

# Application of Genetic Algorithm For Optimal Load Dispatch With Non Smooth Cost Equations (CCPP)

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## ABSTRACT

*The objective of economic load dispatch (ELD) is to minimize the total fuel cost of electric power generation in thermal plants while ensuring high reliability. In ELD problems the cost function for each generator has been approximated by a single quadratic cost equation. However, it is more realistic to represent the generation cost function for fossil fired plants (Oil & natural gas) as a segmented piece wise quadratic function. As fossil fuel cost increases, it becomes even more important to have a good model for the production cost of each generator. A more accurate formulation is obtained for the ELD problem by expressing the generation cost function as a piece wise quadratic cost function. However, the solution methods for ELD problem with piece wise quadratic cost function require much complicated algorithms such as the hierarchical structure approach & Evolutionary computations (Ecs). Evolutionary computations are optimum search methods using genetics and evolution theory has been widely applied to the training of neural networks, tuning of fuzzy membership functions, machine learning, system identification and optimization problems. Obviously applying genetic algorithm to ELD problems will provide an optimal solution. A test system comprising of 10 units*

*with 29 different fuel cost equations are considered the system is found to have minimum and maximum generation capacities of 1353MWs and 3622MWs respectively. The load demand is assumed to vary between 2400MWs to 2700MWs in steps of 100MWs. The applied genetic algorithm method will provide optimal solution for the given load demand.*

**KEYWORDS:** Economic load dispatch (ELD), Combined cycle Power plant, Piece wise quadratic cost function, Quadratic programming Theory, Genetic algorithm (GA).

## 1 INTRODUCTION

The operation planning of a power system is characterized by having to maintain a high degree of economy and reliability, among the options that are available in choosing how to operate the system optimally is Economic Load Dispatch. The Economic Dispatch problem is to determine the optimal combination of power outputs of all generating units to minimize the total fuel cost while satisfying the load demand and operational constraints. It is necessary to have Input-Output characteristic of a generator to analyze the ELD problems. In

existing ELD approaches, the nature of Input-Output characteristic is approximated as a single Quadratic variation curve which gives suboptimal solutions.

Obviously the nature of Input-Output characteristics of modern generating units is highly non linear because of multifuel effects combined cycle power plants(CCPP) and value loading effects, which may lead to multiple local minimum points of cost functions. Hence it is more realistic to represent the Input-Output characteristic as a piecewise quadratic cost function to avoid huge revenue loss over time in ELD problems.

Previous efforts for ELD have applied various mathematical programming methods and optimization techniques. These include the lambda-iteration method, the base point and the gradient methods. Recently a global optimization method known as Genetic algorithm has become a good algorithm tool for many optimization applications due to its flexibility and efficiency. Optimization is the act of obtaining the best result under the given circumstances.

In design, construction and maintenance of any engineering system technologists have to take many decisions at several stages. The ultimate goal of all such decisions is either to minimize the effort required or to maximize the desired benefit. Since the effort required or the benefit desired in any practical situation can be expressed as a function of certain decision variables, obviously the optimization can be defined as the process of finding the conditions that give the maximum or minimum value of a function.

In ELD problems it is necessary to find the minimum value of a function. The optimum seeking methods are also known as

mathematical programming techniques and are generally studied as a part of operations research. It is a branch of mathematics concerned with the application of scientific methods and techniques to decision making problems providing optimal solutions. Therefore quadratic programming using genetic algorithm is more useful in finding the minimum of a function of several variables under a specified set of constraints.

Genetic algorithm (GA) is a stochastic searching algorithm; it combines an artificial survival of the fittest with genetic operators abstracted from nature to form a surprisingly robust mechanism that is suitable for a variety of optimization problems. GA searches randomly from point to point, thus allowing it to escape from local optimum in which other algorithms might land. Therefore the global optimum of the problem can be approached with high probability. GA has been successfully applied in various areas such as feeder reconfiguration, hydro generator governor tuning, load flow problems and so on.

