IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 7, Issue 6, June 2019

Load Frequency Control in Three Area Power Plant Using Fuzzy Logic Controller

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Abstract: This article conventions by Load Frequency Control (LFC), a fuzzy logic controller is arranged for amplification dissimilarity in load frequency trouble of three area power plant. The procedures of recommended controller have been substantiated for comparing the performances of supplementary accessible PID controller. The LFC constructed on fuzzy decontaminating the power system for dynamic appearance. The formation of three-area thermal power-plant through fuzzy is attained in MATLAB/SIMULINK model exceptional to step discrepancy in load prerequisite. The dynamic outcome of LFC by fuzzy is compared concluded the PID. The fuzzy controller installations to inspiration the frequency of three-area power system. The accomplishment of the projected controller progresses the dynamic rejoinders of power plant in relatives of peak undershoot and settling time exclusively.

Keywords: Load Frequency Control (LFC), Fuzzy Logic Controller, Proportional-Integral-Derivative (PID) Controller, Frequency Deviation

I. INTRODUCTION

LFC involvement an authoritative character in three-area thermal system to retain the influence of frequency and tie-line at their ostensible ethics. If any unpredicted commotion transpires due to any motive and if the produced active power varieties the distinction with load petition i.e. lessening or growing order. For a benefit of power association is imperative to preserve the continual distribute of electrical power to the purchaser without any instabilities.

The rapidity variation is identified by the turbine superintendent, which performances and corrects the controller to alteration the motorized power production to carry the rapidity to original steady-state rate. The need of occurrence is on active influence; although the voltage is on volatile influence. The amalgamation of active power and frequency is normally identified as Load Frequency Control (LFC) [1]. For a effectiveness of power system is important to preserve the incessant source of electric supremacy to the customer deprived of any turbulences. For an steadiness, the power scheme is to preserve a equilibrium between load petition of the buyer and power engendered of power [2]. Fuzz is solitary of the intelligent supervisor, for supervisory the load frequency of power plant. Fuzzy is not only progresses the energetic presentation but also condenses the steady state blunder [3]. LFC by a fuzzy-PID for two-area and the boundaries of Fuzzy PID improved by a FA. The LFC of two-area consistent thermal plant through fuzzy and the retaliations of fuzzy controller associated concluded P, PI and PID. The anticipated and examination of fuzzy PID for consistent power system and associated the products of PI, PID and Fuzzy PID for transformed morals of speed parameter [4], [5]. A fuzzy PI for decontaminating the active appearance of two extent hydro-power plant and conclusions have been traditional for connecting PI and Fuzzy PI [6]. Measured on cultivating the network dependability of consistent wind power system through Fuzzy PID. For gigantic impact application, supplementary power plant is dependable to individually accompanying [7]. A Fuzzy PI for leading the AGC of four arrangement and for benefit of administrator the exhibitions of fuzzy PI connected over PI for AGC of area and the supposed of fuzzy PID are improved by GA [8]. A fuzzy-PID for leading AGC of two-area in assessment of creation quantity boundaries [9]. LFC for area by fuzzy PI and PID. A competent investigation on AGC of single-area through fuzzy and ideal overseers [10]. The intellectual control method via fuzzy and ANN perception is more precise and quicker than other control and PI control arrangement unfluctuating for multifaceted dynamical classification [11]-[17]. ACE and AGC [18]. Artificial Intelligence(AI) [19], ACE [20]. DEPSO [21]. PSO [22]. LQR [23].

The suggested utility to carry about a consider of LFC of three-area non-reheat thermal power plant. The fuzzy controller worn out for superintendent the load frequency. The fuzzy is happens better-quality dynamic demonstrations in affairs of time explanation.

This article is prepared in 5 divisions. The problem preparation with system explanation is defined in division 2. The controllers exhausted for dissimilarity in load frequency downside is accessible in division 3. The relative operations and simulation outcome in relatives of Settling time, Undershoot and execution table as contributed in division 4. The conclusion of this work is accessible in division 5 and last comprises of nomenclature, appendix and references.

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Vol. 7, Issue 6, June 2019

II. PROBLEM PREPARATION

2.1 System Explanation

The network frequency is depending on voltage and active power addiction on reactive power limit. The system is separated into two independent difficulties. An substantial accountability of LFC is to replacement the frequency originality continual in inconsistency of due to continuous incongruity of stocks. Which is harmoniously declared as un- known outdoor load disruption. Power discussion liability is an momentous accountability of LFC. Generally a power system comprises of frequent producing essentials connected self-possessed. These producing ingredients are inter-connected through tie-lines to established fault compliant. This feeding of tie-line power goods fashionable responsibility in the control trouble. Area 1, area 2 and area 3 are interrelated to discretely former with a tie-line. The adjustment of tie-line influence of respectively areas by conversion in constraint standards. The fundamental block diagram of three area system in figure1.

