A Multiobjective Optimization Based on Cultural Algorithm for Economic Dispatch with Environmental Constraints

Bidishna Bhattacharya, Dr.Kamal Mandal, Dr.Niladri Chakraborty

Abstract— A knowledge based cultural is used to solve the problem of Combined Economic and Emission Dispatch (CEED) in this paper. Due to the alarming rate of rising pollutants in atmosphere, there arises the necessity to reduce the amount of pollutants released into the atmosphere from the power generation plants. This paper introduces an efficient evolutionary programming based approach of cultural algorithm to solve economic emission load dispatch which belongs to multiobjective constrained optimization problem. The proposed method can efficiently search and actively explore solutions, and it may be employed to handle the equality and inequality constraints of the combined economic and emission problem. The salient features make the proposed cultural algorithm attractive in large-scale highly constrained nonlinear and complex systems. The efficacy and viability of the proposed method is tested with three generator, six generator and fourteen generator system considering transmission losses, ramp rate limits, prohibited operating zone and valve point effect. The solutions obtained are quite encouraging and useful in the economic emission environment.

Index Terms— Cultural algorithm, CEED, evolutionary programming, prohibited operating zone, ramp rate limits, valve point loading.

1 Introduction

NORMALLY electric power plants are operated on the basis of least fuel cost strategies without considering the pollutants produced by the thermal generation. But due to the continual awareness program of society about the global warming people raise questions concerning environmental protection. The Clean Air Act Amendments of 1990 have forced the generating companies to pay much more attentions to environment pollutions brought from power generating stations [1]. Different methods are offered for reducing emissions such as switching to fuels with low emission potential, installing post-combustion cleaning system e.g. electrostatic precipitators etc. These methods of reduction of pollutants give raise the total operating cost of the entire thermal power plant.

To minimize the overall operating cost the environmental–economical generation scheduling is seems to be the preferred choice because it is easily implemented and requires minimal additional costs [2].

The emission dispatching option is a smart alternative in which the emission, in addition to the fuel cost objective, is to be minimized. Thus, the Economic Dispatch problem can be handled as a multiobjective optimization problem with different contradictory objectives. In recent years, this option has acknowledged by many researchers [3], [4], [5].

Combined economic and emission load dispatch is one of the reliable planning in a field of power system optimization where the emissions can be considered either in the objective function or treated them as additional constraints. Since various methods have been proposed [6], [7] Talaq et al [2] presented an exceptional review on the various techniques and emission models to reduce emissions into atmosphere. Hota et al. proposed a sequential quadratic programming technique to solve CEED problem by assigning weighting factors for generation and emission cost functions [8].A Combined Economic and Emission Dispatch (CEED) using neural network method is proposed by Kulkarni et a1 [9] whose solution is much closer than the conventional method. V.C.Ramesh and X.Li [10] have applied fuzzy' techniques to solve multiobjective combined emission and economic dispatch problem. Kito Po Wong and Jason Yuryevich [11] have proposed EP based algorithm for environmentally constrained economic dispatch problem. Hybrid genetic algorithm is also used to solve economic &emission dispatch problems by S.Baskar et al [12]. Different techniques like Genetic Algorithm (CA), Evolutionary programming (EP) Neural networks (NN) and Fuzzy controlled genetic algorithms (FCGA) [13], [14], [15], [16] have been reported in the literature pertaining to the environmental -economic dispatch problem.

Cultural algorithm (CA) was proposed by Reynolds as a vehicle for modeling social evolution [17], [18].

Cultural algorithm is basically a global optimization technique which consists of two evolutionary spaces; an evolutionary population space whose experiences are integrated into a Belief space which influences the search process to converge the

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- *B.Bhattacharya is with the Department of Electrical Engineering, Techno India, Saltlake, Kolkata-700091, India (e-mail: bidishna_inf@yahoo.co.in).*
- *K. K Mandal is with the Power Engg. Dept.of Jadavpur University, Kolkata, India (e-mail: kkm567@yahoo.co.in).*
- *N. Chakraborty is with the Power Engg. Dept. of Jadavpur University, Kolkata, India (e-mail: chakraborty_niladri@hotmail.com).*

problem in a direct way. Cultural algorithms have been successfully applied to global optimization of constrained functions, scheduling and real problems. Cultural Algorithm has been implemented for a few problem of Power System field such as substation planning [19], hydrothermal scheduling [20]. Economic load dispatch [21].

