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MULTIOBJECTIVE ENVIRONMENTAL AND ECONOMIC DISPATCH USING IMPERIALIST COMPETITIVE ALGORITHM

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Abstract- In this research a multi-objective Imperialist Competitive Algorithm (MOICA) is applied for Environmental and Economic Power Dispatch (EED) problem. Due to the environmental concerns that arise from the emissions produced via fossil-fueled electric power plants, the classical economic dispatch, which operates electric power systems so as to minimize only the total fuel cost, can no longer be considered alone. Hence, by environmental dispatch, emissions can be reduced by dispatch of power generation to minimize emissions. Also, power generated, system loads, fuel cost and emission coefficients are subjected to inaccuracies and uncertainties in real-world situations. The proposed technique has been carried out on the IEEE 30-bus and 118-bus test system. The results demonstrate the capability of the proposed MOICA approach to solve of multi-objective EED problem. The comparison reported results with MODE and other techniques reveals the superiority of the proposed MOICA approach and confirms its potential for solving other power systems multi-objective optimization problems.

Keywords: Minimum Cost and Emission, ICA, Environmental and Economic Power Dispatch, Multi-Objective Optimization.

I. INTRODUCTION

According to the increasing concern of environmental pollution, operating at absolute minimum cost can no longer be the only criterion for Economic Dispatch (ED) problem. There is no doubt that, generation of electricity using fossil fuel leads to several contaminants as; SO_2, CO_2 and NO_x, into the atmosphere. In recent years, the pollution minimization due to the pressing public demand for clean air problem has attracted much attention for researchers. While, in some activities have done by countries as; the U.S. Clean Air Act amendments of 1990 and similar acts by European and Japanese governments, environmental constraints have topped the list of utility management concerns [1, 2].

The classical Economic Load Dispatch (ELD) problem is to operate electric power systems so as to minimize the total fuel cost. This single objective can no longer be considered alone due to the environmental concerns that arise from the emissions produced by fossil fueled electric power plants. Indeed, the clean air act amendments have been applied to reduce SO_2 and NO_x emissions from such power plants. Hence, emissions can be reduced by dispatch of power generation to minimize emissions instead of or as a supplement to the usual cost objective of economic dispatch.

The EED problem is a multi-objective problem with conflicting objectives because pollution is conflicting with minimum cost of generation. A summary of environmental and economic dispatch algorithms dating back to 1970 by using conventional optimization methods was reviewed in [3]. The problem of EED in [4] is reduced to a single objective problem by treating the emission as a constraint with a permissible limit. However, this formulation has a severe difficulty in getting the trade-off relations between cost and emission.

Various strategies to reduce the atmospheric emissions have been proposed and discussed. Accordingly, in [5-7] use multi-objective Genetic Algorithm (GA), hierarchical system approach [1], fuzzified multi-objective particle swarm optimization algorithm [8], fuzzy linear programming [9-10], fast Newton-Raphson algorithm [11], linear programming [12].

On the other hand, Imperialist Competitive Algorithm (ICA) is a global search strategy that uses the socio-political competition among empires as a source of inspiration. Similar other evolutionary ones that start with initial population, this technique begin by initial empires. Any individual of an empire is a country. Actually, there are two types of countries in this technique as; colony and imperialist state that collectively form empires. Imperialistic competitions among these empires form the basis of the ICA. During this competition, weak empires collapse and powerful ones take possession of their colonies which improve the algorithm. Imperialistic competition converges to a state in which there exists only one empire and colonies have the same cost function value as the imperialist [13]. These characteristics of the ICA make it feasible and powerful.

In this research, a Multi-Objective ICA (MOICA) is proposed to solve the environmental/ economic power dispatch problem. This newly technique makes ICA technique, more flexible and powerful. The proposed algorithm runs on the IEEE 30-bus and 118-bus test systems and the results are compared with techniques which are presented in [14]. The achieved numerical results of the proposed technique demonstrate the feasibility of the proposed technique to solve the multi-objective EED problem.

II. PROBLEM STATEMENT

It is clear that, the EED problem targets to find the optimal combination of load dispatch of generating units and minimizes both fuel cost and emission while satisfying the total power demand. Therefore, EED consists of two objective functions, which are economic and emission dispatches. Hence, the ELD, considering system loss can reasonably improve real and reactive power dispatch simultaneously [15]. Therefore, the ELD problem should be considered as a multi-objective optimization problem which is based on economic, environment and system loss. The EED problem can be formulated as follows:

A. Problem Objectives

Fuel cost minimization: The cost curves of generators are presented by quadratic functions [16]. Also the total fuel cost $F(PG)$ ($/h) is presented as:

$$F(P_G)=\sum_{i=1}^{N} a_i+b_iP_{Gi}+c_iP_{Gi}^2 \quad (1)$$

where N is the number of generators, a_i, b_i, c_i are the cost coefficients of the ith generator and P_{Gi} is the real power output of the ith generator.

$$P_G=[P_{G1},P_{G2},\dots,P_{GN}]^T \quad (2)$$

where P_G is the vector of real power output generator.

