BBO based Algorithm for Transmission Constrained Economic Load Dispatch problem

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Abstract: **This paper presents an efficient and reliable Biogeography Based Optimization (BBO) algorithm to solve the Economic Load Dispatch problem of thermal power station while satisfying generator and network constraints. Biogeography is the study of the geographical distribution of the biological organism. Biogeography-based optimization is a relatively new optimization approach. Mathematical models of biogeography explain how a organism arises, migrates from one habitat to another, or gets extinct. In BBO algorithm, solutions are represents as habitats and sharing features between solutions is represented as immigration and emigration. This algorithm searches for the global optimum solution mainly through two steps: Migration and Mutation. Results are obtained on the different-different population size and different-different number of trials and proposed method has been verified on IEEE 30- bus, 6 generator system. Considering the quality of the solution obtained, this method is one of the prominent approach for solving the Economic Load Dispatch (ELD) problems under practical conditions.**

Keywords: **BBO, ELD, HSI, IEEE 30-bus standard load flow test system, Migration, Mutation, SIVs.**

1. NOMENCLATURE

P_i	Real Power generation by i^{th} generator (MW)
P_D	Power demand (MW)
P_{imin}	Minimum generation by i^{th} generator (MW)
P_{imax}	Maximum generation by i^{th} generator (MW)
P_L	System power losses (MW)
Q_{imin}	Minimum reactive power generation by i^{th} generator (MVAR)
Q_{imax}	Maximum reactive power generation by i^{th} generator (MVAR)
Q_i	Reactive power generation by i^{th} generator (MVAR)
V_{imin}	Minimum voltage limit at i^{th} bus (p.u.)
V_{imax}	Maximum voltage limit at i^{th} bus (p.u.)
V_i	Bus voltage at i^{th} bus (MW)
F_i	Fuel cost per MW of i^{th} generator ($/hr.)
F_t	Total fuel cost ($/hr.)
I	Maximum immigration rate
E	Maximum emigration rate
P_s	Probability of a habitat having s number of species
P_{max}	Maximum probability

2. INTRODUCTION

The economic load dispatch of generation is the main optimization problems for both the generating plants and the systems operator in charge with a fair managing of transactions between electricity suppliers and their customers. The major part of the variable cost of generation of electricity is The fuel cost, reflected in the electricity bills [1]. The Economic load dispatch is the process of allocate the total load on a system between the various generating plants to gain the more economy of operation. Economic operation is most important for a generating plants to return a profit on the capital investment. Many different-different investigations on ELD have been undertaken until date, as better clarification would result in more economical profit.

The Transmission constrained economic load dispatch (TC-ED) seeks best generation schedule to supply load and losses at minimal cost while the generator as well as transmission network limitations taking into account. The TC-ED can also be viewed as a special case of the optimal power flow (OPF) problem in which the objective is the fuel cost minimization while some of the transmission constraints are consider. Thus three optimization problems are classified according to the degree of complexity and generality as follows: OPF, TC-ED, and ED [2].

The standard example of optimization problem, solved by coventional nonlinear programming techniques, is that of minimizing a convex function over a convex set [3]. This convex minimization problem is assured to have a unique local minima, which is also the global minima. Convex minimization problems may be solved using conventional gradient, sub-gradient, or Newton-based local search techniques, By use of model simplifications, convex ED and TC-ED problems are efficiently solved by traditional, local search ED algorithms such as linear programming [4], quadratic programming and lambda iteration (which ignores network constraints)etc.

In recent times, new advances in the field of global optimization have been used to solve many more problems in engineering and science. There are mainly three wide categories of global optimization techniques [5]: (a) Deterministic approaches, (b) Stochastic approaches; and (c) Meta-heuristics.

Just in recent times, a new optimization concept, based on Biogeography, has been proposed by Dan Simon[6]. Biogeography describes how species travel from one island to another island, how new species arise, and how species become died out. A habitat is any Island that is geographically isolated from other Islands. Geographical areas which are more suited as residences for biological species are said to have a high habitat suitability index (HSI). This factor shows that how a habitat is suitable for living. The environment that is suitable to live has a high HSI but not suitable for low HIS. That Features, correlate with HSI include factors such as rainfall, land area, diversity of topographic features, diversity of vegetation, and temperature affecting HSI are called as suitability index variables (SIVs). SIVs can be considered the independent variables of the habitat, and HSI can be executed by use of these variables. Habitats with a high HSI tends to have a more number of species, while those with a low HSI have a less number of species[7]. BBO poor solutions accept a lot of new features from better solutions. This is a new features to low HSI solutions may raise the quality of those solutions. These adaptable properties of this new algorithm encouraged to apply this newly developed algorithm to solve TC- ED problem.

