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A New Heuristic Algorithm for Solving Non-convex Economic Power Dispatch

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Abstract: Valve-points effects and prohibited operation zones (POZ) make the generating units' cost functions non-linear and non-smooth. Hence, the Economic Dispatch (ED) problem is a highly non-convex optimization problem. The consideration of the transmission losses makes the ED problem even more complicated. This study presents a novel and heuristic algorithm for solving ED problems, by employing a new heuristic method, called Imperialist Competition Algorithm (ICA). The effectiveness of the proposed method is examined and validated by carrying out extensive tests on two different test systems. The valve-point effects, POZs, ramp-rate constraints and transmission losses are considered in the analysis. The numerical results show that the ICA method has good convergence property. Furthermore, the generation costs of the ICA approach are lower than other optimization algorithms reported in recent literature.

Key words: Economic dispatch, imperialist competition algorithm, prohibited operation zone, valve-point effect

INTRODUCTION

The Economic Dispatch (ED) problem is one of the important problems in the operation of power systems. The purpose of ED problem is to determine the economical combination of generators' production to satisfy the constraints while supplying the demand.

ED problem is a non-convex and nonlinear optimization problem. Due to the high economic benefit of better solutions, many researches have been carried out to present solution methods over the years. Many optimization methods including classical and stochastic search approaches applied to ED problem. Applying the conventional methods has their own shortcomings. The most popular conventional method to solve ED problem is lambda-iteration method (Wood and Wollenberg, 1996) which needs that the cost function be continuous and monotonically increasing.

However, the actual cost function is not continuous due to prohibited operation zones. Many stochastic search based methods have been used to solve the ED problem more efficiently. Genetic algorithm (Chiang, 2007; Walters and Sheble, 1993) and its variants like as improved genetic algorithm (Chiang, 2005; Ling and Leung, 2007), Atavistic genetic algorithm (Kim *et al*., 2002), Hybrid genetic algorithm (He *et al*., 2008), self adaptive real-coded genetic algorithm (Subbaraj *et al*., 2009) and real coded genetic algorithm (Amjady and Nasiri-Rad, 2010a) proposed to solve different types of ED problem. Hybrid particle swarm optimization presented (Niknam *et al*., 2011a) for solving ED problem considering valve-point effects. A hybrid multi-agent based particle swarm optimization algorithm proposed by Kumar *et al*. (2011) to solve valve-point constrained ED problem. Other modifications of Particle Swarm Optimization method like as Parallel particle swarm optimization (Subbaraj *et al*., 2010), quantum-behaved particle swarm optimization (Sun *et al*., 2009), fuzzy adaptive hybrid particle swarm optimization algorithm (Niknam, 2010), Anti predatory particle swarm optimization (Selvakumar and Thanushkodi, 2008) applied to solve Ed problem, also. Differential Evolution is used (Nomana and Iba, 2010) to solve ED problem. Application of Modified DE and Hybrid DE in ED presented (Amjady and Sharifzadeh, 2010b; Wang *et al*., 2007).

In this study, an Imperialist Competition Algorithm (ICA) is proposed to solve non-convex dynamic economic dispatch problem with constraints.

ED PROBLEM FORMULATION

The objective function of ED problem is to minimize the total production cost over the operating horizon, which can be written as:

$$\min TC = \sum_{i=1}^{N} C_i (P_i) \qquad (1)$$

where, C_i is the production cost of unit i at time t, N is the number of dispatchable power generation units and P_i is the power output of I-th unit at time t. T is the total

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number of hours in the operating horizon. The production cost of generation unit considering valve-point effects is defined as:

$$C_i\ (P_i) = a_i P_i^2 + b_i P_i + c_i + |\, e_i \sin (f_i (P_i^{min} - P_i))\, | \tag{2}$$

where, a_i, b_i, c_i are the fuel cost coefficients of the i-th unit, e_i and f_i are the valve-point coefficients of the i-th unit. is the minimum capacity limit of unit P_i^{min}. It should be noted that the added sinusoidal term in the production cost function reflects the effect of valve-points. The ED problem will be non-convex and non-differentiable considering valve-point effects.

