2011 International Conference on Signal, Image Processing and Applications
With workshop of ICEEA 2011
IPCSIT vol.21 (2011) © (2011) IACSIT Press, Singapore

Economic Dispatch by Biogeography Based Optimization Method

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Abstract. This paper proposes the application of biogeography based optimization (BBO) to solve the economic dispatch (ED) problem of power systems operation. Biogeography is the study of the geographical distribution of biological organisms. The proposed method has a simple procedure to find a near optimal solution for the non-smooth and non-convex problems mainly through two steps: migration and mutation. There are many constraints in the economic dispatch problem such as generators capacity, ramp rate limit, and prohibited operation zones. There is also the problem of valve point effect which will change the fuel cost equation of the generators, leading to non-convex objective. In this paper, BBO is applied to solve the economic dispatch problem of non-smooth and non-convex objectives. Results are compared with other heuristic methods presented in literature.

Keywords: biogeography based optimization, economic dispatch, heuristic methods, migration, mutation.

1. Introduction

Economic dispatch (ED) main objective is to minimize the generation cost while satisfying load demand and system constraints. There are many constraints in ED such as generators capacity, ramp rate limit, and prohibited operation zones. Valve point loading effect introduce non-convexities to the objective. Methods proposed to solve the economic dispatch problem can be classified into two main methods, classical vs. heuristic. Several classical methods were proposed to solve the economic dispatch problem such as lambda iteration method, gradient method, base point and participation factor method (Allen J. Wood and Bruce F, 1996). All these methods assume that the cost curve is continuous and monotonically increasing. Practical input/output characteristics of modern units are highly non-linear and non-convex. Hence the classical methods fail to solve such problems. Dynamic programming (DP) has no restriction on the nature of the economic dispatch input output characteristic curve so it succeeds in solving the ED problem with non-smooth / non-convex objectives but suffers from the curse of dimensionality (Allen J. Wood and Bruce F, 1996). Heuristic methods such as Genetic algorithms (GA) (Chen, 1995), evolutionary programming (EP) (Jayabarathi, 1999), particle swarm optimization (PSO) (Gaing, 2003), etc. provide an efficient solution to the ED problem with non-smooth / non-convex objectives. GA use parallel search techniques. PSO is a simple and easy algorithm that can generate high quality solutions within shorter computation time. A new technique was proposed known as biogeography based optimization (BBO) (Simon, 2008). Biogeography is the study of the geographical distribution of biological organisms. Mathematical models of biogeography describe how species migrate from one habitat to another, how species arise, and how species become extinct. BBO has features in common with genetic algorithms (GA) and particle swarm optimization (PSO). Hence BBO is applicable to many problems of the same types that GA and PSO are used for. The proposed method has a simple procedure to find a near optimal solution for the non-smooth and non-convex problems mainly through two steps: migration and mutation. A solution in BBO is an island which has species living in it.

2. Economic dispatch problem

Economic dispatch (ED) is finding the minimum cost of generating electrical energy while satisfying load demand and system constraints such as generators capacity, ramp rate limits and prohibited operation zones. The generator fuel cost is usually represented by the following quadratic function

$$\min F_t = \sum_{i=1}^{N} F_i(P_i) = \sum_{i=1}^{N} \left(a_i P_i^2 + b_i P_i + c_i\right) \tag{1}$$

where Pi is the output power of the ith generator, ai, bi and ci are the cost coefficients constants of the i^{th} generator, N is the number of committed generators. Valve point loading effect is represented by Equation 2

$$F_i(P_i) = a_i P_i^2 + b_i P_i + c_i + \left|e_i \sin\left(f_i\left(P_{i\min} - P_i\right)\right)\right| \tag{2}$$

where e_i, f_i are constant cost coefficients for valve point effect and $P_{i\ min}$ is the minimum power limit.

Economic Dispatch Constraints:

1. Generator Power Limit Constraint:

$$P_{i\min} \le P_i \le P_{i\max} \tag{3}$$

2. Real Power Balance Constraint:

$$\sum_{i=1}^{N} P_i - P_D - p_{loss} = 0 \tag{4}$$

where N is the number of generating units; P_D is the demand load; P_{loss} is the power losses.

$$P_{loss} = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \tag{5}$$

where B_{ij} is the Power loss coefficient.

