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CLONAL ALGORITHM FOR EMISSION CONSTRAINED ECONOMIC DISPATCH PROBLEM IN THERMAL POWER PLANTS

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ABSTRACT

These days, power system planners are looking for ways to reduce emission from power generating stations especially coal based thermal power plants without compromising the load factor. The economic dispatch problem allocates units for a given load without considering its emission. The present paper proposes a multi-objective optimization method, which uses Artificial Immune System based Clonal Selection Algorithm to solve problems related to emissions and economic dispatch along with unit commitment of generators in a thermal power system. A penalty factor has been imposed for violating the critical emission limits which is subject to the impact it causes on the environment. An 'Artificial Immune System' based Clonal Selection principle is used to select a suitable generator from a pool of generator units. Fitness has been evaluated for the proliferated units. Emission constrained Economic Dispatch problem involves power demand equality and inequality constraints under various operating conditions. Finally, the best units are selected and committed for a given load. The 'Clonal Selection' method has been compared with Non-Dominated Ranked Genetic Algorithm (NGDA) and Clonal Algorithms to prove its robustness and superior optimal selection. To understand the proposed method, a IEEE -30 bus 6 unit test system (with and without load uncertainty) is considered for solving the EED problem using MATLAB simulation and results are compared.

Keywords: Artificial Immune System (AIS), Clonal Selection Algorithm (CSA), Emission constrained Economic load Dispatch (EED), Non-Dominated ranked Genetic Algorithm (NDGA).

1. INTRODUCTION

Presently, Thermal power plants are largely used for power generation in India. The coal used in these plants is of poor quality and so produces large amounts of ash. Handling, burning poor quality coal and disposing the ash pose serious emission related environmental problems. The objective of the present paper is to find the extent to which power plants cause air pollution. Combustion of coal in the power plants causes emission of atmospheric pollutants like Sulphur Dioxide (SO_2) and Oxides of Nitrogen (Nox). These pollutants adversely affect humans, plants and animals. Minimum emission limits should be imposed by governmental and regulatory bodies in order to check and minimise air pollution effectively.

Economy and reliability are the two important factors that form the basis for the operation and planning of a power system. At the same time, a power plant has to meet the power demand, account for losses during transmission and operate within the constraints at a minimum cost. Economic Load Dispatch [1] ED is a minimization problem, so optimal generation dispatch problems have been limited to minimizing the total power generation cost. However, following the emission control regulations in the recent years, emission control has become a vital operational objective.

Conventional methods have multiple setbacks. They need lot of computational time, require more memory space, linear equations and slow convergence like Dynamic Programming (DP) [2], Linear Programming (LP) [3], Lagrange Relaxation method (LR) [4], Direct Search method (DS) [5]. Solving nonlinear programming also involves many issues. In recent times, heuristic methods like Evolutionary Programming (EP) [6], Simulated Annealing (SA) [7], Genetic Algorithm (GA) [8], Ant Colony Optimization (ACO) [9], Particle Swarm Optimization (PSO) [10], Tabu Search (TS) [11], Fuzzy based System (FS) [12] are used to achieve effective performance and find optimal solutions. A reliable search method has to be chosen for arriving at a global or near global solution.

Heuristic methods provide fast and reasonable solutions. However, they cannot guarantee the discovery of globally optimal solutions in finite time. For some problems, EP converges slowly or optimally. SA cannot be used for tuning the controlling parameters of annealing schedule, as it demands considerable amount of time. Using TS for defining problem oriented effective memory structures and strategies are difficult. At times, GA fails to produce a better offspring. It causes slow convergence near global optimum and sometimes it may be trapped into the local optimum. Differential Equation's high updating principle and inherent differential property often leads the computing process to be stuck at local optima.

In this paper, a multi-objective NDGA approach and adaptive penalty function that uses ranks as penalty parameters is used to arrive at possible Pareto front solutions [13], [14].NDGA is used to compare the effectiveness and robustness of the Clonal Selection Principle for the selected test system.

