Applied Mathematics & Information Sciences
An International Journal

http://dx.doi.org/10.18576/amis/110217

Automatic Generation Control in Deregulated Power System Using Genetic Algorithm Optimized Fuzzy Controller

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Received: 8 Dec. 2016, Revised: 21 Jan. 2017, Accepted: 23 Jan. 2017
Published online: 1 Mar. 2017

Abstract: This work addresses the control of load frequency where the chosen arena is the two area thermal-thermal power systems dealt under deregulated field. Tuning of the fuzzy logic controller is based on genetic algorithm. Graded AC tie-lines are used to relate the regions. Optimization of the scaling gains of the controller is the prime thing in bringing ideal tuning. The controller adopted in this paper has gone through several operating conditions under the field of deregulated two area system. The influence of bilateral accordance between the distribution and generation companies is the part of this work that is simulated via Simulink/MATLAB. Thus, in comparison with performance, the genetic algorithm tuned fuzzy logic controller is better than the existing integral controller or the non-tuned fuzzy logic controller.

Keywords: load frequency control, optimization, deregulated power system, genetic algorithm, fuzzy logic controller

1 Introduction

The mechanism of industrial growth lies in electrical energy and the machines that take up power for their functioning are expected to be operated at standard frequencies. To compensate the electric energy requirement, adequate and dependable power is therefore needed to be provided with remarkable attributes. [2] Frequency control is inevitable as deviation in it results in unstable power system. In order to develop reliable and cheaper systems in terms of power generation and transmission, such devices can be interconnected. At present, Vertically Integrated Utilities (VIU) performs power generation and transmission. In case of systems that are interconnected, use of controllers aids in control of power generation with respect to demand fluctuations. [1] Additionally, frequency is limited from crossing the fixed point. The objective of load frequency control is to stabilize the power circulation and frequency by regulating the output [4,10]. By setting proper settling period and overshoot, it is certain with the results of getting zero steady state error frequency [4]. [5] confronted that the problems and solutions affect the deregulated devices. [6,7,14] Power generation, distribution and transmission companies come under deregulated systems. A deregulated system consists of number of generation and distribution companies, where power flow is done by connecting these two and such bilateral transmission is favored by independent system operator. It monitors and controls the generated power of the deregulated system.

In [10] the traditional working principles of the power system were reviewed. LFC that functions with the help of an ideal feedback controller along with multi-source power generation was discussed in [11]. In [1,5]AGC and load controllers for the sake of LFC were considered that normally works under deregulated field, where the generation companies compete with the individuals in power trading. [4] dealt with LFC that is linked to interline power flow and redox flow batteries, where Bacterial Foraging Optimization algorithm is utilized to improve the controller gain. In [7] optimization of biasing parameters was carried out by Gradient Newton algorithm

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where AGC problems were also analyzed. The authors of [6] developed a three area power system configuration, GA (Genetic algorithm) and automatic generation control were used to optimize the integral gains and bias variable soon after deregulation. In [12] complications relating to LFC and the control strategies that could be assessed by means of conventional techniques were investigated in which robust control mechanisms along with adaptive and variable structural procedures were analyzed. These schemes were intended for Automatic Generation Control (AGC) in context with restructured power structure.

In accordance with the traditional power generation process, identical utility is in the charge for transmission and distribution. In contrast to this, utility that is vertically integrated do not have a part in the system where a 3-non-identical units do the role of power generation, transmission and distribution. Cost reduction to the customers is the reason behind restructuring of power system. [9] To compare the performance of conventional GA and GA-simulated annealing on the basis of load frequency control and to produce minimal area inputs, GA-SA method was formulated. [6,11] Distribution companies are free to get power from generation companies since it can be obtained at affordable prices being in the restructured systems. [5] Generation companies are ought to be controlled by distribution companies in their same or different network. Variable grouping of generation and distribution company agreements are common by this mode of connection, where the autonomous operating system usually clears their transactions. [7] To identify the contract that occur between these two companies, DPM (Distribution Companies Participation Matrix) was developed, where this matrix was composed of equal row and column, and the values were given in the ratio of demand load by the distribution company to the generation company. The ratio of generation companies demand to generation unit is referred diagonally. In converse, the generation company demand to generation one is denoted by off diagonal characters. In case if the power demand exceeds from the contraction, additional supply is provided by generation network of that area.

