Environment Friendly BB-BC Optimized Economic Dispatch with Real and Reactive Power Constraints

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ABSTRACT
The basic objective of Economic Dispatch (ED) of electric power generation is to schedule the committed generating unit outputs to meet the load demand at minimum operating cost subject to equality and inequality constraints. In recent years with increasing awareness about environmental issues this problem has taken an essential development i.e. economic dispatch now includes the dispatch of power to minimize pollutants (from fossil fuel power generating units), as well as to achieve minimum cost. This paper presents comparative study of two algorithms namely Particle Swarm Optimization (PSO) and Big Bang-Big Crunch Optimization (BB-BC) which are implemented on Environment Friendly BB-BC Optimized Economic Dispatch with Real and Reactive Power Constraints problem. It is shown that the performance of BB-BC method demonstrates superiority over PSO algorithm.

Keywords
Particle Swarm Optimization, Big Bang–Big Crunch, economic Dispatch, emission dispatch, fuel cost function, total emission function, penalty factor.

1. INTRODUCTION
The typical economic dispatch problem involves minimization in total operating cost by means of appropriate allotment of total power to be generated by different power generating units. Fossil fuel power generating units are main producer of large amount of emission which includes various harmful gases such as sulfur oxides (SO_2) and nitrogen oxides (NO_x) also some greenhouse gases such as carbon dioxide and chlorofluorocarbons which severely affect the atmosphere. But with the increasing awareness of the environmental pollution caused by these plants, basic economic dispatch is very unsatisfactory as the requirements of environmental protection cannot be accommodated by the traditional economic power dispatch, because it particularly concerns about only reduction in operating cost. The existence of emission dispatch leads to the formulation of Environment Friendly Economic Dispatch.

The main emissions from thermal power plants are the oxides of sulfur and nitrogen which are major contributor to acidic discharge. Hence these emissions are responsible for, producing harmful global warming [1].

The typical economic dispatch reduces total operating cost of the system but this increases the amount of emission where as simple emission dispatch can reduce total emission from the system but operating cost of the system becomes larger in this case. Therefore the Environment Friendly Economic dispatch with Real and Reactive Power constraints finds the optimum solution operating point at which real and reactive power constraints are also satisfied.

There are several optimization techniques such as lambda iteration, quadratic programming, linear programming, non-linear programming, and intelligent search methods (e.g. genetic algorithm [2], evolutionary programming [3], [4], Differential evolution, particle swarm optimization [1], [5], [6] etc) are employed for solving the various economic dispatch problems. A relatively new optimization technique which is based on development of universe namely, the Big Bang - Big Crunch optimization technique introduced by Erol and Eksin, which is having relatively higher convergence speed with low computational time [7], [8], [9].

2. ENVIRONMENT FRIENDLY ECONOMIC DISPATCH WITH REAL AND REACTIVE POWER CONSTRAINTS

2.1 Economic Load Dispatch

2.1.1 Problem Description
The main objective of Economic Load Dispatch (ELD) is to minimize the fuel cost while satisfying the load demand with transmission constraints.

2.1.2 Objective Function

$$\text{minimize } F_t = \sum_{i=1}^{n} F_i(P_i) \qquad \ldots\ldots\ldots..(1)$$

$$F_i(P_i) = \alpha_i P_i^2 + \beta_i P_i + \gamma_i \qquad \ldots\ldots\ldots.(2)$$

Where

F_t	total fuel cost of the generation,
$F_i(P_i)$	fuel cost function of i^{th} generator,
$\alpha_i, \beta_i, \gamma_i$	cost coefficients of i^{th} generator,
P_i	real power generation of i^{th} generator,
n	represents number of generators connected in the network.

The above objective function has to be minimized with satisfying following constraints.

The real power balance constraint

$$\sum_{i=1}^{n_g} P_i - P_D - P_L = 0 \qquad \ldots\ldots\ldots..(3)$$

Where

P_D	total real power demand of the system and
P_L	real power losses of the system obtained from load flow.

The reactive power balance constraint

$$\sum_{i=1}^{n_g} Q_i - Q_D - Q_L = 0 \qquad \ldots\ldots\ldots..(4)$$

Where

Q_D	total load of the system and
Q_L	reactive power losses of the system obtained from load flow.

