Application of a Novel Hybrid Controller in Load Frequency Control

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***Abstract*-This paper presents a new approach to study load frequency control (LFC) problem using a hybrid fuzzy-PID controller. The PID-type fuzzy controller is combined with a conventional PID controller to enhance the performance and robustness of the controller. The proposed control scheme has been designed for a two-area connected power system. Two performance criteria were utilized for the comparison. First, settling time and overshoot of the frequency deviation were compared. Later, the absolute error integral (IAE) analysis was carried out to compare all the controllers. All the models were simulated by MATLAB 7.0 Simulink software. The simulation results show that the proposed controller developed in this study performs better than the other controllers. Robustness of proposed controller is evaluated by analyzing the system response with varying system parameters.**

Keywords-Two Area Power System; Load Frequency Control; PID; Fuzzy Control; Area Control Error

I. INTRODUCTION

Frequency is one of the stability criterions for large-scale stability of power networks. For stable operation, constant frequency and active power balance must be provided. Frequency depends upon active power. Any change in active power demand /generation at power system is reflected throughout the system by a change in frequency. In multi-area power networks, frequency variations can lead to serious stability problems. To improve the stability of the power networks, it is necessary to design a load frequency control (LFC) system that controls the power generation and active power at tie-lines. Classical PID controller is the most popular control tool in many applications because it can improve the transient response as well as the steady state error of the system. Moreover, it has simple architecture and conceivable physical intuition of its parameters. However, such a controller is inefficient for control of a system while the system is disturbed by unknown facts, or the surrounding environment of the system changes. Fuzzy control is robust to the system with variation of system dynamics and is used where precise information is not required. It has been successfully used in the complex ill-defined process with better performance than that of a PID controller. Another important advantage of fuzzy controller is a short rise time and reduction in steady state error of the system. However, PID controller is better able to control and also reduce the overshoot. To enhance the controller performance, hybridization of these two controller structures comes to one's mind immediately to exploit the beneficial side of both the controllers, known as a hybrid of fuzzy and PID controller.

In literature, control strategies based on conventional, fuzzy, and neural network controller are proposed [1-3, 6-8] for load frequency control. Several authors suggest variable-structure systems, various adaptive control techniques, and riccati equation approach for load frequency controller design [4, 5]. There are many studies about different control strategies having advantages and disadvantages. In Reference [7], a load frequency control using a conventional PID controller is applied and it is emphasized that the controller performance is better than the others. However, if a power system structure has nonlinear dynamics and parts, the system operating point varies and conventional controllers needing system model must not be used. Meanwhile, PI or PID controllers for LFC were studied due to their simplicity in execution. References [9] and [10] suggested fuzzy PI controllers for load frequency control of power systems; [11] proposed a derivative structure which can achieve better noise-reduction than a conventional practical differentiator, thus load frequency controller of PID type can be used in LFC; [12] proposed a PID load frequency controller tuning method for a single-machine infinite-bus (SMIB) system based on the PID tuning method proposed in [13], and the method is extended to two-area case [14]. It is shown that the resulted PID setting needs to be modified to achieve desired performance. However, the reason for such a modification is not clear. Fuzzy logic based intelligent controllers can improve transient and steady state response of the system in comparison with PI or PID controller alone. Nonetheless, no performance advantages of intelligent controller in combination with PI or PID controller are investigated in the literature so far.

Motivated by the successful development and application of hybrid controllers in [15-17], we propose to use a hybrid controller consisting of a PID controller and a fuzzy controller in parallel arrangement for LFC. The performance of the proposed controller is compared in terms of several performance measures such as settling time, overshoot, and Integral of absolute error (IAE). Rest of the paper is organized as follows: in the next section, we present the power system investigated and the related concepts. Section III describes the design procedure of the proposed controller. In section IV, we report simulation results. Finally, conclusions based on simulation results are drawn in Section V.

II. TWO AREA POWER SYSTEM

The system investigated for LFC in this study is a two area interconnected power system with non-reheat turbine type thermal unit in each area. In an interconnected power system, a sudden load perturbation in any of the interconnected areas causes the deviation of frequencies of all the areas and also of the tie line powers. Since the time constant of the excitation control system is small as compared to the time constant of the load frequency control system, thus the transients in excitation voltage control vanish much faster and do not affect the dynamics of the load frequency control. That is the reason why excitation control and load frequency control are non-interactive for small changes in load, and therefore, can be modeled and analyzed independently. This important fact simplifies the development of the two-area power system model for load frequency control.

