Economic Load Dispatch using Arifitial Bee Colony Optimization

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***Abstract*— This paper *presents* an Artificial bee colony (ABC) *algorithm* based method for solving the economic load dispatch (ELD) problem. The objective is to minimize the nonlinear function, which is the total fuel cost of thermal generating units, subject to the usual constraints. The proposed ABC method has been examined for Crete Island system consisting of 18 thermal generating units having quadratic (Convex) cost function, standard IEEE 30 bus system consisting of six generating units and a 15 generating unit system with emission constraints. Results obtained with proposed method are compared with other techniques presented in literature. ABC algorithm is easy to implement and capable of searching near global optimum solution at fast convergence and efficiency.**

***Keywords*— Economic dispatch; Emission dispatch; Combined economic and emission dispatch;powerloss.**

I. INTRODUCTION

This paper introduce the economic dispatch problem in a power system is to determine the optimal combination of power output for all generating units which will minimize the total fuel cost while satisfying load and operational constraints. The economic dispatch problem is very complex to solve because of its colossal dimension, a non-linear objective function, and a large number of constraints.

Well known long-established techniques such as integer programming [2], dynamic programming [3], and lagarangian relaxation [4] have been used to solve the economic dispatch problem. Recently other optimization methods such as Simulated Annealing [5], Genetic Algorithm [6], Particle Swarm optimization [9], and Tabu Search Algorithm [22] are presented to solve the economic dispatch problem. This single objective economic dispatch can no longer be considered along due to the environmental concerns that arise from the emission produced by fossil-fuelled electric power plants. Economic and environmental dispatch is a multi-objective problem. Various Multi-objective evolutionary algorithms have been applied to the economic dispatch problem [14-15] based on mathematical approximations have been developed, which directly give the solution faster. In [16-17] including emission constrains to the economic dispatch and unit commitment problems have been presented, under cost-minimization environment.

In this paper ABC algorithm inspired by foraging behavior of honey bees proposed to solve combined economic and emissions dispatch problems is presented and the effectiveness of proposed algorithm is demonstrated using 18 thermal generating units having quadratic (Convex) cost function, standard IEEE 30 bus system consisting of six generating unit with loss and a 15 generating unit systems considering emission constraints.

II. PROLEM FORMULATION

The traditional economic dispatch problem has been defined as minimizing of an objective function i.e. the generation cost function subject to equality constraints (total power generated should be equal to total system load plus losses for all solutions) and inequality constraints (generations should lie between their respective maximum and minimum specified values)

Minimize $\Phi(x,p)$ $\quad \Phi_t(P_i) = \sum_{i=1}^{n} \Phi_i(P_i)$;

Objective function (1)

Subject to g(x,p) $\quad \sum_{i=1}^{n} P_i - P_L - P_D = 0$;

Equality constraint (2)

The transmission losses are given by:

$$P_L = \sum_{i=1}^{n} \sum_{j=1}^{n} P_i B_{ij} P_i \tag{3}$$

Where B_{ij} = transmission loss coefficient

$H(x,P) \le 0 \qquad P_{i\min} \le P_i \le P_{i\max}$;

Inequality constraint (4)

Where *x* is a state variable, P_i is the control variable, i.e., real power setting of *i* th generator and *n* is the number of units or generators.

There are several ways to include emission into the problem of economic dispatch. One approach is to include the reduction of emission as an objective. In this work, only NO_x reduction is considered because it is a significant issue at the global level. A price penalty factor (*h*) is used in the objective function to combine the fuel cost, Rs/hr and emission functions, kg/hr of quadric form.

The combined economic and emission dispatch problem can be formulated as to minimize

$$\varphi_t = \sum_{i=1}^{n} F_i(P_i) + h\sum_{i=1}^{n} E_i(P_i) \text{ Rs/h} \tag{5}$$

$$\varphi_i = \sum_{i=1}^{n}(a_i P_i^2 + b_i P_i + c_i) + h\sum_{i=1}^{n}(d_i P_i^2 + e_i P_i + f_i) Rs/h \tag{6}$$

Subject to equality and inequality constraint defined by equations (2), (4). Once price penalty factor (*h*) is known, equation (5) can be rewritten as

$$\varphi_i = \sum_{i=1}^{n}\{(a_i + hd_i)P_i^2 + (b_i + he_i)P_i + (c_i + hf_i)\} Rs/h \tag{7}$$

