Genetic Algorithm Approach to Solve Economic Load Dispatch Problem on Three Thermal Plants and A Combined Cycle Co-Generation Plant

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Abstract — This paper presents an approach based on Genetic Algorithm to solve the economic load dispatch problem with losses for three thermal plant system and combined cycle co-generation plant. Genetic algorithms are adaptive search methods that simulate some of the natural processes: selection, inheritance, random mutation and population dynamics. This approach is used to test for an example of three thermal plant system and one combined cycle co-generation plant in two ways of dispatching load between three thermal plants and among two thermal plus one combined cycle co-generation plant and the results are compared. In this paper, the results are obtained through the genetic algorithms developed in c Language.

Index Terms — About four key words or phrases in order of importance, separated by commas.

I. Introduction

Economic load dispatch (ELD) is a sub-problem of the optimal power flow (OPF) having the objective of fuel-cost minimization. The classical solutions for ELD problems have used equal incremental criterion for the loss-less system and the use of penalty factors for considering the system losses. However, all these methods are based on the assumption of continuity and differentiability of cost functions. Hence, the cost functions have been approximated in the differentiable form, mostly in the quadratic form. Further, these methods also suffer on two main counts. One is their inability to provide global optimal solution and getting stuck at local optima. The second problem is handling the integer or discrete variables.

Genetic algorithms (GAs) have been proved to be effective and quite robust in solving the optimization problems. GAs can provide near global solutions and also can handle effectively the discrete control variables. Discontinuity and non-differentiability of cost characteristics can be effectively handled by GAs.

Combined cycle co-generation plants (CCCP) have the following advantages over the thermal plants, namely,

1. Higher overall thermal efficiency.
2. Minimum air pollution by nox, dust etc.
3. Independent operation of gas turbine for peak loads.
4. Quick start-up and less capital cost per kw and
5. Less water requirement per unit of electrical output.

This paper proposes the application of GAs to solve the economic load dispatch for two types, that is,

1. The thermal plant systems and the results are compared with conventional method, and
2. Two thermal plant systems and third plant as a combined cycle co-generation plant and the results are included.

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II. Theoretical Analysis on Genetic Algorithm and Economic Load Dispatch

A. Genetic Algorithm

1) Introduction

Genetic algorithms are search algorithms based on the mechanics of natural selection and natural genetics. They combine survival of the fittest among string structures with a structured yet randomized information exchange to form a search algorithm with some of the innovative flair of human search [1]. In every generation,

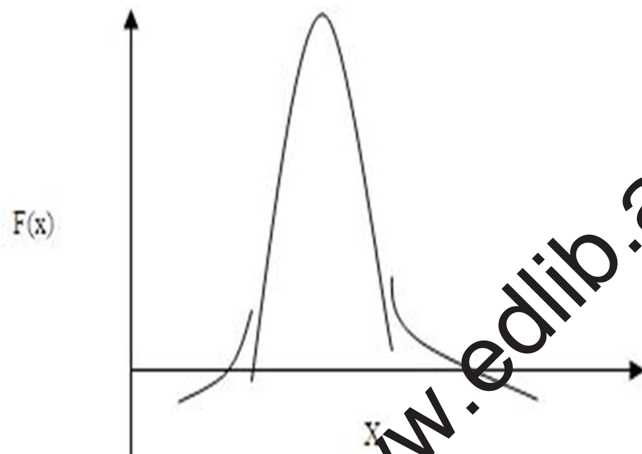


Figure 1 The Single Peak function which is easy for Calculus – Based Methods

A new set of artificial creatures (strings) is created using bits and pieces of the fittest of the old; an occasional new part is tried for good measure.

2) A Simple Genetic Algorithm

The mechanics of simple genetic algorithm are surprisingly simple, involving nothing more complex than copying strings and swapping partial strings. Simplicity of operation and power of effect are two of the main attractions of the genetic algorithm approach.

