Hybrid Fuzzy LFC Design by GA in a Deregulated Power System

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Abstract: - A new Hybrid Fuzzy (HF) PID type controller based on Genetic Algorithms (GAs) is proposed for solution of the Load frequency Control (LFC) problem in a deregulated power system. In order for a fuzzy rule based control system to perform well, the fuzzy sets must be carefully designed. A major problem plaguing the effective use of this method is the difficulty of accurately constructing the membership functions. On the other hand, GAs is a technique that emulates biological evolutionary theories to solve complex optimization problems by using directed random searches to derive a set of optimal solutions. For this reason, in the proposed GA based HF (GAHF) controller the membership functions are tuned automatically using a modified GA's based on the hill climbing method. The aim is to reduce fuzzy system effort and take large parametric uncertainties into account. This newly developed control strategy combines the advantages of GAs and fuzzy system control techniques and leads to a flexible controller with simple stricture that is easy to implement. The proposed method is tested on a three-area deregulated power system under different operating conditions in comparison with the robust mixed H_2/H_∞ controller through some performance indices to illustrate its robust performance.

Key-Words: LFC, Hybrid Fuzzy Controller, GA's, Deregulated Power System, Power System Control.

1 Introduction

In the restructured power system, Load Frequency Control (LFC) will serve as ancillary service and acquires a principal role to enable power exchanges and to provide better condition for electricity trading. In an open energy market a DISCO has the freedom to have a contract with any GENCO for power transaction in its area or other areas [1].

In a real world deregulated power system, each control area contains different kinds of uncertainties and various disturbances due to increasing the complexity, system modeling errors and changing power system structure. As a result, a fixed controller based on classical theory is certainly not suitable for LFC problem. Thus, it is required that a flexible controller be developed. Recently, some authors proposed fuzzy PID methods to improve the performance of AGC problem [2-4]. It should be pointed out that they require a three-dimensional rule base. This problem makes the design process is more difficult. In order to overcome this drawback a Genetic Algorithm (GA) based Hybrid (GAHF) PID controller with a fuzzy switch is presented in this paper. This is a form of behavior based control where the PD controller becomes active when certain conditions are met. The resulting structure is a controller using two-dimensional inference engines (rule base) to reasonably perform the task of a three-dimensional controller. The proposed method requires fewer resources to operate and its role in the system response is more apparent, i.e. it is easier to understand the effect of a two-dimensional controller than a three-dimensional one [1]. One of the importance and essential step toward the design of any successful fuzzy controllers is accurately constructing the membership functions. On the other hand, extraction of an appropriate set of membership functions from the expert may be tedious, time consuming and process specific. Thus, in order to reduce fuzzy system effort a modified GAs is being used for optimum tuning of membership functions in the proposed HF controller automatically. GAs, are a heuristic search; optimization technique inspired by natural evolution and has attractive features such as robustness, simplicity, etc. However, it cannot guarantee that the best solution will be found. In fact, sometimes it converges to local, rather than global optima. To overcome this drawback, a modified GA based on the hill climbing method is proposed to improve optimization synthesis such that the global optima are guaranteed and the speed of algorithms convergence is extremely improved, too. The proposed GAHF controller is tested on a three-area restructured power system under different operating conditions in comparison with the robust mixed H_2/H_∞ [5] controller through some performance indices. Results evaluation show that the proposed method achieves good robust performance for wide range of system parameters and load changes in the presence of system nonlinearities and is superior to the other controllers.

