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Optimal Economic Dispatch Using Genetic Algorithm

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Abstract **- The complexity in modern power system around the world has grown due to its interconnections and the power demand. The focus of any power system remains on enhanced performance of the system, reliable power, low cost, generation cost and the optimal economic dispatch. The economic load dispatch is an integral part of any power system, as the load may be near or at distant from the power generation and the economical dispatch has to be done in either case. Certain Economic Load Dispatch (ELD) problems are signified as non-linear optimization problem having equality and inequality constraints. The cost function for each unit can be resolved using mathematical or analytical methods. The various methods that provide solution to ELD are lambda iteration method, particle swarm optimization, numerical method, evolutionary algorithm; Genetic algorithm etc., In this paper, Real Coded Genetic Algorithm (RCGA) is implemented to find the solution of economic load dispatch problem. It is tested on three generators including equality and inequality constraints without considering the losses. The code is executed in MATLAB and the results are compared against the conventional lambda iteration method satisfying the constraints.**

Keywords - Economic load dispatch, real coded genetic algorithm, genetic algorithm.

I. INTRODUCTION

The functional approach to produce optimal generation for the available thermal units by reducing the charge of generation is acknowledged as economic load dispatch (ELD). When a number of generators are running in a generating station each one of them may be loaded in such a way that optimum economic efficiency may be achieved. The purpose of economic dispatch or optimal dispatch is to reduce fuel costs for the power system[2]. By economic load scheduling, the generation of different generators are found, so that the total fuel cost is minimum and at the same time the total demand and losses at any instant is met by the total generation[16]. The economic dispatch problem involves the solution of:

- Unit commitment
- On-line dispatch

To solve the ELD problem that includes different types of constraints and objective functions many efforts have been developed in recent years through various mathematical programming and optimization techniques. The conventional method to solve ED are Lambda Iteration method, Newton-Raphson method, Base Point and many[17]. These typical economic load dispatch (ELD) algorithms have need of incremental cost curves to be linear or monotonically increasing. As the problem is non-linear, many standard calculation based techniques failed in solving these types of problems. On considering these nonlinear problems, many stochastic search algorithms like genetic algorithm (GA), evolutionary strategy (ES) [5], evolutionary programming (EP) [9], particle swarm optimization (PSO) [8] and Differential Evolution (DE) [14] are proven to be very efficient to solve these highly nonlinear ELD problems without any restrictions on the shape of the cost curves. Hence, the Genetic Algorithm (GA) is a soft computing technique which is used to find the approximate solutions to search problems and optimization with the best solutions using Real Coded technique[1] for encoding and is called the Real Code Genetic Algorithm.

II. ELD PROBLEM

The ELD problem can been formulated by taking the subsequent objectives and constraints as follows:

A. *ELD Problem formulation*

The main aim of economic dispatch problem is to minimize the overall fuel cost and to meet the load demand of a overall power system simultaneously[13]. A typical power system model consists of n generating units connected to the system. The fuel cost function that is to be minimized for the generation can be generally formulated as follows:

$$\text{Min}_{P_{gi}} \sum_{i=1}^{N} (C_i P_{Gi}) \tag{1}$$

$$C_i P_{Gi} = C_i(P_{Gi}) = c_i + b_i P_{Gi} + a_i P_{Gi}^2 \tag{2}$$

Where C_iP_{Gi} is the fuel cost of the real power generation,a_i,b_i,c_i are the cost coefficients of the for the *i*-th generator in a power system and N is the number of generators committed for the power generation. The equation (2) takes up a quadratic form for solving the economic load dispatch problem. The input-output curve for the generating unit is given in the figure.1.

On considering the constraints, the total power generation must be satisfying the power demand and also should compensate the real power losses in the transmission lines.This is called the equality constraint and is formulated as,

$$\sum_{i=1}^{N} (P_G - P_d - P_l) = 0 \qquad (3)$$

Where P_g is the Generated power, P_d is the Demand power and P_l is the Transmission loss. As the losses are neglected for the considered problem, the equation (2) becomes,