A simple genetic algorithm that yields good results in many practical problems is composed of three operators:

a. Reproduction
b. Crossover
c. Mutation

A) Reproduction

Reproduction is a process in which individual strings are copied according to their objective function values, f (biologists call this function the fittest function). This operator is artificial version of natural selection, a Darwinian survival of fittest among string creatures. In natural populations fitness is determined by a creature's ability to survive predators, pestilence and the other obstacles to adulthood and subsequent reproduction. In our artificial setting the objective function is the final arbiter of the string creature's life or death.

No.	String	Fitness	% of Total
1	01101	169	14.4
2	11000	576	49.2
3	01000	64	5.5
4	10011	361	30.9
Total		1170	100.0

Table 1

The reproduction operator may be implemented in an algorithmic form in a number of ways. The easiest is to create a biased roulette wheel where each current string in the population has a roulette wheel slot sized in proportion to its fitness. Suppose the sample population of four strings in the black box problem has objective or fitness function values f as shown in Table1

Summing the fitness over all four strings, one obtains a total of 1170. The percentage of population total fitness is also shown in the table. To reproduce, one simply spin the weighted roulette wheel thus defined four times. For the example problem, string number 1 has a fitness value of 169, which represents 14.4 percent of the total fitness. As a result, string 1 is given 14.4 percent of the biased roulette wheel, and each spin turns up string 1 with probability 0.144.

B) Crossover

After reproduction, simple crossover may proceed into two steps. First, members of the newly of reproduced strings in the matting pool are matted at random. Second, each pair of strings undergoes crossing over as follows: an integer position k along the string is selected uniformly at random between 1 and the string length less 1 (1 to l-1). Swapping all characters between positions k+1 and l inclusively creates two new strings. For example consider strings A1 and A2 from the initial population:

A1=0110/1
A2=1101/0

Suppose in choosing a random number between 1 and 4, we obtain a k=4 (as indicated by a separator symbol '/'). The resulting crossover yields two new strings where the prime (') means the strings are part of the new generation:

A1'=01100
A2'=11011

Consider a population of n strings over some appropriate alphabet, coded so that each is a complete idea or prescription for performing a particular task. Sub strings within each string (idea) contain various notions of what is important or relevant to the task. Genetic algorithms ruthlessly exploit this wealth of information by

(1) Reproducing high-quality notions according to their performance and
(2) Crossing these notions with many other high-performance notions from other strings.

Thus, the action of crossover with previous reproductions speculates on new ideas constructed from the high-performance building blocks (notions) of past trials.

C) Mutation

Mutation plays a decidedly secondary role in the operation of genetic algorithms. Mutation is needed because, even though reproduction and crossover effectively search and recombine extant notions, occasionally they may become overzealous and lose some potentially useful genetic material (1's or 0's at particular locations).

One may notice that the fitness or objective function values are the same as the black box values (compare Tables 1 and 2). There is no coincidence, and the black box optimization problem was well represented by the particular function f(x), and coding one is now using. A generation of the genetic algorithm begins with reproduction. One select the mating pool of the next generation by spinning the weighted roulette wheel four times.

String No.	Initial population (Randomly Generated)					x Value unsingned integer	$f(x)$ x^2	Pselect f_i Σf	Expected count $f_i/\bar{f}$	Actual Count From roulette wheel
1	0	1	1	0	1	13	169	0.14	0.58	1
2	1	1	0	0	0	24	576	0.49	1.97	2
3	0	1	0	0	0	8	64	0.06	0.22	0
4	1	0	0	1	1	19	361	0.31	1.23	1
Sum							1170	1.00	4.00	4.0
Average							293	0.25	1.00	1.0
Max							576	0.49	1.97	2.0

Table 2

Actual simulation of this process using coin tosses has resulted in string 1 and string 4 receiving one copy in the mating pool, string 2 receiving two copies, and string 3 receiving no copies, as shown[9] in the center of Table 2.

B. Economic Load Dispatch

1) Introduction

An early method of attempting to minimize the cost of delivered power called for supplying power from only the most efficient plant at light loads. As load is increased, the most efficient plant would supply power until the point of maximum efficiency of that plant was reached. Even with transmission losses neglected this methods fail to minimize the cost.