The generalized model of the two-area interconnected power system is shown in Fig. 1, where symbols have their usual meanings. Load-frequency control is achieved by two different control actions in two-area power systems: the primary control that makes the initial coarse readjustment of the frequency by making the various generators in the control area track a load variation and share that in proportion to their ratings. The supplementary or secondary control, which operates only after allowing the primary control to act, is a precise control strategy for fine adjustment of the frequency that helps bring back the frequency to nominal or very close to nominal value. The main objective of the supplementary control is to restore balance between each control area load and generation after a load disturbance, so that the system frequency and the tie-line power flows are maintained at their scheduled values. This is achieved conventionally with the help of integral control action. The supplementary controller of the i^{th} area with integral gain K_i is, therefore, made to act on area control error (ACE_i), which is an input to the controller

$$ACE_i = \sum_{j=1}^{n} \Delta P_{tie,ij} + b_i \Delta f_i \qquad (1)$$

where ACE_i is the area control error of the i^{th} area.

Δf_i = frequency error of i^{th} area

$\Delta P_{tie,ij}$ = tie line power flow error between i^{th} area and j^{th} area

b_i = frequency bias coefficient of i^{th} area

The two-area interconnected power system model, as shown in Fig. 1, can be mathematically modeled as a multi-variable state space model in the following form [18]:

$$\dot{x} = Ax(t) + Bu(t) + Ld(t) \qquad (2)$$

where A is system matrix, B is input distribution matrix, L is disturbance distribution matrix, x(t) is state vector, u(t) is cont rol vector and d(t) is disturbance vector of load changes.

$$x(t) = [\Delta f_1 \ \Delta P_{g1} \ \Delta P_{v1} \ \Delta P_{tie12} \ \Delta f_2 \ \Delta P_{g2} \ \Delta P_{v2}]^T \qquad (3)$$

$$u(t) = [u_1 \ u_2]^T ; L(t) = [\Delta P_{d1} \ \Delta P_{d2}]^T \qquad (4)$$

where Δ denotes deviation from the nominal values and u_1 and u_2 are the controller outputs. The system output, which depends on area control error, is written as follows:

$$y(t) = \begin{bmatrix} y_1(t) \\ y_2(t) \end{bmatrix} = \begin{bmatrix} ACE_1 \\ ACE_2 \end{bmatrix} = Cx(t) \qquad (5)$$

Where C is the output matrix.

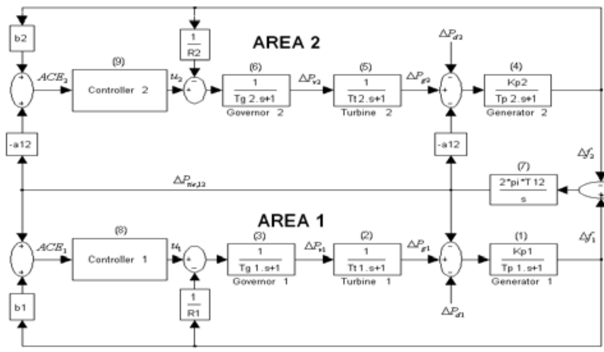


Fig. 1 A two-area inter-connected power system with controllers

III. HYBRID FUZZY PID CONTROLLER STRUCTURE

A standard PID controller is also known as the three term controller, whose transfer function is generally written in the "ideal form" as:

$$G_{PID}(s) = K\left(1 + \frac{1}{T_1 s} + T_d s\right) \qquad (6)$$

where K is the proportional gain, T1 the integral time constant and Td the derivative time constant.

The structure of fuzzy PID controller, which has two inputs and one rule base, is shown in Fig. 2.

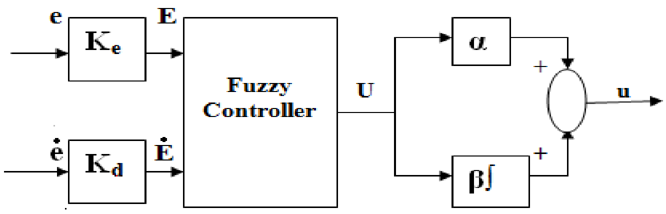


Fig. 2 The fuzzy PID controller structure

The input signal is the Area Control Error (ACE). The output signal (u) is control signal given as

$$u = \alpha U + \beta \int U dt^* \qquad (7)$$

where U is the output of the fuzzy logic controller. For the product–sum crisp type fuzzy controller, the relation between the input and the output variables of the fuzzy logic controller can be given as

$$U = A + PE + DE^* \qquad (8)$$

where $E = K_e e$ and $E^* = K_d e^*$. Therefore, from (7) and (8), the controller output is obtained as

$$u = \alpha A + \beta At + \alpha K_e Pe + \beta K_d De + \beta K_e P \int edt + \alpha K_d De^* \quad (9)$$