This project develops genetic algorithm approach for solving the Economic dispatch problem considering a test system of 10 plants having 29 fuel cost options. A salient feature of proposed approach is that solution time grows approximately linear with problem size other than geometrically. This feature is attractive in large scale problem considering various operational constraints.

## 2 Economic Load Dispatch

The ELD problem is to determine the optimal combination of power outputs of all generating units to minimize the total fuel cost while satisfying the load demand from the operational constraints. Minimum fuel costs are achieved by the economic load scheduling of the different generating units

or plants in the power system. By economic load scheduling we mean to find the generation of the different generators or plants so that the total fuel cost is minimum and at the same time the total load demand at any instant must be met by the total generation.

### 2.1 Economic load dispatch Problem

However, economic load scheduling was not very important in the beginning when there were small power generating plants for each locality, such as urban power system, but now with the growth in the power demand and at the same time guarantee regarding the continuity of power supply to the consumer under normal conditions have forced the power system engineers to develop grid system. For such system the economic dispatch problem has become increasingly important. The objective in the economic dispatch of power system is to minimize the cost of meeting the energy requirements of the system over some appropriate period of time and in a manner consistent with reliable service. The appropriate period may be as short as few minutes or as long as a year or more depending on the nature of the energy sources available to the system.

These sources are frequently referred to as limited energy sources since they cannot continuously maintain full output. Fired combustion turbines depending on the terms of the gas supply contract may fall into this category. Obviously, the aim in the utilization of limited energy sources is to realize the greatest possible value, during the operating cycle in terms of fuel replacement at plants where the available fuel supply is not a limiting factor. Total operating cost generally includes only the applicable fuel cost.

### 2.2 Problem Statement for ELD with Smooth

#### Cost Function

Let  $N$  be the number of units  
 $P_i$  power supplied by each unit to meet load demand

$P_d$  Load demand in MWs

The objective function for each unit can be represented by a quadratic cost function

$$F_i = a_i P_i^2 + b_i P_i + c_i \quad \text{Rs/hour}$$

$$\text{Subject to } \sum P_i = P_d \quad i = 1, 2, 3, \dots, n$$

Where  $a_i$ ,  $b_i$  and  $c_i$  are the fuel consumption cost coefficients of the unit  $i$ .

### 2.3 Equal Incremental cost criteria for Economic Load Dispatch problem

Using lagrangian multiplier method fuel cost equation can be written as

$$\text{Fuel Cost} = \sum (a_i P_i^2 + b_i P_i + c_i) + \lambda (P_d - \sum P_i)$$

For optimal operation of plants partially differentiating the above fuel cost equation w.r.t.  $P_i$  and  $\lambda$  and equating to zero

$$\partial F / \partial P_i = 2 a_i P_i + b_i - \lambda = 0$$

$$\text{where } i = 1, 2, 3, \dots, n$$

$$\partial F / \partial \lambda = \sum P_i - P_d$$

$$2 a_i P_i + b_i = \lambda \quad \text{----- (1)}$$

$$P_1 + b_1 / 2 a_1 = \lambda / 2 a_1$$

$$P_2 + b_2 / 2 a_2 = \lambda / 2 a_2$$

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$$P_n + b_n / 2 a_n = \lambda / 2 a_n$$

Therefore

$$\sum P_i + \sum b_i / 2 a_i = \lambda \sum 1 / 2 a_i$$

$$\lambda = (P_d + \sum b_i / 2 a_i) / \sum 1 / 2 a_i$$

Once after knowing the value of lambda then generation  $P_i$  can be calculated as given below.

$$P_i = (\lambda - b_i) / 2 a_i$$

Hence the above formulation is called the Equal incremental cost procedure for determination of generation.

### 3. Piece wise quadratic cost functions problem formulation

Recently Combined Cycle Power Plants (CCP) has shown their importance in both developing and developed countries in order to improve the efficiency of generation. From the survey, the fuel cost characteristics of CCP is non-smooth. Thus non-linearity in the ELD problem is further increased. Numerical Optimization techniques and evolutionary computation methods can play key role in solving ELD problem.

