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Network and Generator Constrained Economic Dispatch Using Real and Binary Coded Genetic Algorithms

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ABSTRACT
The efficient and optimum economic operations of electric power generation systems have always occupied an important position in the electric power industry. This involves allocation of the total load between the available generating units in such a way that the total cost of operation is kept at a minimum. Network constrained economic dispatch have been applied to obtain optimal fuel cost while satisfying transmission line power flow limits. Similarly generator constrained economic dispatch schedules the outputs of generating units to meet the demand at minimum cost considering the prohibited zones.

This paper proposes different types of Genetic Algorithms such as Binary Coded GA, Real Coded GA and Directional Search GA for solving the classical economic dispatch problem. The purpose of Network Constrained Economic Dispatch (NC-ED) and Generator Constrained Economic Dispatch is to minimize the operating fuel cost while satisfying load demand and operational constraints. As such, a Heuristic Algorithm is developed in this paper to adjust the generation output of a unit in order to avoid unit operation in the prohibited zones.
Keywords - Economic Load Dispatch, Genetic Algorithm, Heuristic Algorithm, Network Constraints.

I. INTRODUCTION

The basic objective of Economic Dispatch (ED) of electric power generation is to schedule the committed generating unit outputs so as to meet the load demand at minimum operating cost while satisfying all unit and system equality and inequality constraints. This involves allocation of active power between the units, as the operating cost is insensitive to the reactive loading of a generator.

The Economic Dispatch problem involves the solution of two different problems. The first of these is the Unit Commitment or pre-dispatch problem wherein it is required to select optimally out of the available generating sources to operate, to meet the expected load and provide a specified margin of operating reserve over a specified period of time. The second aspect of Economic Dispatch is the on-line economic dispatch wherein it is required to distribute the load among the generating units actually paralleled with the system in such a manner as to minimize the total cost of supplying the minute- to - minute requirements of the system.

II. ECONOMIC DISPATCH

1. Development of Economic Load Dispatch Methods

Several Classical Optimization Techniques such as Lambda Iteration Method, Gradient method, Linear Programming method and Newton's method were used to solve the ED problem. The Lambda Iteration method approach has been widely in practice and requires the associated incremental costs of the units to be monotonically increasing. However, the generating units exhibit a greater variation in fuel cost functions due to the physical operational limitations such as valve points and prohibited zones of operation. So inaccurate results can be induced by classical calculus based techniques while solving the Non-convex Economic Dispatch (NED). Hence more advanced algorithms are being developed for solving NED problem. Dynamic Programming (DP) is one of the approaches to solve NED problem. However DP may cause problems associated with curse of dimensionality. In this respect, several optimization algorithms based on Stochastic Searching Techniques, including Simulated Annealing (SA), Tabu Search Algorithm (TSA), Genetic Algorithm (GA), Evolutionary Programming (EP), Particle Swarm Optimization are developed to solve the highly nonlinear ED problem.

1.1. Prohibited Zones and Ramp Rate Limits

In practical systems, due to physical restrictions of power plant components, some of the on-line generating units may have prohibited operating zones lying between the minimum and maximum power outputs. Operating in the Prohibited Zones may result in amplification of vibrations in a shaft bearing, which should be avoided in practical application. For a unit with prohibited zones, its operating region, [P_{min}, P_{max}] will be broken into several isolated sub-regions.

It can only be dispatched to one of the isolated sub-regions in practical operation. The isolated sub-regions will form multiple decision spaces and result in a very challenging task for determining the Optimal Economic Dispatch.

Ramp Rate of generating units is due to the fact that the generating outputs can be not adjusted instantaneously. Therefore, to reflect the actual operating process, ED problem should include the Ramp Rate limits to ensure the feasibility of the solutions.

III. OBJECTIVE

In literature various methods are proposed, to solve Network Constrained Economic Dispatch (NC-ED) and Generator Constrained Economic Dispatch. This paper develops an efficient unit output based approach for solving the Network Constrained Economic Dispatch problem using Real Coded Genetic Algorithm. The salient feature of this approach is that it can handle all types of non convexities that arise in practical power systems which is not possible with the Lambda logic based approaches. Moreover as Real Coding is employed in Genetic Algorithms, the total computation time is decreased. This paper also develops Directional Search Genetic Algorithm for solving Generator Constrained Economic Dispatch considering Prohibited Zones of units. A salient feature of the proposed approach is its fast convergence and low computational time.