In this paper, an alternative approach to cultural algorithm has been proposed to solve the CEED. We worked on evolutionary programming integrated to cultural algorithm to solve the combined economic and emission dispatch problem involving several constraints as ramp rate limits, forbidden zone of operation, valve point loading effects etc. The framework of embedding EP into CA was developed by Chung and Reynolds [22] to investigate the influence of global knowledge on the justification of optimization problem. In this paper we worked on cultural algorithm having EP based population space which is dynamically controlled by the feasible region based records to direct the solutions towards the most promising region to solve constrained optimization problem efficiently.

2 Problem Formulation

2.1 Combined Economic and Emission Dispatch (CEED)

The economic dispatch and emission dispatch are considerably different. The objective of economic dispatch is to find the optimal combination of power generations that minimizes the total generation cost while satisfying an equality constraint and inequality constraints. On the other hand emission dispatch reduces the total emission from the system by an increase in the system operating cost. So it is desirable to get an operating point that makes a balance between cost and emission. This is achieved by combined economic and emission dispatch (CEED).

Commonly the CEED problem is the combination of two single objective functions like economic dispatch and emission dispatch and it is formulated as

$$\min imize \quad f(F_{pg}, E_{pg})$$

subject to demand constraints and generating capacity limits.

F_{pg} is the total fuel cost which is expressed in ELD problem and it may be described as the following optimization problem under a set of operating constraints,

$$F_{pg} = \sum_{i=1}^{n} F\left(P_{gi}\right) = \sum_{i=1}^{n} \alpha_i P_{gi}^2 + \beta_i P_{gi} + \gamma_i \qquad (1)$$

Where α_i, β_i and γ_i are the cost coefficient of the i th generator, P_{gi} is the power generated by the i th unit and n is the number of generators.

The cost is minimized subjected to the following generator capacities and active power balance constraints.

$$P_{gi_{\min}} \le P_{gi} \le P_{gi_{\max}} \quad \text{for } i=1,2,\ldots.n \qquad (2)$$

$$P_D = \sum_{i=1}^{n} P_{gi} - P_{loss} \qquad (3)$$

where $P_{gi_{\min}}$ and $P_{gi_{\max}}$ are the minimum and maximum power output of the i th unit and P_D is the total power demand and P_{loss} is total transmission loss.

The transmission loss P_{loss} can be calculated by using B matrix technique and is defined by (4) as,

$$P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_{gi} B_{ij} P_{gj} \qquad (4)$$

where B_{ij} 's are the elements of loss coefficient matrix B.

The solution of economic dispatch problem will give the amount of power to be generated by various generating units of a power system for a minimum total fuel cost. But limitation on emission release is not considered by this problem. The objective of emission dispatch is to minimize the total environmental degradation or the total pollutant emission due to the burning of fuels for production of power to meet the load demand. The emission can be approximated as a quadratic function of the active power output from the generating units. The emission dispatch problem can be defined as the following optimization problem,

$$E_{pg} = \sum_{i=1}^{n} E\left(P_{gi}\right) = \sum_{i=1}^{n} a_i P_{gi}^2 + b_i P_{gi} + c_i \qquad (5)$$

Where a_i, b_i and c_i are the emission coefficient of the i th generator, P_{gi} is the power generated by the i th unit and n is the number of generators.

Minimization of emission and cost are usually two conflicting objectives. In fact, minimization of cost increases the emission and vice-versa. Emission may be considered with conventional economic load dispatch problems by adding the emission cost with the fuel cost. A price penalty factor is used which blends the emission costs with the normal fuel costs [9]. This is used to convert this bi-objective problem in to a single objective function as,

$$MinimizeTC = F_{pg} + h * E_{pg} \quad \$/h \qquad (6)$$

where, TC is the total operational cost of the system.

The above cost function is minimized subject to the constraints defined by (2) and (3).

