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FUZZY COMPENSATED PI CONTROLLER DESIGN FOR LOAD FREQUENCY CONTROL

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ABSTRACT

This paper presents a Fuzzy compensated PI controller design for load frequency control of the Nigerian Hydrothermal power system. The fuzzy compensator operates on top of the existing PI controller and does not require a priori knowledge of the controlled system and acts as a supplementary controller to the system. A comparative simulation study of conventional PI controller with fuzzy compensated PI controller show that the proposed controller can yield a better dynamic response following a step load change.

KEY WORDS

Power system control, PI control, Fuzzy Control, Load Frequency Control, Automatic generation control.

1. Introduction

Any power system is required to satisfy the prescribed quality of power supply to its consumers. One indicator of this quality is the constant frequency of supply. However, frequency changes occur because system loads randomly vary throughout the day [1,2]. The imbalance between real power generation and load demand causes frequency deviation and power flow deviation on tie line to neigbouring control areas. In interconnected system with two or more independently controlled areas, the generation within each area has to be controlled so as to maintain scheduled power interchange. This is in addition to control of frequency. The control of frequency and generation is referred to as load frequency control (LFC) [3].

Many investigations have been reported on LFC. The conventional control strategy used in the industry is to take the integral of the area control error (ACE) as the control signal [4].This approach will result in relatively large overshoots and long settling time of the system transient deviation. The system response with PI controller eliminates overshoot more than pure integral control but is more oscillatory [5]. LFC design has gradually shifted to the use of artificial intelligence systems that employ neural networks and fuzzy systems [6,7], since the satisfactory dynamic behaviour of a power system can no longer be guaranteed by fixed gain controllers over wide operating conditions. In order to ensure well-damped system dynamics over a wide range of operating conditions, it is necessary to adjust controller gains recursively in accordance with on-line information [8, 9].

In this paper, a fuzzy compensated PI controller design for load frequency control is proposed. The designed controller is applied to the Nigerian Hydrothermal system which consists of two area sytem with the thermal system as area one and the hydro system as area two.

2. Nigerian Hydrothermal System Model

The Nigerian electric power system employed as a test system is essentially an interconnection of a thermal area and hydro area. The two-area system is as shown in Figure 1.The load frequency control problem at hand is that of maintaining zero steady state deviations of the frequency and the tie-line flows when either or both areas are subjected to time dependent load changes. The state equations for the two-area system are expressed in compact form as

$$\begin{aligned} \dot{x}(t) &= A\,x(t) + B\,u(t) + L\,w(t) \\ y &= C\,x(t) + v(t) \end{aligned} \qquad (1)$$

where $x(t) = [\Delta f_1 \;\; \Delta P_{m1} \;\; \Delta P_{t1} \;\; \Delta P_{g1} \;\; \Delta p_{tie} \;\; \Delta f_2 \;\; \Delta P_{m2} \;\; \Delta P_{t2} \;\; \Delta P_{g2}]$ $, u(t) = [u_1 \;, u_2\,]^T = [\Delta P_{c1} \;, \Delta P_{c2}]^T$ $, w(t) = [\Delta P_{L1}, \Delta P_{L2}\,]^T$, matrices A , B , C and L are real and appropriately dimensioned while $w(t)$ and $v(t)$ are the load disturbance and the measurement modelling errors respectively.

The well-known area control error, which is required for the solution of the problem is given by

$$y_i = \Delta P_{tie,\,i} + b_i\,\Delta f_i\,(t) = ACE_i \qquad i - 1,\, 2 \qquad (2)$$

The parameters from available data base for each area is given in Table 1[10].

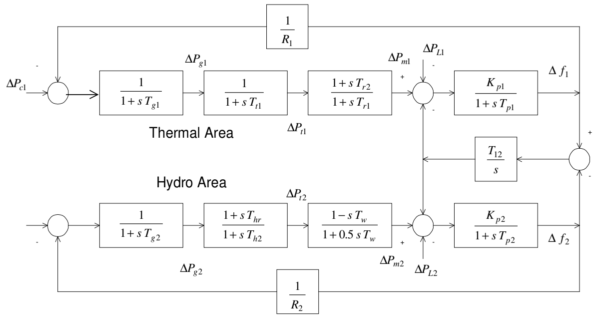


Figure 1: Nigerian Two-area Hydrothermal System

3. Fuzzy Compensated PI Controller

The aim of the load frequency controller is to generate a control signal that maintains system frequency and tie-line interchange power at predetermined values. The block diagram of the fuzzy compensated PI controller is as shown in Figure 2.

