Solution of Economic Load Dispatch Problem Using Biogeography Based Optimization Technique Considering Valve Point Loading Effect

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***Abstract*—The article presents Biogeography-Based Optimization (BBO) algorithm which is applied on convex and non-convex Economic Load Dispatch (ELD) problem of power system. In this article transmission losses are not included. In this method, some non-linearities like valve point loading effect are considered. The primary objective of ELD is to determine optimal power allocation within operating limits such that the power demand is satisfied. Biogeography interacts with the biological distribution of species. The proposed BBO algorithm has been tested on three different test systems considering equality and inequality constraints. The results are checked the convergence characteristics with other techniques which prove the advantage of the proposed BBO algorithms.**

***Index Terms*—biogeography based optimization technique, valve point loading effect, economic load dispatch, particle swarm optimization**

I. Introduction

Since last decades, the electrical power market becomes more complex because of heavy load so optimal power allocation within operating limits is very difficult in electrical engineering. This is defined 'Economic Load Dispatch'. So the main purpose of the ELD is to minimize the total fuel cost of generation such that the equality and inequality constraints are also satisfied.

Dynamic programming is presented by Wood and Wollenberg [1], used to solve both convex and non-convex ELD problems. Quantum genetic algorithm [2] is proposed to solve ELD problem. In the conventional ELD problem, the cost function of generator is represented by a quadratic function and is solved using mathematical programming based techniques such as lambda iteration method, gradient-based method, etc. [3]. A hybrid Bacterial Foraging (BF) method is proposed to solve for economic load dispatch problem considering valve point loading effect [4]. But now a new optimization technique biogeography has been proposed by Simon [5]. An evolutionary programming and simulated annealing is developed for solving ELD problem in [6]. Pothiya et al proposed ant colony optimization for solving the economic dispatch problem with non-smooth cost functions [7]. Biogeography-based optimization algorithm is used to solve the ELD problems of thermal plants [8]. Hota et al presented a newly developed optimization approach involving a modified bacterial foraging algorithm to solve economic load dispatch problem [9]. In [10], Meng proposed quantum-inspired particle swarm optimization to solve the ELD problem. Basu proposed Artificial Bee Colony (ABC) optimization technique for solving ELD problem considering multiple fuels etc. [11]. Multiple tabu search algorithm is proposed to solve the economic dispatch problem considering valve-point effects [12]. Enhanced cross-entropy method is also proposed to solve DED problem considering valve-point effects [13]. DED Problem including valve point effect, ramp rate limits and prohibited operating zone etc. [14] is solved using harmony search algorithm. Dynamic programming method [15] is used to solve ELD considering transmission losses.

This paper presents BBO algorithm to solve ELD problem with valve point loading effect of thermal plants but without considering transmission losses. Section II describes the Economic load dispatch problem, Section III discusses biogeography based optimization (BBO) technique, Section IV describes the steps of implementation of BBO on ELD problems. Section V

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presents the simulation results and performance analysis and Section VI, the conclusion.

II. Economic Load Dispatch Problems

A. Fuel Cost Function

The fuel cost of generator in economic load dispatch of power system is described by quadratic cost function. It is indicated by equation no. 1`.

$$\left\{ Min.C = \sum_{i=1}^{N} C_i\left(P_i\right) \right. \quad (1)$$

where $C_i\left(P_i\right)$ is fuel cost function, P_i is generated power of unit i and N is number of generator units.

The fuel cost function of ith unit can be defined by

$$C_i\left(P_i\right) = a_i P_i^2 + b_i P_i + c_i \quad (2)$$

where a_i, b_i, c_i are the cost coefficients of unit i.

B. Constraints

There are two types of constraints in ELD.

- Equality constraints
- Inequality constraints

i) Equality Constraints

a. System power balance

In equality constraint, the power input of generators are allocated in such a way that it should be equals to the summation of load demand and transmission losses.

$$\sum_{i=1}^{N} P_i = P_D + P_L \quad (3)$$

where P_D is the load demand and P_L is the system's transmission loss.

ii) Inequality Constraints

b. Operating power limit

The generator's output should operate within their ranges.

$$P_i^{\min} \le P_i \le P_i^{\max} \quad (4)$$

where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum operating limits of generator i.

C. Economic Load Dispatch with Valve Point Loading

In ELD with "valve point loadings", objective function F is represented by a formula, given as (5).

$$C = \min\left(\sum_{i=1}^{N} C_i\left(P_i\right)\right) = \min\left(\sum_{i=1}^{N} a_i P_i^2 + b_i P_i + c_i + \left|e_i * \sin\left\{f_i * \left(P_i^{\min} - P_i\right)\right\}\right|\right) \quad (5)$$

where a_i, b_i, c_i, d_i, e_i are the cost coefficients of unit i.