IV. ECONOMIC DISPATCH PROBLEM FORMULATION

The Economic Dispatch problem is a constrained optimization problem and it can be mathematically expressed as follows:

Minimize $$F_T = \sum_{i=1}^{n} f_i(P_i) \tag{1}$$

Where F_T = Total cost of generation (Rs/hr);
n = Number of generators;
P_i = Real power generation of ith generator;
f_i= Fuel cost function of ith generator;

1. System Active Power Balance

The total active power generation must balance the predicted demand plus losses, at each time interval over the scheduling horizon.

$$\sum_{i=1}^{n} P_i = P_D + P_{loss} \tag{2}$$

Where, P_D : total system demand (*MW*);
P_{loss}: transmission loss of the system (*MW*);

1.1. Generation Limits

These constraints reduce our permissible generator operating region to within two bounds. i.e.,

$$P_{i,min} \le P_i \le P_{i,max} \tag{3}$$

Where, $P_{i,min}$: minimum power output limit of i^{th} generator (*MW*)
$P_{i,max}$: maximum power output limit of i^{th} generator (*MW*)

The generation cost function $f_i(P_i)$ is usually expressed as a quadratic polynomial:

$f_i(P_i) = a_iP_i^2 + b_iP_i + c_i$ (4),

Where, a_i , b_i and c_i are fuel cost coefficients.

V. NETWORK CONSTRAINED ECONOMIC DISPATCH

The three power system optimization problems are classified in increasing degree of generality and complexity as follows: ED, NC-ED, and OPF.

In the classical ED and the NC-ED, only the two first sources of non convexities apply. Hence both the ED and the NC-ED are in general non convex optimization problems. Non convex optimization problems have, in general, many local minima, and local search techniques cannot locate the global minimum, since they may be trapped in a local minimum. Metahearistic technique is one of the global optimization approaches.

Metaheuristics have been successfully applied to the solution of the ED problem. The four main classes of Metaheuristics are: Simulated Annealing (SA), Tabu Search (TS), Genetic Algorithms (GA), and Evolutionary Programming (EP).

GA's, in particular, has been successfully employed in to overcome the non convexity problems of the conventional algorithms. Also, GA's ability to model almost any kind of constraints in the form of penalty functions or by using various chromosome coding schemes tailored to the specific problem makes it an attractive method for the solution of the ED problem.

The Network Constrained Economic Dispatch (NC-ED) or DC Optimal Power Flow (DC-OPF) is formulated as an optimization problem as follows:

Minimize $$F_T = \sum_{i=1}^{n} f_i(p_i) \tag{5}$$

Subjected to $$\sum_{i=1}^{n} P_i = P_D; \quad flow_i \le flow_{i\max};$$

$$P_{i\min} \le P_i \le P_{i\max} \quad i = 1 \ldots n \tag{6}$$

Where objective (5) is the total system operating cost to be minimized; (6) represents the system dc power-flow equations and branch power-flow limits and define the feasible region of operation of the generating units. The inequality constraints are handled in the form of penalty factors.

VI. CONVENTIONAL HEURISTIC BASED LAMBDA ITERATIVE METHOD

This is a Conventional Heuristic method for economic dispatch problem which uses equal incremental cost criterion for optimal solution. This Heuristic based method is powerful than simple lambda iterative method.

The detailed algorithm for Heuristic Based Lambda Iterative Method for solving economic dispatch problem is given below.