3. Ramp Rate Limit Constraint:

$$P_{i\ present} - P_{i\ new} \le DR_i \tag{6}$$

$$P_{i\ new} - P_{i\ present} \le UR_i \tag{7}$$

where DR_i is the down ramp limit of the it^h generator, UR_i is the up ramp limit of the i^{th} generator.

4. Prohibited Operating Zone Constraint:

$$\begin{aligned} &P_{i\min} \le P_i \le P_{i,1}^l \\ &P_{i,1}^u \le P_i \le P_{i,2}^l \\ &P_{i,j}^u \le P_i \le P_{i\max} \\ &i = 1,2,......,N \\ &j = 1,2,.....,m_i \end{aligned} \tag{8}$$

where $P^l_{i,j}$ is the lower bound of the j^{th} prohibited zone of the i^{th} generation unit, $P^u_{i,j}$ is the upper bound of the j^{th} is prohibited zone and m_i is the total number of prohibited operating zones of the i^{th} generation unit.

3. Biogeography based Optimization (BBO)

Mathematical models of BBO describe the migration of species from one island to another, how species arise and become extinct. Island in BBO is defined as any habitat that is isolated geographically from other habitats. Well suited habitats for species are said to have high habitat suitability index (HSI) while habitats that are not well suited said to have low HSI. Each habitat consists of features that decide the HSI for the habitat. These features are considered as independent variable and called suitability index variables (SIV) which map the value of the HSI of the habitat. High HSI habitats have large number of species while low HSI habitats have small number of species. High HSI habitats have high emigration rate μ and low immigration rate λ as shown in Fig.1 which represents the model of species abundance in a single habitat. Low HSI habitats have low emigration rate μ and high immigration rate λ as shown in Fig.1. Emigration of species from one habitat to another habitat does not mean that all the species will disappear from its home, only a few reprehensive emigrate. In BBO there are two main operations, migration and mutation. Probability Ps that a habitat contains exactly S species

$$P_s(t + \Delta t) = P_s(t)\left(1 - \lambda_s \Delta t - \mu_s \Delta t\right) + P_{s-1}\lambda_{s-1}\Delta t + P_{s+1}\mu_{s+1}\Delta t \tag{9}$$

In order to have S species at time (t + Δt) we should have one of the following:

1. S species at time t and no immigration or emigration occurred between t and t + Δt.
2. S-1 species at time t and one species immigrated.
3. S+1 species at time t and one species emigrated.

A useful way to calculate Ps in programs is using the differentiation of Ps as shown in the

$$\frac{dP_s}{dt} = \lim_{\Delta t \to 0} \frac{P_s(t+\Delta t) - P_s(t)}{\Delta t} = \begin{cases} -(\lambda_s + \mu_s)P_s + \mu_{s+1}P_{s+1}, & S = 0 \\ -(\lambda_s + \mu_s)P_s + \lambda_{s-1}P_{s-1} + \mu_{s+1}P_{s+1}, & 0 < S < S_{\max} \\ -(\lambda_s + \mu_s)P_s + \lambda_{s-1}P_{s-1}, & S = S_{\max} \end{cases} \quad (10)$$

From Fig.1 μ and λ can be calculated as follows

$$\mu_k = \frac{E.k}{n} \quad (11)$$

$$\lambda_k = I\left(1 - \frac{k}{n}\right) \qquad n = S_{\max} \quad (12)$$

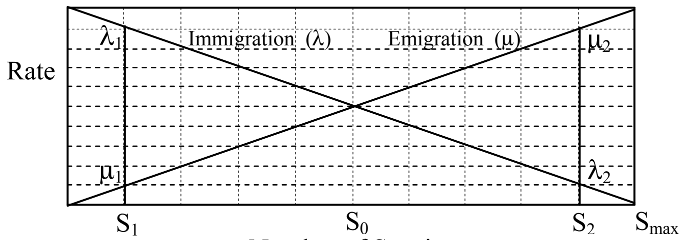

Fig. 1 Species model and two candidate solutions S1 and S2 to some problem

BBO concept is mainly based on migration and mutation operations.