From these referred articles it is understood that almost all of them are confined to optimization techniques that optimize in terms of controller gains under deregulated area. It is also essential to mark that all the terms: networks, systems and companies in case of generation and distribution services stand for same meaning. As stated, the existing controllers such as Integral, Proportional Integral (PI) and Proportional Integral Derivative (PID), though reliable, they do not meet the specifications relating to non-linear complexities. The operating point varies with respect to load variation as the load in the power system keeps on changing. It is also validated that the results of modeled FLC outperforms the traditional controllers. Tuning of membership functions(MF) is important as without tuning, the effectiveness of the proposed controller would be diminished. Hence, the controller is designed in which the scaling gains of membership criteria are tuned based on genetic algorithm. Analysis is made on the view point of thermal-thermal 2-region system where it includes load frequency control and the experimentation is classified under deregulated area. The results of the fuzzy logic controller (FLC) that are tuned on the basis of genetic algorithm are confirmed over a 2-area restructured configuration and hence the developed FLC has been assessed using integral and non tuned fuzzy logic controller.

Nomenclature

F	Nominal System frequency (Hz)
H_i	Inertia constant
Δf	Area frequency error (Hz)
ACE	Area control error
cpf, apf	contract, area participation factor
DPM	Distribution Companies Participation Matrix
K_{pi}	Gain of power system (Hz/p.u.MW)
B_i	Damping coefficient (p.u MW/Hz)
T_{12}	Synchronizing coefficient
T_{ti}	Time constant of turbine
T_{gi}	governing mechanism
T_{pi}	generator (sec)
ΔP_{Gi}	Incremental generation
ΔP_{Di}	change in area i (p.u MW)
K_{pi}	$1/B_i$
T_{pi}	$2H_i/(B_i * f)$
K_i	Gain of integral controller
R	Regulation of governor (Hz/p.u.MW)

2 System investigated

The system that is incorporated in this project consists of two areas where tie lines are used to interconnect them. These areas include two generation and distribution companies each as shown in Fig. 1. Thus the two-area deregulated system with $DISCO_1$ and $DISCO_2$, (Distribution companies) $GENCO_1$, $GENCO_2$ (Generation companies) of area 1 and $GENCO_3$, $GENCO_4$, $DISCO_3$ and $DISCO_4$ of area 2 are structured. The generation companies include non-reheat thermal generators that are of fixed range and capacity. [1] By rebuilding the power system, generation networks supply powerto number of distribution systems at reasonable prices. Eventually the distribution network frames agreement with generation systems within its area or outside of it. [6] The system responsible for contract clearance between these two companies is the independent system operator. [5]proposed the term Distribution company Participation Matrix (DPM) to detect the contracts of distribution companies. Here, the number of generation systems is denoted in place of rows and distribution system by columns. [4,5] In the DPM

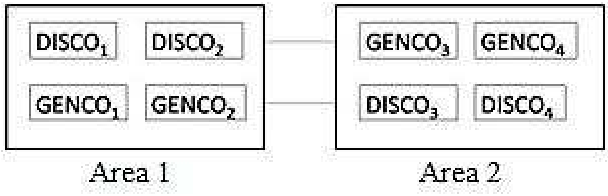

Fig. 1: Design of proposed deregulated power system

matrix given below, cpf_{ij} refers to the power that is signed as agreement between distribution $(DISCO_i)$ and generation $(GENCO_j)$ network and the matrix is related to,

$$DPM = \begin{bmatrix} cpf_{11} & cpf_{12} & cpf_{13} & cpf_{14} \\ cpf_{21} & cpf_{22} & cpf_{23} & cpf_{24} \\ cpf_{31} & cpf_{32} & cpf_{33} & cpf_{34} \\ cpf_{41} & cpf_{42} & cpf_{43} & cpf_{44} \end{bmatrix}$$

In the above matrix, all the values in the column results in unity by addition. Interconnected system error occurs as a result of variation of actual power from the scheduled power generation which is named to be area control error. This is represented by the equation (1) as,

$$ACE = \Delta P_{tie,i} + b_i \Delta f_i \tag{1}$$

where $\Delta P_{tie,i}$, i denotes to the tie-line power change, b_i refers to the frequency bias constant and Δf_i is the frequency deviation.

