# Frequency stabilization using fuzzy logic based controller for multi-area power system

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**ABSTRACT**
*In this paper, a fuzzy logic controller is proposed for load frequency control problem of electrical power system. The fuzzy controller is constructed as a set of control rules and the control signal is directly deduced from the knowledge base and the fuzzy inference. The study has been designed for a two area interconnected power system. A comparison among a conventional proportional integral (PI) controller, some other fuzzy gain scheduling controllers and the proposed fuzzy controller is presented and it has been shown that proposed controller can generate the best dynamic response following a step load change. Robustness of proposed controller is achieved by analyzing the system response with varying system parameters.*
**Keywords:** *Two area power system, load frequency control, fuzzy logic controller, gain scheduling.*

## 1 INTRODUCTION

The large-scale power systems are normally divided into control areas based on the principle of coherency. The coherent areas are interconnected through tie lines, which are used for contractual energy exchange between areas and provide inter-area support during abnormal operations. Automatic generation control (AGC)/ load frequency control (LFC) determines the active power such that overall system generation meets the system load. Further it controls the frequency and the tie-line flows between different power system areas. Many investigations in the area of LFC/AGC of interconnected power system have been reported in the past (Fosha and Elgead 1970; Saadat 2002; Nagrath and Kothari 1994; Elgerd 1982; Kundur 1994 ). Several control strategies, such as classical control, optimal control, suboptimal control, adaptive control, variable structure control etc. have been employed in the past to explore an optimum controller for LFC. Because of the inherent characteristics of changing loads, the operating point of a power system may change significantly during a daily cycle. Thus fixed gain controllers designed at nominal operation point may fail to provide best control performance over a wide range of operating conditions. Adaptive controllers with self-adjusting gain settings have been proposed. Despite the promising results achieved by the adaptive controllers the control adjustments are complicated and require online system model identification. Centralized information structure and knowledge of all system parameters are technically difficult and economically unjustifiable. Conventional controllers are very difficult to implement due to following reasons.

(i) The optimal control is a function of all the states of the system. In practice all the states may not be available. The inaccessible states or missing states are required to be estimated.
(ii) It may not be economical to transfer all the information over long distances.
(iii) The control, which is a function of the states in turn, is dependent on the load demand. Accurate prediction of load demand may be essential for realizing optimal controller.

(iv) The optimal control is also dependent on the weighing matrices and is not unique (Nanda and Kaul 1978; Indulkar and Raj 1995; Ha 1998; Chown and Hartman 1998; Talaq and Fadel 1999; Mathur and Ghosh 2006).

The concept of fuzzy set theory was introduced by Zadeh in 1965 (Zadeh 1965) and it was first introduced in 1979 for solving power system problems. Fuzzy set theory can be considered as a generalization of the classical set theory. In classical set theory an element of the universe either belongs to or does not belong to the set. Thus the degree of association of an element is crisp. In a fuzzy set theory the association of an element can be continuously varying. Mathematically, a fuzzy set is a mapping (known as membership function) from the universe of discourse to the closed interval {0,1}. The membership function is usually designed by taking into consideration the requirement and constraints of the problem. Fuzzy logic implements human experiences and preferences via membership functions and fuzzy rules. Due to the use of fuzzy variables, the system can be made understandable to a non-expert operator. In this way, fuzzy logic can be used as a general methodology to incorporate knowledge, heuristics or theory into controllers and decision makers.

Analytical solution methods exist for power system problems. However, the mathematical formulations of power systems problems are derived under certain restrictive assumptions and even with these assumptions, the solution of large-scale power system problems is not simple. On the other hand, there are many uncertainties in power system problems, because power systems are large, complex, geographically widely distributed, and influenced by unexpected events. These facts make it

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difficult to effectively deal with many power systems problems through strict mathematical formulations alone. Therefore, fuzzy set theory based approach, in recent years has emerged as a complement tool to mathematical approaches for solving power system problems (Bansal 2003; Song and Johns 1998, 1999; Momoh, Ma and Tomsovic 1995) Advantages of fuzzy set theory over conventional methods are as follows:

(i) It is based on natural language and is conceptually easy to understand.
(ii) It resolves conflicting objectives by designing weights appropriate to the selected objectives.
(iii) It is tolerant of imprecise data and provides capability for handling ambiguity expressed in diagnostic processes, which involves systems and causes.
(iv) It develops process control as a fuzzy relation between information about the conditions of the process to be controlled.

