# Economic Load Dispatch Problem of Thermal Generators with Ramp Rate Limit Using Biogeography - Based Optimization

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*Abstract—This paper presents an Efficient and Reliable Biogeography – Based Optimization (BBO) algorithm to solve both convex and non convex Economic Load Dispatch Problem (ELD) with Ramp rate limit of thermal power plants. The main objective is to minimize the total fuel cost of the thermal generating units having quadratic cost characteristics subjected to limits on generator True and Reactive power output, transmission losses, Ramp rate limit. Biogeography-Based Optimization (BBO) [1] is a biology inspired optimization technique developed by Dan Simon in 2008 and is inspired by mathematical models of biogeography by Robert MacArthur and Edward Wilson [2]. This paper presents an application of the BBO algorithm to Economic Load Dispatch Problem with Ramp rate limit of thermal power plants for 18 generator Test Case system [13]. Economic Load Dispatch problems is applied and compared its solution quality and computation efficiency to Genetic algorithm (GA), Particle swarm optimization (PSO), and other optimization techniques. The simulation results show that the proposed algorithm outperforms previous optimization methods.*

*Key words— Economic load dispatch, Ramp rate limit Genetic algorithm, Particle swarm optimization, mutation, migration.*

## I. INTRODUCTION

The Economic Load Dispatch (ELD) problem is one of the non-linear optimization problems in electrical power systems in which the main objective is to reduce the total power generation cost, while satisfying various equality and inequality constraints. The ELD seeks 'the best' generation schedules for the generate plants to supply the essential the total coupled power demand plus transmission losses at least production cost. The cost of power generation, particularly in fossil fuel plants, is very high and ELD helps in economy a considerable amount of profits. The Economic load dispatch is the name given to the process of apportioning the total load on a system between the various generating plants to achieve the greatest economy of operation. .economic operation is very important for a power system to return a profit on the capital invested. Various investigation on ELD have been undertaken until date, as better clarification would result in major economical profit. Earlier a number of derivatives based approach like lambda iteration, based point input factor, gradient method and include lagrangian multiplier method have been apply to solve ELD problems There methods involve that incremental cost curves through quadratic or piecewise monotonically increasing in nature

[3].But in apply the input output character of new generating units are extremely non linear because of valve – point loadings, ramp – rate limits, prohibited operating zones and multi – fuel option etc. their nature have to be about to meet to supplies of typical dispatch algorithms. Wood and Wollenberg proposed dynamic programming [3], which does not impose any restriction on the nature of the cost curves and solves both convex and non-convex ELD problems. But this method suffers from the curse of dimensionality and simulation time increases rapidly with the increase of system size. More interests have been focused on the application of artificial intelligence technology for solution of ELD problems. Several methods, such as genetic algorithm (GA) [4]; artificial neural networks [5]; simulated annealing (SA), Tabu search; evolutionary programming [6]; particle swarm optimization (PSO) [7]; ant colony optimization; differential evolution (DE) [8]; etc. have been developed and applied successfully to ELD problems.

Minimizing the total fuel cost of the thermal power plants while satisfying the demand power and power system constraints is aimed at to overcome the ED problem. The fuel cost effect is shown in fig. 1.
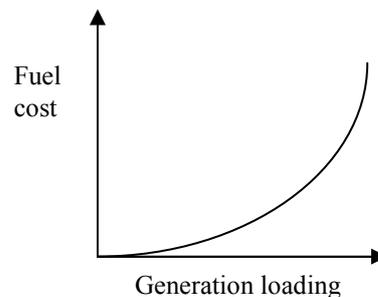