Occurrence of error is common for deregulated networks due to the fluctuation of load [13]. The total number of generation systems is two in the allotted area, along with these two, ACE signal is also a part in them. The entire generation companies share ACE which is related to coefficients termed to be APF (ACE Participation Factors) and its corresponding matrix is given below, where the totality of the diagonal elements relates to unity.

$$apf_{matrix} = \begin{bmatrix} apf_1 & 0 & 0 & 0 \\ 0 & apf_2 & 0 & 0 \\ 0 & 0 & apf_3 & 0 \\ 0 & 0 & 0 & apf_4 \end{bmatrix}$$

The distribution networks that contract power in area 1 and 2 are termed to be $(\Delta P_{L1-cont}$ and $\Delta P_{L2-cont})$ and $(\Delta P_{L3-cont}$ and $\Delta P_{L4-cont})$ respectively.

$$\Delta P_{L-cont} = \begin{bmatrix} \Delta P_{L1-cont} \\ \Delta P_{L2-cont} \\ \Delta P_{L3-cont} \\ \Delta P_{L4-cont} \end{bmatrix}$$

Similarly, power without contract basis is represented by,

$$\Delta P_{L-uncont} = \begin{bmatrix} \Delta P_{L1-uncont} \\ \Delta P_{L2-uncont} \\ \Delta P_{L3-uncont} \\ \Delta P_{L4-uncont} \end{bmatrix}$$

Hence, in the deregulated area, the demand of total power is given by,

$$\Delta P_L = \Delta P_{L-cont} + \Delta P_{L-uncont} \tag{2}$$

ΔP_{G-cont} matrix denotes the contracted powers from the generation systems/companies from both the area.

$$\Delta P_{G-cont} = \begin{bmatrix} \Delta P_{G1-cont} \\ \Delta P_{G2-cont} \\ \Delta P_{G3-cont} \\ \Delta P_{G4-cont} \end{bmatrix}$$

By equation (3) the power generated from the two area power system in accordance with the present contract is determined.

$$\Delta P_{G-cont} = DPM * \Delta P_{L-cont} \tag{3}$$

Likewise apf_{matrix} and the power demand in the absence of contraction give rise to power generation without contract. The relation in terms of this scenario is referred in equation (4),

$$\Delta P_{G-uncont} = apf_{matrix} * \Delta P_{L-uncont} \tag{4}$$

Thus, the total power that results in zero frequency error is the totality of contracted and uncontracted power,

$$\Delta P_G = \Delta P_{G-cont} + \Delta P_{G-uncont} \tag{5}$$

Equation (6) refers to the scheduled steady state power flow over the tie-lines in area i and j.

$$\Delta P_{tieij} = \Sigma_{p,q=1}^{P,Q} \left(cpf_{PQ} * \Delta P_{L(q)-cont}\right) \tag{6}$$

Let p be the p_{th} GENCO of area A_i, q, the q_{th} DISCO of area A_j, P and Q refers to the number of generation and distribution systems of area A_i and A_j respectively. Let P and Q equal 2 in the developed project. Equations (7),(8) and (9) relates to the tie-line power flow processed between the two areas.

$$\Delta P_{tie12,sch} = \Delta P_{tie12} - \Delta P_{tie21} \tag{7}$$

$$\Delta P_{tie12} = cpf_{13} * \Delta P_{L3-cont} + cpf_{23} * \Delta P_{L3-cont} + cpf_{14} * \Delta P_{L4-cont} + cpf_{24} * \Delta P_{L4-cont} \tag{8}$$

$$\Delta P_{tie21} = cpf_{31} * \Delta P_{L1-cont} + cpf_{41} * \Delta P_{L1-cont} + cpf_{32} * \Delta P_{L2-cont} + cpf_{42} * \Delta P_{L2-cont} \tag{9}$$

The proposed system is given in Fig. 2.

