International Journal on
"Technical and Physical Problems of Engineering"
(IJTPE)
Published by International Organization of IOTPE

ISSN 2077-3528
IJTPE Journal
www.iotpe.com
ijtpe@iotpe.com

June 2013 Issue 15 Volume 5 Number 2 Pages 81-89

A NEW MULTIOBJECTIVE META HEURISTIC ALGORITHM BASED ON ENVIRONMENTAL/ECONOMIC LOAD DISPATCH WITH WIND EFFECT

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Abstract- Actually the environmental concerns arise from the emissions produced by fossil fueled electric power plants, the classical economic dispatch, which operates electric power systems to minimize the total fuel cost which can no longer be considered alone. Thus, by environmental dispatch, emissions can be reduced through dispatch of power generation. The proposed Environmental Economic Load Dispatch (EED) is formulated mathematically as a nonlinear constrained multiobjective problem with competing and non-commensurable objectives of fuel cost, emission and system loss. So, a multi-objective meta-heuristic of Improved Harmony Search Algorithm (IHSA) is applied in this paper to solve the EED problem through the advantages of fuzzy mechanism. In addition, renewable sources and wind energy in particular have recently been getting more interest because of various environmental and economic considerations. Accordingly, wind power is included in the problem formulation to find the effects in power system. The proposed technique has been applied over the IEEE 30 and 118-bus test power system. The achieved results demonstrate the validity of proposed technique.

Keywords: Meta-Heristic Algorithm, Environmental Economic Load Dispatch (EED), Wind Effect, Improved Harmony Search Algorithm (IHSA), Fuzzy Mechanism.

I. INTRODUCTION

The Economic Load Dispatch (ELD) optimization as a major economic power system operation problem has been a subject of extensive research studies for decades. The aim of ELD problem is to minimize the fuel cost function of the generation units by optimally allocating the total load between these units. The cost function to be minimized is subject to several constraints that include load balance, upper and lower limits of the generating units and ramp rates [1]. In classic optimization techniques, the ELD problem is approximated by a smooth differentiable quadratic or piecewise quadratic objective function. However, owing to the valve-point effects, the real input-output characteristics contain higher order non-linearity and discontinuity which results in a non-convex, non-smooth fuel cost function [2].

The Environmental/Economic Load Dispatch EED problem is a multi-objective problem with inconsistent objectives because pollution is inconsistent with minimum cost of generation. A short report of EED techniques dating back to 1970 by using conventional optimization methods has been presented 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.

In [5], the EED problem was converted to a single objective problem by linear combination of different objectives as a weighted sum. The advantage of this weighted sum method is that a set of Pareto-optimal solutions can be obtained by varying the weights. However, this requires multiple runs as many times as the number of desired Pareto-optimal solutions. Also, this method cannot be used to find Pareto-optimal solutions in problems having a non-convex Pareto-optimal front. To tackle of this difficulty, the constraint method for multiobjective optimization was presented in [6].

The EED problem is formulated mathematically as a nonlinear constrained multiobjective problem with competing and non-commensurable objectives of fuel cost, emission and system loss [7]. Consequently, single objective and conventional optimization methods that make use of derivatives and gradients, in general, are not able to locate or identify the global optimum. Furthermore, there are many mathematical assumptions such as analytic and differential objective functions that have to be given to simplify the problem [8].

Several reports have been proposed to solve the EED problem in literature as: multi-objective Genetic Algorithm (GA) in [9-11], hierarchical system approach [12], fuzzified multi-objective particle swarm optimization algorithm [13], fuzzy linear programming [14-15], fast Newton-Raphson algorithm [16], linear programming [17].

As a promising renewable energy source, the wind power has been attracted great attention, as various environmental and economic concerns [18]. Integrating wind energy into power system networks introduces many challenges to operation and planning strategies.

The fact that wind power is neither easily predictable nor dispatchable is the main reason behind security and reliability concerns associated with wind-integrated power systems. Wind energy has recently been an ongoing research subject [19-20].

Furthermore, the wind power effects to EED problem is considered as a constrain formulation in this paper. Also, Improved Harmony Search Algorithm (IHSA) which is a new met heuristic algorithm proposed by Geem et al. [21], is derived from the natural phenomena of musicians. There is an analogy between music and optimization: each musical instrument corresponds to each decision variable; musical note corresponds to variable value; and harmony corresponds to solution vector. Just like musicians in Jazz improvisation play notes randomly or based on experiences in order to find fantastic harmony, variables in the harmony search algorithm have random values or previously-memorized good values in order to find optimal solution [22]. Harmony search algorithm has a good ability to deal with discrete and non-convex mathematic problem. It has been successfully applied to various optimization problems in computation and engineering fields including ELD [23].