2. FORMULATION OF THE PROBLEM

The objective of the EED is to reduce the conflicting objectives of fuel cost and emission and at the same time, satisfy equality and inequality constraints. This problem can be expressed as follows:

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The multi-objective linked EED problem with its constraints can be expressed mathematically as a

$$\left[F_C = \sum_{i=1}^{n} F_i\,(P_i) = \sum_{i=1}^{n} (a_i\, P_{i,max}^2 + b_i P_{i,max} + c_i\ )\right][Rs/hr] \quad (1)$$

Where, Fc is the Total Fuel Cost, F_i is the fuel cost of the i^{th} generator, P_i is the real power generation of unit i. a_i, b_i,c_i - are the cost coefficients of generating unit i and n is the number of generating units operating under constraints.

A. Power Balance Constraint

$$\sum_{i=1}^{n} Pi = P_G = P_D\ [MW] \quad (2)$$

(P_G = Total power generation of the system and P_D = Total demand of the system)

B. Generation capacity constraint

For reliable operation, the actual power outputs of the individual generators must be regulated by imposing lower and upper limits:

$$P_{i_{min}} \leq P_i \leq P_{i_{max}}\ [MW] \quad (3)$$

i = 1, 2, …, n (Pi,min = minimum value of real power allowed at generator i and Pi,max = maximum value of real power allowed at Generator i)

C. Problem objectives

a) Reduction of emission

Sulphur dioxide, oxides of nitrogen and carbon dioxide are the major pollutants emitted from a thermal power plant. The problem formulation aims at reducing these emissions. The problem objective can be expressed by the following equation:

$$E_T = \sum_{i=1}^{n} \left(d_i P_{i,max}^2 + e_i P_{i,max} + f_i\right)\ [Kg/hr] \quad (4)$$

(E_T = Total emission and d_i = Emission coefficients of generating unit i)

Through the introduction of price penalty factor hi, multi-objective optimization is transformed into a single objective optimization. This can be expressed as follows:

$$F_T = \sum_{i=1}^{n} (a_i\, P_{i,max}^2 + b_i P_{i,max} + c_i\ ) + h_i\left(d_i P_i^2 + e_i P_i\ + f_i\right)[Rs/hr] \quad (5)$$

(F_T = fuel cost of EED and h_i= Price penalty factor)

b) Formulation of price penalty factor for CEED problem

For each plant, the price penalty factor can be found for a particular power demand as follows:

a) Ratio between the maximum fuel cost and the maximum emission of the generating unit of that plant is determined. It can be expressed as:

$$h_i = F(P_i, max) / E\,(P_i, max) \quad (6)$$

nonlinearly constrained problem: Minimize

b) According to the value of the price penalty factor, power plants are arranged in an ascending order.

c) Starting from the smallest value of hi unit, the maximum capacity of each unit Ui, is added one at time, till

$$\Sigma P_i \geqslant P_d \quad (7)$$

d) For the given load demand, hi related to the last unit in the process is the price penalty factor ‘h’, Rs/Kg.

3. ARTIFICIAL IMMUNE SYSTEM - AN OVERVIEW

As an optimization algorithm, the Artificial Immune System is inspired by the principles and processes of the vertebrate immune system. The AIS uses the characteristics of learning and memory like the vertebrate immune system in order to solve a problem effectively.

a) Implementation of Artificial Immune System (AIS)

The Artificial Immune System applied to the CEED problem utilises four main features. First, a pool of immune cells or antibodies is created. Following this, proliferation takes place by cloning or copying the parents. Then, these clones are allowed to mature. This process can be compared to a hyper mutation. Next, the antibody-antigen interaction is assessed. Finally, the self-reacting immune cells or lymphocytes are eliminated.

b) Encoding, initialization and cloning

Using binary strings, an antibody population is initialized. Each encoding represents a solution to given CEED problem. A string is formed by encoding the power output from each of the generating unit in a binary form. The present paper refers to lymphocytes as antibodies. It does not differentiate a B-cell and its corresponding antibody. Individual binary strings are checked for constraint violation. In case of infeasibility, they are penalized with a penalty that is equivalent to the of constraint violation. Fitness or objective values are used to calculate affinity. The antibodies from the initial pool are copied into a fixed number of clones. Using these clones, a temporary population of clones is created. This clone population is allowed to mature through hyper mutation.

