International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-4 Issue-7, December 2014

Study and Analysis of LFC with Wind Plant in Two Area Power System through Fuzzy Inference Technique

K. Harinadha Reddy

Abstract*—The proposed work is mainly about the study and analysis of load frequency control (LFC) of two area power system consisting thermal power plant and wind power plant. Output of wind plant connected in interconnected power system is regulated with help of Fuzzy Inference Technique. Three Adaptive Neuro-Fuzzy Inference System (ANFIS) controllers are used in proposed work. Gain of speed regulation is controlled by first ANFIS. Two Adaptive Neuro-Fuzzy Inference System's are used to obtain control over the wind and thermal power plant gains. Inputs for FLC are obtained from change in frequency and derivative of change in frequency of interconnected power system. Fuzzy logic Controller (FLC) inputs are properly and carefully taken for obtaining control vector from defuzzified output of FLC. The output of self tuned FLC with all ANFIS's in two plants are shown their performance under test conditions.*

Index Terms: Load Frequency Control, Interconnected Power System, Wind Power Plant, Fuzzy Logic Controller and Adaptive Neuro-Fuzzy Inference System.

NOMENCLATURE

P_G, P_D	Generator, load powers
ΔP_{G1} - ΔP_{D1}	Net Surplus Power
$\Delta P_{tie\text{-}1}$, $\Delta P_{tie\text{-}1}$	Incremental tie line power in area-1, 2
CA-1,CA-2	Control Area-1 and Control Area-2
ΔP_{C1} - ΔP_{C2}	Input Power Commands in CA-1, CA-2
ΔF_1, ΔF_2	Change in frequency in Control Area-1, 2
δ_1, δ_2	Nominal phase angles of voltages and V_1, V_2
T_{12}	Synchronizing coefficient
ΔF	Frequency deviation (ΔF_1-ΔF_2)
$\Delta\delta$	Phase angle deviation
T_{p1}, T_{p2}	Time constants of Plant-1,2
T_{g1}, T_{g2}	Time constants of speed governor-1,2
K_{g1}, K_{g2}	Gains of speed governor-1,2
K_{p1}, K_{p2}	Gains of Plant-1 and Plant-2
R_1,R_2	Feedback gains control area-1,2
D_1, D_2	Speed regulation of governor
B_1, B_2	Load damping parameters
H_1,H_2	Inertia Constant generator-1,2
u	Control vector from output of FLC
u_1,u_2	Control vector from output of ANFIS-2, ANFIS-3

I. INTRODUCTION

In modern power scenario, there is a very essential to control of power generation and transmission for obtaining smooth operation of power industry. The modern power systems with industrial and commercial loads need to operate at constant frequency with reliable power.

Manuscript published on 30 December 2014.
***Correspondence Author(s)**
Dr. K. Harinadha Reddy, Professor, Department of EEE, L B R College of Engineering (Autonomous), Mylavram, Krishna District, A.P., India.

Load Frequency Control (LFC) is a very important issue in power system operation and control for supplying sufficient and reliable electric power with good quality. Two area inter connected power system is considered with two plants, one is thermal power plant model [21] and other one is wind firm. In wind firm speed variations [5] are to be controlled, such that frequency of tie line of interconnected system must not be effected for transmission. Fuzzy [25] based type of controller gives better results in such system control and also to reducing the steady state and transient state error. FLC with other techniques like Genetic Algorithm, Neural nets and optimization techniques are using for the purpose of system manage and control in required area of field. When unrestrained case, more oscillation, negative overshoot be observed but while comparing to conventional type controller P,PI and PID. Also proposed work and simulation result gives better performances of dynamic responses.

Test system used for simulation of interconnected power system is typically divided into control areas, with each consisting of one or more power utility firms. Sufficient supply for generation of each connected area to meet the load demand of its users, load frequency control [5] is one of them. In this work, test system with two areas is considered; both are used to determine the parameters of change in frequency of power plant in interconnected power system and tie line power according to the system dynamics and statistics. Both conventional and fuzzy techniques are similar in the sense that these two techniques are popular to obtain user require control over the designed system parameters with all constrains of load demand.

II. SYSTEM MODELLING

Power system model used for testing in proposed work with interconnected areas is represented by schematic diagram which is shown in figure 1. The detailed designed model of two area power system with wind plant for load frequency control investigation is shown simulation model. Power flow in each stage i.e. governor, turbine and generator of power plant is clearly depicted in schematic diagram. Also general load at the stage of generator is considered for test case. Each control area as possible supply its own load demand [13] and power transfer through tie line should be on mutual agreement. All control areas [16] should controllable to the specific range of frequencies control. In an inaccessible control area case the incremental power ($\Delta P_G - \Delta P_D$) was accounted for by the rate of increase of stored kinetic energy and increase in load caused by change of frequency.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

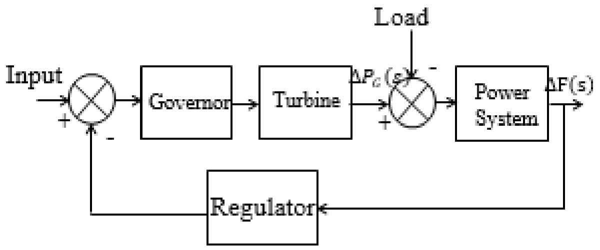

Figure 1. Block Diagram of test Power System

For analysis of load frequency control, power system with single generator that supplying power to load is considered. Mathematical model of power system is shown in figure 2 with block diagram components.

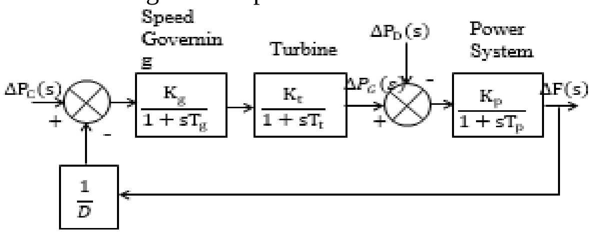

Figure 2. Mathematical Modelling of Block Diagram of test Power System

In order to analyse the load frequency control [4] of power system with mathematical modelling, the needful transfer functions [15] of Speed Governor, Turbine and plant are shown as 1st, 2nd and 3rd term of equation(1).

$$\text{i)}\ \frac{K_g}{1+sT_g}\quad \text{ii)}\ \frac{K_t}{1+sT_t}\quad \text{iii)}\ \frac{K_p}{1+sT_p} \qquad (1)$$

A. GENERATOR-LOAD MODEL

Mathematical model of Generator[6] which supply power to load

$$\Delta P_G - \Delta P_D = \left(\frac{2H}{f_0}\frac{d}{dt}\Delta f\right) + (B\Delta f) \qquad (2)$$

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f_0}s} \qquad (3)$$

$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)] \times \frac{K_P}{1+sT_P} \qquad (4)$$

And we can represent block diagram in figure 3.