B. Emission Minimization

The classical ED problem can be found by the amount of active power to be generated by units at minimum fuel cost, but it is not considered as the amount of emissions released from burning fossil fuels. The total amount of emission such as SO_2 or NO_x depends on the amount of power generated by unit [16-17]. The minimum emission dispatch optimizes the above classical economic dispatch including NO_x emission objective, which can be modeled using second order polynomial functions:

$$E(P_G)=\sum_{i=1}^{N}10^{-2}(a_i+\beta iP_{Gi}+\gamma_iP_{Gi}^2)+\xi_i\exp(\gamma_iP_{Gi}) \quad (3)$$

where, α_i, β_i, γ_i, ζ_i and λ_i are the coefficients of ith generator emission characteristics

Total real power loss's minimization: The objective of the reactive power dispatch is to minimize the real power loss in the transmission network. Also it can be determined by means of a power flow solution exactly and can be presented as:

$$P_L(P_G)=\sum_{K=1}^{N_L} g_k[V_i^2+V_j^2-2V_iV_j\cos(\theta_i-\theta_j)] \quad (4)$$

where K is the network branches that connects bus i to j (i=1,2,…,N_D j=1,2,…,N_j), N_D is the set of numbers of power demand bus, N_j is the set of numbers of buses adjacent to bus j, N_L is the set of numbers of network branches (transmission lines), V_i and V_j are the voltage magnitudes at bus i and j, g_k is the transfer conductance between bus i and j, θ_i and θ_j are the voltage angles at bus i and j, respectively.

C. Problem Constrains

Generation constraints: The upper and lower constrains of generator outputs and bus voltage magnitudes are presented as:

$$\begin{aligned}&P_{Gi}^{\min}\le P_{Gi}\le P_{Gi}^{\max}, i=1,\dots,N\\&Q_{Gi}^{\min}\le Q_{Gi}\le Q_{Gi}^{\max}, i=1,\dots,N\\&V_{Gi}^{\min}\le V_{Gi}\le V_{Gi}^{\max}, i=1,\dots,N\end{aligned} \quad (5)$$

where $P_{Gi}^{\min}$, $P_{Gi}^{\max}$ are the minimum and maximum real power output of the ith generator, $Q_{Gi}^{\min}$, $Q_{Gi}^{\max}$ are the minimum and maximum active power output of the ith generator, $V_{Gi}^{\min}$, $V_{Gi}^{\max}$ are the minimum and maximum voltage magnitude of the ith transmission line, respectively.

Also the power balance constraint is expressed as:

$$\sum_{i=1}^{N}P_{Gi}-P_D-P_L=0 \quad (6)$$

The line loading constrain is explain as:

$$S_{li}\le S_{li}^{\max}, i=1,\dots,N_L \quad (7)$$

where, $S_{li}^{\max}$ is maximum power flow through the ith transmission line.

D. Problem Formulation

According to the above equations, the mathematical formulation of multi-objective optimization problem is presented as:

$$\min_{PG}[F(P_G),E(P_G),P_L(P_G)] \quad (8)$$

subject to: $g(P_G)$=0 and $h(P_G)\le 0$

where g and h are the equality and inequality constraints, respectively.

III. MULTIOBJECTIVE IMPERIALIST COMPETITIVE ALGORITHM

A. Imperialist Competitive Algorithm

Imperialism is the policy of extending the power and rule of a government beyond its own boundaries. A country may attempt to dominate others by direct rule or by less obvious means such as a control of markets for goods or raw materials. The latter is often called neo-colonialism [18]. ICA is a novel global search heuristic that uses imperialism and imperialistic competition process as a source of inspiration. This algorithm starts with some initial countries. Some of the best countries are selected to be the imperialist states and all the other countries form the colonies of these imperialists. The colonies are divided among the mentioned imperialists based on their power. After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their relevant imperialist state. This movement is a simple model of assimilation policy that was pursued by some imperialist states [19]. Figure 1 shows the initial empires. Accordingly, bigger empires have greater number of colonies where weaker ones have less. In this figure, Imperialist 1 has formed the most powerful empire and consequently has the greatest number of colonies.

