A Novel Heuristic Optimization Methodology for Solving of Economic Dispatch Problems

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ABSTRACT
This paper presents a biogeography-based optimization (BBO) algorithm to solve the economic load Dispatch (ELD) problem with generator constraints in thermal plants. The applied method can solve the ELD problem with constraints like transmission losses, ramp rate limits, and prohibited operating zones. Biogeography is the science of the geographical distribution of biological species. The models of biogeography explain how a organisms arises, immigrate from an environment to another and gets eliminated. The BBO has some characteristics that are shared with other population based optimization procedures, similar to genetic algorithms (GAs) and particle swarm optimization (PSO). The BBO algorithm mainly based on two steps: migration and mutation. The BBO has some good features in reaching to the global minimum in comparison to other evolutionary algorithms. This algorithm applied on two practical test systems that have six and fifteen thermal units, results of this paper are used to see the comparison between performances of the BBO algorithm with other existing algorithms. The result of this investigation proves the efficiency and good performance of applying BBO algorithm on ELD problem and show that this method can be a good substitute for other algorithms.

KEYWORDS: biogeography-based optimization, economic load dispatch, prohibited operating zone, ramp rate limits.

1. INTRODUCTION

Economic load dispatch is one of the important problems in power system. The purpose of economic load dispatch is to seek the best answer for minimizing total generation cost of power generation units because of increment of fossil fuel cost in thermal plants [1]. Until this moment various methods applied on ELD problem. Previously some traditional methods like Lagrangian multiplier [2] and lambda iteration method [3] have been applied to ELD problem but these methods were failed to solve the ELD problem because the characteristic of modern power plants is very nonlinear due to constraints like ramp rate limits, valve-point loadings, and multi-fuel options. However this problem should be solve considering power demand, prohibited operated zones and transmission losses in practical systems thus conventional methods cannot reach to global optimum for obtaining minimum generation cost. For solving this problem Wood and Wollenberg introduced dynamic programming method but this method is not good for large systems because simulation time is increases with increasing of system size. Recently all of power system experts focused on artificial intelligence algorithms specially evolutionary algorithms like particle swarm optimization (PSO) [4] , genetic algorithm (GA) [5], ant colony optimization (ACO), improved tabu search [6], and Clonal algorithm [7], simulated annealing(SA) [8], evolutionary programming (EP) [9] all of this algorithms applied on ELD problem successfully. All of these algorithms are classified as iterative algorithms and have some parameters that influence on quality of convergence. GA and SA used for solving ELD problem, GA is faster than SA because GA has parallel seek ability in comparison to SA. PSO method was invented in 1990, this method have less parameters than other high performance evolutionary algorithms therefore have high speed convergence. DE was invented by price and stone and it has three steps: selection, crossover and mutation. This method has high speed in finding global optimum but DE fail when the dimension of system increases.

Recently a new population based evolutionary algorithm has been invented by Simon, based on biogeography [10]. This has better properties than other evolutionary algorithms hence can be employing in power system optimization problems. Biogeography is way of natural for species distribution on the earth. In BBO algorithm a good solution for a problem considered as a habitat with high HSI and a poor solution considered as a habitat with low HSI. A good solution tends resist to any changes but a poor solution has a tendency to copy good properties from a good solution. Good properties remain in the high HSI habitat and at the same time appear in low HSI habitats as a new feature. This accepting of good features from good solutions may help the low HSI habitats to be a high HSI habitat. Similar to PSO and GA, BBO has the feature of sharing information between solutions. The BBO algorithm has some advantages in comparison to other algorithms. In BBO and PSO each solution stay survive to the end of optimization procedure but in most of evolutionary based algorithms, solutions die at the end of each generation. In some of evolutionary due to crossover step, good solutions lose their efficiency but in BBO don't have crossover step [10].

The paper is organized as follows: Section 2 introduces the problem formulation. Section 3 then describes the BBO algorithm. Detailed process of using the BBO method to solve the ELD problems are presented in Section 4, Section 5 shows two application cases using the proposed method to solve the ELD problems and the results have been compared to recently published results and found to be superior.

2. FORMULATION OF ELD WITH GENERATOR CONSTRAINTS

The objective of ELD problem is minimizing total generation (fuel) cost in the power system so that reach to the best generation between power plants and specially satisfying some practical constraints:

2.1 Power balance condition

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

$$P_L = \sum_{i=1}^{m} \sum_{j=1}^{m} P_i B_{ij} P_i + \sum_{i=1}^{m} B_{0i} P_i + B_{00} \quad (2)$$

In (1) P_i is generation of each generator. The P_D is total power demand. P_L is transmission loss and can be expressed with B-coefficient matrix. Formula (1) means that all of generators in addition to provide power demand of consumers are responsible for providing transmission loss of lines.