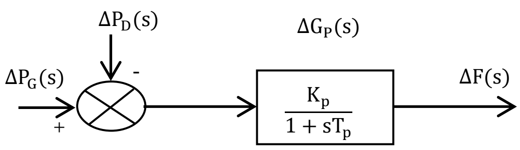

Figure 3. Block diagram of Generator-Load Model

Steady state response with $\Delta P_C = 0$ and for step load change

$$\Delta F(s) = \frac{-K_P \times \Delta P_D(s)}{(1+sT_P) + \left[\frac{K_g K_t K_p}{(1+sT_g)(1+sT_t)}\right]} \qquad (5)$$

B. INTERCONNECTED POWER SYSTEM

If losses of tie line[4,15] are neglected, then power transfer equation

$$P_{tie-1} = \frac{|V_1|\,|V_2|}{X_{12}} \operatorname{Sin}(\delta_1^0 - \delta_2^0) \qquad (6)$$

δ_1, δ_2 – Nominal phase angles of voltages and V_1, V_2 at both ends.

Incremental frequency,

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}(\Delta\delta) \qquad (7)$$

$\Delta\delta$ – Phase angle deviation

Incremental tie line power in Area-1, 2

$$\Delta P_{tie-1} = 2\pi\, T_{12}\left[\int \Delta f_1\, dt - \int \Delta f_2\, dt\right] \text{p.u.} \qquad (8)$$

$$\Delta P_{tie-2} = 2\pi\, T_{21}\left[\int \Delta f_2\, dt - \int \Delta f_1\, dt\right] \text{p.u.} \qquad (9)$$

Net Surplus Power

$$\Delta P_{G1} - \Delta P_{D1} = \frac{2H_1}{f}\frac{d}{dt}(\Delta f_1) + B_1\Delta f_1 + \Delta P_{tie-1} \qquad (10)$$

Laplace transform of above equation

$$[\Delta P_{G1}(s) - \Delta P_{D1}(s) - \Delta P_{tie-1}]G_{p1}(s) = \Delta F_1(s) \qquad (11)$$

Block diagram of system is depicted in figure 4.

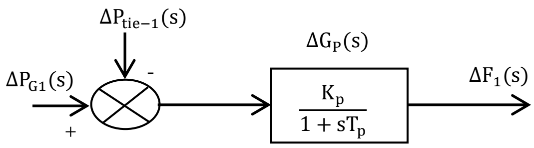

Figure 4. Mathematical of Model of Interconnected Power System block diagram

III. PROPOSED FUZZY INFERENCE METHOD FOR TEST SYSTEM

Three fuzzy inference controller i.e ANFIS's are used in simulation of test system with all defined transfer functions of block diagram shown in figure 1 and figure 2. Original values of data set are change in frequencies $\Delta F_1$and ΔF_2 are used for improving transient response of power system ANFIS's and fuzzy controller. ANFIS is most versatile [28] technique in available solutions of literature and hence ANFIS along with FLC are used in proposed method. The control vectors from ANFIS's used in both wind and thermal power plants as shown in following figure 5.

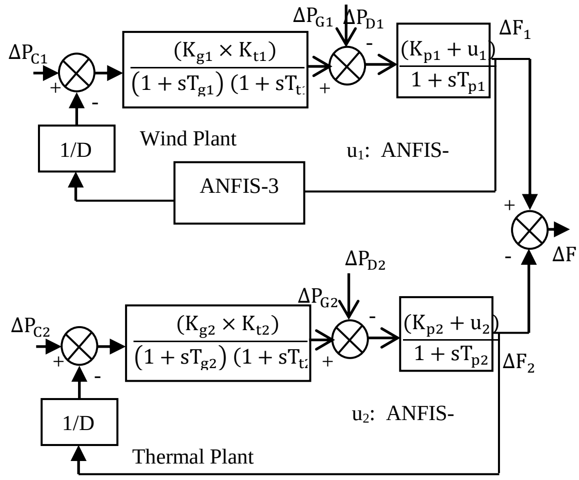

Figure 5: Block diagram of test power system with three ANFIS's

International Journal of Innovative Technology and Exploring Engineering (IJITEE)
ISSN: 2278-3075 (Online), Volume-4 Issue-7, December 2014

A. DESIGN OF FUZZY INFERENCE TECHNIQUE FOR TEST SYSTEM

Fuzzy inference system is popular technique that maps input characteristics to output characteristics with fulfilling of user require constraints. Fuzzy inference system is obtained from the model of ANFIS derives its name from Adaptive Neuro-Fuzzy Inference system and three ANFIS's are used in proposed method.

The gain of speed governor is controlled by ANFIS-1. The inputs for ANFIS-1 are error in frequency, ΔF from output of plant-1, and change in error in frequency, $\Delta\dot{F}$ from output of plant-1. Design of ANFIS-1 using MATLAB Simulink is shown in figure 6.

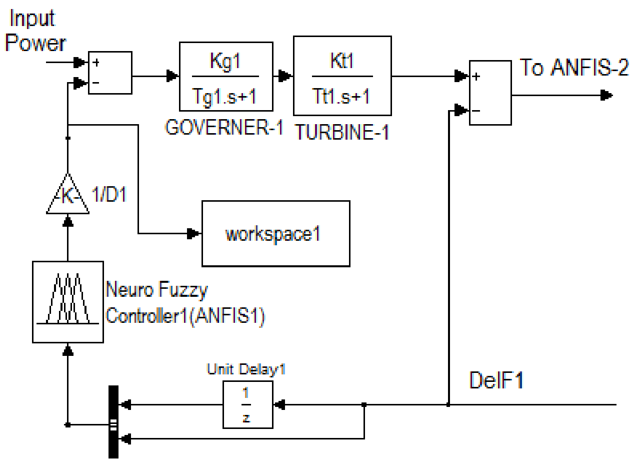

Figure 6: Simulink diagram of ANFIS-1

ANFIS-2 is used for plant-2 and numerator of the transfer function[9] of wind plant is represented

$$\Delta F_1 = [\Delta P_{G1} - \Delta P_{D1}] \times \frac{(K_{P1} + u_1)}{1 + sT_{P1}} \qquad (12)$$

Where u_1 is control vector from ANFIS-2. Disgn of ANFIS-2 using MATLAB Simulink is shown in figure 7.