In recent times, few fuzzy gain scheduling of proportional integral (PI) controllers have been proposed to solve these problems. Chang and Fu (Chang and Fu 1997), and Cam and Kocaarslan (Çam and Kocaarslan 2005) used such methods for load frequency control in power systems. Both of them developed some fuzzy rules for proportional and integral gains separately. In this paper, the rules for the gains are chosen identical. Therefore, the system performance is improved. The comparison among the proposed controller, a conventional PI controller and some other fuzzy controllers shows that the two important dynamic parameters i.e. overshoots and settling time with the proposed controller are better than those of the studies carried out in (Çam and Kocaarslan 2005; Chang and Fu 1997) and conventional PI controllers.

## 2 TWO AREA POWER SYSTEM

Power systems have complex and multi-variable structures. Also they consist of many different controls blocks. Most of them are non-linear and /or non-minimum phase systems. Power systems are divided into control areas connected by tie lines. All generators are supposed to constitute a coherent group in each control area. In the interconnected power systems, it is seen that each area needs its system frequency and tie line power flow to be controlled. Frequency control is accomplished by two different control actions in interconnected two-area power system: primary speed control and supplementary or secondary speed control actions. The primary speed control makes the initial coarse readjustment of the frequency. By its actions, the various generators in the control area track a load variation and share it in proportion to their capacities. The speed of the response is limited only by the natural time lags of the turbine and the system itself. Depending upon the turbine type the primary control loop typically responds within 2-20 seconds. The secondary loop takes over the fine adjustment of frequency by resetting the frequency error to zero through integral action. The relationship between the speed and load can be adjusted by changing a load reference set point input. In practice, the adjustment of the load reference set point is accomplished by operating the speed changer motor. The output of each unit at a given system frequency can be varied only by changing its load reference, which, in effect, moves the speed droop characteristic up and down. This control is considerably slower and goes into action only when the primary control has done its job. For power and load sharing among generators connected to the system, speed regulation or droop characteristics must be provided. The speed-droop or regulation characteristic may be obtained by adding a steady state feed back loop around the integrator (Kundur 1994; Saadat 2002).

A two area interconnected power system of non reheat type turbines with integral controller is shown in Fig. 1, where $R_1$ and $R_2$ are regulation constants (Hz/per unit); Tg1 and $T_{g2}$ are speed governor time constant (s); $T_{t1}$ and $T_{t2}$ are turbine time constant (s); and Tp1 and $T_{p2}$ are power system time constant (s) of area 1 and area 2 respectively. The overall system can be modeled as a multi-variable system in the form of

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

where A is system matrix, B and L are the input and disturbance distribution matrices.

$x(t), u(t)$ and $d(t)$ are state, controls and load changes disturbance vectors, respectively.

$$x(t) = \begin{bmatrix} \Delta f_1 & \Delta P_{g1} & \Delta P_{v1} & \Delta P_{tie12} & \Delta f_2 & \Delta P_{g2} & \Delta P_{v2} \end{bmatrix}^T \qquad (2)$$

$$u(t) = \begin{bmatrix} u_1 & u_2 \end{bmatrix}^T \qquad (3)$$

$$d(t) = \begin{bmatrix} \Delta P_{d1} & \Delta P_{d2} \end{bmatrix}^T \qquad (4)$$

where $\Delta f_1$, $\Delta P_{g1}$, $\Delta Pv_1$ and $\Delta P_{tie\,12}$ denote deviation from the nominal values of area 1 of frequency, governor power, valve power and tie line power between area 1 and area 2 respectively. Variables with subscript 2 are denoting the same changes in area 2. $u_1$ and $u_2$ are the control outputs in Fig. 1 and $\Delta P_{d1}$ and $\Delta P_{d2}$ are disturbance input of area 1 and 2 respectively. The system output, which depends on the area control error (ACE) shown in Fig. 2, is

$$ACE_i = \Delta P_{tie,i} + b_i \Delta f_i \qquad (5)$$

$$y(t) = Cx(t) \qquad (6)$$

where $b_i$ is the frequency bias constant, $\Delta f_i$ is the frequency deviation and $\Delta P_{tie,i}$ is the change in tie line power for area i and is the output matrix (Mathur and Ghosh 2006).