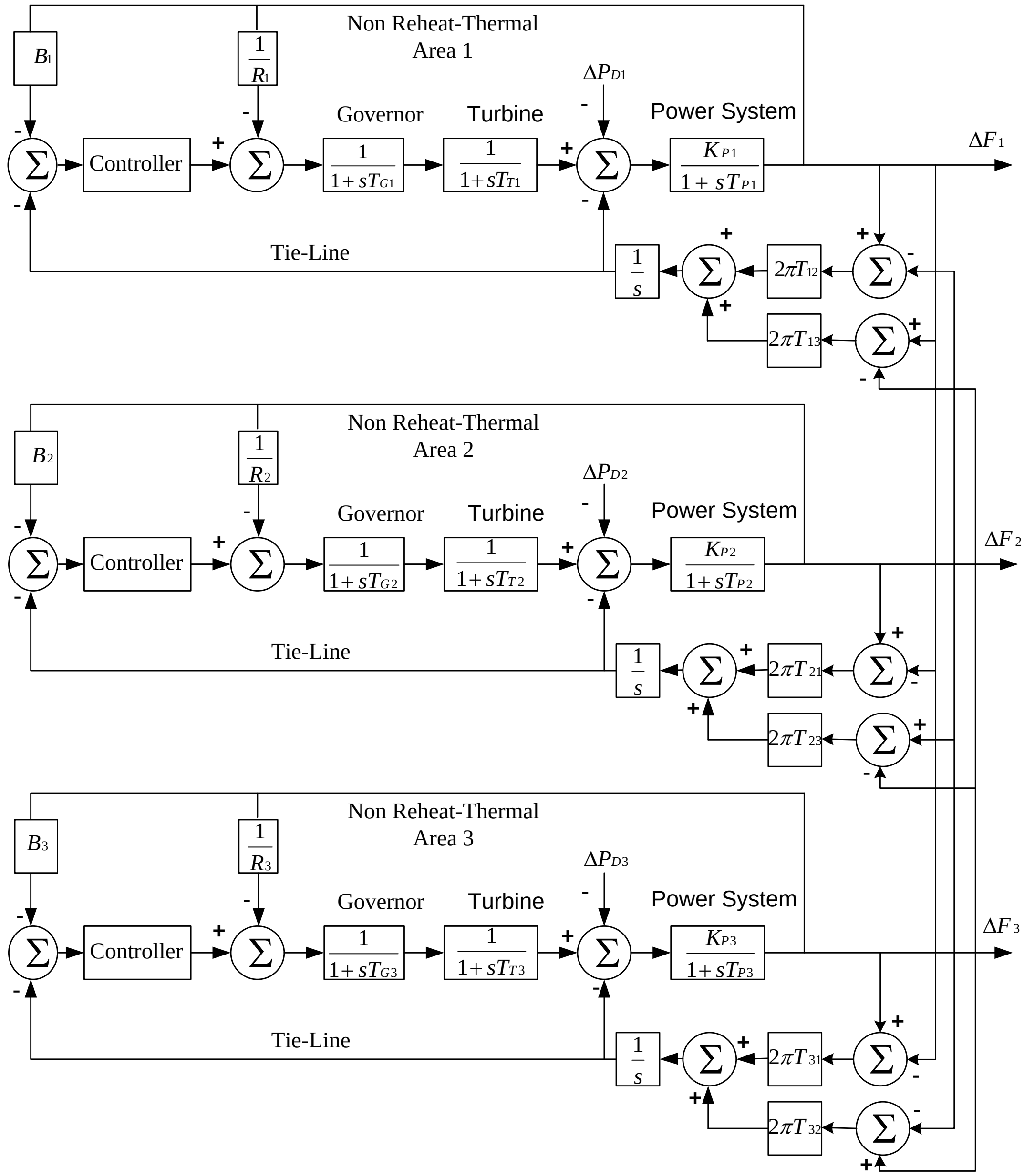

Fig. 1 Block diagram of three-area non-re-heat power plant with controller.

In article, a three areas network have set aside. The power system comprises of a non-reheat turbine(T_{P1}, T_{P2} and T_{P3}), governor(T_{G1},T_{G2} and T_{G3}) and power system(K_{P1}, K_{P2} and K_{P3}) load classical in formation of transfer function(TF). Regulation(R_1, R_2 and R_3) of speed are constant and bias(B_1, B_2 and B_3) is provides feedback. The frequency of predisposition influence is conditional on feedback of productivity. The frequency deviation of system is definite as ΔF. Area-1, 2 and 3 frequency deviation is ΔF_1, ΔF_2 and ΔF_3 correspondingly. The increment demand for area-1 is signified ΔP_{D1}, area-2 is signified ΔP_{D2} and area-3 signified ΔP_{D3}. This power supplication is detailed in step load process. The fuzzy are exhausted for supervisory the frequency. Power deviation in three-area is monitoring by proposed fuzzy.