Thus, because of the following trends in the growth of power systems it has become progressively important to give increasing attention to economic operation of power systems.

1. In many cases, economic factors and the availability of primary essential such as coal, water etc., dictate that new generating plants be located at greater distances from the load centre.
2. The installation of larger blocks of power has resulted in the necessity of transmitting power out of a given area until the load in that area is equal to new block of installed capacity
3. Power systems are interconnecting for purposes of economy interchange and reduction of reserve capacity.
4. In a number of areas of the country the cost of fuel is rapidly increasing.

The main factor controlling the most desirable load allocation between various generating units is the total running cost. The operating cost of a thermal plant is mainly the cost of the fuel. Fuel supplies for thermal plants can be coal/natural gas, oil or nuclear fuel. The other costs such as cost of labour, supplies, maintenance etc., being difficult to be determined and approximate, are assumed to vary as affixed percentage of the fuel cost.

2) Economic Dispatch Neglecting Losses

When transmission distances are very small and load density is very high, transmission losses may be neglected and the optimal dispatch of generation is achieved with all plants operating at equal incremental production cost. .The common for including the effect of transmission losses is to express the total transmission losses as quadratic function of the generator power outputs . The simplest quadratic form is

$$Pl = \sum_{i=1}^{n} \sum_{j=1}^{n} PiBijPj \quad ....(1)$$

Here the coefficients Bij are called loss coefficients or B-coefficients. B-coefficients are assumed constant and reasonable accuracy can be expected provided the actual operating conditions are close to the base values where the B-constants are computed.

For a system with 'n' generating units let

$$Ft = f1 + f2 + ...+ fn$$

Where Ft is the cost function giving all the fuel for the entire system and is the sum of the fuel cost of the individual units f1, f2 , ... f n.

The total megawatt power input to the network from all units is the sum

PG1 +PG 2+PG 3.....PGn.

Where PG1 ,PG2 ,.....PG n are the individual outputs of the units injected into the network. The total Ft of the system is a function of all the power plant outputs. The constraining equation on the minimum value of Ft is given by the power balance equation

$$P1 + Pd - \sum_{i=1}^{n} PGi = 0 \quad ....(.2)$$

Where Pd is the total power received by the loads and P1 is the transmission loss of the system. The objective is to obtain a minimum Ft for affixed system load Pd subjected to the above power balance constraint.

The procedure for solving such minimization problems is called the method of Lagrange's multipliers.

The new cost function F is formed by combining the fuel cost and the equality constraint in the following manner:

$$F = Ft + \lambda \left(P1 + Pd - \sum_{i=1}^{n} PGi \right) .....(.3)$$

The augmented cost function F is also called the Lagrangian and the parameter, which is called the Lagrange multiplier is the effective incremental fuel cost of the system when transmission line losses are taken into account.

The original problem of minimizing Ft subjected to the constraint given by Eq 3.2.4.2 is transformed into an unconstrained problem given by F, where it is required to minimize F with respect to and the generator outputs.

$$F/PGi= Ft/PGi + \lambda \left(Pl+Pd - \sum_{i=0}^{n} PGi \right) / PGi =0 \quad ....(4)$$

Since, Pd is fixed and the fuel cost of any one unit varies only if the power output of that unit is varied. So the above equation yields:

$$F/PGi=Ft/PGi + \lambda\ (Pl/PGi-1) \quad =0 \quad .....(5)$$

for each of the generating unit outputs PG1,PG2,.....PGn.

Because Ft depends on only PGi, the partial derivatives of Ft can be replaced by the full derivative and the Eq 3.2.4.5 gives

$$\lambda = \frac{1}{1-(Pl/PGi)}(dFt/dPGi) \quad ......(6)$$

for every value of i.

