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Modified Artificial Bee Colony Optimization for Cost-Emission Dispatch Using Degree of Satisfaction Method

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Abstract— This paper presents a solution to multi-objective economic emission dispatch problem using three techniques namely, PPF method, degree of satisfaction method (DSM) and weighted sum method (WSM). Modified Artificial bee colony (MABC) algorithm is employed for computing the optimal dispatch where the aim is to minimize both the considered objectives i.e. cost and emission simultaneously and the comparison among all the three methods has been made here. ABC algorithm is superior than other evolutionary techniques because of its most striking feature i.e. it uses only limited number of control parameters to solve the optimization problem namely colony size and maximum cycle. The ABC is unique in its implementation of exploration and exploitation phases while searching for optimized solution. In the MABC algorithm, time varying chaotic mutation is employed for faster convergence. Proposed algorithms have been tested on IEEE 30 bus 6 generator test system and wind integration is also considered.

Keywords— ABC, MABC, economic emission dispatch, degree of satisfaction, PPF, DSM, WSM.

I. INTRODUCTION

In today's era energy saving becomes a major concern throughout the world as usage of energy increases expeditiously. To save energy and make effective use of it , great endeavors have been made by many of the countries and it requires that the generators must be so chosen that they work as per its rank of emission and efficiency both [1]. To fulfill these requirements traditional optimal dispatch model has been built as a new multi-objective model to minimize the environmental emission. This newly constructed model involves different objectives i.e. cost of generation, environmental emission, transmission losses etc. In power system operation Economic dispatch (ED) problem is an important and major issue. It is a non convex, discontinuous, non differentiable problem where the objective is to optimize i.e. minimize in our case the considered objectives simultaneously in case of multiple objective problems.

Solving single objective problem is easy because in that case there is only one objective is required to be optimized and decision making is also easy in such single objective problem. On the other hand, in multi objective problem (MOP) there are multiple conflicting objectives that are to be optimized simultaneously and hence in MOP multi criteria decision-making is difficult. In some works, weighted sum (WSM) is employed to solve MOP [2-3]. But this method is not very much effective due to the reason that there are too many sets of weight and each combination corresponds to only one solution. Therefore it is difficult to allocate these weights of different objectives. To overcome the drawback of this method there are so many techniques has been proposed in literature. Multi-objective evolutionary algorithms [4], particle swarm optimization [5-7], improved bacterial foraging algorithm [8-9], non dominated sorting genetic algorithm-II [10], differential evolution [11-12], Harmony search algorithm [13] are effectively used in literature to solve multi-objective economic/emission dispatch problem.

Here in this paper 3 methods are proposed to solve multi objective problem namely price PPF method and DSM and WSM. In PPF method MOP is converted into single objective using price penalty factor and in degree of satisfaction method a concept of satisfaction rank or aggregation rank is introduced to access the optimization quality and to compromise different objectives coordination rank is introduced. With the continuous search for alternatives to Renewable sources it is necessary or required to embed the wind power in the above mentioned economic dispatch problem. The comparison among all the 3 proposed methods has been made here. The developed model is tested on IEEE 30 bus system and effect of wind is considered in the dispatch process.

II. PROBLEM FORMULATION

The objective of economic/emission dispatch problem is the compution of generated power Pi for total load demand so that total fuel cost F_T and total emission content E_T are minimized simultaneously.

A. Optimal cost dispatch

The aim is to minimize the overall fuel cost which can be stated as:

$$\sum_{i=1}^{N} F_i(P_i) \qquad (1)$$

Where $F_i(P_i) = (a_iP_i^2+b_iP_i+c_i)$ is the fuel cost. a_i, b_i, c_i are the fuel cost coefficients.

B. Optimal emission dispatch

The objective is to minimize the total emission content of atmospheric pollutants caused by thermal generation. The total emission content can be stated as:

$$E_T = \sum_{i=1}^{N} E_i(P_i) = \sum_{i=1}^{N} 10^{-2} \times (\alpha_i + \beta_i P_i + \gamma_i P_i^2) + \xi_i \exp(\lambda_i P_i) \qquad (2)$$

Where E_T is the total emission because of N generating unit and $\alpha_i, \beta_i, \Upsilon_i, \xi_i, \lambda_i$ are the pollution coefficients of generating units.