According to the advantages of HSA, this technique is composed with the capability of fuzzy mechanism to obtain the best solution of EED problem in this paper. In this research, the proposed algorithm runs on the IEEE 30- and 118-bus test systems and the results are compared with techniques which are presented in [7]. The achieved numerical results of the proposed technique demonstrate the feasibility of the proposed technique to solve the multi-objective EED problem through the wind effects.

II. PROBLEM FORMULATION

It is clear that, in solution to an environmental economic dispatch problem gives active power generations for all generation units that minimize the total cost rate, which is the summation of the total thermal cost rate and the total emission cost rate. According to this fact that, the power system stability and power quality are influenced by power system reactive power optimization, it should be noted that the ELD, considering system loss can reasonably improve real and reactive power dispatch simultaneously [24]. Hence, 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. Also the total fuel cost $F(P_G)$ (\$/h) is presented as:

$$F(P_G)=\sum_{i=1}^{N} a_i+b_i P_{Gi}+c_i P_{Gi}^2 \tag{1}$$

where, N is the number of generators, a_i, b_i, c_i are the cost coefficients of the ith generator, P_{Gi} is the real power output of the ith generator, $P_G=[P_{G1},P_{G2},...,P_{GN}]^T$ and P_G is the vector of real power output generator.

B. Emission Minimization

The emission function can be described as the sum of all types of emission considered, such as SO_2, NO_x, and thermal emission, with suitable pricing or weighting on each pollutant emitted. In this study, only one type of emission (NO_x) is taken into account without loss of generality [3]. The amount of NO_x emission is defined as a function of generator output, that is, the sum of a quadratic and exponential function:

The conventional ELD 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 [7]. The NO_x emission amount which is, the sum of a quadratic and exponential function is given as:

$$E(P_G)=\sum_{i=1}^{N} 10^{-2}(\alpha_i+\beta_i P_{Gi}+\gamma_i P_{Gi}^2)+\xi_i \exp(\gamma_i P_{Gi}) \tag{2}$$

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 is based on the objective of the reactive power dispatch to minimize the real power loss in the transmission network. It can be determined by means of a power flow solution exactly and can be presented as:

$$P_L(P_G)=\sum_{k=1}^{N_L} g_k[V_i^2+V_j^2-2V_iV_j\cos(\theta_i-\theta_j)] \tag{3}$$

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, V_j are the voltage magnitudes at bus i and j, g_k is the transfer conductance between bus i and j and θ_i, 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:

$$\begin{aligned} &P_{Gi}^{\min}\le P_{Gi}\le P_{Gi}^{\max} \quad , \quad i=1,...,N\\ &Q_{Gi}^{\min}\le Q_{Gi}\le Q_{Gi}^{\max} \quad , \quad i=1,...,N\\ &V_{Gi}^{\min}\le V_{Gi}\le V_{Gi}^{\max} \quad , \quad i=1,...,N \end{aligned} \tag{4}$$

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

Also the power balance constraint is expressed as:

$$\sum_{i=1}^{N} P_{Gi}-P_D-P_L=0 \tag{5}$$

The line loading constrain is explain as:

$$S_{li} \le S_{li}^{\max} \quad , \quad i = 1,...,N_L \tag{6}$$

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 multiobjective optimization problem is presented as:

$$\min_{PG}[F(P_G), E(P_G), P_L(P_G)] \tag{7}$$

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

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

E. Wind Power Penetration

Load balance including wind power: by modification of Equation (5) the power generated by wind sources P_w is deducted from the total power demand as:

$$\sum_{i=1}^{N_g} P_{g_i} - (P_D - P_W) - P_L = 0 \tag{8}$$

Wind power availability: The wind power, P_w, in Equation (8) is limited by the available amount from the wind park P_{av}.

$$P_L + P_D - \sum_{i=1}^{N_g} P_{gi} \le P_{av} \tag{9}$$

III. MULTIOBJECTIVE HARMONY SEARCH ALGORITHM (MOHSA)

A. Brief Review of Harmony Search Algorithm (HSA)

The flowchart of HSA is presented in [25]. And the brief procedure steps of harmony search for solving optimization problems are described in five steps as:

- Step 1: Identify objective function and Equality and Inequality constraints by using the following relation:

$$\begin{array}{l} \text{minmize } \{f(x), x \in X\} \\ \text{subject to: } g(x) \ge 0 \text{ , } h(x) = 0 \end{array} \tag{10}$$

where, $f(x)$ is the objective function, X_i is the feasible set, x_i is the random choosing parameter, $G(x)$ is the inequality constraint and $h(x)$ is the equality constraint.