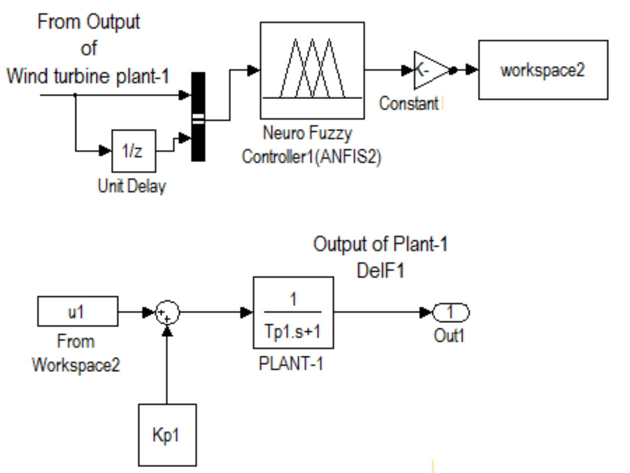

Figure 7: Simulink diagram of ANFIS-2

In test system, ANFIS-3 is designed to thermal plant and similarly the transfer function of thermal plant is represented

$$\Delta F_2 = [\Delta P_{G2} - \Delta P_{D2}] \times \frac{(K_{P2} + u_2)}{1 + sT_{P2}} \qquad (13)$$

Where u_2 is control vector from ANFIS-3. Design of ANFIS-2 using MATLAB Simulink [7] is shown in figure 7.

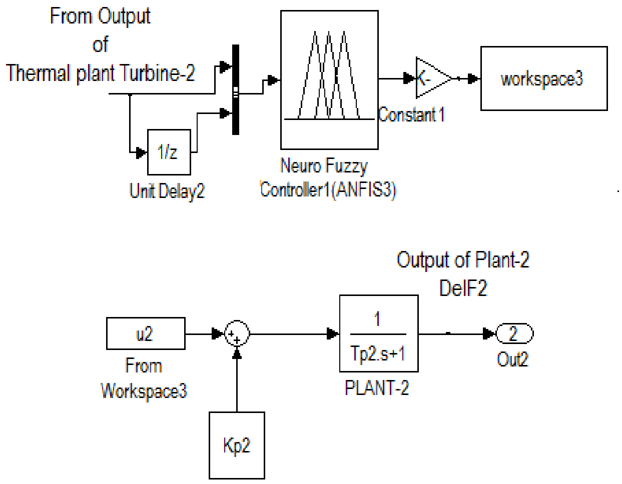

Figure 8: Simulink diagram of ANFIS-3

Input and output membership functions of ANFIS's are taken as trapezoidal and triangular membership functions respectively. And also 5 numbers of membership functions are used in two inputs and one output of ANFIS. First and second inputs of ANFIS's are shown in figures 9 and 10.

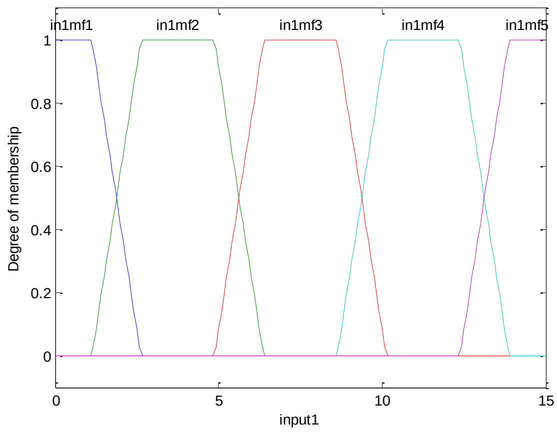

Figure 9. ANFIS Mebembership funtions of Input-1

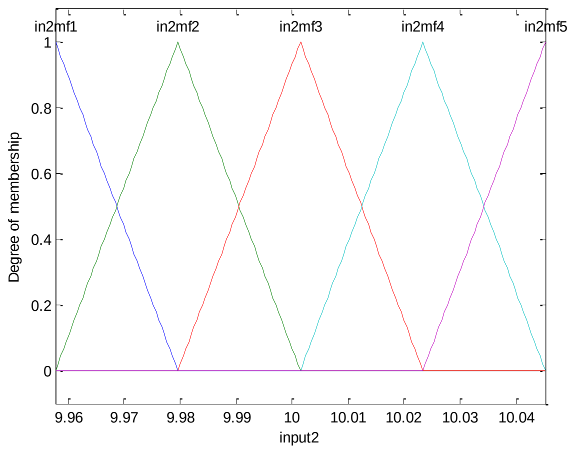

Figure 10. ANFIS Mebembership funtions of Input-2

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

ANFIS with two inputs and one output with 25 rules is shown in figure 11.

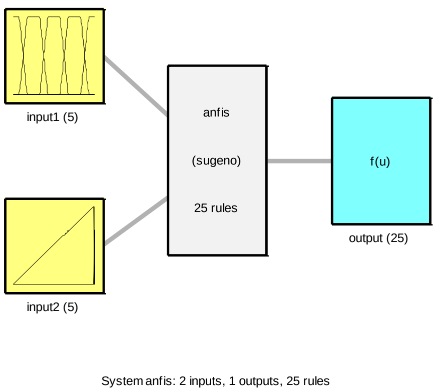

Figure 11. Two input and one output ANFIS structure

The oscillations in frequency deviation in plant-1 and plant-2 are considerably reduced by incorporating control vectors from the different ANFIS's.

B. FUZZY LOGIC CONTROLLER AT TIE-LINE INTERCONNECTION OF POWERSYSTEM

The main components of fuzzy control system are the following blocks:

i) Fuzzification,
ii) Rule base and Inference engine
iii) Defuzzification.

Merits of fuzzy logic controllers are mainly solves the non linear problems with vague inputs, not needed an accurate mathematical model, handling nonlinearity. For controlling such a complicated system, fuzzy logic controllers [6] gives very good results like this application. Inputs of fuzzy logic controller are used from wind turbine plant and thermal plant.