Subject to constraints:

1. **Unit operating limit constraint**

$$P_i^{\min} \le P_i \le P_i^{\max} \qquad \text{For } i=1,2\ldots.N \qquad (3)$$

Where $P_i^{\min}$ and $P_i^{\max}$ are the minimum and maximum limit of power generation.

2. **Power balance constraint**

$$\sum_{i=1}^{n} P_i - P_{load} - P_{loss} = 0 \qquad (4)$$

The losses occurring in the line are expressed as:

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j - \sum_{i=1}^{n} B_{oi} P_i + B_{oo} \qquad (5)$$

Where B_{ij}, B_{oi} and B_{oo} are the loss coefficients of N generating units.

3. **Penalty cost for wind forecast error**

$$CW = C * \exp(DPW / DPW - alpha) * |DPW| \qquad (6)$$

This equation (6) shows the penalty cost for wind forecast error. Where DPW is the wind forecast error. C is fixed value. $C * \exp(DPW / DPW - alpha)$ represents the variable penalty coefficients [15].

C. Optimal cost emission dispatch

In optimal cost dispatch, cost is minimized whereas in optimal emission dispatch emission dispatch, emission is minimized. In combined optimal cost emission dispatch two objectives namely cost and emission are minimized simultaneously. And it is the requirement of the above two objective optimization problem is to convert the two objective problems into single objective by either using some factor or by using some techniques. Here three methods are proposed to solve such multi objective problems namely

a) PPF method

b) Degree of satisfaction method (DSM)

c) Weighted sum method (WSM)

- **PPF method**

In optimal cost dispatch only cost is minimized and in optimal emission dispatch only emission is minimized. In optimal cost/emission dispatch above 2 objectives are converted into a single objective by using a Price Penalty Factor which is defined as the ratio of maximum cost of each generator and its maximum emission. The objective can now be stated as:

$$Z(P_D) = F_T(P_D) + pf(P_D) \times E_T(P_D) \tag{7}$$

- **Degree of satisfaction**

In this section, MOP is reconstructed into the single objective problem. It should be noted that the max and min values of each independent objective must be calculated before final optimization. To combine these different objectives both the distance function approach and weight technique are employed. Aggregation Rank (WSSR) and CR (coordination rank) are introduced [1].

The original optimization problem has been transformed into the following one:

$$\min WSSR \bullet CR$$

Where WSSR is the weighted sum of satisfaction rank.

- Weighted sum of satisfaction rank

WSSR can be expressed as:

$$WSSR = \sum_{k=1}^{k} S_k AR_k SR_k \tag{8}$$

Where AR_k is the aggregation rank and SR_k is the satisfaction rank of *kth* objective. SR_k is defined to describe how much decision maker satisfied with *kth* objective. And it is defined as:

$$\begin{aligned} SR_k &= 1 && \text{if} \quad P_k \le P_k^{\min} \\ &= \frac{P_k^{\max} - P_K}{P_k^{\max} - P_k^{\min}} && \text{if} \quad P_k^{\min} \le P_k \le P_k^{\max} \\ &= 0 && \text{if} \quad P_k^{\max} \le P_k \end{aligned} \tag{9}$$

To transform the SR_k into unified one, the aggregation rank of *kth* objective is introduced which is stated as:

$$AD_c = \frac{SR_c^{th}}{SR_c^{th} + SR_e^{th}} \quad \text{for cost function} \tag{10}$$

$$AD_e = \frac{SR_e^{th}}{SR_c^{th} + SR_e^{th}} \quad \text{for emission function} \tag{11}$$

- Coordination rank

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To coordinate the relationship among all the objectives, Euclidean distance in k-dimension is presented as per distance function approach.

$$D1 = \sqrt{\sum_{k=1}^{k} (P_k^{\max} - P_k)^2}$$
$$D2 = \sqrt{\sum_{k=1}^{k} (P_k^{\max} - P_k^{\min})^2} \quad (12)$$

$$CR = \frac{D1}{D2} \quad (13)$$

- **Weighted sum method**

  In this by taking different weight values optimization is performed.