This has the resemblance of the familiar fuel cost equation, once h is determined. A practical way of determining *h* is discussed by Palanichamy and Srikrishan [7]. Consider that the system is operating with a load of P_D MW, it is necessary to evaluate the maximum cost of each generator at its maximum output, i.e,

(i) Evaluate the maximum cost of each generator at its maximum output, i.e,

$$F_i(P_{i\max}) = (a_i P_{i\max}^2 + b_i P_{i\max} + c_i) \text{ Rs/hr} \tag{8}$$

(ii) Evaluate the maximum NOx emission of each generator at its maximum output, i.e,

$$E_i(P_{i\max}) = (d_i P_{i\max}^2 + e_i P_{i\max} + f_i) \text{ kg/hr} \tag{9}$$

(iii) Divide the maximum cost of each generator by its maximum NO_x emission, i.e.,

$$\frac{F_i(P_{i\max})}{E_i(P_{i\max})} = \frac{(a_i P_{i\max}^2 + b_i P_{i\max} + c_i)}{(d_i P_{i\max}^2 + e_i P_{i\max} + c_i)} \text{ Rs/kg} \tag{10}$$

Recalling that

$$\frac{F_i(P_{i\max})}{E_i(P_{i\max})} = h_i \text{ Rs/kg} \tag{11}$$

(iv) Arrange $h_i (I = 1,2,......,n)$ in ascending order.

(v) Add the maximum capacity of each unit, $(P_{i\max})$ one at a time, starting from the smallest h_i unit until total demand is met as shown below.

$$\sum_{i=1}^{n} P_{i\max} \ge P_D \tag{12}$$

(vi) At this stage, h_i associated with the last unit in the process is the price penalty factor *h* Rs/Kg for the given load.

Arrange h_i in ascending order. Let '*h*' be a vector having '*h*' values in ascending order.

$$h = [h_{1,} h_2, h_3, ..., h_n] \tag{13}$$

For a load of P_D starting from the lowest h_i value unit, maximum capacity of unit is added one by one and when this total equals or exceeds the load, h_i associated with the last unit in the process is the price penalty factor for the given $P_{D.}$ Then equation (6) can be solved to obtain environmental economic dispatch using lamda iteration method [1].

Power flow equality constraints:

$$P_i - P_{Li} - \sum_{j=1}^{n} |\overline{v_i}||\overline{v_j}||y_{ij}| \cos(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{14}$$

$$Q_i - Q_{Li} - \sum_{j=1}^{n} |\overline{v_i}||\overline{v_j}||y_{ij}| Sin(\theta_{ij} - \delta_i + \delta_j) = 0 \tag{15}$$

Power flow equality constraints:

$$P_i^{\min} \le P_i \le P_i^{\max} \text{ , i=1------n.} \tag{16}$$

$$Q_i^{\min} \le Q_i \le Q_i^{\max} \text{ , i=1------n.} \tag{17}$$

$$\overline{|v_i|}^{\min} \le |\overline{v_i}| \le \overline{|v_i|}^{\max} \text{ ; i=1------n.} \tag{18}$$

$$\varphi_i^{\min} \le \varphi_i \le \varphi_i^{\max} \tag{19}$$

$$MVAf_{ij} \le MVAf_{ij}^{\max} \tag{20}$$

Where, *P min; P max*, are the minimum and maximum value of real power allowed at generator i ;

Q min ;Q max, minimum and maximum value of reactive power allowed at generator i;

Pi, Qi, real and reactive power generation at bus i; P_{Li}, Q_{Li}, active and reactive power loss at bus i*;*

|*Vi*|, voltage magnitude at bus i; *δi*, voltage angle at bus i;
Yij, *ijth* elements of Y-bus matrix;
$MVAf_{ij}$, apparent power flow from bus i to bus j;
$MVAf_{ij}^{\max}$, maximum rating of transmission line connecting bus i and j.[13]

III. OVERVIEW OF ARTIFITIAL BEE CLONLONY ALGORITHM

Artificial Bee Colony (ABC) is a swarm based a stochastic search algorithm which imitates the scrounging behavior of honeybees. In ABC algorithm [18-21], the colony of artificial bees consists of three groups of bees: employed bees, onlookers and scouts. Some of the bee of colony consists of employed artificial bees and the some includes the on lookers. In other words, the number of employed bees is equal to the number of food sources around the hive. The employed bee whose food source has been abandoned becomes a scout. In ABC algorithm the position of food source determines the solution and the amount of nectar represents the fitness of the respective solution.