A trade off between fuel cost and emission cost is made and (6) can be revised as (7)

$$MinimizeTC = w_1 * F_{pg} + w_2 * h * E_{pg} \quad \$/h \qquad (7)$$

where, w_1 and w_2 are weight factors and

(i) $w_1 = 1$ and $w_2 = 0$ for pure economic dispatch

(ii) $w_1 = 0$ and $w_2 = 1$ for pure emission dispatch

(iii) $w_1 = w_2 = 1$ for combined economic emission dispatch.

The value of price penalty factor h is found out by a practical method as discussed by Kulkarni et al [9]. It is needed to obtain the value of penalty factor of each generator at its maximum output as. The following method can be adopted to calculate the penalty factor.

$$\frac{F_{pg}\left(P_{gi_{\max}}\right)/P_{gi_{\max}}}{E_{pg}\left(P_{gi_{\max}}\right)/P_{gi_{\max}}}=h_i \quad \text{(i=1.....n)} \quad \text{(Rs/Kg)}$$

h_i is then arranged in ascending order and add the maximum capacity of each unit, $P_{gi_{\max}}$ one at a time, starting from the smallest h_i unit, until

$$\sum_{i=1}^{n} P_{gi_{\max}} \geq P_D$$

At this stage, h_i associated with the last unit in the process is the value of h for the given load.

In reality, the objective function of the economic and emission dispatch problem is considered as a set of non-smooth cost functions due to the prohibited zone of operation and valve-point loadings. This paper considers different cases of cost functions. Where the valve-point effect is under consideration then the objective function is normally described as the superposition of a sinusoidal function and a quadratic function. The other case addresses only ramp rate limits, prohibited zones of power generation and transmission losses where the objective function is expressed as a quadratic function with several constraints.

2.2 CEED Problem Considering Valve-Point Effects

For more rational and precise modeling of economic and emission function, the above expression of cost function is to be modified suitably. Modern thermal power plants are designed to have generating units with multi-valve steam turbines to incorporate flexible operational facilities but it gives a very different cost curve compared with that defined by (1) and exhibit a greater discrepancy in the fuel cost curves. Typically, ripples are introduced in the fuel cost curve as each steam valve starts to operate. The valve-point effect may be considered by adding a sinusoidal function [23] to the quadratic cost function described above. Hence, the problem described by (1) is revised as follows:

$$TC_v=\sum_{i=1}^{n}\alpha_i P_{gi}^2+\beta_i P_{gi}+\gamma_i+h^*(\sum_{i=1}^{n}a_i P_{gi}^2+b_i P_{gi}+c_i) \\ +|e_i\times\sin(f_i\times(P_{gi_{\min}}-P_{gi}))|$$

where TC_v is total fuel cost of generation in ($/hr) including valve point loading, e_i , f_i are fuel cost coefficients of the i th generating unit reflecting valve-point effect.

2.3 CEED Problem With Ramp-Rate Limits and Prohibited Zone

Ramp Rate Limit

Practically, the operating range of all online units is constrained by their ramp rate limits for forcing the units to operate continuously between two adjacent specific operating periods [23],[24]. The generation may increase or decrease with corresponding upper and downward ramp rate limits. So, according to [25], [26], and [27], the inequality constraints due to ramp rate limits for unit generation changes are given as,

If power generation increases, $P_{gi}-P_{gi}^0 \leq UR_i$

If power generation decreases, $P_{gi}-P_{gi}^0 \leq DR_i$

Where P_{gi} is the power generation of unit i at previous hour and UR_i and DR_i are the upper and lower ramp rate limits respectively. The inclusion of ramp rate limits modifies the generator operation constraints (2) as follows,

$$\max\left(P_{gi_{\min}},P_{gi}^0-DR_i\right)\leq P_{gi}\leq\min\left(P_{gi_{\max}},P_{gi}^0+UR_i\right)$$

Prohibited Operating Zone

Due to steam valve operation or vibration in a shaft bearing there are some restricted zones identified in the input-output curve. Because it is difficult to determine the prohibited zone by actual performance testing or operating records, the best economy is achieved by avoiding operation in areas that are in actual operation. Symbolically, for a generating unit i,

$$P_{gi_{\min}}\leq P_{gi}\leq P_{gi,1}^l$$
$$P_{gi,j-1}^u\leq P_{gi}\leq P_{gi,j}^l\,,\ j=1,2,......n_i$$
$$P_{gi,n_i}^u\leq P_{gi}\leq P_{gi_{\max}}$$

where j is the number of prohibited zones of unit .