3 Controller design

3.1 Conventional controller

In the deregulated two area power system, the integral controller is used as the controller, where this is also

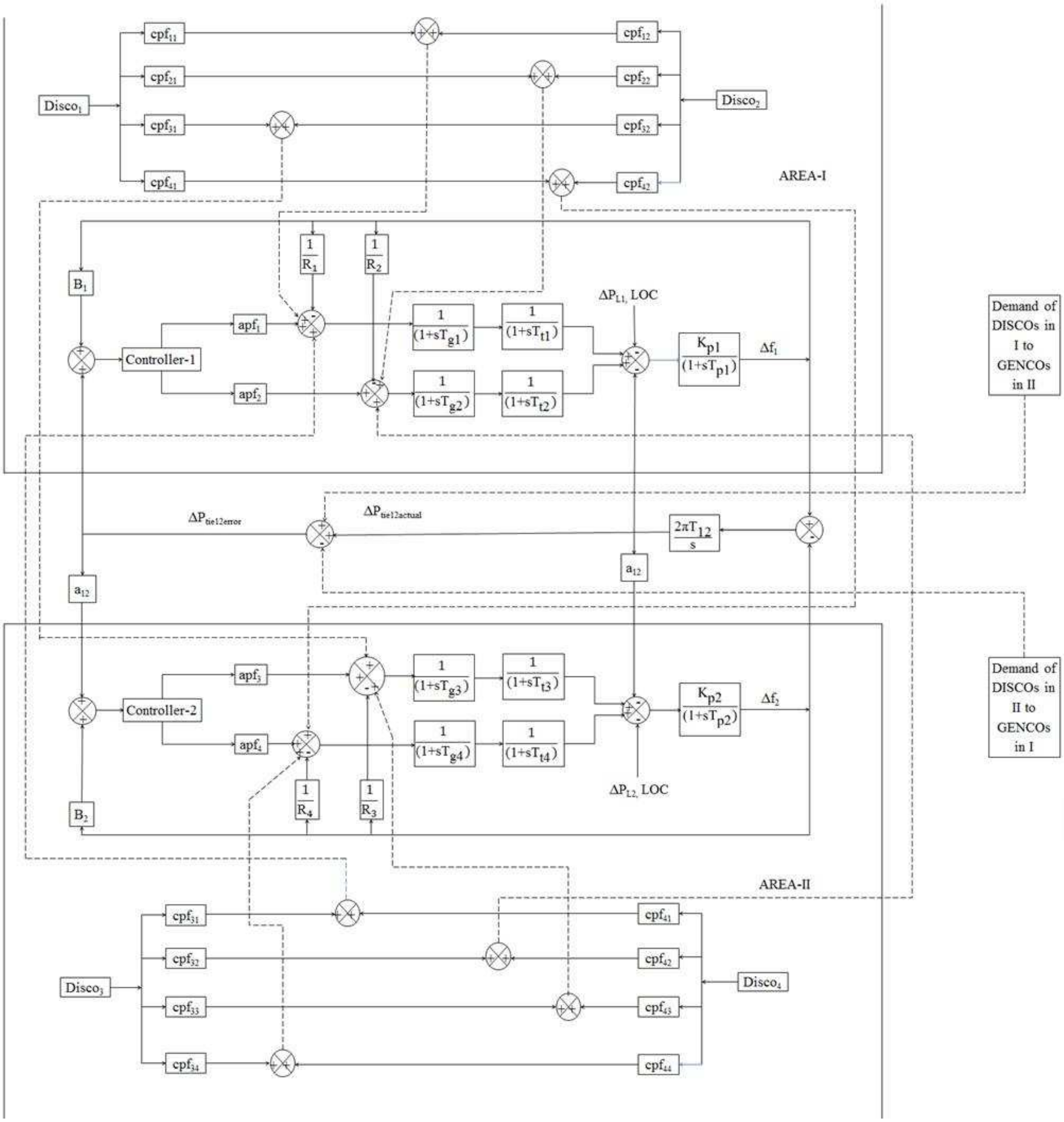

Fig. 2: Representation of the two area deregulated power system

employed in examining the result performance. ACE_i is the input and u_i is the response obtained. It can be denoted as,

$$u_i = -\int K_i(ACE_i)dt = -\int K_i(\Delta P_{tie,i} + b_i\Delta f_i)dt \quad (10)$$

where K_i is the gain of integral Controller and Ziegler Nichols method is ulilised for finding the value of K_i

3.2 GA optimized FLC scheme

[2] Non-linear and indefinite models make use of FLC as control technique. Fuzzy logic is similar to ordinary language and is simpler than the conventional approaches. Though complex, they do not result in better performance, but certain linear models do end up in good results. Hence, FLC is employed as this suit more the

