Solving economic load dispatch problem by Imperialist Competitive Algorithm

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***Abstract*—This research displays an imperialist competitive algorithm (ICA) to solve economic dispatch problem by allocating the load demand among the available thermal units to keep the operating cost minimized as possible. ICA algorithm has been applied on three systems (6-15-40 units) with various restrictions as generation limits, ramp rate limits (RRL), prohibited operating zone (POZ), valve point loading (VPL) and transmission losses. The numerical results found from the suggested algorithm are compared with Vortex Search Algorithm (VSA), Gravitational Search Algorithm (GSA), jaya algorithm (jaya) and Modified Social Spider Algorithm (MSSA). The results exhibited that ICA is more powerful than other methods.**

Keywords*— economic dispatch, Imperialist competitive algorithm, ramp rate limits, prohibited operating zone, valve-loading effect, transmission line losses.

I. INTRODUCTION

One of the important problems in the power systems was the economic dispatch problem. It aimed to minimize the operation cost of the units with satisfying all constraints. Two kinds of methods were utilized for optimizing the output of the units. The first kind is the mathematical techniques such as Quadratic Programming, Linear Programming and etc. these methods need that the cost function to be continuous. However, the actual cost function was intermittent because of prohibited operation zones. These methods were compatible to solve static economic dispatch problems that involve a simple sorting.

In dynamic economic dispatch (DED) problem included many constraints such that generation unit limits, valve point effect, power balance and prohibited operating zones. To solve the (DED) problem, the second kind were suitable which included random search optimization methods, as Moderate-Random-search Particle Swarm Optimization (MRPSO) [1], Weight Improved PSO (WIPSO) [1], Hybrid Modified Particle Swarm Optimization and Genetic Algorithm (MPOGA) [2], Gravitational Search Algorithm (GSA) [3], Modified Social Spider Algorithm (MSSA) [4], Levy Flight Moth-Flame Optimizer (MFO) [5], Vortex Search Algorithm (VSA) [6], jaya algorithm (jaya) [7, 8], Hybrid Big Bang Big Crunch algorithm(HBB-BC) [9], and Chaotic Iteration PSO (CIPSO) [10] .

This paper recommended new algorithm known as Imperialist Competitive Algorithm (ICA). The basis of ICA originated from the trying of the world countries to increase their power over the other countries for utilizing their resources and support their own government. Imperialist countries tried to state their power over the other countries to be from their colonies. Furthermore competitive with the other to take the ownership of the other countries. During this process, empires that had more powerful will gain more power and feeble ones will finally collapse. ICA effort to metaphorically model this process to obtain the optimum solution. Up to now, the ICA introduced a good performance in convergence rate and finding a global solution that encourage to use this application in optimization problems in many. applications [11-13].

This research examined the capability of the ICA technique to solve (DED) problems that keep in mind the generator features for example prohibited operating zones, valve-point effects, and ramp-rate limits. The ICA was carried out with three test systems (6, 15, 40) units. The results found from ICA were compared with other techniques that reported in this research.

II. FORMULATION OF ECONOMIC LOAD DISPATCH PROBLEM

A. Cost function of thermal plants

The basic objective function of ED problem is described by the following equation.

$$\operatorname{Min} F = \sum_{j=1}^{N_G} F_j(p_{gj}) = \sum_{j=1}^{N_G} a_j P_{gj}^2 + b_j P_{gj} + c_j \qquad (1)$$

Where F was the total generation cost, Fj is the fuel cost of generation unit j, NG the number of generators, aj, bj and cj are fuel cost parameters.

A non-smoothing in the fuel rate curve of the thermal units due to the effect valve-point loading. Therefore, equation (1) was modified by adding a sinusoidal term as shown in (2).

$$FC_j(p_{gj}) = a_j p_{gj}^2 + b_j p_{gj} + c_j + \left| e_j \sin(f_j(p_{gjmin} - p_{gj})) \right| \qquad (2)$$

Where e_j and f_j are parameters of reflecting (VPL).

B. *Constraints of thermal plants*

1) *System Power Balance*

The generation power should be meet the demand power and the transmission losses.

$$\sum_{j=1}^{Ng} P_{gj} = P_D + P_L \tag{3}$$

Where P_D was total load demand and P_L was the transmission losses of the network.