3.1 *Step in Algorithm*

Step1: *Initialization*

A randomly distributed initial population solutions ($X_i = 1, 2...$ D) is being dispersed over the D dimensional problem space.

Step 2: *Reproduction*

An artificial onlooker bee chooses a food source depending on probability value associated with food source, P_i, calculated by following expression:

$$P_i = f_i t_i \Big/ \sum_{n=1}^{N} f_i t_n \qquad (21)$$

Where $f_i t_i$ is the fitness value of the solution i which is proportional to the nectar amount of the food source in the position i and N is the number of food sources which is equal to the number of employed bees.

In order to produce a candidate food position from the old one in memory, the ABC used the following expression:

$$V_{ij} = X_{Kj} + \varphi_{ij}(X_{ij} - X_{Kj}) \qquad (22)$$

Where k = {1, 2… D} and j = {1, 2… N} are randomly chosen indexes. φ_{ij}, is a random number between [-1, 1]

Step 3: *Replacement of bee and selection*

In ABC, Providing that a position can not be improved further through a predetermined number of cycles, then that food source is assumed to be abandoned. The value of predetermined number of cycles is an important control parameter of the ABC algorithm, which is called "limit" for abandonment.

Assume that the abandoned source is X_i and j= {1, 2… N} then the scout discovers a new food source to be replaced with *Xi*. This operation can be defined as:

$$X_i^j = X_{\min}^j + rand(0,1) * (X_{\max}^j - X_{\min}^j) \qquad (23)$$

After each candidate source position V_{ij} is produced and then evaluated by the artificial bee, its performance is compared with that of its old one.

If the new food has equal or better fitness than the old source, it is replaced with the old one in the memory. Otherwise, the old one is retained in the memory.

3.2 *Pseudo-code*

```
*initialize the population of solution Xi; i=1…..D

*Evaluate the population

*Iteration=1
 Repeat

*produce new solution Vi for the employed bees by
 using eq. (22)

*apply the greedy selection process for the employed bees.

*Calculate the probability values Pi for the solution Xi
 using  eq. (21)

* produce new solution Vi for the onlookers from the
 Solutions, Xi selected depending on Pi and evaluate them.

*Apply the greedy selection process for the on lookers

*Determine the abandoned solution for scout, if exist, and replace it with the
new the randomly produced solution Xi by eq.(23)

*Memorize the best solution achieved so far.

*iteration=iteration+1

*continue up to terminating condition.
```

IV. RESULTS AND DISCUSSION

The applicability and validity of the ABC algorithm for practical applications has been tested on two test cases. The programs are developed using MATLAB 7.9 and the system configuration is Pentium IV processor with 3.2 GHz speed and 1 GB RAM.

Test case 1: The system consists of 18 thermal units and uses quadratic (convex) unit cost functions. The parameters of all thermal units are presented in table: I

The Parameter for case I using ABC algorithm considered here are: N=40; Food-Number=N/2; maximum cycle=500 and limit=500.

Table: II presents the summarized result of case: 1, with a varying percentage of the maximum demand. Where the maximum power output of the generators sets is MD=433.22 MW.

Form Table: II, it is clear that ABC algorithm gives optimum result in terms of minimum total operating cost for various load.

TABLE I. GENERATOR OPERATING LIMITS AND QUADRATIC COST FUNCTION COEFFICIENT OF 18 UNIT SYSTEMS

Unit	P_{max} (MW)	P_{min} (MW)	a_i ($/h)	b_i ($/MWh)	c_i ($/MW^{2}h)
1	15.00	7	85.74158	22.45526	0.602842
2	45.00	7	85.74158	22.45526	0.602842
3	25.00	13	108.98370	22.45526	0.214263
4	25.00	16	49.06263	26.75263	0.077837
5	25.00	16	49.06263	26.75263	0.077837
6	14.75	3	677.73000	80.39345	0.734763
7	14.75	3	677.73000	80.39345	0.734763
8	12.28	3	44.390000	13.19474	0.514474
9	12.28	3	44.390000	13.19474	0.514474
10	12.28	3	44.390000	13.19474	0.514474
11	12.28	3	44.390000	13.19474	0.514474
12	24.00	3	574.96030	56.70947	0.657079
13	16.20	3	820.37760	84.67579	1.236474
14	36.20	3	603.02370	59.59026	0.394571
15	45.00	3	567.93630	56.70947	0.420789
16	37.00	3	567.93630	55.96500	0.420789
17	45.00	3	567.93630	55.96500	0.420789
18	16.20	3	820.37760	84.67579	1.236474