The objective function of the ED problem (1) should be minimized subject to the following equality and inequality constraints:

Real power balance: Hourly power balance considering network transmission losses is written as:

$$\sum_{i=1}^{N} P_i = P_D + P_{loss} \tag{3}$$

where, P_{loss} (t) and P_D (t) are the total transmission loss and total load demand of the system at time t, respectively. The system loss is a function of units power production and can be calculated using the results of load flow problem Kron's loss formula known as B-matrix coefficients. In this study, B- matrix coefficients method is used to calculate system loss as follows:

$$P_{loss} = \sum_{i=1}^{N}\sum_{j=1}^{N} P_i B_{ij} P_j + \sum_{i=1}^{N} B_{i0} P_i + B_{00} \tag{4}$$

Generation limits of units:

$$P_i^{min} \le P_i \le P_i^{max} \tag{5}$$

where, P_i^{min} is the maximum power outputs of i-th unit.

Ramp up and ramp down constraints: The output power change rate of the thermal unit must be in an acceptable range to avoid undue stresses on the boiler and combustion equipments. The ramp rate limits of generation units can be mathematically stated as follows:

$$P_i - P_{i,0} \le UR_i \tag{6}$$

$$P_{i,0} - P_i \le DR_i \tag{7}$$

where, UR_i is the ramp up limit of the i-th generator (MW/hr) and DR_i is the ramp down limit of the i-th generator (MW/hr). Considering the ramp rate limits of unit, generator capacity limit (5) can be rewritten as follows:

$$\max\ (P_i^{min}, P_{i,0} - DR_i) \le P_{it} \le \min\ (P_i^{max}, P_{i,0} + UR_i) \tag{8}$$

Prohibited Operation Zones limits (POZs): Generating units may have certain restricted operation zone due to limitations of machine components or instability concerns. The allowable operation zones of generation unit can be defined as:

$$P_{it} \in \begin{cases} P_i^{min} \le P_i \le P_{i,1}^{l} \\ P_{i,j-1}^{u} \le P_i \le P_{i,j}^{l}, \\ P_{i,M_i}^{u} \le P_i \le P_i^{max} \end{cases} \quad j = 2,3,\ \ldots, M_i, \quad i = 1,\ldots,N \tag{9}$$

where, $P_{i,j}^{l}$ and $P_{i,j}^{u}$ are the lower and upper limits of the j^{th} prohibited zone of unit i, respectively. M_i is the number of prohibited operation zones of unit i.

IMPERIALIST COMPETITION ALGORITHM (ICA)

The Imperialist Competition Algorithm (ICA) was first proposed by Atashpaz-Gargari and Lucas (2007). It is inspired by the imperialistic competition. It starts with an initial population called colonies. The colonies are then categorized into two groups namely, imperialists (best solutions) and colonies (rest of the solutions). The imperialists try to absorb more colonies to their empire. The colonies will change according to the policies of imperialists. The colonies may take the place of their imperialist if they become stronger than it (propose a better solution). This algorithm has been successfully applied to PSS design (Jalilvand *et al*., 2010) and data clustering (Niknam *et al*., 2011b). The flowchart of proposed algorithm is depicted in Fig. 1. The steps of the proposed ICA are described as follows:

Step 1: Generate an initial set of colonies with a size of N_C

Step 2: Set iteration = 1

Step 3: Calculate the objective function for each colony using (2) and set the power of each colony as Follows:

$$CP_c = OF \tag{10}$$

This means the less OF is, the more stronger IP_i is.

Step 4: Keep the best N_{imp} colonies as the imperialists and set the power of each imperialist as follows:

$$IP_i = OF \tag{11}$$

Step 5: Assign the colonies to each imperialist according to calculated. This means the number of colonies owned by each imperialist is proportional to its power, i.e., IP_i

Step 6: Move the colonies toward their relevant imperialist using crossover and mutation operators

Step 7: Exchange the position of a colony and the imperialist if it is stronger ($CP_c > IP_i$)

Step 8: Compute the empire's power, i.e., EP_i for all empires as follows:

$$\frac{IP_i}{\sum_{j=1}^{N_{imp}} IP_j} \times (N_c - N_{imp}) \tag{12}$$

where, w_1 and w_2 are weighting factors which are adaptively selected.

Step 9: Pick the weakest colony and give it to one of the best empires (select the destination empire probabilistically based on its power (EP_i)

Step 10: Eliminate the empire that has no colony

Step 11: If more than one empire remained then go to Step. 6

Step 12: End

The flowchart of the proposed Algorithm is depicted in Fig. 1.

CASE STUDIES AND NUMERICAL RESULTS

Here, the proposed ICA is applied on two test systems with different number of generating units. After a number of careful experimentation, following optimum values of ICA parameters have finally been settled: = 100; crossover probability = 0.6, mutation probability = 0.2.