1) Read the generator data, p limits and power demand then set an initial lambda.
2) Calculate power output of each unit using eq $P_i=(\lambda-b_i)/2c_i$ and enforce the limits as shown in eq $P_{loss} = \sum_{i=1}^{n}\sum_{j=1}^{n} P_i B_{ij} P_j$.
3) Determine the difference between power demand and total generation using $\Delta P = P_D - \sum_{i=1}^{n} P_i$
4) If difference< tolerance, then go to step 8.
5) Calculate incremental step length using eq. step length = $\Delta P/P_D$.
6) Check whether difference is positive or negative and update lambda using eq. If ΔP >0 then $\lambda = \lambda + (\Delta P/P)_D$, If $\Delta P<0$ then $\lambda = \lambda - (\Delta P/P)_D$.
7) Repeat steps from 2 to 6 until convergence is obtained.
8) Calculate the total fuel cost and print the result & stop.

VII. GENETIC ALGORITHM

1. Economic Dispatch Using Genetic Algorithm (Lambda Based)

Before applying a GA to any task, a computer compatible encoding must be developed.

1.1. Encoding and Decoding

The encoding must be carefully designed to utilize the GA's ability to efficiently transfer information between chromosome strings and objective function of problem. The proposed approach uses the equal system λ (equal system incremental cost) criterion as its basis. The only encoded parameter is the normalized system incremental cost λ. The advantage of using system λ instead of units' output as the encoded parameter is that the number of bits of chromosome will be entirely independent of the number of generator units.

The resolution of the solution depends upon how many bits are used to represent λ. Here, we use 16 bits to represent λ. Fig. 1 shows the encoding scheme of λ.

d1	d2	d3	d4	….	….	….	d15	d16

x x x x ………………. x x

2^{-1} 2^{-2} 2^{-3} 2^{-4} ……………… 2^{-15} 2^{-16}

where, $d_i \in \{0,1\}$ $i = 1,2,.....16$

Fig.1. The encoding scheme of λ

Evaluation of a chromosome is accomplished by decoding the encoded λ chromosome string and computing the chromosome's fitness value using the decoded parameter. The decoding of λ_d can be expressed as:

$$\lambda_d = \sum_{i=1}^{16}\left(d_i \times 2^{-i}\right) \qquad d_i \in \{0,1\} \qquad (7)$$

The relationship between the actual system incremental cost, λ_{act} , and the normalized system incremental *cost*, λ_d, is: $\lambda_{act} = \lambda_{min} + \lambda_d(\lambda_{max} - \lambda_{min})$ (8)

Where, λ_{min} and λ_{max} are the minimum and maximum values of system incremental cost.

1.2. Algorithm

The detailed Algorithm for solving the classical economic dispatch problem using Genetic Algorithm for λ –based method is given below.

1. Read generator data, P limits, power demand and GA parameters.
2 Generate initial population of chromosome of binary bits using random generation technique.
3. Set the iteration count iter=1 and Set chromosome count j=1.
4. Decode the chromosomes of the population and determine normalized system incremental *cost*, λ_d using $\lambda_d = \sum_{i=1}^{16}\left(d_i \times 2^{-i}\right)$
5. Calculate the actual system incremental cost, $\lambda_{act} = \lambda_{min} + \lambda_d(\lambda_{max} - \lambda_{min})$
6. Calculate the generation output of all the units for each chromosome from its λ_{act} value using $P_i=(\lambda_{act}-b_i)/2c_i$ and enforce P_i limits.
7. Calculate the fitness value of the chromosome, using the Fit=1/(1+(error/P_D))
8. Repeat the procedure from step no. 4 until chromosome count>population size.
9. Sort the chromosomes and all their related data in the descending order of fitness.
10. Check if the error of first chromosome is less than tolerance. If yes, go to 17.
11. Copy the P_e % chromosomes of old population to new population starting from the best ones from the top.
12. Perform crossover on selected parents and generate new child chromosomes, repeat it to get required number of chromosomes.
13. Add all the generated child chromosomes to new population.
14. Perform mutation on all chromosomes depending upon the probability of mutation index.
15. Replace old population with new population.
16. Increment iteration count. If iteration count <max. iteration, go to 4, else print the message “problem not converged in maximum number of iterations”.
17. Calculate the powers of all units, total fuel cost etc. Print the result.