#### 3.1 Combined cycle power plant

In CCP gas and steam turbines are working in combination to generate electric power. The exhaust heat produced by the gas turbine is enough to operate the steam turbine. Hence during some range of power generation steam turbine is operated without or with less additional fuel input.

In a heat engine (i.e., a device for converting heat in to work) part of the heat taken up from a source (Ex: burning fuel) at a higher temperature is discharged to a heat sink at a lower temperature.

In a combined cycle system the heat discharged from one heat engine serves as the source for the next engine. The net result is a greater overall operating temperature range (i.e., between the initial heat source and final sink) than is possible with a single heat engine. The thermal efficiency of the combined system (i.e., proportion of heat converted into useful work or electrical energy) is thus greater than for the two heat engines operating independently.

Less fuel is then required to generate a given amount of electrical energy. As a

general rule, combined cycle systems have two heat engine stages, the second stage being a conventional condensing steam turbine.

Consequently in a combined cycle system the steam turbine is preceded by a topping cycle heat engine, which can utilize heat at high temperatures. The working fluid leaves the topping cycle at a sufficient high temperature to generate steam for the steam turbine.

#### 3.2 Piecewise quadratic cost function

It is seen from the earlier chapters that the cost function of generator has been approximated by a single quadratic cost function. However, it is more realistic to represent the generation cost function for fossil fired plants as a segmented piecewise quadratic cost function because of multifuel generation and value point loading effects. As fossil fuel costs increases, it becomes even more important to have a good model for the production cost of each generator. Therefore a more accurate formulation is obtained for the ELD problem by expressing the generation cost function as a piecewise quadratic cost function. However, the solution methods for ELD problem with piecewise quadratic cost function require a much complicated algorithms such as hierarchical structure approach. Recently Genetic algorithms which are probabilistic optimum search methods using genetics and the evolution theory have been widely applied.

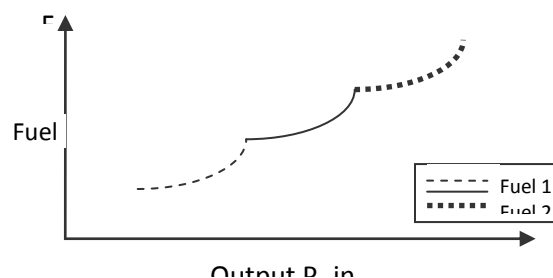


Fig 3.1 Fuel Cost function Of a Thermal generation supplied with Multi Fuels

### 3.2 Non smooth cost functions with multiple fuels

Traditionally the cost function of each generator has been approximately represented by a single quadratic cost function. In practice the operating conditions of many generating units require that the generation cost function be segmented into piece wise quadratic cost function. Therefore it is more realistic to represent generation cost function as segmented into piece wise quadratic cost function. Generally a piece wise quadratic function is used to represent the I-O curve of a generator with multiple fuels. The cost function of ELD problem is defined as follows  $F.c. = \sum F_i (P_i)$

The piecewise quadratic function is given by

$$F_i (P_i) = \begin{cases} \text{fuel 1 } P_{i,\min} \leq P_i < P_{i,1} & a_{i,1} + b_{i,1} P_i + c_{i,1} P_i^2 \\ \text{fuel 2 } P_{i,1} \leq P_i < P_{i,2} & a_{i,2} + b_{i,2} P_i + c_{i,2} P_i^2 \\ \vdots & \vdots \\ \text{fuel n } P_{i,n-1} \leq P_i \leq P_{i,\max} & a_{i,n} + b_{i,n} P_i + c_{i,n} P_i^2 \end{cases}$$

Where  $a_{i,j}$ ,  $b_{i,j}$  and  $c_{i,j}$  are the cost coefficients of generator  $i$  for fuel type  $j$ .  $P_{i,\min}$  and  $P_{i,\max}$  are the minimum and maximum power generations of unit  $i$ . The objective function to solve ELD problem is to minimize  $F.c. = \sum F_i (P_i)$

## 4 Quadratic Programming

The quadratic programming problem is the best behaved nonlinear programming problem. It has a quadratic objective function and linear constraints and is convex (for minimization problems.) Hence the

quadratic programming problem can be solved by suitably modifying the linear programming techniques.