**Fig. 1. Fuel cost effect**

In ELD research, a number of study have focused upon the economical accepts of the problem above the statement that unit generation output can be adjusted instantaneously. Even though this assumption simplifies the problem, it does not reflect the actual operating processes of the generating unit. Ramp rate or power response rate is described as the power response capability of the unit in terms of accommodating power changes in specified time interval. The operating range of all on-line units is restricted by their ramp rate limits. Fig.2 shows three possible situations when a unit is On-line from hour t-1 to hour t. fig.2 (a) shows that the unit is in a steady operating status.
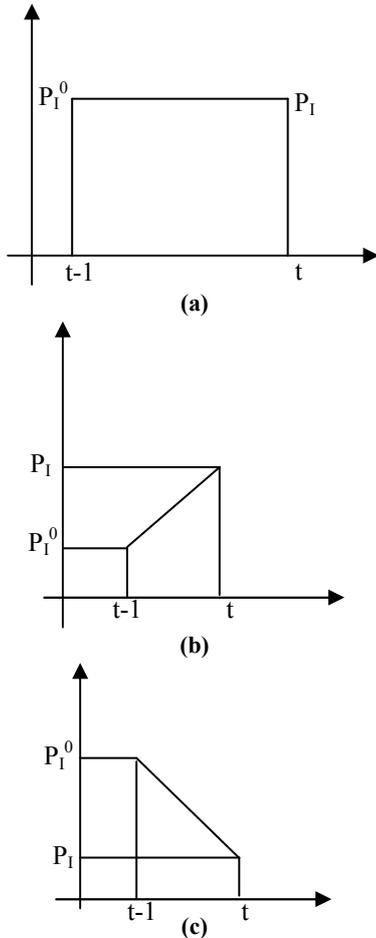
**(a)**



**(b)**



**(c)**

**Fig. 2. Three possible situations of an on-line unit**

Fig.2 (b) shows that the unit is in an increasing power generation status.Fig.2(c) shows that the unit is in a decreasing power generation status.

Artificial Immune System (AIS) [9] is another population based or network-based soft computing technique in the field of optimization that has been successfully implemented in various power system optimization problems. In each iteration of AIS, many operations like affinity calculation, cloning, hyper mutation, and selection are performed. During cloning, operation size of population also increases. Due to increase in number of operations, and larger size of population, convergence speed of AIS is much slower than DE or PSO.

Inspired from the mechanism of the survival of bacteria, e.g., E. coli, an optimization algorithm, called Bacterial Foraging Algorithm (BFA) [10], has been developed. Chemo taxis, reproduction and dispersion are the three processes with the help of which global searching capability of this algorithm has been achieved. These properties have helped BFA to be applied successfully in several kinds of power system optimization problems. But constraints satisfaction creates little trouble in BFA.

Very recently, a new optimization concept, based on biogeography, has been proposed by Simon [11].Biogeography is the nature's way of distributing species. Let us consider an optimization problem with some trial solutions of it. In BBO, a good solution is analogous to an

island with a high Habitat Suitability Index (HSI), and a poor solution represents an island with a low HSI. High HSI solutions resist change more than low HSI solutions. Low HSI solutions tend to copy good features from high HIS solutions. The shared features remain in the high HSI solutions, while at the same time appearing as new features in the low HIS solutions. This is as if some representatives of a species migrating to a habitat, while other representatives remain in their original habitat. Poor solutions accept a lot of new features from good solutions. This addition of new features to low HSI solutions may raise the quality of those solutions. This new approach to solve a problem is known as biogeography-based optimization (BBO) [11].These versatile properties of this new algorithm encouraged the authors to apply this newly developed algorithm to solve non convex complex ELD problems. This paper considers two types of non-convex ELD problems, namely, ELD with quadratic cost function and transmission loss, ELD with Ramp rate limit of thermal power plants. Section II of the paper provides a brief description and mathematical formulation of different types of ELD problems. The concept of biogeography is discussed in Section III. The original BBO approach is described in Section IV along with a short description of the algorithm used in this test system. The parameter settings for the test system to evaluate the performance of BBO and the simulation studies are discussed are discussed in Section V. The conclusion is drawn in Section VI.

## II. PROBLEM FORMULATION

The ELD may be formulated as a nonlinear constrained problem. Both convex and non-convex ELD problems have been modeled in this paper. The convex ELD problem assumes quadratic cost function along with system power demand and operational limit constraints. The practical non-convex ELD problem, in addition, considers generator nonlinearities *Ramp rate limit*.