3. PROBLEM FORMULATION

The objective function of TC-ED problem may be written as-

$$F_t = \min[\sum_{i=0}^{N} F_i(P_i)] \quad (1)$$

Where $F_i(P_i)$ is cost function of the i^{th} generator, *N* is the number of committed generators; P_i is the power output of the i^{th} generator. The ELD problem consists of the following constraints for minimizing the fuel cost:-

(a) Active Power Balance Constraint:-

$$\sum_{i=1}^{N} P_i - P_D - P_L = 0 \quad (2)$$

In Eq. (2) P_i, P_D, and P_L are generation of each generator, total power demand and power loss in transmission which can be expressed in term of B-coefficient matrix. Formula (1) shows the all of generators in addition to provide power demand of consumers [1].

The transmission loss P_L may be expressed in term of B-coefficients as

$$P_L = \sum_{i=1}^{N} \sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{0i} P_i + B_{00} \quad (3)$$

(b) Generator Capacity Constraints:-

The power generated by each generator will be within their lower limit and upper limit. So

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

(c) Bus Voltage Constraint:-

The voltage on each bus shall be within their lower limit and upper limit. So

$$V_i^{min} \le V_i \le V_i^{max} \quad (5)$$

(d) Reactive Power Constraint:-

The reactive power generated by ith generator shall be within their lower limit and upper limit. So

$$Q_i^{min} \le Q_i \le Q_i^{max} \quad (6)$$

4. ABOUT THE BIOGEOGRAPHY

4.1. Biogeography

Mathematical models of biogeography express how species travel from one island to another, how new species arise, and how species become died out. Island is any habitat that is geographically isolated from other habitats. Habitats which have a high HSI tends to have a more species, while Habitats which have a low HSI have a less species. Habitats with a high HSI have more species that emigrate to nearby habitats, simply by virtue of the more species that they host. Biogeography is the nature of way of distributing species, and is comparable to general problem solutions.

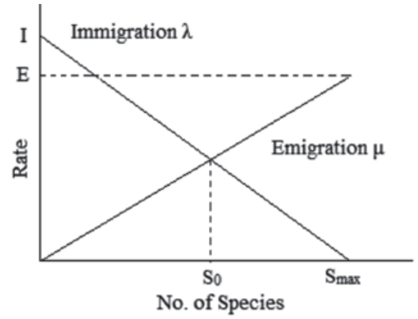

Fig 2: Species Model of a Single Habitat

Now, consider the probability P_S that the habitat contains S species. probability P_S changes from time t to time (t+Δt) are as follows:

$$P_S(t+\Delta t) = (1-\lambda_S \Delta t - \mu_S \Delta t) P_S(t) + P_{S-1} \lambda_{S-1} \Delta t + P_{S+1} \mu_{S+1} \Delta t \quad (7)$$

This equation holds because it have S species at time (t+Δt), one of the following conditions must hold[7]:

$$P_s = \begin{cases} -(\lambda_s + \mu_s)P_s + \mu_{s+1}P_{s+1} & S = 0 \\ (\lambda_s + \mu_s)P_s + \lambda_{s-1}P_{s-1} + \mu_{s+1}P_{s+1} & 1 \le S \le S_{max} - 1 \\ -(\lambda_s + \mu_s)P_s + \lambda_{s-1}P_{s-1} & S = S_{max} \end{cases} \quad (8)$$

From the straight-line graph of Fig.2, the equation for emigration rate λ_K and immigration rate μ_K for k number of species can be written as per the following way:

$$\mu_k = \left(\frac{EK}{n}\right) \quad (9)$$

$$\lambda_k = I\left(1 - \frac{K}{n}\right) \quad (10)$$

When value of, E=I then combining (9) and (10)

$$\mu_K + \lambda_k = E \quad (11)$$

4.2. BBO Algorithm to Solve TC-ED Problem

The concept of BBO is based on the migration and mutation operations. The concept and mathematical formulation of the migration and mutation operations are as follows:

4.2.1 Migration

In BBO, the migration operation refers to the process of traveling the species from one habitat to another. Like particle swarm optimization (PSO) and other population based technique, BBO also uses a population of candidate solutions for optimization purpose. The solution can represent as a vector of real numbers that each real number is a SIV in BBO algorithm [3]. The fitness of each solution can be calculated by its objective function. This fitness is the same HSI in BBO algorithm. These SIVs are analogous to the power output of the generators In ED problem. The SIVs in one array are used to calculate the habitat suitability index (HSI) of a habitat. The HSI is analogous to the objective function as used in other techniques. In ED problem, the HSI is analogous to the cost of power generation of a generator. Solutions with high HSI represent a greater solution whereas solutions with low HSI represent an poorer solution. Transferring creatures from one habitat to another is known as emigration. The process of entering creatures to a habitat from another habitat is known as immigration.[1]. The immigration rate, λ and the emigration rate, μ of each habitat is used to probabilistically share information with other solutions. Each solution is modified according to probability $P_{modify,}$ that is known as the habitat modification probability. If a particular habitat is selected for modification, then its λ is used to probabilistically decide to modify each SIV for that habitat. If a particular SIV in a given habitat is selected for modification, then μ of other habitats are used to probabilistically decide which of the habitats should migrate a randomly selected SIV from those habitats to that particular habitat. The migration operation in BBO is used to obtain the changes within an existing solution. In order to prevent the best solutions from being changed by the migration process, few best solutions are kept the same in the consequent iterations. Immigration and emigration rate for habitat containing *n* species is given as in equation (9-10) [6]

4.2.2 Mutation

Each candidate solution of the population have a probability, which indicates that, which candidate exists as a solution or not. If the probability of a selected candidate is too low then that candidate is likely to mutate to some other solution. Similarly, if the probability of a given candidate is too high, then it has obtained very little chances to mutate. Consequently, very high HSI solutions and very low HSI solutions are equally improbable to mutate. But medium HSI solutions have a greater chance to produce the better solutions after mutation. Mutation rate of each set of solution is calculated in terms of organism count probability using the equation (12) [8].

$$m(s) = m_{max}\left(\frac{1-P_s}{P_{max}}\right) \quad (12)$$

Where m_{max} is the Maximum mutation rate.

With the help of this mutation process diversity among the population is increased. Without the mutation process, the solutions with high probability will try to become more dominant in the population. This mutation scheme helps low HSI solutions to mutate, hence giving a chance to improve the solution. It also makes high HSI solutions to mutate in that way giving them a chance of again improvement. An elitism approach is also used to save the features of the habitat that contains the elite solution in the Biogeography Based Optimization algorithm process[7]. If a solution becomes poorer after mutation process then previous solution can go back to your old ways to that place again if needed. Therefore, mutation process is a high possibility process. It is normally applied to both poor and better solutions. In ED problem, the mutation process is performed just by replacing a selected solution with a randomly generated solution set that satisfies the given constraints [9].

5. BBO ALGORITHM FOR ELD PROBLEM

A new approach to implement the BBO algorithm will be described for solving the ELD problems. Especially, a suggestions shell be given on how to deal with the equality and inequality constraints of the Economic Load Dispatch problems when modifying each search point of individual in the BBO algorithm. The procedure of the BBO algorithm is as follows.

1. Initialize number of habitat (possible solutions) and BBO parameters as follows: maximum mutation rate m_{max}, maximum immigration rate *I*, maximum emigration rate *E,* elitism parameter "*p*", Set maximum number of iteration, number of SIVs of biogeography algorithm, number generating units, etc.
2. Randomly initialize the generation of all the generators (SIVs to a habitat) excluding slack generator while satisfying generator constraints. Several number of habitats depending upon the population are being generated.
3. Calculate HSI or the total fuel cost of each habitat.
4. Based on the HIS values some best habitats are identified.
5. Perform the probabilistically immigration and emigration operation on non-elite solutions.
6. Check for all constraints.
7. Again calculate the total fuel cost of each possible solution obtained after migration and identify elite solutions.
8. Perform mutation operation on a non-elite solution and calculate the total fuel cost.
9. Go to step 6.
10. Go to step 3, this process would be continuous till all the possible solution represents same fuel cost.
11. Calculate network parameters and value of slack generator through Newton-Raphson load flow solution.