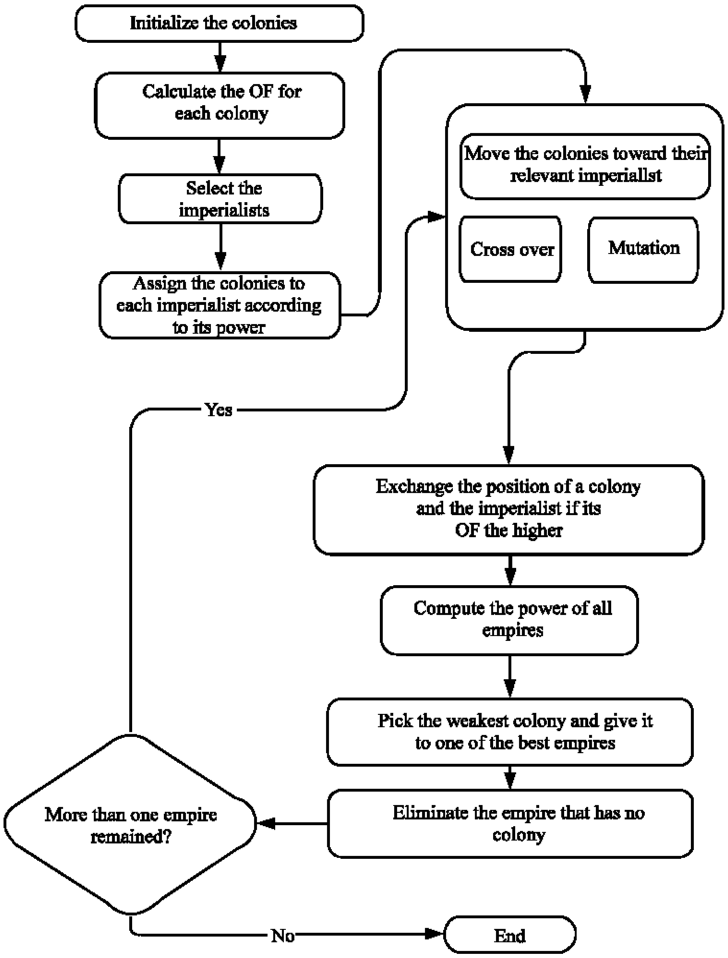

Fig. 1: The flowchart of the proposed ICA algorithm

The stopping criteria is defined as reaching to the maximum number of iterations (here 600 iterations) or when no significant changes observed in the objective function.

Case 1: 6-unit system: The first test system is a 6-unit system. System's total demand is 1263 MW. The data for this system is provided by Pothiya *et al.* (2008). In this test system, the transmission losses, POZs and ramp-rate constraints are considered.

Table 1 shows the obtained results for this system. These results are compared with multiple Tabu search (MTS) algorithm (Pothiya *et al.*, 2008), new PSO with local random search (NPSOLRS) (Selvakumar and Thanushkodi, 2007), bacterial foraging optimization (BFO) (Panigrahi and Pandi, 2008), new adaptive PSO (NAPSO) algorithm (Niknam *et al.*, 2011c), GA (Selvakumar and Thanushkodi, 2007) and PSO (Selvakumar and Thanushkodi, 2007).

The obtained results outperform the existing methods and hence the proposed method is so effective for solving such non-convex ED problems.

Case 2: 40-unit system: This test case consists of 40 generating units with valve-point effects (Sinha *et al.*, 2003). Total load demand of the system is 10500 MW. The obtained results by the proposed ICA are presented in Table 2. The obtained results are

Table 1: Comparison of simulation results for the 6-unit system

Unit	MTS	NPSO-LRS	BFO	NAPSO	SOH-PSO	Proposed
1	448.1277	446.96	449.46	446.4232	438.21	447.399
2	172.8082	173.3944	172.88	172.608	172.58	173.241
3	262.5932	262.3436	263.41	262.6183	257.42	263.382
4	136.9605	139.512	143.49	142.7752	141.09	138.98
5	168.2031	164.7089	164.91	164.665	179.37	165.392
6	87.3304	89.0162	81.252	86.323	86.88	87.052
TG	1276.023	1275.935	1275.402	1275.413	1275.55	1275.445
TL	13.0205	12.9351	12.402	12.4127	12.55	12.445
TC	15450.06	15450	15443.85	15443.77	15446.02	15443.06