- Step 2: Initialize harmony memory (HM). In this step chooses the initial value of x_i from X_i parameters and fill them in HM matrix randomly.

$$HM = \begin{bmatrix} x_1^1 & x_2^1 & \cdots & x_{N-1}^1 & x_N^1 \\ x_1^1 & x_2^2 & \cdots & x_{N-1}^2 & x_N^2 \\ \vdots & \vdots & \vdots & \vdots & \vdots \\ x_1^{HMS-1} & x_2^{HMS-1} & \cdots & x_{N-1}^{HMS-1} & x_N^{HMS-1} \\ x_1^{HMS} & x_2^{HMS} & \cdots & x_{N-1}^{HMS} & x_N^{HMS} \end{bmatrix} \frac{\Delta y}{\Delta x} \tag{11}$$

- Step 3: Improvise New Harmony Improvise new x_i from harmony memory considers rated ($HMCR$) and pith adjust rated (PAR).

Step 3.1: Harmony consider rated ($HMCR$)

$$x_i' \leftarrow \begin{Bmatrix} x_i' \in \left\{x_i^1, x_i^2, ..., x_i^{HMS}\right\} (HMCR) \\ x_i' \in X_i (1 - HMCR) \end{Bmatrix} \tag{12}$$

where, x_i' is new value of x_i which $HMCR$ is probability of choosing x_i' w.p. means with probability.

Step 3.2**:** Pitch Adjust Rate (PAR)

$$x_i' \leftarrow \begin{Bmatrix} \text{Yes}, \Pr(PAR) \\ \text{No}, \Pr(1 - PAR) \end{Bmatrix} \tag{13}$$

where PAR is probability to shift x_i

$$x_i' \leftarrow x_i' \pm \text{rand}() \times b_w \tag{14}$$

where, b_w is range of X_i rand is random number during 0-1. In this step, random choose the value of x_i'. If the value of x_i' is in the range of X_i which it has probability $HMCR$. If out of condition probability of x_i' is $1-HMCR$ and then will check PAR, if PAR of x_i' is carry on the condition Equation (10), shift x_i' by the equation.

- Step 4: Update HM and check the stopping criterion Find value of $f(x_i')$ from substitute x_i' in Equation (9) if value of $f(x_i')$ is better than the worst value of $f(x)$ in HM, substitute x_i' instead the worst x_i in HM.

- Step 5: To check the stopping criterion, set the NI (Number of Iteration) before begins to run the simulation; HS can stop calculation instantaneously when NI is reached. The aim of this paper is to apply multiobjective harmony search for AGC problem. Results show that harmony search can solve this problem intelligently and find a near optimal solution.

B. Improved HSA

Because of slow convergence especially over multimodal fitness landscape in classic HSA and this fact that the performance of the classical HSA deteriorates with the growth of search space dimensionality. The improved HSA is presented in this paper through replacing the pitch adjustment operation in classical HSA with a mutation strategy borrowed from the realm of the DE algorithms. The replacing demonstrate that the HSA is improved very good to solve the optimization problems [26]. Following the perturbation process of DE/rand/1/bin, we mutate the target vector with the difference of two randomly selected population members. The process has been presented as:

$$\vec{x}_i' = \vec{x}_i' + F(\vec{x}_{r1} - \vec{x}_{r2}) \tag{15}$$

where F is a scalar number called the scale factor which is random number between 0 and 1. A flowchart of the algorithm has been provided in Figure 1.

C. Multiobjective HSA

A Multiobjective optimization problem always has a set of optimal solutions, for which there is no way to improve one objective value without deterioration of at least one of the other objective values. Pareto dominance concept classifies solutions as dominated or non-dominated solutions and the "best solutions" are selected from the non-dominated solutions. To sort non-dominated solutions, the first front of the non-dominated solution is assigned the highest rank and the last one is assigned the lowest rank.

