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Load Frequency Control with Fuzzy Logic Controller Considering Governor Dead Band and Generation Rate Constraint Non-Linearities

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Abstract: This paper describes the Load Frequency Control (LFC) of interconnected reheat thermal system using conventional Proportional-Integral (PI) controller with Fuzzy logic Controller (FLC). The conventional LFC scheme does not yield adequate control performance with the consideration of non-linearities such as Governor Dead Band (GDB) and Generation Rate Constraint (GRC). To overcome this short-coming Fuzzy logic controller was implemented in the system. The aim of the FLC is to restore the frequency and tie line power in a very smooth way to its nominal value in the shortest possible time. The performance of FLC has been compared with conventional PI both in the presence of GRC & GDB.

Key words: Area Control Error (ACE) · Fuzzy Logic Controller (FLC) · Load Frequency Control (LFC) · Generation Rate Constraint (GRC) · Governor Dead Band (GDB) · Proportional-Integral (PI)

INTRODUCTION

In power generation, system disturbances due to load fluctuations tend to variation in desired frequency value. Automatic Generation Control (AGC) is a very important concern in power system operation and control for supplying sufficient and consistent electric power with good quality. An interconnected power system can be considered as being divided into control areas, which are connected by the tie lines. In each control area, all generators are assumed to form a coherent group. The power system is subjected to local variations of random magnitude and duration. For satisfactory operation of a power system the frequency should remain nearly constant. The frequency of a system depends on active power balance. As frequency is a common factor throughout the system, a change in active power demand at one point is reflected through out the system. Many investigations [1-3] have been reported in the past pertaining to LFC of a multi area interconnected power system. Among the various types of controllers most widely employed method is the Proportional-Integral (PI) controller. However the inherent singular characteristics of speed governor system have a great influence on LFC behavior, which makes it more difficult to maintain the required frequency accuracy. The speed governor system should be operated within the restricted control range of feedback gain due to the system instability. In the deregulated environment frequent on-off control of large capacity units may bring about large amount of power disturbances, which has not been experienced before [4].

Literature survey shows that [5], only a few investigations have been carried out using FLC to LFC with the consideration of Non-linearity. It has been discussed that the implementation of such FLC has greatly improved the performance of the controller "without negatively affecting the consumers' quality of supply". This paper addresses the comparison between the performances of FLC and conventional PI controller both in the presence of non-linearity [6-10]. The transfer function model of two area interconnected reheat thermal system with non-linearity is shown in the Fig.2.

System Investigated: System investigation has been carried out on a two equal area reheat thermal power system considering GDB and GRC [11]. The nominal parameters of the system are given in Appendix. Matlab version 7.3 has been used to obtain dynamic response of change in frequencies ΔF_1, ΔF_2 and ΔP_{tie} for 1% step load perturbation in either area of the system. Proper assumptions and approximations are made to linearize the mathematical equations which describe the system and transfer function model [6]. the objective function used is,

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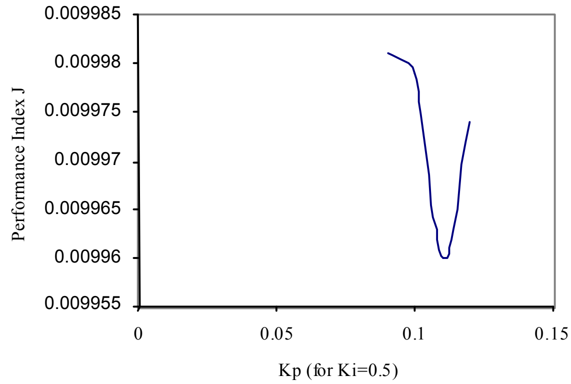