2 Generalized LFC Scheme Model

Generalized dynamical model for LFC scheme has been developed in Ref. [6] based on the possible contracts in the restructured environments. This section gives a brief overview on this generalized model that uses all the information required in a VIU industry plus the contract data information. In the new structure, GENCOs may or may not participate in the LFC task and DISCOs have the liberty to contract with any available GENCOs in their own or other areas. The concept of an Augmented Generation Participation Matrix (AGPM) is introduced to express these possible contracts in the generalized model. The rows and columns of AGPM is equal with the total number of GENCOs and DISCOs in the overall power system, respectively. The AGPM structure for a large scale power system with N control area is given by:

$$AGPM = \begin{bmatrix} AGPM_{11} & \cdots & AGPM_{1N} \\ \vdots & \ddots & \vdots \\ AGPM_{N1} & \cdots & AGPM_{NN} \end{bmatrix} \quad (1)$$

where,

$$AGPM_{ij} = \begin{bmatrix} gpf_{(s_i+1)(z_j+1)} & \cdots & gpf_{(s_i+1)(z_j+m_j)} \\ \vdots & \ddots & \vdots \\ gpf_{(s_i+n_i)(z_j+1)} & \cdots & gpf_{(s_i+n_i)(z_j+m_j)} \end{bmatrix} \quad for\ i, j = 1, \cdots, N$$

$$\&\ s_i = \sum_{k=1}^{i-1} n_i\ ,\ z_j = \sum_{k=1}^{j-1} m_j\ , \qquad s_1 = z_1 = 0$$

In the above, n_i and m_i are the number of GENCOs and DISCOs in area i and gpf_{ij} refer to '*generation participation factor*' and shows the participation factor GENCO i in total load following requirement of DISCO j based on the possible contract. The sum of all entries in each column of AGPM is unity. To illustrate the effectiveness of the proposed control design and modeling strategy, a three control area power system is considered as a test system. It is assumed that each control area includes two GENCOs and one DISCO. Block diagram of the generalized LFC scheme for a three-area restructured power system is shown in Fig. 1 (see Ref. [6] for the nomenclature used). The power system parameters are considered the same as Ref. [5]. The dashed lines show the demand signals based on the possible contracts between GENCOs and DISCOs which carry information as to which GENCO has to follow a load demanded by which DISCO. As there are many GENCOs in each area, ACE signal has to be distributed among them due to their ACE participation factor in the LFC task and $\sum_{j=1}^{n_i} \alpha_{ji} = 1$.

We can write [6]:

$$d_i = \Delta P_{Loc,j} + \Delta P_{di}\,,\ \Delta P_{Loc,j} = \sum_{j=1}^{m_i} \Delta P_{Lj-i}\ , \quad \Delta P_{di} = \sum_{j=1}^{m_i} \Delta P_{ULj-i} \quad (2)$$

$$\eta_i = \sum_{j=1\&j\neq i}^{N} T_{ij}\Delta f_j \quad (3)$$

$$\zeta_i = \Delta P_{tie,i,sch} = \sum_{k=1\&k\neq i}^{N} \Delta P_{tie,ik,sch} \quad (4)$$

$$\Delta P_{tie,ik,sch} = \sum_{j=1}^{n_i}\sum_{i=1}^{m_k} apf_{(s_i+j)(z_k+i)}\Delta P_{L(z_k+i)-k} - \sum_{i=1}^{n_k}\sum_{j=1}^{m_i} apf_{(s_k+i)(z_i+j)}\Delta P_{L(z_i+j)-l} \quad (5)$$

$$\rho_i = [\rho_{1i} \ \cdots \ \rho_{ki} \ \cdots \ \rho_{n_i i}],\ \rho_{ki} = \sum_{j=1}^{N}[\sum_{t=1}^{m_j} gpf_{(s_i+k)(z_j+t)}\Delta P_{Lt-j}] \quad (6)$$

$$\Delta P_{m,k-i} = \rho_{ki} + apf_{ki}\Delta P_{di}\ , \quad k = 1,2,...,n_i \quad (7)$$