This equation can also be written in the form

$$\lambda=L\ i\ (dFt\ /dPGi) \quad ....(.7)$$

where Li is called penalty factor of plant i, and is given by

$$Li = \frac{1}{1-(Pl/PGi)} \quad .....(.8)$$

The result for Eq (7) means that the minimum fuel cost is obtained when the incremental fuel cost of each unit multiplied by its penalty factor is the same for all the generating units in the system. The products Li (dFt/dPGi) are each equal to called the system, which are approximately the cost in Rs/h to increase the total delivered load by one MW.

Eq (7) governs the coordination of transmission loss into the problem of economic loading of units in plants, which are geographically dispersed throughout the system.

3) Combined Cycle Co-Generation Plant

Combined cycle co generation plants have the following advantages over the thermal plants, namely,

1. higher overall thermal efficiency
2. minimum air pollution by nox, dust etc.
3. independent operation of gas turbine for peak loads.
4. quick start-up and less capital cost per KW and
5. less water requirement per unit of electrical output.

The fuel consumption and the cost characteristics of such plants, in general, are not differentiable. The application of the genetic algorithms is the only viable solution for power system with combined cycle cogeneration plants and it is not possible to solve such a ELD problem by conventional technique. Till date only limited work has been reported in the area of CCCP economic load dispatch.

4) Two Thermal Plants and One CCCP System

In the three thermal plant systems, the third thermal plant is to be replaced by combined cycle cogeneration plant CCCP(two 75MW gas turbines and one 50 MW steam turbines). The fuel cost characteristics of this plant is shown in figure below[6] :

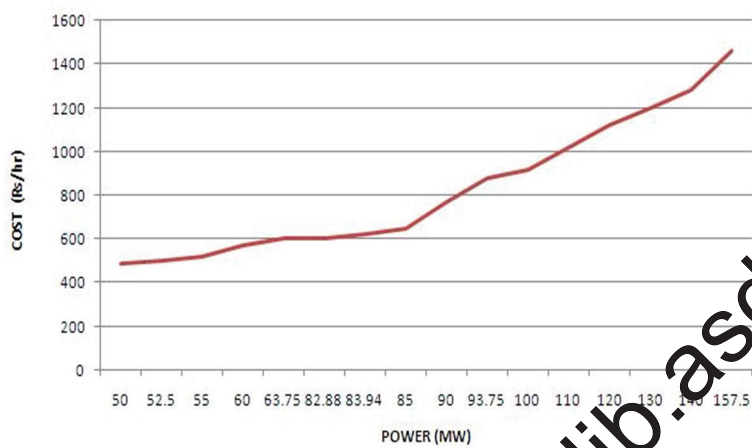


Figure .2: Fuel characteristics of co-generation plant

Power(MW)	Cost(Rs/h)
50	490
52.5	505
55	520
60	570
63.75	605
82.88	605
83.94	625
85	650
90	770
93.75	880
100	920
110	1020
120	1120
130	1200
140	1280
157.5	1460
166	1460
176.63	1460
178.32	1490
180	1520
185	1600
190	1720
200	1850

Table.3

Using the given set of points, a polynomial of specific order can be fitted using polynomial regression technique. We assume that the quadratic is to be fitted here for the cost curve. Assume that n pairs of coordinates (xi,yi) are given which are to be approximated by a quadratic. Let the quadratic be represented as

$$Y = AX^2+BX+C$$

When X=Xi The left hand side of the above equation is represented by Yci

$$Y_{ci}=AX_i^2+BX_i+C$$

The sum of squares of the deviations is given by

$$S=\Sigma\ (Y_i - Y_{ci})^2 = \Sigma(\ Y_i - A\ X_i^2 - BX_i - C\ )^2$$

Differentiating S w.r.t A,B,C respectively and setting each of the co-efficient equal to zero, we get

$$nC+B\Sigma X_i+A\Sigma X_i^2 = \Sigma\ Y_i$$
$$C\Sigma X_i+B\Sigma X_i^2+A\Sigma X_i^3 = \Sigma X_i\ Y_i$$
$$C\Sigma X_i^2+B\Sigma X_i^3+A\Sigma X_i^4 = \Sigma X_i^2 Y_i$$

These are three linear equations in three unknowns. These are called normal equations for quadratic regression. These may be solved by Gauss – Jordan procedure.
Finally we obtain the curve as

$$F = A\ PG_i^2 + B\ PG_i + C$$

For the problem, the solution was obtained through the genetic algorithms developed in c language. It is observed that this method is accurate and may replace effectively the conventional practices presently performed in different central load dispatch centers.