III. Biogeography Based Optimization Technique

Biogeography means the geological distribution of species.

Suitability index variables (SIVs) are defined as variables that evaluate habitability. In biogeography, a habitat can be defined as the ecological area that is inhabited by particular plant and separated geographically from other habitats. Those most suitable areas have a high habitat suitability index (HSI). The rate of immigration (μ) and the emigration (λ) are the functions of the number of species in the habitat. I is the maximum possible immigration rate. The model of species abundance in a single habitat is described by Fig. 1.

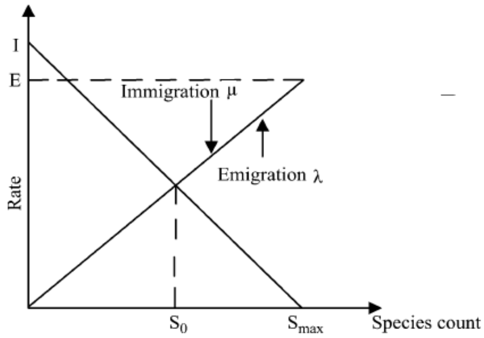

Figure 1. Species model of a single habitat.

S_0 is the point where the immigration and emigration rates are equal. At $S_{\max}$ the emigration rate is maximum. Let us consider the probability P_S that the island has exactly S species at t. It changes from t to $t + \Delta t$

$$P_S\left(t+\Delta t\right) = P_S\left(t\right)\left(1 - \mu_S \Delta t - \lambda_S \Delta t\right) + P_{S-1}\mu_{S-1}\Delta t + P_{S+1}\mu_{S+1}\Delta t \quad (6)$$

Here μ_S is the immigration rate and λ_S is the emigration rate. The equation (6) also holds for S species at time $t + \Delta t$. One of the following conditions must grip.

In Δt interval no emigration and immigration take place; there exist S species at time t.

If one species moves from this habitat that means immigrated, so there exist (S-1) species at time t.

If one specie enters into this habitat that means emigrated, so there exist (S+1) species at time t.

If $\Delta t \rightarrow 0$, the equation (6) becomes

$$\dot{P_S} = \begin{cases} -\left(\lambda_S + \mu_S\right)P_S + \lambda_{S+1}P_{S+1} & S = 0 \\ -\left(\lambda_S + \mu_S\right)P_S + \mu_{S-1}P_{S-1} + \lambda_{S+1}P_{S+1} & 1 \le S \le S_{\max} - 1 \\ -\left(\lambda_S + \mu_S\right)P_S + \mu_{S-1}P_{S-1} & S = S_{\max} \end{cases} \quad (7)$$

For k number of species the emigration rate and immigration rate can be calculated using following equation (8) and (9).

$$\lambda_k = \frac{E_k}{n} \quad (8)$$

$$\mu_k = I\left(1-\frac{k}{n}\right) \tag{9}$$

$$\mu_k + \lambda_k = E \qquad when \quad E = I \tag{10}$$

After mutation if solution is better from previous one then it is modified otherwise it is not changed. The steps of BBO algorithm is follows:

Step 1: Initialize all BBO parameter P_mod - modification probability,P_max - mutation probability,m_max - maximum mutation rate,I - maximum immigration rate,E -maximum emigration rate,Lower bound and upper bound for immigration Probability,dt - step size for numerical integration,N - number of habitats,D - number of SIV's, p - elitism parameter. A complete solution having SIVs is known as one habitat.

Step 2: Assume minimizing a function, first SIVs of all habitat are initialized randomly within their limits. So each habitat is the solution. Now total habitat set is formed.HSI value for each habitat of the population set for given emigration rate, immigration rate are calculated using the objective function. Those habitats, whose fitness values, are finite, are considered as valid species.

Step 3: Elite habitats are identified depends on their HSI values which are optimum.

Step 4: Assume i is the habitat for modification and j is the habitat that is resource of modification. First a habitat(i) is selected whose probability is proportional to μ_i for migration. An another habitat(j) is also selected whose probability is proportional to λ_j as the source of modification. Then randomly select an *SIV* from habitat j. It is replaced by a random SIV of ith habitat.

Step 5: Depending on their HSI values the elite habitats are identified. The elite habitats are to be kept. The non-elite habitats undergo for mutation operation. For each habitat the species count probability is calculated using (7). Then mutation rate of all habitat is calculated using (11).

$$m(s) = m_{max}\left(\frac{1-\dot{P}_S}{P_{max}}\right) \tag{11}$$

Here m_{max} is a user-defined parameter. Here also best solutions are kept.