3 GAHF LFC Scheme

Because of the complexity and multi-variable conditions of the power system, conventional control methods may not give satisfactory solutions. On the other hand, their robustness and reliability make fuzzy controllers useful for solving a wide range of control problems in power systems. In this paper, a modified GA-based HF controller is proposed for the solution of LFC problem. The motivation of using the proposed GAHF controller is to take large parametric uncertainties, system nonlinearities and minimize of area load disturbances into account. This control strategy combines fuzzy PD controller and integral controller with a fuzzy switch. The fuzzy PD stage is employed to penalize fast change and large overshoots in the control input due to corresponding practical constraints. The integral stage is also used to get disturbance rejection and zero steady state error. In order for a fuzzy rule based control system to perform well, the fuzzy sets must be carefully designed. A major problem plaguing the effective use of this method is the difficulty of accurately and automatically tuning of the membership functions. Because it is a computationally expensive combinatorial optimization problem and also extraction of an appropriate set of membership function from the expert may be tedious, time consuming and process specific. On the other hand, GAs, which are known as time intensive, are a heuristic search and optimization technique inspired by natural evolution which have been successfully applied to a wide range of real-world problems of significant complexity [7]. They require only information the quality of the fitness value produced by each parameter set during evolution. This differs from many optimization methods requiring derivative information or complete know-ledge of the problem structure and parameter. Hence, the GA is more suitable to deal with the problem of lacking experience or knowledge than other searching methods in particular, when the phenomena being analyzed are describable in terms of rules for action and learning processes. Thus, in order to reduce fuzzy system effort and cost, a modified GA based on the hill climbing method is being used to optimal tune of membership functions in the proposed HF controller. Fig. 2 shows the structure of the proposed controller for the solution of LFC problem. In this structure, input values are converted to truth-value vectors and applied to their respective rule base. The output truth-value vectors are not defuzzified to crisp value as with a single stage fuzzy logic controller but are passed onto the next stage as a truth value vector input. The darkened lines in Fig. 2 indicate truth value vectors. In this effort, all membership functions are defined as triangular partitions with seven segments from -1 to 1. Zero is the center membership function which is centered at zero. The partitions are also symmetric about the ZO membership function as shown in Fig. 3.