III. Classical Economic Load Dispatch Problem

The object of ELD problem is to minimize the total fuel cost at thermal plants

$$OBJ=\sum_{i=1}^{n} F_i(P_i)$$

Subject to the constraint of equality in real power balance

$$\sum_{i=1}^{n} P_i-P_l-P_d=0$$

The inequalities of real power limits on the generator outputs are

$$P_{imin} < P_i < P_{imax}$$

Where Fi(Pi) is the individual generation production in terms of its real power generation Pi, Pi is the output generation for unit i, n the number of generators in the system, Pd the total current system load demand, and Pl the total system transmission losses.

The thermal plant can be expressed as input-output models (cost function), where the input is the fuel cost and the output the power output of each unit. In practice, the cost function could be represented by a quadratic function.

$$Fi(Pi)=Ai.Pi^2+Bi.Pi+Ci$$

The incremental cost curve data are obtained by taking the derivative of the unit input-output equation resulting in the following equation for each generator:

$$dFi(Pi)/dPi=2.Ai.Pi+Bi$$

transmission losses are a function of the unit generations and are based on the system topology. Solving the ELD equation for a specified system requires an iterative approach since all unit generation allocation are embedded in the equation for each unit .

$$Pl=PiBijPj$$

Where Bij are coefficients, constant for certain conditions.
Application of GA to economic load dispatch problem.

$$Value=bit0*20+bit1*21+.........+biti*2i+......+bitchrom\text{-}length*2chrom\text{-}length$$

If the optimized parameter belongs to (Pimax,Pimin),decoding value of the parameter is computed by equation(4.1.1).

$$Pi = Pimin + \frac{value*(Pimax- Pimin)}{2chrom\text{-}length -1}$$

Objective Function and Fitness Function Formulation

In the ELD problem, the goal is to minimize the objective function

$$Ft = \sum_{i=1}^{n} Fi\ (Pi)$$

with the constraint of equality

$$\sum_{i=1}^{n} Pi-PL-Pd=0$$

is changed to constrained optimization problem and thus forming fitness function

$$Fct=Ft+PF\ (\sum Pi-PL-Pd)$$

where pf is penalty factor .the penalty function is placed into the objective function in such away that it penalizes any violation of the constraint and forces that unconstrained optima toward the feasible region . in the ELD problem the goal is to minimize the objective function Fct, while the objective when using GAs is to maximize a fitness function Ftt in the given form[10].

$$Ftt=EXP(-(K1*Fct)k2)$$

K_1 and K_2 are constants and the value is problem dependent .considering the evolutionary process of the GAs ,the solution is improved through the generation and also to decrease the penalty function over successive iterations can be adapted with the penalty function varying directly with the number of generations.

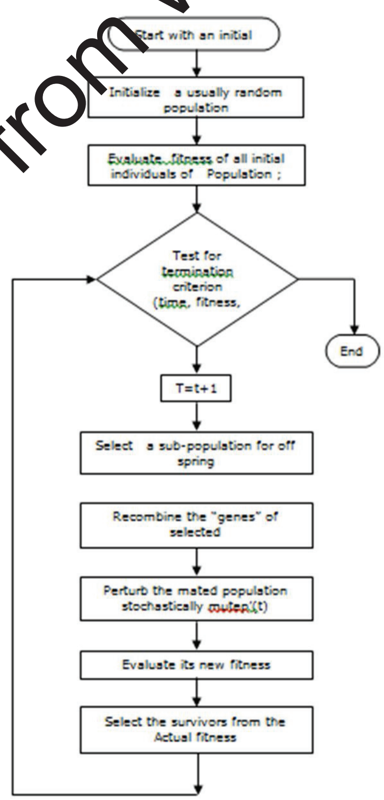
IV. Software and Results

The cost functions of the three thermal plants considered in this paper are obtained from Sheble and Britting [11]and they are as follows.