III. STANDARD ARTIFICIAL BEE COLONY ALGORITHM

Artificial bee colony (ABC) algorithm is a meta- heuristic evolutionary technique for solving optimization problems which was proposed by Dervis karaboga in 2005 and it is motivated by the foraging behavior of honey bees. It is as simple as other optimization techniques such as PSO and DE, ACO algorithms and uses only limited number of control parameters such as max cycle number and colony size which is the most striking feature of this algorithm over other techniques. It is a population based search technique in which colony contains three types of bees: employed bees, onlooker bees and scout bees.

A. Mechanism of ABC algorithm

In this algorithm, there are three main groups of bees: employed bees, onlookers and scouts. Colony size represents both the numbers of employed bees and onlookers and is equal to that of food sources and is denoted by NP.

Step 1. At first step of this algorithm i.e. at employed bee phase employed bees search for a new better food source in the neighborhood of selected base reference food source by modifying its position as per eq. (14):

$$v_{i,j} = x_{i,j} + \Phi(x_{i,j} - x_{k,j}) \qquad i \neq \mathrm{k} \quad (14)$$

Where k € {1,2,……NP},j € {1,2,…..,D} (D denotes the problem dimension), φ is a uniform random number between [-1,1], $x_{i,j}$ and $x_{k,j}$ is the location of reference food source and the randomly selected food source in dimension j, respectively. When the candidate food source found is better than the reference one, the reference food source is replaced with the candidate food source.

Step 2. In second step i.e. At Onlooker Bees Step, the onlookers try to search better food sources around available food sources in the search space as the employed bees do. The only difference is that onlooker bees decide the reference food source to search for the food source around according to some probability P_i calculated by eq. (15):

$$P_i = fit_i / \sum_{n=1}^{NP} fit_n \quad (15)$$

fit_i is the fitness value of ith food source and it takes a value that is varied inversely to its objective value in function optimization problems.

Step 3: At the last step of this algorithm, food sources which are not improved are find out using limit parameter, and then they are abandoned. Then scout bees find a new food sources in a similar way according to eq. (16):

$$x_{i,j} = x_j^{min} + rand[0,1](x_j^{max} - x_j^{min}) \quad (16)$$

Where x_j^{min} and x_j^{max} represents the minimum and maximum range in jth dimension.

B. Modified ABC technique

Recently, in some optimization problems chaos has been widely used. Chaotic orders are very quick and easier to generate and memorize therefore it is effective for solution exploring in the optimization issues. A chaotically varying chemo tactic mutation factor is embedded here to update the position of bee to new foraging locations. The chaotic mutation factor is chaotically varied in this MABC technique by making use of iterator called the logistic map [14], which is one of the simplest systems indicating chaotic behavior

The chaotic variation using logistic map can be stated as:

$$y(t) = \mu \times y(t-1) \times [1 - y(t-1)] \quad (17)$$

Where μ is a controlling factor in the range 0≤ μ≤4 and t is iteration count. Factor μ controls the variation of the chaotic sequence. The mutation factor φ is expressed as:

$$\Phi(t) = \mu \times \Phi(t-1) \times [1 - \Phi(t-1)] \quad (18)$$

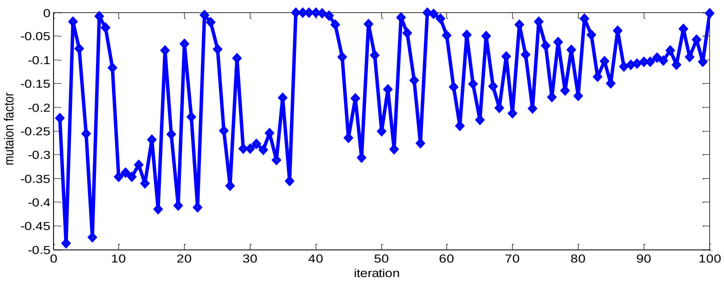

Figure 1. Step length in MCABC (μ=4.)