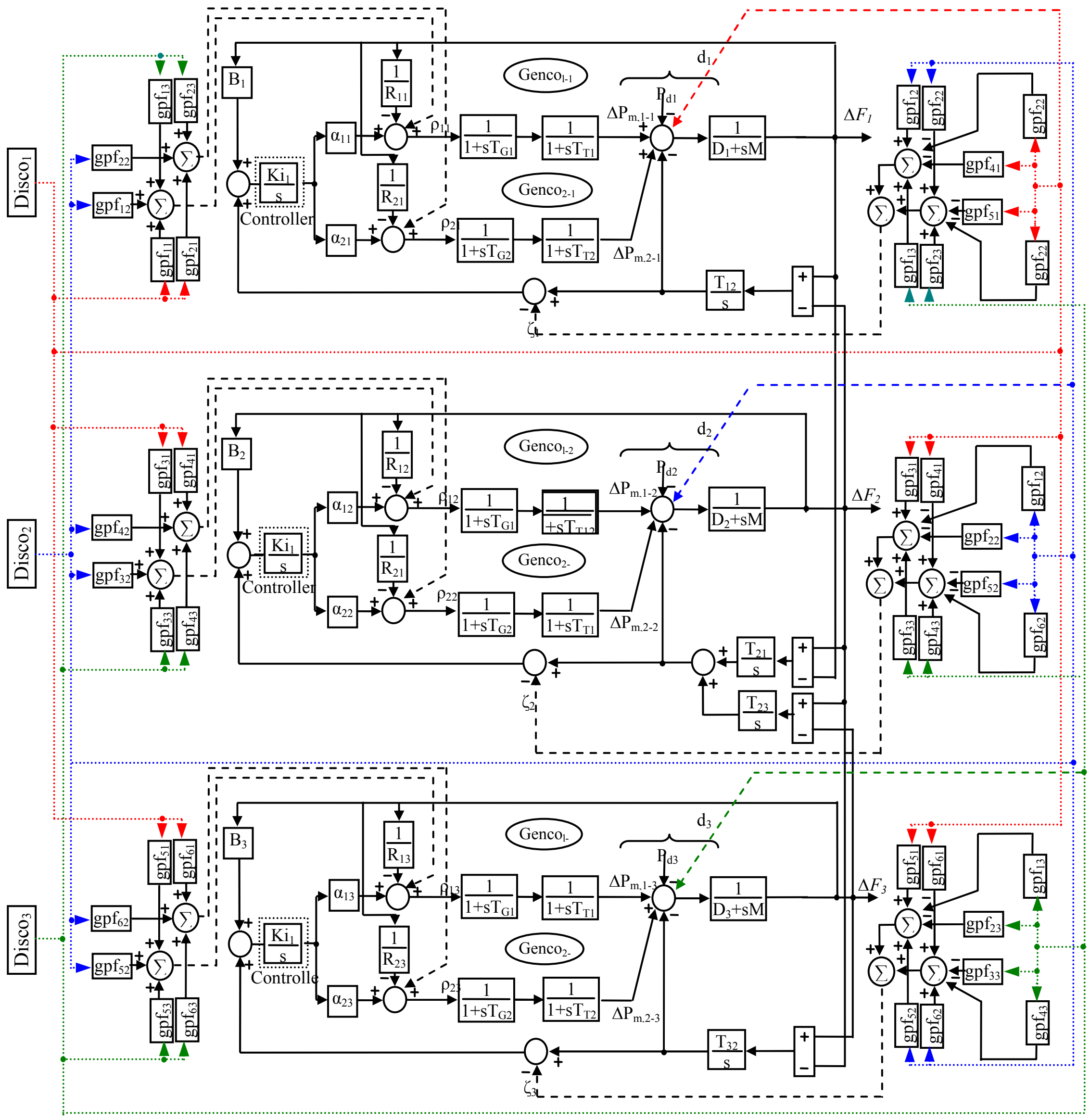

Fig. 1. Modified control area in a restructured environment

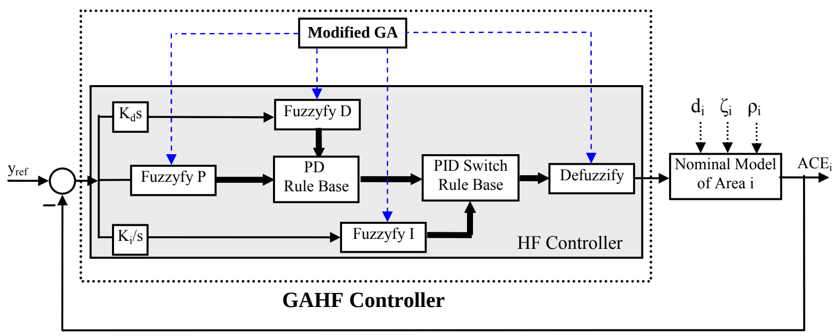

Fig. 2. Structure of the proposed GAHF control strategy.

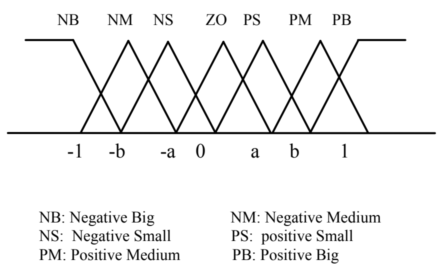

Fig. 3. Symmetric fuzzy partition.

There are two rule bases used in the GAHF controller. The first is called the PD rule bases as it operates on truth vectors form the error (*e*) and change in error (Δ*e*) inputs. A typical PD rule base for the fuzzy logic controller is given in Table 1. This rule base responds to a negative input from either error (*e*) or change in error (Δ*e*) with a negative value thus driving the system to ward the commanded value. Table 2 shows a PID switch rule base.

