

FUZZY LIKE PID CONTROLLER TUNING BY MULTI-OBJECTIVE GENETIC ALGORITHM FOR LOAD FREQUENCY CONTROL IN NONLINEAR ELECTRIC POWER SYSTEMS

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ABSTRACT

This paper studies control of load frequency in single and two area power systems with fuzzy like PID controller. In this study, multi-objective genetic algorithm is used to determine the parameters of the fuzzy like PID controller according to the system dynamics. The proposed controller has been compared with the conventional PID controllers tuned by Ziegler-Nichols method and Particle Swarm Optimization technique. The overshoots and settling times with the proposed Genetic-PID controller are superior to the outputs of the same characteristics of the conventional PID controllers. The effectiveness of the proposed schemes is confirmed via extensive study using single area and two areas load frequency control examples through the application of MATLAB-Simulink software.

KEYWORDS: Load Frequency Control, Electric Power System, Fuzzy Logic, Multi-Objective Genetic Algorithm.

I. INTRODUCTION

Load Frequency Control (LFC) as a major function of Automatic Generation Control (AGC) is one of the important control problems in electric power system design and operation. It is becoming more significant today because of the increasing size, changing structure, emerging new uncertainties, environmental constraints and the complexity of power systems.

A large frequency deviation can damage equipment, corrupt load performance, reason of the overloading of the transmission lines and can interfere with system protection schemes, ultimately leading to an unstable condition for the electric power system. Maintaining frequency and power interchanges with neighboring control areas at the scheduled values are the two main primary objectives of a power system LFC [1].

Many control strategies for Load Frequency Control in electric power systems have been proposed by researchers over the past decades. This extensive research is due to fact that LFC constitutes an important function of power system operation where the main objective is to regulate the output power of each generator at prescribed levels while keeping the frequency fluctuations within pre-specified limits. A unified tuning of PID load frequency controller for power systems via internal model control has been proposed [2]. In this paper the tuning method is based on the two-degree-of-freedom (TDF) internal model control (IMC) design method and a PID approximation procedure. A new discrete-time sliding mode controller for load-frequency control in areas control of a power system has been presented [3]. In this paper full-state feedback is applied for LFC not only in control areas with thermal power plants but also in control areas with hydro power plants, in spite of their non-minimum phase behaviors. To enable full-state feedback, a state estimation method based on fast

sampling of measured output variables has been applied. The applications of artificial neural network, genetic algorithms and optimal control to LFC have been reported in [4-7]. An adaptive decentralized load frequency control of multi-area power systems has been presented in [7]. Also the application of robust control and adaptive methods for load frequency control problem has been presented in [8-10]. Furthermore, the application of some evolutionary techniques on LFC has been reported for single area and multi-areas power systems in literature [11-18]

As stated in some literature [19], some control strategies have been suggested based on the conventional linear control theory. These controllers may be inappropriate in some operating conditions. This could be due to the complexity of the electric power systems such as nonlinear load characteristics and variable operating points.

Now-a-days the LFC systems are faced by new uncertainties in the electrical market. To meet these uncertainties and to support the control process an open communication infra-structure is important. In conventional LFC schemes dedicated communication channels are used for transmit the measurements to the control centre and then to the generator unit. The communication delays are considered as significant uncertainties in the LFC due to the complexity of the power system and cause the system instability. This also degrades the system performance. Thus the analysis of LFC model in the presence of time delays is most important. Now-a-days many researchers concentrate on LFC modeling/synthesis in the presence of time delays [20-24]. They mainly focused on the network delay models and the communication network requirements. The incorporation of power system nonlinearities in the LFC strategies has been described by some researchers [25].

In this study, multi-objective genetic algorithm is used to determine the parameters of the fuzzy like PID controller according to the system dynamics. Adjusting the maximum and minimum values of the PID gains (K_p, K_i and K_d) and output gain (K_u) respectively, the outputs of the system (voltage, frequency) could be improved.

