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OPTIMAL ECONOMIC LOAD DISPATCH USING FUZZY LOGIC & GENETIC ALGORITHMS

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ABSTRACT

Many traditional optimization methods have been successfully used from years to deal with ELD problem. However these techniques have limitations in many aspects as they provide inaccurate results. The objective is to minimize total fuel cost of power generation so as to meet the power demands to satisfy all constraints. In present paper, the parameters of the fuzzy logic are tuned using genetic algorithms. By using GA with fuzzy logic leads to an intelligent dimension for ELD solution space to obtain an optimum solution for ELD.

Key words: GA, FCGA, LIM, ELD, FL

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1. INTRODUCTION

Electrical power system is vast interconnected system which plays an imperative part in economy of the nation. Hence, for the efficient and reliable operation of such vast interconnected power framework, there is a need of proper analysis to explore the way to operate such system economically [1].From last few decades, most significant concern in thermal power generating industry that has attained potentially the focus on efficient, secure, reliable and optimally economic operation of electric power systems which is referred as Economic Load Dispatch [2]. This may also formulated as a minimization problem of the fuel cost under load demand constraint and various other constraints at a certain instant of time. In recent years, utilities have taken the responsibility to meet the customer demands for profit with minimum cost. The emergence of powerful numerical optimization methods for power system operation contributes much for ensuring the best financial and electrical performance in terms of both reliability and security [3].

Due to the rapid advances in the civilization day by day demand of electricity is also increasing accordingly. This has resulted into the installation of extensive number of power plants to meet the load demands and subsequently the consumption of coal burnt also increased[4].As the consumption of massive amount of coal leaves many harmful gases at thermal power plants due to which environment contamination along with degradation occurs. Environment contamination is extremely harmful as it increases the global warming and damage the ozone layer. Hence, it is the nick of the time to generate the power with minimum cost and minimize the pollutant environment emission. The study of economic load dispatch serves to generate power on minimum cost and also reduce the environmental emission effects [5].

2. ECONOMIC LOAD DISPATCH

Economic Load Dispatch is a fundamental area of consideration for power systems. The main objective is to minimize the total fuel cost while meeting all the load demands with all system constraints. It is the schedule of generation of the individual units which minimizes total operating cost of a power system to meet total load plus transmission losses within generator limits [6]. It is of great significance to save energy and reducing emission.

ELD problem further involves different problems which are further categorized based on time frame. In this regard the two classifications are: operational and planning problems. The operational problems are handled on hourly basis while the planning problems are solved by the time span of years. The former classification includes the Unit Commitment issue. In Unit Commitment Issue, out of the available generating sources, a unit is optimally selected so as to meet the load demands[7].The second aspectual of ELD is on-line economic dispatch where required to distribute load for different generating units parallel with the system in such a manner as to minimize total cost of supplying power. For ELD, power generations are not fixed but they are allowed to obtain values again within certain limits to meet a particular load demand with minimum fuel consumption [8].

The issue of ELD turns more complex in large scale system hence it become difficult to find out optimal solution due to nonlinear function and it contains number of local optimal variables [9]. It is therefore of great importance to solve this problem as quickly and accurately. Hence, for economic operation of the system, the total demand must be optimally shared among all generating units for minimizing the total generation cost while satisfying operational constraints on the system [10]. Fuel cost for all the power generation unit is defined initially. The total cost function of economic dispatch problem is referred as total sum of the fuel costs of all the generating plant units as mentioned below [11]:

FT = Σi=1NG {aiPi2 + biPi + Ci| di sinei (Pimin - Pi)|} (1)

Here, NG is total number of generating units

F_T is total cost of production

P_i is tpower output of generating unit i

Pi^{min} is minimum output of generating unit i

a_i, b_i, c_i, d_i, e_i are cost coefficients of fuel for unit i

This equation helps in determining total production cost of the generating plant [27].

A. Cost Function

The cost function calculation of each generator in traditional ELD problems included only a simple quadratic equation and these problems are addressed with mathematical programming mainly referring deterministic optimization techniques such as lambda iteration. Unlike this, the complete practical ELD problem formulation involves the use of valve point loading effects in addition to the multi fuel options and prohibited operating zones. The resultant ELD is a non-convex optimization problem and cannot be handled by the traditional methods [25].