Fig. 1: Performance index curve

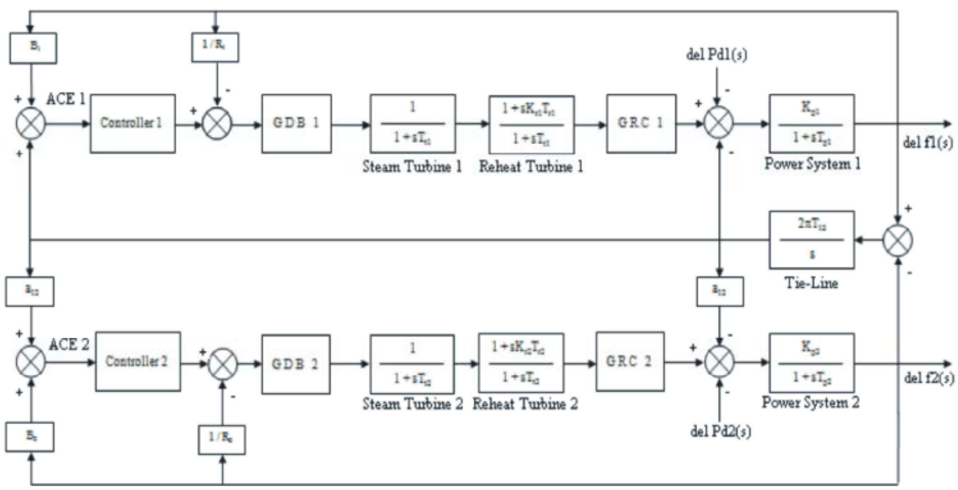

Fig. 2: Transfer function model of two area thermal interconnected system.

$$J = \int (\Delta F_i^2 + \Delta P_{tie}^2)\Delta T \quad (1)$$

where i = 1, 2,….,n

[12] The above figure shows the optimum value of conventional PI controller, using the Eq.(1). It is clear that the gain value, K_p = 0.11 for K_i = 0.5.

Governor Dead Band: Governor Dead Band is defined as the total magnitude of a sustained speed change within which there is no resulting change in valve position. The Backlash non-linearity tends to produce a sinusoidal oscillation with a natural period of about 2s [8-10]. The speed governor dead band has important result on the dynamic performance of load frequency control system. The hysteresis type of non-linearities are expressed as,

$y = F(x, x)$ rather than as $y = F(x)$ (2)

To solve the non-linear problem, it is necessary to make the basic assumption that the variable x, appearing in the above equation is sufficiently close to a sinusoidal equation that is

$$x = A \sin \omega_0 t \quad (3)$$

As the variable function is complex and periodic function of time, it can be developed in a Fourier series,

$$F(x, \dot{x}) = F^0 + N_1 x + \frac{N_2}{\omega_0}\dot{x} + ... \quad (4)$$

From the above equation Fourier co-efficient are derived as N_1=0.8 & N_2=-0.2. By substituting the values in Eq.(4) the transfer function for GDB is expressed as follows.