Table 1: Rule based FLC

ACE / $\int$ACE	NB	NM	NS	ZE	PS	PM	PB
NB	PB	PB	PM	PM	PS	ZE	ZE
NM	PB	PB	PM	PM	PS	ZE	ZE
NS	PB	PB	PM	PS	ZE	NM	NM
ZE	PB	PB	PM	ZE	NM	NB	NM
PS	PM	PM	ZE	NS	NM	NB	NB
PM	ZE	ZE	NS	NM	NM	NB	NB
PB	ZE	ZE	NS	NM	NM	NB	NB

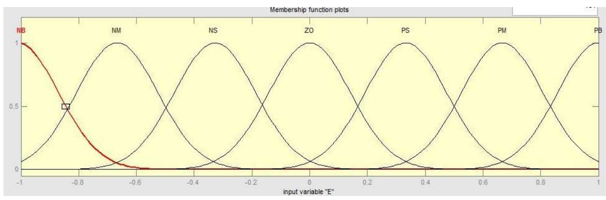

Fig. 3a: Member function for ACE_i

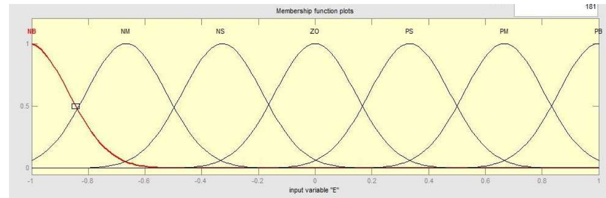

Fig. 3b: Member function for $\int ACE_i$

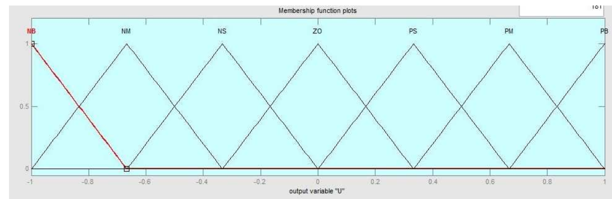

Fig. 3c: Output member function

nonlinear forms also. [3]Fuzzification and defuzzification are the main process in FLC apart from fuzzy inference that comes in the middle, where if-then rules are developed from the history. During defuzzification, real data as in the case of fuzzification is obtained from inference parameter.

A Multiple-Input-Single-Output fuzzy logic controller consisting of two inputs and a single output is developed in this work. The two inputs are denoted as ACEi and $\int ACE_i$ and the output is in controlled format. Since tuning a fuzzy controller by means of scaling factor is tedious, genetic algorithm is adopted in tuning the scaling parameters, where the inference system and the included membership values add up-to seven levels.

In the aim of getting better results, seven variables are used for all the inputs and for identification of these input values, Gaussian membership relation is employed and triangular membership function is used for output variable and as a result of this a total of 49 rules are obtained from the given seven levels. A type of Mamdani rules is incorporated and the rule based inputs are denoted in Table 1.

The controller member functions are represented in Fig. 3.

The given member functions are,
NB: Negative Big
NM: Negative Medium
NS: Negative Small
ZE: Zero
PS: Positive Small
PM: Positive Medium
PB: Positive Big

The scaling factors of the controller are optimally varied to tune the member function of the Mamdani-type controller. Generally in solving non-linear optimization complexities, genetic algorithms are put into practice where this performs the function in short time period which is also highly accurate. It is performed on the basis of natural selection criteria and the concept behind this is that it alters each solution occasionally. The integral square error (ISE) criterion is used as objective function to optimize the parameters of proposed controller and is given in equation (11).

$$F = \int_0^t (\Delta f_1^2 + \Delta f_2^2 + \Delta P_{tie}^2) dt \qquad (11)$$

Where Δf_1 and Δf_2 = Frequency deviation in area-1 and area-2 $\Delta P_t ie$ = Incremental change in tie-line power t = time range of simulation

[6,8] A random selection of individuals from the present group is executed in each step, where these individuals can be trained up for the development of future offspring. On completion of each generation, the population get evolved to the ideal solution. Following are the steps that describe the working principle of GA.
1. Initially, a population is developed in a random manner.
2. A set of new group is initialized by the present generation individuals according to the following steps.

a. Current population members are valued in terms of fitness value.