TABLE II. ECONOMIC LOAD DISPATCH FOR VARIOUS LOAD

MD=433.22 MW	λ Iteration [8] Cost ($)	Proposed Method Cost ($)
0.95 * MD	29731.05	29730.8
0.90 * MD	27652.47	27653.3
0.80 * MD	23861.58	23859.4
0.70 * MD	20393.43	20391.6

The convergence tendency of proposed ABC based strategy for power demand of 0.95MD, 0.9MD, 0.8MD and 0.7MD is plotted in figure: 1

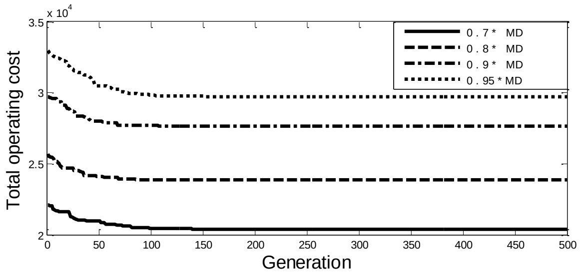

Figure 1. Covergence of 18 thermal units for Various Load

It shows that the technique converges in relatively fewer cycles thereby possessing good convergence property and resulting in low operating cost. Its Elapsed time is 2.105 seconds.

Test case II: The simulation was performed on the standard IEEE 30 bus – 6 generators test system. Table III shows the generator data of the IEEE-30 bus system consisting of six generators.

The Parameter for case II using ABC algorithm considered here are: N=20; Food-Number=N/2; maximum cycle=100 and limit=500.

TABLE III. GENERATOR DATA OF THE IEEE 30 BUS TEST SYSTEM

	Gen 1	Gen 2	Gen. 3	Gen. 4	Gen 5	Gen 6
a [$/h]	0	0	0	0	0	0
b [$/MWh]	2.00	1.75	1.00	3.25	3.00	3.00
c [$/MW^2 h]	0.00375	0.0175	0.0625	0.00834	0.025	0.025
P_{gmin} (MW)	50	20	15	10	10	12
P_{gmax} (MW)	200	80	50	35	30	40

TABLE IV. COMPARISION OF ABC WITH DIFFERENT EVOLUTIONARY METHODS OF OPTIMIZATION

	IEP [9]	EP-OPF [10]	SADE_ALM [11]	PS [12]	GA-PS [12]	Purposed Method
Pg1 (MW)	176.235	173.8262	176.1522	175.727	175.6627	**176.2631**
Pg2 (MW)	49.0093	49.998	48.8391	48.6812	48.6413	**48.3829**
Pg3 (MW)	21.5023	21.386	21.5144	21.4282	21.4222	**20.8706**
Pg4 (MW)	21.8115	22.63	22.1299	22.8313	22.6219	**22.7130**
Pg5 (MW)	12.3387	12.928	12.2435	12.0667	12.3806	**12.4534**
Pg6 (MW)	12.0129	12.00	12.00	12.00	12.0000	**12.0000**
Power loss (MW)	9.5105	9.3683	9.4791	9.3349	9.3286	**9.2830**
Generation Cost ($/hr)	802.465	802.5557	802.404	802.0150	802.0138	**801.7211**

Summarized result of test case: II is presented in table: IV, considering the transmission loss coefficient. Result shows that, ABC algorithm gives the optimum result in terms of minimum generation cost and power loss in comparison to the result reported in [10, 11 and 12].

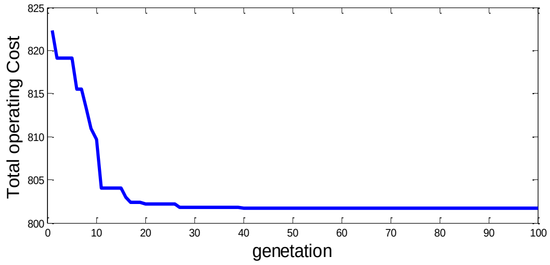

Figure 2. Covergence of IEEE-30 bus System with Loss

The convergence tendency of proposed ABC based strategy for power demand of 283.4 MW, for test case II is plotted in figure: 2, it shows that the technique converges in relatively fewer cycles thereby possessing good convergence property and resulting in low operating cost. Its Elapsed time is 1.454425 seconds.

Test case III: It consists of 15-unit systems and its generator characteristic is given in Table: V and The real power generation output and the transitional cost obtained for 15-unit systems using ABC algorithm along with various proposed intelligent techniques is given in Table: VI

The Parameter for case III using ABC algorithm considered here are: N=20; Food-Number=N/2; maximum cycle=500 and limit=500.