$$F(x, \dot{x}) = 0.8x - \frac{0.2}{\pi}\dot{x} \quad (5)$$

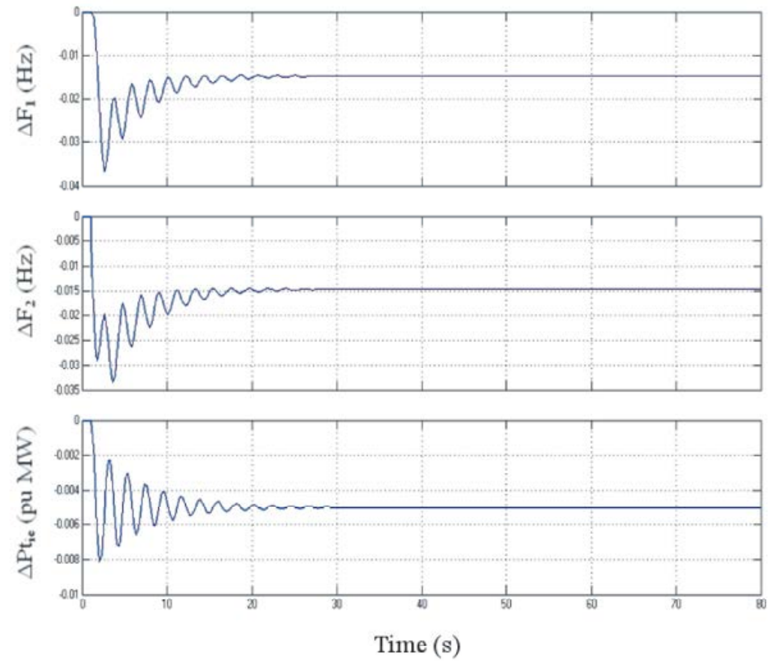

Fig. 3a: Open Loop Response with GDB

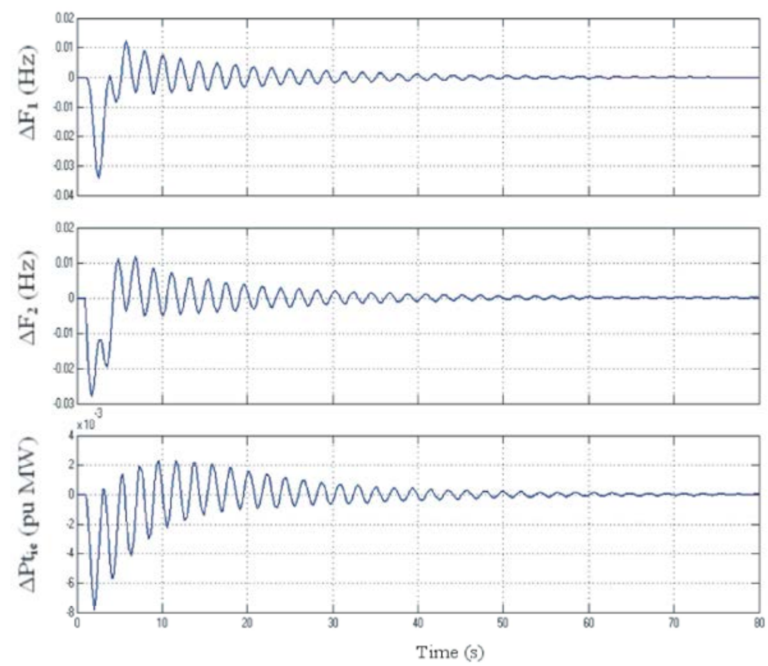

Fig. 3b: Conventional PI Response with GDB

The dynamic responses of the system for open loop and conventional PI controller with the presence of GDB are shown in Fig.3 a,b.

Generation Rate Constraint: In practical steam turbine system, due to thermodynamic and mechanical constraint, there is a limit to the rate at which its output power (dp_t/dt) can be changed. This limit is referred to as generation rate constraint [2, 3, 6]. Rate limits are imposed to avoid a wide variation in process variables like temperature and pressure for the safety of equipment [13]. Generation rate constraint of 3% p.u.MW/min are usually applied to reheat turbines.