b. Then the obtained values are turned to usable range parameters using scaling method.

c. Group members are chosen as parents on the basis of the fitness value.

d. The members with low fitness values are referred to be elite members where they are fed to the successive population.

e. Offsprings are generated through mutation (randomly modifying any one of the parents) or crossover

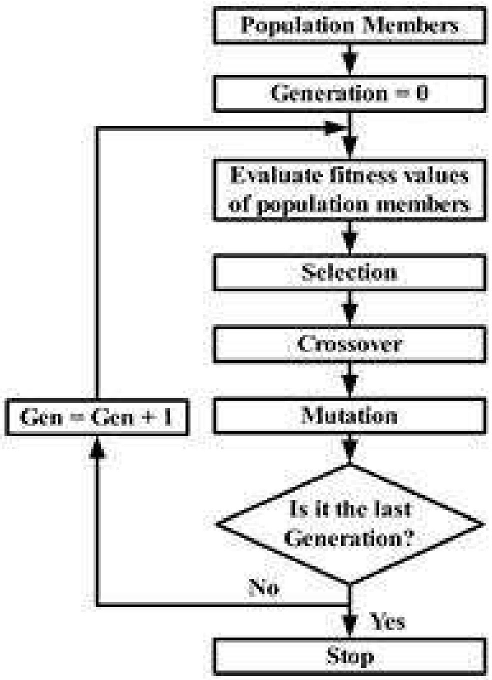

Fig. 4: Flowchart of genetic algorithm technique

(combination of vector entries of both the parents) means.
3. At last, offspring replace the present group, so that the next generation is thus developed.
4. After reaching any stopping factor, algorithm gets halted.

The flowchart of the proposed genetic algorithm is shown in Fig. 4.

4 Simulation studies and performance evaluation

As mentioned, the overall assessment is formulated by the consideration of two generation and distribution systems in two area thermal power systems where their modeling is based on Simulink and fuzzy toolbox that are developed to be run under MATLAB entity. This framework is developed to determine step load disturbances. The controllers used in this set up are proportional integral and fuzzy logic controllers (i.e.one of them is tuned by genetic algorithm and another one without any tuning procedures). Table 2 consists of system parameters and their values [9].

DPM and apf_{matrix} are varied and are represented by three cases.

4.1 Case 1

If the distribution systems of area 1 demand power from the generation networks, these networks share power in equal amount using AGC. In this regard, the apf_{matrix} elements are 0.5 each. Considering the load fluctuation of area 1, the loads as per demand are given as 0.1 p.u. MW. The corresponding matrices are related by,

$$apf_{matrix} = \begin{bmatrix} 0.5 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0.5 \end{bmatrix}$$

$$DPM = \begin{bmatrix} 0.5 & 0.5 & 0 & 0 \\ 0.5 & 0.5 & 0 & 0 \\ 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & 0 \end{bmatrix}$$

The value of column 3 and 4 in DP matrix and their corresponding cpfs (contract participation factors) are zero since there is no contraction with generation networks by the third and fourth distribution systems. Therefore, the demand of the first and second distribution systems is also equal.

Fig. 5 describes the tie line power and its deviated frequency. It is the fact that frequency deviates more in area 1 due to its load instability. The steady state power flow remains null as there is no power contraction between certain areas. To maintain stability, there should not be any deviation between generation and power demand where these must be kept balanced.

Power production by the generation network is denoted as the summation of power demand by distribution services and cpfs which can be related by,

$$\Delta P_{Mi} = \Sigma_j cpf_{ij} \Delta P_{Lj} \quad (12)$$

Let ΔP_{Lj} be the total demand of $DISCO_j$ and cpfs are considered as given by the DP Matrix. When the same factors in two area-deregulated LFC system is considered, then,

$$\Delta P_{Mi} = cpf_{i1}\Delta P_{L1} + cpf_{i2}\Delta P_{L2} + cpf_{i3}\Delta P_{L3} + cpf_{i4}\Delta P_{L4} \quad (13)$$

4.2 Case 2

In case 2, agreement of power supply in between both the generated and distributed systems is considered. Generation networks of the area are concerned with that of automatic generation controller and all the apf_{matrix} elements are 0.5. The variation of load is also to be