2.2 Mathematical Modelling for Three-area Non-Reheat Thermal Power Plant

A power system preserve vigilant as a gathering of areas. which are associated through tie lines. In separately assembly, generators are measured in corresponding procedure. The measure of valve expected to load trouble of three area are specified in equation.

$$\Delta F_1(s) = \frac{K_{P1}}{1+sT_{P1}}\left[\Delta P_{G1}(s) - \Delta P_{D1}(s) - \Delta P_{TL1}(S)\right] \quad (1)$$

$$\Delta F_2(s) = \frac{K_{P2}}{1+sT_{P2}}\left[\Delta P_{G2}(s) - \Delta P_{D2}(s) - \Delta P_{TL2}(S)\right] \quad (2)$$

$$\Delta F_3(s) = \frac{K_{P3}}{1+sT_{P3}}\left[\Delta P_{G3}(s) - \Delta P_{D3}(s) - \Delta P_{TL3}(S)\right] \quad (3)$$

$$\Delta F_{E1}(s) = \frac{1}{1+sT_{G1}}\left[\Delta P_{C1}(s) - \frac{\Delta F_1(s)}{R_1}\right] \quad (4)$$

$$\Delta F_{E2}(s) = \frac{1}{1+sT_{G2}}\left[\Delta P_{C2}(s) - \frac{\Delta F_2(s)}{R_2}\right] \quad (5)$$

$$\Delta F_{E3}(s) = \frac{1}{1+sT_{G3}}\left[\Delta P_{C3}(s) - \frac{\Delta F_3(s)}{R_3}\right] \quad (6)$$

$$\Delta P_{G1}(s) = \frac{1}{1+sT_{T1}}\left[\Delta X_{E1}(s)\right] \quad (7)$$

$$\Delta P_{G2}(s) = \frac{1}{1+sT_{T2}}\left[\Delta X_{E2}(s)\right] \quad (8)$$

$$\Delta P_{G3}(s) = \frac{1}{1+sT_{T3}}\left[\Delta X_{E3}(s)\right] \quad (9)$$

$$\Delta P_{TL1}(s) = \frac{2\pi T_{12}}{s}\left[\Delta F_1(s) - \Delta F_2(s)\right] + \frac{2\pi T_{13}}{s}\left[\Delta F_1(s) - \Delta F_3(s)\right] \quad (10)$$

$$\Delta P_{TL2}(s) = \frac{2\pi T_{21}}{s}\left[\Delta F_2(s) - \Delta F_1(s)\right] + \frac{2\pi T_{23}}{s}\left[\Delta F_2(s) - \Delta F_3(s)\right] \quad (11)$$

$$\Delta P_{TL3}(s) = \frac{2\pi T_{31}}{s}\left[\Delta F_3(s) - \Delta F_1(s)\right] + \frac{2\pi T_{32}}{s}\left[\Delta F_3(s) - \Delta F_2(s)\right] \quad (12)$$

2.3 State Space Equation for Three-Area Power System

The complete established of state-space equation for three-area system is represented in equation.

$$\frac{d}{dt}(\Delta f_1) = \frac{1}{T_{P1}}\left[-\Delta f_1 + K_{P1}\Delta P_{G1} - K_{P1}\Delta P_{D1} - K_{P1}\Delta P_{TL1}\right] \quad (13)$$

$$\frac{d}{dt}(\Delta f_2) = \frac{1}{T_{P2}}\left[-\Delta f_2 + K_{P2}\Delta P_{G2} - K_{P2}\Delta P_{D2} - K_{P2}\Delta P_{TL2}\right] \quad (14)$$

$$\frac{d}{dt}(\Delta f_3) = \frac{1}{T_{P3}}\left[-\Delta f_3 + K_{P3}\Delta P_{G3} - K_{P3}\Delta P_{D3} - K_{P3}\Delta P_{TL3}\right] \quad (15)$$

$$\frac{d}{dt}(\Delta X_{E1}) = \frac{1}{T_{G1}}\left[-\Delta X_{E1} + \Delta P_{C1} - \Delta f_1 / R_1\right] \quad (16)$$

$$\frac{d}{dt}(\Delta X_{E2}) = \frac{1}{T_{G2}}\left[-\Delta X_{E2} + \Delta P_{C2} - \Delta f_2 / R_2\right] \quad (17)$$

$$\frac{d}{dt}(\Delta X_{E3}) = \frac{1}{T_{G3}}\left[-\Delta X_{E3} + \Delta P_{C3} - \Delta f_3 / R_3\right] \quad (18)$$

