i=1}^{n} \sum_{j=1}^{n} P_{Gi} B_{ij} P_{Gj} \tag{5}$$

Where B_{ij} are constants called B or loss coefficients.

Emission Dispatch Problem Formulation

The solution of economic dispatch problem gives the amount of power to be generated by different generators to obtain the minimum total generation cost. However, the limitation on the amount of emission release is not considered by this problem. The objective of emission dispatch is to minimize the total environmental degradation. The emission function can be represented as the sum of all types of pollutants such as NO_X, SO_2, particulate materials and thermal radiation with suitable pricing for each pollutant emitted. Here, NO_X emission is considered as it is more harmful than other. The emission minimization objective function is expressed as,

Minimize,

$$E = \sum_{i=1}^{n} (\alpha_i P_{Gi}^2 + \beta_i P_{Gi} + \gamma_i) \tag{6}$$

Subject to the load demand and generating unit capacity constraints. The combined economic and emission dispatch problem is formulated as,

Minimize,

$$(F, E) \tag{7}$$

Subjected to the above mentioned equality and inequality constraints.

MULTI-OBJECTIVE BASED ADAPTIVE IMMUNE ALGORITHM

The proposed combined economic and emission dispatch problem has been solved using the multi-objective based artificial immune algorithm [22]. For solving this problem, the objective function i.e., Eq. (7) is considered as the antigens. The control variables are considered as the antibodies. The proposed algorithm is inspired by the immunology, simulates the immune function, principle and model to solve the complex problems. In the multi-objective based artificial immune algorithm, the feasible solution of optimization problem corresponds to the antibody, and the Pareto optimal individual corresponds to the antigen [23-24]. The flow chart of proposed multi-objective based artificial immune algorithm for solving the combined economic and emission dispatch problem is presented in Fig. 1.

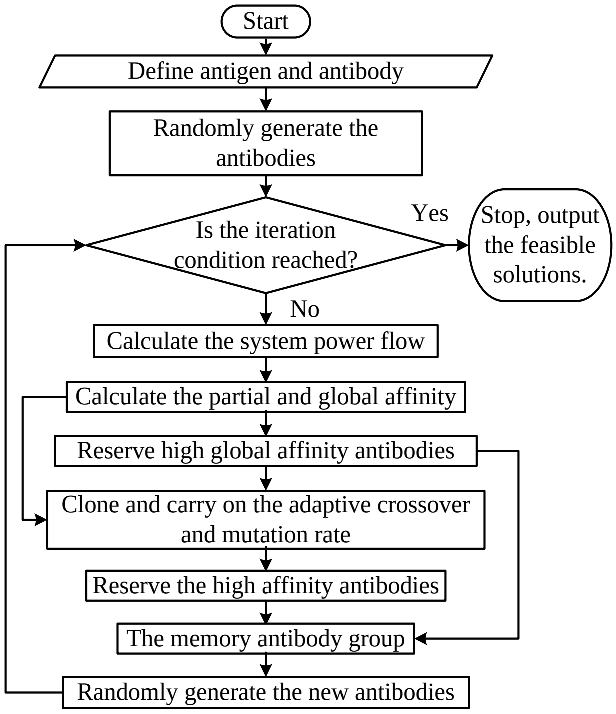

Figure 1. Flow chart of proposed multi-objective based artificial immune algorithm for solving the combined economic and emission dispatch problem.

RESULTS AND DISCUSSION

As mentioned earlier, the combined economic and emission dispatch is solved using the multi-objective based artificial immune algorithm and its performance has been examined on a standard IEEE 30 bus system with six generators and a total load demand of 1800MW. The generating units' data and fuel cost coefficients data are presented in Table 1. The emission coefficients data are presented in Table 2.

Table 1. Generator cost coefficients and capacity limits.

Generator	a	b	c	P_{Gi}^{min}	P_{Gi}^{max}
1	85.635	8.432	0.002035	150	400
2	303.778	6.410	0.003866	200	400
3	847.148	7.429	0.002182	350	600
4	274.224	8.302	0.001345	5	400
5	847.149	7.429	0.002182	270	500
6	202.026	6.916	0.005963	170	300

Table 2. NO_x emission coefficients.