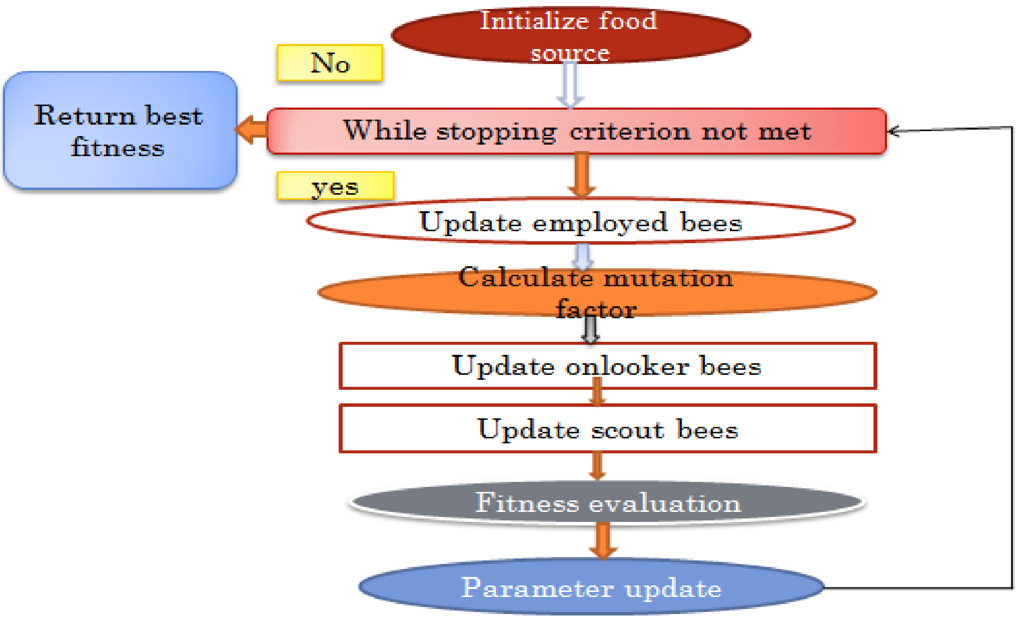

Figure 2. Folwchart of MABC technique

IV. RESULTS AND DISCUSSION

Three techniques namely PPF method, degree of satisfaction method and weighted sum method has been proposed here to solve multi-objective economic/emission dispatch problem. The proposed algorithms have been applied to IEEE 30 bus 6 generator test system for the load demand of 2.834 p.u. Proposed algorithms have been applied to test system with wind integrated and the comparison among all proposed techniques have been made here. here the 6th generator has been replaced by wind generator. Data used in the proposed work has been taken from reference [8]. Fig (3) shows the wind forecast error vs cost curve.

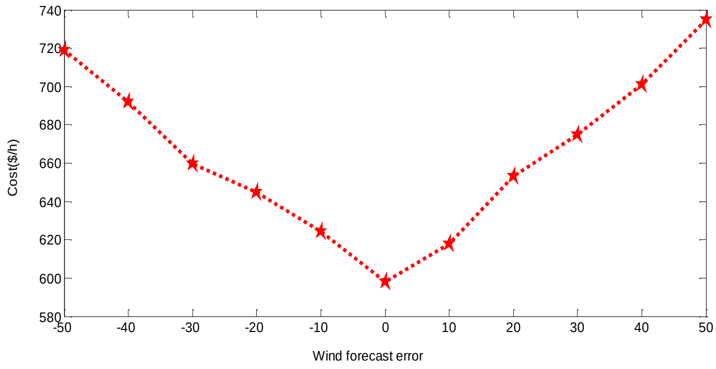

Figure 3. Wind forecast error vs cost curve

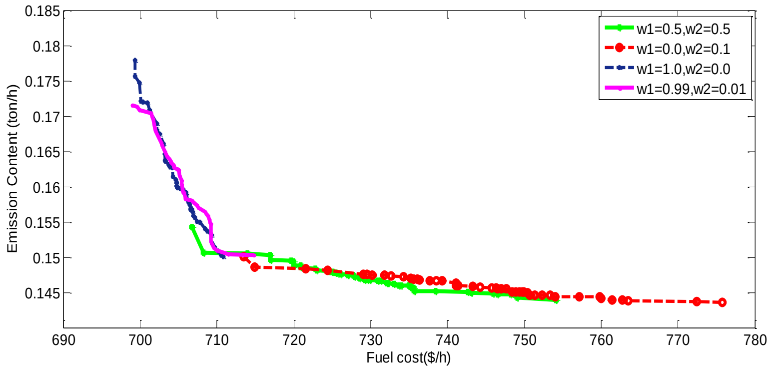

Figure 4. Pareto Front for ABC with PPF and Wind Embedded (For PD=2.834, H=5928.7134)