In this simulation study, a single and two-area nonlinear electric power system is chosen and load frequency control of this system is made by genetic based fuzzy like PID controller.

This paper is organized as follow: Section II will give an overview of the genetic algorithm (GA). In section III provides the multi-objective optimization technique using the GA. In section VI introduces the fuzzy-like PID controller structure. Section V presents the nonlinear load frequency modeling technique. Simulation results will be given in section VI. The main conclusions have been introduced in section VII. In section VIII, possible future work has been suggested. Some references are listed at the end of the paper.

II. OVERVIEW ON GENETIC ALGORITHM

The Genetic Algorithm (GA) is an optimization and search technique based on the principles of genetics and Darwinian selection. The GA allows a population composed of many individuals to evolve under specified selection rules to a state that maximizes the “fitness” (i.e., minimizes the cost function), many versions of evolutionary programming have been tried with varying degrees of success. Some of the advantages of a GA include [26-27]:

- Optimization with continuous or discrete variables.
- Derivative information is not required.
- Simultaneously searching from a wide sampling of the cost surface.
- Optimization of the variables with extremely complex cost surfaces (they can jump out of a local minimum).
- Encode the variables so that the optimization is done with the encoded variables.
- Working with numerically generated data, experimental data, or analytical functions.

These advantages are interesting and produce surprising results when traditional optimization approaches fail miserably.

There are many variations of the genetic algorithms but the basic form is simple genetic algorithm (SGA). This algorithm works with a set of population of candidate solution represented as strings. The initial population consists of randomly generated individuals. Then the fitness of each individual in current population is computed. The population is then transformed in stages to yield a new current population for next iteration. The transformation is usually done in three stages by simply applying the following genetic operators: (1) Selection, (2) Crossover, and (3) Mutation.

In the first stage selection operator is applied as many times as there are individuals in the population. In this stage every individual is replicated with a probability proportional to its relative fitness in the population. In the next stage, the crossover operator is applied. Two individuals (parents) are chosen and combined to produce two new individuals. The combination is done by choosing at random a cutting point at which each of parents is divided into two parts; these are exchanged to form the two offspring which replace their parents in the population. In the final stage, the mutation operator changes the values in a randomly chosen location on an individual.

The algorithm terminates after a fixed number of iterations and the best individual generated during the run is taken as the solution.

III. MULTI-OBJECTIVE GA

In many real-life problems, objectives under consideration conflict with each other, and optimizing a particular solution with respect to a single objective can result in unacceptable results with respect to the other objectives [26].

A reasonable solution to a multi-objective problem is to investigate a set of solutions, each of which satisfies the objectives at an acceptable level without being dominated by any other solution [27].

Being a population based approach, GA are well suited to solve multi-objective optimization problems. A generic single-objective GA can be modified to find a set of multiple non-dominated solutions in a single run. The ability of GA to simultaneously search different regions of a solution space makes it possible to find a diverse set of solutions for difficult problems with non-convex, discontinuous and multi-modal solutions spaces. The cross over operator of GA may exploit structures of good solutions with respect to different objectives to create new non - dominated solutions [26].

The goal of MOO is to find as many of these solutions as possible. If reallocation of resources cannot improve one cost without raising another cost, then the solution is Pareto optimal. A Pareto GA returns a population with many members on the Pareto front. The population is ordered based on dominance.

Several different algorithms have been proposed and successfully applied to various problems such as [28-30]: Vector-Evaluated GA (VEGA), Multi-Objective GA (MOGA), A Non-Dominated Sorting GA (NSGA) and Non-Dominated Sorting GA (NSGA II) which is used in the proposed research.