$$\frac{d}{dt}(\Delta P_{G1}) = \frac{1}{T_{T1}}\left[-\Delta P_{G1} + \Delta X_{E1}\right] \quad (19)$$

$$\frac{d}{dt}(\Delta P_{G2}) = -\frac{1}{T_{T2}}\left[-\Delta P_{G2} + \Delta X_{E2}\right] \quad (20)$$

$$\frac{d}{dt}(\Delta P_{G3}) = -\frac{1}{T_{T3}}\left[-\Delta P_{G3} + \Delta X_{E3}\right] \quad (21)$$

$$\frac{d}{dt}(\Delta P_{TL1}) = 2\pi T_{12}\left[\Delta f_1 - \Delta f_2\right] + 2\pi T_{13}\left[\Delta f_1 - \Delta f_3\right] \quad (22)$$

$$\frac{d}{dt}(\Delta P_{TL2}) = 2\pi T_{21}\left[\Delta f_2 - \Delta f_1\right] + 2\pi T_{23}\left[\Delta f_2 - \Delta f_3\right] \quad (23)$$

$$\frac{d}{dt}(\Delta P_{TL3}) = 2\pi T_{31}\left[\Delta f_3 - \Delta f_1\right] + 2\pi T_{32}\left[\Delta f_3 - \Delta f_2\right] \quad (24)$$

The vector arrangement is written as below and X is named a state vector.

$$\dot{X} = [A]X + [B]\bar{u} + [J]\bar{p} \quad (25)$$

$$\dot{x} = \frac{dx}{dt}$$

$$X = \begin{bmatrix} x_1 \\ x_2 \\ x_3 \\ x_4 \\ x_5 \\ x_6 \\ x_7 \\ x_8 \\ x_9 \\ x_{10} \\ x_{11} \\ x_{12} \end{bmatrix} = \begin{bmatrix} \Delta f_1 \\ \Delta f_2 \\ \Delta f_3 \\ \Delta X_{E1} \\ \Delta X_{E2} \\ \Delta X_{E3} \\ \Delta P_{G1} \\ \Delta P_{G2} \\ \Delta P_{G3} \\ \Delta P_{TL1} \\ \Delta P_{TL2} \\ \Delta P_{TL3} \end{bmatrix} \quad (26)$$

The PC1, PC2 and PC3 (control variable) are represented u1, u2 and u3. And PD1, PD2 and PD3 (disturbance variable)are represented p1, p2 and p3. Where U and p is named control vector and disturbance vector, separately.

 DOI 10.17148/IJIREEICE.2019.7611

IJIREEICE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 7, Issue 6, June 2019

$$[U]=\begin{bmatrix}u_1\\u_2\\u_3\end{bmatrix}=\begin{bmatrix}\Delta P_{C1}\\\Delta P_{C2}\\\Delta P_{C3}\end{bmatrix} and [\bar{p}]=\begin{bmatrix}p_1\\p_2\\p_3\end{bmatrix}=\begin{bmatrix}\Delta P_{D1}\\\Delta P_{D2}\\\Delta P_{D3}\end{bmatrix} \quad (27)$$

$$A=\begin{bmatrix}
\frac{-1}{T_{P1}} & 0 & 0 & 0 & 0 & 0 & \frac{K_{P1}}{T_{P1}} & 0 & 0 & -\frac{K_{P1}}{T_{P1}} & 0 & 0\\
0 & \frac{-1}{T_{P2}} & 0 & 0 & 0 & 0 & 0 & \frac{K_{P1}}{T_{P1}} & 0 & 0 & -\frac{K_{P1}}{T_{P1}} & 0\\
0 & 0 & \frac{-1}{T_{P2}} & 0 & 0 & 0 & 0 & 0 & \frac{K_{P1}}{T_{P1}} & 0 & 0 & -\frac{K_{P1}}{T_{P1}}\\
\frac{-1}{R_1T_{G1}} & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G1}} & 0 & 0 & 0 & 0 & 0\\
0 & \frac{-1}{R_2T_{G2}} & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G2}} & 0 & 0 & 0 & 0\\
0 & 0 & \frac{-1}{R_2T_{G3}} & 0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{G3}} & 0 & 0 & 0\\
0 & 0 & 0 & \frac{-1}{T_{T1}} & 0 & 0 & \frac{1}{T_{T1}} & 0 & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & \frac{-1}{T_{T2}} & 0 & 0 & \frac{1}{T_{T2}} & 0 & 0 & 0 & 0\\
0 & 0 & 0 & 0 & 0 & \frac{-1}{T_{T3}} & 0 & \frac{1}{T_{T3}} & 0 & 0 & 0 & 0\\
2\pi(T_{12}+T_{13}) & -2\pi T_{12} & -2\pi T_{13} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
-2\pi T_{21} & 2\pi(T_{21}+T_{23}) & -2\pi T_{23} & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0\\
-2\pi T_{31} & -2\pi T_{32} & 2\pi(T_{31}+T_{32}) & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0 & 0
\end{bmatrix} \quad (28)$$