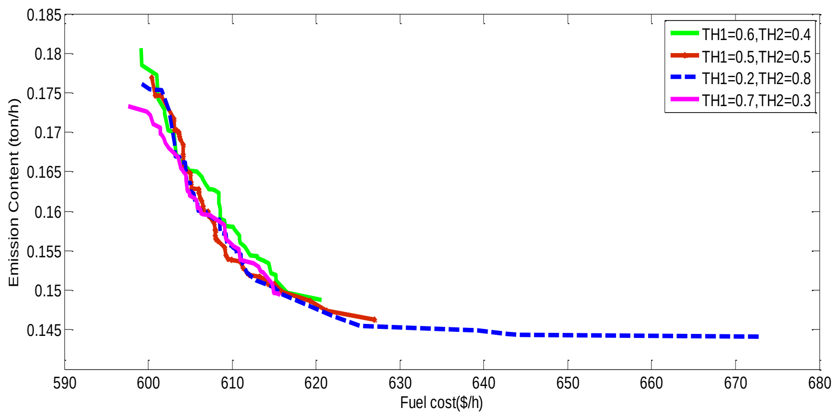

Figure 5. Pareto Front for ABC with DSM With Wind Embedded (For PD=2.834)

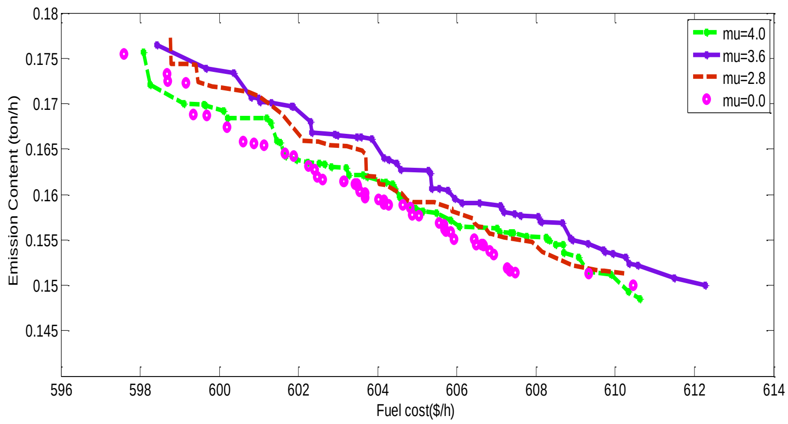

Figure 6. Pareto Front For MABC With Wind (PD=2.834 p.u.)

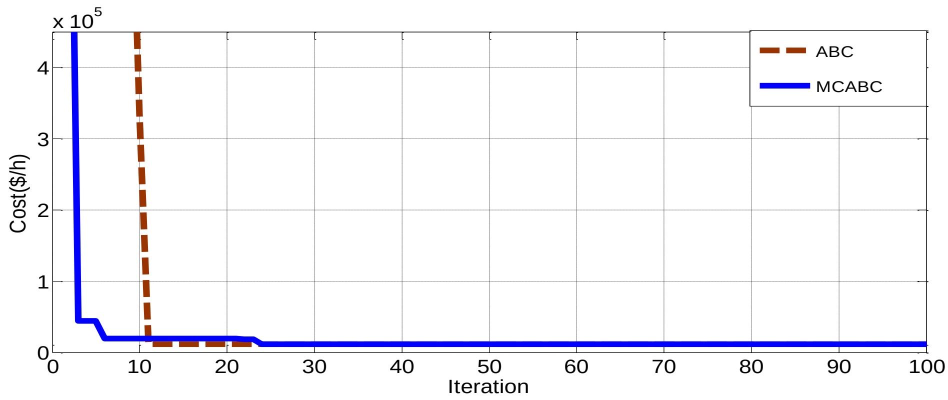

Figure 7. Combined convergence of ABC and MABC

Table 1: Some non-dominated competing solutions obtained with ABC-PPF method (Price Penalty Factor= 5928.7134).