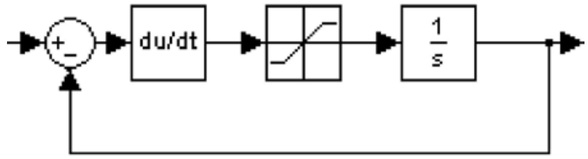

Fig. 4: Generation Rate Constraint

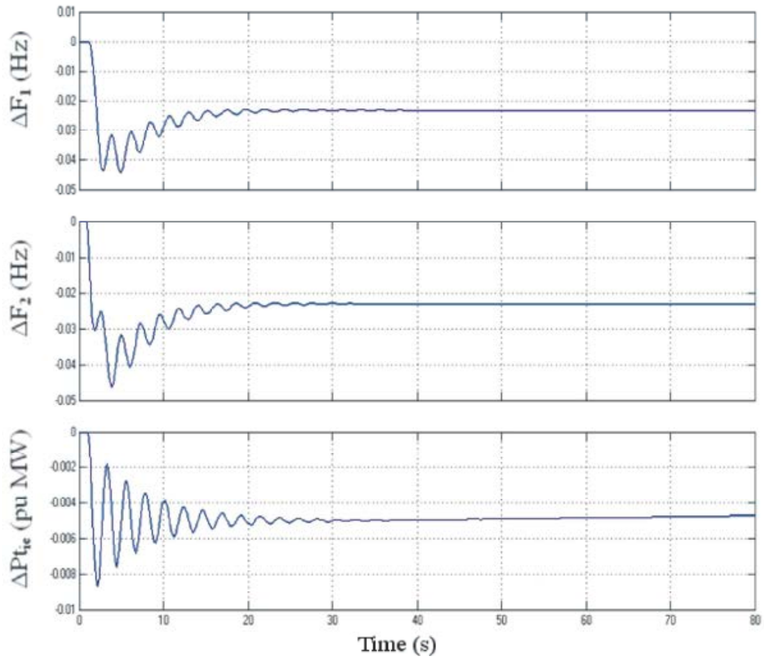

Fig. 5a: Open Loop Response with GRC

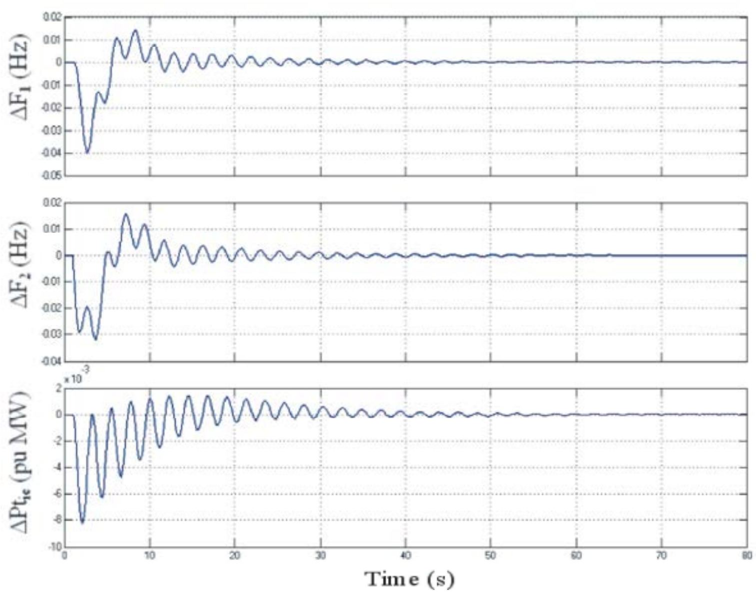

Fig. 5b: Conventional PI Response with GRC

The dynamic responses of the system for open loop and conventional PI controller with the presence of GRC are shown in Fig. 5a,b.

C.GDB & GRC: When both the non-linearities are included in two area power system the dynamic response of the system exhibits