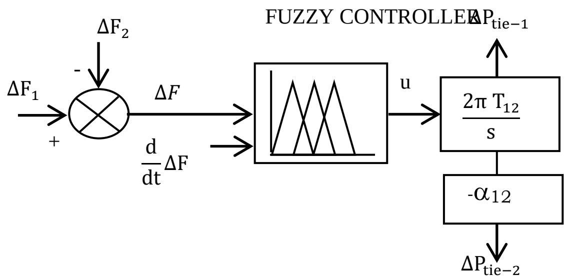

Figure 12. Fuzzy Logic Controller with interconnected power system

Inputs to a fuzzy logic controller are usually a frequency deviation and change in frequency deviation. Here the two inputs for fuzzy logic controller are ΔF and $\Delta \dot{F}$. The values that indicate input variables change of frequency and derivative of change in frequency. Linguistic terms used for the membership functions are such that, the terms will be NL(Negative Large), NM(Negative Medium), NS(Negative Small), ZE(Zero), PS(Positive Small), PM(Positive Medium) and PL(Positive Large).

Fuzzification block converts crisp inputs to one or many membership grade values; where the change in frequency and derivative of change in frequecy accordance with variation of tie-line power, are described by membership functions given in Figure 13 and Figure 14. Membership function [6] of output of control vector is shown in Figure 15. Afterwards, it is possible to apply descriptive rules of reasoning power searching was POSITIVE and LARGE and the last change of desired change in frequency was PL then keeps tracking the derivative of change in frequency in the same PL direction with PL increment. Rules like this are involved in block "rules table", and they are given in Table 2. Finally, the fuzzy set of output reference change in frequency is back "deffuzified" to convert it into the actual value.

That means the output values are PL, PM, ZE, SMALL are translated to numbers which indicates a measurable (but normalized) value of the change in frequency. It could be also noticed the output of controller is added by control vector in order to avoid local minima in characteristics due to the changes in frequency value. That means the output values such are PB, PM, PS are translated to numbers which indicates a measurable (but normalized) value of the changes in frequency. Min-max implication method has been used for getting output from all rules of decision table.

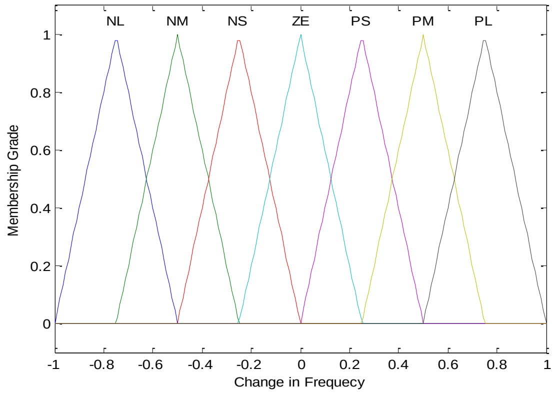

Figure 13. 1st Input membership functions, ΔF

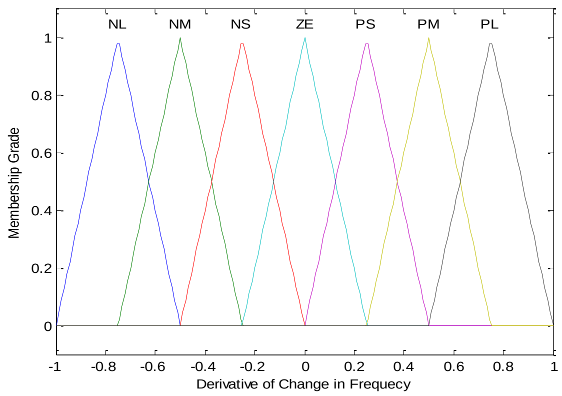

Figure 14. 2nd Input membership functions, $\Delta \dot{F}$

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)

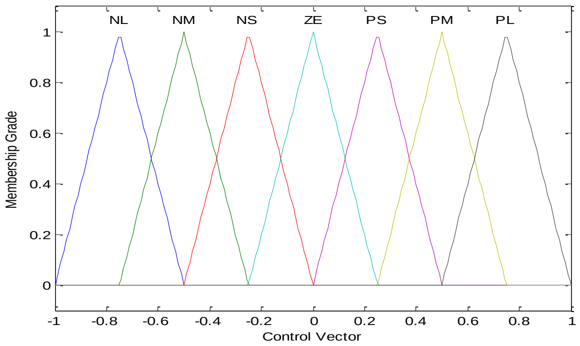

Figure 15. Output Membership Function, u

Fuzzy control is based on a logical system called fuzzy logic. It is much close in spirit to human thinking and natural language than classical logical systems. The LFC has been reported in several papers is to maintain balance between production and consumption of electrical power. Due to the complexity and multi-variable nature of power systems, a conventional control method has not provided satisfactory solutions. The fuzzy logic control has tried to handle the robustness, reliability and nonlinearities associated with power system controls.

The block diagram of figure 2 shows the single area fuzzy load frequency controller. It uses two input membership variables (frequency deviation ΔF and derivative of change in frequency deviation, $\Delta\dot{F}(s)$). Fig. 9, 10 and 11 shows the membership functions for the ΔF , ΔḞ(s) and the control output u. The input signals[6] are first expressed in some linguistic variables using fuzzy set notations such as NL(Negative Large), NM(Negative Medium), NS(Negative Small), ZE(Zero), PS(Positive Small), PM(Positive Medium) and PL(Positive Large).

Table 1: Decision table of 7×7 rule base

ΔF(s)	ΔḞ(s)						
	NL	NM	NS	ZE	PS	PM	PL
NL	ZE	PS	PM	PL	PL	PL	PL
NM	NS	ZE	PS	PM	PM	PL	PL
NS	NM	NS	ZE	PS	PS	PM	PL
ZE	NM	NM	NS	ZE	PS	PM	PM
PS	NL	NM	NS	NS	ZE	PS	PM
PM	NL	NL	NM	NM	NS	ZE	PS
PL	NL	NL	NL	NL	NM	NS	ZE

Table 1 shows a set of decision rules[9], also expressed in linguistic variables relating input signals to the control signal.