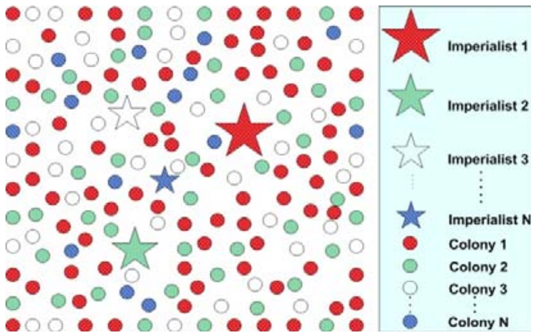

Figure 1. Generation of initial empires

B. Movement of Colonies toward the Imperialist

It is clear that, imperialist countries start to improve their colonies. We have modeled this fact by moving all the colonies toward the imperialist. Figure 2 shows a colony moving toward the imperialist by units. The direction of the movement is shown by the arrow extending from a colony to an imperialist [20]. In this figure x is a random variable with uniform (or any proper) distribution. Then for x we have:

$$x \approx U(0, \beta \times d) \tag{9}$$

where d is the distance between the colony and the imperialist state. The condition β >1 causes the colonies to get closer to the imperialist state from both sides.

After dividing all colonies among imperialists and creating the initial empires, these colonies start moving toward their relevant imperialist state which is based on assimilation policy [21]. Figure 3 shows the movement of a colony towards the imperialist. In this movement, θ and x are random numbers with uniform distribution as illustrated in Equation (2) and d is the distance between colony and the imperialist.

$$x \approx U(0, \beta \times d), \theta \approx U(-\gamma, \gamma) \tag{10}$$

where β and γ are parameters that modify the area that colonies randomly search around the imperialist.

The total power of an empire depends on both the power of the imperialist country and the power of its colonies. In this algorithm, this fact is modeled by defining the total power of an empire by the power of imperialist state plus a percentage of the mean power of its colonies. Any empire that is not able to succeed in imperialist competition and cannot increase its power (or at least prevent decreasing its power) will be eliminated.

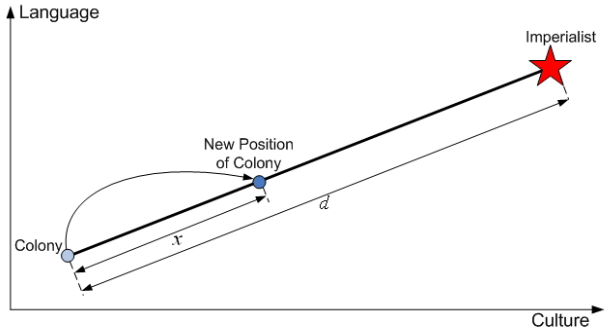

Figure 2. Movement of colonies toward their relevant imperialist

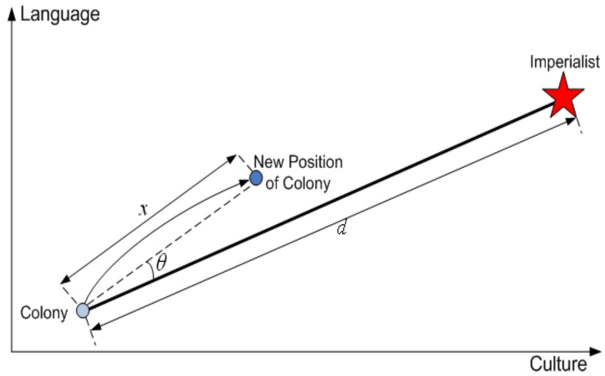

Figure 3. Movement of colonies toward their relevant imperialist in a randomly deviated direction

The imperialistic competition will gradually result in an increase in the power of great empires and a decrease in the power of weaker ones. Weak empires will lose their power gradually and ultimately they will collapse [22]. The movement of colonies toward their relevant imperialists along with competition among empires and also collapse mechanism will hopefully cause all the countries to converge to a state in which there exist just one empire in the world and all the other countries are its colonies. In this ideal new world colonies have the same position and power as the imperialist. Figure 4 shows a big picture of the modeled imperialistic competition. Based on their total power, in this competition, each of the empires will have a likelihood of taking possession of the mentioned colonies.