$F_1=(0.00156)P_1^2+(7.92)P_1+561$ Rs/h
$F_2=(0.00194)P_2^2+(7.85)P_2+310$ Rs/h
$F_3=(0.00482)P_3^2+(7.97)P_3+78$ Rs/h
The loss co-efficients of the considered system are
0.000075 0.000005 0.000008
0.000005 0.000015 0.000010
0.000008 0.000010 0.000045
The Operating ranges for three plants are :

$100MW < P_1 < 600MW$
$100MW < P_2 < 400MW$
$50MW < P_3 < 200MW$

Population size :10
Chromosome length :36
Maximum number of generations : 1000
Crossover probability :0.50
Mutation probability : 0.01



Total load P_D MW	Classical Kirchmayer Method				Cost Rs./h	GA				Cost Rs./h
	P_{G1}	P_{G2}	P_{G3}	P_L		P_{G1}	P_{G2}	P_{G3}	P_L	
812.57	325.116	371.012	130.000	13.558	7986.093	314.381	383.003	128.334	13.146	7986.068
585.33	233.258	268.106	90.933	6.962	5890.063	243.450	257.655	91.475	7.250	5890.094
869.00	345.120	400.660	138.610	15.420	8522.450	355.524	395.091	134.196	15.812	8522.875

Table.4

Here the range of limits for the load can be taken as 250MW – 1200 MW.

Genetic Algorithm claims to provide near optimal or optimal solution for computationally intensive problems. Therefore the effectiveness of the genetic algorithm solutions should always be evaluated by experimental results. For economic load dispatch problem, the results obtained through genetic algorithms developed in C language was tested for three thermal plant systems and extended to one plant as combined cycle co-generation plant in three thermal plant systems. The execution time takes two seconds in Pentium 120 MHz processor.

The performance of GA approach is compared with the classical Kirchmayer method as given in table 5.1. For the load of 585.33 MW, ΣPi-PD-PL = 592.297 – 585.33 – 6.962 = 0.005 MW in Classical Kirchmayer method, and it is 592.850 – 585.330 – 7.25 = 0 in GA approach. For the load of 869 MW ΣPi-PD-PL = 884.390 – 869.000 – 15.420 = -0.030 in conventional method and it is 884.811 – 869.000 – 15.812 = -0.001 MW in GA approach. The constraint of equality ΣPi-PD-PL = 0 does not hold good for classical Kirchmayer method. But this constraint is almost equal to or nearer to zero in GA approach. It at all it is having some value, it is multiplied by the penalty factor (PF) which is placed into the objective function in such a way that it penalizes any violation of the constraints and forces that unconstrained optima towards the feasible region. The solution of GA is improved through the generations, and also by decreasing the penalty function.

In conventional method, the values of PG1,PG2,PG3 are not optimal values as the constraint of equality does not hold good and also the cost functions of the plants are non-linear and they are approximated as either linear or quadratic.

It is observed that for any load, GA approach provides optimal values as the constraint of equality is almost zero or nearer to zero to minimize the objective function and there is no need of approximating the cost functions. Hence it is more accurate method and may replace effectively the conventional methods.

The cost functions of two thermal plants of taken as same as in the case of three thermal plants and the cost function of combined cycle co-generation plant (CCCP) can be taken as F3=(0.003210) P3^2+(7.927738) P3+56.6678[illegible]4 Rs/h. The loss co-efficients, operating ranges and the other data used in GA are same as in the first case.