2. Economic Dispatch using Real Coded Genetic Algorithm (Unit Output Based)

If there are n units say 6, P1,P_2,P_3,P_4,P_5 outputs are selected randomly satisfying their P limits and P_6 is predetermined as P_D-(P_1+P_2+P_3+P_4+P_5). Units 1 to 5 are taken as free units and 6th unit as reference unit. In the GA solution, the outputs of the (n-1) “free units” can be chosen arbitrarily within limits (3) while the output of the “reference unit” is constrained by the system power balance equation (2).

2.1. Algorithm

The detailed Algorithm for solving the classical economic dispatch problem using unit output based Real Coded Genetic Algorithm method is given below

1. Read generator data, P limits, power demand and GA parameters.
2. Generate initial population of floating point numbers using random generation technique. Each chromosome consists of concatenated string of powers of (n-1) free units within limits.
3. et chromosome count i =1.
4. Chromosome evaluation consists of following steps;
   4.1.Decompose each chromosome and calculate the powers of (n-1) free units. Then the output of reference unit is calculated by $P_n = P_D - \sum_{i=1}^{n-1} P_i$
   4.2.The reference unit limit violations are accounted by adding non-negative penalty terms to the total fuel cost using $F_A = \sum_{i=1}^{n} F_i(P_i) + W_P$ then calculate the fitness value of the chromosomes.
5. Repeat the procedure for step no. 4 until chromosome count>population size.
6. Set generation count j=1.
7. Sort the chromosomes and all their related data in the descending order of fitness.
8. Copy the P_e % chromosomes of old population to new population starting from the best ones from the top.
9. Perform Max-min arithmetical crossover on selected parents and generate new child chromosomes, repeat it to get required number of chromosomes.
10. Add all the generated child chromosomes to new population.
11. Perform mutation on all chromosomes using Michalwiez's non uniform operator.
12. Replace old population with new population.
13. Perform chromosome evaluation described in step 4 for new population.
14. Increment generation count. If generation count <max. generation, go to 7.
15. Calculate the powers of all units, total fuel cost etc. Print the result.

3. Directional Search Genetic Algorithms for Economic Dispatch

It is named so because in this approach, instead of searching for final best fit chromosome in the entire random search space, a direction is followed to reach the solution. This results in reduction of total execution time, number of iterations taken to converge and population size. Hence directional algorithm can overcome the disadvantages of the conventional genetic algorithm.

3.1. Algorithm

The detailed Algorithm for solving the classical economic dispatch problem using Lambda based step length directional search genetic algorithm method given below.

1. Read generator data, P limits, power demand and GA parameters.
2. Initial population generation;
   2.1.Set chromosome count=1&initially generate a chromosome randomly to represent lambda.
   2.2.Decode the chromosome and determine normalized value of lambda using $\lambda_d = \sum_{i=1}^{16}(d_i \times 2^{-i})$.
   2.3.Determine actual value of lambda using eq (8) and calculate powers of all units subjected to p limits eq$P_i = (\lambda_{act} - b_i)/2c_i$.
   2.4.Then calculate difference between demand and generation using $diff = P_D - \sum_{i=1}^{n} P_i$ and decide the direction for next chromosome generation.
   2.5.Calculate λ_{next} using $\lambda_{next}=\lambda_{act}+(error/P_D)$ or $\lambda_{next}=\lambda_{act}-(error/P_D)$ and determine normalized value λ_{dnext} using $\lambda_{dnext}= (\lambda_{next}- \lambda_{min})/ (\lambda_{max}- \lambda_{min})$
   2.6 Then next chromosome is generated by setting or resetting bits of the chromosome such that the decoded value is near to λ_{dnext}.
   2.7 Increment chromosome count and repeat the procedure for step no.2.2 until chromosome count>population size.
3. Set iteration count=1 and Calculate the fitness values of all chromosomes.
4. Sort the chromosomes and all their related data in the descending order of fitness.
5. Check if the error of first chromosome is less than tolerance. If yes, go to 12.
6. Copy the P_e % chromosomes of old population to new population starting from the best ones from the top.
7. Perform crossover on selected parents using and generate new child chromosomes, repeat it to get required number of chromosomes.
8. Add all the generated child chromosomes to new population.
9. Perform mutation on all chromosomes then Replace old population with new population.
10. Then evaluate the new population.
    10.1.Decode the chromosomes and calculate actual value of lambda.
    10.2.Calculate powers of all units subjected to p limits.
    10.3.Calculate fitness values of all chromosomes.
11. Increment iteration count. If iteration count <max. iteration, go to 4, else print the message "problem not converged in maximum number of iterations".
12. Calculate the powers of all units, total fuel cost etc. Print the result.