Hyper mutation is performed through an affinity based hyper mutation rate. For clones with lower affinity, a larger hyper mutation rate is set and vice versa. Affinity is evaluated and penalty in the event of violation of constraint is then carried out. A new population of antibodies which is of the same size as the initial population is selected from modified clones. This completes the first cycle.

In the cycle that follows, this fresh population of antibodies undergoes cloning and hyper mutation. The cycle discussed above is carried out again on these. In

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order to obtain the global optimal solution for CEED problem, the following parameters were identified:

c) Selection of parameters

Size of the population = 30
Length of the string = 15
Max. no. of generations = 100
Hyper mutation probability = 0.035-0.010

d) Stopping criterion

Criteria like tolerance, number of functional evaluations and maximum number of cycles are available to stop a stochastic optimization algorithm. In order to correlate with the previously obtained results, the criterion of maximum number of cycles is chosen as the stopping criterion in this paper. Stopping criteria which is taken as the number of cycles is maintained to a maximum of 100. Implementation of AIS to solve CEED problem is explained in the following steps and the algorithm used for the above purpose is given below:

Step 1: In order to check for constraint violation, binary strings are generated randomly and then interpreted into real values.

Step 2: In the event of violation of constraint, the string is generated randomly again, decoded and verified for violation. This process is iterated till a specific population size of is reached.

Step 3: When the population reaches its full size, the antibodies are evaluated and their clones are produced.

Step 4: Through hyper mutation, the clone population becomes mature.

Step 5: The clones which are mutated are decoded. Then, their fitness values are assessed.

Step 6: Selection of tournament is performed to choose the same number of mutated clones as there were in initial population. This completes a cycle of CSA.

Step 7: This process (steps 1 to 6) is repeated until a maximum number of cycles is reached. (a stopping criteria of 100 cycles is maintained).

4. PROPOSED METHOD

This paper proposes the Artificial Immune System for solving the combinatorial objective function of Economic and Emission Dispatch problem.

Minimize as in Eqn. (1) subject to constraints in power balance and emission limit. Eqn. (2) and Eqn. (4) gives the 'price penalty factor' or 'scaling factor'. It is multiplied with the emission function and an equivalent cost curve in Rs/hr is arrived. Price penalty factor value shows comparative significance between two objectives. The constrained optimization problem of Eqn. (1) along with power balance constraint of Eqn. (2) and generation limit constraint of Eqn. (3) can be resolved for a desirable number of generations with a particular penalty factor value.

The AIS based Optimization problem of EED, provides the solution by selecting the parameters like size of the population, length of the string, maximum number of generations and hyper mutation probability. The net fuel cost and emissions can be computed as shown in Figure-1 and Figure-2. The flow chart represents the problem variables and the formation of a fitness function.

5. CASE STUDY

The loads of 700MW and 900MW of IEEE-30 bus system is considered. AIS is applied to the system for obtaining economic load dispatch of the similar load under the same objective functions are performed. Table - 1 shows the economic load dispatch of the system with all constraints.Table-2 shows the comparison results of NDGA and Clonal algorithm.

Table-1. IEEE - 30 bus 6 generating units system.

No. of Units	Generator limits (MW)		Fuel cost coefficients			Emission coefficients		
	P_{max}	P_{min}	ax e-2	b	C	dx e^{-4}	exe^{-2}	f
1	125	10	15.3	38.540	756.8	42	33	13.86
2	150	10	10.6	46.160	451.32	42	33	13.86
3	225	35	2.80	40.400	1050	68.3	-54.55	40.27
4	210	35	3.55	38.310	1243.53	68.3	-54.55	40.27
5	325	130	2.11	36.328	1658.570	46	-51.12	42.9
6	315	125	1.80	38.270	1356.660	46	-51.12	42.9