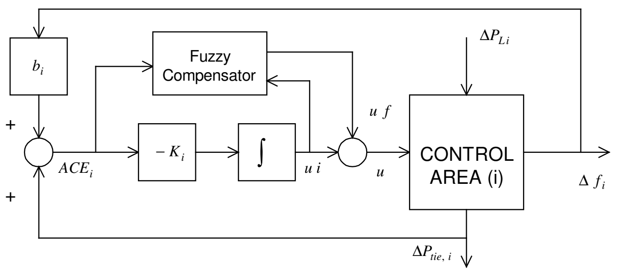


Figure 2: Fuzzy Compensated PI Controller installed on Area i

3.1 PI Controller

The PI controller output is given by [3].

$$u_i = -k_i \int_0^t (ACE_i)\,dt = -k_i \int_0^t (\Delta p_{tie,\,i} + b_i\, \Delta f_i)\,dt \qquad (3)$$

Taking the derivative of (3), one obtains

$$\dot{u}_i = -k_i\,(ACE_i) = -k_i(\Delta p_{tie,\,i} + b_i\,\Delta f_i) \qquad (4)$$

In matrix form,

$$\dot{u}_i = -K_I C x \qquad (5)$$

where $K_I = \begin{bmatrix} k_1 & 0 \\ 0 & k_2 \end{bmatrix}$

3.2 Fuzzy Compensator

Integral control can cause excessive oscillations due to build-up in the integrator when the control signal is not effective. Thus, to eliminate the steady state error due to the ineffective performance of the PI controller, a second level controller (fuzzy controller) is introduced as shown in Figure 2. The fuzzy compensator is introduced to compensate the input control signal directly.

Manual human intervention can be carried out to rectify this problem, by monitoring the control signal, the operator can judge the magnitude of the compensation signal required. The following linguistic rules are typical ΔP_{c2} action taken by humans for compensation.

IF *the output is responding to the control signal* u_i **THEN** *do nothing*.

IF *the steady state error is non-zero* **AND** *the control signal* u_i *is non-zero* **THEN** increment *or decrement* u .

These rules can be shown in flowchart of figure 3.

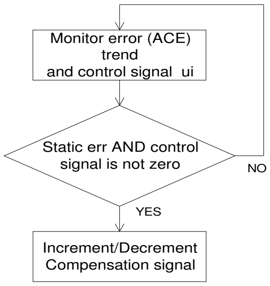
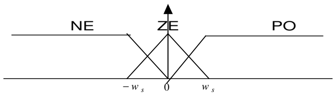


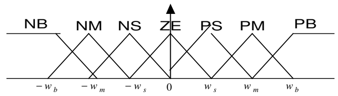
Figure 3: Flow Chart of Fuzzy Compensator

3.2.1 Fuzzification

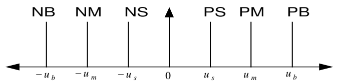
Fuzzification is performed by membership functions. For the fuzzy compensator, the fuzzy sets and their associated membership functions are shown in Figure 4.



(a) Membeship function for the error (ACE)



(b) Membership function for the ui



(c) Membership function for the compensation signal uf

Figure 4: Membership functions for the error (ACE), ui and Compensation signal

3.2.2 Fuzzy rules, Inferences and Defuzzification

The fuzzy rules for compensation signal used are as follows:

IF error (ACE) is NE **THEN** u_f is ZE

IF error (ACE) is PO THEN u_f is ZE

IF error (ACE) is ZE **AND** u_i is NB **THEN** u_f is NS*$|u_i|$

IF error (ACE) is ZE **AND** u_i is NM **THEN** u_f is NM*$|u_i|$

IF error (ACE) is ZE **AND** u_i is NS **THEN** u_f is NB*$|u_i|$

IF error (ACE) is ZE **AND** u_i is ZE **THEN** u_f is ZE

IF error (ACE) is ZE **AND** u_i is PS **THEN** u_f is PB*$|u_i|$

IF error (ACE) is ZE **AND** u_i is PM **THEN** u_f is PM*$|u_i|$

IF error (ACE) is ZE **AND** u_i is PB **THEN** u_f is PS*$|u_i|$

The variables ACE, u_i and u_f are shown in figure 2.