Step 6: For next iteration, returns to step 3. When stopping criteria is satisfied that means completed the predefined number of iteration, then the loop is to be terminated.

IV. Implementation of BBO Algorithm on Economic Load Dispatch Problem

In this section, BBO algorithm is implemented on economic load dispatch problems.

The steps for BBO algorithm on ELD problem are follows:

Step 1: SIV's of the habitat initialization: Initialize all BBO parameter.

Step 2: Checking feasibility of habitats and calculation of HSI: Each SIV of a given habitat of matrix is initialized. In ELD problem HSI represents the total fuel cost of each solution.

Step 3: Elite habitat identification: Value elite habitats are identified based on the HSI (fuel cost in case of ELD problem). Elite habitats are those habitat sets of generator power output, which give best fuel cost. The fuel cost is arranged in ascending order. Then top "m" habitat sets are kept without any modification on it. Those habitats, whose fuel costs are finite, are considered as valid species in ELD problem.

Step 4: Migration operation: Perform migration operation on those SIVs of each non-elite habitat those are selected for migration. First select those habitats that undergo for migration operation. After migration of non-elite habitats, the unchanged elite habitats are added with the migrated non-elite habitats. The constraints of all habitats should be satisfied using (3) and (4).

Step 5: Mutation operation: For each habitat the species count probability is calculated using (7).Then mutation rate of all habitat is calculated using (11). After mutation of non-elite habitats, the unchanged elite habitats are added with the migrated non-elite habitats. Then the fuel cost of all habitats is calculated.

Step 6: Termination: For next iteration, returns to step 3. When stopping criteria is satisfied that means completed the predefined number of iteration, then the loop is to be terminated.

V. Results and Discussions

The applicability of the BBO algorithm has been tested in three cases. Case 1 is three unit systems [16], case 2 is thirteen unit systems [17] and case 3 is forty unit systems [17]. The programs are developed using MATLAB 7.01. Computational results are based on 30 trials.

Case 1: Three unit system

TABLE I. Optimal Power Output for Three Generator System ($P_D = 585MW$)

Unit Power Output	BBO	Classical PSO [16]
$P_1(MW)$	384.7354	268.89
$P_2(MW)$	149.7197	234.266
$P_3(MW)$	50.5449	81.8412
Total Generation Cost($/h)	**5525.0**	5821.44

TABLE II. Comparison of Other Different Methods for Three Generator System

Sl No.	Load Demand (MW)	Conventional Method ($/h) [16]	GA Method ($/h) [16]	BBO Method ($/h)
1.	585	5821.45	5827.5	**5525.0**

TABLE III. OPTIMAL POWER OUTPUT FOR THREE GENERATOR SYSTEM WITH VALVE POINT LOADING EFFECT $(P_D = 585MW)$

Unit Power Output	BBO
$P_1(MW)$	360.2586
$P_2(MW)$	174.3926
$P_3(MW)$	50.3488
Total Generation Cost($/h)	**5606.8**

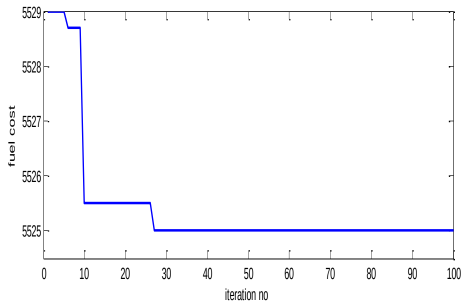

Figure 2. Fuel cost vs. iteration characteristic of 3-generator system for 585 MW using BBO.

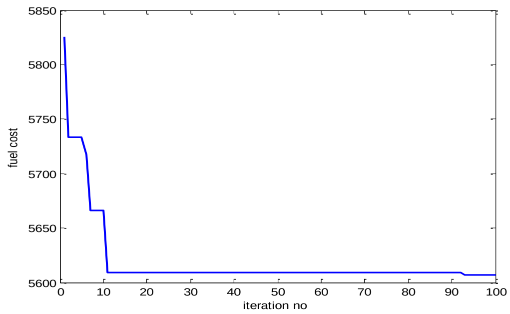

Figure 3. Fuel cost vs. iteration characteristic of 3-generator system with valve point loading effect for 585 MW using BBO.