IV. FUZZY LIKE PID CONTROLLER STRUCTURE

Fuzzy logic (FL) was first proposed by Lotfi A. Zadeh (1965) [31] and is based on the concept of fuzzy sets. Fuzzy set theory provides a means for representing uncertainty. In general, probability theory is the primary tool for analyzing uncertainty, and assumes that the uncertainty is a random process. However, not all uncertainty is random, and fuzzy set theory is used to model the kind of uncertainty associated with imprecision, vagueness and lack of information.

In this work; the development of the fuzzy logic approach here is limited to the design and structure of the controller.

The input constraints were terminal voltage error (e), error derivative (de) and error integration (se); the output constraint was the increment of the voltage exciter as shown in Figure 1.

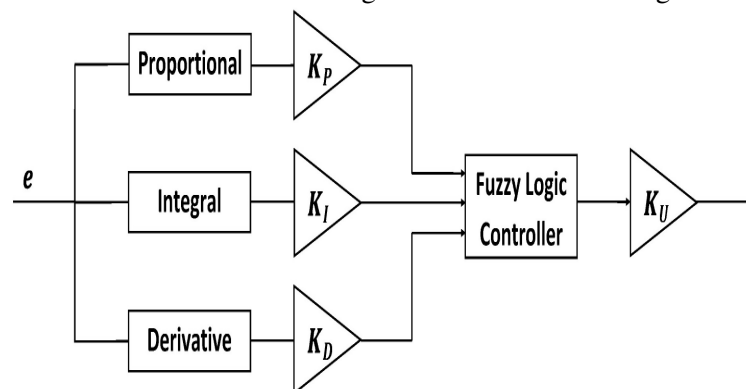


Figure 1: Fuzzy Like PID Controller

Three fuzzy sets are defined for each input variable; (N - negative, Z - zero, P - positive). Five fuzzy sets are defined for the output variable; (LN – Large negative, N - negative, Z - zero, P – positive, LP –Large positive) with 27 rules as shown in Table 1.

The membership functions for input and output variable are triangular. The complete set of control rules is shown in Table 1; each of the control rules represents the desired controller response to a particular situation.

Table 1: Rule Base for Fuzzy like PID Controller

e de se	N			Z			P		
	N	Z	P	N	Z	P	N	Z	P
N	LP	P	P	P	P	Z	P	Z	N
Z	P	P	Z	P	Z	N	Z	N	N
P	P	Z	N	Z	N	N	N	N	LN

The min-max method inference engine is used; the defuzzify method used in is the center of area, the input and output normalized to the [-1, 1] universe.

The optimal values of the Fuzzy like PID controller parameters K_p , K_i , K_d and K_u in Figure 1 are found using genetic Algorithm multi-objective optimization [32-33].

V. NONLINEAR LOAD FREQUENCY CONTROL MODEL

Non-reheat type nonlinear electric power system represented by a block diagram of a closed loop controlled system model is shown in Figure 2, Figure 3 for single area, two-area electric power system respectively; where f is the system frequency (Hz), R_i is regulation constant (Hz/unit), T_{gi} is speed governor time constant (sec), T_{ti} is turbine time constant (sec), H_i is inertia constant (s) and D_i is area parameter (Mw/Hz) [34-35].

The model includes the effect of Generation Rate Constraint (GRC) and limits on the position of the governor valve, which are caused by the mechanical and thermodynamic constraints in practical steam turbines systems.

A typical value of 0.01 p.u. /min has been included in the model as stated in [36].

A. Single Area Nonlinear Electric Power System

The system can be modeled by the following form:

$$\dot{x} = Ax(t) + Bu(t) + Ld(t) \quad (1)$$

Where: A, B, L are the system, the input and disturbance matrices.

$x(t)$, $u(t)$ and $d(t)$ are state, control signal and load change disturbance vectors respectively defined as $x(t) = [\Delta f \Delta P_g \Delta P_t]$ AND $d(t) = [\Delta P_d]^T$.

