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Using the Barnacles Mating Optimizer for Economic Emission Load Dispatch Problems

Abstract. *This paper proposes a recent nature inspired algorithm namely Barnacle Mating Optimizer (BMO) for solving the economic emission load dispatch (EELD) problems. BMO is based on the mating behaviour of barnacles and is treated as an evolutionary computation algorithm in solving the optimization problems. Three cases have been tested using the proposed BMO: 3-units, 10 -units and 40-units system and the performances of BMO are compared with other recent selected algorithms to show the effectiveness of the proposed BMO in solving the EELD problems.*

Streszczenie. *W artykule zaprezentowany inspirowany naturą algorytm nazwany Barnacle Mating przeznaczony do rozwiązywania problemu optymalizacji dystrybucji energii uwzglęa)dniające emisję. Analizowano trzy przypadki – system trzech, dziesięciu I czterdziestu jednostek.* ***Wykorzystanie algorytmu Barnbacles Mating do optymalizacji przesyłu energii uwzględniającej emisję.***

Keywords: Barnacles mating optimizer, economic emission load dispatch, evolutionary computation, price penalty factor.
Słowa kluczowe: algorytm Barnacles Mating, optymalizacja przesyłu energii, emisja.

Introduction

Economic dispatch (ED) problem is one of the most popular problems in power system operation and control. It is a fundamental problem which the system operator needs to decide the optimal power generation to meet the demand with fulfilling all the equality and inequality constraints. The problem is extended by introducing the awareness of the environmental consideration where the power generation is also bounded to the minimizing the level of pollution. Thus, a new term of problem is emerged: economic emission load dispatch (EELD). The EELD is a nonlinear multi-objective problem where the necessity of solving the optimal generation of thermal fuel by minimizing the cost and emission level simultaneously.

There are various approaches have been proposed to solve the EELD problems whether to treat the problem as multi-objectives or combining two objectives to produce a single objective. This paper will focus on the combining the bi-objectives into a single objective in order to obtain better results. An application of Genetic Algorithm (GA) into solving EELD has been proposed in [1, 2] where the implementation of hybrid factor in combining the bi-objective into single objective of EELD has been done. A Shuffle Frog Leap Algorithm (SFLA) and Cuckoo Search Algorithm (CSA) have been proposed to solve EELD in [3, 4] respectively.

Ref. [5, 6] proposes Flower Pollination Algorithm (FPA) to solve EELD problem. Nevertheless, the results presented may varies when compared to the manual calculations. There are also many attempts to solve EELD by modifications of available algorithms such as Modified Harmony Search Algorithm (MHSA) [7], modified group search optimization [8] and Chaotic Improved Harmony Search Algorithm [9]. Recent algorithms also have been proposed to solve EELD in literature such as parallel hurricane optimization algorithm [10], symbiotic organisms search algorithm [11] and floating search space algorithm [12]. The application of harmony search algorithm into dynamic economic emission dispatch problem also has been attempted in [13].

In this paper, the usage of Barnacles Mating Optimizer (BMO) which has been proposed by [14, 15] has been applied in solving EELD problems. The rest of the paper is organized as follows: Section 2 discusses the EELD problem formulation followed by the explanation of BMO in brief. Section 4 presents the implementation of BMO into EELD problems followed by results and discussion in Section 5. Section 6 concludes the paper.

Economic Emission Load Dispatch (EELD)

The objective of EELD is to find the optimal power generation in order to obtain the minimum cost and emission simultaneously without violating any constraints. The formulation of EELD is defined as follows:

(1) $$\min(C_T) = wF + (1-w)hE$$

where C_T is the total cost in \$/hour, w is the weighting factor that can be varied between 0 and 1, F is the cost function, E is the total emission generated by power plants and h is the price penalty factor. Total cost F, and total emission E can be formulated as follow:

(2)
$$F_i(P_{G_i}) = \sum_{i=1}^{N}\left(a_i P_{G_i}{}^2 + b_i P_{G_i} + c_i + \left|d_i \sin\left\{e_i\left(P_{G_i}{}^{\min} - P_{G_i}\right)\right\}\right|\right)$$

(3) $$E_i(P_{G_i}) = \sum_{i=1}^{N}\left(f_i P_{G_i}{}^2 + g_i P_{G_i} + j_i + k_i \exp\left(m_i P_{G_i}\right)\right)$$

where P_{Gi} is the real power generation of generator i for dispatched hour, N is the total number of generation units, a_i, b_i, c_i are the coefficients of the fuel cost function and f_i, g_i, and j_i are the coefficients of the emission function. the coefficients d_i, e_i, k_i and m_i are used only if the valve-loading effect is considered. The price penalty factor h_i is the ratio between the maximum fuel cost and maximum emission of corresponding generator as follows [16]:

(4) $$h_i \frac{F\left(P_{G_i}^{\max}\right)}{E\left(P_{G_i}^{\max}\right)} \$/kg \qquad i = 1, 2, ..., N$$

Detail steps to find the price penalty factor can be obtained in [16]. The formulation of EELD is subjected to the equality and inequality constraints. The equality constraint for this problem is the total power generation must equal to the load demand, P_{Demand} and real power loss, P_{Loss} as follows:

(5) $$\sum_{i=1}^{N} P_{G_i} = P_{Demand} + P_{Loss}$$

For inequality constraint on the other hand, the power generated by each individual unit must be within the generation's minimum, P_{Gi}^{min} and maximum capacity, P_{Gi}^{max} as shown below:

(6) $$P_{G_i}^{\min} \le P_{G_i} \le P_{G_i}^{\max}$$

Barnacles Mating Optimizer (BMO)

Barnacles Mating Optimizer (BMO) is the recent evolutionary meta-heuristic algorithm proposed by [14] which mimics the mating of barnacles based on the length of the barnacles' penis. Barnacles are known as hermaphroditic micro-organism where they have both male and female reproduction organs. To copulate, one barnacle will search for partner by random penis movements within the range. This is the special about barnacles where they may stretch their penis up to seven times from the length of their bodies [17]. In the case of isolated barnacle, the copulation is done by the sperm-cast mating where the sperms released by other barnacles in the water fertilized the egg of isolated barnacle. This concept becomes the inspiration of the BMO development as optimizer solution to solve optimization problems for exploitation and exploration processes. Detail concept and implementation of BMO into benchmark functions can be obtained in [14, 15].

BMO for EELD Solution

In order to solve EELD problems, BMO is started with the initialization process which is similar with other optimization algorithms. The candidate of solutions, X can be expressed as follow:

(7) $$X = \begin{bmatrix} x_1^1 & \cdots & x_1^{nG} \\ \vdots & \ddots & \vdots \\ x_n^1 & \cdots & x_n^{nG} \end{bmatrix}$$

where n is the number of barnacles and nG is the number of power generation to be optimized. Each initialized barnacle then will be evaluated using Eq. (1-3) and sorting process is executed to locate the best solution so far at the top of the population.

Next step is the selection of two barnacles for mating to generate new off springs which is done randomly. However, it is subject to the predetermined of the size of barnacle's penis, *pl*. This is the only control parameter need to be set and tuned in order to obtain the optimal results apart from the number of population and maximum iteration. If the selection of barnacles to be mated out of range of *pl*, the new off-springs are generated by using the sperm-cast mating as shown in Eqn. (9) below:

(8) $$x_n^{nG\_new} = p x_{dad}^{nG} + q x_{mum}^{nG} \qquad k \le pl$$

(9) $$x_n^{nG\_new} = rand() \times x_{mum}^{nG} \qquad k > pl$$

where p is the distributed random numbers, $q = (1-p)$, x^{nG}_{dad} and x^{nG}_{mum} are the control variables (generator's output) of *Dad* and *Mum* of barnacles which has been selected for mating, k is the range of barnacle's penis can be reached for mating process and *rand*() is the random number (0-1). At this stage, if the new solution is out of boundary, the algorithm will be pegging at the boundary values before going to the evaluation process again to obtain objective function. The objective function from Eqn (1) is modified where the penalty function, *PF* is enforced to deal with the equality constraints such in Eqn. (5), as follows:

(10)

$$C_T = C_T + PF \times \left| \left(\sum_{i=1}^{N} P_{G_i} \right) - P_{Demand} - P_{Loss} \right|$$

Details flow of proposed BMO into solving EELD problem is exhibited in Figure 1.

Results and Discussion

Performance of BMO into EELD problems has been tested on three cases viz. 3-units, 10-units and 40-units generators systems. These test systems are widely used for testing the algorithms' performances in EELD problem. Thus, the results obtained by BMO are compared with various recent algorithms that can be obtained from literature.