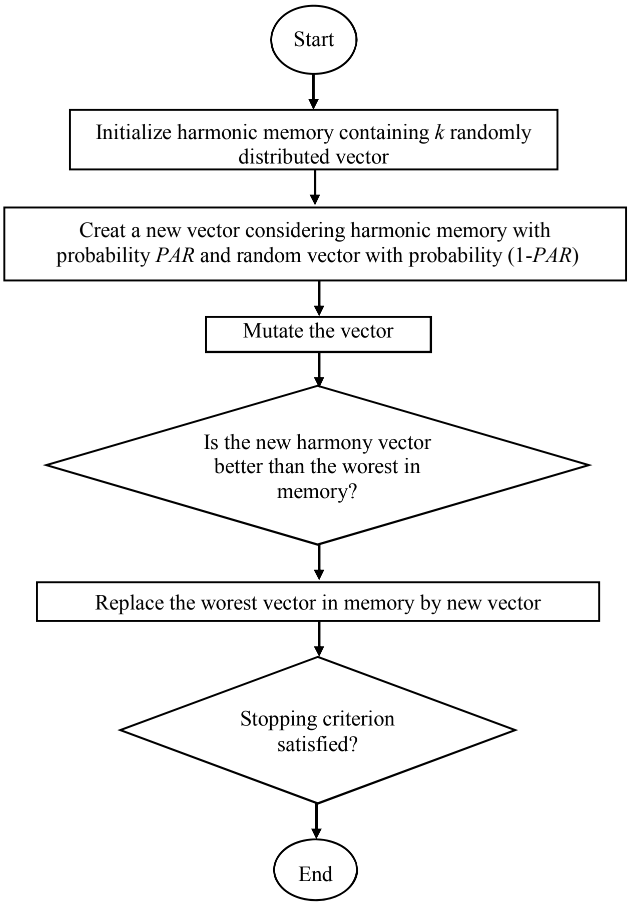

Figure 1. The proposed algorithm flowchart

When comparing solutions that belong to a same front, another parameter called crowding distance is calculated for each solution. The crowding distance is a measure of how close an individual is to its neighbors. Large average crowding distance will result in better diversity in the population. In order to investigate multi-objective problems, some modifications in the HSA algorithm were made. The main steps of the MOHSA algorithm are explained in more detail.

C. Fuzzy Mechanism

Upon having the Pareto-optimal set of non-dominated solution, the proposed approach presents one solution to the decision maker as the best compromise solutions. Due to imprecise nature of the decision maker's judgment, the *i*th objective function is represented by a membership function μi defined as [21]:

$$\mu_i(P_{gi}) = \frac{f_i^{\max} - f_i(P_{gi})}{f_i^{\max} - f_i^{\min}} \tag{16}$$

where $f_i^{\max}$ and $f_i^{\min}$ are the maximum and minimum values of *i*th objective, respectively.

$$FDM_i(P_{gi}) = \begin{cases} 0 & \mu_i(P_{gi}) \le 0 \\ \mu_i(P_{gi}) & 0 < \mu_i(P_{gi}) < 1 \\ 1 & \mu_i(P_{gi}) \ge 1 \end{cases} \tag{17}$$

For each non-dominated solution *k*, the normalized membership function FDM^k:

$$FDM^k = \left[\frac{\sum_{i=1}^{2} FDM_i^k(P_{gi})}{\sum_{j=1}^{M}\sum_{i=1}^{2} FDM_i^j} \right] \tag{18}$$

The best compromise solution of EED problem is the one having the maximum value of FDM^k as fuzzy decision making function, where *M* is the total number of non-dominated solutions. Then all the solutions are arranged in descending order according to their membership function values which will guide the decision makers with a priority list of non-dominated solutions in view of the current operating conditions. Figure 2 shows the membership structure μ_c for the fuzzy logical variable signifying total fuel cost $f_i(P_{gi})$.

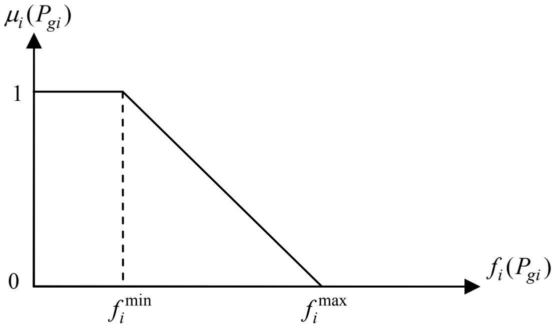

Figure 2. Membership function of fuzzy fuel cost

IV. NUMERICAL RESULTS

A. IEEE 30-Bus Test System

In this research the IEEE 6-generator 30-bus test system and IEEE 14-generator and 118-bus test system are considered as case studies for solving the EED problem using the proposed MOIHSA technique and fuzzy mechanism. 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 [7]. Also, 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 are given in Table 2, and the load of this system was set to 950 MW [7].