The system output depends on the objective function which is Integral Absolute Error (IAE) can be given as:

$$y(t) = IAE = \int |e(t)| dt = Cx(t) \quad (2)$$

The control signal for the fuzzy like PID controller can be given as:

$$u(t) = - \left(K_p y + K_i \int y dt + K_d \frac{dy}{dt} \right) \quad (3)$$

Percentage of overshoot and settling time are two more objective functions have been added to the IAE performance index to define the multi-objective genetic algorithm problem.

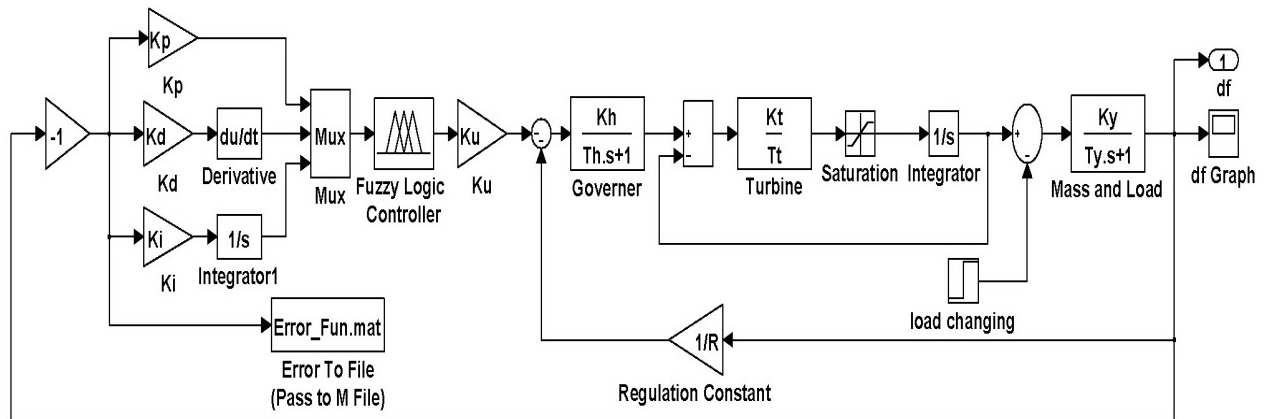


Figure 2: Non-Linearized Single Area Power System Simulink Model with Multi-Objective Genetic Algorithm-Tuned Fuzzy like PID Controller

The nominal system parameters are:

$$K_h = 1, T_h = 0.08 \text{ sec}, K_t = 1, T_t = 0.3 \text{ sec}, K_y = 120, T_y = 20 \text{ sec}, R = 2.4$$

B. Two-Area Nonlinear Electric Power System

An interconnected power system is divided into control areas connected by a tie line. In each control area, all generators are supposed to constitute a coherent group. The tie-line power flow and frequency of the area are affected by the load changes. Therefore, it can be considered that each area needs its system frequency and tie-line power flow to be controlled.

Area Control Error (ACE) signal is used as the plant output of each power generating area. Driving ACEs in all areas to zeros will result in zeros for all frequency and tie-line power errors in the system. So it can be defined as:

$$ACE_I = \sum_{j=1, \dots, N, j \neq I} \Delta P_{TIE, Ij} + B_I \Delta F_I \quad (4)$$

Where: B_i is the frequency response characteristic for area I defined as $b_i = D_i + \frac{1}{R}$.

The system can be modeled by the following form:

$$\dot{x} = Ax(t) + Bu(t) + Ld(t) \quad (5)$$

Where A is the system matrix, B, L the input and disturbance matrices and $x(t)$, $u(t)$ and $d(t)$ are state, control signal and load change disturbance vectors respectively defined as $x(t) = [\Delta f_1 \Delta P_{g1} \Delta P_{t1} \Delta P_{tie} \Delta f_2 \Delta P_{g2} \Delta P_{t2}]$, $u(t) = [u_1 u_2]^T$ and $d(t) = [\Delta P_{d1} \Delta P_{d2}]^T$ where u_1 and u_2 are the control signals in area 1, area 2 respectively.