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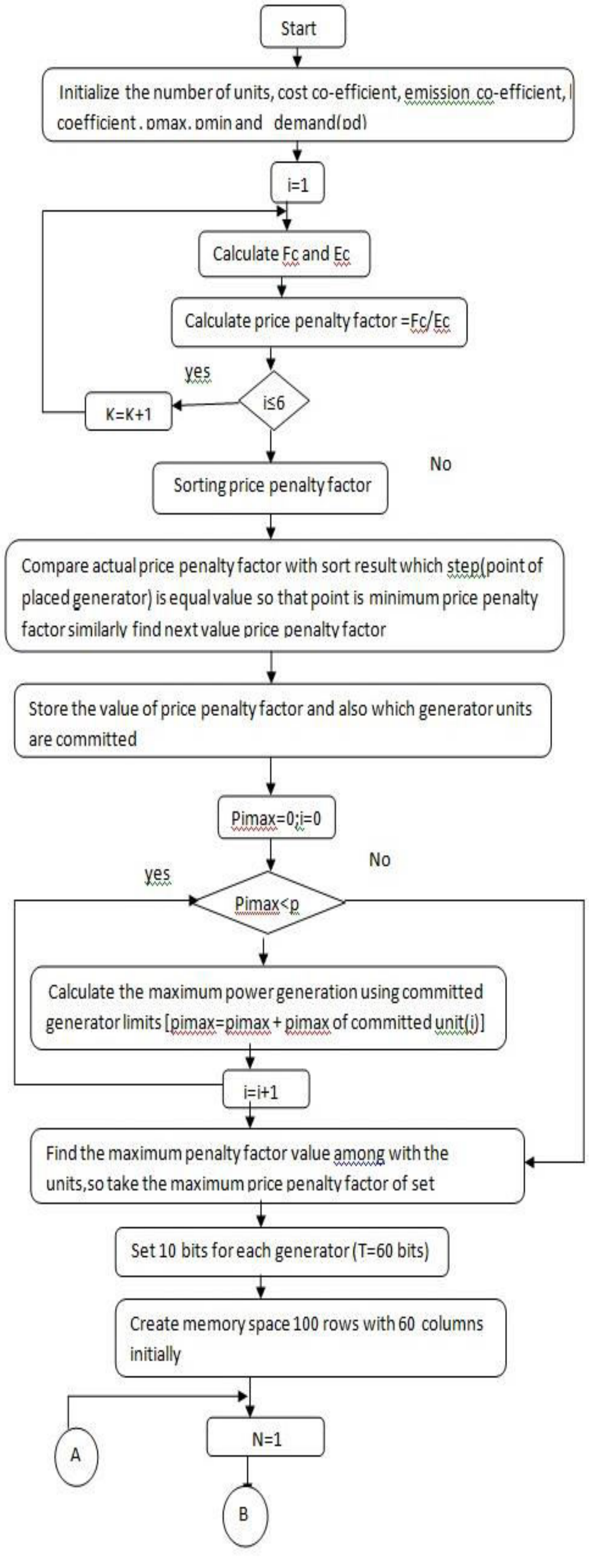

Figure-1.