The inequality constraint on real power generation P_i and reactive power generation for each generator are given by

$$P_i^{(min)} \leq P_i \leq P_i^{(max)} \quad \ldots\ldots\ldots..(5)$$

$$Q_i^{(min)} \leq Q_i \leq Q_i^{(max)} \quad \ldots\ldots\ldots..(6)$$

Where in equation (5) P_i^{min} and P_i^{max} are respectively minimum and maximum values of real power allowed at generator i. and in equation (6) Q_i^{min} and Q_i^{max} are respectively minimum and maximum values of reactive power allowed at generator i.

2.2 Environment Friendly Economic Dispatch with Real and Reactive Power Constraints

2.2.1 Problem Description

The conventional economic dispatch may not be best in terms of environmental criteria. The reduction in the amount of harmful ecological effects by emission of gaseous pollutants from fossil fuel power generating units can be obtained by proper load allocation among the various generating units of plant. But it causes increase in the operating cost therefore it is necessary to find the optimum solution which can be achieved by Environment Friendly Economic dispatch with Real and Reactive Power constraints [5].

2.2.2 Objective Function

$$\text{Minimize } [FC, E] = \sum_{i=1}^{n} (\alpha_i P_i^2 + \beta_i P_i + \gamma_i)$$

$$+h \sum_{i=1}^{n} (a_i P_i^2 + b_i P_i + c_i) \quad \ldots\ldots\ldots..(7)$$

Where

FC	expected fuel cost,
E	expected emission,
n	number of generating units,
$\alpha_i, \beta_i, \gamma_i$	cost coefficients of i^{th} generator,
a, b_i, c_i	emission coefficients of i^{th} generator,
P_i	real power generation of i^{th} generator,
h	price penalty factor.

In above equation dual-objective function is converted into single optimization problem by using price penalty factor h which blends emission with fuel cost. The approximate value of h can be determined by following steps:

<u>Step 1</u>: Compute the average cost of each generator at its maximum output; i.e.

$$\frac{FC(P_i^{max})}{(P_i^{max})} \quad Rs/MWhr \quad \ldots\ldots\ldots..(8)$$

<u>Step 2</u>: Compute the average NO_X emission of each generator at its maximum output; i.e.

$$\frac{E(P_i^{max})}{(P_i^{max})} \quad kg/MWhr \quad \ldots\ldots...(9)$$

<u>Step 3</u>: from above equation Penalty factor can be obtained as;

$$\frac{FC(P_i^{max})}{E(P_i^{max})} = h_i \quad Rs/kg \quad \ldots\ldots.(10)$$

<u>Step 4</u>: Arrange the values of price penalty factor (h_i ,i=1, 2, ….,n) in ascending order.

<u>Step 5</u>: Add the maximum capacity of each unit (P_i^{max}) one at a time, starting from the smallest h_i unit until $\sum_{i=1}^{n} P_i^{max} \geq$ Pidemand, where Pidemand is the power demand.

<u>Step 6</u>: At this stage, h_i associated with the last generator in the process is the price penalty factor h_i (Rs/kg) for the given power demand [5].

3. ENVIRONMENT FRIENDLY ECONOMIC DISPATCH WITH REAL AND REACTIVE POWER CONSTRAINTS USING PSO

3.1 Overview of Particle Swarm Optimization (PSO)

Particle swarm optimization (PSO) is a population based stochastic optimization technique developed by Dr. Ebehart and Dr. Kennedy in 1995, inspired by social behavior of bird flocking or fish schooling [10], [11]. Consider that the number of birds searching food in a field and the food is located only at one point in that field also all the birds are not aware of the location of food but they know the distance of food, so the best way for finding the food is to follow the bird, which is nearest to the food. PSO applied this strategy to solve the optimization problems. In PSO, each single particle acts as a bird. All the particles having fitness values, which are calculated by the fitness function of the particular problem and they also having velocities, which shows the particle's movement in the field. For each particle the current position, velocity and the best position found in the search field by swarm are kept as a record.