The system output which depends on Area Control Error (ACE) can be given as:

$$y(t) = \begin{bmatrix} ACE_1 \\ ACE_2 \end{bmatrix} = Cx(t) \quad (6)$$

The control signal for the fuzzy like PID controller can be given as:

$$u(t) = - \left(K_p y + K_i \int y dt + K_d \frac{dy}{dt} \right) \quad (7)$$

To simplify the study, for the two interconnected areas were considered identical. So the optimal parameter chosen such that $G_{c1} = G_{c2} = G_c$ and $B_1 = B_2 = B$.

Percentage of overshoot and settling time are two more Objective functions have been added to the IAE performance index to define the multi-Objective genetic Algorithm problem.

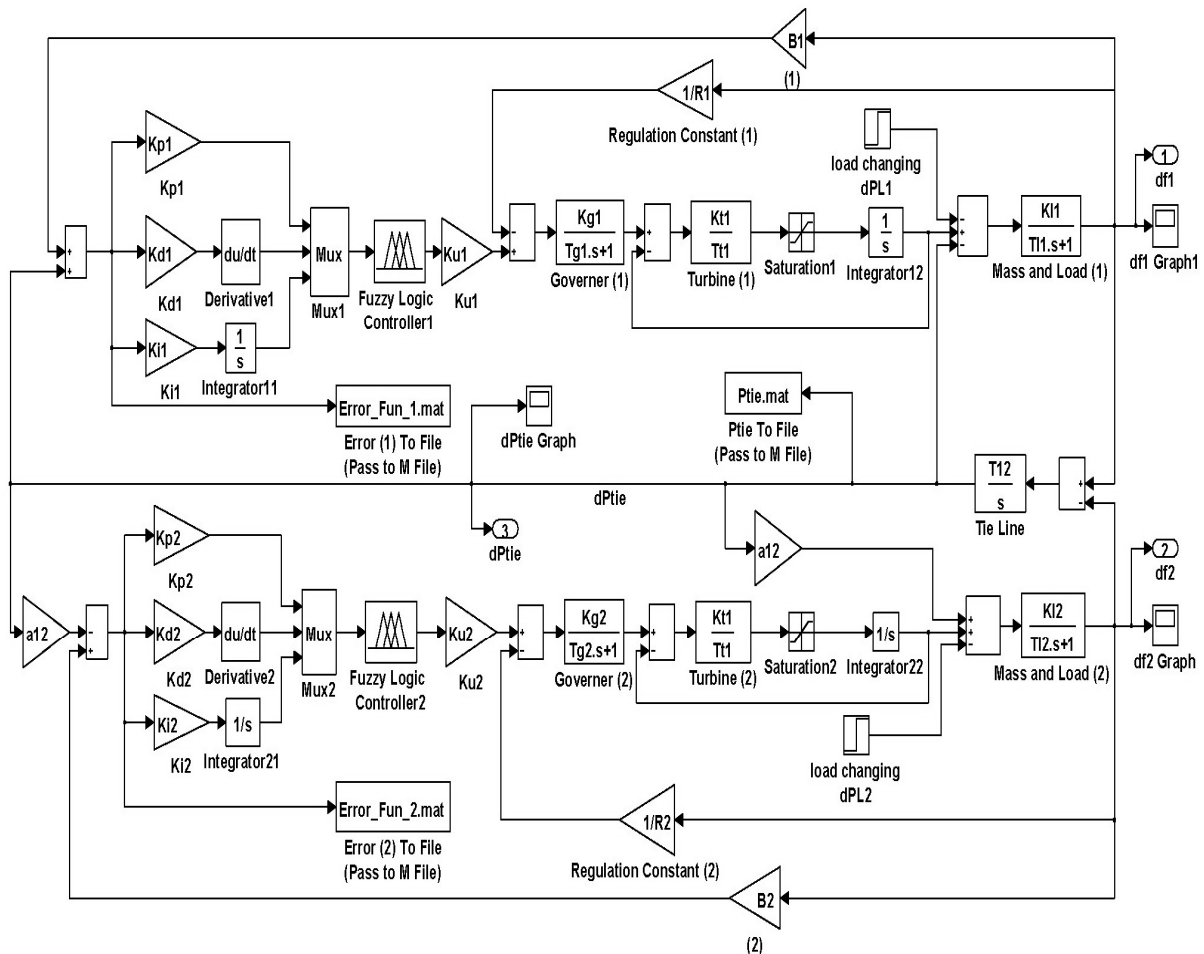


Figure 3: Non-Linearized Two-Area Power System Simulink Model with Multi-Objective Genetic Algorithm-Tuned Fuzzy like PID Controller

The nominal system parameters are:

$$T_{g1} = T_{g2} = 0.08 \text{ sec}, T_{t1} = T_{t2} = 0.3 \text{ sec}, T_{y1} = T_{y2} = 20 \text{ sec}, K_{y1} = K_{y2} = 100, R_1 = R_2 = 2.4, \\ B_1 = B_2 = 0.425, T_{12} = 0.05 \text{ sec}, a_{12} = 1.$$

VI. SIMULATION RESULTS

The simulation set up needs only the incorporation of single area and two areas models of Figures 2 and 3 in the Simulink tool of MATLAB and run the simulation to get the results described in this paper as follow:

A. Single Area Nonlinear Electric Power System

