# Optimal Economic Load Dispatch Using Genetic Algorithms

Vijay Kumar, Jagdev Singh, Yaduvir Singh, Sanjay Sood

***Abstract*—**In a practical power system, the power plants are not located at the same distance from the center of loads and their fuel costs are different. Also, under normal operating conditions, the generation capacity is more than the total load demand and losses. Thus, there are many options for scheduling generation. In an interconnected power system, the objective is to find the real and reactive power scheduling of each power plant in such a way as to minimize the operating cost. This means that the generator's real and reactive powers are allowed to vary within certain limits so as to meet a particular load demand with minimum fuel cost. This is called optimal power flow problem. In this paper, Economic Load Dispatch (ELD) of real power generation is considered. Economic Load Dispatch (ELD) is the scheduling of generators to minimize total operating cost of generator units subjected to equality constraint of power balance within the minimum and maximum operating limits of the generating units. In this paper, genetic algorithms are considered. ELD solutions are found by solving the conventional load flow equations while at the same time minimizing the fuel costs.

***Keywords*—**ELD, Equality constraints, Genetic algorithms, Strings.

## I. Introduction

ECONOMIC dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, subject to transmission and operational constraints. The Economic Dispatch Problem is solved by specialized computer software which should honor the operational and system constraints of the available resources and corresponding transmission capabilities [1].

In an electrical power system, a continuous balance must be maintained between electrical generation and varying load demand, while the system frequency, voltage levels, and security also must be kept constant [2]. Furthermore, it is desirable that the cost of such generation be minimal. In addition, the division of load in the generating plant becomes an important operation as well as an economic issue which could be solved at every load change (1%) or every 2-3 minutes [3]. Research techniques have been successfully used to solve optimal load flow problems by using linear or nonlinear programming, but these algorithms are generally limited to convex regular functions [4].

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Many functions are multi-modal, discontinuous and not differentiable. Stochastic sampling methods have been used to optimize these functions. Whereas traditional resolution techniques use the characteristics of the problem to determine the next sampling point (e.g. gradient, Hessians, linearity and continuity), stochastic resolution techniques make no such assumptions. Instead, the next sampled point is determined based on stochastic sampling or decision rules rather than on a set of deterministic decision rules. Genetic algorithms have been used to solve difficult problems with objective functions that do not possess properties such as continuity, differentiability and so forth. These algorithms maintain and manipulate a set of solutions and implement a survival of the fittest strategy in their search for a better solution [5].

The operation of generation facilities is to produce energy at the lowest cost to reliably serve consumers by recognizing any operational limits of generation and transmission facilities. Planning and operation of power systems under existing conditions, its improvement and also future expansion requires the load flow studies, short circuit studies and stability studies. However the load flow studies are very important for planning, control and operations of existing systems as well as planning its future expansion as the satisfactory operation of the system depends upon knowing the effects of inter connection, new loads, new generating stations or new transmission lines etc. before they are installed [6]. Genetic Algorithm has implemented and the results of the twenty six bus system are shown in this paper.

## II. Methodology

A simple GA is an iterative procedure, which maintains a constant size population P of candidate solution. During each iteration step (generation) three genetic operators (reproduction, Crossover and mutation) are performing to generate new populations (offspring's), and the chromosomes of the new population are evaluated via the values to the fitness which is related to the cost function. Based on these genetic operators and the evaluation, the better new population of candidate solutions is formed [7].

With the above description, a simple genetic algorithm is given as follows:

- Generate randomly a population of binary string.
- Calculate the fitness for each string in the population.
- Create offspring through reproduction, crossover and mutation operation.
- Evaluate the new string and calculate the fitness for each generation.

- If the search goal is achieved, or an allowable generation is attained, return the best chromosome as the solution; otherwise go to step.

The general structures of genetic algorithms are described as; P(t) and C(t) be parents and offspring in current generation t.