3 EP BASED CULTURAL ALGORITHM

3.1 Cultural Algorithm (CA)

Reynolds first proposed Cultural Algorithm (CA) as a vehicle for modeling social evolution and learning the behavioral traits [18]. It is a high level searching technique. This evolutionary technique follows the cultural evolution of the society. Every society consisting of several classes of people has some rules and regulations which are obeyed by them and their offspring. A particular class, whom we called the elite class, is selected on the basis of their knowledge & wealth. This elite class people define and regulate the norms. The knowledge and concept of those people becomes the governing factor of the society. In this way culture or knowledge progresses from generations to generations making the new generation more up-to-date and fit for the survival. CA is nothing but the mathematical implementation of this learning procedure. The knowledge acquired by individuals through generations is stored to guide the behavior of the individuals. This acquired knowledge is stored in the search space called belief space in CA during the evolution of the population. Interaction between the two basic components i.e., population space and belief space make cultural algorithm as a dual inheritance system. Population space is that where the information about individuals is stored and the belief space is where the culture knowledge is formed and maintained during the evolution of the population.

In Fig. 1, the conceptual diagram of CA is shown. Belief space is basically a set of promising variable ranges that provide standards and guidelines within which individual adjustments can be made leading the individuals to go to the good range of solution. An acceptance function *accept ()* and updating function *update ()* play very vital role in belief space. After evolution of population space with a performance function *obj (), accept ()* will determine which individuals are kept aside for Belief space. Experiences of those elite individuals will update the knowledge of the Belief space via *update ()*.These updated knowledge are used to influence the evolution of the population.

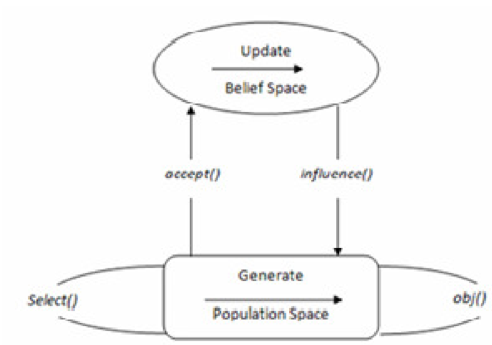

Fig1. Cultural Algorithm Concept

3.2 The Proposed Algorithm

The basic idea of using CA with evolutionary programming is to influence the mutation operator so that the current knowledge stored in the search space can be suitably implemented. The proposed method is basically a probabilistic search technique, which generates the initial parent vectors distributed uniformly in intervals within the limits and obtains global optimum solution over number of iterations. The main stages of this technique are initialization, acceptation and updating of belief space, creation of offspring vectors by mutation and competition and selection of best vectors to evaluate best solution. The implementation of the proposed algorithm is given below.

Initialization

Initial population is one of the deciding factors for reaching the optimum solution. The initial population is composed of K parent individuals who are randomly created. Each element in a population is uniformly distributed within its feasible range. The initial population should satisfy all the constraints .The initialized parent vectors are

$$X_{i,j} = \begin{bmatrix} x_{11} & x_{12} & \cdots & x_{1n} \\ x_{21} & x_{22} & \cdots & x_{2n} \\ \vdots & & & \\ x_{i1} & x_{i2} & \cdots & x_{in} \end{bmatrix}$$

i=1,2,…k and *n* is the number parameters.

Belief Space Structure

In this paper two types of knowledge are used, one is situational knowledge and another is normative knowledge. For *j* number of parameters the formal syntax of the belief space used here is *<N[j],S[j]>* , where *S* stands for situational knowledge which is the set of best individuals and Normative belief *N* is a set of interval information for each domain variable. For domain variable *j, N[j]* is represented as *<I,L,U>*. *I* denote the closed interval, that is a continuous set of real numbers, *x*, and is represented as:

$$I = [l,u] = \{x \mid l \le x \le u$$

Usually, *l* (lower bound) and *u* (upper bound) are initialized as the given domain values. *L* represents the performance score of the individual for the lower bound and *U* represents the performance score of the individual for the upper bound.