By using the Simulink model shown in Figure 2 with multi-objective genetic algorithm technique in conjunction with equation (1)-(3), optimal controller parameters were obtained as shown in Table 2. Figure 4 shows the time domain performance of the nonlinear electric power system under the proposed multi-objective genetic algorithm based PID controller with step change of 0.01 p.u. At the simulation, the genetic algorithm was run for 1000 generations with a population size of 100.

Table 2: Single Area Fuzzy like PID Controller Parameters using Multi-Objective Genetic Algorithm Technique

Fuzzy like PID Parameters	K_p	K_i	K_d	K_u
Values	3.358	0.557	0.984	0.821

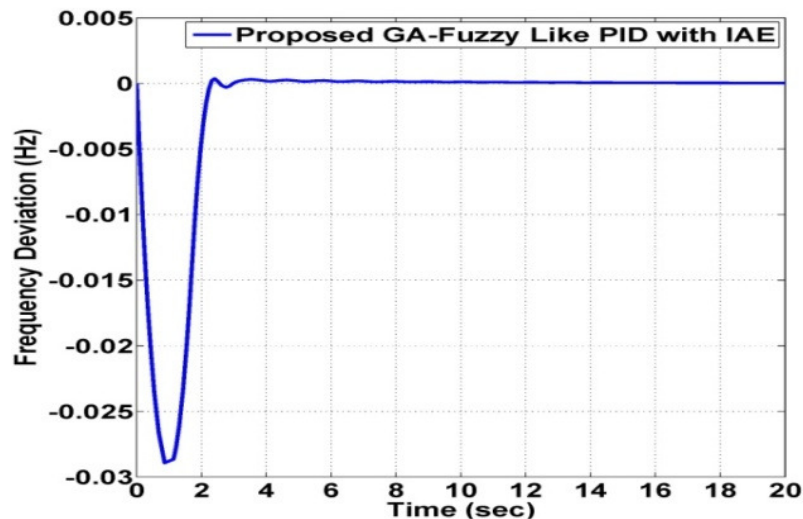


Figure 4: Single Area Nonlinear Electric Power System Response with Multi-Objective Genetic Algorithm Tuned Fuzzy like PID

Table 3: Response Characteristics Using Genetic Algorithm-Tuned Fuzzy like PID Technique in Non-Linearized Single Area Electric Power System

Overshoot (Hz)	Settling Time (Sec)
0.0289	2.2142

B. Two-Area Nonlinear Electric Power System

By using the Simulink model shown in Figure 3 with multi-objective genetic algorithm technique in conjunction with equation (4)-(7), optimal controller parameters were obtained as shown in Table 4. Figure 5-a, 5-b, 5-c show the time domain performance of the frequency deviation in first area, second area and tie line power deviation respectively under the proposed multi-objective genetic algorithm based fuzzy like PID controller with step change of 0.01 p.u.