One of the difficulties in certain practical Linear programming problem is that the number of variables and / or the number of constraints is so large that it exceeds the storage capacity of the available computer. If the LP problem has a special structure, a principle known as decomposition principle can be used to solve the problem more efficiently. In many practical problems, one will be interested not only in finding the optimum solution to LP problem, but also in finding how the optimum solution changes when some parameters of the problem, such as cost coefficients change. Hence the sensitivity or post optimality analysis becomes very important.

### 4.1 Problem statement for quadratic programming

A quadratic programming problem can be stated as Minimize  $f(x) = \frac{1}{2} x^T H x + f^T x$

such that it satisfies following constraints  $A.x \leq b$

$$Aeq .x = beq$$

$$Lb < x < Ub$$

Where  $H$ ,  $A$ , and  $Aeq$  are matrices, and  $f$ ,  $b$ ,  $beq$ ,  $lb$ ,  $ub$ , and  $x$  are vectors to be specified by the constrained problem.

### 4.2 Syntax for quadratic programming

$$x = \text{quadprog}(H,f,A,b,Aeq,beq,lb,ub)$$

The term  $x^T H x / 2$  represents the quadratic part of objective function with  $H$  being a symmetric positive definite matrix. If  $H=0$  the problem reduces to a linear programming problem. The solution of the

quadratic programming problem stated in the above equation can be obtained by the Lagrange multiplier technique.

## 5 Genetic Algorithm

Genetic algorithm (GA), first introduced by John Holland in early seventies, is become a flagship among various techniques of machine learning and function optimization. Algorithm is a set of sequential steps needs to be executed in order to achieve a task. A GA is an algorithm with some of the principles of genetics included in it. The genetic principles “natural selection” and “evaluation Theory” are main guiding principles in the implementation of GA. The GA combines the adaptive nature of the natural genetics and search is carried out through randomized information exchanged.

There is multitude of search techniques. Among them calculus based, enumerative and random search techniques are mostly used. The first two techniques, i.e., Calculus based and enumerative are capable of arriving at reasonable good solutions for search spaces of smaller size and wide variation from point to point in their precinct, like all practical systems, there efficiency is low in delivering solution for complex problems involving huge search space due to their lack of ability to overcome these local optimum points and reach the global optimum point. In order to overcome local optimum points we use random search techniques. It's important to note that this randomized search is not a directional search. The search is carried out randomly and information gained from a search is utilized in guiding the next search. Genetic algorithm is an example of such search technique.

Genetic algorithm surpasses all the above limitations of conventional algorithms by using the basic building blocks that are different from those of conventional algorithms. It is different from them in the following aspects.

1. GA works with a coding of the parameters set and not the parameters themselves.
2. GA searches from a population of points and not from a single point like conventional algorithm.
3. GA uses objective function information, not derivative or other auxiliary data.
4. GA use probabilistic transition rules by stochastic operands, not deterministic rules.

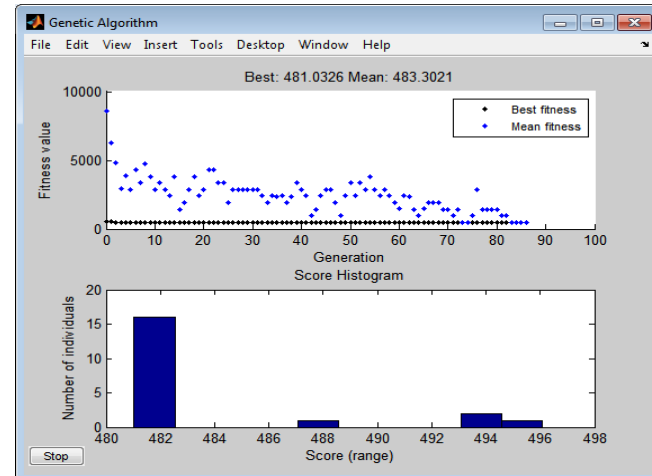
The very first step of GA is the random selection of initial search points from the total search space. Each and every point in the search space corresponds to one set of values for the parameters of the problem. Each parameter is coded with a string of bits. The individual bit is called “gene”. The content of each gene is called “allele”. The total string of such genes of all parameters written in a sequence is called a “chromosome”. So there exists a chromosome for each point in the search space. The sea of search points selected and used for processing is called a population. That means population is a set of chromosomes. The no of chromosomes in population is called “population size” and the total number of genes in a string is called “string length”. The population is processed and evaluated through various operators of GA to generate a new population and this process is carried out till global optimum point is reached. The two parts of the process are called “generation and evaluation”.