## 3 FUZZY LOGIC CONTROLLER

Fuzzy set theory and fuzzy logic establish the rules of a nonlinear mapping. The use of fuzzy sets provides a basis for a systematic ways for the application of uncertain and indefinite models. Fuzzy control is based on a logical system called fuzzy logic, which is much closer in spirit to human thinking and natural language than classical logical systems. Nowadays fuzzy logic is used in almost all sectors of industry and science.

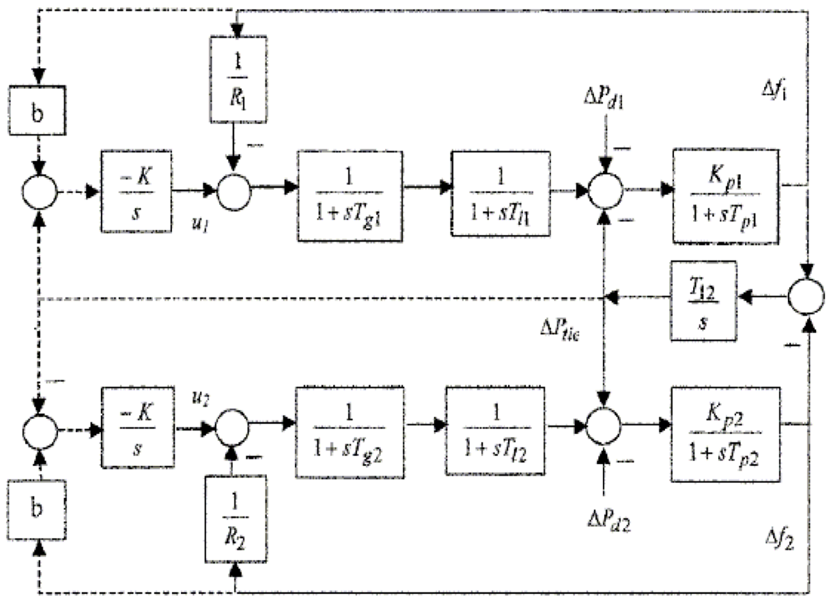

**Figure 1.** Two area interconnected power system

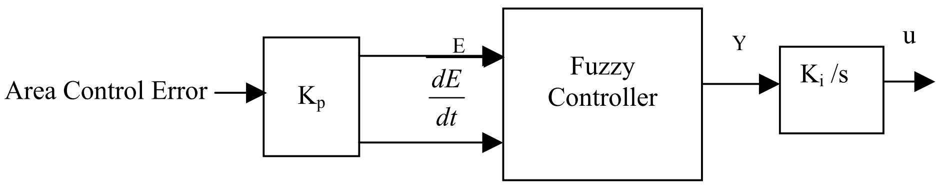


**Figure 2.** The MISO type fuzzy controller

The main goal of LFC in interconnected power systems is to maintain the balance between active power generation and its consumption. 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 in solving a wide range of control problems . The fuzzy controller for the two input and single output type of systems is shown in Fig. 2. $K_p$ and Ki are the proportional and integral gains respectively. In this work derivative of E i.e. ($\frac{dE}{dt}$) together with E is fed to fuzzy controller. The fuzzy controller block is formed by fuzzification of E and $\frac{dE}{dt}$, the inference mechanism and defuzzification. Therefore, Y is a crisp value and u is a control signal for the system. Mamdani fuzzy theory has been applied to determining the gain of controller (Çam and Kocaarslan 2005).