### A. ELD with quadratic cost function and without transmission loss.

The objective function $F_T$ of ELD problem may be written as:-

$$F_T = MIN\left(\sum_{K=1}^{N} F_K(P_k)\right) \tag{1}$$

$$F_T = MIN\left(\sum_{K=1}^{N} a_k + b_k P_k + c_k P_k^2\right) \tag{2}$$

$$F_K(P_k) = a_k + b_k P_k + c_k P_k^2 \tag{3}$$

The ELD problem consists in minimizing subject to the following constraints: -
*1. Real Power Balance Constraint:*

$$\sum_{k=1}^{n} P_k - P_D = 0 \qquad (4)$$

*2. Generator Capacity Constraints:* The power generated by each generator shall be within their lower operating limit and upper operating limit.
So that,

$$P_k^{min} \le P_k \le P_k^{max} \qquad (5)$$

*B. ELD with quadratic cost function with transmission loss.*

The objective function $F_T$ of ELD problem may be written as:-

$$F_T = MIN \left( \sum_{K=1}^{n} F_K(P_k) \right) \qquad (6)$$

$$F_T = MIN \left( \sum_{K=1}^{n} a_k + b_k P_k + c_k P_k^2 \right) \qquad (7)$$

$$F_K(P_k) = a_k + b_k P_k + c_k P_k^2 \qquad (8)$$

The ELD problem consists in minimizing subject to the following constraints: -

*1. Real Power Balance Constraint:*

$$\sum_{k=1}^{n} P_k - (P_D + P_L) = 0. \qquad (9)$$

*2. Generator Capacity Constraints:* The power generated by each generator shall be within their lower operating limit and upper operating limit.
So that,

$$P_k^{min} \le P_k \le P_k^{max} \qquad (10)$$

*C. ELD with quadratic cost function with Ramp rate constraint.*

The objective function $F_T$ of ELD problem may be written as:-

$$F_T = MIN \left( \sum_{K=1}^{n} F_K(P_k) \right) \qquad (11)$$

$$F_T = MIN \left( \sum_{K=1}^{n} a_k + b_k P_k + c_k P_k^2 \right) \qquad (12)$$

$$F_K(P_k) = a_k + b_k P_k + c_k P_k^2 \qquad (13)$$

The ELD problem consists in minimizing subject to the following constraints: -

*1. Real Power Balance Constraint:*

$$\sum_{k=1}^{n} P_k - (P_D + P_L) = 0. \qquad (14)$$

*2. Generator Capacity Constraints:* The power generated by each generator shall be within their lower operating limit and upper operating limit.
So that,

$$P_k^{min} \le P_k \le P_k^{max} \qquad (15)$$

3. *Ramp rate limit constraint:* The power generated, $P_{i0}$ by the ith generator in certain interval may not exceed that of previous interval $P_{i0}$ by more than a certain amount $UR_i$ , the up-ramp rate limit and neither may it be less than that of the previous interval by more than some amount $DR_i$ the down- ramp rate limit of the generator. These give rise to the following constraints.
As generation increases
$$P_i - P_{i0} \le UR_i \qquad (16)$$
As generation decreases

$$P_{i0} - P_i \le DR_i \qquad (17)$$
and

$$Max\ (P_i^{min}, P_{i0} - DR_i) \le P_i \le min(P_i^{max}, P_{i0} + UR_i) \qquad (18)$$

### III. BIOGEOGRAPHY – BASED OPTIMIZATION

Biogeography-Based Optimization technique (BBO) [11] has been developed based on the theory of Biogeography. Biogeography – Based Optimization (BBO) is a novel evolutionary algorithm that is based on the mathematics of biogeography. Biogeography is the study of the geographical distribution of biological species. In the BBO model, problem solutions are represented as islands, and the sharing of features between solutions is represented as immigration and emigration between the islands. BBO has some features that are in common with other biology-based optimization methods, like genetic algorithms (GAs) and particle swarm optimization (PSO).Biogeography is nature's way of distributing species. Figure 3. Describes a model of species abundance in a habitat [12]. The immigration curve of Figure 3. Shows that immigration rate to the habitat is maximum ( I ), when there are zero species in the habitat. As the number of species increases, the habitat becomes more crowded, fewer species are able to successfully survive immigration to the habitat, and the immigration rate decreases. The largest possible number of species that the habitat can support is Smax, at which point the immigration rate becomes zero. The emigration curve of Figure 2 depicts that if there is no species in the habitat, the emigration rate will be zero. As the number of species increases, the habitat becomes more crowded, more species are able to leave the habitat to explore other possible residences and the emigration rate increases. The maximum emigration rate is E, which occurs when the habitat contains the largest number of species (Smax). The