This rule base is designed to pass through the PD input if the PD input is not in zero fuzzy set. If the PD input is in the zero fuzzy set, then the PID switch rule base passes the integral error values ($\int e$). This rule base operates as the behavior switch, giving control to PD feedback when the system is in motion and reverting to integral feedback to remove steady state error when the system is no longer moving.

Table 1 . PD rule base

		ΔACE						
		NB	NM	NS	ZO	PS	PM	PB
e=ACE	NB	NB	NB	NB	NB	NM	NS	ZO
	NM	NB	NB	NB	NM	NS	ZO	PS
	NS	NB	NB	NM	NS	ZO	PS	PM
	ZO	NB	NM	NS	ZO	PS	PM	PB
	PS	NM	NS	ZO	PS	PM	PB	PB
	PM	NS	ZO	PS	PM	PB	PB	PB
	PB	ZO	PS	PM	PB	PB	PB	PB

Table 2. PID switch rule base.

		PD Values						
		NB	NM	NS	ZO	PS	PM	PB
∫ACE	NB	NB	NM	NS	NB	PS	PM	PB
	NM	NB	NM	NS	NM	PS	PM	PB
	NS	NB	NM	NS	NS	PS	PM	PB
	ZO	NB	NM	NS	ZO	PS	PM	PB
	PS	NB	NM	NS	PS	PS	PM	PB
	PM	NB	NM	NS	PM	PS	PM	PB
	PB	NB	NM	NS	PB	PS	PM	PB

According to Fig. 4 for exact tuning of used membership functions in the proposed method we must find the optimal value for *a* and *b* parameters, where $0<a<b<1$. To acquire an optimal combination, we adopt the modified GA's as the search method. Fig. 4 shows the flowchart of the modified GA approach for optimization. In this algorithm, the classical GA is used to find near optimal global value and then the proposed hill climbing method is used to find global optimum value. In order to guarantee global optima and improve the convergence speed, results of the GA is being used as initial conditions for the hill climbing method.

Before proceeding with the GA approach, the suitable coding and fitness function should be chosen. In this study, *a* and *b* parameters for the *ACE*, Δ*ACE*, ∫*ACE* and output membership functions are expressed in term of string consisting of 0 and 1 as shown in Fig. 5 by binary coding. It can be seen that length of the chromosome is 40 genes (bit). For our optimization, the following fitness function is proposed:

$$f(ITAE)=\frac{1}{1+MSE(ITAE)}\,,\quad MSE(ITAE)=(\sqrt{\sum_{i=1}^{3}\int_0^t |ACE_i|dt})/3 \qquad (8)$$

For acquiring better performance, number of generation, population size, crossover rate and mutation rate is chosen 200, 30, 0.97 and 0.08 respectively. Here, the modified GA evolution procedure is applied to exact tune of membership functions of the proposed HF controller for the solution of LFC problem. The Results of membership function set values are listed in Table 3. Fitness value by classical GA is 0.10237 that is improved to 0.11241by the proposed hill climbing method.

Table 3. Optimal values of parameters *a* and *b*

Membership function	Classical GA		Modified GA	
	a	b	a	b
ACE_i	0.2250	0.5806	0.2258	0.5806
ΔACE_i	0.323	0.7419	0.323	0.7419
∫ACE	0.4829	0.9811	0.4839	0.9811
output	0.4655	0.9192	0.4645	0.9291