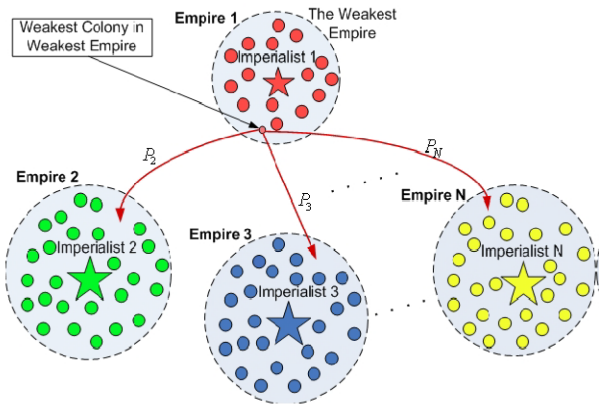

Figure 4. Imperialistic competition: The more powerful an empire is the more likely it will possess the weakest colony of weakest empire

IV. APPLICATION OF ICA TO EED PROBLEM

A. IEEE 30-Bus Test System

In this paper the IEEE 6-generator 30-bus test system and IEEE 14-generator 118-bus test system are considered as case studies for solving the EED problem using the proposed ICA technique. The values of the fuel and emission coefficients of the IEEE 30-bus system are given in Table 1. The line data and bus data of the system are presented in [23]. Furthermore, the load of the IEEE 30-bus system was set to 2.834 pu on a 100MVA base. The values of the fuel and emission coefficients of the IEEE 118-bus system is given in Table 2 [24-25], and the load of this system was set to 950MW.

To demonstrate the effectiveness of the proposed ICA, the multi-objective EED problem with two objective functions of fuel cost is considered in case one. Case two is the emission objective function. Case 3 is the fuel cost and emission together. Also three objective functions of fuel cost, emission and system loss are considered which is called case four.

The fuel cost, emission and system loss objectives are optimized individually to explore the extreme points of the tradeoff surface in all cases. Therefore, the basic DE for this case has been implemented as the problem becomes a single-objective optimization problem. The min and max objective values of case studies when optimized individually for all cases are presented in Tables 3 and 4, respectively.

Table 3. The minimum and maximum objective values of IEEE 30-bus system

Objective	Fuel cost ($)	Emission (ton)	System loss (MW)
Max	646.335	0.22635	3.6061
Min	606.03	0.19418	1.7176

Table 4. The minimum and maximum objective values of IEEE 118-bus system

Objective	Fuel cost ($)	Emission (ton)	System loss (MW)
Max	4571.350	152.613	10.059
Min	4420.801	25.248	8.531

The efficiency of the proposed ICA technique for solving the EED problem is compared with the MODE [14], NSGA [23], NPGA [26], SPEA [27] and MOPSO [28]. The numerical results of best cost and best emission solutions achieved by ICA are compared with other techniques which are given in Tables 5 and 6. It is obvious that, the proposed ICA obtains the best cost and best emission compared to other techniques. Also the trend of objective function variation of cost function and variation of emission function are presented in Figures 5-6 respectively.

Table 1. Generator and emission coefficients of the IEEE 30-bus system

$P_{G\min}$ (MW)	$P_{G\max}$ (MW)	λ	ζ	γ	β	α	c	b	a	No
5	150	2.857	2.0e−4	6.490	−5.543	4.091	100	200	10	P_{G1}
5	150	3.333	5.0e−4	5.638	−6.047	2.543	120	150	10	P_{G2}
5	150	8.000	1.0e−6	4.586	−5.094	4.258	40	180	20	P_{G3}
5	150	2.000	2.0e−3	3.380	−3.550	5.326	60	100	10	P_{G4}
5	150	8.000	1.0e−6	4.586	−5.094	4.258	40	180	20	P_{G5}
5	150	6.667	1.0e−5	5.151	−5.555	6.131	100	150	10	P_{G6}

Table 2. Generator and emission coefficients of the IEEE 118-bus system

$P_{G\min}$ (MW)	$P_{G\max}$ (MW)	γ	β	α	c	b	a	No
50	300	23.333	−1.500	0.016	0.50	189	150	P_{G1}
50	300	21.022	−1.820	0.031	0.55	200	115	P_{G2}
50	300	22.050	−1.249	0.013	0.60	350	40	P_{G3}
50	300	22.983	−1.355	0.012	0.50	315	122	P_{G4}
50	300	21.313	−1.900	0.020	0.50	305	125	P_{G5}
50	300	21.900	0.805	0.007	0.70	275	70	P_{G6}
50	300	23.001	−1.401	0.015	0.70	345	70	P_{G7}
50	300	24.003	−1.800	0.018	0.70	345	70	P_{G8}
50	300	25.121	−2.000	0.019	0.50	245	130	P_{G9}
50	300	22.990	−1.360	0.012	0.50	245	130	P_{G10}
50	300	27.010	−2.100	0.033	0.55	235	135	P_{G11}
50	300	25.101	−1.800	0.018	0.45	130	200	P_{G12}
50	300	24.313	−1.810	0.018	0.70	345	70	P_{G13}
50	300	27.119	−1.921	0.030	0.60	389	45	P_{G14}