2.2 Generator constraints

$$P_i^{min} \leq P_i \leq P_i^{max} \quad (3)$$

Each generator has specific interval for power generation and cannot generate more or less than specified values.

2.3 Ramp rate limit limitations

a) If power generation increases

$$P_i - P_i^0 \leq UR_i \quad (4)$$

b) If power generation decreases

$$P_i^0 - P_i \leq DR_i \quad (5)$$

For each power plant, output power is limited to above constraints. Which UR_i is the up ramp limit of ith generator and DR_i is the down ramp limit of the generator. With applying ramp rate limit constraints and generator constraints we can reach below formulation

$$Max(P_i^{min}, P_{i0} - DR_i) \leq Pi \leq Min(P_i^{max}, P_{i0} + UR_i) \quad (6)$$

2.4 Prohibited operating zones

The prohibited operating zones are the ranges confines of generator power that working in this range might create vibrations in turbine shaft and cause some detriments because of opening and closing of valves. Therefore, generators must avoid operation in these regions. If we consider prohibited operating zones constraints and generator limit constraints, we can assume that, practical formulations can provided as mentioned below:

$$\begin{aligned} &P_i^{min} \leq P_i \leq P_{i,1}^l \\ &P_{i,j-1}^u \leq P_i \leq P_{i,j}^l \,; j = 2,3,\ldots,ni \\ &P_{i,ni}^u \leq P_i \leq P_i^{max} \end{aligned} \quad (7)$$

In above formula, j is number of prohibited operating zones of ith generator. $P_{i,j-1}^u$ Is the upper limit of (j - 1) th prohibited operating zone of i th generator and $P_{i,j}^l$ is the lower limit of j th prohibited operating zone of i th generator. n_i is the total number of prohibited operating zone of i th generator.

3. PROPOSED TECHNIQUE

3.1 Biogeography

Biogeography shows a model of migrating a type of living thing from an island to another. And it shows the overthrow and rise of living things in an environment [10]. Habitat is an island that is physically separated from other islands. a factor that is important for a habitats is HSI (habitat suitability index). This factor shows that how a habitat is suitable for living. The environment that is suitable for live has a high HSI and vice versa. Some

Factors can impress the quality and quantity of HSI and there are SIV (suitability index variable). These variables can regard as an independent variable and HSI can be calculated on the basis of SIV's. Temperature, diversity of vegetation, rain downfall and etc are examples of SIV's. Habitats that have high HSI can have large number of living things and habitats that have low HSI, have small number of living things [10]. Habitats with high HSI, because of their large number of creature, have many species that they can migrate to other habitats. Transferring creatures from one habitat to another is called emigration. The process of entering creatures to a habitat from another habitat is called immigration. Thus a habitat with high HSI has a high emigration rate and habitat with low HSI has high immigration rate. This immigration of creatures from high HSI habitats to low HSI habitats can enhance the HSI of this habitat because the HSI of habitat is directly proportional to creatures variety. Fig.1 gives a full model of immigration rate and emigration rate [10]. In the immigration figure we can see that maximum immigration rate occurred when there are no creatures in the habitat. If there are small numbers of creatures in the habitat, large number of living things can enter to the habitat and consequently immigration rate is high. When number of creatures in the habitat goes up and habitat becomes populated, small number of creatures can live in this habitat and immigration rate decreases. The maximum number of creatures that can live in the habitat is S_{max}. In this condition immigration rate is zero because no creatures can enter to this habitat. With considering emigration diagram of figure 1, we can understand that when there are no creatures in the habitat, there is no living thing to immigrate to another habitat and the emigration rate is zero. When the number of creatures increases and habitat becomes populated, large number of creatures can leave their own habitats and seek a new habitat for live and consequently emigration rate increases. the maximum emigration rate Occurs when the number of creatures is S_{max}. In the figure 1 the immigration and emigration lines are in form of straight lines but these lines might be more complicated lines. Calculation of immigration an emigration values in BBO algorithm is so important. Immigration and emigration rate have a important role in selecting those SIV's that migration process should be apply on them.