Thus, the equivalent control components of the fuzzy PID type controller are obtained as follows:

1. Proportional gain: $\alpha K_e P + \beta K_d D$
2. Integral gain: $\beta K_e P$
3. Derivative gain: $\alpha K_d D$

In this study, the fuzzy logic controller block is formed by fuzzification of area control error ACE_i and the rate of change of area control error ΔACE_i. It consists of three membership functions with two-inputs and one output. Each membership function consists of two trapezoidal memberships and five triangular memberships as shown in Fig. 3. The inference mechanism is realized by 49 (7×7) rules for the fuzzy controller block. The appropriate rules used in this study are given in Table 1, where every cell shows the output membership functions of a control rule with two input membership functions.

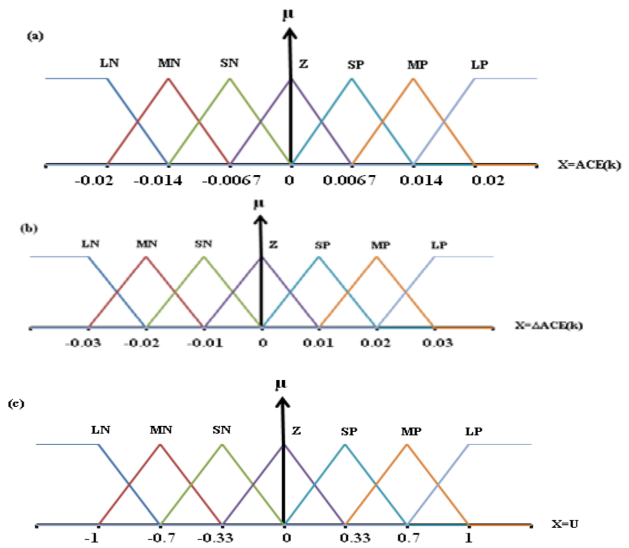


Fig. 3 Membership functions of (a) ACE (b) ΔACE (c) U for the FLC controller

TABLE 1 FUZZY LOGIC RULES FOR FLPID CONTROLLER

ACE / ΔACE	LN	MN	SN	Z	SP	MP	LP
LN	LP	LP	LP	MP	MP	SP	Z
MN	LP	MP	MP	MP	SP	Z	SN
SN	LP	MP	SP	SP	Z	SN	MN
Z	MP	MP	SP	Z	SN	MN	MN
SP	MP	SP	Z	SN	SN	MN	LN
MP	SP	Z	SN	MN	MN	MN	LN
LP	Z	SN	MN	MN	LN	LN	LN

LN: Large Negative; MN: Medium Negative; SN: Small Negative; Z: Zero; SP: Small Positive; MP: Medium Positive; LP: Large Positive

As for the proposed hybrid fuzzy PID controller (HFLPID), the classical PID and fuzzy PID controller (FLPID) are combined and tuned in parallel. The Simulink model of the proposed hybrid fuzzy-PID (HFLPID) controller is shown in Fig. 4.

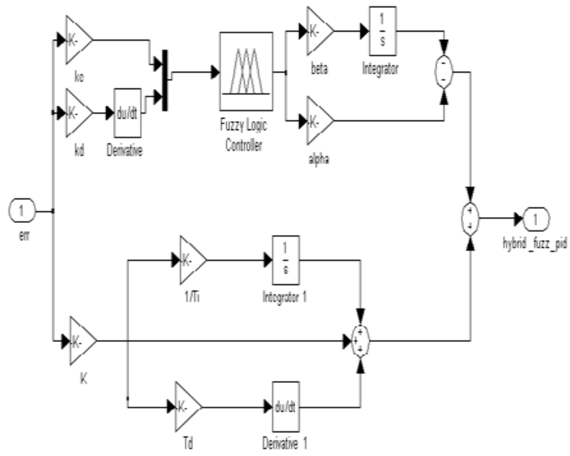


Fig. 4 Hybrid fuzzy-PID controller structure

IV. SIMULATIONS AND RESULTS

To verify the effectiveness of the proposed HFLPID controller, simulations were performed by using proposed controller, FLPID and conventional PID controller applied to a two area interconnected electrical power system and by applying 0.01 p.u. MW step load disturbance to Area 1. The same system parameters, given appendix A, were used in all controllers for a comparison. In the optimization, the integral absolute error (IAE) of the frequency deviation of the first area is selected as the performance index. Accordingly, the objective function J is set by