4. Network Constrained Economic Dispatch Using Real Coded GA (Unit Output Based)

4.1. Algorithm

The detailed Algorithm for solving the Network constrained economic dispatch problem using unit output based Real coded Genetic Algorithm method is given below.

1. Read generator data, P limits, power demand and GA parameters.
2. Generate initial population of floating point numbers using random generation technique. Each chromosome consists of concatenated string of powers of (n-1) free units within limits.
3. Set chromosome count =1 then Chromosome evaluation consists of following steps;
   3.1. Decompose each chromosome and calculate the powers of (n-1) free units. Then the output of reference unit is calculated by $P_n = P_D - \sum_{i=1}^{n-1} P_i$.
   3.2. Calculate voltage phase angles of all buses and determine power flow of all branches.
   3.3. The reference unit limit violations and branch power flow limit violations are accounted by adding nonnegative penalty terms to the total fuel cost using eq $P_n^{\min} \le P_n \le P_n^{\max}$ and eq $W_F = \sum_{l=1}^{L} \overline{F}.\frac{\left(|R_l| - R_l^{\max}\right)}{R_l^{\max}}.\mathrm{H}\left(|R_l| - R_l^{\max}\right)$ for $|R_l| > R_l^{\max}$.
   3.4. Calculate the fitness value of the chromosome, using the eq. K/F_A
4. Repeat the procedure for step no. 3 until chromosome count>population size.
5. Set generation count=1
6. Sort the chromosomes and all their related data in the descending order of fitness.
7. Copy the P_e % chromosomes of old population to new population starting from the best ones from the top.
8. Perform Max-min arithmetical crossover on selected parents and generate new child chromosomes, repeat it to get required number of chromosomes.
9. Add all the generated child chromosomes to new population.
10. Perform mutation on all chromosomes using Michalwiez's non uniform operator.
11. Replace old population with new population.
12. Perform chromosome evaluation described in step 3 for new population.
13. Increment generation count. If generation count <max. generation, go to 6.
14. Calculate the powers of all units, total fuel cost etc. after the specified number of generations. Print the result.

VIII. NETWORK CONSTRAINED ECONOMIC DISPATCH BY QUADRATIC PROGRAMMING

1. Problem Formulation

The network-constrained economic dispatch (NC-ED) or dc optimal power flow (DC-OPF) is formulated as an optimization problem as follows:

Minimize $F_T = \sum_{i=1}^{n} f_i(P_i)$ (9),

Where $f_i(P_i) = a_i + b_i P_i + c_i P_i^2$

Subjected to equality constraint $\sum_{i=1}^{n} P_i - P_D = 0$ (10)

And inequality constraints

$P_{i,min} \le P_i \le P_{i,max}$ $i=1\ldots n$; $P_{ij} \le P_{ij,max}$ (11)

For using quadratic programming to above problem formulation, constraint $P_{ij} \le P_{ij,max}$ has to be expressed in terms of generation outputs.

2. Problem Formulation

A Quadratic programming problem is the most well behaved non linear programming. In this problem, the objective function is convex (for minimization) and all the constraints are linear. A Quadratic programming problem can be stated as

Minimize $f(x) - f^T x + ½ x^T Hx$

Subject to lb≤X≤ub; AX≤b ; $A_{eq}X = b_{eq}$

Where

$$X = \begin{bmatrix} x_1 \\ x_2 \\ \vdots \\ x_n \end{bmatrix} \quad f = \begin{bmatrix} f_1 \\ f_2 \\ \vdots \\ f_n \end{bmatrix} \quad H = \begin{bmatrix} h_{11} & h_{12} & \cdots & h_{1n} \\ h_{21} & h_{22} & \cdots & h_{2n} \\ \vdots & & & \\ h_{n1} & h_{n2} & & h_{nn} \end{bmatrix}$$

The term $½ x^T Hx$ represents the quadratic part of the objective function with H being a symmetric positive definite matrix. If H=0 the problem reduces to a Linear Programming problem.