The evaluation of GA we define a fitness function and evaluates the fitness for

each chromosome of a population. This fitness is an indication of the suitability of the values of the parameters, as represented by that chromosome, as a solution of the optimization problem under consideration. This fitness is used as bias for selecting the parents and generating a new population from the existing one.

## 6 Simulation results

For a Load demand of 2400MWs Minimum value of fuel cost for 10 units is 481.0326 \$/hour Generations in MW from each unit among 10 units.



Simulation result for 2400Mw load using best fitness and score histogram

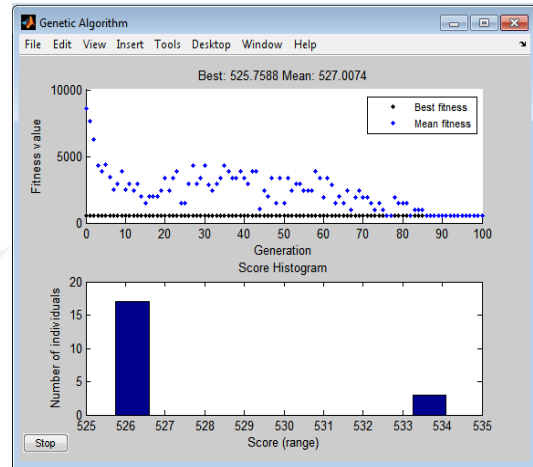
Generations in MW	Fuel cost coefficients			Incremental fuel cost in \$/Mwh	fuel options
	a	b	C		
189.7405	<b>0.0022</b>	<b>-0.3975</b>	<b>26.7600</b>	<b>0.4283</b>	1
202.3427	<b>0.0042</b>	<b>-1.2690</b>	<b>118.400</b>	<b>0.4283</b>	1
253.8953	<b>0.0015</b>	<b>-0.3116</b>	<b>39.7900</b>	<b>0.4283</b>	1
233.0456	<b>0.0059</b>	<b>-2.3380</b>	<b>266.800</b>	<b>0.4283</b>	3
241.8297	<b>0.0011</b>	<b>-0.0873</b>	<b>13.9200</b>	<b>0.4283</b>	1
233.0456	<b>0.0059</b>	<b>-2.3380</b>	<b>266.300</b>	<b>0.4283</b>	3
<b>253.2750</b>	<b>0.0011</b>	<b>-0.1325</b>	<b>18.9500</b>	<b>0.4283</b>	1
<b>233.0456</b>	<b>0.0059</b>	<b>-2.3380</b>	<b>266.800</b>	<b>0.4283</b>	3
<b>320.3832</b>	<b>0.0016</b>	<b>-0.5675</b>	<b>88.5300</b>	<b>0.4283</b>	1
<b>239.3969</b>	<b>.0011</b>	<b>-0.0994</b>	<b>13.9700</b>	<b>0.4283</b>	1

For a Load demand of 2500MWs  
Minimum value of fuel cost for 10 units is  
525.7588 \$/hour

Generations in MW	Fuel cost coefficients			Incremental fuel cost in \$/Mwh	fuel options
	a	b	C		
196.0000	0.0022	-0.3975	26.7600	0.4671	2
206.9774	0.0042	-1.2690	118.4000	0.4671	1
267.2362	0.0015	-0.3116	39.7900	0.4671	1
236.3207	0.0059	-2.3380	266.8000	0.4671	3
260.0639	0.0011	-0.0873	13.9200	0.4671	1