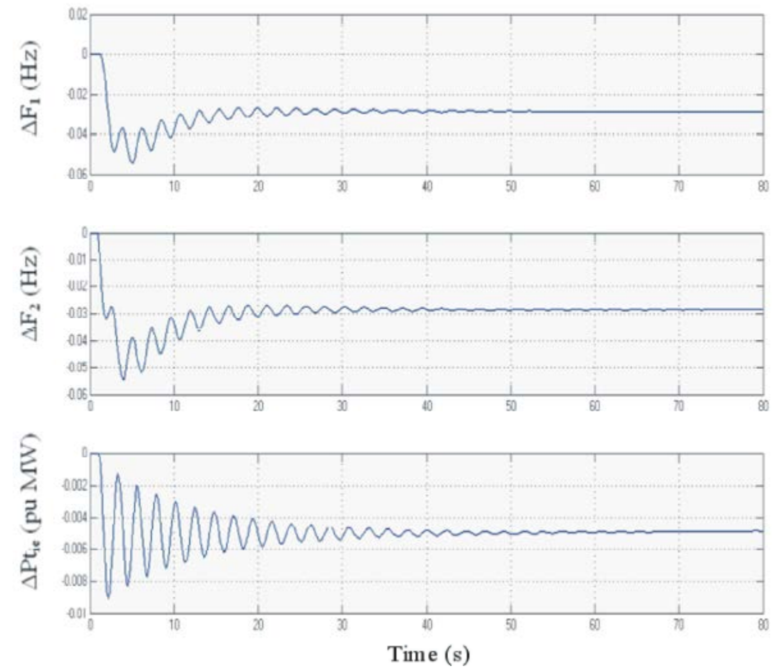

Fig. 6a: Open Loop Response with GDB and GRC

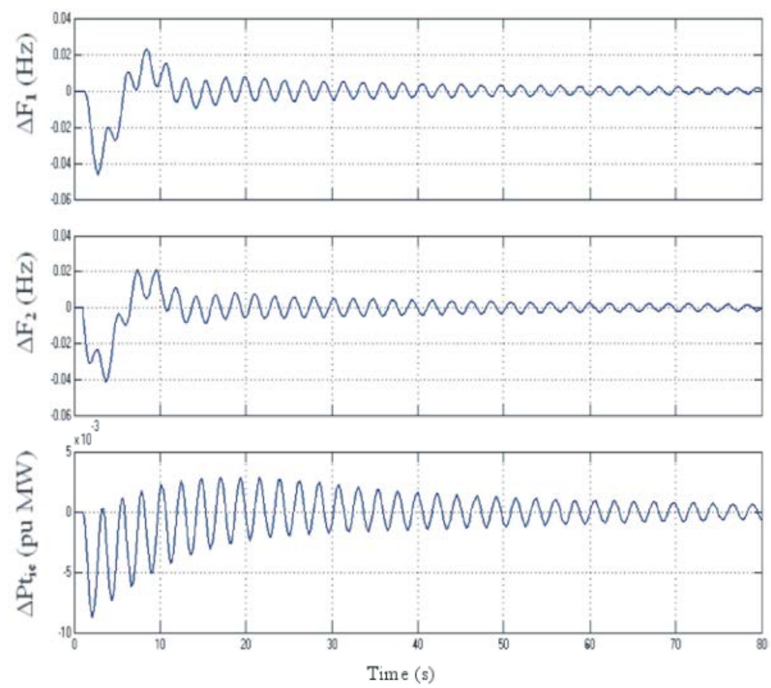

Fig. 6b: Conventional PI Response with GDB and GRC

relatively poor performance as evidenced by large overshoot and transient frequency oscillations [11, 12].

The simulation results of the open loop and conventional PI controller both in the presence of GDB and GRC is shown in Fig. 6a, b.

Fuzzy Logic Controller: The design of FLC can be normally divided into three areas namely allocation of area of inputs, determination of rules and defuzzifying of output into a real value. In this paper the suggested fuzzy controller takes the input as ACE and ACË, which is given as,