3. Complete DC OPF Formulation

Minimize $\sum_{i=1}^{n}\left(a_i + b_i P_i + c_i P_i^2\right)$

Subjected to equality constraint $\sum_{i=1}^{n} P_i - P_D = 0$

And inequality constraints $P_{i\min} \le P_i \le P_{i\max}$

$i=1\ldots n$ and $\sum_{j=1}^{n} A_{ij} P_j \le b_{i\max}$ j = 1……..L

DC OPF is solved by quadratic programming tool box available in MATLAB 6.5 or MATLAB.

4. Directional Search GA applied for Economic Dispatch considering Prohibited Zones

A unit with prohibited operating zones has a discontinuous input- output power generation characteristics.

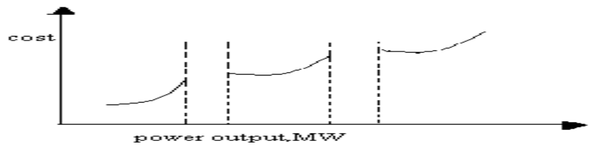

Fig 2. Unit input/ output characteristics

For a unit with prohibited zones, its operating region, $[P_{min}, P_{max}]$ will be broken into several isolated sub-regions.

4.1. Problem Formulation

To solve the standard economic dispatch problem, consider the operation of a power system with n units, each loaded to P_i MW, to satisfy a total load demand P_D. Let the fuel input output cost function of each unit be represented by a function f_i. The units are to be loaded so that the total fuel cost, F_T is minimized subjected to the power balance and unit loading limits.

Minimize $F_T = \sum_{i=1}^{n} f_i(P_i)$ (12)

Where $f_i(P_i) = a_i + b_iP_i + c_iP_i^2$

Subjected to $\sum_{i=1}^{n} P_i - P_D = 0$;

$P_{i\min} \le P_i \le P_{i\max}$ i=1,2,…n (13)

For units with prohibited operating zones, there are additional constraints on the unit operating range:

$P_{i,min} \le P_i \le P^L_{i,1}$; $P^U_{i,1} \le P_i \le P^L_{i,K}$ k=2,….n_i; $P^U_{i,ni} \le P_i \le P_{i,\max}$ (14)

where n_i = number of prohibited zones for unit I; $P^L_{i,K}$ = Lower limit of k^{th} prohibited zone

$P^L_{i,K}$ = Upper limit of k^{th} prohibited zone

To avoid the prohibited zone operation, we adjust the generation output of the unit depending upon the loading conditions. If the generation output calculated is located in a prohibited zone, it needs heuristic adjustment to leave this area. Here Directional search GA is used for solving the economic dispatch problem considering prohibited zones as it is effective compared to conventional GA in terms of execution time, population size etc.

4.2. Algorithm

The detailed Algorithm for solving the economic dispatch problem considering prohibited zones using unit output based Real coded Genetic Algorithm method is given below.