To demonstrate the effectiveness of the proposed hybrid strategy, 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 three 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.

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

Table 1. The values of the fuel and emission coefficients of the IEEE 118-bus system [7]

$P_{G,\min}$ (MW)	$P_{G,\max}$ (MW)	λ	ζ	γ	β	α	c	b	a	Gen.
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 [7]

$P_{G,\min}$ (MW)	$P_{G,\max}$ (MW)	γ	β	α	c	b	a	Gen.
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 3. The minimum and maximum objective values of IEEE 30-bus system [7]

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 [7]

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

Also, beside the EED results, the wind constrain are considered in this problem. So, the result of this considering is presented in tables too. The effectiveness of the proposed hybrid strategy is compared with the MODE [27], NSGA [28], NPGA [3], SPEA [29] and MOPSO [30]. The numerical results of best cost and best emission solutions achieved by MOIHS and fuzzy mechanism are compared with other techniques which are given in Tables 5 and 6. The obtained results demonstrate the superiority of this strategy. Also the results with wind effect proof that the total cost is reduce by considering this clean energy.

Table 3. IEEE 30-bus system best solutions out of ten runs for cost of IHSA, Case 1

SPEA	NPGA	NSGA	MOPSO	IHSA without Wind	IHSA with Wind	Gen.
0.1279	0.1425	0.1447	0.1207	0.1331	0.1638	P_{G1}
0.3163	0.2693	0.3066	0.3131	0.2722	0.2691	P_{G2}
0.5803	0.5908	0.5493	0.5907	0.6015	0.5865	P_{G3}
0.9580	0.9944	0.9894	0.9769	0.9747	0.8997	P_{G4}
0.5258	0.5315	0.5244	0.5155	0.5149	0.5716	P_{G5}
0.3589	0.3392	0.3542	0.3504	0.3619	0.3437	P_{G6}
607.86	608.06	607.98	607.790	606.143	**601.7591**	Cost ($/h)
0.2176	0.2207	0.2191	0.2193	0.2195	**0.2006**	Emission (ton/h)

According to Table 3, it can be said that the proposed strategy is achieved 606.143 $/h as a minimum cost in comparison with other techniques in case one. Also, by applying the wind effect, it is clear that the cost is reduced again to 601.7591 $/h. The convergence trend of proposed algorithm over case one is presented in Figure 3.

For case two the proposed technique is achieved 642.878 $/h as a minimum cost in comparison with other techniques in case two which is presented in Table 4. Also, by applying the wind effect, it is clear that the cost is reduced again to 637.7050 $/h. Also, the convergence trend of proposed algorithm over case one is presented in Figure 4.