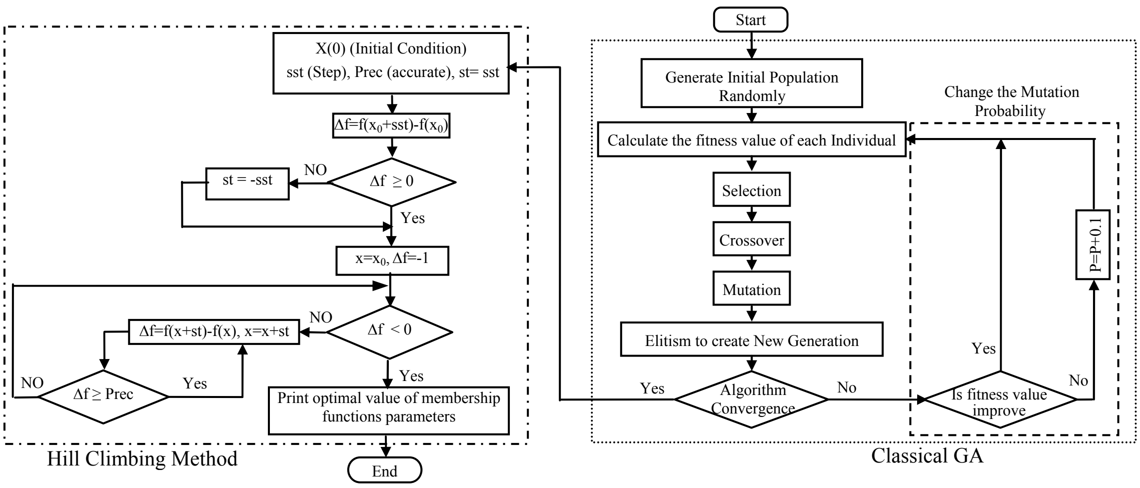

Fig. 4. Flowchart of the proposed GA based on the hill climbing method.

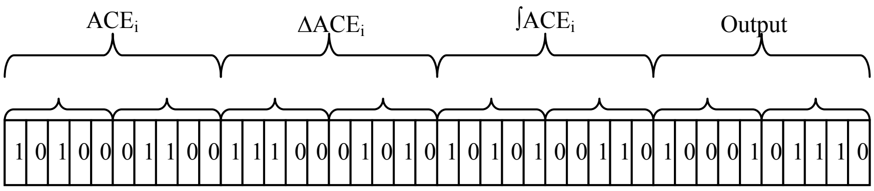

Fig. 5. String encoding membership function

4 Simulation Results

In the simulation study, the linear model of a turbine $\Delta P_{VKi}/\Delta P_{TKi}$ in Fig. 1 is replaced by a nonlinear model with ±0.1 limit (see Ref. [6] for more detail). This is to take GRC into account, i.e. the practical limit on the rate of change in the generating power of each GENCO. The proposed GAHF controller is applied for each control area of the restructured power system as shown in Fig. 1. Simulations are carried out for two cases of operating conditions under large load demands and area load disturbances in comparison with the robust mixed H_2/H_∞ controller (see Ref. [5] for more detail) to illustrate robustness of the proposed control strategy against parametric uncertainties.

Case 1: *Bilateral Based Transactions*

In this case, DISCOs have the freedom to have a contract with any GENCO in their and other areas. Consider the all the DISCOs contract with the available GENCOs for power as follows AGPM:

$$AGPM^T = \begin{bmatrix} 0.25 & 0.5 & 0 & 0.25 & 0 & 0 \\ 0.25 & 0 & 0.25 & 0.25 & 0.25 & 0 \\ 0 & 0 & 0.75 & 0 & 0 & 0.25 \end{bmatrix}$$

It is assumed that each DISCO demands 0.1 puMw power from GENCOs. Power system responses with 25% increase in system parameters are shown in Fig. 6. Using the proposed method, the frequency deviation of the all areas are quickly driven back to zero and has small settling time. Also the tie-line power flow properly converges to the specified value, of Eq. (4), in the steady state case (Fig. 6), i.e.; $\Delta P_{tie21,sch}=0$ and $\Delta P_{tie23},sch=-0.05\,pu$.

Case 2: *Random disturbance load patterns*

Consider case 2 again. Assume, in addition to the specified contracted load demands 0.1 *pu MW*, a bounded random step load change as a large uncontracted demand as shown in Fig. 7 appears in each control area, where: $-0.05<\Delta P_{di}<+0.05$ *pu.* The propose of this scenario is to test the robustness of the proposed controller against uncertainties and random large load disturbances. The power system responses in this case with 25% decrease in system parameters are shown in Figs. 8 and 9. The simulation results demonstrate that the proposed control strategy track the load fluctuations and meet robustness for a wide range of load disturbances and possible contract scenarios under plant parameter changes.