Generator	α	β	γ
1	80.9019	-0.38128	0.006323
2	28.8249	-0.79027	0.006483
3	324.1775	-1.36061	0.003174
4	610.2535	-2.39928	0.006732
5	324.1775	-1.36061	0.003174
6	50.3808	-0.39077	0.006181

Case 1: In this case, the economic and emission dispatch functions are optimized independently and obtained results are depicted in Table 3.

Table 3. Results of Case 1, i.e., fuel cost and emission functions are optimized independently.

	Fuel Cost Minimization (F)	**Emission Minimization (E)**
P_{G1} (MW)	282.8235	193.6593
P_{G2} (MW)	294.6215	210.8889
P_{G3} (MW)	468.4434	525.7681
P_{G4} (MW)	353.0812	325.7273
P_{G5} (MW)	293.0731	476.5907
P_{G6} (MW)	216.1467	195.7489
P_{loss}(MW)	108.1894	128.3833
Fuel Cost ($/h)	18527.3	18767.19
Emission (kg/h)	2275.974	2031.29

Case 2: In this case, the two objectives i.e., fuel cost minimization and emission minimization are combined. Each pair of objectives was combined to form a single objective function using the weight factors. The objective function including the weight factor (W) can be expressed as,

Minimize,

$$(F+W.E) \tag{8}$$

In this case, the Pareto optimal solution set i.e., Pareto optimal front is obtained by changing the weight of each objective function and the simulation results are shown in Table 4.

Table 4. Pareto optimal set for fuel cost and emission minimization objective functions.

Weight Factor (W)	**Fuel Cost Minimization (F)**	**Emission Minimization (E)**
0	18767.2	2031.3
0.1	18720.1	2033.8
0.2	18678.9	2041.0
0.3	18643.3	2052.9
0.4	18612.8	2069.3
0.5	18587.2	2090.3
0.6	18566.1	2116.0
0.7	18549.5	2146.8
0.8	18537.5	2183.1
0.9	18530.0	2225.7
1.0	18527.3	2276.0

Case 3: In this case, the solution of multi-objective based economic and emission dispatch problem is obtained by assigning different weight factors to the two objective functions. Here, three different scenarios are studied and they are described next:

- ***Scenario 1:*** Two objective functions (F and E) have equal weights of 25.
- ***Scenario 2:*** F has a weight of 40 and E has a weight of 30.
- ***Scenario 3:*** F has a weight of 60 and E has a weight of 20.

Table 5 presents the optimum total generation cost and the emission obtained for the above mentioned three scenarios.

Table 5. Optimum objective function values for Case 3.

	Scenario 1	**Scenario 2**	**Scenario 3**
P_{G1} (MW)	270.99	279.19	271.53
P_{G2} (MW)	352.90	350.52	341.19
P_{G3} (MW)	438.63	467.90	446.72
P_{G4} (MW)	226.92	176.26	237.65
P_{G5} (MW)	381.64	394.74	373.82
P_{G6} (MW)	251.55	256.20	249.24
P_{loss} (MW)	122.62	124.81	120.16
Fuel Cost ($/h)	**18639.30**	**18689.01**	**18615.73**
Emission (kg/h)	**2360.12**	**2432.25**	**2323.54**

Case 4: Solving the fuel cost and emission minimization objectives simultaneously

In this case, the two objectives F and E are optimized simultaneously using multi-objective based artificial immune algorithm. Here, the total system load demand is 283.4MW and the obtained system generation is 288.036MW. The final trade-off/best compromised solution is presented in Table 6. The transformer tap positions and shunt susceptance values obtained for Case 4 are presented in Tables 7 and 8. The obtained optimum generator voltage magnitudes, active and reactive power generations for Case 4 are presented in Table 9.

Table 6. Final bet compromised solution for IEEE 30 bus test system.

Optimization Problem	**Fuel Cost (in $/hr)**	**Emission (in kg/hr)**
Fuel cost minimization problem	**806.498**	381.671
Emission minimization problem	932.095	**229.145**
Final trade-off solution	**926.201**	**242.142**

Table 7. Optimum transformer taps settings for Case 4.

S.No	**From-To buses**	**Tap value**
1.	6-9	0.915
2.	6-10	1.100
3.	4-12	0.9875
4.	28-27	0.975

Table 8. Optimum bus shunt suceptance values for Case 4.

S.No	**From-To buses**	**Shunt suceptance**
1.	10	1.0125
2.	24	1.0

Table 9. Optimum bus voltages, active and reactive power generations for Case 4.