## 4 SIMULATION ANALYSIS AND RESULTS

A fuzzy logic controller has been applied to a two area power system. Matlab/Simulink version 7 is used for simulation purpose. The same values of system parameters (Çam and Kocaarslan 2005), given in Table 1, are used for all controllers for a comparative study. Figure 3 presents the view of rules for fuzzy logic controller under study. In all 49 rules are designed to get the response. There are 7 triangular membership functions are considered for inputs (E and $\frac{dE}{dt}$) and one output (Ki) as shown in Fig. 4. Frequency deviations of both areas and tie line deviation after sudden load change in area 1 are shown in Fig. 5. Settling time for 5% band of the step load change and peak overshoots are given in Table 2. The comparison of dynamic performances of various controllers with the proposed controller shows better results in terms of lesser settling time and peak overshoot. The simulation was repeated with various instantaneous of load changes and always found that results from proposed controller are better. The simulations results show that proposed method of fuzzy logic controller for load frequency control is giving 17.1 % reduction in settling time and 25 % reduction in peak overshoot when compared with recent Cam and Kocaarslan's study (for same values of parameters). Other simulations in Fig. 6 and Fig. 7 are carried out for $\pm 25$ % change in parameter values for values of b, $T_{12}$ and $T_p$. In Fig. 6, load change on 0.01 p.u.

is in area 1 and it indicates that change in frequency in area 1, area 2 and change in tie line power are getting settled within reasonably good time. Similarly with same amount of disturbance in area 1 in Fig. 7, it is observed that system is settled quite fast. This justifies the robustness of proposed controller, which is capable to withstand the changes in dynamic parameters of system.