With regard to immigration and emigration diagrams in figure 1, we can extract the following formulas [10]:

$$\mu_k = \frac{Ek}{n} \tag{8}$$

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

Where μ_k is emigration rate for k number of creatures and λ_k is immigration rate for k number of creatures.

If $E = I$, with combining of (8) and (9) will results

$$\mu_k + \lambda_k = E \tag{10}$$

3.2 biogeography based optimization

This section refers to application of biogeography based optimization in solving problems and surveying different parts of this algorithm. The basis of BBO algorithm is based on two main parts: 1 – Migration 2 – Mutation

Migration

In BBO algorithm a population is selected as a solution. This solution can represent as

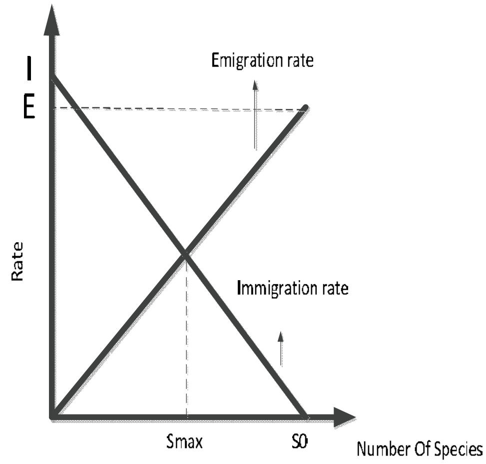

Fig. 1 full model of immigration rate and emigration rate

a vector of real numbers that each real number is a SIV in BBO algorithm [11].The fitness of each solution can be calculated with its objective function. This fitness is the same HSI in BBO algorithm. In BBO solutions with high HSI represents a good solution and solution with low HSI represents a bad solution. The information of habitats probabilistically shares between other habitats using emigration rate and immigration rate of each solution. Each solution can modify on basis of P_{mod}, modification probability of each solution. In BBO one solution S_i is selected for modification and then using immigration rate of that solution, is decided that modification be imposed on which SIV in that solution. Emigration rate of other solution is used for choosing a SIV that with that SIV, modification will be apply and then a SIV will select randomly to migrate to the solution S_i. in BBO algorithm an elitism process is included to prevent deterioration of best solution During the migration. In this process, a number of best solutions are transferred to next iteration without migration procedure [11].

Mutation

Sudden changes in climate of one habitat or other incidents will cause the sudden changes in HSI of that habitat [11]. In BBO algorithm this situation can be model in the form of sudden changes in value of SIV. The probability of any organism can be calculated by the following equation (11).

$$\dot{P}_s = \begin{cases} -(\lambda_s + \mu_s)P_s \ \mu_{s+1}P_{s+1} & S=0 \\ -(\lambda_s + \mu_s)P_s \ \mu_{s-1}P_{s-1} \ \mu_{s+1}P_{s+1} & 1 \le P_i \le S_{max} - 1 \\ -(\lambda_s + \mu_s)P_s \ \mu_{s-1}P_{s-1} & S=S_{max} \end{cases} \qquad (11)$$

Each member of one habitat has its own probability. If this probability is too low, then this solution has high chance to mutate. In the same manner if probability of a solution is high that solution has a little chance to mutate. Consequently solutions with high HSI and low HSI have a little chance to development a better SIV in the next iteration. Unlike high HSI and low HSI solutions, medium HSI solutions have a greater chance to development better solutions after mutation procedure. In the following equation mutation rate of each solution can be calculated [10].

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

At this stage m_{max} is a parameter that is determined by the user. At this stage there is also a elitism to prevent the answers from getting worse after mutation procedure. In this case if a SIV is selected for mutation operation, one authorized random number is substituted.

3.3 BBO algorithm

The process of the IPSO algorithm for solving ELD problems can be summarized as follows:

Step 1: Initializing BBO parameter as mentioned below

- 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
- m - number of SIV's
- p - elitism parameter
- Maximum number of iteration

After initializing parameters, SIV Initial values must be generated in their feasible intervals using random numbers.