The total cost of operation is composed of various components such as fuel cost, labour cost, cost of supplies and maintenance where the cost of labour, maintenance and supplies are fixed percentages of incoming fuel costs. If cost of generating energy in the generator unit I is denoted as Ci, then the total controllable system production cost can be calculated as [26]:

C=Σi=1N C (i) (2)

Since the generated real power P_{Gi} highly influences Ci, then the individual production cost Ci of generators unit I can be defined as a function of P_{Gi},
Hence, the total controllable production cost is calculated as:

C=Σi=1 n C (PGi) (3)

It illustrates that the cost function C can be written as a sum of terms where each term depends only upon one independent variable [35].

B. System Constraints

Two types of constraints are considered in broad view:

- **Equality constraints:** These constraints state the condition that the sum total of demand and losses in system must be equal to the total power generated in the system. Since it deals with balancing power, these are termed as power balance constraints. It is mathematically represented as:

$^{NG}P_{gi} = P_L + P_D$ (4)

Where P_D is total demand and P_L is losses.

The transmission loss can be calculated by the B coefficients method or power flow analysis.

$P_L = P_T BP + P_T B_o + B_{oo}$ (5)

Here P_T is an associative matrix of P. B is an Ng X Ng coefficient matrix. B_o is Ng dimensional coefficient column vector. B_{oo} is a coefficient [28].

- **Inequality constraints:** Here, a lower (P_i min) and an upper (P_{gi} max) generation limits is maintained in each generation unit [41]. The upper limit signifies the maximum active power generation which is bounded for thermal consideration and the flame instability of boiler to decide the minimum generation. These bounds can be defined as a pair of inequality constraints, as follows:

$$Pmingi \leq Pming\ I \leq Pmaxgi \quad (6)$$

Where i=1 to Ng

3. FUZZY LOGIC

Though fuzzy sets presented in their modern form by Zadeh in 1965 but the concept of a multi-valued logic to manage vagueness is not new and has been around from the earliest part of the century. One such great scholar known as Peirce seriously considered ambiguity. He didn't have confidence in the separation between true and false and believed everything in life is a continuum [29].Different popular scientists and philosophers probed this topic further. Fuzzy Logic is a widely accepted problem-solving control system methodology that is implemented in all kinds of systems like embedded micro-controllers, huge and complex networked multichannel computers or workstation-based data acquisition and control systems. In addition to this, the implementation can also be performed at different levels like hardware, software or the combination of both. Fuzzy set theory is seen as generalization of classical set theory where the membership degree of an object of a set is not confined to the integers 0 and 1 and may include any value in [0,1].Fuzzy Logic Systems can further be elaborated with the reference of fuzzy sets and fuzzy relations. These systems are referred as rule-based systems since they begin with the fuzzification of input which is followed by processing phase where the inference engine processes input data and derives knowledge in the form of fuzzy rules contained in a rule-base system which further output the fuzzy sets. Finally, defuzzification of the resultant fuzzy sets is performed. A fuzzy logic system can actually be seen as a nonlinear mapping from input to output space [12, 13].

The extensive application range of fuzzy logic covers many different real time scenarios listed as facial pattern recognition, air conditioners, washing machines, vacuum cleaners, braking systems, transmission systems, knowledge-based systems for multi-objective optimization of power systems, weather forecasting systems, project risk assessment, medical diagnosis and treatment plants, stock trading etc..

A. Membership Function

A membership function is a graphical representation of the magnitude of participation of each input which actually provides definition to a fuzzy set. Each fuzzy set has a membership value that falls between [0, 1]. Further, the membership values need not necessarily be the discrete values rather mostly they turn out to be described by continuous function. Unlike any crisp set where the decision says either element belongs to the set or does not, in fuzzy sets, many degrees of membership falls between 0 to1.