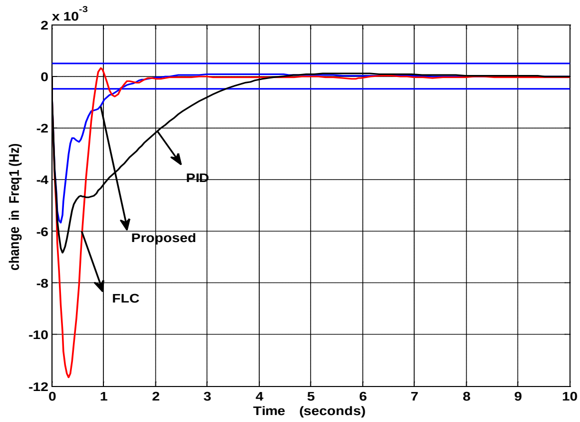
$$\text{Minimize} \quad J = \int_0^{\infty} |ACE(t)| dt$$

A well tuned PID controller and Fuzzy PID controller are taken for comparison. The same controller parameters are used for the proposed HFLPID controller. The controller parameters of the classical PID controller are set to K=1.212, T1 =1 and Td =1 to have a smooth response with small overshoot. On the other hand, the fuzzy PID controller has the following parameters: K_e =6.56, K_d =5.6, α =0.02, β =0.0113.

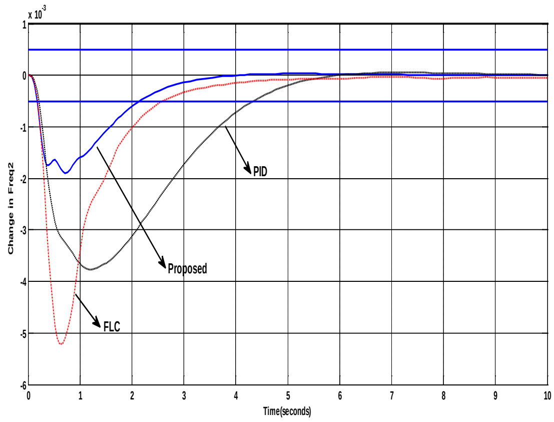
The frequency deviation of Area 1, Area 2 and change in tie line power after a sudden load change are shown in Fig. 5. The frequency deviation plots were obtained with MATLAB 7.0 Simulink software and therefore, settling time for a 5% band of the step change and peak overshoots of the frequency deviation of all the controllers were compared against each other. The comparison results are provided in Table Ⅱ.

The comparison of dynamic performances of the proposed controller with respect to other controllers shows better results in terms of lesser settling time and peak overshoots. The values of IAE of the proposed controller and other controllers are given in Table II. An examination of the integral of absolute error values indicates that the proposed controller has the smallest value. Simulations were repeated with simultaneous application of 1% step load disturbance in Area 1 and Area 2.

(a)



(b)



(c)

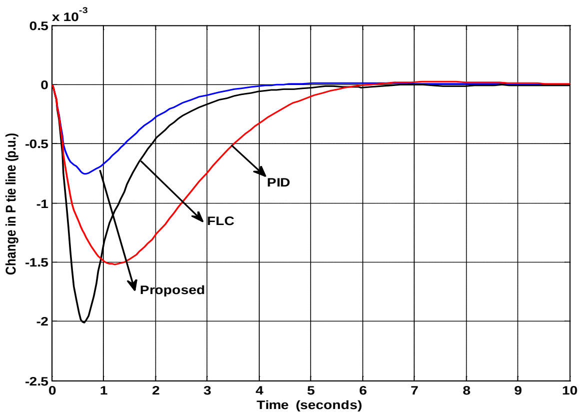


Fig. 5 Deviation of frequency of (a) area 1 (b) area 2 (c) deviation in tie line power for 1% change in load applied on Area 1

TABLE II SYSTEM PERFORMANCES FOR ALL CONTROLLERS ON SETTLING TIME, OVERSHOOTS AND IAE FOR FREQUENCY DEVIATION OF AREA 1WITH 1% DISTURBANCE APPLIED ON AREA 1

	Frequency Deviation in Area 1 (Δf1)		
	Settling Times (sec.) (for 5% Band of the Step Change)	Maximum Overshoot (Hz)	IAE
PID	3.33	-0.0068	0.0085
FLPID	1.3	-0.0117	0.0053
HFLPID	1.3	-0.0056	0.0026

The frequency deviation of the Area 1 after sudden load change on both areas is shown in Fig. 6. Again the results given by the proposed controller are better.