Migration

A process of probabilistically sharing information between habitat using the immigration and emigration rate is known as migration. We modify each solution based on other solutions. In Fig.1, solution S1 represents a low HSI and solution S2 represents a High HSI solution. S1 has a high immigration rate λ and a low emigration rate μ. S2 has a low immigration rate λ and a high emigration rate μ. Hence high HSI habitats are selected based on probability proportional to the emigration rate μ and low HSI habitat are selected based on probability proportional to the immigration rate λ. Consider H_i as a habitat with low HSI and needs to be modified through habitat H_x with high HSI. Then randomly selected SIV from H_x replace randomly selected SIV in H_i.

Mutation

Severely destructive events can extremely change the HSI of a habitat and can cause the species count to deviate from its equilibrium point. In BBO the mutation is modeled as SIV mutation using species count probabilities to determine mutation rate. Very high HSI and very low HSI solutions are likely to be mutated to a different solution using the mutation rate m that is calculated using

$$m(s) = m_{\max}\left(1 - \frac{P_s}{P_{\max}}\right) \quad (13)$$

where m(s) is the mutation rate, m_{max} is the maximum mutation rate, Ps is the probability that S species in a habitat, and P_{max} is the maximum probability that S species in a habitat. When a solution is selected for mutation then we replace a randomly chosen SIV in the habitat with a new randomly generated SIV.

BBO algorithm for solving economic dispatch problem

In the EDC problem each habitat represent a candidate solution consist of SIVs. Each SIV represents the output power generated by a specific generation unit and satisfying it’s different constrains.

1. Initialize BBO parameters.
2. Generate a random set of habitats that consists of SIVs representing feasible solutions.
3. Calculate HSI for all habitats and their corresponding rates μ and λ.
4. Identify the best solutions based on the HSI value and save the best solutions.
5. Probabilistically use λ and μ to modify the non elite habitat using the migration process.
6. Based on species count probability of each habitat mutate the non-elite habitat then go to step (3).
7. After specified number of generation this loop is terminated.

After the modification of each habitat (steps 2,5,6) the feasibility of the habitat as a candidate solution should be tested and if it is not feasible then variables are tuned to convert it to a feasible solution.

4. Numerical examples and Results

The proposed algorithm was tested on three test cases. These are a three generators system with quadratic cost functions valve-point loading effects [10], a six generators system with prohibited operating zones, ramp rate limits and transmission loss [5] and a forty generators system with valve-point loading effects without transmission loss [10]. The program was written in MATLAB and executed on a 3.06 GHz Intel® Core ™ i3 CPU 540 PC with 4GB RAM. The results are shown in Tables 1, 2, 3, 4, 5 and 6. Convergence characteristics of the three cases are shown in Figures 2, 3 and 4.

Table 1 Comparison results for test case1 with load=850MW

Unit	BBO	GA [7]	PSO [7]
	Power	Power	Power
1	300.2829	299.100	300.268
2	149.7377	150.800	149.732
3	399.9794	399.00	400.00
Total Power(MW)	850	850	850
Total Cost($/hr)	8234.0777	8239.20	8234.72
Time(sec)	26.239785	-	-

Table 2 Minimum, maximum and average cost for 50 trials of Case 1

TRIALS	Minimum Cost	Average cost	Maximum cost
50	8234.073	8234.1215	8235.0669

Table 3 Comparison results for test case 2 with Load=1263MW

Unit	BBO	GA [5]	PSO [5]
	Power	Power	Power
1	447.1710	474.8066	447.497
2	173.3850	178.6363	173.3221
3	262.8670	262.2089	263.4745
4	139.5146	134.2826	139.0594
5	166.0163	151.9039	165.4761
6	87.0004	74.1812	87.1280
Total Power(MW)	1275.9543	1276.03	1276.01
P_{loss}(MW)	12.9543	13.0217	12.9584
Total Cost($/hr)	15449.9087	15459	15450
Time(sec)	22.837647	-	-

Table 4 Minimum, maximum and average cost for 50 trials of Case 2

TRIALS	Minimum Cost	Average cost	Maximum cost
50	15449.9087	15450.1451	15451.5972