equilibrium number of species is S0, at which point the immigration and emigration rates are equal. The immigration and emigration curves in Figure 2 are shown as straight lines but, in general, they might be more complicated curves.
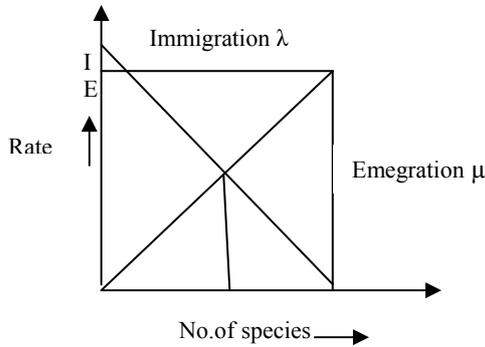


**Fig. 3. Species model of a single habitat**

Nevertheless, this simple model gives us a general description of the process of immigration and emigration. From Figure 1, immigration rate $\lambda s$ and the emigration rate $\mu s$ for S number of species may be formulated as follows:

$$\lambda_s = I\,[1\text{-}s\backslash s_{max}] \qquad (19)$$

$$\mu_{s} = E.S/S_{max} \qquad (20)$$

Mathematically the concept of emigration and immigration can be represented by a probabilistic model. Ps is the probability of the habitat that contains exactly S species. Ps changes from time t to time t + Δt as follows [12]:

$$p_s(t+\Delta t)=P_s(1\text{-}\lambda_s\Delta t\text{-}\mu_s\Delta t)+P_{s\text{-}1}\lambda_{s\text{-}1}\Delta t+P_{s+1}\lambda_{s+1}\Delta t \quad (21)$$

Where $\lambda_s$ and $\mu_s$ are the immigration and emigration rates when there are S species in the habitat. This equation holds because in order to have S species at time t + Δt , one of the following conditions must hold:

1) There are S species at time t, and no immigration or emigration occurs between t and t + Δt;
2) There are (S −1) species at time t, and one species immigrates;
3) There are (S +1) species at time t, and one species emigrates.

If time Δt is small enough so that the probability of more than one immigration or emigration can be ignored then taking the limit of (16) as Δt →0 gives the following equation

$$-\,(\lambda_s+\mu_s)\,P_s+\mu_{s+1}\,P_{s+1} \qquad,\ S{=}0$$

$$P_{s=}\text{-}(\lambda_s+\mu_s)\,Ps+\lambda_{s\text{-}1}P_{s+1}+\ \mu_{s+1}\,P_{s+1}\ \ 1{\leq}S{\leq}S_{max}\text{-}1 \qquad (22)$$

$$-\,(\lambda_s+\mu_s)\,P_s+\lambda_{s\text{-}1}P_{s+1} \qquad,\ S{=}\ S_{max}$$

This algorithm searches for the global optimum mainly through two steps: migration and mutation. The concept and mathematical formulation of Migration and Mutation steps are given below

### A. Migration

This BBO algorithm [11] is similar to other population based optimization techniques where population of candidate solutions can be represented as vectors of real numbers. Each real number in the vector is considered as one suitability index variable (SIV). Fitness (in BBO, a term called habitat suitability index (HSI)) of each candidate solution is evaluated using its SIVs.HSI represents the quality of each candidate solution. High HIS solution represents better quality solution and low HSI solution represents inferior solution in the optimization problem. The emigration and immigration rates of each solution are used to probabilistically share information between habitats. Immigration rate (λs) and emigration rate (μs) can be evaluated by the equations (14) and (15). Using Habitat Modification Probability each solution is modified based on other solutions. Immigration rate, λs of each solution is used to probabilistically decide whether or not to modify each SIV in that solution. If a SIV in a given solution is selected for modification, emigration rates, μs of other solutions are used to probabilistically select which of the solutions should migrate a randomly selected SIV to that solution. The main difference between recombination approach of evolutionary strategies (ES) and migration process of BBO is that in ES, global recombination process is used to create a completely new solution, while in BBO; migration is used to bring changes within the existing solutions. In order to prevent the best solutions from being corrupted by the immigration process, few elite solutions are kept in BBO algorithm.