In this case a three unit system is solved for ELD problem using the proposed BBO algorithm. The generation cost coefficients and power generation limits are taken from [16]. The total production cost obtained for the three unit systems of 585 MW without losses using BBO given in Table I. Table II provides comparison of the total cost obtained using BBO algorithm with that of other techniques for without losses. Table III gives best power output with valve point loading effect for 585 MW using BBO. Fig. 2 and Fig. 3 shows the graphs between number of iterations vs. cost in $/hr for load of 585 MW without and with considering valve point loading effect respectively using BBO.

Case 2: Thirteen unit system

In this case a thirteen unit system is solved for ELD problem using the proposed BBO algorithm. The generation cost coefficients and power generation limits are taken from [17]. Power generation limits and valve point loading are also included. The corresponding dispatch of units is shown in Table IV using BBO with load demand 2520 MW without considering valve point loading effect. Table V represents optimal power outputs of thirteen generators using BBO with load demand 2520 MW considering valve point loading effect. It has been seen that from Table V, BBO is very efficient technique compared to other existing techniques like SA [17], GA [17], GA-SA [17], EP-SQP [17], PSO-SQP [17], EP-EPSO [17]. Fig. 4 and Fig. 5 show fuel cost vs. iteration characteristics for load of 2520 MW without and with considering valve point loading effect using BBO respectively.

TABLE IV. OPTIMAL POWER OUTPUT FOR THIRTEEN GENERATOR SYSTEM $(P_D = 2520MW)$

Unit Power Output	BBO
$P_1(MW)$	675.1799
$P_2(MW)$	358.2288
$P_3(MW)$	357.7181
$P_4(MW)$	161.7774
$P_5(MW)$	132.1721
$P_6(MW)$	152.6643
$P_7(MW)$	162.4479
$P_8(MW)$	157.2090
$P_9(MW)$	149.6440
$P_{10}(MW)$	49.1116
$P_{11}(MW)$	40.3572
$P_{12}(MW)$	65.4139
$P_{13}(MW)$	58.0758
Total Generation Cost($/h)	**24058**

TABLE V. OPTIMAL POWER OUTPUT FOR THIRTEEN GENERATOR SYSTEM WITH VALVE POINT LOADING EFFECT $(P_D = 2520MW)$

Unit Power Output	BBO	SA [17]	GA [17]	GA-SA [17]	EP-SQP [17]	PSO-SQP [17]	EP-EPSO [17]
$P_1(MW)$	629.0384	668.40	628.32	628.23	628.3136	628.3205	680.0000
$P_2(MW)$	299.4	359.78	356.49	299.22	299.1715	299.0524	360.0000
$P_3(MW)$	300.9	358.20	359.43	299.17	299.0474	298.9681	360.0000
$P_4(MW)$	160.0331	104.28	159.73	159.12	159.6399	159.4680	180.0000

$P_5(MW)$	158.5731	60.36	109.86	159.95	159.6560	159.1429	150.3476
$P_6(MW)$	158.7641	110.64	159.73	158.85	158.4831	159.2724	151.2105
$P_7(MW)$	160.8360	162.12	159.63	157.26	159.6749	159.5371	149.6332
$P_8(MW)$	158.8546	163.03	159.73	159.93	159.7265	158.8522	149.8140
$P_9(MW)$	158.3287	161.52	159.73	159.86	159.6653	159.7845	148.9940
$P_{10}(MW)$	75.3916	117.09	77.31	110.78	114.0334	110.9618	40.0000
$P_{11}(MW)$	76.3812	75.00	75.00	75.00	75.0000	75.0000	40.0000
$P_{12}(MW)$	92.5633	60.00	60.00	60.00	60.0000	60.0000	55.0000
$P_{13}(MW)$	90.8731	119.58	55.00	92.62	87.5884	91.6401	55.0004
Total Generation Cost($/h)	**24249**	24970.91	24398.23	24275.71	24266.44	24261.05	24050.1519

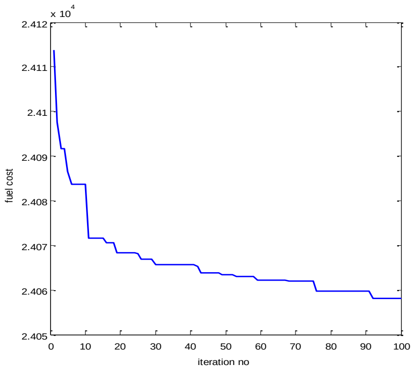

Figure 4. Fuel cost vs. iteration characteristic of 13-generator system for 2520 MW using BBO.