6. RESULTS

The IEEE 30-bus, 6 generators standard load-flow test system is used to demonstrate the performance of the proposed approach. Data for the proposed approach are take from [10] and the parameters of BBO are given in [10]. The lower and upper voltage limits at all the buses are 0.9 p.u. and 1.1 p.u. respectively. Fig.3 and fig.4 shows the convergence characteristics of the algorithm for the population size of 50 and 100 respectively, It can be observed from the curve converges in 25 and 30 iterations respectively.

Table 1 & table 2 shows solutions obtained after 10 trials with the population size of 50 and 100 respectively. Table 3 shows the optimum generation schedule, time taken in execution and number of iterations at minimal cost obtained after different-different no. of trials with population size of 100. Table 4 shows the optimal results for IEEE 30 bus system. It can be observed from the tables that the standard deviation of fuel costs obtained after 10 trials is within permissible limits and hence obtain the better result. Also the Better fuel cost obtained with the population size of 100 as compared to the fuel cost obtained with the population size of 50.

Fig. 2 shows the convergence characteristics of the BBO algorithm for the population size of 50 and this characteristic is observed for 25 iteration and Fig. 3 and Fig. 4 shows the convergence characteristics of the BBO algorithm for the population size of 100 and obtained at 10, and 50 trials respectively.

Table 5 shows the generation schedule, losses, computational time and number of iterations at minimal cost obtained after 50 trials with population size of 100.

The standard deviation of fuel costs are obtained after different-different no. of trials and then obtain the best result. The result obtained with the population size 100 is better than the result obtained with the population size 50. The performance of the BBO algorithm is better than the other methods. The better results obtained by increasing the population size.

Table 1: COMPUTATION RESULTS FOR A POP SIZE OF 50

Slack Generator (MW)	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	Losses (MW)	cost ($/hr.)	computational time(sec)	No.of iterations
175.076	48.9	23.2708	23.366	10.9178	12.69	10.867	807.878	145.387	26
174.534	47.7	22.1619	24.771	12.0964	12.84	10.7939	807.736	125.054	22
172.28	48.2	23.0642	24.05	12.1653	14.17	10.6117	807.942	142.334	25
162.847	**48.2**	**21.9926**	**24.008**	**24.0075**	**12.07**	**9.81071**	**807.666**	**118.721**	**21**
175.276	47.5	21.5906	23.215	13.9659	12.65	10.8652	807.754	163.623	29
171.967	50	22.9537	24.18	12.6247	12.21	10.6414	807.773	162.595	26
172.578	47.9	21.7509	26.69	12.8023	12.26	10.6279	807.785	113.854	20
177.83	49	22.7071	19.701	12.9283	12.3	11.1401	807.876	181.759	25
174.33	49.5	23.2067	21.828	12.9309	12.33	10.8291	807.799	190.966	31
175.709	48.1	20.3259	22.377	12.9762	14.85	10.9996	808.079	150.546	23

Table 2: COMPUTATION RESULTS FOR A POP SIZE OF 100

Slack Generator (MW)	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	Losses (MW)	Cost ($/hr.)	Computational time(sec)	No.of Iterations
173.615	50.4	21.299	23.504	12.9519	12.42	10.8527	807.704	291.736	25
175.044	48.9	21.1123	24.676	12.461	12.01	10.9118	807.688	290.821	25
174.42	48.9	22.19919	24.316	12.2114	12.09	10.8275	807.662	315.943	27
174.192	49.3	21.89499	23.147	12.8799	12.8	10.8423	807.672	291.775	25
174.841	49.1	21.54831	23.586	12.9991	12.12	10.8937	807.65	370.838	26
173.714	48.9	21.37522	24.699	13.0997	12.31	10.789	807.682	305.339	27
174.576	49	21.92003	23.668	12.6515	12.35	10.8583	807.649	314.492	28
173.258	48.8	22.14392	25.381	12.3194	12.11	10.7202	807.692	417.029	36
174.172	**48.9**	**21.88749**	**24.385**	**12.7467**	**12.01**	**10.8132**	**807.648**	**366.404**	**30**
173.918	49.7	22.03767	23.245	12.9599	12.29	10.8272	807.66	302.785	26