Let X and V denote a particle coordinates (position) and its corresponding flight speed (velocity) in a search space, respectively, which can be determined within their minimum and maximum range by following equations:

$$X_i^u = X_{min} + (rand * (X_{max} - X_{min})/V_{max}) \ldots..(11)$$

$$V_i^u = 0.4 * rand * V_{max} \quad \ldots\ldots\ldots..(12)$$

The best previous position of a particle is recorded and represented as personal best or *pbest*. The location of the best particle among all the particles in the group is represented as global best or *gbest*. The particle tries to modify its position using the current velocity and the distance from *pbest* and *gbest* [11]. The velocity and position of each particle can be updated using the following equations:

$$V_i^{(u+1)} = W * V_i^{(u)} + C_1 * rand1 * (pbset_i - X_i^u) + C_2 * rand2 * (gbest_i - X_i^{(u)}) \quad \ldots\ldots..(13)$$

$$X_i^{(u+1)} = X_i^u + V_i^{(u+1)} \quad \ldots\ldots\ldots..(14)$$

Where

V_i^u	velocity of particle i at iteration u,
W	inertia weight factor,
C_1, C_2	acceleration constants,
rand1, rand2	random number between 0 and 1,
X_i^u	position of particle i at iteration u.

In equation (13) the first term is the inertia component, mainly responsible for moving particle in the same direction towards its original address. The value of the inertia coefficient W is typically between 0.8 and 1.2, which can either accelerate or decelerate the particle in its original direction. The lower values of the inertia coefficient are responsible for higher convergence speed where as higher values of W force it to cover entire search space for obtaining better solution. The second term called the cognitive component C_1, which plays the role of particle's memory, causing it to return to the area of the search field where it has higher individual fitness. The cognitive coefficient C_1 usually lies between 0 to 2, and this affects the size of the step by which particle obtains its personal best solution. The third term called the social component which forces the particle to move towards the highest fitness swarm has achieved so far. The value of social coefficient C_2 also lies between 0 to 2 and it indicates the size of the step by which particle runs towards the global best solution. The inertia weight W is linearly decreasing as the iteration proceeds and obtained as [12]:

$$W = W_{max} - \frac{(W_{max} - W_{min})}{ITER_{max}} \times ITER \quad \dots\dots\dots (15)$$

3.2 Optimization Algorithm

1. Generate the particles:
   $X_{gi} = [X_{i1}, X_{i2}, \dots, X_{in}]$ ……….(16)
   (Using equation (11)).
2. Generate the velocity V_i (using equation (12)).
3. Evaluate the fitness function.
4. Evaluate *pbest* value and then identify *gbest* value.
5. Update the velocities (using equation 13).
6. Update generation (using equation 14).

3.3 Implementation of Proposed Algorithm

The practical Environment Friendly Economic dispatch with Real and Reactive Power constraints problems are represented as a nonlinear programming problem with equality and inequality constraints, and this makes the problem of finding the global optimum difficult. This study presents an optimal solution to the Environmental Economic dispatch with Real and Reactive Power constraints problem using the PSO algorithm.

Fitness= equ.(7)+P_{pf} *[equ.(3)]+Q_{pf}*[equ.(4)] …… (17)

Its implementation can be better understood by following flow chart:

In equation (17) P_{pf} and Q_{pf} are real power balance penalty factor and reactive power balance penalty factor which are placed into objective function in such a way that these impose the penalty for any violations of the constraints and force the optimal solution towards the appropriate region.