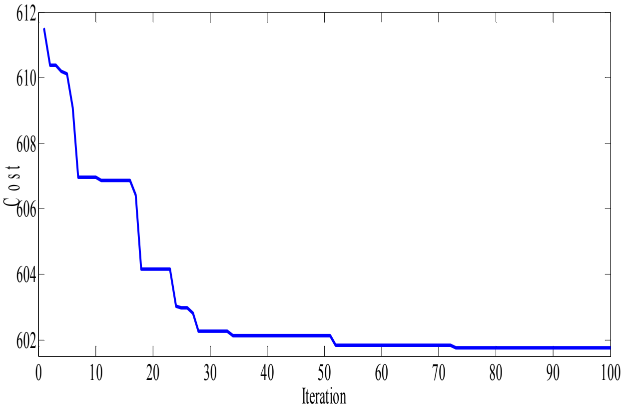

Figure 3. Objective function variation of cost function in Case 1

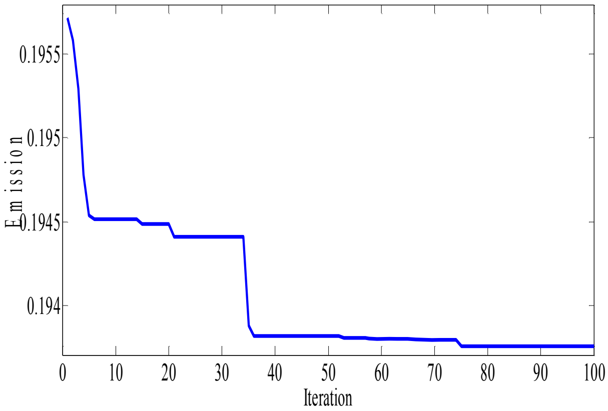

Figure 4. Objective function variation of emission function

For the third case, the proposed strategy achieved minimum cost in comparison other technique as 613.27 \$/h. Also, by considering the wind effect in this case the minimum cost is reached to 607.6244 \$/h. In this case, the Pareto front of algorithm is presented in Figure 5.

In the last case of IEEE 30 bus power system, the proposed strategy is compared with MOPSO [31]. The numerical result of this case is presented in Table 6, where, the minimum results is 614.170 \$/h without considering the wind effect and 608.4449 \$/h, by considering the wind effect. Same as the previous case the Pareto front of algorithm is presented in this step as Figure 6.

Table 4. IEEE 30-bus system best solutions out of ten runs for emission of ABC, Case 2

SPEA	NPGA	NSGA	MOPSO	IHSA without Wind	IHSA with Wind	Gen.
0.4145	0.4064	0.3929	0.4101	0.39278	0.3922	P_{G1}
0.4450	0.4876	0.3937	0.4594	0.46276	0.4962	P_{G2}
0.5799	0.5251	0.5815	0.5511	0.56351	0.5061	P_{G3}
0.3847	0.4085	0.4316	0.3919	0.40304	0.4582	P_{G4}
0.5348	0.5386	0.5445	0.5413	0.5653	0.5061	P_{G5}
0.5051	0.4992	0.5192	0.5111	0.47456	0.4953	P_{G6}
644.77	644.23	638.98	644.740	642.878	**637.7050**	Cost (\$/h)
0.1943	0.1943	0.1947	0.1942	0.1942	**0.19127**	Emission (ton/h)
0.0300	0.0314	0.0294	0.0309	0.0333	**0.0000**	Mismatch power

Table 5. IEEE 30-bus system best compromise solutions of ABC, Case 3

SPEA	NPGA	NSGA	MOPSO	IHSA without Wind	IHSA with Wind	Gen.
0.2752	0.2976	0.2935	0.2367	0.23556	0.2697	P_{G1}
0.3752	0.3956	0.3645	0.3616	0.34889	0.3892	P_{G2}
0.5796	0.5673	0.5833	0.5887	0.57076	0.5369	P_{G3}
0.6770	0.6928	0.6763	0.7041	0.72554	0.7709	P_{G4}
0.5283	0.5201	0.5383	0.5635	0.55379	0.4632	P_{G5}
0.4282	0.3904	0.4076	0.4087	0.42623	0.4041	P_{G6}
617.57	617.79	617.80	615.00	613.27	**607.6244**	Cost (\$/h)
0.2001	0.2004	0.2002	0.2021	0.2026	**0.2024**	Emission (ton/h)
0.0295	0.0298	0.0295	0.0293	0.0254	**4.4112e-005**	Mismatch power