Table 5. IEEE 30-bus system best solutions out of ten runs for cost of MOICA, Case 1

SPEA	NPGA	NSGA	MOPSO	MODE	MOICA	No. Gen
0.1279	0.1425	0.1447	0.1207	0.1332	0.2754	P_{G1}
0.3163	0.2693	0.3066	0.3131	0.2727	0.3338	P_{G2}
0.5803	0.5908	0.5493	0.5907	0.6018	0.5369	P_{G3}
0.9580	0.9944	0.9894	0.9769	0.9747	0.8030	P_{G4}
0.5258	0.5315	0.5244	0.5155	0.5146	0.5741	P_{G5}
0.3589	0.3392	0.3542	0.3504	0.3617	0.3109	P_{G6}
607.86	608.06	607.98	607.790	606.126	**606.0817**	Cost ($/h)
0.2176	0.2207	0.2191	0.2193	0.2195	**0.1946**	Emission (ton/h)
0.0332	0.0337	0.0346	0.0333	0.0247	**7.4985 e-005**	Mismatch power

Table 6. IEEE 30-bus system best solutions out of ten runs for emission of MOICA, Case 2

SPEA	NPGA	NSGA	MOPSO	MODE	MOICA	No. Gen
0.4145	0.4064	0.3929	0.4101	0.39266	0.4000	P_{G1}
0.4450	0.4876	0.3937	0.4594	0.46256	0.3770	P_{G2}
0.5799	0.5251	0.5815	0.5511	0.56311	0.5574	P_{G3}
0.3847	0.4085	0.4316	0.3919	0.40309	0.6271	P_{G4}
0.5348	0.5386	0.5445	0.5413	0.5676	0.5469	P_{G5}
0.5051	0.4992	0.5192	0.5111	0.47826	0.3445	P_{G6}
644.77	644.23	638.98	644.740	642.849	**622.612**	Cost ($/h)
0.1943	0.1943	0.1947	0.1942	0.1942	**0.1892**	Emission (ton/h)
0.0300	0.0314	0.0294	0.0309	0.0333	**0.0189**	Mismatch power

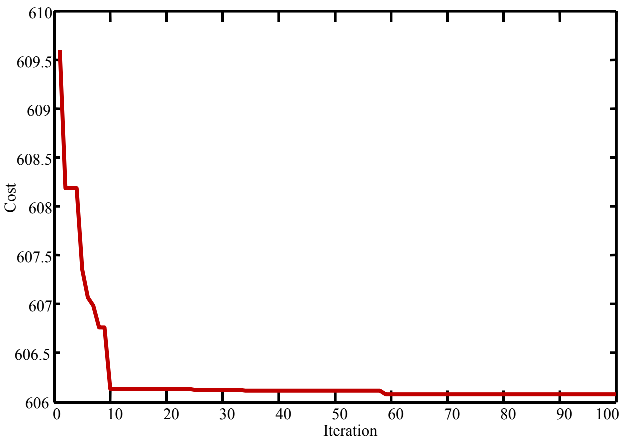

Figure 5. Objective function variation of cost function

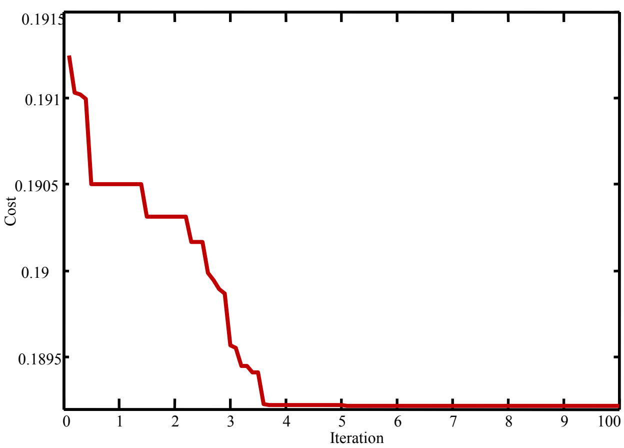

Figure 6. Objective function variation of emission function

Consequently, the best compromise solution of the proposed MOIABC in case 3 is presented in Table 7. Also a typical Pareto front of case 3 and 4 obtained by MOIABC is shown in Figure 7 and 8, respectively [29]. For case 4, the solutions of MODE, MOPSO and MOICA are presented in Table 8. The Pareto front of this case is presented in Figure 8.