The fuzzy inference employs the fuzzy logic principle to combine the IF-THEN rules in the fuzzy rules base to generate the output fuzzy set.

The final output is calculated as the weighted average of the output from each rule [11,12] i.e

$$u_f = \frac{\sum_{all\ \ rules} W_i\ O_i}{\sum_{all\ \ rules} W_i} \tag{6}$$

where W_i is the overall truth value of the premise of rule i, O_i is the output from rule i

The overall control law is obtained by combining equations (4) and (6) as given by equation (7).

$$u = u_i + u_f \tag{7}$$

4. Simulation, Results and Discussions

The test system used in this work is a two-area system made up of a thermal area and hydro area. This is a representative of the aggregate thermal and hydro generations in the Nigerian power system. The base system parameters used in the simulations are given in Table 1.

Areas	Parameters-Base 3000 MVA
Thermal 1	$T_{g1} = 0.59\,s$, $T_{t1} = 0.4\,s$, $T_{R1} = 8\,s$, $T_{R2} = 3.2\,s$, $R_1 = 2.6\,Hz/puMW$, $K_{p1} = 130\,Hz/pu\,MW$, $H_1 = 6.5\,s$, $T_{tie}^0 = 0.245$ & $B_1 = 0.425$
Hydro 2	$T_{g2} = 0.51\,s$, $T_{hR} = 10\,s$, $T_{h2} = 50\,s$, $T_w = 1.7\,s$, $R_2 = 2.24\,Hz/pu\,MW$, $K_{p2} = 112\,Hz/pu\,MW$, $H_2 = 8\,s$ & $B_2 = 0.425$

Table 1: Parameters of the Hydrothermal System

The effectiveness of the fuzzy compensated PI controller and conventional PI controller in reducing the errors to zero is shown in Figures 5, 6 and 7 for a load change of 0.1 in hydro area, 0.1 in thermal area and 0.1 in both the hydro and thermal areas respectively. It is evident from these responses that system with integral controller reaches the steady state value slower than the system with fuzzy compensated PI controller and also that the system with PI controller shows greater overshoot than system with fuzzy compensated PI controller.

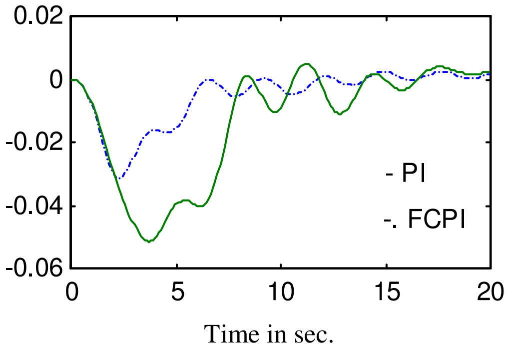


Figure 5 (a): Thermal Area Fequency Deviation (Hz)

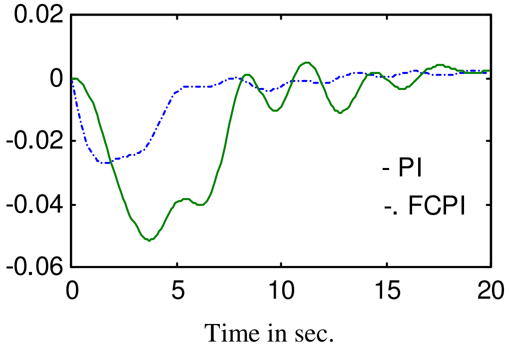


Figure 5 b: Hydro Area Frequency Deviation(Hz)

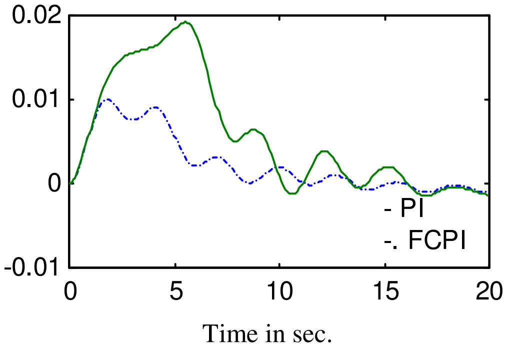


Figure 5c: Tie-line Power Deviation (p.u)