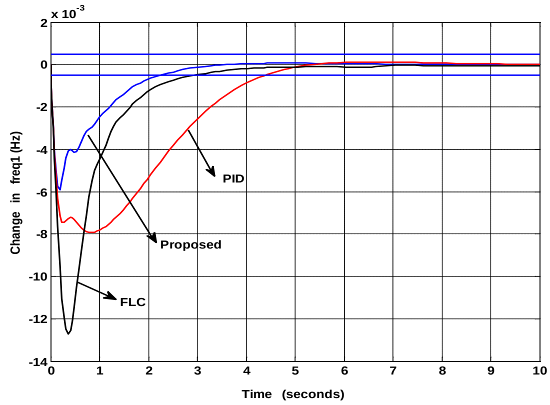


Fig. 6 Deviation of frequency of area 1 for 1% change in load applied in area 1 and Area 2

Next, the robustness of each controller against system parameters variations are evaluated in terms of settling time, overshoot, and IAE. These values are calculated under an occurrence of load disturbances while the system parameters are varied from -30% to 30% of the nominal values. The comparison results are indicated in Figs. 7, 8 and 9 and show the values of settling time, overshoot of Δf1 and IAE respectively.

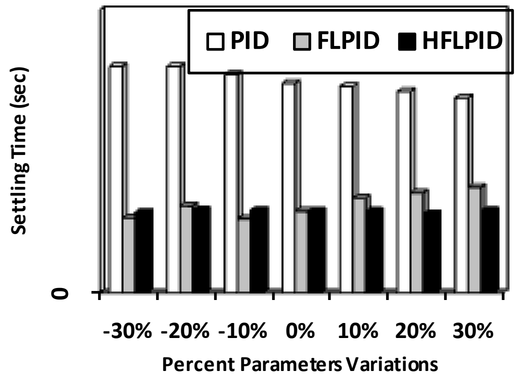


Fig. 7 Comparison results of settling time Δf1 under parameter variations

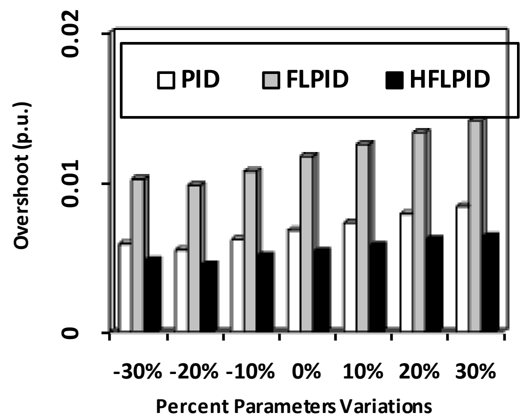


Fig. 8 Comparison results of overshoots Δf1 under parameter variations

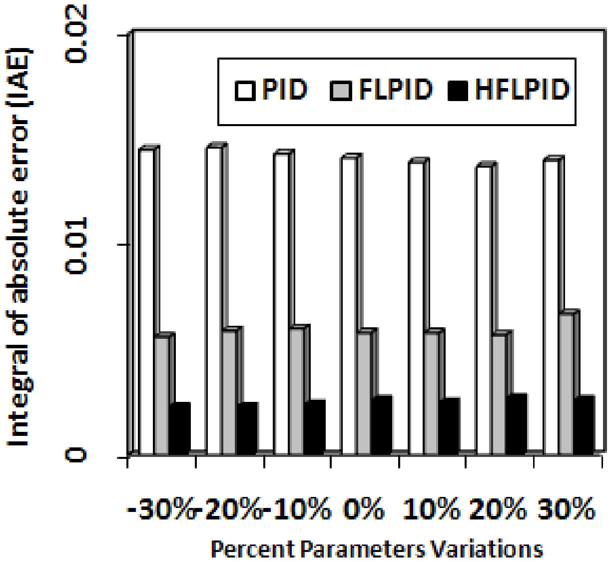


Fig. 9 Comparison results of Δf1 under parameter variations by IAE

Considering Figs. 7-9, in case of PID and FLPID controllers, the values of the settling time, overshoot, and IAE change as system parameters are varied. In contrast, the values of the settling time, overshoot, and IAE in case of HFLPID controller are lower and slightly changed. This clarifies that the robustness of the proposed controller against parameter variations is superior to that of the convention PID and FLPID controller.