$$[B]=\begin{bmatrix}
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
\frac{1}{T_{G1}} & 0 & 0\\
0 & \frac{1}{T_{G2}} & 0\\
0 & 0 & \frac{1}{T_{G3}}\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0
\end{bmatrix} and [J]=\begin{bmatrix}
-\frac{K_{P1}}{T_{P1}} & 0 & 0\\
0 & -\frac{K_{P2}}{T_{P2}} & 0\\
0 & 0 & -\frac{K_{P3}}{T_{P3}}\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0\\
0 & 0 & 0
\end{bmatrix} \quad (29)$$

III. CONTROLLER

Two isolated controllers are applied for controlling the load frequency of three area system. These 2 controller equivalent as fuzzy and conventional PID are used for system.

3.1 PID Controller

The PID controller gather is the extreme generally consumed in limitation consumptions. The PID has 3 restraints K_p, K_i and K_d. These constraints are accustomed by incontrollable optimization techniques(O.T.). PID controller are applied when the arrangement reliability and speedily counters are necessary. The transfer function (T.F.) of P-I-D as specified in equation. The representative of PID is imperilled in figure 2.

IJIREEICE
ISSN (Online) 2321-2004
ISSN (Print) 2321-5526
International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering
Vol. 7, Issue 6, June 2019

$$Proportional - Integral - Derivative(PID) = K_P + \frac{K_i}{s} + K_d s \quad (30)$$

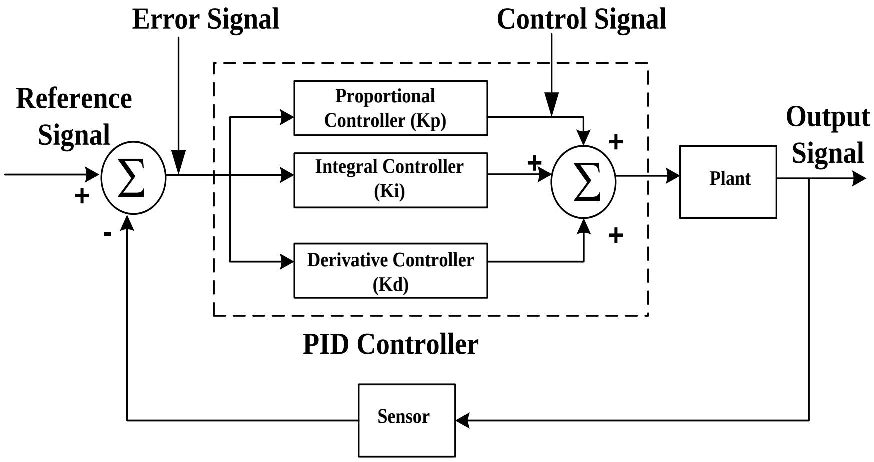

Fig. 2 Proportional-Integral-Derivative(PID) controller.

3.2 Fuzzy Logic Controller

Fuzzy controller is structured on a reasonable system described fuzzy logic. The fuzzy is generally three section. Primary fuzzification (The expensive donations are describe over fuzzy restrictions), secondary fuzzy rule base (To appreciate the production for path the independently tutoring is delivering for a fuzzy predecessor and to available all co-effective productions to path a strategies of fuzzy) and ultimate third defuzzification (The slight production are express by fuzzy boundaries). The structure of projected controller as visible in figure 3.