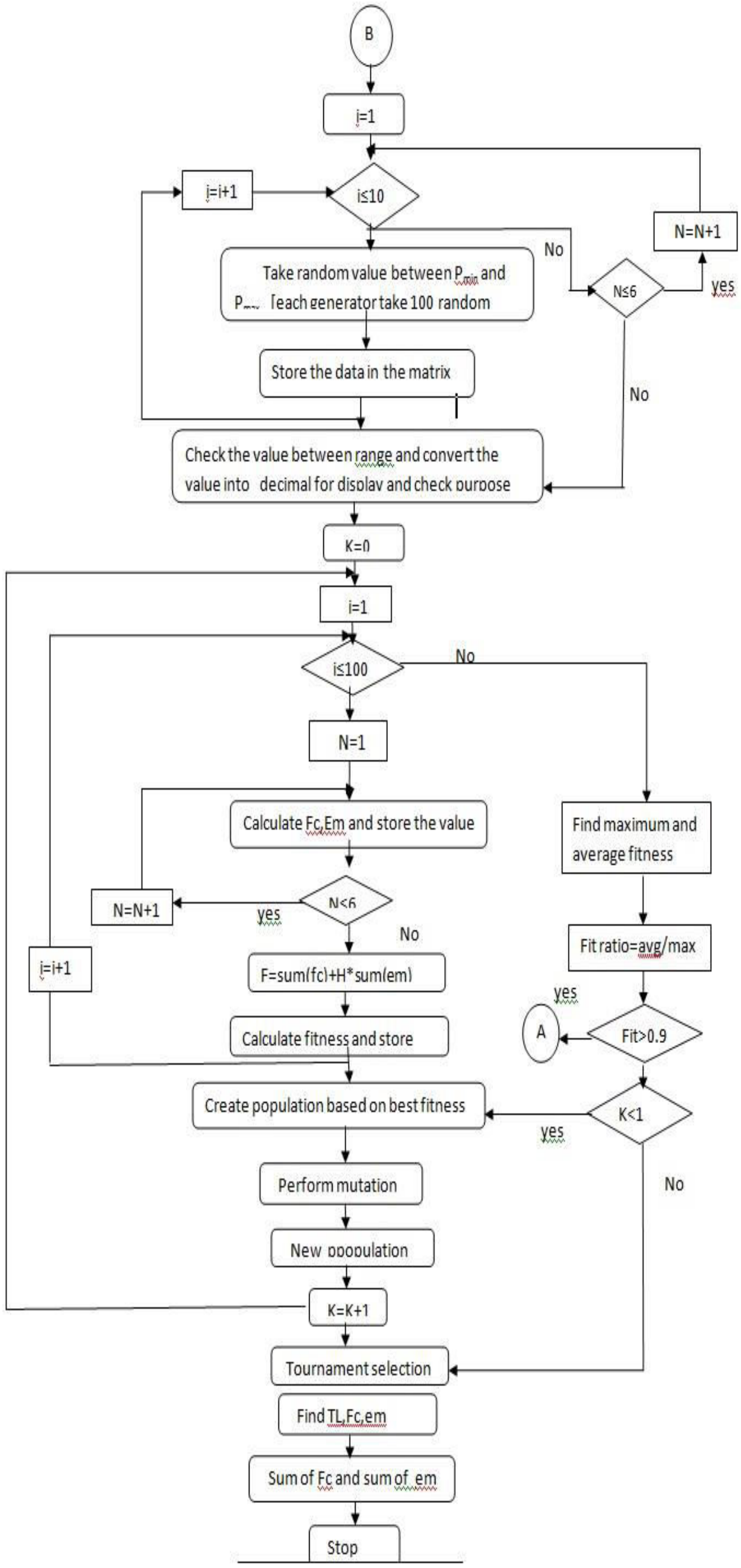

Figure-2.

Figure-1 and Figure-2 shows the flow chart for combined economic and emission dispatch using AIS.

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Table-2. Comparison of results with NDGA and AIS for a given power demand and penalty factor.

Algorithm	**Power demand** (MW)	**Penalty factor**	**Generating schedule** P_G (MW)						**Loss** P_L (MW)	**Cost of fuel** (Rs/hr)	**Emission** (Kg/hr)
CLONAL	700	44.7879	100.381	52.013	116.720	104.452	159.354	183.132	17.308	38031.1	441.058
NDGA	900	44.7879	29.9031	120.32	153.659	101.812	166.777	143.311	15.794	38529.3	464.784
CLONAL	700	47.8222	85.4301	91.153	175.039	186.564	155.733	231.979	27.525	48335.2	728.736
NDGA	900	47.8222	86.7206	116.21	210.764	158.334	193.286	160.998	26.340	48951.2	732.541

The loss coefficient B_{mn} of 6-unit system (in the Order of 10^{-4})

$$B_{mn}= \begin{matrix} 1.40 & 0.17 & 0.19 & 0.26 & 0.26 & 0.22 \\ 0.17 & 0.60 & 0.16 & 0.15 & 0.15 & 0.20 \\ 0.15 & 0.13 & 0.17 & 0.24 & 0.24 & 0.19 \\ 0.19 & 0.16 & 0.71 & 0.30 & 0.30 & 0.25 \\ 0.26 & 0.15 & 0.24 & 0.69 & 0.69 & 0.32 \\ 0.22 & 0.20 & 0.19 & 0.32 & 0.32 & 0.85 \end{matrix}$$