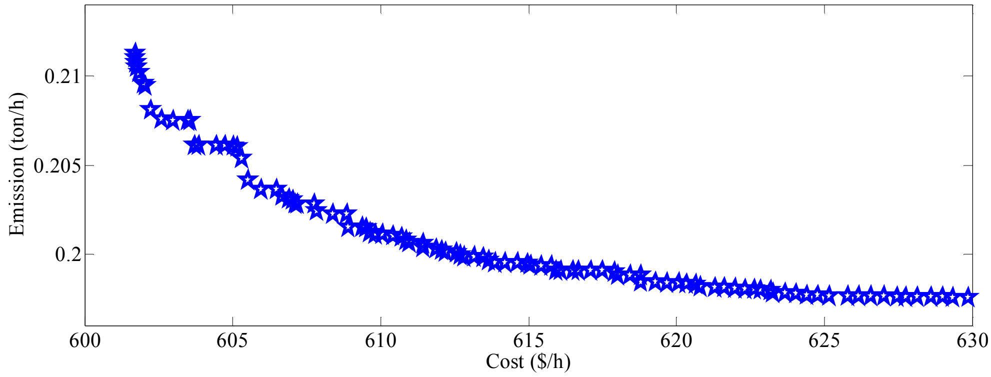

Figure 5. IEEE 30-bus system Pareto front using IHSA in Case 3

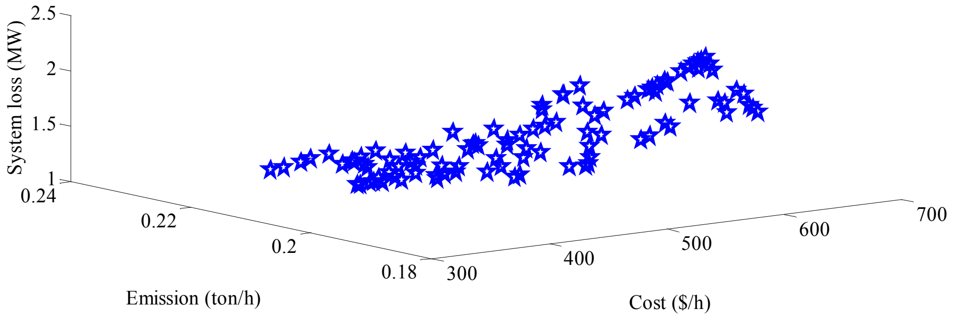

Figure 6. IEEE 30-bus system Pareto front using IHSA in Case 4

Table 6. IEEE 30-bus system best compromise solutions of MOPSO and IHSA, Case 4

MOPSO	IHSA without Wind	IHSA with Wind	Gen.
0.39768	0.21223	0.1800	P_{G1}
0.41814	0.30624	0.3075	P_{G2}
0.64404	0.68863	0.7262	P_{G3}
0.75147	0.67962	0.7047	P_{G4}
0.44620	0.58248	0.5764	P_{G5}
0.48973	0.38664	0.3401	P_{G6}
614.913	614.170	**608.4449**	Cost ($/h)
0.2081	0.2043	**0.2038**	Emission (ton/h)
2.8865	2.2009	**2.1886**	System loss (MW)
0.3133	0.0219	**8.4361e-004**	Mismatch power

B. IEEE 118-Bus Test System

For the second power system case study, a standard IEEE 14-generator, 118-bus test system [7] 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 [7]. 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 case 1 and 2 are presented in Table 9 and 10, respectively. The results of the proposed algorithm is compared with PSO based weighted aggregation (WA) approach and a Multiobjective Evolutionary Algorithm (MOEA), fuzzified multi-objective particle swarm algorithm (FMPSO) and MODE [7]. The obtained results verified the validity of proposed strategy.

For the first case, the proposed strategy achieved minimum cost in comparison other technique as 4508.5 $/h based on Table 7. Also, by considering the wind effect in this case the minimum cost is reached to 4491.62 $/h. In this case, the Pareto front of algorithm is presented in Figure 7. In the second case this technique achieved 4524 $/h without wind effect and 4509.181 $/h with wind effect based on Table 8. Also, the Pareto front of this case is presented in Figure 8.

Table 7. IEEE 118-bus system best compromise solutions from different algorithms, Case 1

WA	MOEA	FMPSO	IHSA without Wind	IHSA with Wind	Gen.
91.1562	81.6684	94.5703	82.1553	73.4419	P_{G1}
109.584	108.597	105.728	50.4605	64.9553	P_{G2}
51.4286	50.3574	50.992	68.8532	67.3207	P_{G3}
50.1945	50.0378	50.0	83.5675	57.6855	P_{G4}
68.3609	88.2061	75.7894	68.1288	57.5407	P_{G5}
90.6869	89.5116	84.6362	50.0295	50.7901	P_{G6}
53.5931	50.0	53.3723	65.3041	67.6242	P_{G7}
56.4637	51.6133	54.8911	66.7954	72.5777	P_{G8}
77.0796	82.3149	83.6218	75.7766	56.5547	P_{G9}
51.234	54.5174	52.5273	95.4343	94.5154	P_{G10}
87.3122	84.3849	79.5150	50.4067	72.0711	P_{G11}
110.159	112.184	106.104	87.1776	80.8908	P_{G12}
55.1502	51.427	58.1926	65.6473	83.8234	P_{G13}
50.722	50.408	50.1546	50.1154	50.9384	P_{G14}
4558.0	4565.1	4548.6	4508.5	**4491.62**	Cost ($/h)
39.2491	39.7978	38.0501	37.3536	**36.3274**	Emission (ton/h)
53.1249	55.2278	50.0946	9.8317	**0.7300**	Mismatch power