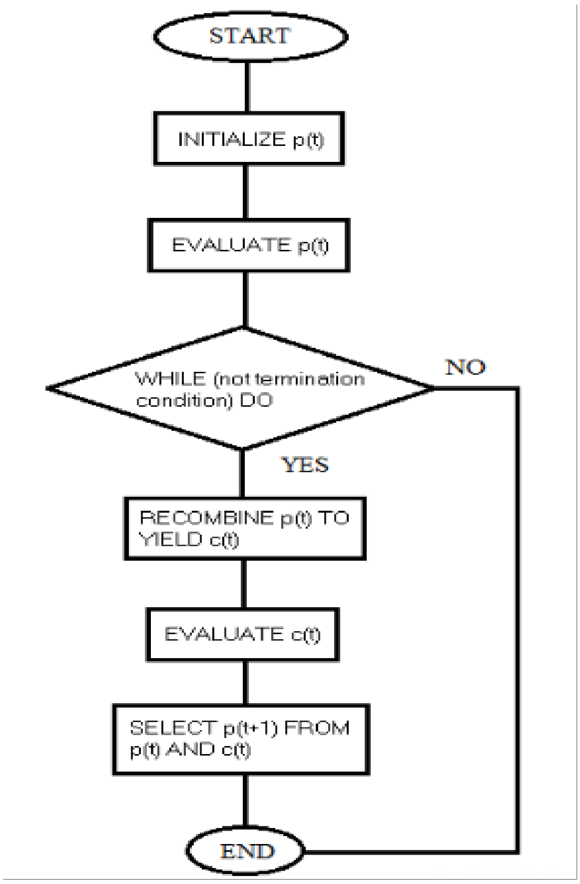


Fig. 1 Flow chart

## III. Economic Load Dispatch(ELD)

Economic load dispatch is defined as the process of allocating generation levels to the generating units in the mix, so that the system load is supplied entirely & most economically.

Economic dispatch is the short-term determination of the optimal output of a number of electricity generation facilities, to meet the system load, at the lowest possible cost, subject to transmission and operational constraints. The Economic Dispatch Problem is solved by specialized computer software which should honor the operational and system constraints of the available resources and corresponding transmission capabilities. The term is defined as "the operation of generation facilities to produce energy at the lowest cost to reliably serve consumers, recognizing any operational limits of generation and transmission facilities" [8]-[10].

The main idea is that in order to serve load at minimum total cost, the set of generators with the lowest marginal cost must be used first, with the marginal cost of the final generator needed to meet load setting the system marginal cost. This is the cost of delivering one additional MW of energy onto the system. The historic methodology for economic dispatch was developed to manage fossil fuel burning power plants, relying on calculations involving the input/output characteristics of power stations [11].

## IV. ELD Solution through GA

GA differs from classical optimization techniques in that it works on a population of solutions and searching are on a bit string of the real parameters rather than the parameters themselves. Each string in the population representing a possible solution is made up of a number of substrings. The algorithm starts from an initial population generated randomly. This population undergoes three genetic operations, Selection, Crossover and Mutation to produce a new generation after duly considering the fitness of strings, which corresponds to the objective function for the concerned problem. A trial solution for the problem requires the selection of a number of populations for a generation and a number for several such generations in order to find the best fitness of strings in that trial. Several such trails are considered to evaluate the overall best objective function. The best value of the fitness of the strings is dependent on the number of population in a generation, the number of generations and the number of the trails while solving the problem through GA [13]-[15].

### *A. Terms Involved*

1.Population

Genetic Algorithm differing from conventional search techniques, start with an initial set of random solutions called population.

2.Chromosome

Each individual in the population is called a chromosome. It represents a solution to the problem at hand. It is a string of symbols and it is usually a binary bit string but not necessarily.

3.Generations

Chromosomes evolve through successive iterations called generations. During each generation, the chromosome is evaluated using some measures of fitness.

4.Offspring’s

To create the next generation, new chromosome are formed by either merging two chromosomes from current using a crossover operator or modifying a chromosome using a mutation operator. For creating new generation, it is formed according to the fitness values by selecting some of the parents and offspring, rejecting others so as to keep the population size constant. Recombination typically involves crossover and mutation to yield offspring.

5.Crossover

Crossover is the main genetic operator. It operates on two chromosomes at a time and generates offspring by combing both chromosomes features. A simple way to achieve crossover would be to choose a random cut-point and generate the offspring by combing the segment of one parent to the left of the cut point with the segment of other parent to the right of the cut point.

6.Mutation

Mutation is the background operator which produces spontaneous random changes in various chromosomes. A simple way to achieve mutation would be alter one or more genes. It serves the crucial role of either replacing the genes lost from the population during the selection process so that they can be tired in a new context or providing the genes that were not present in the initial population.