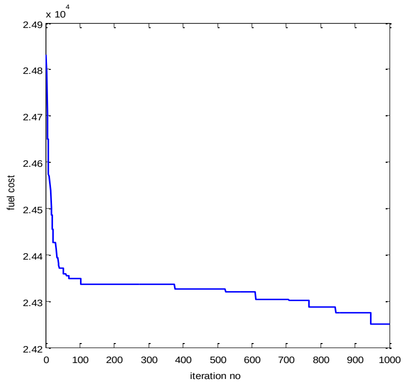

Figure 5. Fuel cost vs. iteration characteristic of 13-generator system with valve point loading effect for 2520 MW using BBO.

Case 3: Forty unit system

In this case a forty unit system is solved for ELD problem using the proposed BBO algorithm. The generation cost coefficients and power generation limits are taken from [17]. In this case power generation limits and valve point loading effect is also included. The corresponding dispatch of units is shown in Table VI using BBO. The power output for each unit satisfies the generation limit constraints. It can be seen from Table VI that fuel cost obtained from BBO is less compared with NN-EPSO [17]. Fig. 6 shows convergence characteristic for 10500 MW with considering valve point loading effect using BBO.

TABLE VI. BEST POWER OUTPUT FOR FORTY GENERATOR SYSTEM WITH VALVE POINT LOADING EFFECT $(P_D = 10500MW)$

Unit Power Output	BBO	NN-EPSO [17]
$P_1(MW)$	98.8896	114.0000
$P_2(MW)$	90.1587	114.0000
$P_3(MW)$	89.8095	120.0000
$P_4(MW)$	125.0444	190.0000
$P_5(MW)$	95.6842	97.0000
$P_6(MW)$	133.3026	140.0000
$P_7(MW)$	262.8127	300.0000
$P_8(MW)$	293.0266	300.0000
$P_9(MW)$	291.9984	300.0000
$P_{10}(MW)$	215.0590	300.0000
$P_{11}(MW)$	301.7632	375.0000
$P_{12}(MW)$	322.3709	375.0000
$P_{13}(MW)$	218.3955	500.0000
$P_{14}(MW)$	387.0909	500.0000
$P_{15}(MW)$	380.3957	500.0000
$P_{16}(MW)$	399.2478	500.0000
$P_{17}(MW)$	482.6137	402.6000
$P_{18}(MW)$	466.6080	225.0000
$P_{19}(MW)$	504.8264	508.0000
$P_{20}(MW)$	539.4209	458.0000
$P_{21}(MW)$	547.7423	356.0000
$P_{22}(MW)$	541.3735	394.0000
$P_{23}(MW)$	545.5207	355.0000
$P_{24}(MW)$	377.3290	525.0000
$P_{25}(MW)$	535.7328	310.0000
$P_{26}(MW)$	477.1911	448.0000
$P_{27}(MW)$	19.2830	72.0000
$P_{28}(MW)$	11.3058	131.0000
$P_{29}(MW)$	24.5712	75.0000
$P_{30}(MW)$	73.2394	67.0000
$P_{31}(MW)$	164.5544	151.0000
$P_{32}(MW)$	185.8322	112.0000
$P_{33}(MW)$	127.2772	139.0000

$P_{34}(MW)$	183.2367	90.0000
$P_{35}(MW)$	196.8634	129.0000
$P_{36}(MW)$	133.9944	104.0000
$P_{37}(MW)$	107.2968	36.0000
$P_{38}(MW)$	93.3959	89.0000
$P_{39}(MW)$	45.4849	104.0000
$P_{40}(MW)$	410.2564	550.0000
Total Generation Cost($/h)	**128190**	130328.325

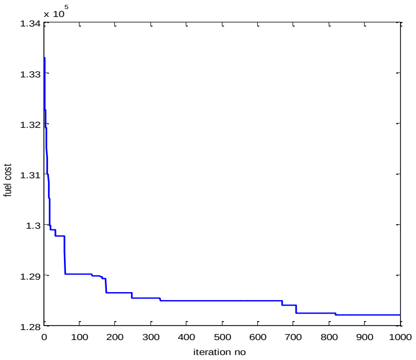

Figure 6. Convergence characteristic of 40-generator system with valve point loading effect for 10500 MW using BBO.

VI. CONCLUSIONS

The biogeography based optimization method has been successfully implemented to solve economic load dispatch problem by considering valve point loading effect. The BBO algorithm has superior characteristic to find the better quality solution due to better convergence characteristics, computational efficiency, and robustness. The comparison of the results with other existing methods reported in the literature shows the superiority of the proposed methods. It can be concluded that BBO technique is a promising method for solving ELD problems in power system operation.

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