Acceptance Function

The acceptance function controls the information flow from the population space to the belief space. The acceptance function determines which individuals and their behavior impact the belief space knowledge.

Updating the Belief Space

Here in this paper, the situational knowledge *S* consists of a current best solution and the elite *S* is updated by the following rule:

$$S = \begin{cases} x_{best} \; ; f(x_{best}) \le f(s) \\ s ; otherwise \end{cases}$$

The parameter values for the current selected individuals by the acceptance function are used to determine the current satisfactory range of the normative knowledge. To update the normative knowledge minimum (x_i) and maximum (x_k) values for parameter j between the accepted individuals in the current generation are selected. Then the updated interval of normative knowledge is as follows,

$$l_j^{t+1} = \begin{cases} x_{i,j} \; , \; \text{if } x_{i,j} \le l_j^t \text{ or } f(x_i^t) < L_j^t \\ l_j^t \quad otherwise \end{cases}$$

$$L_j^{t+1} = \begin{cases} f(x_i) \quad \text{if } x_{i,j} \le l_j^t \text{ or } f(x_i) < L_j^t \\ L_j^t \quad otherwise \end{cases}$$

and

$$u_j^{t+1} = \begin{cases} x_{k,j} \; , \; \text{if } x_{k,j} \le u_j^t \text{ or } f(x_k^t) < U_j^t \\ u_j^t \quad otherwise \end{cases}$$

$$U_j^{t+1} = \begin{cases} f(x_k) \quad \text{if } x_{k,j} \le u_j^t \text{ or } f(x_k) < U_j^t \\ U_j^t \quad otherwise \end{cases}$$

Where, l_j^t represents lower bound for parameter j at generation t and L_j^t denotes the performance score for it and u_j^t represents upper bound for parameter j at generation t and U_j^t denotes the performance score for it.

Influence the Belief Space

The influence function is liable for choosing the individuals of population space within the updated interval stored in belief space. The current individual of n numbers of candidate for parameter j can be selected by the formula given,

$$x_{i+n,j} = \begin{cases} x_{n,j} + |(u_j - l_j) * N_{n,j}(0,1)| & if\ x_{n,j} < l_j \\ x_{n,j} - |(u_j - l_j) * N_{n,j}(0,1)| & if\ x_{n,j} < u_j \end{cases}$$

where u_j and l_j represent the upper value and lower value of parameter j of current elite in the belief space.

Mutation

Gaussian mutation is used for the parameter j an offspring vector $x^{'}_{i,j}$ is created from each parent by adding to each component of $x_{i,j}$, a Gaussian random variable with a zero mean and a standard deviation proportional to the scaled cost values of the parent trial solution, i.e.,

$$x^{'}_{i,j} = x_{i,j} + N(0, \sigma_i^2) \quad for\ i = 1,2.....n$$

where $N(0, \sigma_i^2)$ represents a Gaussian random variable with mean 0 and standard deviation σ_i^2 .

Selection

The selection technique used in this paper is the tournament selection method. The parent trial vectors x_i and the corresponding offspring $x^{'}_i$ (2k number) vectors compete with each other for survival within the contending group. The individuals who have the greatest number of wins will be the parents for the next generation. In this way the whole process goes on until the convergence of the program.

4 Improved Cultural EP Algorithm Implement For Economic Load Dispatch Problem

4.1 Representation of Individual String

The generation power output of every unit is chosen as a gene and many genes comprise an individual which represent a candidate solution for the ELD problems. For example, suppose there are N units that should be operated to provide power to loads, then we define the *i*-th individual P_i as,

Pi= [*Pi*1,*Pi*2,......*Pid*] *i*=,2,.......*N*, where *N* is the size of the population, *d* represents the generator number, and *Pid* means the generation power output of the *d*-th unit at *i*-th individual. We use real values to represent the genes in the individuals.