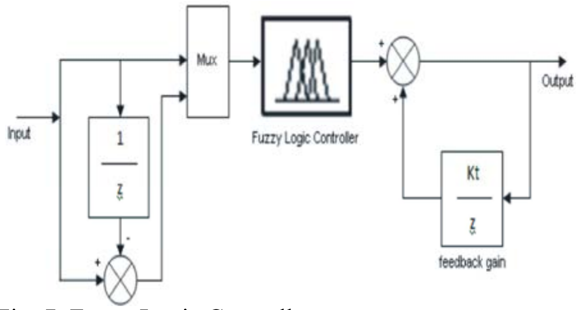

Fig. 7: Fuzzy Logic Controller

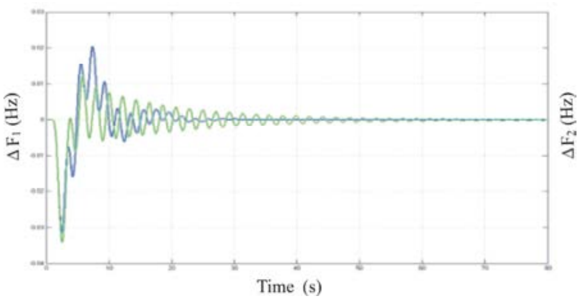

Fig. 8a: Change in frequency in area 1 with GDB

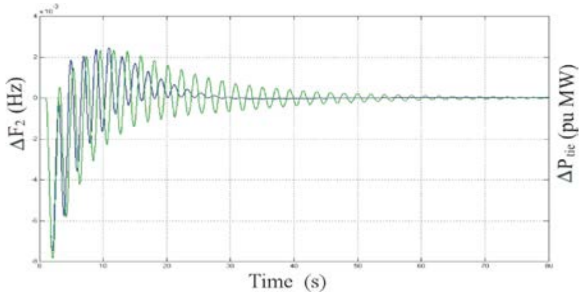

Fig. 8b: Change in frequency in area 2 with GDB

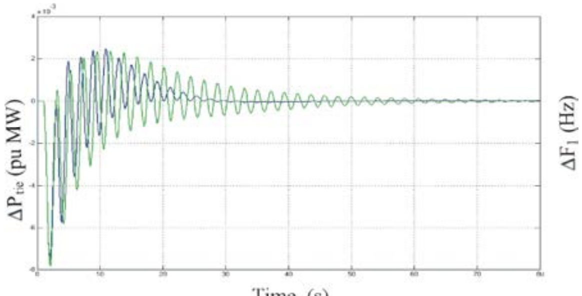

Fig. 8c: Change in tie line power with GDB

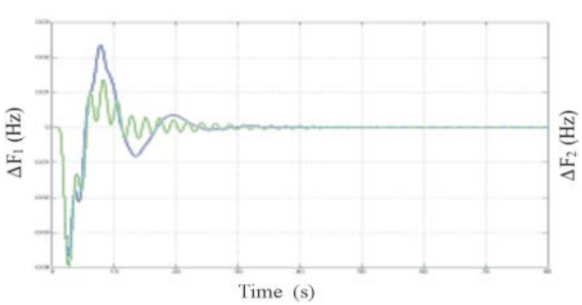

Fig. 8d: Change in frequency in area 1 with GRC

Table 1: Fuzzy Rules

		ACE						
		NB	NM	NS	ZO	PS	PM	PB
ACË	NB	PB	PB	PB	PB	PM	PM	PS
	NM	PB	PM	PM	PM	PS	PS	PS
	NS	PM	PM	PS	PS	PS	PS	ZO
	ZO	NS	NS	NS	ZO	PS	PS	PS
	PS	ZO	NS	NS	NS	NS	NM	NM
	PM	NS	NS	NM	NM	NM	NB	NB
	PB	NS	NM	NB	NB	NB	NB	NB

shows Fuzzy
shows PI

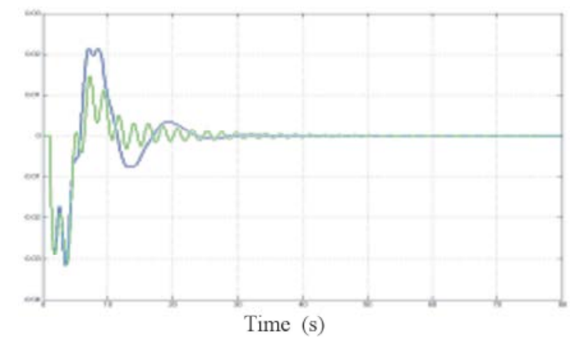

Fig. 8e: Change in frequency in area 2 with GRC

$$ACE_i = \Delta F_i B_i + \Delta P_{tie} \qquad (6)$$

The Block diagram of Fuzzy Logic Controller is shown in Fig. 7. Seven Membership Functions (MF) have been used to explore the best settling time.

MF specifies the degree to which a given input belongs to a set. Here seven membership functions namely Negative Big (NB), Negative Medium (NM), Negative Small (NS), Zero (ZO), Positive Small (PS), Positive Medium (PM) Positive Big (PB) are used.

If ACE is NB and ACË is NB then output is PB.

Defuzzification to obtain crisp value of FLC output is done by center of area method. Fuzzy rules specify the relationship among the fuzzy variables. These rules help us to explain the control action in qualitative terms. The simulation results of the system with FLC are shown in Fig. 8(a-i). Rules are given in Table 1.