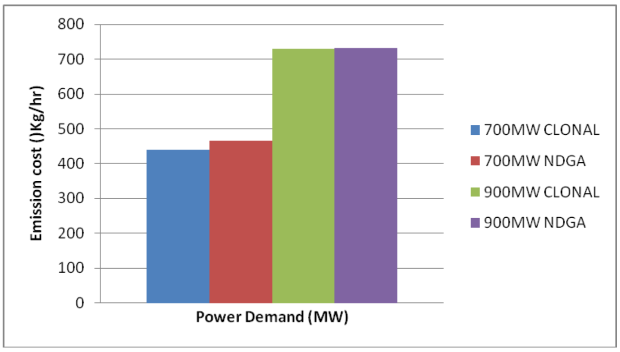

Figure-3. Comparison of emission (Kg/hr) from Clonal and NDGA for 700MW and 900MW power demand.

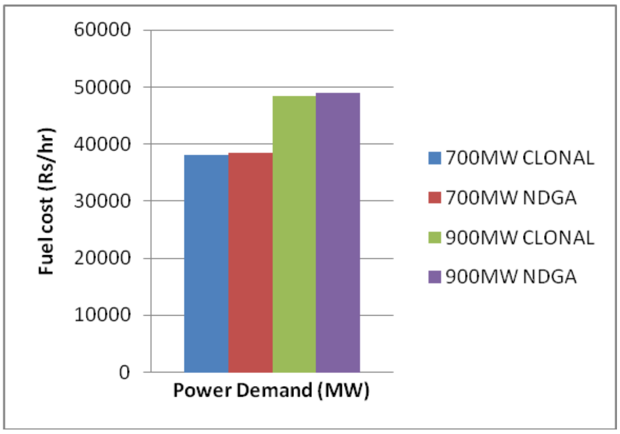

Figure-4. Comparison of fuel cost (Rs/hr) from Clonal and NDGA for 700MW and 900MW power demand.

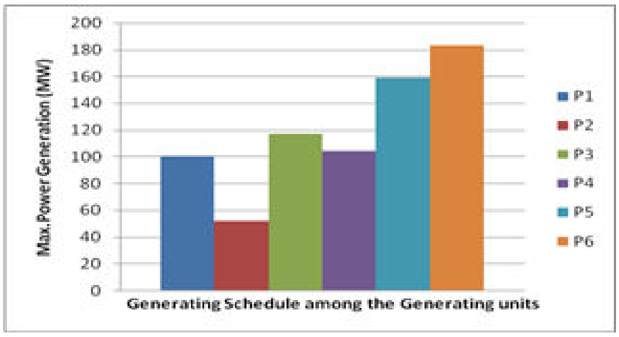

Figure-5. Contribution of six generating units with penalty factor.

6. RESULTS AND DISCUSSIONS

The CEED models proposed are validated and tried on an IEEE 30-bus system six units system to demonstrate the performance of the algorithm intended to solve the ELD problem considering the constraints related to line flow and emission. In the suggested approach, for the CEED schedule, using different intelligent techniques such as NDGA and Clonal algorithm, minimal generation and unit generating cost are obtained considering system and power flow constraints.

Table-1 shows the characteristics of the IEEE 30-bus system. Table-3 shows the real power generation output and transitional cost arrived for IEEE 30-bus system by applying intelligent techniques.

Figure-3 to Figure-5 show the criteria for convergence of the IEEE 30-bus system while considering line flow constraints and using NDGA and Clonal algorithm and also provides a comparison of minimal total production cost obtained for a power demand of 700 and 900 MW using NDGA and Clonal Selection Algorithm. It can be inferred from Table-2 that the total minimal production cost got by using Clonal Selection algorithm is relatively smaller when compared to other algorithms

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examined in the beginning of this paper. Number of generations needed for arriving at a convergence in Clonal Selection Algorithm is rather large when compared to other intelligent techniques are discussed.

7. CONCLUSIONS

In this paper, a list of optimal units for the given load is tested. The committed units are economically justified through fuel cost function. Emission from the same units are justified through a penalty factor method using Artificial Immune System based Clonal Selection principle. The proposed method was implemented in 6 unit test system. The results obtained were compared with the NDGA method. The comparative analysis proves the accuracy of fast convergence with a target value of the objective Emission function of a constrained Economic Dispatch problem. This can also be implemented in a larger system.

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