Thus in a formal representation, Membership function denoted as μ_A associated with fuzzy set A can be written as:

$$\mu_A{}^{X}: X \rightarrow [0, 1] \quad (7)$$

which illustrates the mapping of elements of refrence set X to membership interval [0,1].Membership function can assum any shape during simulation. They are often defined by straight segments and said to be “piece-wise linear”. In few cases, membership functions may be equal to 1 for a single value of a variable, and equal to 0 else. They are then known as “singleton membership functions” [15, 17, 18]. Here, two input and two output membership functions are used. The input membership functions are: average fitness and change in fitness. The output membership functions include optimized crossover probability and optimized mutation probability.

Table 1 Input output values

Fitness	Change in avg_fitness	Crossover Probability	Mutation Probability
0.217	0.361	0.035	0.666
0.313	0.554	0.0498	0.749
0.587	0.627	0.0599	0.800
0.771	0.718	0.0772	0.888

B. Linguistic Variables

Linguistic Variables are expressed in plain language words and statements. Linguistic variables play an important role to represent crisp information in such a way that it is precisely appropriate for the problem. Since the use of linguistic variables is observed to reduce the overall computation complexity in many applications. Therefore, they are found useful in addressing complex non-linear applications. Linguistic variables are central to fuzzy logic manipulations, though these ignored in the debates on the merits of fuzzy logic. In fuzzy logic applications, non-numeric linguistic variables are used comparative to the numerical values [16, 19].

Each of the input and output membership variables are assigned nine linguistic fuzzy linguistic variables which are enlisted as:

NL- Negative Larger

NR- Negative Large

NM- Negative medium

NS- Negative Small

ZE- Zero

PS- Positive Small

PM- Positive Medium

PR- Positive Large

PL- Positive Larger

4. GENETIC ALGORITHM

John Holland of Michigan University introduced for the first time the concept of Genetic Algorithm (GA) in 1970s. The natural genetic and evolution mechanisms found in natural systems are the primary source of inspiration for development of the Genetic Algorithm [40,41]. GA is a simple concept which is easy for implemention and computationally efficient. The Darwinian principle of biological evolution, reproduction and survival perceives GA as a general-purpose search method, an optimization method, or a learning mechanism [34, 36]. This is a search technique utilised for computing purpose to find true or nearly true solutions to optimization problems and classified as global search heuristics. The basic idea behind GA is to mathematically imitation of the evolution process of nature [39].GA includes three primary phases-

- Initialization
- Evaluation
- Genetic Operation

In first phase, the working of GA begins with an initial random population of members known as chromosome in GA terminology. The GA works on string structures which is composed of sub strings, each representing a problem variable. A string is a sequence of binary digits which is an encoded form of control parameter for a problem. Each individual bit is called gene and the sequence of all such strings of genes form “Chromosome”.

In evaluation phase, the population of chromosomes is evaluated using some fitness criteria or an objective function. It includes a standard fitness function to decide the selection or rejection of parents/ offspring’s. The chromosomes with high fitness value are selected while the low valued are discarded.

Talking about the last phase, the three most preferred genetic operations Reproduction, Crossover and Mutation are performed to produce a new generation. In reproduction, fitness values based individual strings are copied. Duplication strings pursuance to their fitness values means that strings with higher values have a higher probability of contributing one or more offspring in the next generation.Crossover involves producing new individuals or offspring chromosomes as a result of merging of parent individuals/ chromosomes. Mutation also involves the production of new individuals but involves modification approach. It leads to diversity in population. The other distinguishing aspect between crossover and mutation is that in crossover the offspring inherits the information from both parents while in mutation it does not perform inheritance.Genetic algorithm technique successfully applies to ELD problem up to a much context [43, 44]. GA offers a wide range of applications for the power systems and found a success address problem such as ELD, unit commitment, reactive power control, hydrothermal scheduling and distribution system planning.