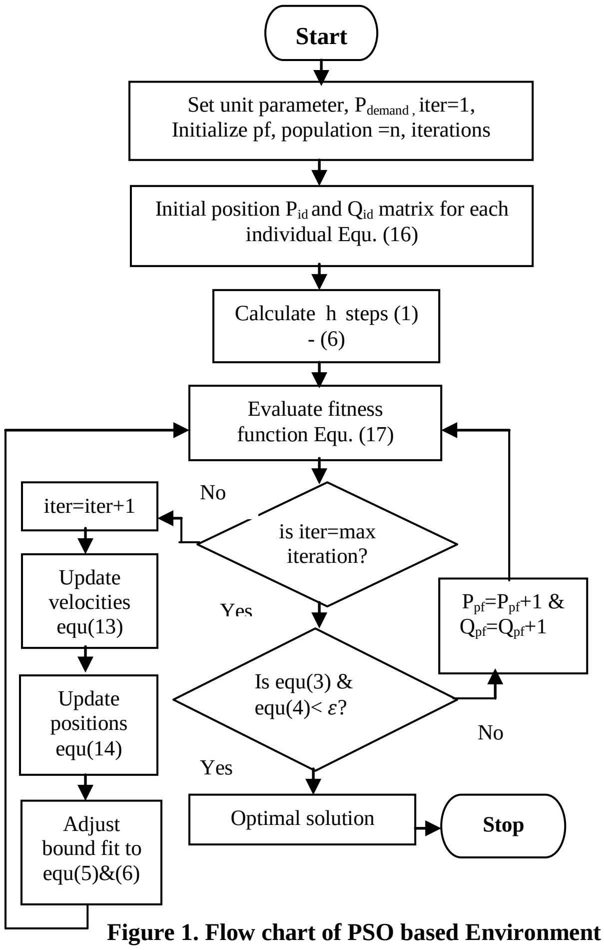

Figure 1. Flow chart of PSO based Environment Friendly Economic dispatch with Real and Reactive Power constraints problem

4. ENVIRONMENT FRIENDLY ECONOMIC DISPATCH WITH REAL AND REACTIVE POWER CONSTRAINTS USING BB-BC OPTIMIZATION

4.1 Overview of Big Bang-Big Crunch Optimization (BB-BC)

About the growth of universe there are two famous theories: Big bang and Big crunch theories. Big bang theory states that the universe originally was in an extremely hot and infinitely dense state that expanded rapidly and due to expansion has since cooled and continues to expand today. This theory only explains the commencement of universe very well, but doesn't explain the end of the universe. Another theory considered by astronomers is namely Big Crunch theory which is about the end of the universe according to this theory universe's expansion, which is due to Big Bang, will stop at a certain point and eventually all matter would collapse into a biggest black hole ever [7].

Erol and Eksin inspired from these theories, and in 2006 they introduced a new optimization algorithm named Big Bang-Big Crunch (BB-BC) algorithm. In this algorithm there are two phases; Big Bang phase which is based on Big Bang Theory and Big Crunch phase which is based on Big Crunch Theory. In Big Bang Phase, the candidate's population is randomly generated over the search space and in Big Crunch phase these candidates are concentrated towards center of mass which acts as a convergence operator. Evaluation of new position of each candidate is done using center of mass. This process continues until convergence is obtained [7], [13], [14].In the original version of the algorithm, center of mass is calculated as follows:

$$x_c = \frac{\sum_{i=1}^{N} \frac{1}{f^i} x_i}{\sum_{i=1}^{N} \frac{1}{f^i}} \qquad \dots\dots\dots\dots(18)$$

Where

x_c position of center of mass,
x_i position of candidate,
f^i fitness function value of candidate i,
N population size.

The new generation for next iteration Big Bang phase is normally distributed around x_c. The new candidates around center of mass are calculated by adding or subtracting standard deviation of normal distribution.

$$x_i^{new} = x_c + \sigma \qquad \dots\dots\dots..(19)$$

The standard deviation decreases as the iteration elapse according to following formula

$$\sigma = \frac{\alpha.(x_{max} - x_{min}).rand}{k} \qquad \dots\dots..\dots(20)$$

Where

x_{min}, x_{max} minimum and maximum range respectively,
rand random number between 0 and 1,
k number of iterations.
α parameter limiting size of search space

Therefore the new candidate is generated as follows:

$$x_i^{new} = x_c + \alpha.(x_{max} - x_{min}).rand/k \quad \dots.(21)$$

Also it is necessary to limit population to the prescribed search space boundaries.

4.2 Optimization Algorithm

(Big Bang Phase)

1).Generate randomly N number of candidates with in the search space.

2). Obtain the fitness function values of all candidate solutions.

(Big Crunch Phase)

3). Evaluate the center of mass using equation (18).

4).The new candidates are evaluated around the new point calculated in step 3 by adding or subtracting the standard deviation whose value decreases as the iteration elapse. (Using equation (21))

5).Return to step 2 until stopping criteria has been met [7], [15].

4.3 Implementation of Proposed Algorithm

This study presents an optimal solution to the Environment Friendly Economic dispatch with Real and Reactive Power constraints problem using the Big Bang-Big Crunch (BB-BC) algorithm. Its implementation can be easily understood by using following flow chart.