Finally, the frequency control effects of conventional PID, FLPID and proposed HFLPID controllers are evaluated under different random step load variations that are applied to both areas as indicated in Fig. 10. The result of the frequency deviations of the first area is shown in Fig. 11. Furthermore, Fig. 12 presents the results of the change in tie-line power for the first area. The frequency deviations and the change in tie-line power for the first area are improved considerably by the proposed HFLPID controller in comparison with the case of the conventional PID and FLPID.

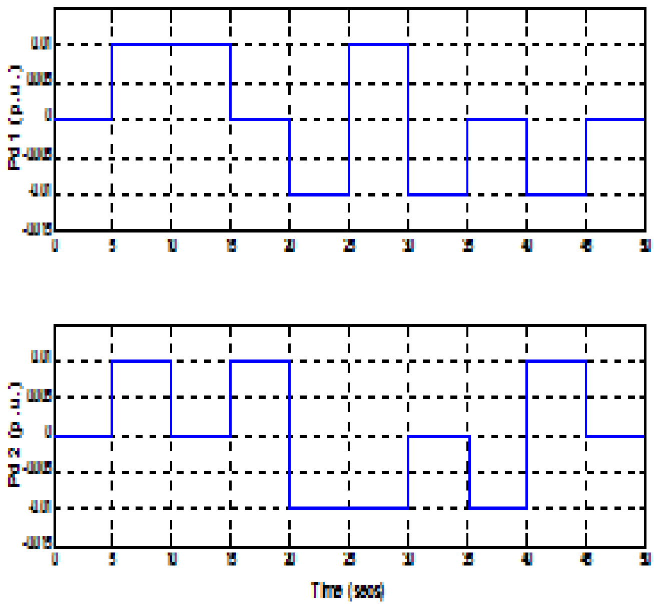


Fig. 10 Step load change in Areas 1 and 2

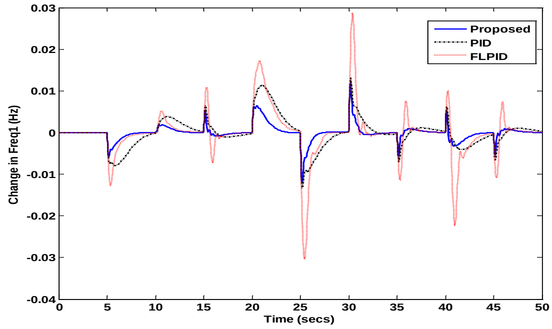


Fig. 11 Time response of Δf1 under load change

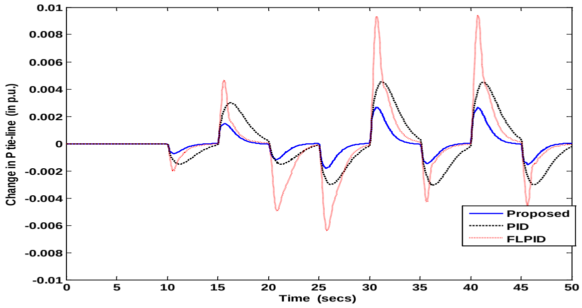


Fig. 12 Time response of ΔPtie under load change

V. CONCLUSIONS

In this paper, hybrid Fuzzy-PID controller (HFLPID) is applied to power systems. This application is an alternative and successful control for LFC. Simulation studies have been carried out using MATLAB platform to study the transient behaviour of the frequency in each area and tie-line power deviations due to load perturbations in one of the areas. Results of the proposed HFLPID controller were compared against conventional PID controller, and Fuzzy logic controller, implemented on the same system and for same operation cases. It is seen from the simulations that, the proposed controller causes less frequency drop than other controllers and oscillations in frequency rapidly damp out. Simulation results establish the usefulness of the proposed controller for LFC.

APPENDIX A TWO AREA POWER SYSTEM PARAMETERS

Rating (MW)	2000
$P_{tie,max}$ (MW)	200
T_{gi} (sec.)	0.08
T_{ti} (sec.)	0.3
b_i (p.u.MW/Hz)	0.425
Ri (Hz/p.u.MW)	2.4
K_{pi} (Hz/p.u.MW)	120
T_{pi} (sec.)	20
T_{12}	0.08674
a_{12}	-1
i	1 and 2

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