Table 7. IEEE 30-bus system best compromise solutions of MOICA, Case3

SPEA	NPGA	NSGA	MOPSO	MODE	MOICA	No. Gen
0.2752	0.2976	0.2935	0.2367	0.23555	0.2033	P_{G1}
0.3752	0.3956	0.3645	0.3616	0.34896	0.3981	P_{G2}
0.5796	0.5673	0.5833	0.5887	0.57001	0.5200	P_{G3}
0.6770	0.6928	0.6763	0.7041	0.72519	0.8192	P_{G4}
0.5283	0.5201	0.5383	0.5635	0.55357	0.4741	P_{G5}
0.4282	0.3904	0.4076	0.4087	0.42609	0.4210	P_{G6}
617.57	617.79	617.80	615.00	613.27	**605.3085**	Cost ($/h)
0.2001	0.2004	0.2002	0.2021	0.2026	**0.1938**	Emission (ton/h)
0.0295	0.0298	0.0295	0.0293	0.0254	**0.0016**	Mismatch power

Table 8. IEEE 30-bus system best compromise solutions of MODE, MOPSO and MOICA, Case 4

MOPSO	MODE	MOICA	No. Gen
0.39768	0.21207	0.2315	P_{G1}
0.41814	0.30659	0.3782	P_{G2}
0.64404	0.68878	0.6530	P_{G3}
0.75147	0.67937	0.6407	P_{G4}
0.44620	0.58218	0.5391	P_{G5}
0.48973	0.38691	0.3952	P_{G6}
614.913	614.170	**612.3993**	Cost ($/h)
0.2081	0.2043	**0.2010**	Emission (ton/h)
2.8865	2.2009	**2.0810**	System loss (MW)
0.3133	0.0219	0.2315	Mismatch power

B. IEEE 118-Bus Test System

In this case study, a standard IEEE 14-generator 118-bus test system [24-25] is considered. Since the network branches data is not available in the existing literature, transmission loss for this system is calculated using the Kron’s loss formula [25]. In this case study, two cases is considered as a test functions. For case 1, the bi-objective optimization problem with cost and emission objectives is considered. And for case 2, the transmission losses PL is regard as the third objective. In this regard, the best compromise solution of cases 1 and 2 are presented in Tables 9 and 10, respectively. The results of the proposed algorithm is compared with PSO based weighted aggregation (WA) approach and a Multi-objective Evolutionary Algorithm (MOEA), fuzzified multi-objective particle swarm algorithm (FMPSO) and MODE [14]. It is clear that the proposed MOIABC algorithm is superior to other compared techniques.