Sr. no.	P1	P2	P3	P4	P5	P6	COST	EMISSION	LOSS
1	0.3475	0.5074	0.5340	0.4625	0.544	0.470	635.630	0.1438	0.0323
2	0.3724	0.4872	0.5077	0.4193	0.483	0.599	630.399	0.1442	0.0357
3	0.4129	0.3972	0.4485	0.5054	0.507	0.600	624.472	0.1448	0.0376
4	**0.2872**	**0.4977**	**0.5340**	**0.5369**	**0.410**	**0.600**	**619.285**	**0.1455**	**0.0326**
5	0.1805	0.2829	0.6531	0.7003	0.442	0.599	602.875	0.1529	0.0248
6	0.0553	0.2993	0.5127	0.9527	0.446	0.600	597.762	0.1624	0.0317

In this table 1. While applying degree of satisfaction method on this test case solution 4 is found to be best compromise solution among all the six solutions with threshold values of 0.4 and 0.7 for cost and emission function respectively.

Table 2: Some non-dominated solutions obtained using weighted sum with MABC technique

SR.NO.	P1	P2	P3	P4	P5	P6	COST	EMISSION	LOSS	μ
1	0.1562	0.313	0.578	0.987	0.229	0.598	600.60	0.1631	0.029	3.5
2	0.2077	0.322	0.503	0.887	0.343	0.600	600.02	0.1557	0.030	3.0
3	0.1475	0.249	0.480	1.073	0.315	0.600	599.40	0.1662	0.032	0.0
4	0.0500	0.323	0.555	0.815	0.519	0.600	599.31	0.1581	0.029	2.8
5	0.0877	0.269	0.381	1.022	0.508	0.600	598.75	0.1648	0.035	4.0
6	**0.1424**	**0.239**	**0.62**	**0.880**	**0.370**	**0.600**	**598.69**	**0.1597**	**0.026**	**3.8**

In this table 2. While applying degree of satisfaction method on this test case solution 6 is found to be best compromise solution among all the six solutions with threshold values of 0.4 and 0.7 for cost and emission function respectively.

Table3. Effect of Dm's Priority On BCS

Sr. No.	SR_c^{th}	SR_e^{th}	COST($/H)	EMISSION(TON/H)	LOSS
1	**0.2**	**0.8**	**621.9881**	**0.1449**	**0.0327**
2	0.5	0.7	619.8127	0.1471	0.0301
3	0.6	0.4	606.4553	0.1517	0.0274
4	0.7	0.3	604.9042	0.1523	0.0329
5	0.8	0.3	598.9533	0.1572	0.0306
6	0.4	0.8	598.5368	0.1576	0.0321

In a similar way, While applying degree of satisfaction method on this test case solution 1 is found to be best compromise solution among all the six solutions with threshold values of 0.4 and 0.7 for cost and emission function respectively.

Table4. Best compromise solution find out by degree of satisfaction method for ABC-PPF and MABC-WSM

Method name	P1	P2	P3	P4	P5	P6	cost($/h)	emission(ton/h)	loss
ABC-PPF	0.2872	.0497	0.5340	0.5369	0.410	0.600	619.285	0.1455	0.0326
MABC-WSM	0.1424	0.239	0.62	0.880	0.370	0.600	598.69	0.1597	0.026

Table5. Best compromise solution find out by ABC-degree of satisfaction method

Sr. no.	SR_c^{th}	SR_e^{th}	cost($/h)	emission(ton/h)	loss
1	0.2	0.8	621.9881	0.1449	0.0327

V. CONCLUSION

To solve multi objective economic emission dispatch problem three methods namely PPF method, degree of satisfaction method and weighted sum method are proposed here and the comparison among them is made. On comparing all the 3 proposed techniques i.e. table4 and table 5 it is found that cost is found to be the best i.e. minimized (**598.69 $**) with MCABC-weighted sum method. On the other hand emission is best minimized (**0.1449 tonn**) in ABC-degree of satisfaction method.

As a whole analysis reveals that MCABC-weighted sum method is found to be superior because both the cost and emission are best minimized with this method and losses are also less than obtained with other 2 methods which is our objective.

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