5. MOTIVATION

Over the recent decades, many efforts have been utilised to solve the ELD problem which includes a lot kinds of constraints and multiple objectives through different mathematical and optimization techniques. The techniques may be conventional or stochastic method. The conventional methods include Newton-Raphson method, Lambda Iteration Method, Base Point and Participation Method, Gradient Method and so on. Conventional methods work according to simple mathematical model and works with good speed but they have a drawback of multiple local minimum points in the cost function. Hence, a highly robust algorithm is needed to deal with these issues. In this respect, stochastic methods such as Genetic Algorithms (GAs), Fuzzy Algorithms Adaptive Hopfield Neural Network, the Simulated Annealing method, evolutionary programming (EP), Tabu search (TS), pattern search may prove to be very efficient to deal with the non-linear ELD problem. In addition to this, a step has been taken forward to propose a hybrid algorithm of fuzzy logic and GA. This is named as genetic algorithm infused with Fuzzy logic or Fuzzy controlled genetic algoritm (FCGA).These modern methods offer alternative techniques which try to overcome the limitationss of conventional methods.

6. METHODOLOGY

A. Genetic Algorithm Infused with fuzzy logic or FCGA:

The proposed system is an integration of the fuzzy logic and Genetic algorithm fundamental operation. This is an attempt to effectively address the most common concern of ELD by obtaining an optimal solution to problems with fuzzy constraints, fuzzy variables and genetic operations.

B. Fuzzy rules for optimized crossover and mutation probability:

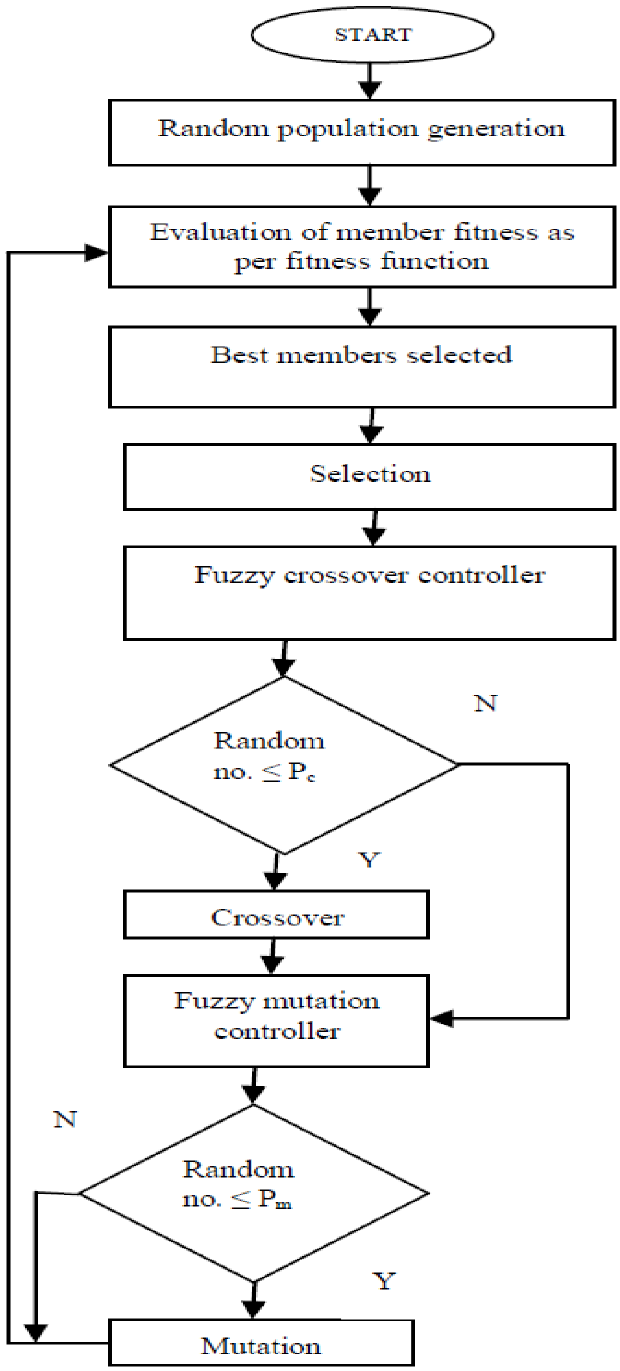
Since conventional GA method has shortcoming to address the complex problems, hence to achieve better results and faster convergence, it is must to modify the conventional GA methods. In recent years many attempts have been made to achieve the same objective, these include:

- Use of advanced string coding.
- Generating initial population with few prior knowledge.
- Establishement of some better evaluation function.
- By including new operators like elitism, multi point or uniform crossover and creep mutation.