The rules[9] interpreted as follows:

1. If (ΔF(s) is NL) and (ΔḞ(s) is NL) then (Control Vector, u is ZE)
2. If (ΔF(s) is NL) and (ΔḞ(s) is NM) then (Control Vector, u is PS)
3. If (ΔF(s) is NL) and (ΔḞ(s) is NS) then (Control Vector, u is PM)
4. If (ΔF(s) is NL) and (ΔḞ(s) is ZE) then (Control Vector, u is PL)
5. If (ΔF(s) is NL) and (ΔḞ(s) is PS) then (Control Vector, u is PL)
6. If (ΔF(s) is NL) and (ΔḞ(s) is PM) then (Control Vector, u is PL)
7. If (ΔF(s) is NL) and (ΔḞ(s) is PL) then (Control Vector, u is PL)
8. If (ΔF(s) is NM) and (ΔḞ(s) is NL) then (Control Vector, u is NS)
9. If (ΔF(s) is NM) and (ΔḞ(s) is NM) then (Control Vector, u is ZE)
10. If (ΔF(s) is NM) and (ΔḞ(s) is NS) then (Control Vector, u is PS)
11. If (ΔF(s) is NM) and (ΔḞ(s) is ZE) then (Control Vector, u is PM)
12. If (ΔF(s) is NM) and (ΔḞ(s) is PS) then (Control Vector, u is PM)
13. If (ΔF(s) is NM) and (ΔḞ(s) is PM) then (Control Vector, u is PL)
14. If (ΔF(s) is NM) and (ΔḞ(s) is PL) then (Control Vector, u is PL)
15. If (ΔF(s) is NS) and (ΔḞ(s) is NL) then (Control Vector, u is NM)
16. If (ΔF(s) is NS) and (ΔḞ(s) is NM) then (Control Vector, u is NS)
17. If (ΔF(s) is NS) and (ΔḞ(s) is NS then (Control Vector, u is ZE)
18. If (ΔF(s) is NS) and (ΔḞ(s) is ZE) then (Control Vector, u is PS)
19. If (ΔF(s) is NS) and (ΔḞ(s) is PS) then (Control Vector, u is PS)
20. If (ΔF(s) is NS) and (ΔḞ(s) is PM) then (Control Vector, u is PM)
21. If (ΔF(s) is NS) and (ΔḞ(s) is PL) then (Control Vector, u is PL)
22. If (ΔF(s) is ZE) and (ΔḞ(s) is NL) then (Control Vector, u is NM)
23. If (ΔF(s) is ZE) and (ΔḞ(s) is NM) then (Control Vector, u is NM)
24. If (ΔF(s) is ZE) and (ΔḞ(s) is NS) then (Control Vector, u is NS)

Similarly remaining all rows of decision table will be written as ‘IF’ and ‘THEN’ propositions. Propositions (IF, THEN) with all 49 rules are used to develop programming code in MATLAB. After developing rule base, MATLAB programming is used for implementation of all rules.

IV.SIMULATION OF TEST SYSTEM AND RESULTS

MATLAB simulink is used for simulation two area test power system. Each area is represented by governor, turbine and plant; also two areas are combined with tie line. Developed MATLAB simulink [7] diagram of test system and shown in figure 16. For ANFIS-1, two inputs are taken from plant output and unit delay of plant output. ANFIS-1 controls the gain of speed governor of wind power plant. For ANFIS-2, two inputs are taken from governor output of wind plant and unit delay of governor output of wind plant [9].

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Output of ANFIS-2 is control vector, u_1 taken to workspace and normalized accordingly. Control vecotor, u_1 is always add with gain of the plant-1. For ANFIS-3, two inputs are taken from governor output of thermal plant and unit delay of governor output of thermal plant. Output of ANFIS-3 is control vector, u_2 taken to workspace and normalized accordingly. Control vecotor, u_2 is always add with gain of the plant-2. For Fuzzy controller , two inputs are taken from frequency deviation and derivative of frequency deviation. Output of fuzzy controller[9] is control vector, u taken to workspace and normalized accordingly. Control vecotor, u is always add with constant of tie-line of interconnected power system.

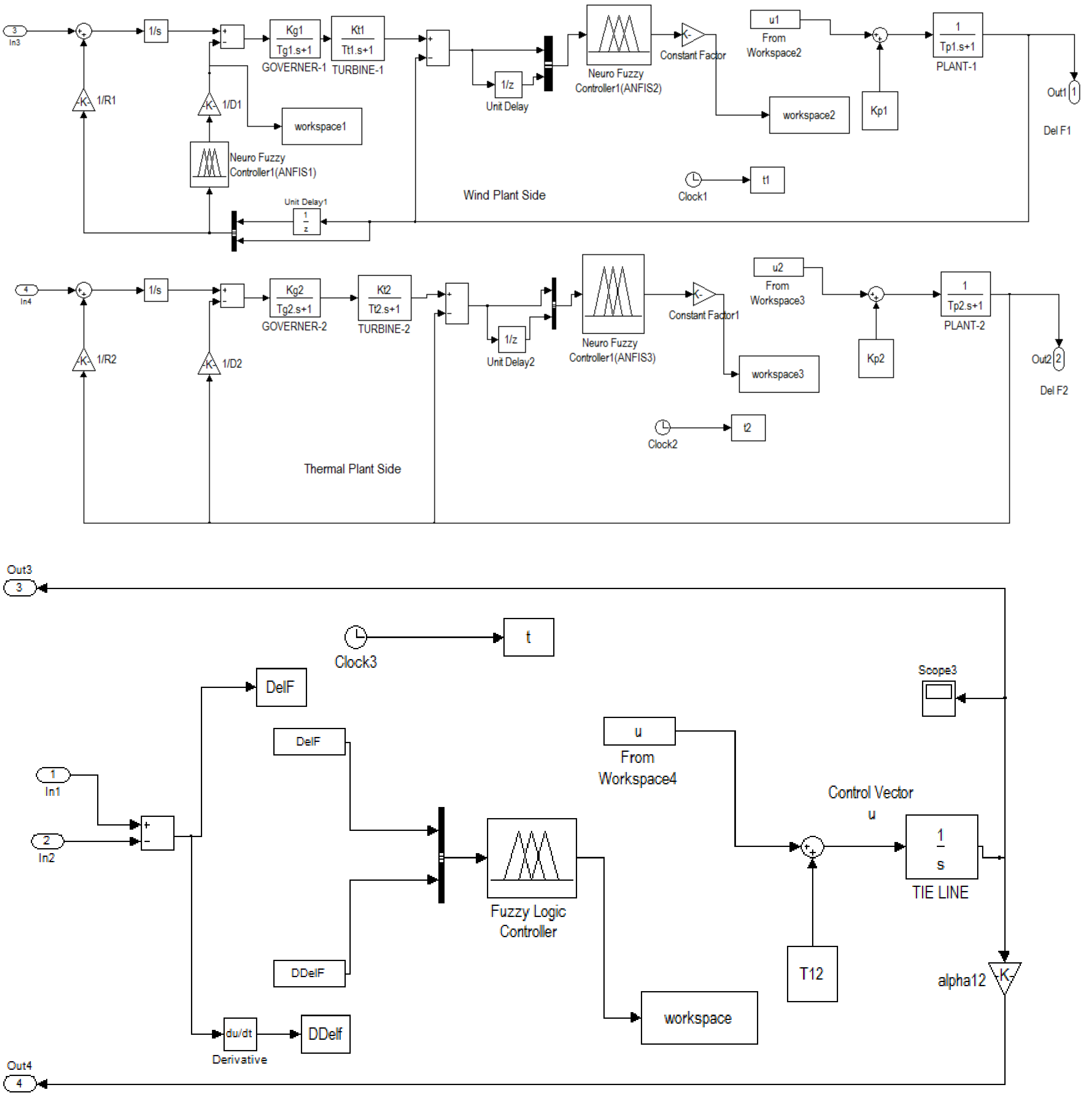

Figure 16. Matlab Simulink model of Test power system with three ANFIS's and Fuzzy Controller