7.Crossover Rate

It is defined as the ratio of the number of offspring's produced in each generation to the population size. This ratio Controls the expected number of chromosomes to undergo the crossover operation. A higher crossover rate allows exploration of more of the solution space and reduces the chances of settling for a false optimum; but if this rate is too high, it results in the wastage of a lot of computation time in exploring unpromising regions of the solution space.

8.Mutation Rate

It is defined as the percentage of the total number of genes in the population. It controls the rate at which new genes are introduced into the populations for trial. If it is low, many genes that would have been useful are never tried out; but if it is too high, there will be much random perturbation, the offspring's will start losing their resemblance to the parents, and the algorithm will lose the ability to learn from the history of the search.

9.Selector

Selection creates a new population from the old population. In selection process, strings are picked up from the present population based on their fitness values to form a new population. For this process, Roulette Wheel selection procedure is followed.

*B. Formulation of ELD*

The ELD problem is considered as a general minimization problem with constraints and can be written as:

$$Minimize \quad f(x) \tag{1}$$

$$Subject\ to: \; g(x) = 0 \tag{2}$$

$$h(x) \leq 0 \tag{3}$$

f(x) is the objective function, g(x) and h(x) are respectively the set of equality and inequality constraints. x is the vector of control and state variables. The control variables are generator active and reactive power outputs, bus voltages, shunt capacitors/rectors and transformers tap setting. The state variables are voltage & angles of load buses [12], [16].

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

$$OBJ = \sum_{i=1}^{n} \; Fi(Pi) \tag{4}$$

Subject to the constraint of equality in real power balance:

$$\sum_{i=1}^{n} Pi - PL - PD = 0 \tag{5}$$

The inequality constraints of real power limits of the generation outputs are:

$$Pimin < Pi < Pi\,max \tag{6}$$

where: Fi (Pi) is the individual generation production in terms of its real power generation. Pi is the output generation for unit i, n the number of generators in the system. Pd is the total current system load demand, and $P_L$ the total system transmission losses. Pimin is minimum output power limit of ith generating unit, Pi max is maximum output power limit of ith generating unit. PD denotes total load. PL denotes power 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.

$$Fi(Pi) = Ai * Pi2 + Bi * Pi + Ci \tag{7}$$

where $A_{i,}$ Bi & Ci are the cost coefficients of the ith generator.

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:

$$dFi(Pi) \,/\, dPi = 2\,Ai * Pi + Bi \tag{8}$$

Transmission loss is a function of the unit generations and is based on the system topology. Solving the ELD equations for a specified system requires an iterative approach since all unit generation allocations are embedded in the equation for each unit. In practice, the loss penalty factors are usually obtained using on line power flow software. This information is updated to ensure accuracy. They can also be calculated directly using the $B_{mn}$ matrix loss formula [17]-[21].

$$PL = Pi\,Bij\,Pj \tag{9}$$

where $B_{ij}$ are coefficients, constants for certain conditions, voltage and angle of load buses.

*C. Objective Function*

The objective function for the ELD reflects the costs associated with generating power in the system. The quadratic cost model is used. The objective function for the entire power system can then be written as the sum of the quadratic cost model for each generator:

$$f(x) = \sum ngi = 1\; ai + biPgi + ciPgi2 \tag{10}$$

Here ng is the number of thermal units, $P_{gi}$ is the active power generation at unit i and $a_i$, $b_i$ and $c_i$ are the cost coefficients of the ith generator.

*D. Equality Constraints*

The equality constraints g(x) of the ELD problem are represented by the power balance constraint, where the total power generation must cover the total power demand and the power loss. This implies solving the load flow problem, which has equality constraints on active and reactive power at each bus as:

$$Pi = Pgi - Pdi = \sum nj = 1\, vivj(Gij\cos\theta ij + Bij\sin\theta ij) \quad (11)$$

$$Qi = Qgi - Qdi = \sum nj = 1\, vivj(Gij\sin\theta ij - Bij\cos\theta ij) \quad (12)$$

$$Where: i = 1,2,3, \ldots N \;\&\theta ij = \theta i - \theta j$$

$P_i$, $Q_i$ are injected active and reactive power at bus I; Pdi & Qdi are active and reactive power demand at the bus I; Vi is bus voltage magnitude and angle at bus I; Gij & Bij are conductance and inductance of the (i,j) element in the admittance matrix [22], [23].