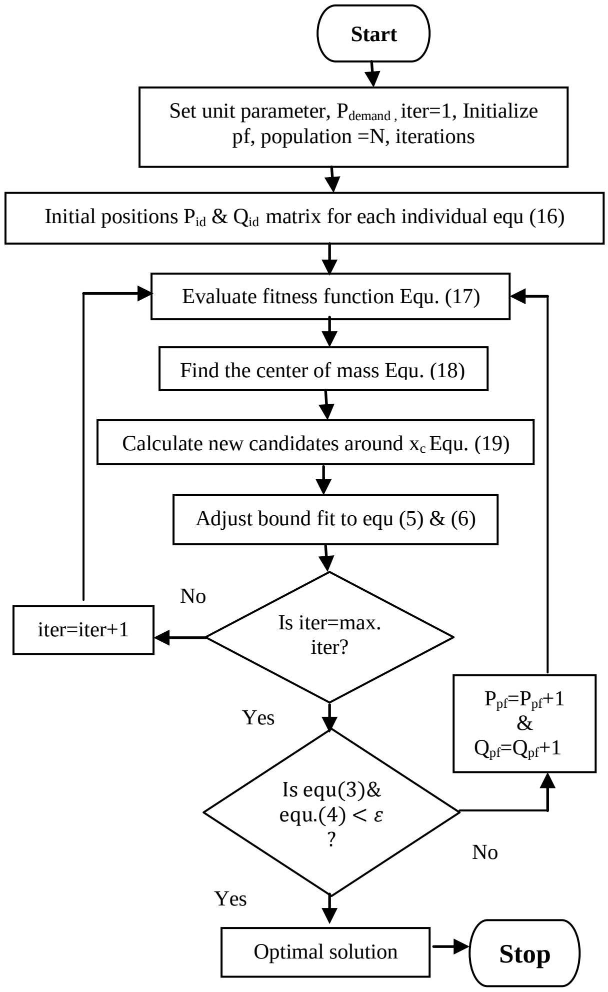

Figure 2. Flow chart of BB-BC based Environment Friendly Economic dispatch with Real and Reactive Power constraints problem

5. RESULTS AND DISCUSSION

The effectiveness of the proposed method is tested with 30 bus six generating unit system, where PSO and BB-BC methods are applied to solve the problem. The fuel cost coefficients and emission coefficients of IEEE 30 bus six generating units are given in table 1 and table 2 respectively. Also the test results obtained from PSO and proposed BB-BC is given in table 3.

Table 1 Fuel cost coefficients of six generating units

Unit i	Fuel Cost Coefficients			P_{Gmin} (MW)	P_{Gmax} (MW)
	Alpha	Beta	Gamma		
1	0.15247	38.539	756.79	10	125
2	0.10587	46.159	451.32	10	150
3	0.02803	40.396	1049.99	35	225
4	0.03546	38.305	1243.53	35	210
5	0.02111	36.327	1658.56	130	325
6	0.01799	38.270	1356.65	125	315

Table 2 Emission coefficients of six generating units

Unit i	Emission Coefficients a	b	c	Q_{Gmin} (MVAR)	Q_{Gmax} (MVAR)
1	0.00419	0.32767	13.859	-200	300
2	0.00419	0.32767	13.859	-17	50
3	0.00683	-0.54551	40.266	-10	60
4	0.00683	-0.54551	40.266	-8	25
5	0.00461	-0.51116	42.895	-140	200
6	0.00461	-0.51116	42.895	-150	155

Table 3 Comparison of test result obtained from PSO and BB-BC

	PD=800MW & QD=370MVAR		PD=900MW & QD=470MVAR		PD=1000MW & QD=570MVAR	
	PSO	BB-BC	PSO	BB-BC	PSO	BB-BC
P_1 (MW)	41.479	51.087	106.107	63.963	40.954	69.585
P_2 (MW)	106.840	62.630	49.7806	81.816	129.901	93.359
P_3 (MW)	79.027	116.228	100.905	146.970	111.526	175.157
P_4 (MW)	133.590	103.678	86.9686	118.894	175.892	128.273
P_5 (MW)	147.465	245.938	266.238	247.519	284.049	269.420
P_6 (MW)	292.054	221.007	291.488	242.891	259.078	268.709
Q_1 (MVAR)	96.616	54.440	210.945	199.949	277.499	166.309
Q_2 (MVAR)	1.678	30.299	5.767	30.855	37.642	48.552
Q_3 (MVAR)	45.221	32.035	24.543	40.662	12.615	43.419
Q_4 (MVAR)	1.211	12.678	9.318	18.680	1.8499	19.432
Q_5 (MVAR)	143.996	148.346	184.605	128.902	186.320	147.586
Q_6 (MVAR)	91.075	100.618	41.495	59.224	61.045	145.249
Fuel Cost (Rs/h)	42163	41164	46696	46331	51966	51504
Total Emission (Kg/h)	615.036	569.722	754.763	689.774	870.987	853.064
Total optimum cost (Rs/h)	71859	68672	83138	79635	94021	92693