4.2 Handling of Constraint Condition

The value of each power in the population is constrained by the corresponding range. If the generation of power exceeded the span, then the method for creation of revised generation is,

if $P_{id} > P_{\max}$, then $P_{id} = P_{\max}$ and

if $P_{id} < P_{\min}$, then $P_{id} = P_{\min}$

Where $P_{\max}$ and $P_{\min}$ are the lower and upper bounds of the parameter respectively to be optimized in the *d* *d*imensional space.

5 Implementation and Simulation Results

Proposed algorithm has been implemented to CEED problems having four different generating systems to verify its viability and effectiveness. The performance of each system has been compared with other methods like PSO, GA etc. The algorithm has been written in MATLAB and run a 3.0 MHZ, 1GB RAM PC.

5.1 Description of the Test Systems

Test Case 1:

The Test system consists of three thermal generating units with the transmission loss to test the effectiveness of proposed algorithm. The cost coefficients, generation limits and emission coefficients are derived from [28] and hence not repeated here. The loss coefficient matrix given as,

$$B_{ij} = \begin{matrix} 0.000071 & 0.000030 & 0.000025 \\ 0.000030 & 0.000069 & 0.000032 \\ 0.000025 & 0.000032 & 0.000080 \end{matrix}$$

TABLE 1
Solution for three-Generator System – Pure Economic Dispatch

Unit (MW)	Demand (MW)		
	650	700	750
P1	137.7171	170.2135	166.5358
P2	272.8246	283.6523	315.2507
P3	259.9675	269.6797	295.6714
Total generation	670.5386	723.6990	777.4580
Losses	20.4728	23.5146	27.3978
Fuel Cost (Rs./hr)	32854.00	35438.00	38060.00
EmissionOutput (Kg/hr)	562.5886	654.1895	773.2569

TABLE 2
Solution for Three-Generator System – Pure Emission Dispatch

Unit (MW)	Demand (MW)		
	650	700	750
P1	154.1088	177.2582	170.4134
P2	256.2113	275.0809	308.0601
P3	259.9702	271.0957	298.9869
Total generation	670.6104	723.5040	777.5874
Losses	20.2575	23.4325	27.3537
Fuel Cost (Rs./hr)	32862.00	35450.00	38061.00
EmissionOutput (Kg/hr)	554.3053	652.1782	770.4748

The problem is solved separately for pure economic dispatch

(ELD) problem neglecting emission constraints and pure emission dispatch (EED) problem where priority is not given to the fuel cost. Finally simulate the problem for combined economic emission dispatch (CEED).

The results for optimized fuel cost, generation schedule, losses and emission output for various demands (650MW, 700MW and 750MW) are shown in the Table 1, 2 and 3 for ELD, EED and CEED respectively. The randomness of the projected method has been verified by testing with same demand for quite a few times. The convergence characteristic for minimum fuel cost is shown in fig.2.

TABLE 3
SOLUTION FOR THREE-GENERATOR SYSTEM – COMBINED ECONOMIC EMISSION DISPATCH (CEED)

Unit (MW)	Demand(MW)		
	650	700	750
P1	157.5395	182.7369	192.8946
P2	248.7636	276.0215	292.1908
P3	264.0454	264.6389	291.9240
Total generation	670.3485	723.5368	777.4081
Losses	20.2448	23.3498	27.0066
Fuel Cost ($/hr)	32876.00	35466.00	38089.00
Emission Output (Kg/hr)	553.9684	651.9255	762.5753

The performance of the proposed method is compared with genetic algorithm (GA) and particle swarm optimization (PSO) method [29] and the result is shown in Table 4. It is observed that proposed hybrid cultural algorithm based method can provide better results compared with modern heuristic methods.