The transmission loss was calculated by kron's loss formula that shown in (4) which expressed as a function of the output generation power.

$$P_{L,t} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{g_{i,t}} B_{ij} P_{g_{i,t}} + \sum_{i=1}^{n} B_{o,i} P_{g_{i,t}} + B_{oo} \tag{4}$$

Where B_{ij}, B_{oi}, B_{oo} are B-coefficients or power loss coefficients.

2) *Operating limits of the generation power*

The output power of the generator should be in between its minimum and maximum limits as defined by (5).

$$P_{gjmin} \le p_{gj} \le P_{gjmax} \tag{5}$$

Where P_{gjmin} and P_{gjmax} are the minimum and maximum limits for jth generator.

3) *Constraints of Prohibited Operating Zones*

The output of the generation units was limited by actual operation due to the characteristic of the boilers or the auxiliaries, so the DED problem is adheres as the following.

$$P_{gj} \in \begin{cases} P_{gj}^{min} \le P_{gj} \le P_{gj}^{LB_1} \\ P_{gj}^{UB_{K-1}} \le P_{gj} \le P_{gj}^{LB_K} \\ P_{gj}^{UB_K} \le P_{gj} \le P_{gj}^{max} \end{cases} \quad j=1, 2, 3, \ldots.. N_g \tag{6}$$

Where $P_{gj}{}^{LB}{}_k$, $P_{gj}{}^{UB}{}_k$ were the lower and upper limits of the kth prohibited zone of jth unit and k was the prohibited zone's index.

4) *Generator Ramp-Rate Limits*

The operation of running generated units was limited by its ramp-rate limits. The ramp-down and ramp-up was written as the following:

$$\max (P_j^{min} \ , P_j^{\circ} - DR_j) \le P_{gj} \le \min (P_j^{max} \ , P_j^{\circ} + UR_j) \tag{7}$$

III. AN OVERVIEW OF IMPERIALIST COMPETITIVE ALGORITHM

The improvement of ICA rule was first by Atashpaz-Gargari and Lucas (2007) [14]. The ICA simulated the social political development of imperialism and compete the imperialist. ICA began with initial population called countries that were divided into two kinds of countries; the strongest countries were chosen to be the imperialist and the residual countries establish the colonies of these imperialists. The colonies of initial countries were distributed among the imperialists constructed on the imperialist's power. All the imperialists and their colonies gathered together forming empires.

After the formation of empires, the competition of empires began the weaker empires lose their colonies to the powerful empires until we reach one empire and the other rest of their colonies. This empire represents the finial best solution. The algorithm was divided into the following five stages:

A. *Initializing phase:*

Firstly, Preparation of initial populations. Each solution (i.e., country) in form of an array as (8).

$$X = [P1, P2, P3, \ldots , P_{Ng}] \tag{8}$$

Where P was represent a variable, and N_{var} is the n–dimension of the optimized problems. The cost function of the countries can depict as (9).

$$Cost=f\,(country) = f\,(P_1 P_2 P_3 ,......, P_{N_{var}}) \tag{9}$$

Then Initializing the empires with initial populations (Npop) involved two types of countries [i.e., colony (Ncol) and imperialist (Nimp)] which together form the empires. The normalized cost C_n of an imperialist was depicted as.

$$C_n = c_n - \max\{c_i\} \tag{10}$$

Whereas, c_n is the nth imperialist cost.

The colonies of initial countries were distributed among the imperialists constructed on the imperialist's power. The normalized power P_n of each imperialist was depicted as.

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \tag{11}$$

B. *Moving phase:*

Colonies moved toward their imperialist with x units as depicted in (12).

$$x : U(0, \beta \times d) \tag{12}$$

Where x is a random variable with uniform distribution, β is a number greater than 1, and d is the distance between an imperialist and it's colony. And the directions of movement of colonies were depicted as (13).

$$\theta : U(-\gamma, \gamma) \tag{13}$$

Where θ was a random variable with uniform distribution, and γ was a parameter that regulated the change from the original direction.