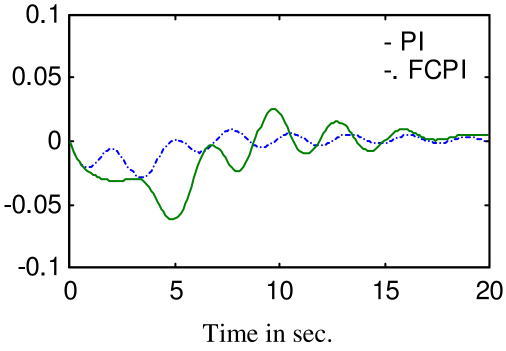


Figure 6a: Thermal Area Frequency Deviation (Hz)

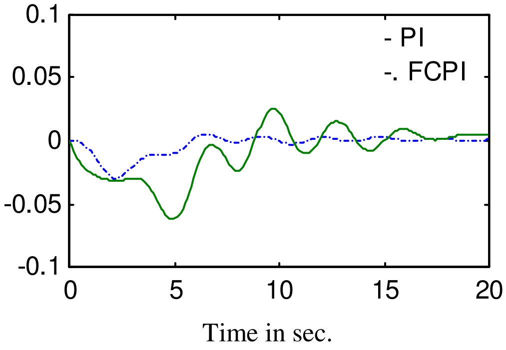


Figure 6b: Hydro Area Frequency Deviation (Hz)

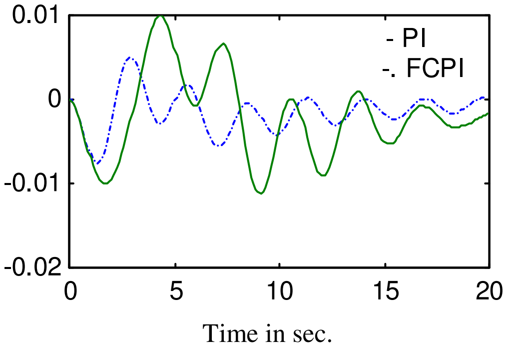


Figure 6c: Tie-line Power Deviation (p.u)

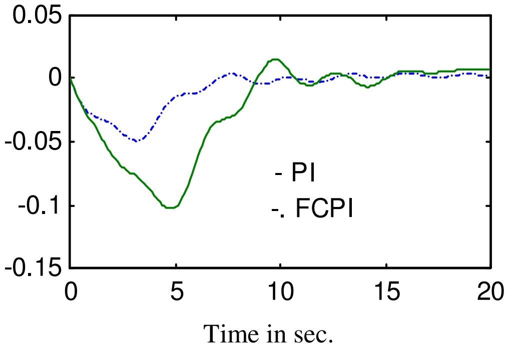


Figure 7 a: Thermal Area Frequency Deviation (Hz)

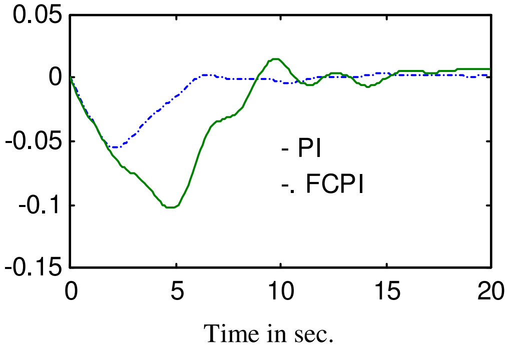


Figure 7b: Hydro Area Frequency Deviation (Hz)

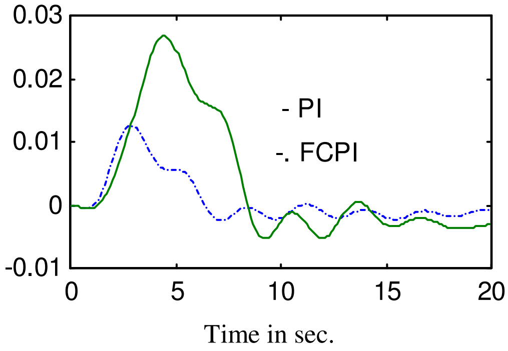


Figure 7c: Tie-line Frequency Deviation (Hz)

5. Conclusion

A fuzzy compensated PI controller has been proposed for load frequency control. The controllers have been simulated on a two area (hydrothermal) interconnected system. A comparison between conventional PI controller and the proposed fuzzy compensated PI controller reveals the effectiveness of fuzzy compensated scheme used for off nominal operating conditions.

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