*E. Inequality Constraints*

The inequality constraints h(x) reflect the limits on physical devices in power system as well as the limits created to ensure security.

Upper and lower bounds on the active and reactive generations:

$$Pgimin \leq Pgi \leq Pgimax \quad (13)$$

$$Qgimin \leq Qgi \leq Qgimax \quad (14)$$

Upper and lower bounds on the tap ratio *(t)* and phase shifting *(α)* of variable transformers:

$$tijmin \leq tij \leq tijmax \quad (15)$$

$$\alpha ijmin \leq \alpha ij \leq \alpha ijmax \quad (16)$$

$$Upper\ limit\ on\ the\ active\ power\ flow\ (Pij)\ of\ line\ i - j:$$
$$|Pij| \leq Pijmax;$$

where (5):

$$Pij = |-Gijv2i + G_{ij}V_iV_j\cos(\theta_i - \theta j) + BijViVjsin(\theta i - \theta j)| \quad (17)$$

Upper and lower bounds on bus voltage magnitude

$$V_{\mathrm{imin}} \leq V_{\mathrm{i}} \leq V_{\mathrm{imax}}; \quad (18)$$

It can be seen that the generalized objective function F is a nonlinear, the number of the equality and inequality constraints increase with the size of power distribution systems. Applications of a conventional optimization technique such as the gradient based algorithms to a large power distribution system with a very nonlinear objective functions and great number of constraints are not good enough to solve this problem. Because it depend on the well computing of these derivatives in large search space [24]-[26].

*F. String Representation*

GA works on a population of strings consisting of a generation. A string consists of sub strings, each representing a problem variable. In the present ELD problem, the problem variables correspond to the power generations of the units. Each string represents a possible solution and is made of substrings, each corresponding to a generating unit. The length of each sub string is decided based on the maximum/minimum limits on the power generation of the unit it represents and the solution accuracy desired. The string length, which depends upon the length of each substring, is chosen based on a tradeoff between solution accuracy and solution time. Longer strings may provide better accuracy, but result in higher solution time.

Let the step-size is given by;

$$\text{Step-size a} = \text{Pmax-Pmin}/\ (2^n\text{-}1) \quad (19)$$

where n is the length of substring in binary codes corresponding to a unit. For a typical substring with three units and each unit described in binary codes is shown.

| 0 1 1 0 1 | 1 0 0 1 1 | 0 1 1 1 0 |
|---|---|---|
| Unit 1 | Unit 2 | Unit 3 |

It may be seen earlier string has three substrings, each substring corresponding to a unit. Each sub string has a five bits randomly coded in this example. In the earlier Situation, as an example, if for unit 1, Pmax=600MW and Pmin = 50MW, then step size for unit 1=600-50/($2^5$-1) =550/31=17.742. [Power generation of unit 1] [Decimal equivalent of binary coded string for unit 1]+PG1Min. =17.742 X 13+50=280.645MW. Thus the sub string corresponding to unit 1 coded as 01101 Corresponds to a random generation of 280.645MW.

*G. Initial Population*

Initial Population is randomly chosen considering a number of strings. Each string consists of several substrings which are binary coded randomly as explained earlier.

*H. Genetic Operations*

Fitness Evaluation: As a first step in the determination of fitness of a solution candidate, the augmented cost is found out. Augmented cost C*(in$/h)=Total Generation Cost C (in $/h) + KL1. [Violation of Power Generation limit of Slack bus unit] + KL2 [sum of all line flow limits]. Here KL1and KL2 are penalty factors for the constraints violations. In GA, we consider several generations randomly at each generation consisting of several populations randomly Following is the fitness formulation adopted: Fitness of a cost of population member = [Maximum augmented cost of Population Member] - [Augmented cost of the population member under construction]

The selection of suitable scalar value for penalty factor KL1 and KL2 is critical in order to satisfy the unit constraints at the slack bus and the Line flow constraints, respectively. The augmented cost C* has to be minimized for finding the solution by GA.