Step 2: For example, assume that we are applying this algorithm on following function:

$$f(x) = \sum_{i=1}^{m} \cos x \tag{13}$$

SIV's should be generated in the allowed range. Due to the number of habitats N and SIV's m the Habitat matrix can form as below. Each row of habitat matrix represents a solution for problem.

$$H = \begin{bmatrix} x_{11} & x_{12} & x_{13} & x_{14} & \cdots & x_{1m} \\ x_{21} & x_{22} & x_{23} & x_{24} & \cdots & x_{2m} \\ x_{31} & x_{32} & x_{33} & x_{34} & \cdots & x_{3m} \\ \cdot & \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \cdot & & \cdot \\ \cdot & \cdot & \cdot & \cdot & & \cdot \\ x_{N1} & x_{N2} & x_{N3} & x_{N4} & \cdots & x_{Nm} \end{bmatrix} \tag{14}$$

Step 3: Calculation of HSI quantity for each solution of habitat matrix as follows:

$$HSI_1 = [\cos x_{11} + \cos x_{12} + \cos x_{13} + \cos x_{14} + \dots \cos x_{1m}]$$

$$HSI_2 = [\cos x_{21} + \cos x_{24} + \cos x_{24} + \cos x_{24} + \dots \cos x_{2m}]$$

$$HSI_3 = [\cos x_{31} + \cos x_{32} + \cos x_{33} + \cos x_{34} + \dots \cos x_{3m}]$$

$$\vdots$$

$$HSI_N = [\cos x_{N1} + \cos x_{N2} + \cos x_{N3} + \cos x_{N4} + \dots \cos x_{Nm}]$$

Step 4: Selection stage

Select p number of the best solutions in each iteration and Move them to the next iteration.

Step 5: Migration operation [11]

Migration operation is used for modifying habitats those are selected probabilistically. If our goal is to modify habitat H_i with replacing habitat H_j, the probability of election of H_i is proportional to immigration rate λ_k and the probability of election of H_j is proportional to emigration rate μ_k. The migration procedure can be demonstrated as follows:

Select a habitat H_i with probability proportional to λ_i

If H_i is selected

For j = 1 to N

Select another habitat H_j with probability proportional to μ_i

If H_j is selected

Randomly select an SIV from habitat H_j

Replace a random SIV in H_i with that selected SIV of H_j

End

End

End

After applying this operation on selected habitats, feasibility of each habitat should be reviewed. If any of habitats is not suitable after migration, this procedure must be repeated on the habitat to achieve the desired result. After applying migration procedure on selected habitats, HSI values must be computed again.

Step 6: Mutation operation [11]

Mutation operation is applied on each selected habitat as follow and then quantity of HSI for each habitat must be computed again.

For i = 1 to N
For j = 1 to m
Use λ_i and μ_i to compute probability of P_i using (11)
Select SIV $H_i(j)$ with probability proportional to P_i
If $H_i(j)$ is selected
Replace $H_i(j)$ with a randomly generated SIV in its feasible rergion
End
End
End

After above operation feasibility of habitats should be checked and if it's not a feasible solution the operation should be done again to enrich the feasible solutions.

Step 7: Go to step – 3 for next iteration.

The algorithm ends after a certain number of iterations.

4. SOLUTION OF ELD PROBLEM WITH BBO ALGORITHM

In this section, a new method is presented for solving ELD problems. The main goal of ELD is obtaining the values of each generator in range of allowed values. What is important is that this algorithm is able to satisfy certain constraints like ramp rate limit and prohibited operating zones. The procedure of BBO algorithm can be presented as follows:

1) Initializing SIV's

The Output power of each generator is assumed as a SIV in this algorithm. Each SIV should be chosen in the range of its authorized. In this algorithm N is the number of solutions and m is the number of generators.

2) Checking feasibility of habitats

After generating random numbers with regard to generator provisions (3),(6), we should check the constraint (1) to have a feasible solution for ELD problem.

3) Calculating HSI

HSI value should be computed to each row of habitat matrix considering each individual's objective function. In ELD problem HSI represents the total fuel cost of each solution. For example if we have m generators with their own cost functions, HSI represent the summation of fuel cost of each generator.

4) Selection stage

At this stage, according to the HSI values obtained for each solution, p number of best solutions that they have best fuel cost are kept without modifying on them and transferred to next iteration.

5) Migration

Applying migration procedure on those SIV's of each non-elite habitats. This procedure is work probabilistically as mentioned before.

6) Mutation

After updating probability of each habitat from (11), mutation procedure is performed on non-elite habitats as mentioned before.