Figure 3, Figure 4 and Figure 5 shows convergence characteristics for different loads. It is clear that BB-BC has better convergence characteristics than PSO.

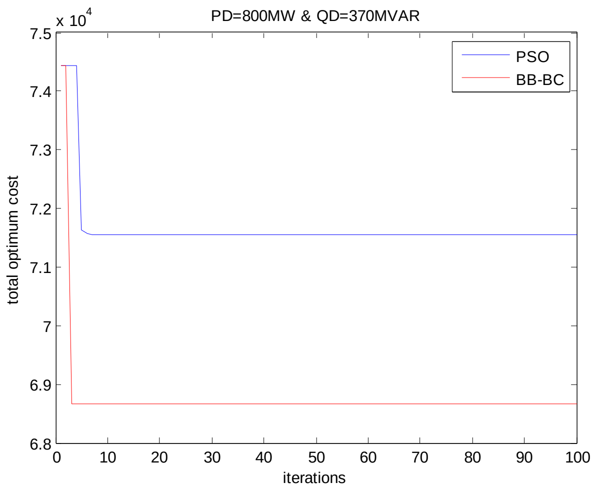

Figure 3. Convergence characteristics at 800MW load

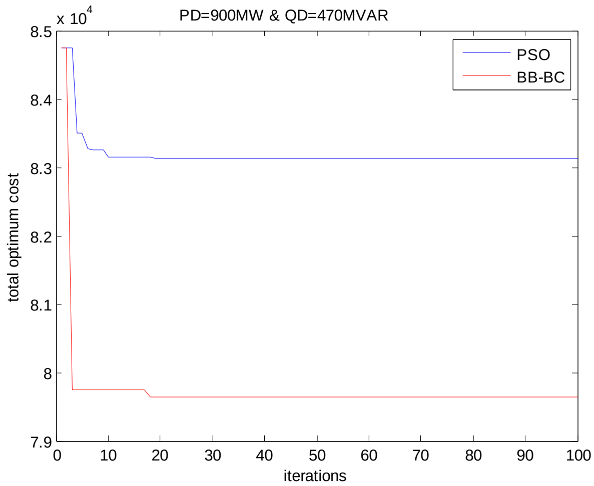

Figure 4. Convergence characteristics at 900 MW load

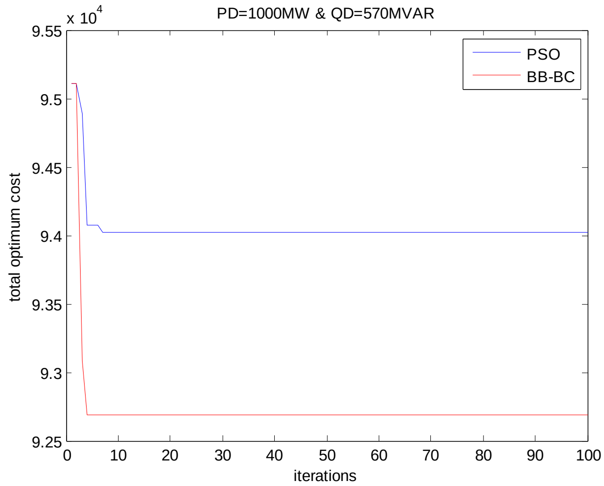

Figure 5. Convergence characteristics at 1000 MW load

6. CONCLUSION

In this study Particle Swarm Optimization (PSO) and Big Bang Big Crunch (BB-BC) optimization techniques are applied on Environment Friendly Economic dispatch with Real and Reactive Power constraints problem and from this it is clear that the main advantage of BB-BC optimization is its numerically simple algorithm and with relatively few control parameters it gives better convergence result as compared to PSO because PSO has problems of dependency on initial coefficients and parameters and difficulty in finding their optimal design parameters.

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