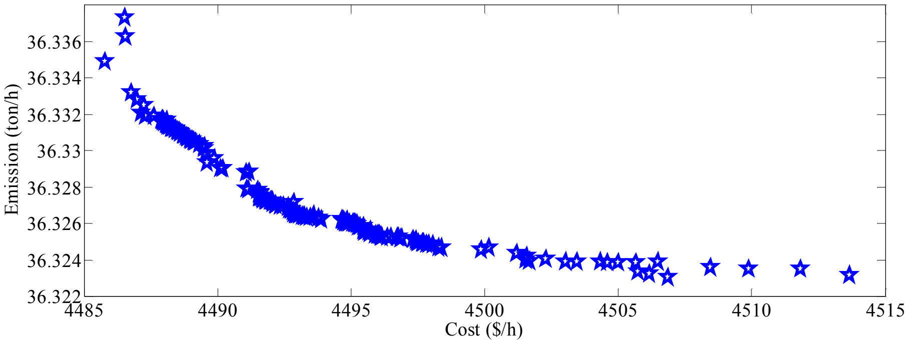

Figure 7. IEEE 118-bus system Pareto front using IHSA in Case 1

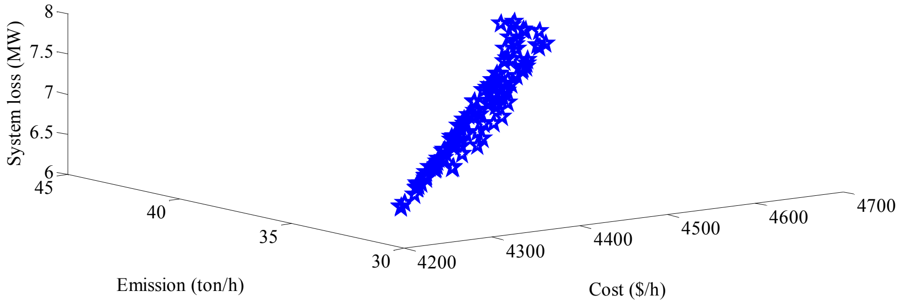

Figure 8. IEEE 118-bus system Pareto front using IHSA in Case 2

Table 8. IEEE 118-bus system best compromise solutions of MODE and ABC, Case 2

ABC without Wind	ABC with Wind	Gen.
70.9093	72.1580	P_{G1}
51.1465	75.5503	P_{G2}
69.1607	64.3251	P_{G3}
77.3749	50.8180	P_{G4}
68.9125	68.5596	P_{G5}
50.5837	80.5832	P_{G6}
72.0346	84.7973	P_{G7}
69.6676	53.2983	P_{G8}
73.4244	73.9362	P_{G9}
101.075	51.1889	P_{G10}
53.8765	63.1396	P_{G11}
ABC without Wind	ABC with Wind	
86.9133	75.7774	P_{G12}
64.1278	69.0346	P_{G13}
50.1243	66.8512	P_{G14}
4524.9	**4509.181**	Cost ($/h)
37.629	**33.20795**	Emission (ton/h)
9.3301	**6.80132**	System loss (MW)
9.3984	**0.0178**	Mismatch power

By achieving the numerical results it is clear that the proposed technique choose optimum answer than the previous one. Also, 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. Furthermore, by applying the wind effect in power system, this fact demonstrated that all of the cost results is reduced.

V. CONCLUSIONS

The environmental/economic load dispatch is a nonlinear, non-convex optimization problem which should solved by multi-objective strategy. Also, the environmental concerns arise from the emissions produced by 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.

So, this paper is applied the multi-objective harmony search algorithm to solve the mentioned problem. Also, to improve the capability of the proposed technique the advantages of this technique is added with mutation strategy borrowed from the realm of the DE algorithm which is named IHSA. On the other hand the fuzzy mechanism is applied to choose the best answer in optimization problem. Beside the EED problem, the wind effect is considered in this paper to find its effect.

The IEEE 30- and 118-bus test systems were used to investigate the effectiveness of the proposed technique. The IHSA is compared with other multi-objective meta-heuristic algorithms, such as NPGA, NSGA, SPEA, MOPSO and MODE. It is obvious that, the proposed technique achieve appropriate results is power systems. The numerical results demonstrate the superiority of the proposed optimization strategy. Also, by applying the wind effect, this fact is achieved that all of the cost in different scenario and case studies are reduced.

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