The proposed algorithm named as Genetic Algorithm infused with Fuzzy Logic or FCGA is a flexible Genetic Algorithm involving fuzzy logic rules possess the ability to adjust continuously crossover and mutation parameters. Crossover and Mutation hold a great importance for GA convergence. In order to establish an equilibrium state between global and local exploration abilities, a suitable value for mutation is needed which further results in less of number of iterations required to locate optimum solution. The experiments based on the application of GA in practical networks suggest adjusting the value of crossover and mutation dynamically. The proposed approach also dynamically adjusts the crossover and mutation parameters since it involves practical rules interpreted in fuzzy logic.

C. Methodology

1. Firsty, initialization of all parameters- population size, number of generations, sub-strings length is done.
2. Initialy random population of individuals is generated where the individuals are the coded string of binary digits.
3. Evaluation of fitness for the population members is performed on the basis of a fitness function.
4. Once the optimization criterion is met, the selected population members are further passed for different operations.
5. The selection operation is performed.
6. After this, fuzzy logic comes into play with the fuzzy crossover.
7. The random member is first compared with the crossover probability value and if the criterion is satisfied, crossover is performed.
8. Similarly for mutation, the random member is in prior compared against the mutation probability value.



Flowchart of proposed algorithm

Fuzzy rule base is a accumulation of conditional statements consist of a structure of IF THEN rules. Fuzzy sets and fuzzy operators are subjects and verbs of fuzzy logic. Such if-then rule statements formulate conditional statements which formulates fuzzy logic.

A fuzzy rule can be in form as:

If x is A then y is B.

where A and B are linguistic values defined by fuzzy sets on the ranges x and y respectively. The if-part of the rule “x is A” is called a antecedent or premise, while the then-part of the rule “y is B” is called as a consequent or conclusion.

D. Fuzzy Rules in ELD:

1. If (Fitness is NL) and (change_in_fitness is NL) then (crossover_prob is NL)(Mutation_prob is NL) (1)
2. If (Fitness is NL) and (change_in_fitness is NR) then (crossover_prob is NR)(Mutation_prob is NR) (1)
3. If (Fitness is NL) and (change_in_fitness is NM) then (crossover_prob is NR)(Mutation_prob is NR) (1)
4. If (Fitness is NL) and (change_in_fitness is NS) then (crossover_prob is NM)(Mutation_prob is NM) (1)
5. If (Fitness is NL) and (change_in_fitness is NS) then (crossover_prob is NM)(Mutation_prob is NM) (1)
6. If (Fitness is NL) and (change_in_fitness is PS) then (crossover_prob is NS)(Mutation_prob is NS) (1)
7. If (Fitness is NL) and (change_in_fitness is PM) then (crossover_prob is NS)(Mutation_prob is NS) (1)
8. If (Fitness is NL) and (change_in_fitness is PR) then (crossover_prob is ZE)(Mutation_prob is ZE) (1)
9. If (Fitness is NL) and (change_in_fitness is PL) then (crossover_prob is ZE)(Mutation_prob is ZE) (1)
10. If (Fitness is NR) and (change_in_fitness is NL) then (crossover_prob is NR)(Mutation_prob is NR) (1)
11. If (Fitness is NR) and (change_in_fitness is NR) then (crossover_prob is NR)(Mutation_prob is NR) (1)
12. If (Fitness is NR) and (change_in_fitness is NM) then (crossover_prob is NM)(Mutation_prob is NM) (1)
13. And so on

7. EXPERIMENTAL RESULTS

The results of ELD after the implementation of proposed fuzzy logic are discussed. Implementation is done in MATLAB to solve ELD problem

A. Ruler Viewer

Ruler Viewer used to view whole implication process from starting to end. Ruleview ('a') depicts the fuzzy inference diagram for the fuzzy inference system stored in file. For example, which rules are active, or how individual membership function shapes influence the results.