$$\sum_{i=1}^{N} (P_G - P_d) = 0 \qquad (4)$$

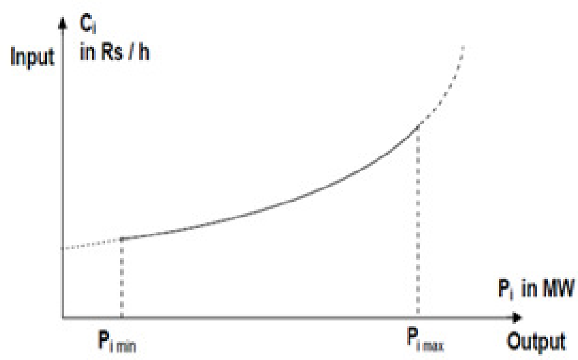

Figure 1. Input-Output curve of generating unit

The other constraint that is considered for the system operation for the economic load dispatch is the inequality constraint. Real power output of each generating unit must operate between the defined (restricted) zone of minimum and maximum limits that is assigned for each generator in the system, the constraints is given by,

$$P_{Gmin} \le P_G \le P_{Gmax} \qquad (5)$$

Where P_{gmin} is the minimum limit and P_{gmax} is the maximum limit of the power generated.

B. *Lambda Iteration method*

The lambda iteration method is the conventional method used for minimizing the fuel cost (2),

$$\sum C_i(P_{Gi}) = c_i + b_i.P_{Gi} + a_i.P_{Gi}^2 \quad \text{Rs/hr}$$

The slope of fuel cost curve i.e. $\frac{dCi}{dPGi}$ Rs/MWh can be obtained by differentiating the above equation with respect to P_{Gi}, and the incremental cost is given by,

$$\text{Incremental cost} = \frac{\text{Small change in input}}{\text{Small change in input}}$$

Hence on differentiating,

$$\lambda = IC = 2a_i\, P_{Gi} + b_i \quad \text{Rs/MWhr} \qquad (6)$$

Thus the incremental cost is a linear relationship
Using equal incremental cost, the generations can be found,

$$P_{Gi} = \frac{\lambda - bi}{2ai} \qquad (7)$$

Substituting the P_{Gi} in power balance equation, the λ is given by,

$$\frac{Pd + \sum_{i=1}^{N} \frac{bi}{2ai}}{\sum_{i=1}^{N} \frac{1}{2ai}} \qquad (8)$$

Thus the incremental cost that is used to find the generation of each unit.

III. GENETIC ALGORITHM

An algorithm that is inspired from nature is the Genetic algorithm(GA)[10], which inspires Darwins' theory of Evolution.This theory basically depicts that when a organism is subjected to a new environment,the genes of the organisms undergo changes inorder to survive in the environment it is exposed to live in.This algorithm was first developed by John Holland at the University of Michigan[10], has since been tried on various optimization problems with a high degree of success. The genetic algorithm is mainly based on randomness, and hence the population or the search space in which the optimal solution has to be found is generated randomly. This is called the random population or random search space. From the random population generated each member of the population is called the chromosome. Each chromosome will be a potential solution for the optimization problem considered. The optimization is performed in the genes(DNA) of the chromosome to satisfy the fitness function assigned for the optimization [12].

A. *Structure of Genetic Algorithm*

Parent selection is the important task and it contributes the most for the optimization problem. The random population is generated as the GA works on randomness. The goal of the parent selection process is to select the best fitted individual from the random population, to reproduce a new set of fitted offspring that optimizes the problem. There are various methods for the parent selection that includes Roulette wheel selection[4], Tournament selection and Random Selection methods. The Tournament selection method is used to select the parent in this paper as it finds the best fitted parents for the reproduction.

Tournament selection

A tournament selection is a competition that is held between two individuals and between both, the one that wins the tournament is selected as the parent and each individual participate exactly two times in a competition. The selected individuals are then put into the mating pool. There may be individual that is selected even more than one time also and that ensures the individuals with best fitness, as the probability of selection of individual with better fitness is higher.

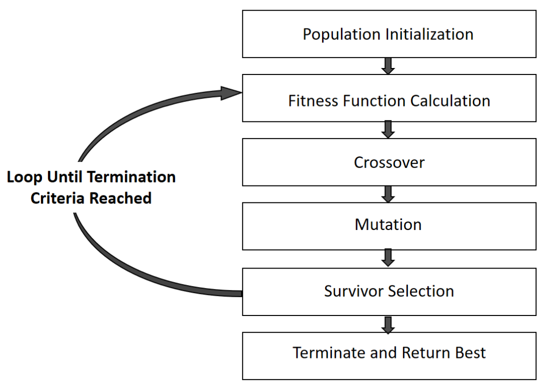

Figure 2.Genetic Algorithm Flow chart

Reproduction

Reproduction, in general is a combination of two types of genes that undergoes interchange of DNA to produce a new offspring. In Genetic Algorithm, it is a process based on the objective function (fitness function) of each string(chromosome) that is assigned. This objective function identifies the fitness of each string to find the optimal solution. During reproduction, recombination (or crossover) first occurs. Genes from parents combines to form a whole new chromosome. The newly created offspring can then be mutated.