TG: Total generation, TL: Total loss, TC: Total cost

Table 2: Comparison of simulation results for the 40-unit system

Unit	DE/BBO	FAPSO–VDE	QPSO	HMAPSO	BBO	HGA	Proposed
1	110.7998	110.80182	111.2	111.136	111.0465	111.3793	110.906
2	110.7998	110.80003	111.7	111.135	111.5915	110.9278	110.804
3	97.3999	97.399913	97.4	120	97.60077	97.4104	97.4
4	179.7331	179.7331	179.73	177.221	179.7095	179.7331	179.733
5	87.9576	87.799785	90.14	88.699	88.30605	89.2188	87.828
6	140	140	140	140	139.9992	140.0	140.0
7	259.5997	259.59965	259.6	260.157	259.6313	259.6198	259.609
8	284.5997	284.59965	284.8	284.723	284.7366	284.657	284.6
9	284.5997	284.59965	284.84	285.523	284.7801	284.6588	284.601
10	130	130	130	130	130.2484	130	130.0
11	168.7998	94	168.8	168.805	168.8461	168.8214	168.8
12	94	94	168.8	168.689	168.8329	168.8496	94.0
13	214.7598	214.75979	214.76	304.123	214.7038	214.7524	214.76
14	394.2794	394.27937	304.53	304.678	304.5894	394.2848	394.279
15	394.2794	394.27937	394.28	304.317	394.2761	304.5361	394.279
16	304.5196	394.27937	394.28	304.317	394.2409	394.2987	304.52
17	489.2794	489.27937	489.28	489.187	489.2919	489.2877	489.279
18	489.2794	489.27937	489.28	489.455	489.4188	489.2869	489.28
19	511.2794	511.27937	511.28	512.097	511.2997	511.2752	511.28
20	511.2794	511.27937	511.28	511.349	511.3073	511.2857	511.28
21	523.2794	523.27937	523.28	523.247	523.417	523.2961	523.279
22	523.2794	523.28065	523.28	523.515	523.2795	523.3202	523.28
23	523.2794	523	523.29	523.454	523.2793	523.2916	523.279
24	523.2794	523	523.28	523.453	523.3225	523.3014	523.279
25	523.2794	523	523.29	523.492	523.3661	523.2675	523.279
26	523.2794	523	523.28	523.307	523.4362	523.2787	523.279
27	10	10	10.01	10	10.05316	10	10
28	10	10	10.01	10	10.01135	10	10
29	10	10	10	10	10.00302	10	10
30	97	87.799891	88.47	88.691	88.47754	88.6376	97
31	190	190	190	190	189.9983	190	190

Table 2: Continue

Unit	DE/BBO	FAPSO–VDE	QPSO	HMAPSO	BBO	HGA	Proposed
32	190	190	190	190	189.9881	190	190
33	190	190	190	190	189.9663	190	190
34	164.7998	164.8015	164.91	164.218	164.8054	164.9795	164.805
35	200	194.39276	165.36	200	165.1267	165.997	200
36	200	200	167.19	200	165.7695	165.0464	200
37	110	110	110	110	109.9059	110	110
38	110	110	107.01	110	109.9971	110	110
39	110	110	110	110	109.9695	110	110
40	511.2794	511.27937	11.36	511.009	511.2794	511.3005	511.279
TG	10500.001	10498.88252	10500	10499.997	10499.9087	10500	10499.997
TC	121420.9	121413.3	121448.21	121586.9	121426.953	121418.27	121416.937

TG: Total generation, TC: Total cost

compared with the results of hybrid DE with biogeography-based optimization (DE/BBO) algorithm (Bhattacharya and Chattopadhyay, 2010a), variable DE with the fuzzy adaptive PSO (FAPSO-VDE) (Niknam *et al.*, 2011a), quantum-inspired PSO (QPSO) (Meng *et al.*, 2010), multi-agent based hybrid PSO technique (HMAPSO) (Kumar *et al.*, 2011), biogeography-based optimization (BBO) algorithm (Bhattacharya and Chattopadhyay, 2010b) and hybrid GA (HGA) (He *et al.*, 2008).

These results imply the efficiency of the proposed ICA method for dealing with the ED problem.

CONCLUSION

In this study, a new approach to solve power systems economic dispatch problem, called imperialist competition algorithm (ICA), is proposed. The valve-point effect, prohibited operation zones, ramp-rate constraints and transmission losses are modeled and the resulting non-linear and non-convex optimization problem is solved by ICA. The proposed method is applied on two test systems. The analysis results have demonstrated that for such a complicated problem, ICA founds solutions better than so far best known results by any other method in terms of cost and power losses.

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