B. Surface Viewer

Surface viewer is a GUI tool which observes output surface of a FIS stored in a file, a.fis for any one or two inputs. This is a read only editor which analyse the smooth plots having two variables. These are assigned to input axis on X axis and output on Y axis. Surface Viewer using surf view ('a'), is a GUI tool that examines output surface of a FIS stored in a file for any one or two inputs. It does not alter the fuzzy system or its associated FIS structure in any way, Surface Viewer is a read-only editor.

This section presents the results of ELD obtained after the successful implementation of proposed Genetic algorithm infused with Fuzzy logic.

The algorithms are implemented in MATLAB to solve ELD problem. The main objective is to practically use the proposed system to reduce the cost of generation of thermal plants.

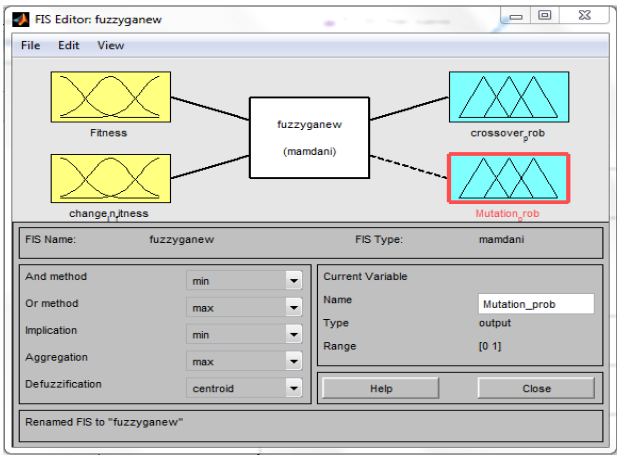


Figure 1 Shows the Fuzzy Inference System for Proposed Work

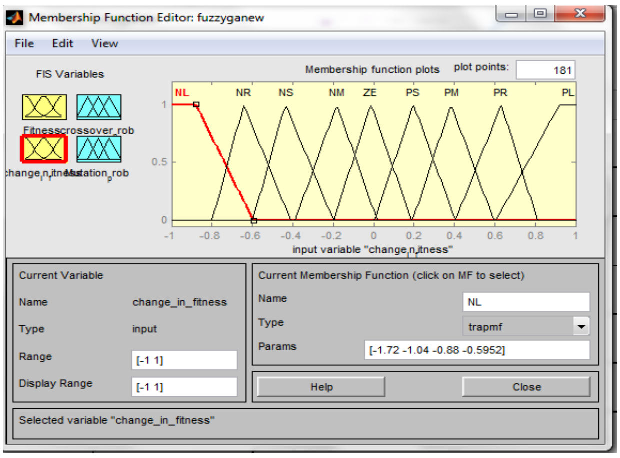


Figure 2 Shows Input Membership Function for Change Fitness Input

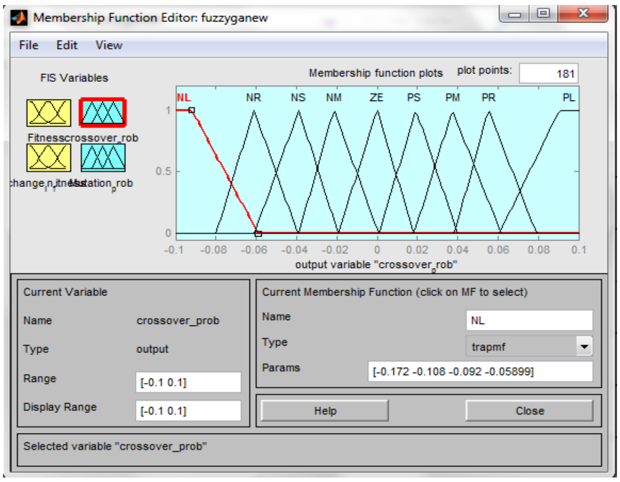


Figure 3 Shows Input Membership Function for Fitness

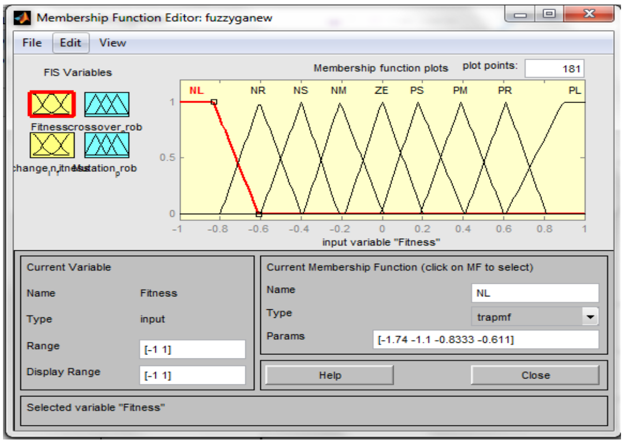


Figure 4 Shows Output Membership Function for Mutation Probability

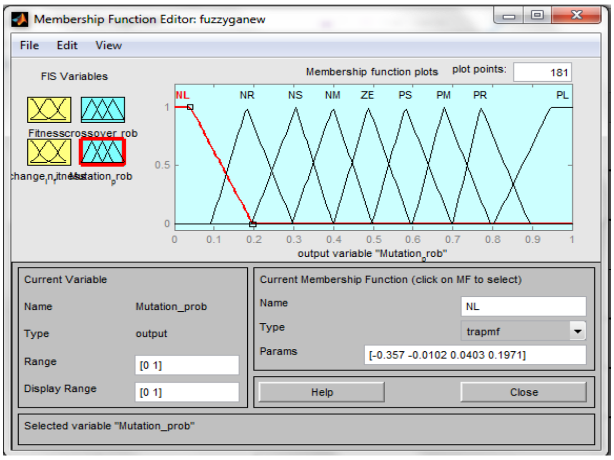


Figure 5 Shows Output Membership Function for Crossover Probability

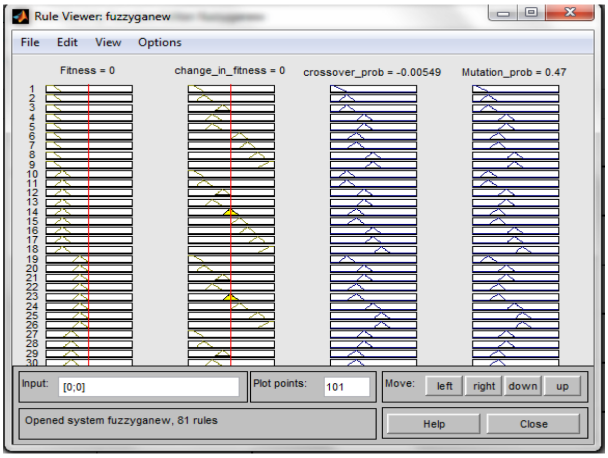


Figure 6 Represents the Rule Viewer

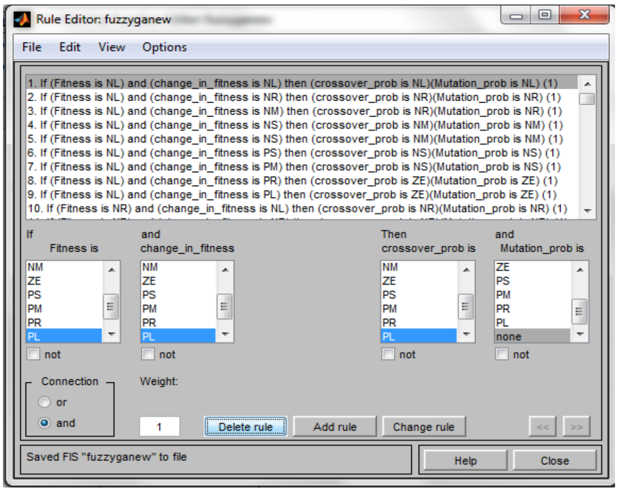


Figure 7 Shows the Rule Window