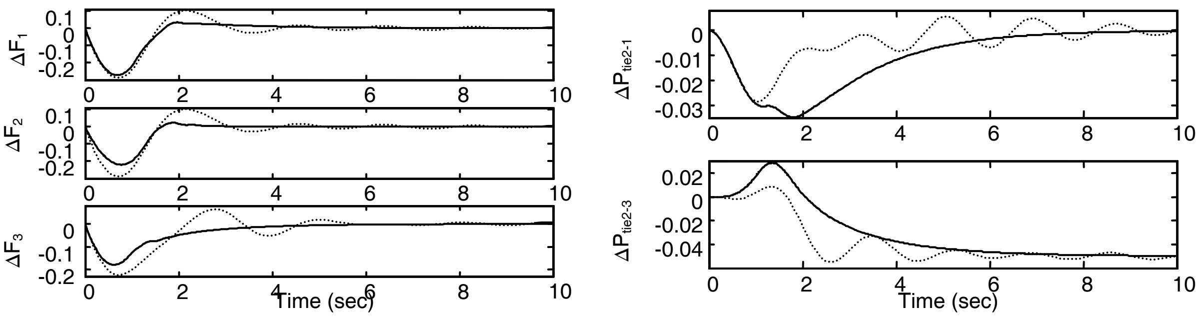

Fig. 6. Deviation of frequency and tile lines power flows; Solid (GAHF), Dotted (Mixed H_2/H_∞).

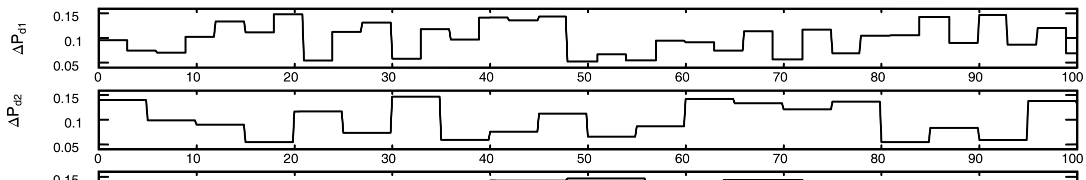

Fig. 7. Random disturbance load patterns in areas 1, 2 and 3.