Table 5 Comparison results for test case 3 with Load=10500MW

Unit	BBO	PSO [3]	FAPSNM [1]	Unit	BBO	PSO [3]	FAPSNM [1]
	Power	Power	Power		Power	Power	Power
1	110.7998	113.116	111.380	21	523.3192	524.814	523.3300
2	110.7998	113.010	110.9300	22	523.3040	524.775	523.4800
3	97.3999	119.702	97.4100	23	523.2945	525.563	523.3300
4	179.7331	81.647	179.330	24	523.2887	522.712	523.330
5	87.7999	95.062	89.220	25	523.2851	503.211	523.330
6	140.0000	139.209	140	26	523.2829	524.199	523.330
7	259.5997	299.127	259.620	27	10.0000	10.082	10
8	284.5997	287.491	284.6600	28	10.0000	10.663	10
9	284.5997	292.316	284.660	29	10.0035	10.418	10
10	204.7998	279.273	130	30	87.7999	94.244	88.700
11	170.6990	169.766	168.820	31	190.0000	189.377	190
12	95.1717	94.344	168.820	32	190.0000	189.796	190
13	125.7229	214.871	214.750	33	190.0000	189.813	190
14	394.7254	304.790	394.2800	34	164.7998	199.797	165
15	394.5545	304.563	304.5400	35	164.7998	199.284	166
16	394.4491	304.302	394.300	36	164.7998	198.165	165
17	489.2794	489.173	489.2900	37	110.0000	109.291	110
18	489.2794	491.336	489.290	38	110.0000	109.087	110
19	511.3841	510.880	511.280	39	110.0000	109.909	110

20	511.3440	511.474	511.290	40	511.2816	512.348	511.30
Total Power (MW)					10500	10500	10500
Fuel Cost($/hr)					121510.8489	122,323.97	121418.3

Table 6 Minimum, maximum and average cost for 50 trials of Case 3

TRIALS	Minimum Cost	Average cost	Maximum cost
50	121510.7684	121749.179	121899.6994

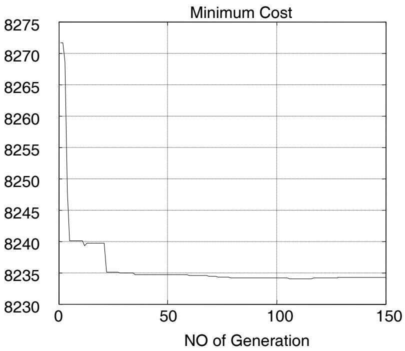

Figure 2 Cost vs. generation curve for three units system

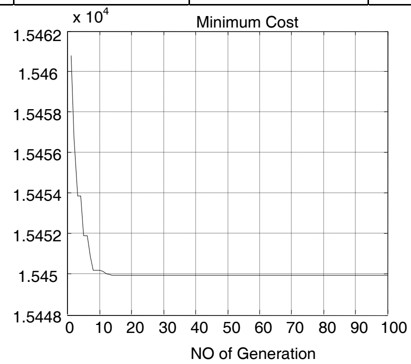

Figure 3 Cost vs. generation curve for six units system

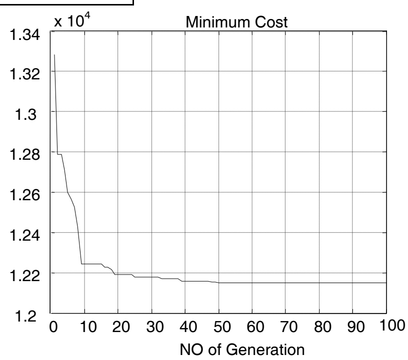

Figure 4 Cost vs. generation curve for forty units system

5. Conclusions

Economic dispatch is a fundamental optimization problem in power system operation. In this paper, biogeography based optimization (BBO) algorithm is employed to solve the economic dispatch problem. The proposed algorithm is capable of solving the economic dispatch problem with different constraints such as real power balance, generator power limits, ramp rate limits and prohibited operating zones. The problem includes valve point loading effect and transmission losses. Three test cases with three, six, and forty generators are tested. The results obtained by the algorithm are compared with other techniques presented in literature. It is obvious that the proposed algorithm have the capability to obtain better solutions than other techniques in terms of minimal fuel cost.

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