Figs. 3 give the convergence criteria of 15-unit system with emission and line flow constraints using ABC approach for a demand of 2630MW and compared with the result provided in [13] using GA,EP,PSO and DE. Its Elapsed time is 3.0975 seconds.

TABLE V. GENERATOR CHARACTERISTICS OF 15 UNIT SYSTEMS

Unit	P_i^{max} (MW)	P_i^{min} (MW)	a_i (\$/MW^{2}h)	b_i (\$/MWh)	c_i (\$/h)
1	455	150	0.000299	10.1	671
2	455	150	0.000183	10.2	574
3	130	20	0.001126	8.8	374
4	130	20	0.001126	8.8	374
5	470	150	0.000205	10.4	461
6	460	135	0.000301	10.1	630
7	465	135	0.000364	9.8	548
8	300	60	0.000338	11.2	227
9	162	25	0.000807	11.2	173
10	160	25	0.001203	10.7	175
11	80	20	0.003586	10.2	186
12	80	20	0.005513	9.9	230
13	85	25	0.000371	13.1	225
14	55	15	0.001929	12.1	309
15	55	15	0.004447	12.4	323

TABLE VI. COMPARISON OF TEST RESULTS OF 15 GENERATING UNIT SYSTEM

Units	**GA[13]**	**EP [13]**	**PSO [13]**	**DE [13]**	**Purposed method**
P1	455 . 0000	283 . 6025	219 . 4531	168 . 9527	**454 . 6509**
P2	303 . 7664	151 . 6028	150 . 0000	150 . 0000	**455 . 0000**
P3	75 . 4567	130 . 0000	130 . 0000	130 . 0000	**130 . 0000**
P4	75 . 4567	130 . 0000	130 . 0000	130 . 0000	**130 . 0000**
P5	311 . 3287	236 . 9869	183 . 4387	150 . 0000	**312 . 2096**
P6	289 . 8495	460 . 0000	460 . 0000	460 . 0000	**451 . 3811**
P7	301 . 3702	305 . 1626	465 . 0000	465 . 0000	**465 . 0000**
P8	180 . 9965	257 . 3319	216 . 2897	300 . 0000	**60 . 0000**
P9	94 . 0688	162 . 0000	162 . 0000	162 . 0000	**25 . 0000**
P10	93 . 0605	160 . 0000	160 . 0000	160 . 0000	**25 . 0000**
P11	50 . 2491	79 . 9141	80 . 0000	80 . 0000	**23 . 9541**
P12	50 . 2491	80 . 0000	80 . 0000	80 . 0000	**42 . 8043**
P13	55 . 2491	85 . 0000	85 . 0000	85 . 0000	**25 . 0000**
P14	35 . 1660	55 . 0000	55 . 0000	55 . 0000	**15 . 0000**
P15	35 . 1660	55 . 0000	55 . 0000	55 . 0000	**15 . 0000**
Total Fuel Cost(\$/h)	64046 . 51	64246 . 00	66993 . 00	68231 . 00	**64040 . 4**

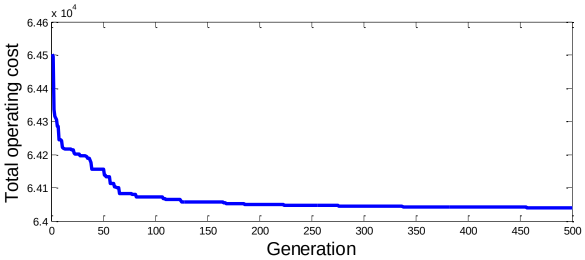

Figure 3. Covergence characteristics of 15 unit System wth contraits

V. CONCLUSION

In this paper, a new optimization of artificial bee colony (ABC) algorithm has been proposed. In order to prove the effectiveness of algorithm it is applied to three different test cases. Test Case I consist of 18 thermal units and uses quadratic (convex) unit cost functions. Test Case II consists of standard IEEE 30 bus with 6 generator unit system and Test case III consists of 15-unit systems with constraints. The results obtained by proposed method were compared to those available in various literatures. The comparison shows that ABC algorithm performs better then reported methods in efficient manner. The ABC algorithm has superior features, including quality of solution, stable convergence characteristics and good computational efficiency.

Therefore, this results shows that ABC optimization is a promising technique for solving complicated problems in power system

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