At the simulation, the genetic algorithm was run for 100 generations with a population size of 100.

Table 4: Two-Area Fuzzy like PID Controller Parameters using Multi-Objective Genetic Algorithm Technique

Fuzzy like PID Parameters	$K_{p1} = K_{p2}$	$K_{i1} = K_{i2}$	$K_{d1} = K_{d2}$	$K_{u1} = K_{u2}$
Values	4.216	0.368	1.833	3.827

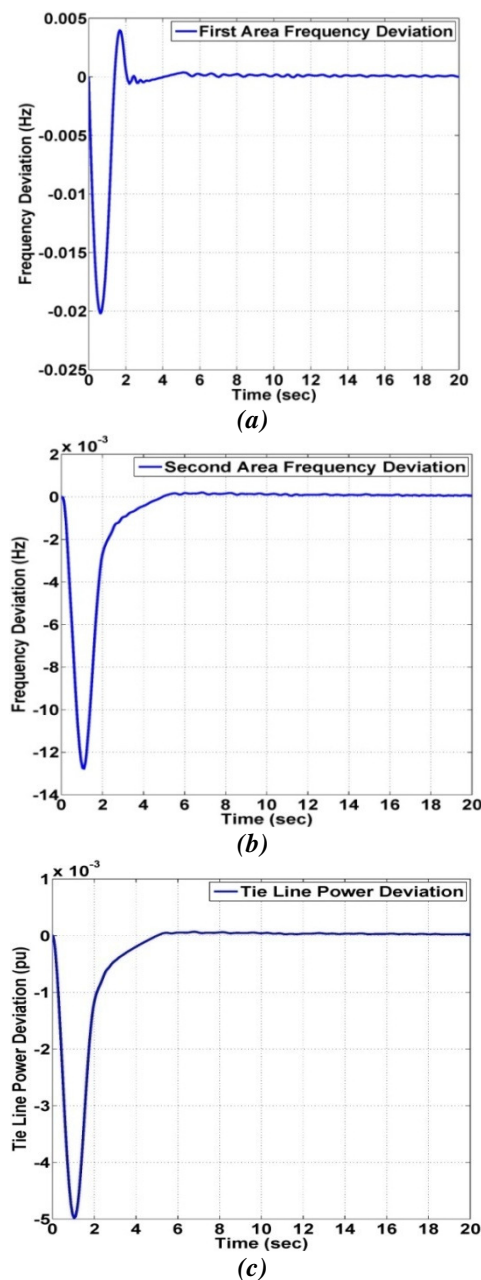


Figure 5: Two-Area Nonlinear Electric Power System Response with Multi-Objective Genetic Algorithm Tuned Fuzzy like PID

a) First Area Frequency

b) Second Area Frequency

c) Tie Line Power

Table 5: Response Characteristics Using Genetic Algorithm-Tuned Fuzzy like PID Technique in Non-Linearized Two-Area Electric Power System

	Overshoot	Settling Time (Sec)
First Area Frequency (Hz)	0.0202	3.0257
Second Area Frequency (Hz)	0.0128	4.3364
Tie Line Power (P.u)	0.0050	4.4746

VII. CONCLUSION

In this proposed study, a multi-objective genetic algorithm based fuzzy like PID technique has been applied for automatic load frequency control of a nonlinear single and two-area electric power system. For this purpose, first, a fuzzy like PID controller has been proposed then the parameters of the fuzzy like PID controller has been added to the model the PID gains (K_p, K_i and K_d) and output gain (K_u) and at last, a tuning mechanism for the fuzzy like PID controller parameters is obtained. The single area and two areas power systems have been simulated using MATLAB/Simulink software on a standard personal computer.