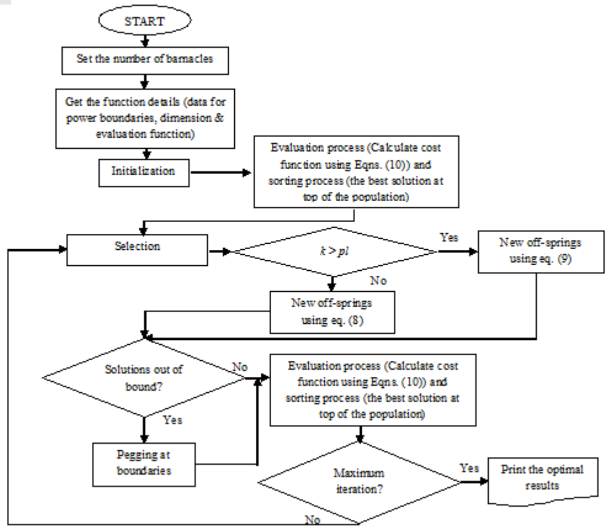

Fig.1. Flow of BMO application to solve EELD problem

3-units generator

This case system consists of 3-units generating thermal system where the cost coefficients, emission coefficients, limits of generator output and loss coefficients can be obtained in [6]. Tables 1 summarizes the results obtained by BMO together with other recent algorithms available in literature. The power demand is 400 MW and the value of price penalty factor, h is 43.55982. From this table, it can be seen that BMO produces similar competitive results compared to GA, PSO, FPA and CSA. From these results also show that all algorithms produce close results in terms of power generation and fulfilling all the inequality constraints.

Table 1. Results for the best simulations for EELD (3-units system)

Power outputs	GA [18]	FPA [6]	CSA [4]	BMO
P_1 (MW)	102.617	102.4468	102.3715	102.4708
P_2 (MW)	153.825	153.8341	153.9637	153.8110
P_3 (MW)	151.011	151.1321	151.0782	151.1311
P_{Loss} (MW)	7.41324	7.4126	7.4133	7.4129
Cost ($/hr)	20840.1	20838.1	20837.78	20838.08
Emi (Kg/hr)	200.256	200.2266	200.2324	200.2253
Total Cost ($)	29563.2	29559.90	29559.9	29559.9

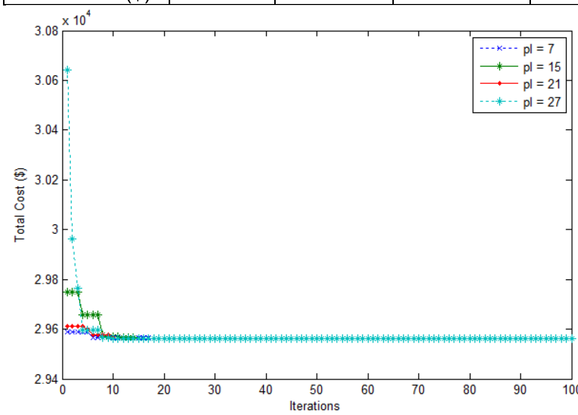

Fig.2. Convergence curves for various value of *pl* to solve EELD problem (3-units system)

Figure 2 shows the convergence curves of BMO for different values of *pl* for 30 populations. It can be seen that the best value is set to 7 where the worst is set to 27. Nevertheless, all the selections of *pl* are converged within 20 iterations and finally converged at total cost of $29559.90 per hour.

10-units generator

This case system consists of 10-units generating thermal system where the cost coefficients, emission coefficients, limits of generator output and loss coefficients also can be obtained in [6]. This case system is with the valve-loading effect and the load demand is set 2000 MW. Detail results of EELD using BMO with various algorithms are tabulated in Table 2. It can be seen that BMO able to obtain the minimum cost compared to others but CSA able to obtain minimum emission as well as for the power loss. It is also worth to highlight that the results obtained from FPA is recalculated and the exhibited results are different with the reported in [6].

Table 2. Results for the best simulations for EELD (10-units system)

Outputs	NSGA II	FPA	CSA	BMO
P_1 (MW)	51.952	53.188	54.961	54.237
P_2 (MW)	67.258	79.975	78.905	80.000
P_3 (MW)	73.688	78.105	88.759	82.565
P_4 (MW)	91.355	97.119	83.809	79.114
P_5 (MW)	134.052	152.740	134.559	151.641
P_6 (MW)	174.950	163.080	172.327	151.162
P_7 (MW)	289.435	258.610	287.127	300.000
P_8 (MW)	314.056	302.220	307.277	310.042
P_9 (MW)	455.698	433.210	443.066	442.946
P_{10} (MW)	431.805	466.070	433.026	432.408
P_L (MW)	84.25	84.317	**83.816**	84.113
Cost ($/hr)	**113542.9**	113658.96	113421.46	**113389.02**
Emi (Kg/hr)	4151	4147.1677	**4121.6658**	4125.8961