C. *Exchanging phase:*

During movement of colonies, if the new situation of the colony is better (based on the cost function) than the corresponding imperialist, so imperialist and the colony change their positions.

D. *Competition phase:*

Firstly, calculated the total power of an empire as (14).

$$T.C_n = cost\ (imperialist_n) + \xi\ mean\ (cost\ (colonies\ of\ empire_n)) \tag{14}$$

Where,$T.C_n$ is the total power of the nth empire and ξ is appositive number less than 1.

Then all empires were tried to Acquire. more colonies from other empires. The weakest empires lose its colonies during competition between them.

E. *Eliminating phase:*

The empires that lose their colonies were collapsed and eliminated. Finally, all the colonies will be under the dominance of the most powerful empire.

IV. IMPLEMENTATION OF ICA ON ED PROBLEM.

The performance of the ICA algorithm to ED problem was examined. For DED problem, the output power P, of

each generating unit was considered a variable. Therefore, the power outputs of all units forms a solution vector, X. This solution X, was depicted as (8)
The steps of applying the suggested algorithm on economic dispatch problem can be concise as the following:

Step 1: (Initialization) Specify input parameters of the system like generator cost coefficients (a_j, b_j and c_j), valve-point coefficients (e_j and f_j) and the constraints of the problem also, define the ICA parameters.

Step 2: (Assimilation) start the countries randomly, and compute the cost function for each country based on equation (2).

Step 3: (Revolution) randomly change the colonies position.

Step 4: (Position-exchange) reciprocate the positions of that colony and the imperialist, if there was a colony in an empire has lower cost than the imperialist.

Step 5: (Power computation) Compute the cost function of all empires.

Step 6: (Imperialist competition) choose the weakest colony from the weakest empires and provides it to the additional powerful empires.

Step 7: (Elimination) Eliminate the weak empires.

Step 8: (Termination) If stop conditions satisfied, move to step 9, if not move to step 2. exchange the positions of that colony and also the imperialist.

Step 9: Stop and print the results.

V. CASE STUDIES AND NUMERICAL RESULTS

To examine the flexibility of the ICA to find the optimal solution of ED problem, the ICA algorithm has been applied on three case studies with different constraints and also that the results were compared with different algorithms within the literature.
The parameters of the proposed ICA are maximum iter. =100, number of population = 100, number of imperialist=5, revolution probability = 0.7, revolution rate=0.2, colonies mean cost coefficient=0.2. All the programs were processed using MATLAB 2016 on a Pentium i3 laptop computer , 2.53 GHz processor speed and 3 GB RAM.

A. Test system (1)

1) Case study (1)

System information can be found in [6].This case study included 6 units with load demand 1263 MW. In this case study, ramp rate constraints and transmission losses were taken into account. The best cost recounted until now is 15,448 ($/h). The results found from the ICA algorithm were given in Table I. The numerical results were compared with the result from VSA [6], PSO [1], CPSO [1], WIPSO [1] and it Show that the ICA has the lowest cost between the all methods. Fig.1. display the convergence behavior of the ICA algorithm.

TABLE I. BEST SOLUTION OF 6-UNITS SYSTEM (CASE STUDY 1).

Unit	**VSA[6]**	**PSO[1]**	**CPSO[1]**	**WIPSO[1]**	**ICA**
P1(MW)	457.06	493.24	471.66	454.39	455.703
P2(MW)	172.37	114.63	140.03	164.279	162.451
P3(MW)	264.39	263.41	240.06	264.223	265
P4(MW)	141.43	139.71	149.97	123.21	132.745
P5(MW)	164.054	179.65	173.78	167.22	162.710
P6(MW)	76.169	84.83	99.97	120	84.204
Ploss	12.488	12.22	12.38	12.24	12.311
Cost($/h)	15448	15489	15481.87	15453.13	15444.348

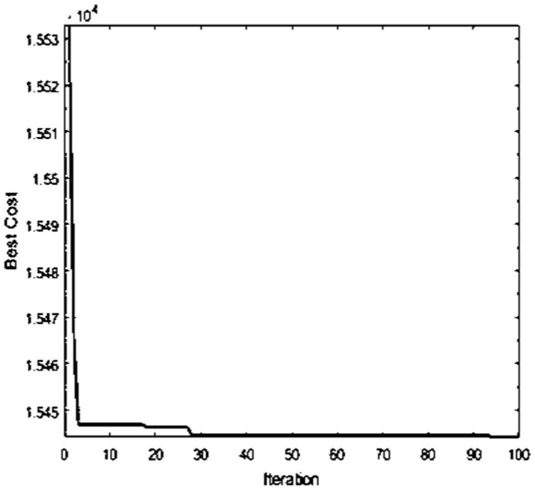

Fig. 1. 6-unit system with loss, (R.R.L).