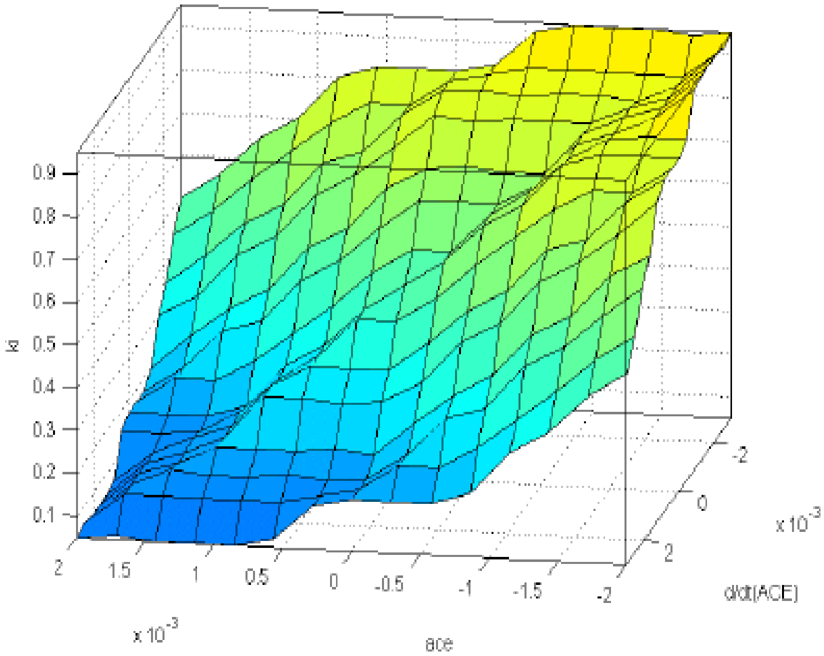


**Figure 3.** Surface view of inputs and output

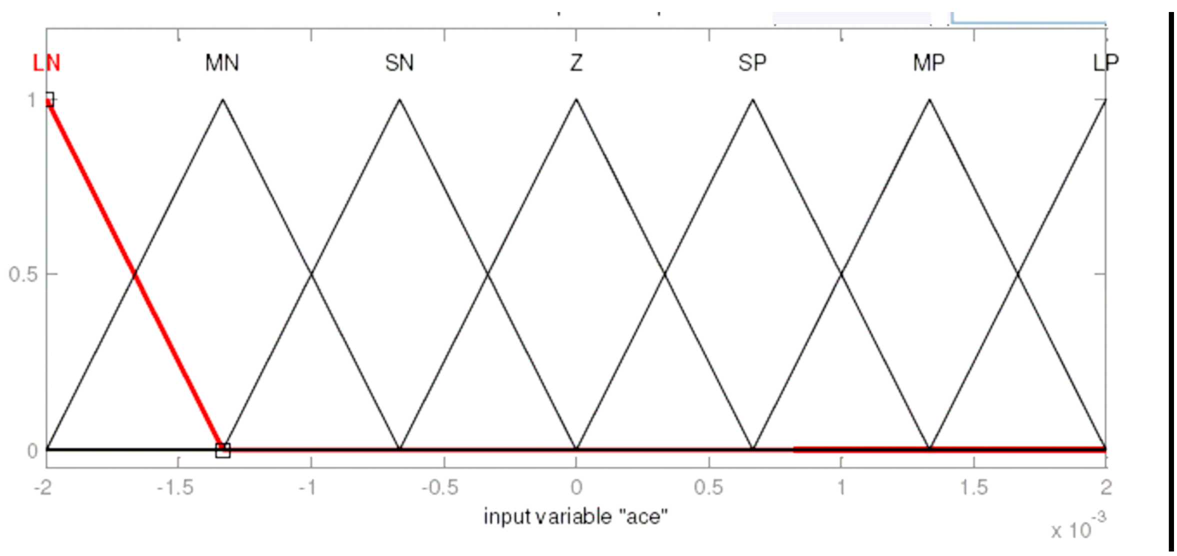


**Figure 4.** Seven triangular membership function of one input variable

**Table 1.** System parameters

| | |
|---|---|
| Rating (MW) | 2000 |
| $T_{g1}$ and $T_{g2}$ (sec.) | 0.08 |
| $T_{t1}$ and $T_{t2}$ (sec.) | 0.3 |
| $b_1$ and $b_2$ | 0.425 |
| $R_1$ and $R_2$ | 2.4 |
| $K_{p1}$ and $K_{p2}$ | 120 |
| $T_{p1}$ and $T_{p2}$ (sec.) | 20 |

**Table 2.** Comparison of dynamic performances of various controllers.

| For $\Delta f_1$ | Settling time for 5 % band of step change | Peak overshoot |
|---|---|---|
| Proposed study | 3.53 | -0.0202 |
| Cam and Kocaarslan's study | 4.26 | -0.027 |
| Conventional PI | 6.92 | -0.028 |
| Chang and Fu's study | 7.20 | -0.022 |