Control vectors of ANFIS-2 and ANFIS-3 are shown in table 2 for control area-1 and control area-2 for response of ΔF_1, ΔF_2. Control vectors for 10 epochs for ANFIS training are shown in figures 17 to 18.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

Table 2: Control vectors of ANFIS-2 and ANFIS-3 for ΔF_1, ΔF_2

S.No.	Control Area-1		Control Area-2	
	u_1	u_2	u_1	u_2
1	0.0015188	0.608401	0.00149922	0.345062
2	0.00153154	0.32171	0.00151429	0.350867
3	0.00152872	0.32182	0.00151687	0.35241
4	0.00153972	0.322241	0.00151517	0.354367
5	0.00153108	0.324281	0.00151933	0.331029
6	0.00152863	0.323043	0.0015053	0.348363
7	0.00152328	0.326743	0.00151163	0.305937
8	0.00152179	0.511909	0.00151294	0.700384
9	0.00151363	1.52947	0.0015118	0.568575
10	0.00151962	0.472503	0.00150289	0.412319

In Control Area-1, Step size decreases to 0.009000 after epoch 5. Step size increases to 0.009900 after epoch 8. In Control Area-2, Step size decreases to 0.009000 after epoch 6.

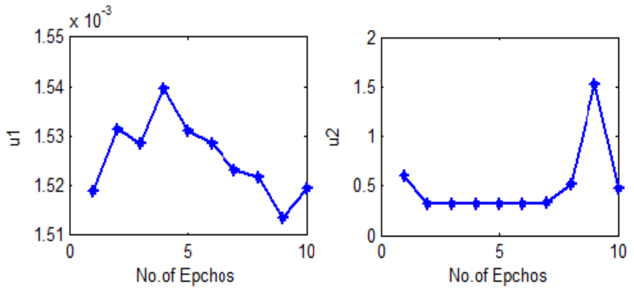

Figure 17. Control vectors u_1, u_2 for response in Control Area-1, ΔF_1

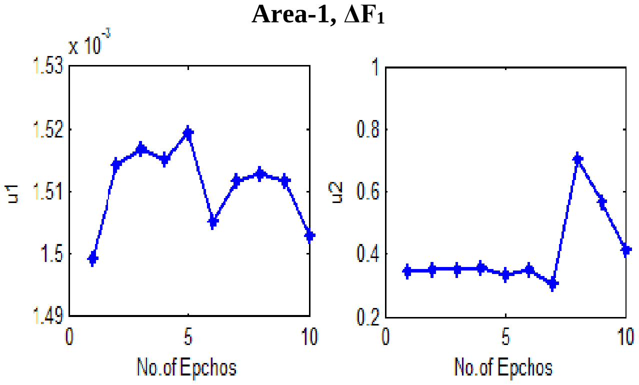

Figure 18. Control vectors u_1, u_2 for response in Control Area-2, ΔF_2

Control vector of ANFIS-2 and ANFIS-3 are shown in table 3 for tie-line power of test system. Control vectors for 10 epochs for ANFIS training are shown in figures 19.

Table 3: Control vectors of ANFIS-2 and ANFIS-3 for ΔP_{tie}.

S.No.	Tie-line Power	
	u_1	u_2
1	0.00149922	0.568527
2	0.00151429	0.612834
3	0.00151687	0.612926
4	0.00151517	0.61332
5	0.00151933	0.520102
6	0.0015053	0.572612
7	0.00151164	0.518039
8	0.00151297	0.723099
9	0.0015111	0.418748
10	0.00149558	0.580489

In interconnection of power system, step size decreases to 0.009000 after epoch 6.

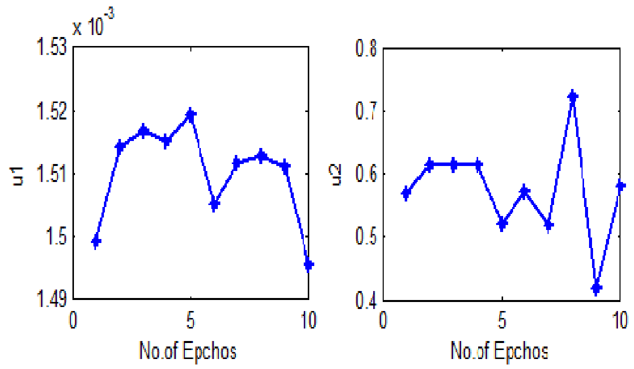

Figure 19. Control vectors u_1, u_2 for Tie-line power, ΔP_{tie}

ANFIS-1 and ANFIS-2 are used in plant to determine the transient response of power system. Similarly ANFIS-3 is used in plant-2. Change in frequency of area-1, ΔF_1 and change in frequency of area-2, ΔF_2 are taken to determine change in frequency ΔF with three ANFIS's. To test power system transfer function blocks are used in simulation model. Obtained transient response of ΔF_1, ΔF_2 are shown in figures 20, 21 for simulated test system. Output response of tie line power is shown in figure 22.