270.8339	0.0011	-0.1325	18.9500	0.4671	1
236.3207	0.0059	-2.3380	266.8000	0.4671	3
332.8913	0.0016	-0.5675	88.5300	0.4671	1
257.0355	0.0011	-0.0994	13.9700	0.4671	1

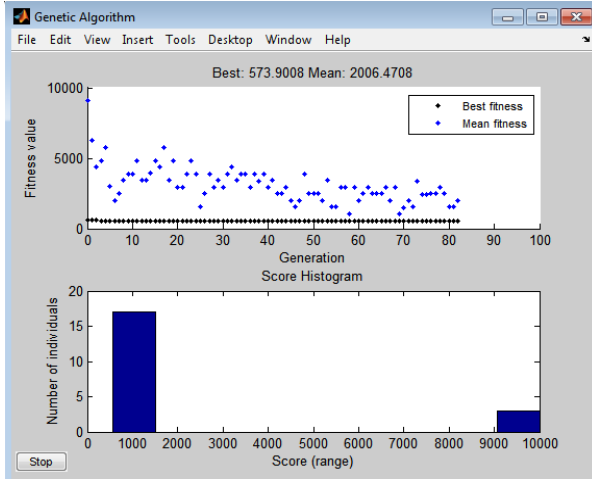
Generations in MW	Fuel cost coefficients			Incremental fuel cost in \$/Mwh	fuel options
	a	b	C		
189.7405	0.0022	-0.3975	26.7600	0.4283	1
202.3427	0.0042	-1.2690	118.4000	0.4283	1
253.8953	0.0015	-0.3116	39.7900	0.4283	1
233.0456	0.0059	-2.3380	266.8000	0.4283	3
241.8297	0.0011	-0.0873	13.9200	0.4283	1
233.0456	0.0059	-2.3380	266.3000	0.4283	3
253.2750	0.0011	-0.1325	18.9500	0.4283	1
233.0456	0.0059	-2.3380	266.8000	0.4283	3
320.3832	0.0016	-0.5675	88.5300	0.4283	1
239.3969	.0011	-0.0994	13.9700	0.4283	1
236.3207	0.0059	-2.3380	266.3000	0.4671	3



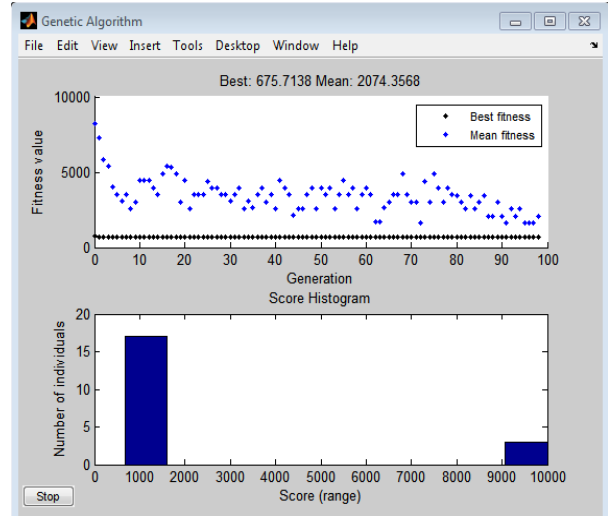
Simulation result for 2500Mw load using best fitness and score histogram

For a Load demand of 2600MWs  
Minimum value of fuel cost for 10 units is 573.9008\$/hour





Simulation result for 2600Mw load using best fitness and score histogram  
 For a Load demand of 2700MWs  
 Minimum value of fuel cost for 10 units is 623.3292\$/hour



Simulation result for 2600Mw load using best fitness and score histogram  
 Annual savings in \$ for four different load demands in MW compared with Hierarchical ELD approach  
 [Ref. IEEE transactions on PAS, VOL.20, NO.4, NOVEMBER 2005]