Simulation Results: Due to this the change in dynamic response of the system with open loop and conventional PI controller has been observed in the presence of GRC & GDB.With the consideration of non-linearities conventional PI controller does not yield good settling time [14]. Finally the dynamic responses of the system with FLC have been compared with conventional PI

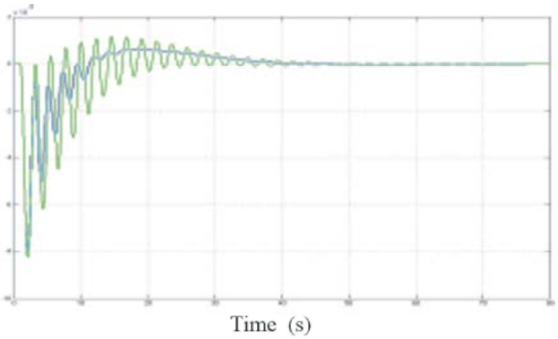

Fig. 8f: Change in tie line power with GRC

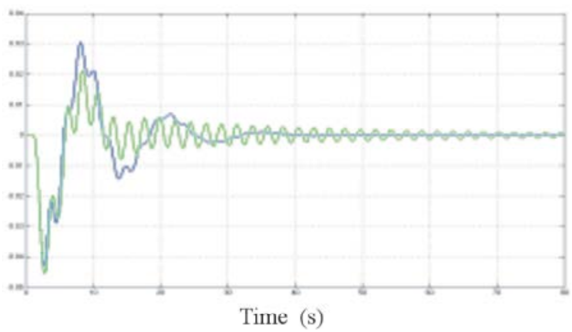

Fig. 8g: Change in frequency in area 1 with GDB and GRC

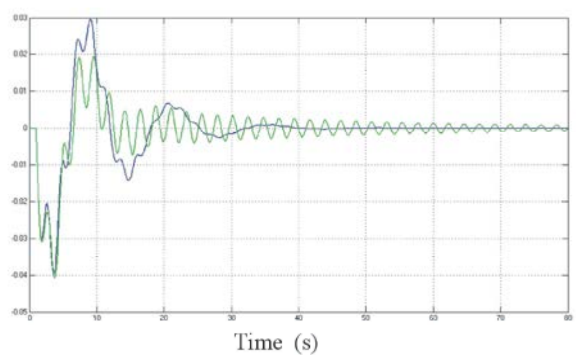

Fig. 8h: Change in frequency in area 2 with GDB and GRC

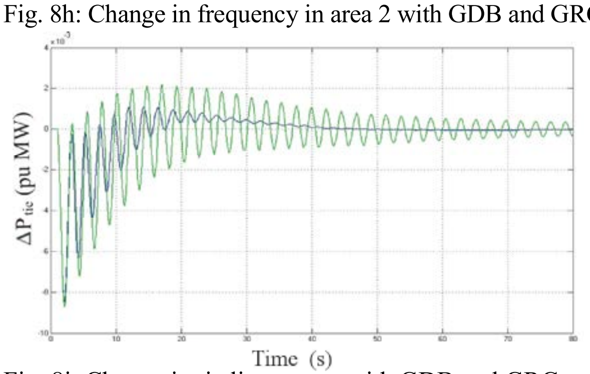

Fig. 8i: Change in tie line power with GDB and GRC

controller. FLC yields fast settling time with less number of oscillations which advocates the smooth settlement of the quality power supply even with the consideration of non-linearity.

Table 2: Comparison Study of Settling Time

Non-Linearity	Controllers	ΔF_1 (s)	ΔF_2 (s)	ΔP_{tie} (s)
With GDB	Fuzzy	35	40	44
	PI	-	-	-
With GRC	Fuzzy	36	35	43
	PI	-	-	-
With GRC & GDB	Fuzzy	52	53	72
	PI	-	-	-

CONCLUSION

In this paper FLC is designed for automatic load frequency control of two area interconnected power system. The system performance is experimental on the source of dynamic parameter (i.e.) settling time (ΔF_1 and ΔF_2) and tie line power deviation (ΔP_{tie}). The comparison of the dynamic responses of proposed controllers is shown in Table 2. The model result shows that the FLC yields much improved control performance when compared to conventional PI controller [15-19].

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Appendix:

	P_{ri} = 2000 MW T_{ti} = 0.3s T_{gi}= 0.08s
K_{ri}= 0.5	T_{ri}= 10s K_{pi}= 120 Hz/pu MW T_{pi}= 20 s T_{12}= 0.086 R_i= 2.4 Hz/ pu MW N_1= 0.8, N_2= -0.2 f= 60 Hz B_i= 0.425 pu MW/Hz