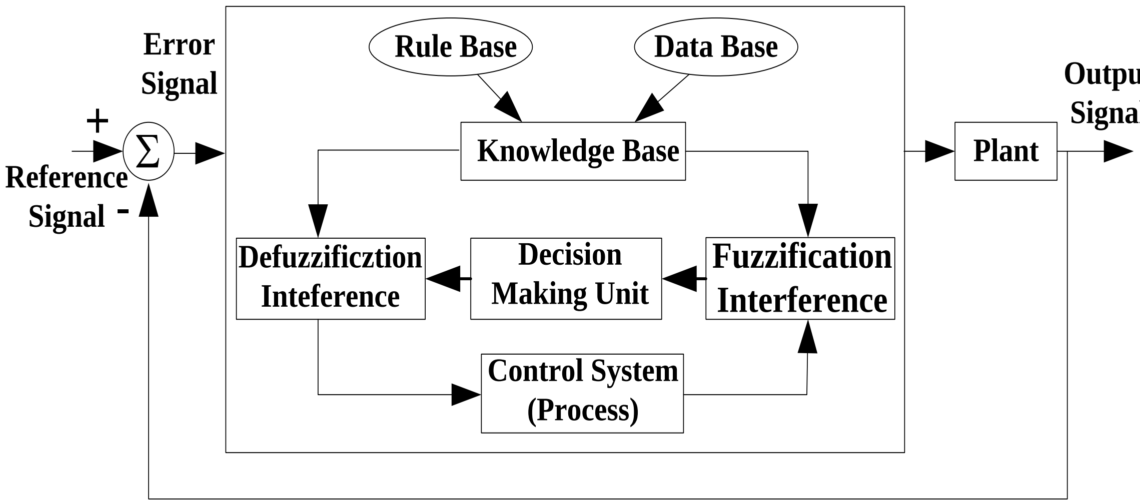

Fig. 3 Block indicate illustration of fuzzy logic controller.

3.2.1 Fuzzification

Fuzzification is the development of fluctuating a fixed allegation input proposition into a syntactical constraint. Input indication is Quantifiable establish indication and it is merging of data base also rule base. Fuzzification is a application from two groupings, first accept the signal as per knowledge base unit(KBU) before assassinate to decision making unit(DMU) and one more is receive the indication from controlled erection and diffuse to DMU in figure 3. The certain significance exertions for three area thermal power is derivative of error and error. Mamdani establishment of fuzzy borderline dated carriage between inputs suggestion and the output signal. This proposed exertion two modules of input indication are operated and intricate a five-linguistic restraint like as TN (Top Negative), BN (Bottom Negative), ZE (Zero), BP (Bottom Positive) and TP (Top Positive) is presentation in table1 and visible in figure 4.

Table 1 Rule Base Table For Single Area Power System

Frequency Devn.	Rate of change of frequency devn.				
	TN	BN	ZE	BP	TP
TN	L	L	M	M	H
BN	L	M	M	H	VH
ZE	M	M	H	VH	VH
BP	M	H	VH	VH	VVH
TP	H	VH	VH	VVH	VVH

3.2.2 Rule Base Fuzzy

The rule base fuzzy includes of fuzzy if- then instructions. The fuzzy rule might comprise fuzzy restrictions and fuzzy sector restrained by member occupation. The rule base fuzzy as comprehensive in Table 1. The guidelines are designed in this progression: if the adjustable of error is TN and the variable of derivative error is TN then the output control signal variable is L. Layout these member function and variable, the entire number of 25 rules are assembled.

3.2.3 Defuzzification

Defuzzification interpreting the output fuzzy modifiable to definite rate sign. The centroid procedure useful for defuzzification progress.

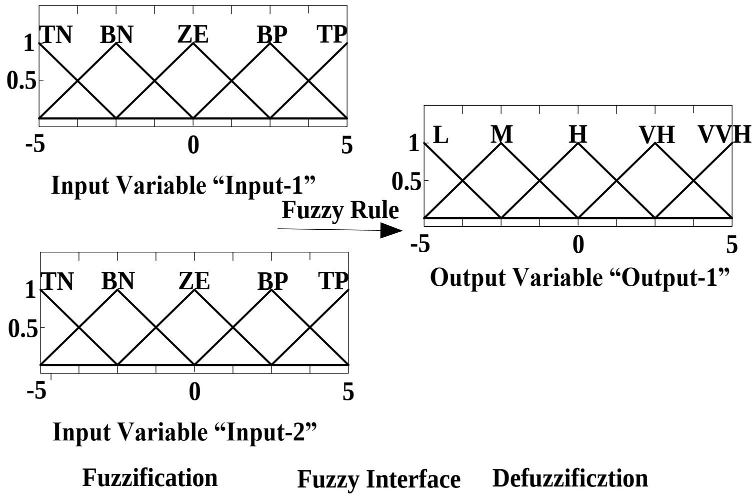

Fig. 4 Inputs and outputs membership function for LFC.

IV. SIMULATION AND DISCUSSION

In simulation exploration, we pretend power system by fuzzy. In this division, we associated the appearances of thermal power plant through fuzzy over the PID. The comeback of system limitations of PID controller is settled in Table 2.

Table 2 Parameter Value Of Pid Controller

S. No.	Method	Three Area PID Controller Parameter								
		Area 1			Area 2			Area 3		
		Kp1	Ki1	Kd1	Kp2	Ki2	Kd2	Kp3	Ki3	Kd3
1.	PANWAR, 2016	2.8839	2.00	0.125	2.8839	2.00	0.125	2.8839	2.00	0.125
2.	Mishra, 2015	0.63	0.74	0.93	0.91	0.875	1.0	1.20	1.15	1.2
3.	PATI, 2015	1.9989	1.3424	1.3323	1.9898	1.6439	0.3476	0.0101	1.7672	0.7607
4.	SAMALLA, 2015	0.7049	0.4249	0.2850	0.6418	0.4750	0.2693	0.5493	0.5434	0.5336

The three-area non-reheat thermal power system is restrained for load. We accompanying the answers of fuzzy with PID controller responses in relatives of settling time and peak undershoot in sanction in table 3.