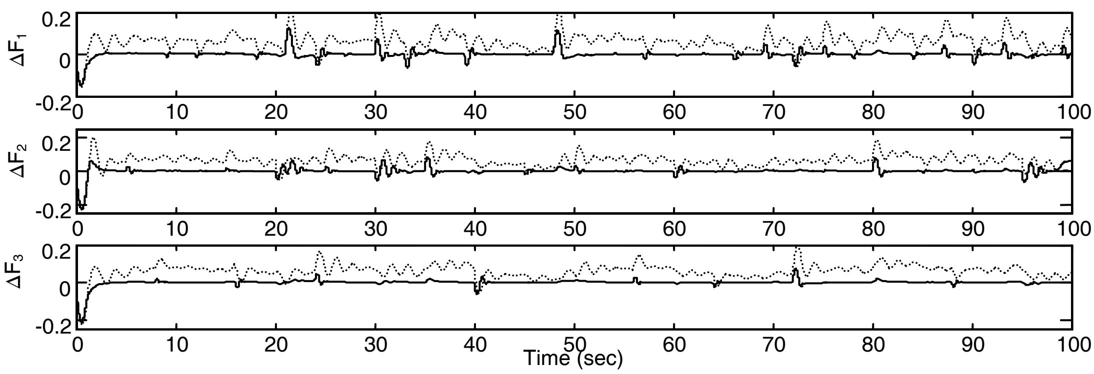

Fig. 8. Deviation of frequency; Solid (GAHF), Dotted (Mixed H_2/H_∞).1

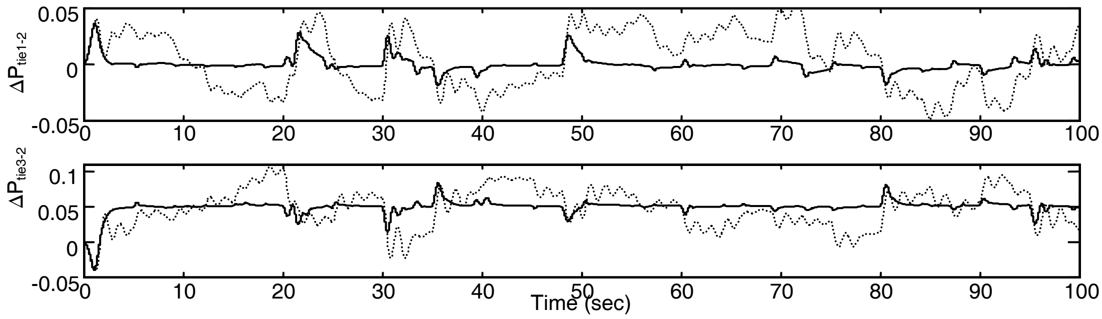

Fig. 9. Deviation of tie lines power flows; Solid (GAHF), Dotted (Mixed H_2/H_∞).

To demonstrate performance robustness of the proposed method, the ITAE and Figure of Demerit (FD) based on the system performance characteristics are being used as:

$$ITAE = \int_0^{10} t\ (|ACE_1(t)| + |ACE_2(t)| + |ACE_3(t)|)dt \quad (9)$$

$$FD = (OS \times 100)^2 + (US \times 40)^2 + (Ts \times 3)^2 \quad (10)$$

Where, Overshoot (OS) Undershoot (US) and settling time of frequency deviation area 1 is considered for evaluation of the FD. Numerical results of performance robustness for case 1 are listed in Tables 4, whereas the system parameters are varied from -25% to 25% of the nominal values. It can be seen that the proposed control strategy achieve good robust performance.

Table 4. Performance indices of ITAE and FD

Test No.	Parameter Changes (%)	ITAE		FD	
		GAHF	Mixed	GAHF	Mixed
0	Nominal	14.9	76.5	45.7	117.3
1	-5	14.8	71.0	49.3	121.7
2	+5	15	81.9	42.4	113.8
3	-10	14.7	67.3	53.6	126.1
4	+10	15.1	85.9	39.6	112.0
5	-15	14.8	63.4	58.8	137.5
6	+15	15.3	89.7	37.1	109.8
7	-20	14.8	63.5	65.1	143.1
8	+20	15.6	94.4	34.8	113.0
9	-25	14.9	68.9	72.7	178.3
10	+25	16.0	101.4	32.9	112.0

5 Conclusion

In this paper, A new Hybrid Fuzzy PID type controller based on GAs is proposed for solution of the Load frequency Control (LFC) problem in a deregulated power system. In order for a fuzzy rule based control system to perform well, the fuzzy sets must be carefully designed. A major problem plaguing the effective use of rule based fuzzy control system is the difficulty of accurately constructing the membership functions. Because it is a computationally expensive combinatorial optimization problem. For this reason, a modified GA based on the hill climbing method is being used to optimal tune of membership functions automatically to reduce fuzzy system effort and cost. The proposed control strategy combines advantage of fuzzy PD and integral controllers with a fuzzy switch and leads to a flexible controller with simple structure which requires fewer resources to operate and its role in the system response is more apparent. Thus its construction and implementation are fairly easy, which can be useful in real world deregulated power system. The effectiveness of the proposed method has been tested on a three-area power system in comparison with the robust mixed H_2/H_∞ controller under different operating condiions. The simulation results show that it is effective and gives good robust performance against parametric uncertainties and load disturbances even in the presence of GRC.

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