It has been shown that the proposed control algorithm is effective and provides significant improvement in system performance both in the transient and steady state responses. Therefore, the proposed multi-objective genetic based fuzzy like PID controller is recommended to generate a good quality and reliable electric energy.

In addition, the proposed controller is very simple and easy to implement since it does not require many information about system parameters.

VIII. FUTURE WORK

The work presented in this paper can be extended in several directions. Some possible areas of extension are given below.

a) Improvement on the Model of the Power Systems

The performed studies in the previous sections on LFC dynamic performance have been made based upon

- A linearized model analysis.
- A non linear model analysis with a saturated steam or hydrocontrol valve.

The described LFC model so far does not consider the effects of all the physical constraints; an important physical constraint can be a point of a research in the LFC is on the rate of change of power generation due to the limitation of thermal and mechanical movements. LFC studies that do not take into account the delays caused by the crossover elements in a thermal unit, or the behavior of the penstocks in a hydraulic installation, in addition to the sampling interval of the data acquisition system, results in a situation where frequency and tie-line power could be returned to their scheduled value within 1 s. For the LFC problem, some of the plant limits such as generation rate constraints and dead bands are disregarded in this paper. However, in reality, they exist in power systems. In the future, a plan should be done to include the plant limits in the model of the power system to make the model more practical. Accordingly, LFC will be modified so as to successfully apply it to the new model. It should be noted that most of the proposed control strategies, so far, for solution of the LFC problem have not been implemented due to system operational constraints associated with thermal power plants. The main reason is the non-availability of the required power. Also, due to the persistence of the system frequency and tie line deviations for a long duration in the case of small load disturbances.

On the other hand, electromechanical oscillations in a power system can be effectively damped by fast acting energy storage devices, because additional energy storage capacity is provided as a supplement to the kinetic energy storage. The energy storage devices share the sudden changes in power requirement in the load. Thus, in a power system, the instantaneous mismatch between supply and demand of real power for sudden load changes can be reduced by the addition of active power sources with fast response such as BES, SMES and CES devices.

Another competitive point of research is the LFC in a deregulated environment. Nowadays, the electric power industry is in transition to a competitive energy market. In the new structure, GENCOs may not participate in the LFC task and DISCOs have the liberty to control any available GENCOs in their own or other areas.

On the other hand, the real world power system contains different kinds of uncertainties and disturbances, and coming deregulation significantly increases the severity of this problem. Under this condition, the classical controller is certainly not suitable for the LFC problem.

b) Improvement on the Load Frequency Controller

From the point of view of control, among all categories of LFC strategies, robust control and AI-based methods have shown an ability to give better performance in dealing with the system non linearities, modeling uncertainties and area load disturbances under different operating conditions. The main capability of robust control approaches is alleviation of the impossibility of controller design based on a more complete model of the system that considers uncertainties and physical constraints, too. The salient feature of the AI technique is that it provides a model-free description of the control system and does not require an accurate model of the plant.

A continuation of this work could be using a different kind of controller other than Genetic Algorithm based PID controller, Genetic Algorithm based Fuzzy Like PID controller such as Genetic Algorithm based ANFIS controller; so that GA can be used to optimize the membership functions of the ANFIS controller.

Comparison between control strategies can be done with the aid of different kinds of power systems uncertainties and models in order to reach for the most suitable controller for the real world two-area power system. The authors suggest, for future work, the extension of the proposed algorithm on multi area power systems including different generation renewable resources such as wind and solar systems. Also the investigation of the algorithm sensitivity for system parameters would be considered in future research studies.

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BIOGRAPHIES

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