IV. Operators of Genetic Algorithm

Overview

The main operators of the Genetic Algorithm are the crossover and the mutation, where the problem optimization is performed to obtain the optimal solution. The performance of operators are discussed in this section.

A. Crossover

Crossover is an operator that accepts data from two parent chromosomes that is selected for the reproduction process which is called the recombination. It is an operator that accepts data from two parents and produces an offspring that has the combination of both the parents. Crossover uses a mathematical operator [6] to combine the information from two parents. Crossover improves the solution for the problem and if the crossover operation is performed in several generation ,the better the solutions and at some level of iteration the optimal solution can be obtained. The mathematical operator for the binary encoded crossover is given by,

$$Y_{1i} = \propto i\, X_{1i} + (1- \propto i)X_{2i} \qquad (9)$$

Where Y_{1i} is the offspring for the *i-th* generation and X_{1i} and X_{2i} are the parent chromosomes selected.The above equation gives the offspring of the next generation.

There are two tyoes of crossover depending on the number of points where the genes are being transferred from the parent chromosome.

Chromosome1	11011|00100110110
Chromosome2	11011|11000011110
Offspring1	11011|11000011110
Offspring2	11011|00100110110

Figure 3.Single point Crossover

Real coded encoding

Though the binary representation is generally used for the encoding of chromosomes in power optimization problems, in this paper, the binary simulated crossover is used where the method of binary crossover is done on real random number. This encoding for in the GA is claimed by Wright [8] which is the Real Coded Genetic Algorithm (RCGA) to offer a number of advantages in numerical function optimization over binary encoding. The advantages of this method are, to increase the efficiency of the GA as there is no need to convert chromosomes to the binary type that reduces the steps and time, it requires less memory as efficient floating-point internal computer representations can be used directly, it also increases the precision of the solution; and there is greater freedom to use different genetic operators [7]. For the encoding using the method considering for the parents P_1 and P_2 which consists of two parent vectors that consist of rows of selected individuals. The beta(β) is an operator used for the encoding technique,calculated as

$$\beta = (2*r)\hat{}(1/(nc+1)) \qquad (10)$$

where r is the random number and n_c is the distribution index for crossover. On calculating the beta value, the recombination of genes takes place by considering the parent individual in the column vector to be multiplied by (1+ β) to the P_1 individual and (1- β) to the P_2 individual there by producing an offspring1 from two strings and for second offspring,the individuals are multiplied to (1- β) to the P_1 individual and (1+ β) to the P_2.

B. Mutation

After a crossover is performed, mutation operation takes place. Mutation is a kind of error in replicating or copying genes that increases the abilities of GA and to create innovative and revolutionary solutions for the problem. This operation randomly changes the offspring resulted from crossover. The mutation rate is the rate at which the gene of the chromosome is recombined or swap out of total chromosomes. For the real coded GA the n_m which is distribution index for mutation is used. For the mutation to take place the delta value is calculated from,

$$\delta = (1/(2*(1-r)))^{\wedge}(1/(nm+1))-1 \quad (11)$$

The muation is performed on a particular gene in a chromosome and the fitness is thus improved.

V. ECONOMIC DISPATCH USING GA

The implementation of the genetic algorithm depends on the formulation of problem that includes the transformation of the problem solution into a chromosome representation and the fitness function is formulated to assess the quality and fitness of a solution obtained. The fitted chromosome in each generation represents the scheduling for solving the economic load dispatch using the genetic algorithm [6]. In the economic load dispatch problem, the real power output of each unit is the main decision variable. The main objective of the economic dispatch is to minimize the fuel costs, satisfying the constraints considered such as the power balance equation and the generator limit constraint. The individuals that fits the fitness function most will have the lowest cost for the objective function formulated for the economic dispatch problem. The fitness function is used to transform the cost function value into a measure of relative fitness. For the economic dispatch problem, the fitness function is given by,

$$\sum C_i(P_{Gi}) = c_i + b_i.P_{Gi} + a_i.P_{Gi}^2 \quad (12)$$

The objective function to be minimized requires a random population that is generated using the initialization formula. The fitness function for each individuals in the random population that is to be verified is assigned and the parent selection is done using the Tournament selection. The selected parents undergo binary simulated crossover to produce the offspring. The mutation takes place after the crossover, where the particular gene of the cross overed chromosome is mutated or changed and the minimum, maximum violations are checked for the mutated chromosome. And by using the fitness function, the fitness is evaluated and the best fitted individual is chosen as the best solution for the current generation, The number of generation is repeated until the maximum number of generation limit is reached and till the objective function is minimized with the best solution.