Selection with Embedded Elitism

Selection creates a new population from the old population. In selection process strings are picked up from the present population based on their fitness values to form a new population. For this process, Roulette Wheel selection procedure is followed. Elitism is based on a comparison of the augmented costs for the strings. The basic premise of Elitism is survival of the fittest. The implementation is as follows: For the first generation after evaluation of the augmented costs for all the string (i.e. population members), the member with the least is identified as the Elitist copy. The Elitist copy is made a member of the population pool for crossover. The augmented costs of the Elitist copy are compared with the augmented costs for all the members in the second generation. If any member in the second generation has an augmented cost lower than that of the Elitist Copy on hand, then that particular member is selected as the new Elitist copy. This procedure is repeated for all the generations in a trial so as to find out the overall Elitist copy in a trial. The Elitist copy (i.e. the string having the minimum augmented cost) is identified as the best solution of this trial. This procedure is carried out for several trials and the overall Elitist copy is identified as the global minimum for these trials.

Crossover with Embedded Mutation

A pair of string is randomly chosen from the population in a generation. The bits of these strings are swapped at a randomly selected crossover site. This is called single point crossover. When swapping is done at more than one point, it is called Multipoint Crossover. Based on the modes of application, Crossover can be Head-Head, Head-Tail or Tail-Tail Crossover site, the portion to the left of the Crossover site shall be considered as the head and the portion to the right of the Crossover Site shall be considered as the tail of the string [27]-[39].

*I. Implementation of GA Solution to ELD with Line Flow Constraints*

The various stages involved in the solution Algorithm for GA are the following:

1. Choose the Population size, number of generations, sub-strings length and the number of trials.
2. Generate initially randomly coded strings as population members in the first generation.
3. Decode the population to get power generation of the units in the strings.
4. Execute load flow considering the unit generations in step (3) except for the slack bus, in order to evaluate the system transmission losses, slack bus generation, line flows and hence any violation for the slack bus generation and violation the line flow limits.
5. Evaluate the fitness of population members.
6. Execute selection based on Reproduction considering. Roulette Wheel procedure with embedded Elitism followed by crossover with embedded. Mutation to create the new population for the next generation.

Steps (2)-(6) are repeated for all the number of generations and the minimum augmented cost is noted for the first trial. This operation is carried out for the selected number of trials and the overall minimum for the augmented cost is taken as the solution point [40]-[54].

## V. Results

Results of three units for power generation, fuel cost are obtained & shown with the help of minimum & maximum power limits respectively. Fig. 2 shows the results obtained for the power generated for all three units, whereas Fig. 3 shows the results for fuel cost. Fig. 4 shows the result for total power. Figs. 5, 6 show the graph for total fuel cost & total power loss respectively obtained for all three different units.