2) Case study (2)

By considering prohibited zones (POZ) to case study (1) with load demand 1263 MW. System data were taken from [6]. Table II. Show that the optimal cost obtained from ICA less than the optimal cost obtained from VSA [6], MFO [5], MSSA [4] and jaya [7]. The fuel cost obtained by ICA is nearly equal to the fuel cost obtained from HBB–BC [9]. However, ICA gives lower losses than HBB–BC. Table III. Illustrate that the ICA and HBB–BC provided the best results at lower number of iteration. Fig.2. Display the convergence behavior of the ICA algorithm.

TABLE II. BEST SOLUTION OF 6-UNIT SYSTEM (CASE STUDY 2).

Unit	**VSA [6]**	**MFO [5]**	**MSSA [4]**	**Jaya [7]**	**HBB–BC[9]**	**ICA**
P1	446.0	426.08	447.502	451.424	441.36	440.11
P2	181.0	199.8	173.318	176.092	175.68	176.97
P3	263.4	247.49	263.463	255.899	262.82	264.63
P4	133.9	136.94	139.065	150	134.57	137.40
P5	176.6	166.24	165.473	174.244	169.98	163.99
P6	74.53	98.93	87.134	67.7409	91.16	92.318
P1oss	12.73	12.51	12.958	12.40	12.57	12.44
Cost	15447	15448.7	15449.89	15448.78	15444.26	15444.5

TABLE III. THE PERFORMANCE OF ICA FOR CASES STUDY (2).

Method	**Max Cost**	**Min Cost**	**Mean Cost**	**Standard Deviation**	**Max iter.**
MSSA[4]	15453.545	15449.899	15449.937	0.3647	12000
Jaya[8]	15573.515	15446.567	15489.703	13.31	2000
Jaya[8]	15498.524	15446.019	15464.879	10.93	2000
Jaya-M[8]	15468.92	15445.80	15459.47	8.46	2000
Jaya-SML[8]	15450.64	15445.16	15447.29	6.22	2000
HBB-BC[9]	15448.89	15444.26	15446.46	1.52	100
ICA	15471.21	15444.56	15456.75	9.743	100

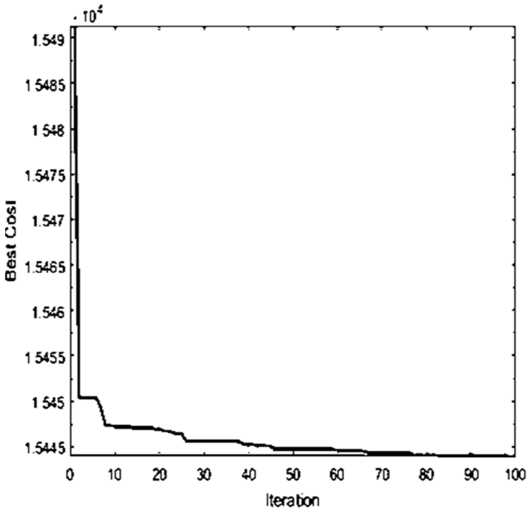

Fig. 2. 6-unit system with loss, (R.R.L)&(P.O.Z).

3) *Case study (3)*

System information can be found in [6]. This case study included 6 units with load demand 1263 MW. Ramp rate limits, transmission losses and a valve point loading constraint were taken into account. In addition, the prohibited zones were not considered. A convergence feature of this case study was depicted in Fig. 3. & Table IV. Illustrate that the ICA method has the best cost among all of other methods as VSA [6], PSO [1], CPSO [1], WIPSO [1] and MRPSO [1].