Generations in MW	Fuel cost coefficients			Incremental fuel cost in \$/Mwh	fuel options
	a	b	C		
218.2499	0.0019	- 0.3059	21.1300	0.5064	2
211.6626	0.0042	- 1.2690	118.4000	0.5064	1
280.7228	0.0015	- 0.3116	39.7900	0.5064	1
239.6315	0.0059	- 2.3380	39.7900	0.5064	3
278.4973	0.0011	- 0.0873	13.9200	0.5064	1
239.6315	0.0059	- 2.3380	266.3000	0.5064	3
288.5845	0.0011	- 0.1325	18.9500	0.5064	1
239.6315	0.0059	- 2.3380	266.8000	0.5064	3
428.5216	0.0006	- 0.0182	14.2300	0.5064	3
274.8667	0.0011	- 0.0994	13.9700	0.5064	1

Generations in MW	Fuel cost coefficients			Incremental fuel cost in \$/Mwh	fuel options
	a	b	C		
216.5442	0.0019	- 0.3059	21.1300	0.5001	2
210.9058	0.0042	- 1.2690	118.4000	0.5001	1
278.5441	0.0015	- 0.3116	39.7900	0.5001	1
239.0967	0.0059	- 2.3380	266.8000	0.5001	3
275.5194	0.0011	- 0.0873	13.9200	0.5001	1
239.0967	0.0059	- 2.3380	266.3000	0.5001	3
285.7170	0.0011	- 0.1325	18.9500	0.5001	1
239.0967	0.0059	- 2.3380	266.8000	0.5001	3
343.4934	0.0016	- 0.5675	88.5300	0.5001	1
271.9861	0.0011	- 0.0994	13.9700	0.5001	1

S. No.	Load Demand in MW	Fuel cost from Hierarchical ELD approach		Fuel cost from Genetic Algorithm ELD approach		Annual Savings in \$
		\$/Hour	\$/year	\$/Hour	\$/year	
1	2400	487.91	4274091.60	481.0326	4213845.58	60246.02
2	2500	526.69	4613804.40	525.7588	4605647.09	8157.31
3	2600	574.28	5030692.80	573.9008	5027371.01	3321.79
4	2700	623.81	5464575.60	623.3292	5460363.79	4211.80

**Table 6.1** Annual savings in \$ compared with Hierarchical ELD approach

#### SIMULATION PARAMETERS in GAs.

Fitness function	@f2
Number of variables	10
Type of the plot	Best fitness
Population size	25
String length	88 bits
Initial Population	[ ]
Reproduction	Elite count 2
Cross over	Multipoint or scattered
Stopping criteria	
Number of generations	120
Stall time limit	50 seconds
Stall generations	105

## References

- [1] RMS Dana raj, Dr F gajendran; An efficient algorithm to find optimal economic load dispatch for plants having discontinuous fuel cost functions., Journal of institution of engineers(India)., Vol 83,pt El dec 2004.
- [2] Kwang Y.Lee and Arthit Sode – Yome ,June Ho Park; Adaptive Hop field neural networks for economic load dispatch. IEEE transactions on power systems. Vol 13 No 2. May 1998.
- [3] Po-Hung Chen, Hong-Chan Chang; Large – scale economic dispatch by genetic algorithm. IEEE transactions on power systems, Vol10, No 4, Nov 1995.
- [4] Derong Liu, Ying Cai; Taguchi method for solving economic dispatch problem with non smooth cost function. IEEE transactions on power systems, Vol.20, No. 4, Nov 2005.
- [5] N Rama raj, R. RajaRam; Analytical approach to optimize generation schedule of plant with multiple fuel options. Journal of institution of engineers (India), Vol68. pt EL Dec 1987.
- [6] C E Lin, GL Vivianib; Hierarchical economic

dispatch of piece wise quadratic cost functions.,

IEEE transactions on PAS, Vol PAS - 103, No 6  
June 1984.

[7] Singiresu S.Rao Engineering Optimization theory and practice third edition, New Age International(p) Limited, Publishers.

[8] Allen J.Wood, Bruce F. WollenBerg, Power generation operation and control, Wiley India edition.

[9] S.Rajasekaran, G.A Vijaya Lakshmi Pai, Nueral Networks Fuzzy Logic and Genetic Algorithms, Prentice Hall of India private Limited.

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