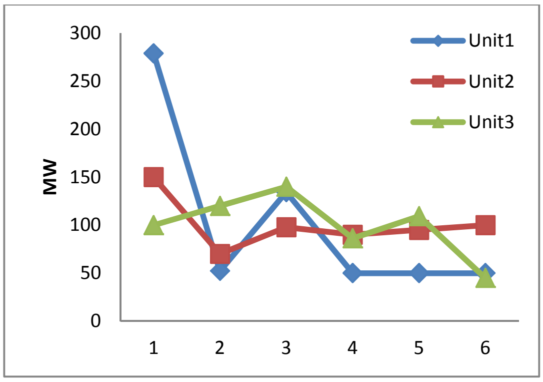


Fig. 2 Power Generated

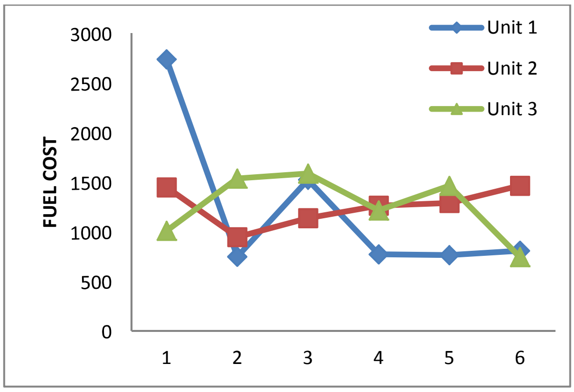


Fig. 3 Fuel Cost of Generated Power

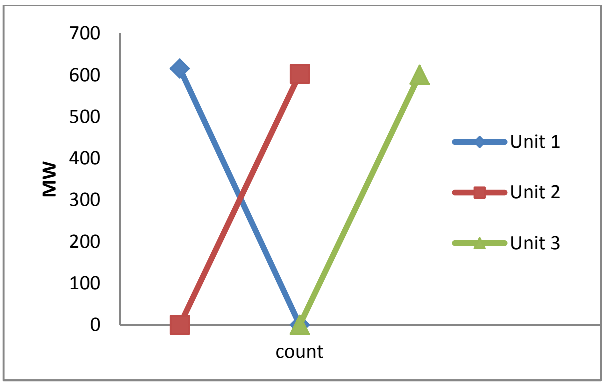


Fig. 4 Total Power

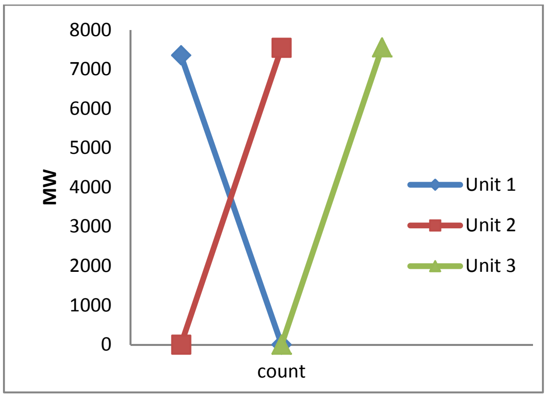


Fig. 5 Total Fuel Cost

TABLE I
POWER DISTRIBUTION

| S. no. | Pmin | Pmax | Power generated | Fuel cost | Unit No. |
|---|---|---|---|---|---|
| I. | 100 | 500 | 278.912 | 2736.93 | 1 |
| II. | 50 | 200 | 52.2608 | 748.554 | 1 |
| III. | 80 | 300 | 134.305 | 1523.93 | 1 |
| IV. | 50 | 150 | 50 | 772.5 | 1 |
| V. | 50 | 200 | 50 | 765 | 1 |
| VI. | 50 | 120 | 50 | 808.75 | 1 |
| VII. | 60 | 150 | 150 | 1447.5 | 2 |
| VIII. | 70 | 250 | 70 | 946.55 | 2 |
| IX. | 80 | 350 | 97.7722 | 1137.1 | 2 |
| X. | 90 | 450 | 90 | 1262.9 | 2 |
| XI. | 95 | 550 | 95 | 1289.7 | 2 |
| XII. | 100 | 650 | 100 | 1465 | 2 |
| XIII. | 20 | 100 | 100 | 1010 | 3 |
| XIV. | 25 | 120 | 120 | 1536.8 | 3 |
| XV. | 30 | 140 | 140 | 1586.4 | 3 |
| XVI. | 35 | 160 | 86.2319 | 1215.47 | 3 |
| XVII. | 40 | 180 | 109.306 | 1463.29 | 3 |
| XVIII. | 45 | 200 | 45 | 745.188 | 3 |

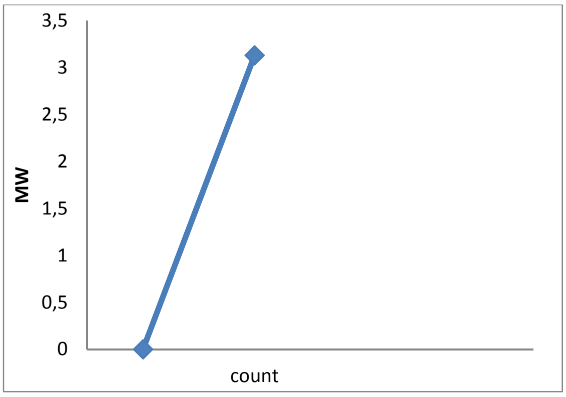


Fig. 6 Total Power Loss

## VI. CONCLUSION

Application of Genetic approach to Economic Load dispatch has been explored and tested on Matlab 7.0 showing that a simple genetic algorithm can give a best result. A genetic algorithm solution has been developed in this paper, based on the Lagrange method. The numerical results in both cases indicate that the proposed method can be used to determine the optimum control for the generation of power with the minimum fuel cost and lower transmission line losses, and with accurate results obtained in a short enough period of time to be compatible with on-line applications. It's recommended to indicate that in a large scale system the numbers of constraints are very large, consequently the GA accomplished in a large CPU for less computing time.

Solutions obtained with the developed Genetic Algorithm Economic Dispatch program has shown to be almost as fast as the solutions given by a conventional language.

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