5. SIMULATION RESULTS

In order to validate the proposed method, we employed the BBO approach for ELD problems in a 6 unit system and a 15 unit system. In these cases, the ramp rate limits

Table 1: Best simulation results of 6-unit system

Generator Power Output (MW)	Methods						
	BBO	GA [12]	PSO[12]	PSO-LRS[13]	NPSO [13]	NPSO-LRS[13]	SOH-PSO[14]
G1	447.1828	474.81	447.50	447.4440	447.4734	446.96	438.21
G2	173.1249	178.64	173.32	173.3430	173.1012	173.3944	172.58
G3	264.2082	262.21	263.47	263.3646	262.6804	262.3436	257.42
G4	138.4957	134.28	139.06	139.1279	139.4156	139.5120	141.09
G5	165.8612	151.90	165.48	165.5076	165.3003	164.7089	179.37
G6	86.5572	74.18	87.13	87.1698	87.9761	89.0162	86.88
Total Power Output	**1275.43**	1276.03	1276.01	1275.95	1275.95	1275.94	1275.55
PLOSS	**12.43**	13.03	12.958	12.9571	12.9470	12.9361	12.55
Total generation cost	**15442.6773**	15459	15450	15450	15450	15450	15446.02

Table 2: Best simulation results of 15-unit system

Generator Power Output (MW)	Method						
	BBO	GA[12]	PSO[12]	ES[15]	SPSO[14]	PC_PSO[14]	SOH_PSO[14]
G1	450.951	415.31	439.12	455	455	455	455
G2	402.951	359.72	407.97	380	380	380	380
G3	127.5847	104.42	119.63	130	130	130	130
G4	129.6629	74.98	129.99	150	129.28	127.15	130
G5	357.8484	380.28	151.07	168.92	164.77	169.91	170
G6	415.6189	426.79	459.99	459.34	460	460	459.96
G7	463.4147	341.32	425.56	430	424.52	430	430
G8	61.8705	124.79	98.56	97.42	60	108.38	117.53
G9	34.3134	133.14	113.49	30.61	25	44.41	77.90
G10	48.0068	89.26	101.11	142.56	160	97.76	119.54
G11	30.2575	60.06	33.91	80	80	67.61	54.50
G12	74.5209	50.00	79.96	85	72.62	73.26	80
G13	26.7615	38.77	25	15	25	25.57	25
G14	15.3425	41.94	41.41	15	44.83	19.57	17.86
G15	15.5912	22.64	35.61	15	49.42	38.93	15
Total Power Output	**2654.4671**	2668.44	2662.41	2653.85	2660.44	2660.55	2662.29
PLOSS	24.4671	38.28	32.42	**23.85**	30.49	30.54	32.28
Total generation cost	**32558.7261**	33113	32858	32568.54	32798.69	32775.36	32751.39

and prohibited zones of the units were taken into account in the practical application. The obtained results are compared with the reported results. The BBO approach was implemented in MATLAB software. In each case study, 50 independent runs were made for each of the optimization methods. The parameters of BBO are selected as following: P_{mod}= 1; m_{max} = 0.05; I= 1; E= 1 and p = 2. In these case studies, the stopping criterion iteration maximum was 500 generations. The population size was 50 to different case studies.

5.1 Case study I: Six unit system

The system contains six thermal generating limits, 26 buses and 46 transmission lines. The load demand is 1263 MW. The characteristics of the six thermal units are given in [12]. The network losses are calculated by B matrix loss formula [12]. The best solutions using the proposed optimizer are shown in Table 1 that satisfies the generator constraints. It can be evident from Table 1 that the technique provided better results compared with other reported evolutionary algorithm techniques. It is also observed that the mean cost using the proposed approach is less than the reported minimum cost using some of other methods.

5.2 Case study II: Fifteen unit system

The system contains 15 thermal units whose characteristics are given in [12]. The load demand of the system is 2630MW. The loss coefficients matrix was shown in the [12]. In this second case, the results of numerical simulation of tested BBO method are shown in Table 2 that also satisfy the system constrains. It can be seen from Table 2 that the BBO perform better than the PSO, GA, ES, SPSO, PC_PSO and SOH_PSO methods in terms of solution quality.

6. CONCLUSIONS

In this paper, a BBO algorithm is applied to solve the ELD problem with non smooth cost function with constraints of the prohibited zones and ramp rate limits. To enrich the searching behavior and to avoid being trapped into local optimum, BBO technique is used, which is a novel population-based search technique. The proposed approach has produced results comparable or better than those generated by other algorithms and the solutions obtained have superior solution quality. The results obtained for both the cases were always comparable or better that the earlier best reported results. From this limited comparative study, it can be concluded that the BBO can be effectively used to solve ELD problems.

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