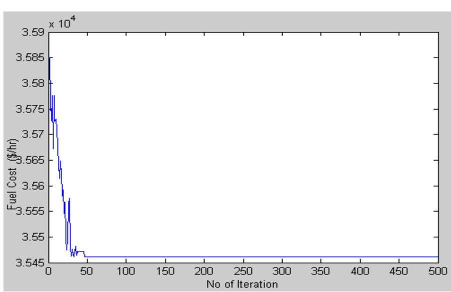

Fig. 2 Convergence characteristic for load demand 700MW

TABLE 4
COMPARISON OF RESULTS BY DIFFERENT METHODS FOR CEED WITH A DEMAND OF 650 MW

	Methods		
	EP Based CA	GA	PSO
Fuel Cost (Rs./hr)	**32876.00**	32888.6	32888.0
Emission (Kg/hr)	553.9684	551.299	551.274
Losses (MW)	20.2448	20.0477	20.0466

Test Case 2:

This system of six generators with transmission loss having quadratic cost and emission function is used in this paper. Cost and emission coefficients and generation limits of this system are taken from [30]. The simulation results obtained from the proposed method for 900MW load demand are given in Table 5.

TABLE 5
SOLUTION FOR SIX-GENERATOR SYSTEM – COMBINED ECONOMIC EMISSION DISPATCH (CEED)

	Demand (900 MW)				
	NR	FCGA	NSGA	BBO	EP Based CA
P1	122.004	111.40	120.06	115.71	76.213
P2	86.523	69.33	85.202	100.76	92.283
P3	59.947	59.43	89.57	101.45	171.56
P4	140.96	143.26	140.28	145.02	140.38
P5	325	319.40	288.61	282.06	231.58
P6	220.063	252.11	233.69	212.42	215.51
Losses	54.50	54.92	57.40	57.40	27.46
Fuel Cost (Rs./hr)	50807.24	49674.28	50126.06	50297.27	47960
Emission Output (Kg/hr)	864.060	850.29	784.696	765.087	707.33

The comparative results with NR, FCGA, NSGA, and BBO in Table 5 firm the effectiveness of the proposed method for six generator system also.

Test Case 3:

A system with six generators is used to proof the efficacy of the proposed system in this paper. Here the practical constraints like ramp rate limits and prohibited zone of operation of thermal units are considered. Cost coefficients, generation limits, ramp rate limits and data for prohibited zones of six units system are taken from [31].The transmission loss is also considered here. The best solution obtained from the proposed method for the load demand of 1200MW is given in Table 6. A convergence characteristic of the said system with load demand of 1200MW is shown in Fig.3.

TABLE 6
SOLUTION FOR SIX GENERATOR SYSTEM WITH A DEMAND OF 1200 MW HAVING RAMP RATE LIMIT AND PROHIBITED OPERATING ZONE

Unit (MW)	PSO	GA	BBO	EP Based CA
P1	329.6465	329.1083	349.2169	437.1196
P2	198.1324	198.0966	200.0000	132.9836
P3	240.0493	243.8283	211.7796	256.1380
P4	124.792	121.3974	131.0000	117.6766
P5	199.5031	199.8071	200.0000	173.0317
P6	119.9729	119.4460	120.0000	94.5980
Total generation	1212.116	1212.173	1211.997	1212.1
Losses	12.116	12.1823	11.9964	11.5353
Fuel Cost ($/hr)	14725.4	14725.9	14715.4	14611.00
Emission (Kg/hr)	2790.95	2797.0	2766.9	3337.1

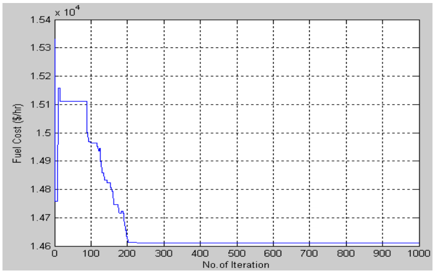

Fig. 3 Convergence characteristic for load demand 1200MW

Test Case 4:

In this case a fourteen generator system with valve point discontinuity is used in this paper. Cost coefficients and generation limits of fourteen units system are taken from [32].The transmission loss is considered here. The best solution obtained from the proposed method is given in Table 7. The method gives the comparable solution. A convergence characteristic of the said system with load demand of 2500MW is shown in Fig.4.