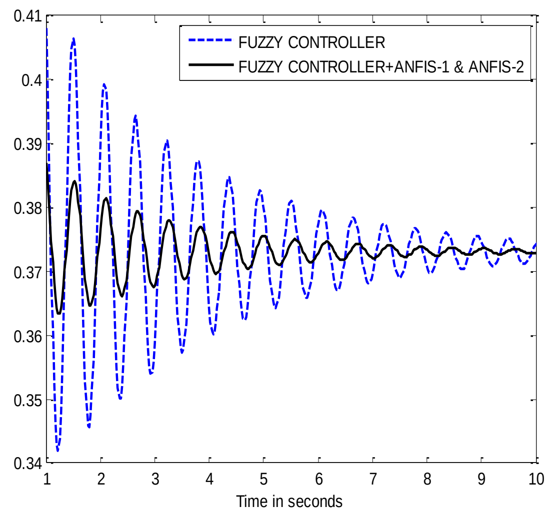

Figure 20. Frequency deviation in Control Area-1, ΔF_1

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

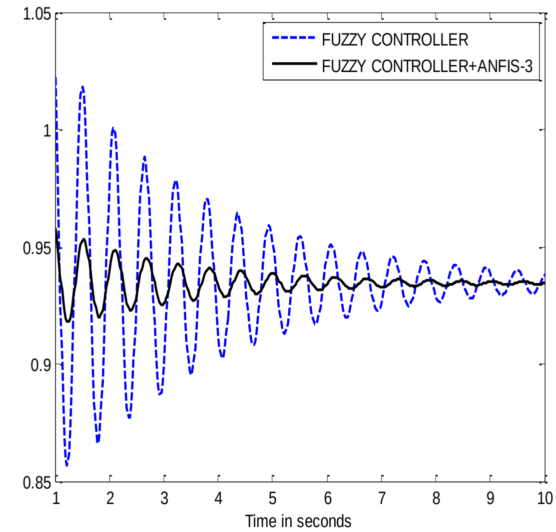

Figure 21. Frequency deviation in Control Area-2, ΔF_2

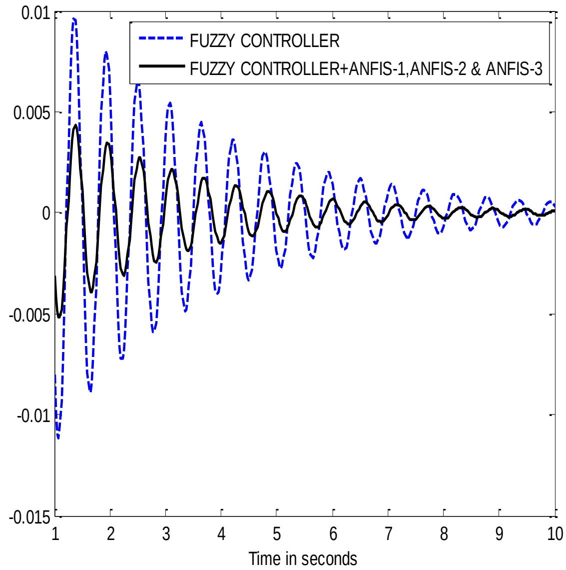

Figure 22. Change in tie line power, ΔP_{tie}

Simulation carried out for response of load variation (0.01p.u.) and shown in figures 23 to 25.

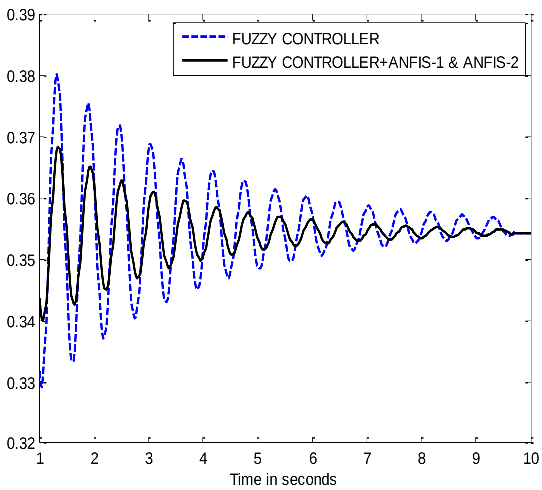

Figure 23. Response of ΔF_1 for 0.01 p.u. change in load variation in CA-1

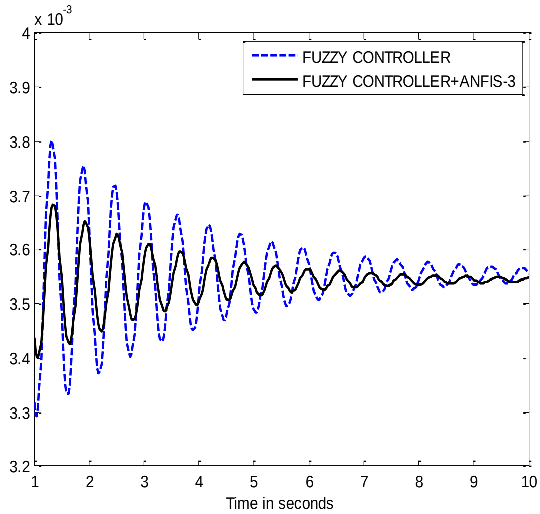

Figure 24. Response of ΔF_2 for 0.01 p.u. change in load variation CA-2

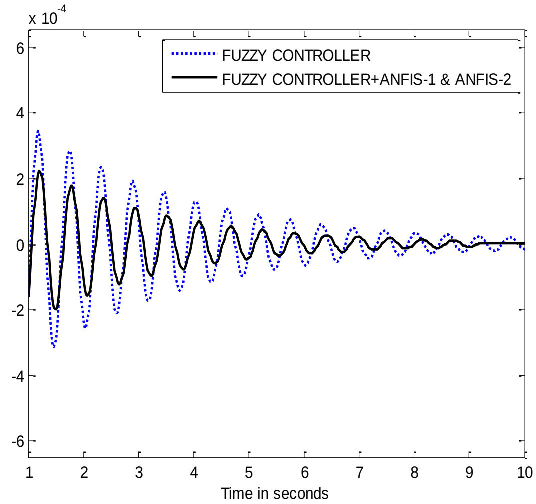

Figure 25. Response of ΔP_{tie} for 0.01 p.u. change in load variation

Analysis has been done and results of output response (Change in frequenciesΔF_1, ΔF_2 and change in tie line power ΔP_{Tie}) are shown in table 3 and table 4. Also output response (Change in frequenciesΔF_1, ΔF_2 and change in tie line power ΔP_{Tie}) for 0.01p.u. change in load variation is also shown in table 4 and table 5.