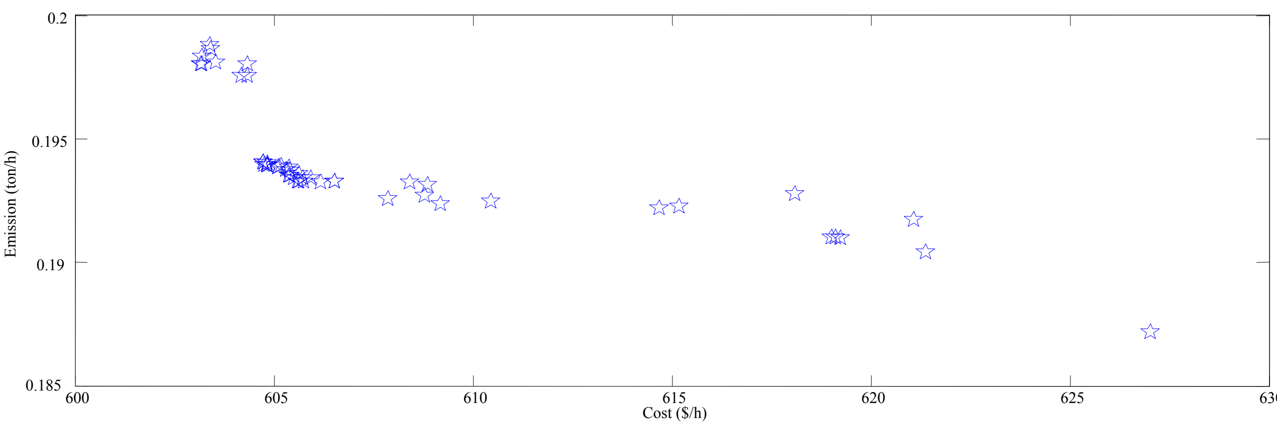

Figure 7. IEEE 30-bus system Pareto front using MOICA in Case 3

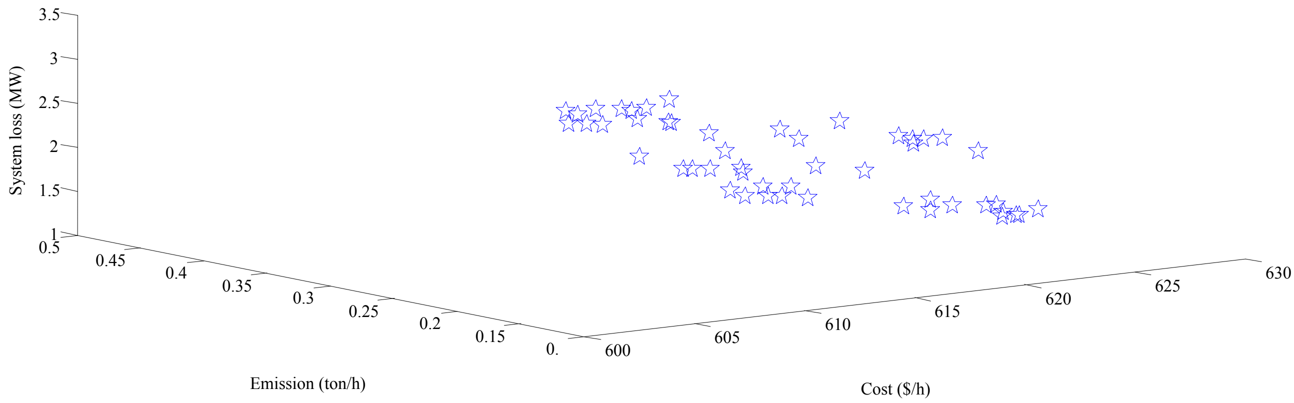

Figure 8. IEEE 30-bus system Pareto front using MOICA in Case 4

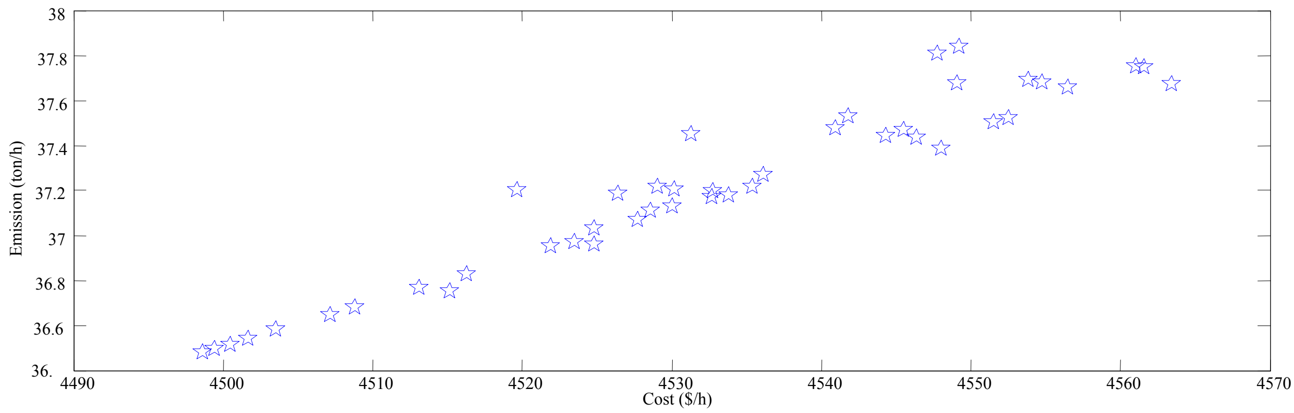

Figure 9. IEEE 118-bus system Pareto front using MOICA in Case 1

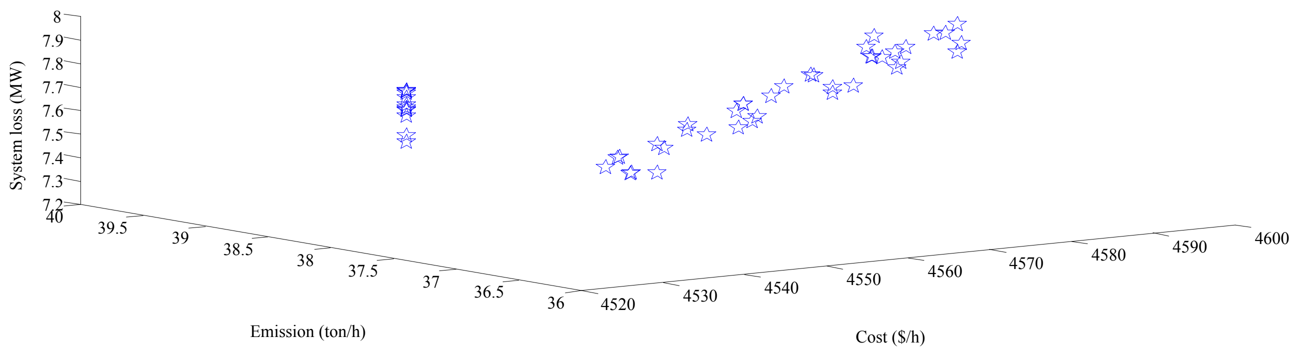

Figure 10. IEEE 118-bus system Pareto front using MOICA in Case 2

Table 9. IEEE 118-bus system best compromise solutions from different algorithms, Case 1

WA	MOEA	FMPSO	MODE	MOICA	No. Gen
91.156	81.6684	94.5703	82.1555	87.1377	P_{G1}
109.58	108.597	105.728	50.4606	74.0418	P_{G2}
51.428	50.3574	50.992	68.8527	67.4055	P_{G3}
50.194	50.0378	50.0	83.5687	84.0244	P_{G4}
68.360	88.2061	75.7894	68.1255	59.2016	P_{G5}
90.686	89.5116	84.6362	50.0254	78.1571	P_{G6}
53.593	50.0	53.3723	65.3001	67.7338	P_{G7}
56.463	51.6133	54.8911	66.7923	51.0865	P_{G8}
77.079	82.3149	83.6218	75.7799	82.1726	P_{G9}
51.234	54.5174	52.5273	95.4330	53.9062	P_{G10}
87.312	84.3849	79.5150	50.4028	73.8256	P_{G11}
110.15	112.184	106.104	87.1779	54.3821	P_{G12}
55.150	51.427	58.1926	65.6425	57.0208	P_{G13}
50.722	50.408	50.1546	50.1148	60.0506	P_{G14}
4558.0	4565.1	4548.6	4508.5	**4498.7**	Cost ($/h)
39.249	39.7978	38.0501	37.3536	**36.5543**	Emission (ton/h)
53.124	55.2278	50.0946	9.8317	**0.1462**	Mismatch power

Table 10. IEEE 118-bus system best compromise solutions of MODE and MOICA, Case 2

MODE	MOICA	No. Gen
70.9094	50.8175	P_{G1}
51.1464	84.1043	P_{G2}
69.1604	51.9069	P_{G3}
77.3742	73.9239	P_{G4}
68.9120	80.9592	P_{G5}
50.5830	76.7525	P_{G6}
72.0363	78.9325	P_{G7}
69.6698	61.5719	P_{G8}
73.4252	59.0870	P_{G9}