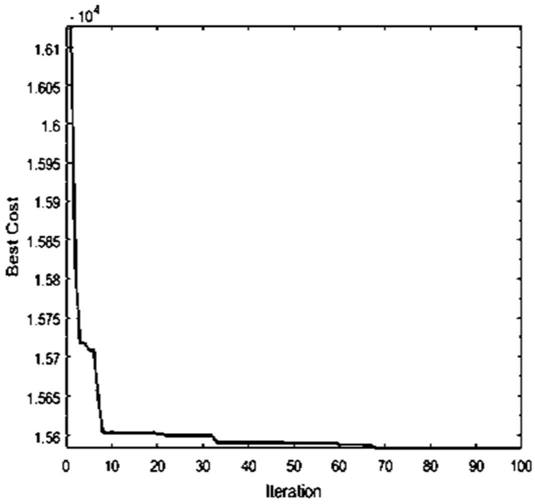

Fig. 3. 6-unit system with loss, (R.R.L)&(V.P.E).

TABLE IV. BEST SOLUTION OF 6-UNIT SYSTEM (CASE STUDY 3).

Unit	VSA [6]	PSO [1]	CPSO [1]	WIPSO [1]	MRPSO [1]	ICA
P1(MW)	495.29	443.03	467.55	437.820	442.070	403.969
P2(MW)	195.90	169.03	163.05	173.280	167.230	200
P3(MW)	235.79	262.02	253.41	271.970	267.090	228.846
P4(MW)	65.62	134.78	115.07	138.70	132.810	128.417
P5(MW)	197.82	147.47	169.45	146.980	155.020	197.908
P6(MW)	87.270	125.35	113.24	103.630	107.020	116.994
P1oss	12.920	18.680	18.70	18.080	18.030	13.095
Cost($/h)	15746	16372.9	16329.2	16327	16310.76	15587.523

4) *Case study (4)*

System information can be obtained from [6].This case study include 6 units with load demand 1263 MW. In this case study, ramp rate constraints, transmission losses, valve point loading constraint and the prohibited zones were taken into account.

There was no result reported on this case study until now, so The results were compared with case study (3) and it was obtained that the losses less than case (3), but case (3) has better convergence than case (4) as depict in Fig 3 and Fig 4. Table V. Show the performance of ICA on case study (3) and case study (4).

TABLE V. BEST SOLUTION OF 6-UNIT SYSTEM (CASE STUDY 3&4).

Unit	ICA(case 3)	ICA(case 4)
P1(MW)	403.9695	403.835
P2(MW)	200	199.5412
P3(MW)	228.8467	240
P4(MW)	128.41721	145.514
P5(MW)	197.9084	199.3583
P6(MW)	116.9948	87.566
P1oss	13.095	12.7397
Cost($/h)	15587.523	15669.595
Max cost	15765.891	15817.970
Mean cost	15660.814	15745.516
Standard deviation	60.6034	60.9764
time	5.513	6.699

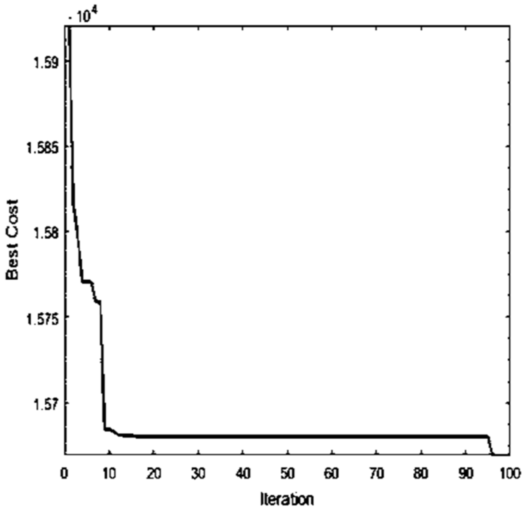

Fig. 4. 6-unit system with loss, (R.R.L), (V.P.L)&(P.O.Z).