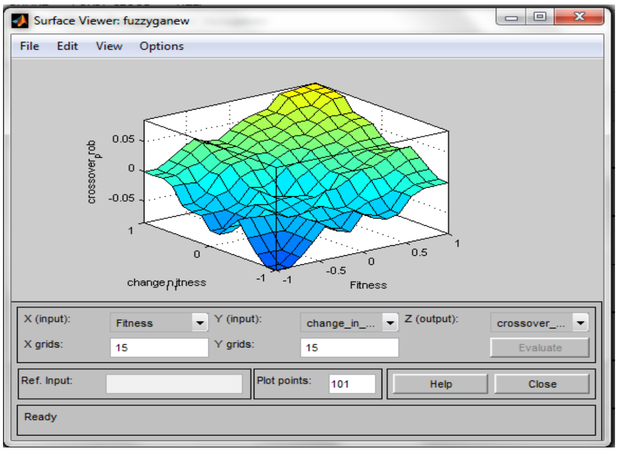


Figure 8 Shows the Surface Viewer

```
F =

   8.3526e+03


P1 =

  323.6378   76.6747  158.4469   50.0000   51.9761   50.0000


lam =

   7.1054e-14
```

Figure 8 Shows the Power Values for ELD Unit1

Table 2 Input/ Output Membership Functions

Input- membership parameters				**Output-membership parameters**			
Average fitness		**Change in fitness**		**Optimized crossover probability**		**Optimized mutation probability**	
L.V	Range	L.V	Range	L.V	Range	L.V	Range
NL	-0.1,-0.06	NL	-1 , -0.6	NL	0-0.2	NL	-1,-0.6
NR	-0.08,-0.06	NR	-0.8, -0.4	NR	0.1-0.3	NR	-0.8,-0.4
NM	-0.04,0	NM	-0.4,0	NM	0.3-0.5	NM	-0.4,0
NS	-0.06,-0.02	NS	-0.6,-0.2	NS	0.2-0.4	NS	-0.6,-0.2
ZE	-0.02,0.02	ZE	-0.2,0.2	ZE	0.4-0.6	ZE	-0.2,0.2
PS	0,0.04	PS	0 , 0.4	PS	0.5-0.7	PS	0,0.4
PM	0.02,0.06	PM	0.2, 0.6	PM	0.6-0.8	PM	0.2,0.6
PR	0.04,0.08	PR	0.4, 0.8	PR	0.7-0.9	PR	0.4,0.8
PL	0.06,0.1	PL	0.6, 1	PL	0.8-1	PL	0.6,1

8. CONCLUSION

The main intent of this paper is to produce an effective solution for ELD problem. In this paper, a Genetic algorithm infused with Fuzzy Logic i.e. Fuzzy Logic Controlled Genetic Algorithm has been successfully introduced to obtain the optimum solution of ELD. In this method fuzzy controllers has been designed to adaptively adjust the crossover probability and mutation rate during the optimization process based on some heuristics.

It is found that FCGA is giving better results than GA and LIM. i.e. FCGA proves their fast algorithm and yields true optimum generations of both operating costs and transmission line losses of the power system.

FCGA approach has been successfully introduced to obtain the optimum solution of ELD. The problem arises due to the unexpected timely variation in power system load hence making it very nearly impossible to meet all continuous load demands. Despite of the continuous efforts made in addressing this issue, there is still not a full-fledged self-efficient optimum solution for economic load dispatch. For solving all these issues, a system has been proposed which performs the genetic operations in addition to the fuzzy logic. The paper concludes with presenting the simulation results of the proposed approach.

Fuzzy Logic Controlled Genetic Algorithm is introduced successfully to obtain the optimum solution of ELD. In this method, FCGA technique is implemented to adjust the crossover probability and mutation rate during the optimization process based on few heuristics. It is observed that FCGA is giving better results than LIM and Fuzzy methods. Also FCGA provides its fast response for algorithms and occupies true optimum generations for operating costs and transmission line losses of the power system.

9. FUTURE SCOPE OF WORK

Problem of ELD can be optimized using TABU search method & also with TABU & fuzzy hybridization implementation. Further, extension of GA based ELD solution with inclusion of different measuring devices can be performed. We can extend FCGA technique for large no. of power units.

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