101.0704	89.3426	P_{G10}
53.8714	54.4148	P_{G11}
86.9146	65.6772	P_{G12}
64.1231,	71.8764	P_{G13}
50.1213	51.3775	P_{G14}
4524.9	**4523.9**	Cost ($/h)
37.629	**36.234**	Emission (ton/h)
9.3301	**7.7431**	System loss (MW)
9.3984	**0.7443**	Mismatch power

According to the numerical results, it should be noted that in all cases the results of the proposed technique are better. Moreover, the close agreement of the results shows clearly the capability of the proposed approach to handle multi-objective optimization problems as the best solution of EED problem for each objective in case studies.

V. CONCLUSIONS

In this paper, the EED optimization problem formulated as multi-objective optimization problem with competing objectives of fuel cost, emission and system loss. This difficult optimization problem is solved by using the MOICA algorithm. ICA is a global search strategy that uses the socio-political competition among empires as a source of inspiration. Similar other evolutionary ones that start with initial population, this technique begin by initial empires. During the competition, weak empires collapse and powerful ones take possession of their colonies which improve the algorithm. The achieved numerical results of the proposed technique demonstrate the feasibility of the proposed technique to solve the multi-objective EED problem. The IEEE 30-bus and 118-bus test systems were used to investigate the effectiveness of the proposed technique. The ICA is compared with other MOEAs, such as NPGA, NSGA, SPEA, MOPSO and MODE. It is obvious that, the proposed technique achieve appropriate results is power systems.

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