B. *Test system (2)*

This study system included 15 units with ramp rate limits, prohibited zones and transmission losses were considered. The load demand is 2630MW. The input data of this system were given in [15]. The best generation cost recounted until now is 32,702 ($/h). The results were compared with DEGSA [3], CIPSO [10] and MPSOGA [2]. A convergence feature of this test study was exhibited in Fig 5. Table VI. Show that the ICA method has the lowest cost between all the mention methods. Table VII. Show that the ICA technique has best values of minimum cost, maximum cost, mean cost and Standard deviation between all the compared techniques.

TABLE VI. BEST SOLUTION OF 15-UNIT (TEST SYSTEM 2).

Unit	ICA	DEGSA [3]	CIPSO [10]	MPSO GA[2]
P1 (MW)	455	454.998	415.85	455
P2 (MW)	380	380	411	380
P3 (MW)	130	130	128.85	130
P4 (MW)	130	130	126.19	130
P5 (MW)	169.5686	170	188.1	169.96
P6 (MW)	460	460	427.7	460
P7 (MW)	430	430	431.73	430.088
P8 (MW)	106.2896	72.2117	99.8	60.13
P9 (MW)	30.4583	58.4538	95.02	72.6064
P10 (MW)	148.439	160	117.73	157.009
P11 (MW)	80	80	70.87	80
P12 (MW)	80	80	52.74	79.2381
P13(MW)	25	25	27.16	26.0017
P14 (MW)	19.738	15	35.76	15
P15 (MW)	15.000	15	26.64	15
Total gen.(MW)	2659.495	2660.6628	2655.16	2660.03
P1oss(MW)	29.480	30.6635	25.16	29.4031
Cost ($/h)	32697.80	32704.4536	32745.35	32,702

TABLE VII. THE PERFORMANCE OF ICA WITH OTHER METHODS FOR 15-UNIT (TEST SYSTEM 2).

Method	Max Cost	Min Cost	Mean Cost	Standard Deviation
DEGSA[3]	32707.717	32704.453	32705.276	0.9335
GSA[3]	32727.552	32704.466	32706.565	22.9006
Jaya[8]	32822.993	32712.645	32713.4613	47.0256
Jaya-M[8]	32743.680	32707.031	32714.438	12.0972
MPSO-GA[2]	32755.19	32,702.00	32733.29	-
Jaya-SML[8]	32707.292	32706.357	32706.676	2.3244
ICA	32684.011	32684.010	32684.0107	0

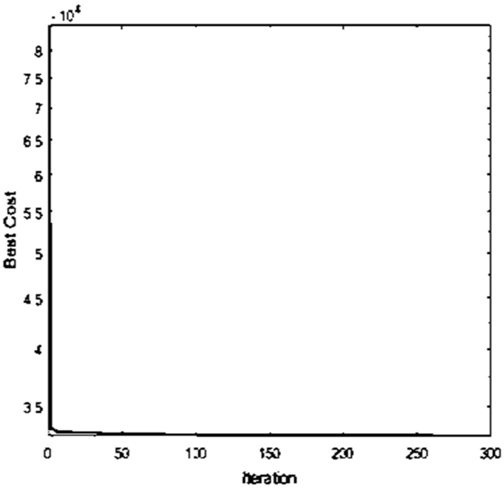

Fig. 5. 15-unit system with loss, (R.R.L)

C. *Test system (3)*

This study consists of 40-unit with load demand 10500MW and the system information is given in [15]. Only the valve-point effect was considered.

This case study was larger than the previous cases and the performance of the ICA algorithm will be more obvious. The optimal cost recounted until now is 121412.54 $/h. Table VIII. Show that the best cost of the ICA algorithm was lower than that in MSSA [4], HBB–BC [9] and DEGSA [3]. A convergence feature of the 40-unit illustrated in Fig 6. Table IX. Showed that the ICA algorithm has better performance and more powerful than other methods.

TABLE VIII. BEST SOLUTION OF 40-UNIT AT 10500 MW.