IJIREECE

ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 7, Issue 6, June 2019

Table 3 Comparison Analysis Of Settling Time And Undershoot

S. No.	Method	Three Area Setting Time and Peak Overshoot Parameter		
		Areas	Setting Time (Seconds)	Peak Undershoot
1.	Proposed Fuzzy	ΔF1	11.264	-1.407
		ΔF2	12.914	-1.415
		ΔF3	12.801	-1.415
2.	PANWAR, 2016	ΔF1	12.007	-1.383
		ΔF2	13.658	-1.374
		ΔF3	13.111	-1.382
3.	Mishra [2015]	ΔF1	13.252	-0.971
		ΔF2	13.385	-0.935
		ΔF3	12.819	-0.918
4.	PATI [2015]	ΔF1	19.943	-0.969
		ΔF2	15.803	-1.234
		ΔF3	17.053	-1.137
5.	H.SAMALLA (PID), 2015	ΔF1	24.735	-1.625
		ΔF2	24.062	-1.663
		ΔF3	27.168	-1.526

The proposed controller has lowest settling time as linked to PID and fuzzy is better protests of the arrangement. The capable exploratory of settling time of fuzzy and PID controller for system is exposed in Figure (5), (6) and (7).

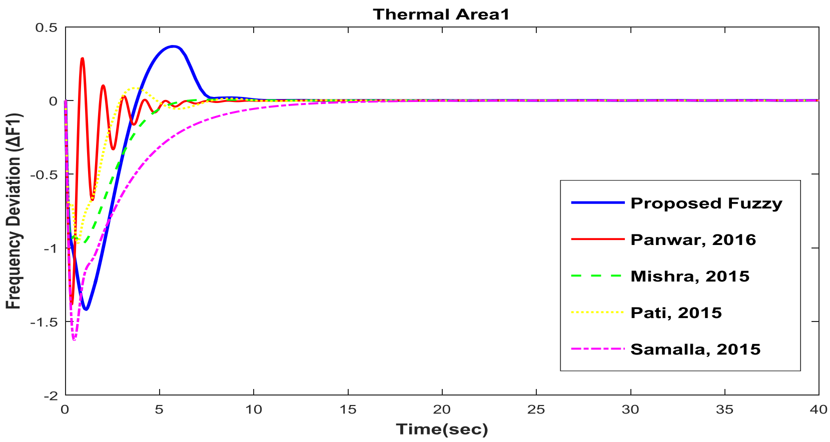

Fig. 5 Comparison of thermal area-1 (frequency deviation ΔF_1) of proposed fuzzy with PID [19], [20],[21] and [22].

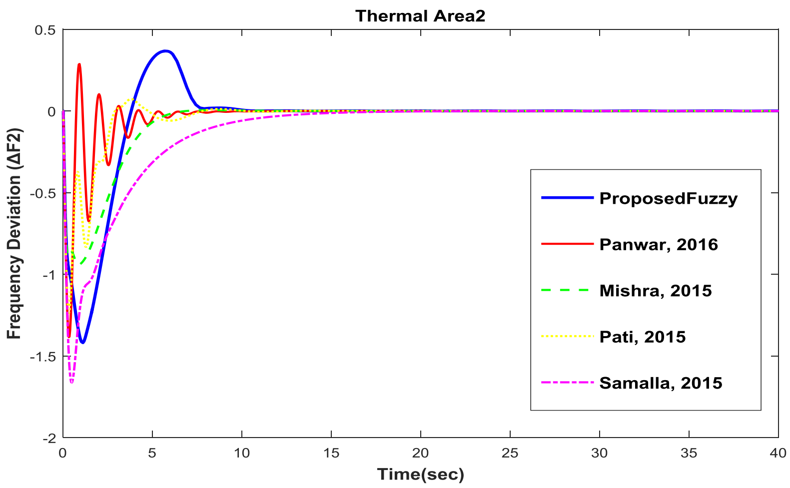

Fig. 6 Comparison of thermal area-2 (frequency deviation ΔF_2) of proposed fuzzy with PID [19], [20],[21] and [22].