TABLE 7
SOLUTION FOR FOURTEEN GENERATOR SYSTEM WITH A DEMAND OF 2500 MW

Unit (MW)	DE	PSO	GA	BBO	EP Based CA
P1	329.53	329.520	339.119	329.520	417.1010
P2	219.54	150.000	226.037	157.368	325.9805
P3	129.99	130.000	103.585	130.000	82.5994
P4	120.06	129.999	122.985	130.000	111.7550
P5	249.75	231.14	250.000	249.748	237.0330
P6	384.25	384.33	420.894	434.221	419.8427
P7	284.43	284.600	258.318	284.741	288.2073
P8	209.56	300.000	240.000	209.825	243.0497
P9	161.74	162.000	162.924	162.000	140.2797
P10	159.89	160.000	138.968	160.000	118.7059
P11	79.95	80.0000	68.667	80.000	30.6858
P12	79.93	80.0000	79.990	80.000	55.7411
P13	84.84	85.0000	84.562	85.000	58.5843
P14	52.65	52.3999	52.401	54.999	41.4455
Total generation	2546.1	2559.0	2548.4	2547.42	2546.6
Losses	46.11	58.9872	48.449	47.4223	46.7349
Fuel Cost ($/hr)	12,871	13,427.0	13,301.8	13,223.7	12,496.0
Emission (Kg/hr)	6,316.3	6,188.5	6,619.2	6,054.2	8,838.4

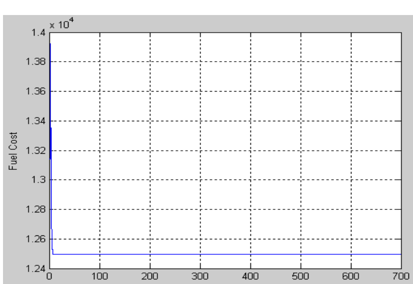

Fig. 4 Convergence characteristic for load demand 2500MW

5.2 Determination of Parameters for Proposed Algorithm

The parameter values are selected by trial and error method. The following values are selected for optimal results. Population size is 50, mutation probability is taken as 0.75, and maximum iterative generation number is 500 for three generator system. And maximum iterative generation number 1000 with population size 100 and mutation probability as 0.75 is taken for six generator system. And the maximum iterative generation number 700 with population size 250 is taken for fourteen generator system.

5.3 A Comparative Study

In the first case the optimal results are shown in Table 1,2 and 3. Table 3 shows that the result of the fuel cost and emission is good enough with respect to Table 1 and Table 2to proof the effectiveness of the objective function through the proposed method. It is seen from Table 4, it is found that optimal fuel cost for three generator systm (32876.00 Rs/hr) is comparatively lower than the fuel cost obtained in PSO(32888.0 Rs/hr) and in GA(32888.6 Rs/hr) [28].

In the second example the fuel cost (47960 $/hr) as well as the emission output (707.33 Kg/hr) obtained from the proposed method is much lower than the other methods like NR (50807.24 $/hr, 864.060 lb/hr), FCGA (49674.28 $/hr, 850.29 lb/hr), NSGA (50126.06 $/hr, 784.696 lb/hr) and BBO (50297.27 $/hr, 765.087 lb/hr). In case of six generator system of test system three for load demand of 1200MW, the fuel cost is 14,725.4 $/hr in PSO and in GA it was 14,725.9$/hr and 14,715.4 $/hr in BBO. But from the Table 6 it is seen that the fuel cost (14,611 $/hr) obtained in proposed method is comparatively lower than the other methods.

The effectiveness of the proposed method is also determined for a large system of fourteen generators. The comparative test results with DE (12871$/hr), PSO (13427 $/hr), GA (13301.8 $/hr) and BBO (13223.7 $/hr) verifies better solution of proposed method (12496 $/hr).

6 CONCLUTION

This paper has proposed a different approach to cultural algorithm for the combined economic and emission problem in power systems. The simulation results have shown that the proposed method is better than other methods in terms of the convergence characteristics and accuracy. Practical generator operation is modeled using several non linear characteristics like ramp rate limits, prohibited operating zones. From this limited comparative study, it can be concluded that the applied algorithm can be effectively used to solve smooth as well as non-smooth constrained CEED problems. In future, efforts will be made to incorporate more realistic constraints to the problem structure and the practical large sized problems would be attempted by the proposed methodology.

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