Table 2: System parameters

System parameters	Values Inertia constant
Governor Time constant of thermal area, (Tg1=Tg2)	0.08
Governor Gain Constant, (Kg1 = Kg2)	1
Frequency bias constants, (b1=b2)	0.425
Governor Speed regulation parameter, (R1=R2)	2.43 Hz/p.u.MW
Synchronizing coefficient, (T12)	0.0707 p.u.Mw/rad
Inertia Constant, (H1 = H2)	5
Turbine time constant, (Tt1=Tt2)	0.3 s
Turbine Gain Constant, (Kt1 = Kt2)	1
Power system time constant, (Tp1=Tp2)	20 s
Power system Gains, (Kp1=Kp2)	120

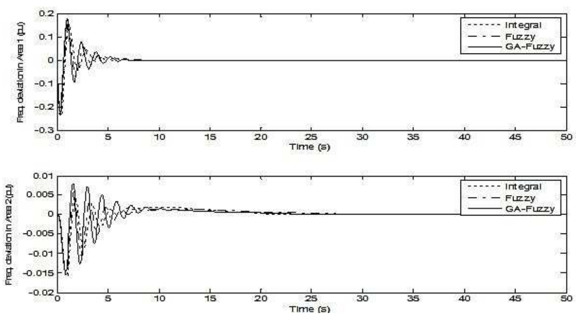

Fig. 5a: Frequency deviation in area 1 and area 2 technique

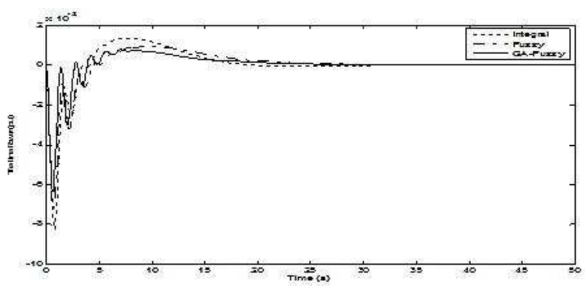

Fig. 5b: Deviation :Tie line power error
Fig. 5: Frequency and tie-line power deviations

measured for both the areas, where the demand load is 0.01 pu MW. Hence the apf and DP Matrices for case 2 can be defined as,

$$apf_{matrix} = \begin{bmatrix} 0.5 & 0 & 0 & 0 \\ 0 & 0.5 & 0 & 0 \\ 0 & 0 & 0.5 & 0 \\ 0 & 0 & 0 & 0.5 \end{bmatrix}$$

$$DPM = \begin{bmatrix} 0.4 & 0.35 & 0 & 0.15 \\ 0.4 & 0.35 & 0 & 0.7 \\ 0.1 & 0 & 1 & 0.15 \\ 0.1 & 0.15 & 0 & 0 \end{bmatrix}$$

Tie line power is given by,

$$\Delta P_{tie1-2,scheduled} = \Sigma_{i=1}^{2}\Sigma_{j=3}^{4} cpf_{ij}\Delta P_{Lj} - \Sigma_{i=3}^{4}\Sigma_{j=1}^{2} cpf_{ij}\Delta P_{Lj} \tag{14}$$

$$\Delta P_{tie1-2,scheduled} = (cpf_{13}\Delta P_{L3} + cpf_{14}\Delta P_{L2} + cpf_{23}\Delta P_{L3} + cpf_{24}\Delta P_{L4}) - (cpf_{31}\Delta P_{L1} + cpf_{32}\Delta P_{L2} + cpf_{42}\Delta P_{L2})$$

$$\Delta P_{tie1-2,scheduled} = ((0*0.1)+(0.15*0.1)+(0*0.1)+(0.7*0.1)) ((0.1*0.1)+(0*0.1)+(0.1*0.1)+(0.15*0.1)) = 0.05puMW$$

The demand of power by distribution networks is equal. Fig. 6 represents the frequency deviation with respect to the tie line power, when the step load gets altered in the respective areas. Other strategies are similar to that of case 1. The total power that should be produced from the generation system is referred as the addition of power demand and cpfs. This is related in equation (12).

4.3 Case 3

The power demand exceeds from the contract signed and hence this is termed to be violation of law. Though demand rises, it is compensated by the generation systems of the same area. The actual and the additional demand are given by 0.1 p.u MW and 0.1 pu MW accordingly.