Unit	ICA	MSSA [4]	HBB–BC [9]	DEGSA [3]
P1(MW)	70.437	110.8	114	110.7999
P2(MW)	108.305	110.83	114	110.7999
P3(MW)	117.005	97.4	97.4243	97.3999
P4(MW)	133.7190	179.73	179.7324	179.7331
P5(MW)	47	87.81	88.6784	87.7999
P6(MW)	139.194	140	140	140
P7(MW)	236.682	259.6	300	259.5996
P8(MW)	275.062	284.6	284.5997	284.5997
P9(MW)	180.383	284.6	284.5737	284.5996
P10(MW)	218.0771	130	130	130
P11(MW)	144.886	94	94	94
P12(MW)	185.881	94	94	94
P13(MW)	193.434	214.76	214.7623	214.7598
P14(MW)	345.487	394.28	304.5196	394.2793
P15(MW)	423.433	394.28	394.2794	394.2794
P16(MW)	282.544	394.28	394.2794	394.2793
P17(MW)	483.714	489.28	489.2795	489.2794
P18(MW)	500	489.28	489.2795	489.2794
P19(MW)	528.418	511.28	511.2845	511.2793
P20(MW)	550	511.28	511.2845	511.2794
P21(MW)	548.871	523.28	523.2196	523.2794
P22(MW)	549.929	523.28	523.2196	523.2794
P23(MW)	540.852	523.28	523.2196	523.2794
P24(MW)	550	523.28	523.2196	523.2794
P25(MW)	523.202	523.28	523.2196	523.2794
P26(MW)	550	523.28	523.2196	523.2794
P27(MW)	10	10	10	10
P28(MW)	10.164	10	10	10
P29(MW)	20.6467	10	10	10
P30(MW)	97	87.93	89.3218	87.7999
P31(MW)	185.750	190	190	190
P32(MW)	189.322	190	190	190
P33(MW)	183.297	190	190	190
P34(MW)	182.823	164.8	200	164.7998
P35(MW)	200	194.22	200	199.9996
P36(MW)	199.992	200	200	194.3983
P37(MW)	102.9223	110	110	109.9999
P38(MW)	80.5183	110	110	110
P39(MW)	106.531	110	110	109.9998
P40(MW)	511.1648	511.28	511.2845	511.2793
P Total (MW)	10506.659	10500	10500	10500
Total cost ($/h)	121381.0775	121413.4686	121471.72	121412.5455

TABLE IX. THE PERFORMANCE OF ICA WITH OTHER METHODS FOR 40-UNIT (PD = 10,500 MW).

Method	Min Cost	Max Cost	Mean Cost	Standard Deviation
DEGSA[3]	121412.54	122231.16	121625.74	155.93
HBB-BC[9]	121471.72	122137.42	121984.24	-
MSSA[4]	121413.46	121521.73	121466.61	28.69
CIHBMO[15]	121412.57	-	121412.59	0.0213
DHS[16]	121415.63	121418.63	121417.27	0.8614
ICA	121381.077	121594.039	121487.558	0.087

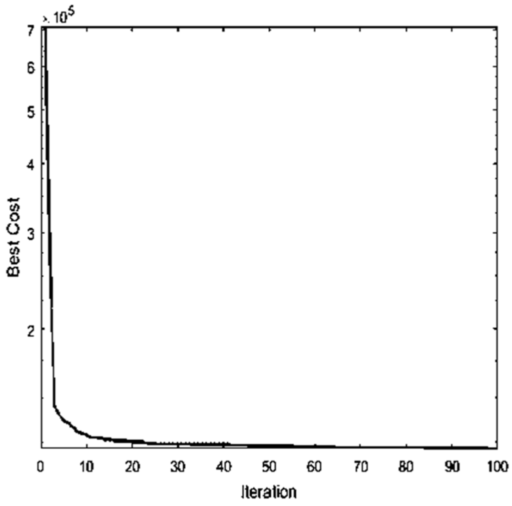

Fig. 6. 40-unit system with (V.P.L).

VI. CONCLUSION

In this paper has shown the application of ICA on DED problem by considering ramp rate limits, transmission losses, prohibited operating zones and valve loading effects. Three separate test systems has been used with different constraints to show the ability of the ICA technique to reach the minimum generation cost in term of the scheduling problem of the thermal generation units. The results show the ICA method has a good performance, stable convergence characteristic and good computation efficiency than other optimization techniques such as MSSA, jaya, MFO, VSA, CIPSO and GSA. Moreover, the ICA method is very effective for solving large systems with non-convex cost functions.

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