1. Read generator data, P limits, prohibited zone data, GA parameters and power demand.
2. Initial population generation.
   2.1.Set chromosome count=1&initially generate a chromosome randomly to represent lambda.
   2.2.Decode the chromosome and determine normalized value of lambda using $\lambda_d = \sum_{i=1}^{16}\left(d_i \times 2^{-i}\right)$.
   2.3.Determine actual value of lambda using eq $P_{i,min} \le P_i \le P_{i,max}$ i=1,2,…n and calculate powers of all units subjected to p limits eq $P_{ij} \le P_{i,,max}$.
   2.4.Then calculate difference between demand and generation using $diff = P_D - \sum_{i=1}^{n} P_i$ and decide the direction for next chromosome generation.
   2.5.Calculate λ_{next} using $A=LB^{-1}$or b=($P_{i,max}$+$LB^{-1}P_D$) and determine normalized value λ_{dnext} using $F_T = \sum_{i=1}^{n} f_i(P_i)$.
   2.6 Then next chromosome is generated by setting or resetting bits of the chromosome such that the decoded value is near to λ_{dnext}.
   2.7 Increment chromosome count and repeat the procedure for step no.2.2 until chromosome count>population size.
3. Set iteration count=1 and Calculate the fitness values of all chromosomes.
4. Sort the chromosomes and all their related data in the descending order of fitness.
5. Check if the error of first chromosome is less than tolerance. If yes, go to 12.
6. Copy the P_e % chromosomes of old population to new population starting from the best ones from the top.
7. Perform crossover on selected parents using and generate new child chromosomes, repeat it to get required number of chromosomes.
8. Add all the generated child chromosomes to new population.
9. Perform mutation on all chromosomes and Replace old population with new population.
10 Then evaluate the new population.
   10.1.Decode the chromosomes and calculate actual value of lambda.
   10.2.Calculate powers of all units subjected to p limits.
   10.3.Calculate fitness values of all chromosomes.
11. Increment iteration count. If iteration count <max. iteration, go to 4, else print the message “problem not converged in maximum number of iterations”.
12. Calculate the powers of all units.
13. If any of the generator output falls in the prohibited zones, adjust the generation of that unit.
   a)If the generator output is greater than average value of the zone in which the unit falls, then set that generator output to upper limit of that zone.
   b)If the generator output is lesser than average value of the zone in which the unit falls, then set that generator output to lower limit of that zone.
14. Then calculate power demand met by the units that have prohibited operating zones i.e. P_{D_pr}.
15. Then calculate remaining power demand $P_{D\_remaining} = P_D - P_{D\_proh}$.
18.Exclude the generators that are having the prohibited zones from the actual generator set.
19. Repeat the steps from 2 to 14 for power demand $P_{D\_remaining}$ and with present generator set.
20. Calculate the powers of units and total fuel cost etc. Print the result.

IX. TEST RESULTS

The effectiveness of proposed approaches has been tested with different test systems which are given below.

1) Classical economic dispatch

Binary and real coded GA (Unit output based) --> 3 unit and 6 unit test systems.

Directional searches GA (Lambda based) ---------> 3 unit and 6 unit test systems.
2) Network constrained economic dispatch --------> IEEE 14 and 30 bus systems.
3) Generator constrained economic dispatch -------> 4 unit and 15 unit systems.

Table 1
Comparison of test results of conventional Lambda-iteration (heuristic based), Binary and Real coded GA methods for 3- units system (P_i based coding for binary GA and real coded GA)

Sl No	Power Demand(MW)	Method	P_1 (MW)	P_2 (MW)	P_3 (MW)	Fuel Cost (Rs/hr)	Execution Time(sec.)
1	650	Conventional	299.238	258.974	91.7865	6394.05	0.145
		Binary GA	299.414	258.789	91.796	6394.047	5.567
		Real GA	299.238	258.974	91.7865	6394.047	0.981
2	750	Conventional	346.204	296.789	107.006	7286.86	0.203
		Binary GA	345.996	296.875	107.128	7286.86	1.890
		Real GA	346.204	296.789	107.006	7286.86	1.166

Table 2.
Comparison of test results of conventional Lambda-iteration (heuristic based), Binary and Real coded GA methods for 6- units system (P_i based coding for binary GA and real coded GA)

Power Demand (MW)	Method	P_1 (MW)	P2 (MW)	P_3 (MW)	P_4 (MW)	P_5 (MW)	P_6 (MW)	Fuel Cost Rs/hr	Execution Time (sec.)
175	Conventional	28.470	15.000	10.00	10.000	12.000	99.529	434.712	0.016
	Binary GA	28.496	15.000	10.00	10.000	12.000	99.503	434.711	3.094
	Real GA	28.470	15.000	10.00	10.000	12.000	99.529	434.711	2.453
250	Conventional	41.255	17.551	10.00	10.000	12.000	159.192	657.641	0.016
	Binary GA	41.269	17.563	10.00	10.000	12.000	159.166	657.641	4.265
	Real GA	41.255	17.551	10.00	10.000	12.000	159.192	657.641	2.568