### B. Mutation

Due to some natural calamities or other events HSI of a natural habitat can change suddenly and it may deviate from its equilibrium value. In BBO, this event is represented by the mutation of SIV and species count probabilities are used to determine mutation rates. The species count probability can be calculated using the differential equation (17). Each population member has an associated probability, which indicates the likelihood that it exists as a solution for a given problem. If the probability of a given solution is very low then that solution is likely to mutate to some other solution. Similarly if the probability of some other solution is high then that solution has very little chance to mutate. Therefore, very high HSI solutions and very low HSI solutions are equally improbable for mutation i.e. they have less chances to produce more improved SIVs in the later stage. But medium HSI solutions have better chances to create much better solutions after mutation operation. Mutation rate of each set of solution can be calculated in terms of species count probability using the equation (18) [11]:

$$m(s)=m_{max}1\text{-}P_S/P_{max} \qquad (23)$$

Where

$m(s)$ =the mutation rate for habitat containing S species,
$m_{max}$ = maximum mutation rate,:
$P_{max}$ = maximum probability.

This mutation scheme tends to increase diversity among the populations. Without this modification, the highly probable solutions will tend to be more dominant in the

population. This mutation approach makes both low and high HSI solutions likely to mutate, which gives a chance of improving both types of solutions in comparison to their earlier values. Few elite solutions are kept in mutation process to save the features of a solution, so if a solution becomes inferior after mutation process then previous solution (solution of that set before mutation) can revert back to that place again if needed. So, mutation operation is a high-risk process. It is normally applied to both poor and good solutions.[12] Since medium quality solutions are in improving stage so it is better not to apply mutation on medium quality solutions. Here, mutation of a selected solution is performed simply by replacing it with randomly generated new solution set. Other than this any other mutation scheme that has been implemented for GA can also be implemented for BBO.

## IV. THE PROPOSED SOLUTION METHOD

In this paper BBO algorithm has been employed to solve constrained ELD problem and to find optimal solutions satisfying both equality and inequality constraints. In BBO algorithm, applied to the ELD problem,[12] each candidate solution (i.e. each habitat) is defined by a vector with m SIVs where each SIV represents the value of power output. If there are m independent variables, then the i-th individual habitat Hi can be defined as follows:

$$H^i = SIV^{iq} = \{ SIV^{1q}, SIV^{2q} \ldots \ldots SIV^{im} \} \qquad (24)$$
Where: $i =1, 2,...,n$; $q = 1,2,...m$

$SIV^{iq}$ is the $q$-th independent variable of the i-th individual Hi. The dimension of the population is n×m. All these components in each individual are real values. HSIi indicates the objective function of the i-th habitat containing m independent variables (SIVs).The algorithm of the proposed method is as enumerated below.

*Step1:* Initialization of the BBO parameters.
*Step2:* The initial position of SIV of each habitat should be randomly selected while satisfying different equality and inequality constraints of ELD problems. Several numbers of habitats depending upon the population size are being generated. Each habitat represents a potential solution to the given problem.
*Step3:* Calculate each HSIi i.e. value of objective function for each i-th habitat of the population set n for given emigration rate μs, immigration rate λs and species S.
*Step4:* Based on the HSI values some elite habitats are identified.
*Step5:* Each non-elite habitat is modified by performing probabilistically immigration and emigration operation as described in section III. A.
*Step6:* Species count probability of each habitat is updated using. Mutation operation is performed on the non-elite habitat and HSI value of each new habitat is computed.
*Step7:* Feasibility of a problem solution is verified i.e. each SIV should satisfy equality and inequality constraints.
*Step8:* Go to step 3 for the next iteration.
*Step9:* Stop iterations after a predefined number of iterations.

## V. SIMULATION RESULTS

A power system with 18 generators data are given in table I.this power system is loaded with different load demands that are given in table II.In this power system economic dispatch is made by using different methods and loads. Economic dispatch results are given in table III.The solution presented in this paper based on a hybrid GA-PSO to solve various ED problems. If economic dispatch is done by using proposed method, total fuel costs significant gains can be achieved.