Total load P_D MW	GA Method on three thermal plants					Cost Rs./h
	No.of generations	P_{G1}	P_{G2}	P_{G3}	P_L	
750	26	370.556	266.333	131.167	14.480	7415.401
650	203	317.018	230.211	115.106	10.725	6521.871
869	0	435.484	301.29	150.645	19.791	8532.77
1000	386	508.764	345.258	172.269	26.782	9842.026
812.57	256	404.262	282.557	141.279	17.133	7986.512

Total load P_D MW	GA Method on two thermal plants and one CCCP					Cost Rs./h
	No.of generations	P_{G1}	P_{G2}	P_{G3}	P_L	
750	676	371.418	262.85	131.425	14.545	7404.04
650	364	316.971	230.183	115.091	10.722	6471.786
869	37	436.787	302.072	151.036	19.906	8511.479
1000	284	508.343	345.006	172.503	26.739	9752.957
812.57	326	404.629	282.777	141.389	17.163	7938.337

Tables.5.1 and 5.2

As combined cycle co-generation plant (CCCP) is having low cost, total cost of two thermal plants with one combined cycle co-generation plant is lower than the total cost of three thermal plant system for any load and it is proved by the GA approach given in the table 5.2. The method is accurate and may replays effectively the conventional practices presently performed in different central load dispatched centers. This approach is only viable solution for power system with combined cycle co-generation plants and it is not possible to solve such a ELD problem by conventional technique and it is given table 5.2

V. Conclusions

The genetic algorithm is a searching or optimizing algorithm based on the natural evolution principles. Because of its capability to solve nonlinear optimization problems, the application of GAs to power system is a promising area to explore.

There is no need of approximating the cost functions of the plants in the differentiable form or quadratic form as in the case of conventional methods as Genetic Algorithms are used for solving the functions whether they are differentiable or not, continuous or not effectively. They do not stuck into local optima, because these begin with many initial points and search for the most optimum in parallel and these have been proved to be effective and quite robust in solving the optimization problems and can handle discrete control variable effectively and provide global solutions.

VI. Scope for Enhancement

Movement in the simple genetic algorithm is accomplished using three primary operators: reproduction, crossover and mutation. A genetic algorithm works with a population of chromosomes.

Refined genetic algorithms differ from simple genetic algorithms by some improvements made to ensure faster convergence. They are elitism, changing probabilities of mutation and crossover..

It is having a wide variety of current applications in science, engineering business and the social sciences. For other applications like multi-objective optimization etc. the advanced operators like Dominance, Diploid and Abeyance, Inversion and other Recording operators may be used.

VII.References

1. D.E. Goldberg. ‘Genetic Algorithms in Search Optimization and Machine Learning.’ Addison Wesley, 1989. P1 to P 144
2. H. Saadat, ‘Power System Analysis’. Mc.Graw- Hill, 1999. P. 257 to P 373.
3. I. J. Nagarath, D.P.Kothari, ‘Power System Engineering’ TMH, 1999. P 273-P337
4. C.L. Wadhwa. ‘ Electrical Power Systems’ New age International, 1983. P.646 - P 681.
5. O.L. Elegerd. ‘ An Introduction of Electrical Energy System Theory’ TMH, P 274-P 292.
6. P. Venkatesh, Dr. P.S.Kannan, M.sudhakaran. ‘Application of Computational Intelligence to Economic Load Dispatch Problem’. JIE, September 2000. Vol 81, P 39 – P 43.

7. RAJARAMAN. 'COMPUTER ORIENTED NUMERICAL METHODS'. PRENTICE –HALL OF INIDA. 2002, P. 124.
8. A.J. Wood & B.F. Wollenburg. 'Power Generation operation and Control' John Wiley and sons, 1984.
9. Z. Michalewicz. ' Genetic Algorithms + Data Structure = Evolution programs'. Springer Verlag, Berlin, Heidelberg, New York, 1992.
10. Y.H. Song and C.S.V. Chou. ' Advanced Engineered Conditioning Genetic Approach to power Economic Dispatch'. IEE proceedings – Generation, Transmission and Distribution, Vol 144, No.3, May 1997, P. 285.
11. G.B. Sheble and K.Britting. ' Refined Genetic Algorithm: Economic Dispatch Example. ' IEEE Transactions on power system, Vol .10, No. 1, 1995 P.117.