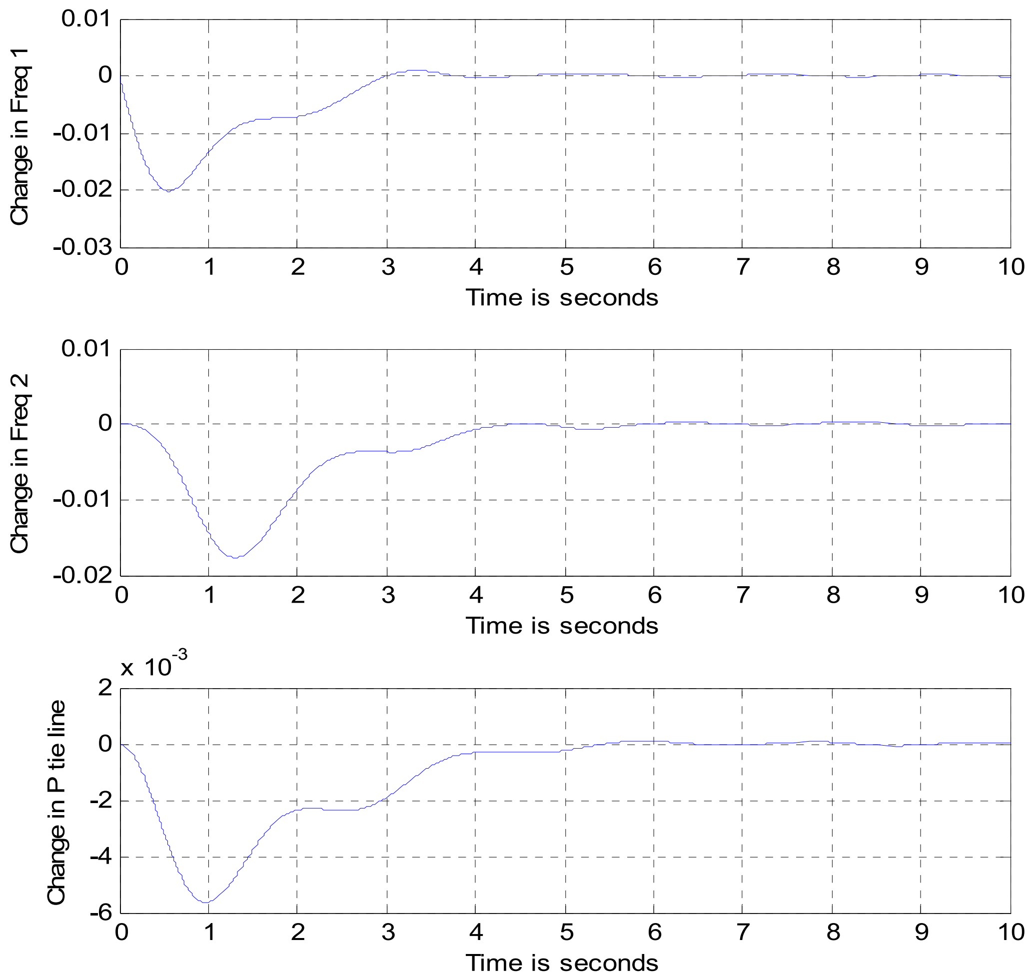


**Figure 5.** Deviation of frequency of area 1, area 2 and deviation in tie line power for 1% change in load

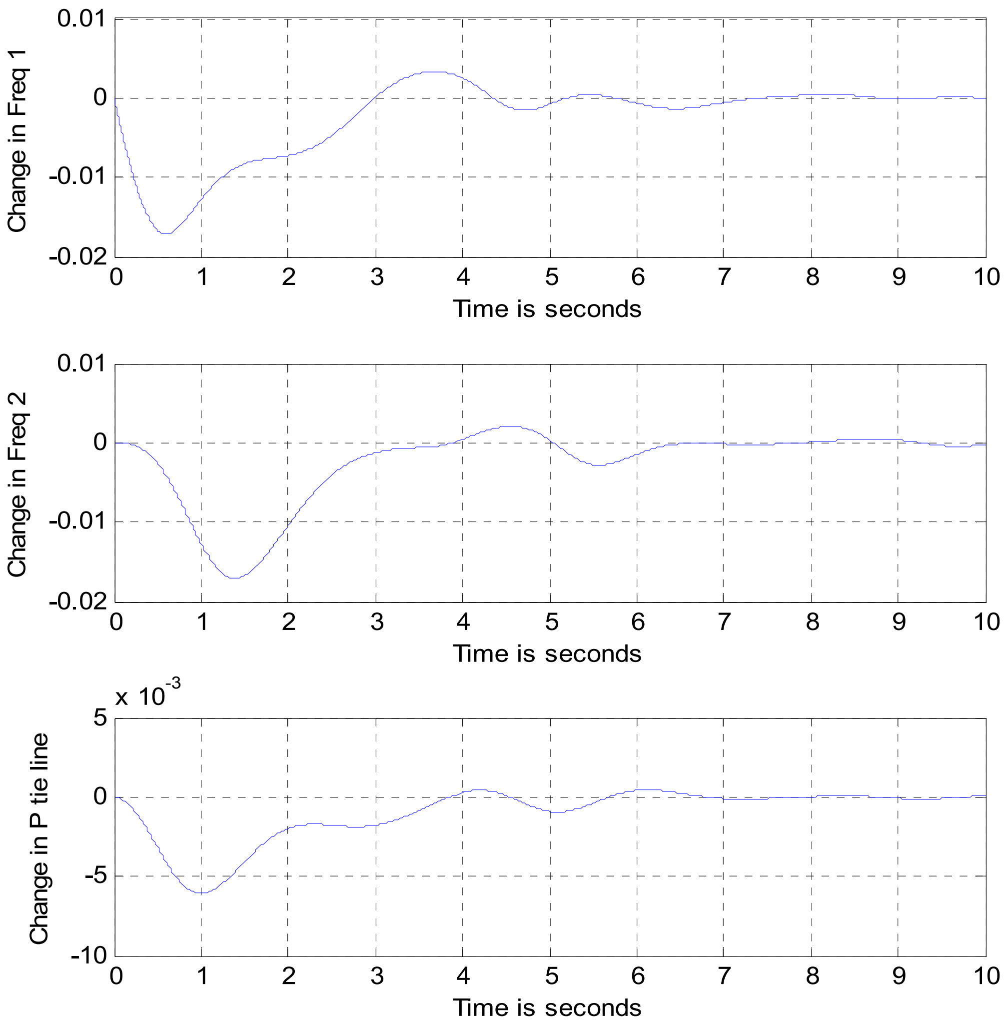


**Figure 6.** Deviation of frequency of area 1, area 2 and deviation in tie line power for +25% change in parameters with 1% change in load

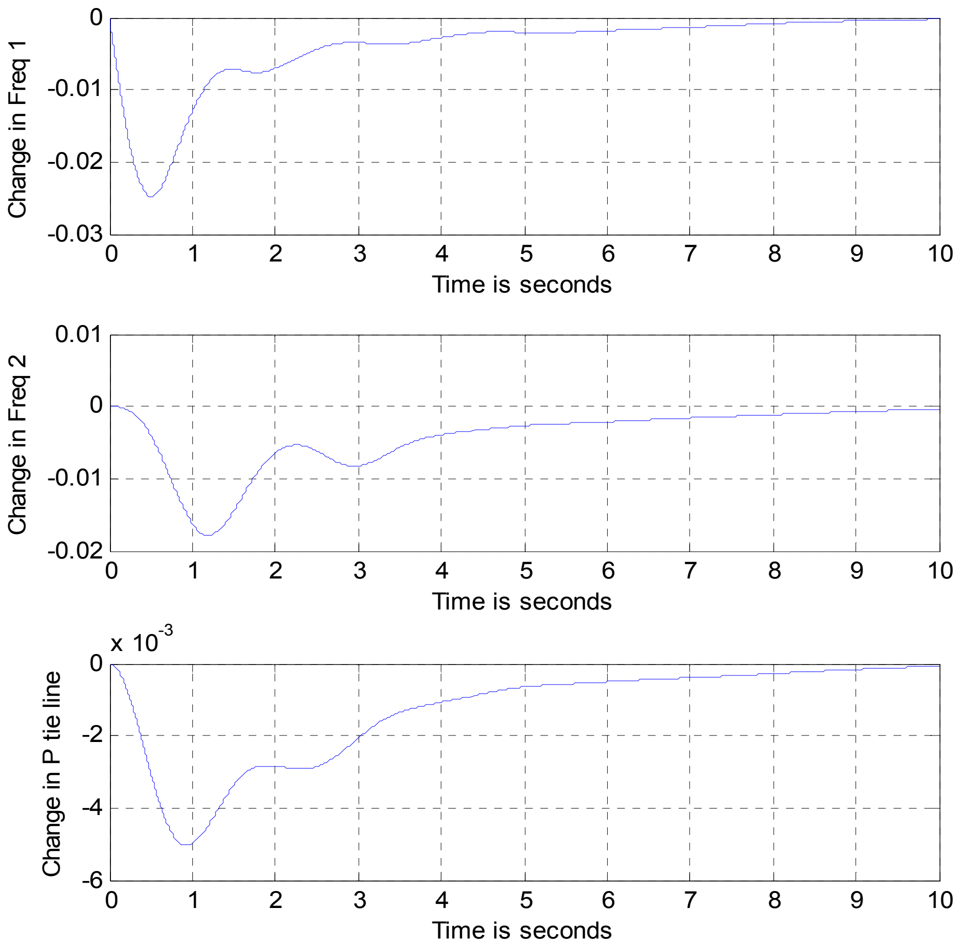


**Figure 7.** Deviation of frequency of area 1, area 2 and deviation in tie line power for –25% change in parameters with 1% change in load

# 5 CONCLUSION

In this paper, a new robust fuzzy logic controller is designed for automatic load frequency control of interconnected power systems. The controller performance is observed on the basis of dynamic parameters i.e. settling time and peak overshoot. Results of simulation presented a better performance when compared with others for same parameters. Robustness of the controller is also checked with changing parameters of the system studied. In addition, the proposed controller is very simple and easy to implement.

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