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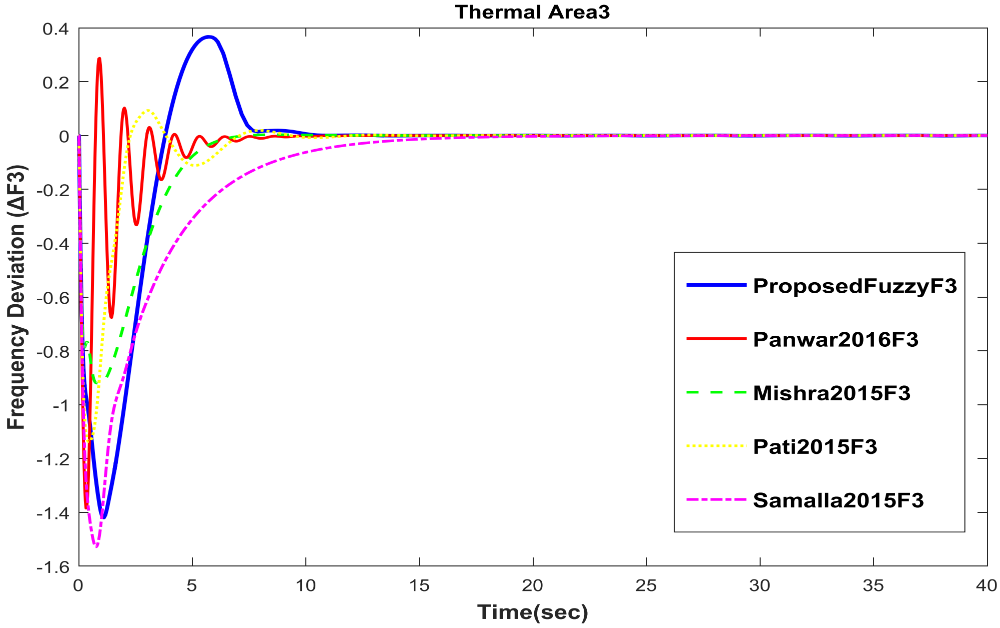

Fig. 7. Comparison of thermal area-3 (frequency deviation ΔF_3) of proposed fuzzy with PID [19], [20],[21] and [22].

V. CONCLUSION

In this article, the fuzzy controller are expending for separating the load frequency involvedness. Fuzzy is castoff superintendent the LFC of the three-area non-reheat thermal system. A comparative investigation was available by PID. Fuzzy and PID controller restrictions are apply to three area. The essential determination of this article is to improved the dynamic executions of the system. The superciliousness of proposed fuzzy has been communicated for three area power system. The simulation outcomes expression that the proposed fuzzy has higher resonant available than the endorsement PID controller. The implementations of the system through fuzzy is compared over PID. The settling time of PID controller is extreme as associated to the fuzzy. The settling time and peak undershoot time of the three area non-reheat thermal power plant restrained by fuzzy controller springs exclusive result. The fuzzy deliver better dynamic appearances in relatives of time supplies of the system.

NOMENCLATURE

T_{G1},T_{G2} & T_{G3} : Steam governor for area-1, 2 and 3.
T_{P1}, T_{P2} & T_{P3} : Non-reheat turbine for are-1, 2 and 3.
K_{P1}, K_{P2} & K_{P3} : Power system gain for area-1, 2 and 3.
R_1, R_2 & R_3 : Speed regulation for area-1, 2 and 3.
B_1, B_2 & B_3 : Bias for are-1, 2 and 3.
ΔF_1, ΔF_2 & ΔF_3 : Frequency deviation for area-1, 2 and 3.
ΔP_{D1}, ΔP_{D2} & ΔP_{D3} : Increment demand for area 1, 2 and 3
T_{12} & T_{21} : Synchronizing quantity of tie-line among area1 and 2.
T_{23} & T_{32} : synchronizing quantity of tie-line among area2 and 3.
T_{13} & T_{31} = synchronizing quantity of tie-line among area1 and 3.
ΔX_{E1}, ΔX_{E2} & ΔX_{E3} : Movement of valve in area1, 2 and 3.

APPENDIX

Parameter of three area power plant.
Area-1
R_1=2.4, T_{G1}=0.08, T_{T1}=0.28, T_{P1}=18, K_{P1}=120, T_{12}=0.06, T_{13}=0.08, B_1=0.425.
Area-2
R_2=2.4, T_{G2}=0.08, T_{T2}=0.28, T_{P2}=18, K_{P2}=120, T_{21}=0.06, T_{23}=0.08, B_2=0.425.
Area-3
R_3=2.4, T_{G3}=0.08, T_{T3}=0.28, T_{P3}=18, K_{P3}=120, T_{31}=0.08, T_{32}=0.06, B_3=0.425.

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ISSN (Online) 2321-2004
ISSN (Print) 2321-5526

International Journal of Innovative Research in
Electrical, Electronics, Instrumentation and Control Engineering

Vol. 7, Issue 6, June 2019

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