S.No	**Voltage (p.u.)**	**P_{Gi} (p.u.)**	**Q_{Gi} (MW)**
1.	1.000000	0.712626	-0.231329
2.	1.003158	0.729346	-0.027326
3.	0.991421	0.500045	0.130286
4.	0.995914	0.349738	0.633051
5.	1.013388	0.222398	0.008802
6.	1.000000	0.365994	0.674902
7.	1.004216	-0.000000	-0.000000
8.	0.998299	-0.000001	-0.000000
9.	1.065043	0.000114	-0.000000
10.	1.042844	0.000594	-0.000001
11.	1.065043	0.000000	0.000000
12.	1.055699	-0.000930	-0.000005
13.	1.045549	-0.000019	-0.000007
14.	1.040786	-0.000015	0.000001
15.	1.036565	-0.000020	0.000002
16.	1.027964	0.000961	0.000004
17.	1.033049	0.000009	0.000002
18.	1.025878	-0.000003	0.000001
19.	1.023364	-0.000002	-0.000000
20.	1.027458	0.000004	-0.000001
21.	1.027112	0.000018	-0.000005
22.	1.026608	-0.000500	-0.000001
23.	1.026413	-0.000004	-0.000000
24.	1.021240	0.000003	-0.000002
25.	1.043109	-0.000003	0.000000
26.	1.025885	-0.000002	-0.000000
27.	1.064945	0.000067	-0.000003
28.	0.992422	-0.000060	0.000000
29.	1.045961	-0.000002	0.000000
30.	1.034977	-0.000008	0.000001

CONCLUSIONS

In this paper, an approach for solving the economic and emission dispatch problem is solved by minimizing the generation cost and the amount of emission release using the multi-objective based artificial immune algorithm. The proposed algorithm presents the partial and global affinities to find the antibody affinity to multi-objective functions. This algorithm has achieved a balance between the individual diversity and the population convergence. The optimum and efficient economic operations of electrical generation systems have much important position in the electric power industry. This involves the allocation of total load between the available generating units in such a way that the total cost of operation is kept at a minimum. The combined economic and environmental dispatch has been applied to obtain optimum generation cost and emission of generating units. The harmful ecological effects caused by the emission of gaseous pollutants like sulfur dioxide (SO_2) and oxides of nitrogen (NOx) can be reduced by the distribution of load demand between various plants of power system. The proposed algorithm has been solved on a standard IEEE 30 bus test system. The simulation results showed the effectiveness of the proposed approach.

REFERENCES

[1] E.H. Chowdhury, S. Rahrnan, "A Review of Recent Advances in Economic Dispatch", *IEEE Trans. Power Syst.*, Vol. 5, No. 4, pp 1248- 1259, Nov. 1990.

[2] A.J. Wood, B.F. Wollenberg, "Power Generation, Operation, and Control", *John Wiley & Sona, Inc.,* New York, 2004.

[3] J. Kennedy, R. Eberhart, "Particle swarm optimization," *Proc. IEEE Int. Conf. Neural Networks*, vol. IV, Perth, Australia, pp. 1942-1948, 1995.

[4] M.R. AlRashidi, M.E. El-Hawary, "A Survey of Particle Swarm Optimization Applications in Electric Power Systems" *IEEE Trans. Evolutionary Comput.*, vol. 13, no. 4, pp. 913-918, 2006.

[5] J.B. Park, K.S. Lee, J.R. Shin, K.Y. Lee, "A Particle Swarm Optimization for Economic Dispatch with Non-smooth Cost Functions", *IEEE Trans. Power Syst.*, Vol. 20, No.1, pp 34- 42, Feb. 2005.

[6] Z.L. Gaing, "Particle Swarm Optimization to Solving the Economic Dispatch Considering the Generator Constraints", *IEEE Tans. Power Syst.*, Vol. 18, No. 3, pp. 1187-1195, Aug. 2003.

[7] A.A. El-Keib, H. Ma, J.L.Hart, "Economic dispatch in view of the Clean Air Act of 1990", *IEEE Trans. Power Syst.*, Vol. 9, No. 2, pp. 972-978, May 1994.

[8] J.H.Talaq, F.El-Hawary, and M.E.El-Hawary, "A Summary of Environmental/Economic Dispatch algorithms," *IEEE Trans. Power Syst.*, vol. 9, pp. 1508–1516, Aug. 1994.