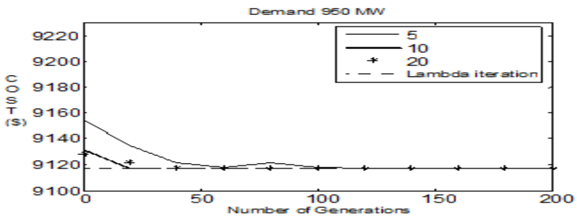

Fig 3 Effect of Real coded GA population size on augmented cost function for 3-units system

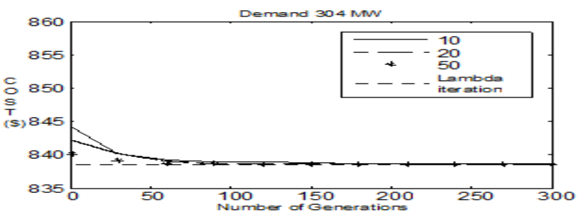

Fig 4 Effect of Real coded GA population size on augmented cost function for 6-units system

Table 3
Comparison of test results of conventional GA and step length based Directional search GA (DSGA) for 3- units system

S.No	Power Demand(MW)	Method	FuelCost (Rs/hr)	Number of Iterations to converge	Population size	Execution Time(sec.)
1	650	GA	6393.53	58	30	0.421
		DSGA	6393.53	1	30	0.016
2	750	GA	7286.76	18	30	0.125
		DSGA	7286.76	1	30	0.016

Table 4
Comparison of test results of conventional GA and step length based Directional search GA (DSGA) for 6- units system

S.No	Power Demand (MW)	Method	Fuel Cost (Rs/hr)	Number of iterations to converge	Population size	Execution Time(sec.)
1	175	GA	434.707	45	30	0.328
		DSGA	434.707	1	6	0.001
2	250	GA	657.670	23	30	0.187
		DSGA	657.629	1	12	0.001

Table 5
Experiments with varying population size for IEEE 14 bus system, with Demand as 305MW and Real coded GA runs for 500 generations

S.No	Population size	Cost in Rs	Distance from minimum cost	Execution Time (sec.)
1	5	1023.021	0.48%	0.657
2	8	1021.182	0.3%	1.522
3	10	1020.984	0.288%	2.312
4	15	1019.948	0.18%	3.153
5	20	1020.951	0.285%	4.063

Table 6.
Experiments with varying population size for IEEE 30 bus system, with Demand as 283.4 MW and Real coded GA runs for 500 generations

S.No	Population size	Cost in Rs	Distance from minimum cost	Execution Time (sec.)
1	5	776.866	0.11%	0.88
2	8	781.167	0.66%	1.234
3	10	780.631	0.59%	1.892
4	15	779.184	0.41%	2.345
5	20	777.427	0.18%	3.432

Table 7.
Results of Directional Search GA for various Load Demands for 4 unit system.

S.No	Power Demand (MW)	Cost in Rs	P1(MW)	P2(MW)	P3(MW)	P4(MW)	number of iterations	Execution Time (sec.)
1	750	9640.619	187.500	187.500	187.499	187.499	2	0.015
2	950	11726.80	250.000	260.000	219.995	219.995	2	0.010

Table 8
Results of Directional Search GA for various Load Demands for 15 unit system.

S.No	Power Demand(MW)	Cost in Rs	number of iterations to converge	Execution Time (sec.)
1	1771.0	23442.785	2	0.015
2	2125.2	27086.210	2	0.016

X. CONCLUSION

Hence from the results reported above, it can be concluded that different GA approaches have been developed for the determination of the global or near-global optimal solution for the Classical Economic Dispatch, Network constrained Economic Dispatch and Generator constrained Economic Dispatch problem. The solution algorithms have been tested for different test systems. The results obtained are compared with conventional methods. In Real coded GA, the coding of generator outputs in the chromosome using floating point numbers instead of binary representation not only improved the accuracy of the algorithm but also reduced the execution time. In this way it retained the advantages of GA over traditional ED methods but also eliminated the main disadvantage of the GA which is long execution time. And also Directional search Genetic Algorithms are capable of providing the solution within few iterations with small execution time and less population size.

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