Table 3: OPTIMUM GENERATION SCHEDULE AT DIFFERENT-DIFFERENT NO. OF TRIALS WITH POP SIZE 100

No.of trials	Slack Generator (MW)	G1 (MW)	G2 (MW)	G3 (MW)	G4 (MW)	G5 (MW)	Cost ($/hr.)	Computational Time(sec)	No.of iterations
10	173.0402	49.3603	21.5015	24.7681	12.3715	12.0784	807.6669	635.5941	24
20	174.0517	49.6843	21.901	22.6242	12.6799	12.1789	807.6588	669.5786	28
30	173.2846	49.2855	21.8341	23.5502	13.156	12.0096	807.6456	474.359	23
40	173.2846	49.2855	21.8341	23.5502	13.156	12.0096	807.6457	571.8229	23
50	173.9908	49.1385	21.9039	23.5804	12.5004	12.006	807.6421	410.8958	25

Table 4: OPTIMAL RESULTS FOR IEEE 30-BUS SYSTEM

Population Size	50	100
Max. Fuel Cost ($/hr.)	807.942	807.704
Min. Fuel Cost ($/hr.)	807.666	807.648
Average Fuel Cost ($/hr.)	807.828	807.67
Standard Deviation	0.1186	0.02
Average Computational Time (Sec.)	149.48	326.71
Min. Bus Voltage (p.u.)	0.93937	0.93926

Table 5: GENERATION SCHEDULE AND OTHER PARAMETERS AT OPTIMUM COST

Slack Generator (MW)	174.341	173.9908
G1 (MW)	49.285	49.1385
G2 (MW)	21.834	21.9039
G3 (MW)	23.551	23.5804
G4 (MW)	13.156	12.5004
G5 (MW)	12.009	12.006
Losses (MW)	10.847	9.8046
Cost ($/hr.)	807.645	807.642
Computational time (Sec.)	615.13	410.895
Number of iteration	23	25

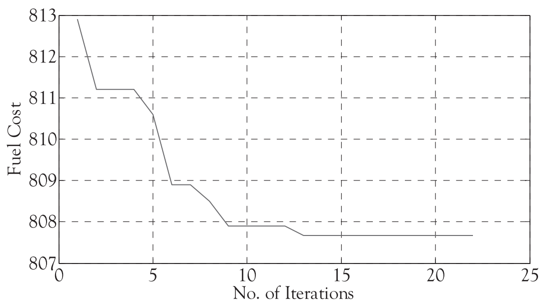

Fig 2: Convergence Characteristic of 6 Generator System with POP Size-50 and no. of trials-10

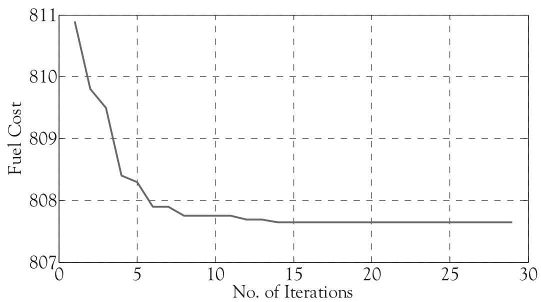

Fig 3: Convergence Characteristic of 6 Generator System with POP Size-100 and no. of trials-10

Fig 4: Convergence Characteristic of 6 Generator System with POP Size-100 and no. of trials-50

7. CONCLUSION

Recently, most of the countries suffer from the power crisis. The generation is not enough to meet the demands of consumers. Under these situations the power system must be efficient and reliable in Economic Load Dispatch which optimizes the generation cost. A new method, Biogeography Based Optimization has been proposed to solve the convex and non-convex Economic Load Dispatch problem with generator and network constraints. The good solution quality as the standard deviation between fuel costs obtained after a number of trials is within in permissible limit, convergence characteristics, computational efficiency and the calculation time, is improved. The proposed approach has been demonstrated by IEEE 30 bus system and got the optimum result after 50 trials for population size 100. The proposed approach proven to have superior features including good quality solutions. In future, Biogeography Based Optimization Technique can be applied to solve multi-objective Transmission Constrained Economic Load Dispatch problem in which the fuel cost, losses, bus voltage and computational time can be minimized and complex unit commitment, dynamic ELD problems in the search of better quality results.

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