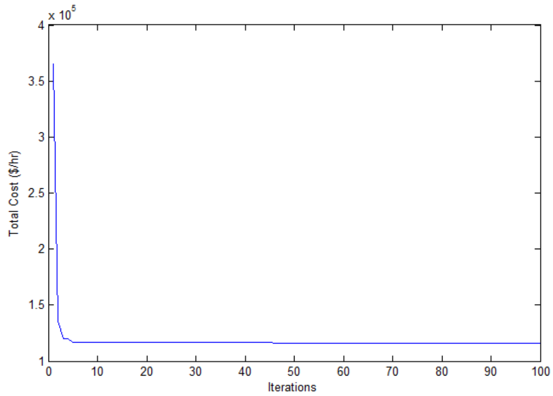

Fig.3. Convergence curve for BMO for EELD problem (10-units system)

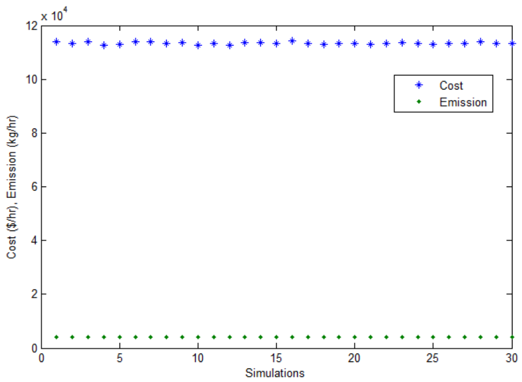

Fig.4. Results of 30 simulations of BMO for *pl* = 21.

For this case system, BMO is run for 30 times in order to obtain the optimal results. From the simulations, the best results obtained using 30 population, *pl* = 21, and the maximum iteration is set to 100 iterations. The convergence curve for the best results is shown in Figure 3, while in Figure 4, the simulations of BMO for solving EELD problem for 30 free running simulations is depicted. It can be seen that BMO is able to produce a stable result throughout 30 running of simulations.

40-units generator

This case system consists of 40-units generating thermal system. The data for this system also can be obtained in [jestec]. The power demand for this system is set to 10,500 MW and this system is lossless system. The results obtained by BMO with other selected results are shown in Table 3. From this table, it can be noted that BMO produces the minimum cost of generation compared to CSA and FPA. It is also to highlight that the results of FPA is recalculated in order to verify the results presented in [FPA] where the results presented in [FPA] were different with manual calculation. However, CSA is slightly better compared to BMO in terms of emission calculations.

Table 3. Results for the best simulations for EELD (40-units system)

Unit	FPA	CSA	BMO
P1	43.405	113.98818	114.00
P2	113.95	113.99523	114.000
P3	105.86	119.99972	120.00
P4	169.65	179.75966	179.74
P5	96.659	96.995612	97.00
P6	139.02	139.99999	140.00
P7	273.28	299.99738	300.00
P8	285.17	299.9809	300.00
P9	241.96	299.99472	300.00
P10	131.26	130.00533	130.00
P11	312.13	318.30706	318.42
P12	362.58	318.3063	318.40
P13	346.24	394.29512	394.28
P14	306.06	394.29438	394.29
P15	358.78	394.32171	394.28
P16	260.68	394.31316	394.28
P17	415.19	488.85764	488.3
P18	423.94	489.20876	489.17
P19	549.12	425.53926	426.72
P20	496.7	423.98713	428.34
P21	539.17	434.06391	434.7
P22	546.46	434.21623	433.53
P23	540.06	434.69497	434.39
P24	514.5	435.25837	434.646
P25	453.46	433.68418	433.55
P26	517.31	433.69492	433.696
P27	14.881	11.935874	11.920
P28	18.79	11.69589	10.00
P29	26.611	12.134612	10.00
P30	59.581	96.989112	97.00
P31	183.48	189.9299	190.00
P32	183.39	189.99725	190.00
P33	189.02	189.99742	190.00
P34	198.73	199.98956	200.000
P35	198.77	199.99951	200.000
P36	182.23	199.99986	200.00
P37	39.673	109.9882	110.00
P38	81.596	110	**109.99998**
P39	42.96	109.99968	**110.0000**
P40	537.17	425.58329	**425.41**
Total	10499.48	10500.00	10500.00
Cost	128508.232	125701.968	125700.191
Emission	388263.583	195125.497	195183.053

Conclusion

In this paper, the implementation of recent nature inspired algorithm namely Barnacles Mating Optimizer (BMO) into economic emission load dispatch has been done. The performance of BMO was tested for three cases and compared with the recent reported cases in the literature. From the simulations, it can be said that BMO able to produce promising and competitive results and can be applied to solve complicated problems in any optimization problems. The application of BMO into other real optimization problem especially in power system are the future scope of this works.

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