Local load total in area 1,

$$\Delta P_{L1,LOC} = DISCO_1Load + DISCO_2Load$$

$$= (0.1+0.1)+0.1$$

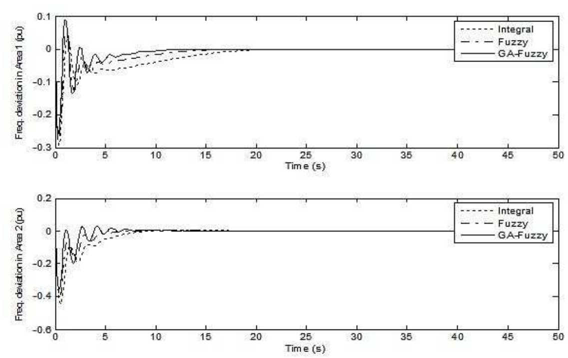

Fig. 6a: Frequency deviation in area 1 and 2 technique

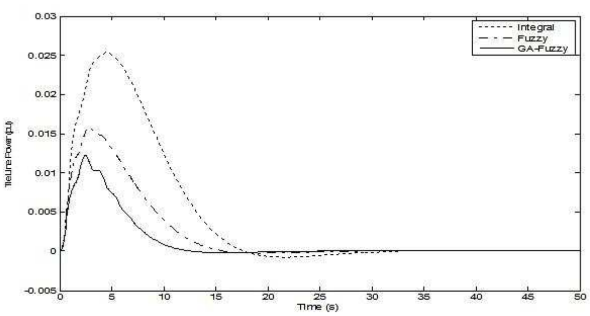

Fig. 6b: Deviation :Tie line power error
Fig. 6: Deviations in frequency and tie-line power

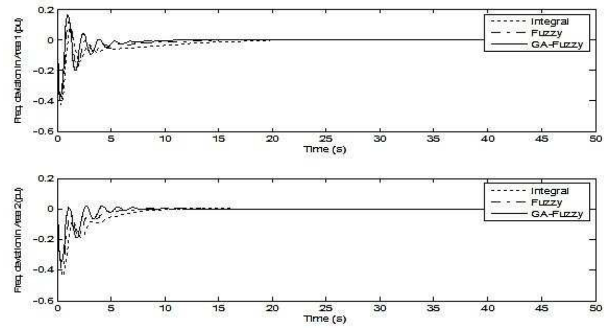

Fig. 7a: Frequency deviation in area 1 and 2 technique

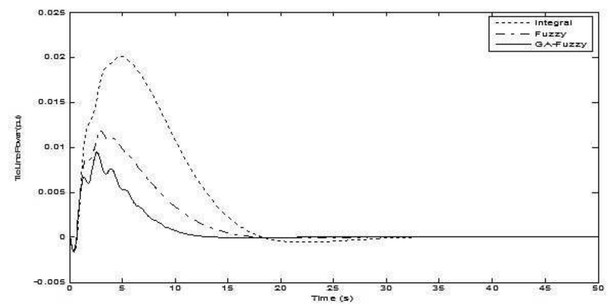

Fig. 7b: Deviation :Tie line power error
Fig. 7: Deviations in frequency and tie-line power

$$= 0.3puMW$$

Local load total in area 2,

$$\Delta P_{L2,LOC} = DISCO_3Load + DISCO_4Load$$
$$= 0.1 + 0.1$$
$$= 0.2puMW$$

There is no error in frequency at steady state. In the second case considered, the tie line power is equal. The excess demand of power by distribution sector of area 1is related only to power generation made by generation companies. It is validated that when the state is stabilized, compensation of extra load is dealt by the ACE participation factors. These results and the performance factors of all the controllers are indicated in Fig. 7.

5 Conclusion

An intelligent controller has been tuned by employing genetic algorithm where the procedures are conducted in deregulated platform and the chosen field is two-area thermal-thermal power system. The validation of the developed system has gone through a list of market schemes including unilateral, bilateral and contract violation and proved to be compatible in all sectors. Evaluation in terms of peak under/over shoot and settling time is regarded to prove controllers performance and efficiency. Results of Integral ,non tuned Fuzzy Logic Controller and the GA-tuned FLC are compared and discussions are made on how the proposed system outperforms the existing/traditional approaches. The developed GA-tuned FLC suits for the control of load frequency under deregulated area.

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