**TABLE I. Generator operating limits and cost coefficients of the test system.**

| Unit | $P_{mini}$ | $P_{maxi}$ | $a_i$ | $b_i$ | $c_i$ |
|---|---|---|---|---|---|
| 1 | 15,00 | 7 | 85,74158 | 22,45526 | 0,602842 |
| 2 | 45,00 | 7 | 85,74158 | 22,45526 | 0,602842 |
| 3 | 25,00 | 13 | 108,9837 | 22,52789 | 0,214263 |
| 4 | 25,00 | 16 | 49,06263 | 26,75263 | 0,077837 |
| 5 | 25,00 | 16 | 49,06263 | 26,75263 | 0,077837 |
| 6 | 14,75 | 3 | 677,73 | 80,39345 | 0,734763 |
| 7 | 14,75 | 3 | 677,73 | 80,39345 | 0,734763 |
| 8 | 12,28 | 3 | 44,39 | 13,19474 | 0,514474 |
| 9 | 12,28 | 3 | 44,39 | 13,19474 | 0,514474 |
| 10 | 12,28 | 3 | 44,39 | 13,19474 | 0,514474 |
| 11 | 12,28 | 3 | 44,39 | 13,19474 | 0,514474 |
| 12 | 24,00 | 3 | 574,9603 | 56,70947 | 0,657079 |
| 13 | 16,20 | 3 | 820,3776 | 84,67579 | 1,236474 |
| 14 | 36,20 | 3 | 603,0237 | 59,59026 | 0,394571 |
| 15 | 45,00 | 3 | 567,9363 | 56,70947 | 0,420789 |
| 16 | 37,00 | 3 | 567,9363 | 55,965 | 0,420789 |
| 17 | 45,00 | 3 | 567,9363 | 55,965 | 0,420789 |
| 18 | 16,20 | 3 | 820,3776 | 84,67579 | 1,236474 |

**TABLE II. Generator loading and fuel cost determined by the proposed method for different load demand.**

| Generator | POWER OUTPUT | | |
|---|---|---|---|
| | 80% P | 70%P | 365 MW |
| $P_{g1}$ | 14,9998 | 14,9998 | 14,9998 |
| $P_{g2}$ | 44,9998 | 43,7578 | 44,8294 |
| $P_{g3}$ | 24,9998 | 24,9998 | 24,9998 |
| $P_{g4}$ | 24,9998 | 24,9998 | 24,9894 |
| $P_{g5}$ | 24,9998 | 24,9998 | 24,9998 |
| $P_{g6}$ | 3,9966 | 2,9998 | 5.6012 |
| $P_{g7}$ | 3,2609 | 2,9998 | 6,1008 |
| $P_{g8}$ | 12,2798 | 12,2600 | 12,2600 |
| $P_{g9}$ | 12,2798 | 12,2600 | 12,2600 |
| $P_{g10}$ | 12,2798 | 12,2600 | 12,2600 |
| $P_{g11}$ | 12,2798 | 12,2600 | 12,2600 |
| $P_{g12}$ | 20,6580 | 13,7111 | 20,8518 |
| $P_{g13}$ | 2,9998 | 2,9998 | 3,3998 |
| $P_{g14}$ | 30,0735 | 22,2346 | 31,9144 |
| $P_{g15}$ | 30,7528 | 22,7579 | 36,1415 |
| $P_{g16}$ | 33,5614 | 24,9048 | 36,2579 |
| $P_{g17}$ | 33,9289 | 24,7225 | 36,3379 |
| $P_{g18}$ | 3,1326 | 2,9998 | 4,3080 |
| Total cost ($/h) | 23748.0009 | 20278,2321 | 25343,4549 |

**TABLE III. Comparison of proposed method for different Load demands.**

| Demand | y-iteration | GA | Real GA | BBO |
|---|---|---|---|---|
| 80%P | 23861,58 | 23980,24 | 23861,58 | 23748,0009 |

| 70%P | 20393,43 | 20444,68 | 20396,39 | 20278,2321 |
|------|----------|----------|----------|------------|
| 365MW | | | 25768,57 | 25343,4549 |

## VI. CONCLUSION

In this paper, authors have successfully introduced Biogeography Based Optimization algorithm to solve Economic Load Dispatch problem and compared its results to those of other well established algorithms. It is observed that the proposed algorithm exhibits a comparative performance with respect to other population based techniques. It is clear from the results that Biogeography Based Optimization algorithm is capable of obtaining higher quality solution with better computation efficiency and stable convergence characteristic.

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