VI. SIMULATION RESULTS

In this segment the results obtained for the economic load dispatch problem implementing the proposed method are verified with the conventional lambda iteration method. The proposed method has been implemented in a standard IEEE-14 bus system [16] with three thermal generating units whose cost function is the quadratic equation for the test system. The GA is implemented using the MATLAB computing software of version R2018a.The input data for the test system is given in the Table 1.

a_i	b_i	c_i	P_{min}	P_{max}
0.005	2.450	105.00	10	160
0.005	3.510	44.100	20	80
0.005	3.890	40.600	20	50

Table 1 Features of three generator Test system

Optimum solution using lambda iteration method for the ELD problem.
Case study 1

The results obtained for the conventional lambda iteration method using the MATLAB software is given in the Table 2 with a demand of 75 MW.

Generation	λ – Iteration method
P_1 (MW)	45
P_2 (MW)	10
P_3 (MW)	20
TOTAL COST(Rs/hr)	433.1250

Table 2 Optimal result for lamda iteration for *case study 1*

Optimum solution using Genetic Algorithm method for the ELD problem.
Case study 1

The results for the ELD problem using GA is given in the Table 3 for a power demand of 75 MW.In the genetic algorithm, the number of generations is 1000, population size is 500, the crossover probability(P_c) is 0.9, mutation probability(P_m) is 0.2, the distribution index for crossover (n_c)and mutation(n_m) is 20.

Generation	GA method
P_1 (MW)	33.4309
P_2 (MW)	20
P_3 (MW)	21.5691
TOTAL COST(Rs/hr)	429.9569

Table 3 Optimal result for GA method for *case study 1*

Optimum solution using lambda iteration method for the ELD problem.
Case study 2

The results obtained for the conventional lambda iteration method using the MATLAB software is given in the Table 4 with a demand of 150 MW.

Generation	λ – Iteration method
P_1 (MW)	117.65
P_2 (MW)	12.35
P_3 (MW)	20
TOTAL COST(Rs/hr)	671.8848

Table 4 Optimal result for lamda iteration for *case study 2*

Optimum solution using Genetic Algorithm method for the ELD problem.
Case study 2

The results obtained for the ELD method using the GA method in the MATLAB software is given in the Table 5 with a demand of 150 MW.

Generation	GA method
P_1 (MW)	107.8400
P_2 (MW)	22.1601
P_3 (MW)	20.00
TOTAL COST(Rs/hr)	667.8549

Table 5 Optimal result for GA method for *case study 2*

Comparison of Case study 1 and for Case study 2

Table 6 and Table 7 shows the comparison of optimum scheduling and total cost ($/hr) of three generator test system for different methods for a demand of 75 MW and 150 MW respectively. This shows that Genetic Algorithm results minimum operating cost compared to the conventional lambda iteration method.

Generation	λ – Iteration method	GA method
P_1 (MW)	45	33.4309
P_2 (MW)	10	20
P_3 (MW)	20	21.5691
TOTAL COST(Rs/hr)	433.1250	429.9569

Table 6 Comparison of Lambda iteration method and GA for *case study 1*

Generation	λ – Iteration method	GA method
P_1 (MW)	117.65	107.8400
P_2 (MW)	12.35	22.1601
P_3 (MW)	20	20.00
TOTAL COST(Rs/hr)	671.8848	667.8549

Table 7 Comparison of Lambda iteration method and GA for *case study 2*

VII. Conclusion

In this paper, a new approach to the Economic Load Dispatch problem for without loss case using Real Coded Genetic Algorithm(RCGA) has been presented. The real valued scheme is encoded using the Binary simulated crossover technique that produced a successive set of offspring population. In the case studies, proposed method is implemented for the ELD problem in a standard IEEE-14 bus system with three generators. The test results shows that the proposed RCGA provides the better solutions than the conventional lambda iteration method and the cost of the system is minimized subsequently.

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