[9] A.I.Selva Kumar, K. Dhanushkodi, J.Jaya Kumar, C.K.Charlie Paul, "Particle Swarm Optimization Solution to Emission and Economic Dispatch Problem", *IEEE TENCON*, Oct. 2003, pp. 435-439.

[10] J. Zhou, C. Wang, Y. Li, P. Wang, C. Li, P. Lu, L. Mo, "A multi-objective multi-population ant colony optimization for economic emission dispatch considering power system security", *Applied Mathematical Modelling*, vol. 45, pp. 684-704, May 2017.

[11] D. Zou, S. Li, Z. Li, X. Kong, "A new global particle swarm optimization for the economic emission dispatch with or without transmission losses", *Energy Conversion and Management*, vol. 139, pp. 45-70, May 2017.

[12] C. Shilaja, K. Ravi, "Optimization of emission/economic dispatch using euclidean affine flower pollination algorithm (eFPA) and binary FPA (BFPA) in solar photo voltaic generation", *Renewable Energy*, vol. 107, pp. 550-566, Jul. 2017.

[13] H.L. Liao, Q.H. Wu, Y.Z. Li, L. Jiang, "Economic emission dispatching with variations of wind power and loads using multi-objective optimization by learning automata", *Energy Conversion and Management*, vol. 87, pp. 990-999, Nov. 2014.

[14] M.S. Li, Q.H. Wu, T.Y. Ji, H. Rao, "Stochastic multi-objective optimization for economic-emission dispatch with uncertain wind power and distributed loads", *Electric Power Systems Research*, vol. 116, pp. 367-373, Nov. 2014.

[15] Y. Zhu, J. Wang, B. Qu, "Multi-objective economic emission dispatch considering wind power using evolutionary algorithm based on decomposition", *International Journal of Electrical Power & Energy Systems*, vol. 63, pp. 434-445, Dec. 2014.

[16] T. Dinesh Varma, D.M. Vinod Kumar, "Multi-Objective Economic Emission Load Dispatch using Teacher-Learning-Based Optimization Technique", *IFAC Proceedings of 3rd International Conference on Advances in Control and Optimization of Dynamical Systems*, vol. 47, no. 1, pp. 819-826, 2014.

[17] A. Ahmadi, H. Moghimi, A.E. Nezhad, V.G. Agelidis, A.M. Sharaf, "Multi-objective economic emission dispatch considering combined heat and power by normal boundary intersection method", *Electric Power Systems Research*, vol. 129, pp. 32-43, Dec. 2015.

[18] M. Modiri-Delshad, N.A. Rahim, "Multi-objective backtracking search algorithm for economic emission dispatch problem", *Applied Soft Computing*, vol. 40, pp. 479-494, Mar. 2016.

[19] P.K. Roy, S. Bhui, "Multi-objective quasi-oppositional teaching learning based optimization for economic emission load dispatch problem", *International Journal of Electrical Power & Energy Systems*, vol. 53, pp. 937-948, Dec. 2013.

[20] Y. Di, M. Fei, L. Wang, W. Wu, "Multi-objective Optimization for Economic Emission Dispatch Using an Improved Multi-objective Binary Differential Evolution Algorithm", *Energy Procedia, International Conference on Applied Energy*, vol. 61, pp. 2016-2021, 2014.

[21] H. Bilil, G. Aniba, M. Maaroufi, “Probabilistic Economic Emission Dispatch Optimization of Multi-sources Power System”, *Energy Procedia*, vol. 50, pp. 789-796, 2014.

[22] X. Hugang, C. Haozhong, L. Haiyu, “Optimal reactive power flow incorporating static voltage stability based on multi-objective adaptive immune algorithm”, *Energy Conversion and Management*, vol. 49, pp. 1175-1181, 2008.

[23] L. Jikeng, W. Xudong, Z. Weihong, “Reactive Power Optimization Based on Adaptive Immune Algorithm, *Proc. of the International Multi Conference of Engineers and Computer Scientists*, vol. 2, Mar. 2008.

[24] S. Sheng, J. Li, “Study of reactive power optimization based on Artificial Immune Ant Colony Algorithm”, *Third International Conference on Electric Utility Deregulation and Restructuring and Power Technologies*, Nanjuing, 2008, pp. 2311-2315.