Table 4. Results Comparison-Settling time

	Fuzzy Controller	Fuzzy+ANFIS Controllers
ΔF_1 in CA-1 (Sec)	11	10
ΔF_2 in CA-2 (Sec)	11	9
ΔP_{Tie} (Sec)	11	10

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

0.01 p.u. Change in Load Variation		
ΔF_1 in CA-1 (Sec)	10.5	9.5
ΔF_2 in CA-2 (Sec)	11	10
ΔP_{Tie} (Sec)	11	8.5

Table 5. Results Comparison – Maximum Overshoot

	Fuzzy Controller	Fuzzy+ANFIS Controllers
ΔF_1 in CA-1	0.408	0.385
ΔF_2 in CA-2	1.04	0.95
ΔP_{Tie}	0.01	0.003
0.01 p.u. Change in Load Variation		
ΔF_1 in CA-1	0.38	0.366
ΔF_2 in CA-2	3.8	3.68
ΔP_{Tie} (Sec)	3.5	2

Response of CA-1 and CA-2 with proposed method is compared with only fuzzy controller. Frequency Oscillations in CA-1 and CA-2 and power oscillation in tie-line of test model are die out at 11 seconds with fuzzy controller, whereas with proposed method oscillations are die out within 10 seconds. With 0.01 p.u. change in load variation, the maximum overshoot is reduced in almost 10% either in frequency and tie-line power oscillations of test model. In all test cases of results shown in table 4 and table 5, it is observed that the performance test model is improved by fuzzy controller with ANFIS's.

V. CONCLUSION

In this present work, the control strategy for improving performance and stability of two area power system based on FLC and Fuzzy Inference Techniques. In proposed work, ANFIS-1 is used to control the gain of speed governor. Here the inputs to ANFIS-2 and ANFIS-3 are taken governor model of plant-1 and plant-2 to frequency oscillations in each control area and tie line power deviation of test system and observed that they has been considerably reduced with test conditions of work. The simulation studies also tested for 0.01p.u. change in load variations of two area test system. In further scope future work, the membership function of ANFIS's structure may be obtained with predetermine techniques and also rules used in fuzzy controller can change with prerequisites of test conditions of power system.

VI. APPENDIX

Base and rated values of Generator are as follows

Base frequency, f_{base} - 50Hz
Base voltage, V_{base} - 450V
Base MVA, S_{base} - 5MW
Base angular frequency, ω_{base} - 2π rad /sec
Stator resistance - 0.01 p.u.
Rotor resistance - 0.015 p.u.
Rated Voltage - 0.44 kV
Rated Power - 3MW
Stator/Rotor ratio - 0.36
Angular Moment of Ineteria, J - 1.5 p.u.
Mechanical damping - 0.01
Stator leakage inductance - 0.54
Rotor leakage inductance - 0.23
Mutual inductance - 4.2

Typical values transfer function parameters of Control area-1are

T_{g1}=0.01, T_{t1}=0.09, H_1=0.132, R_1=1.9, D_1=0.008, T_{12}=0.52. K_{g1}=3, K_{t1}= 0.45, K_{p1}=5.

Typical values transfer function parameters of Control area-2 are

T_{g1}=0.02, T_{t1}=0.05, H_1=0.35, R_1=1.0, D_1=0.019, T_{12}=0.31. K_{g1}=3.5, K_{t1}= 1.48, K_{p1}=10.

REFERENCES

1. Shashi KantPandey, Soumya R.Mohanty, NandKishor, "A literaturesurveyonload – frequency control for conventional and distribution generation power systems", Renewable and Sustainable Energy Reviews, No.25, pp.318–334, 2013
2. Wen Tan, Unified tuning of PID load frequency controller for power system via IMC,IEEE Trans. Power Systems, vol. 25, no. 1, pp. 341-350, 2010.
3. Esmaeil Rezaei, Ahmadreza Tabesh, Member, IEEE, and Mohammad Ebrahimi, "Dynamic Model and Control of DFIG Wind Energy Systems Based on Power Transfer Matrix", IEEE transactions on Power Delivery, pp. 1485-1494, vol. 27, no. 3, 2012.
4. Aldeen, M. and Marah, J.F., "Decentralized Proportional – Plus-Integral Design Method for Interconnected Power Systems", IEE Proceedings-C, Vol. 138, No. 4, 1991.
5. Yamashika, K., and Miyagi, H., "Multivariable self-Tuning Regulator for Load Frequency Control System with Interaction of Voltage on Load Demand", IEEE Proceedings-D, Vol. 138, NO. 2, March 1999.
6. Dr.K.Harinadha Reddy, Member IEEE, Fellow IETE, "Analysis of Load Frequency Control in Power System with GA Computational data to Fuzzy Logic Controller", International Journal of Engineering and Technical Research (IJETR), Vol.2, No.11, 2014
7. MATLAB Supplement to Fuzzy & Neural approach in Engineering, John Wiley NY.
8. Spooner J. T., Maggiore M., Ordonez R., Passino K. M., "Stable adaptative control and estimation for nonlinear system, Neural and fuzzy approximator techniques", Willey-Interscience, 2002.
9. Dr.K.Harinadha Reddy., "Power Control using Fuzzy Logic Controller in DFIG Wind Farm", IJST, vol 2,issue 11, pp 47-51, 2014.
10. Ross T.J. 1995. Fuzzy logic with engineering application. Mc Gro Hill, International Edition.
11. Shayeghi H., Shayanfar H.A. "Power system load frequency control using RBF neural network based on μ-Synthesis theory", Proceeding of IEEE conference on cybernatics and intelligent system Singapore, 1-3 Dec 2004, pp 93-98.
12. L. Fan, H. Yin, and Z. Miao, "On active/reactive power modulation of DFIG-based wind generation for interarea oscillation damping," IEEE Trans. Energy Convers., vol. 26, no. 2, pp. 513–521, Jun. 2011.
13. S. Muller, M. Deicke, and R. De Doncker, "Doubly fed induction generator systems for wind turbines," IEEE Ind. Appl. Mag., vol. 8, no. 3, pp. 26–33, May/Jun. 2002.
14. E. Tremblay, S. Atayde, and A. Chandra, "Comparative study of control strategies for the doubly fed induction generator in wind energy conversion systems:ADSP-based implementation approach," IEEE Trans. Sustain. Energy, vol. 2, no. 3, pp. 288–299, Jul. 2011.

Published By:
Blue Eyes Intelligence Engineering
and Sciences Publication (BEIESP)

15. M. Mohseni, S. Islam, and M. Masoum, “Enhanced hysteresis-based current regulators in vector control of DFIG wind turbines,” IEEE Trans. Power Electron., vol. 26, no. 1, pp. 223–234, Jan. 2011.
16. Z.Wang, G. Li, Y. Sun, and B. Ooi, “Effect of erroneous position measurements in vector-controlled doubly fed induction generator,” IEEE Trans. Energy Convers., vol. 25, no. 1, pp. 59–69, Mar. 2010.
17. Nanda J., Kakkarum J.S., “Automatic Generation Control with Fuzzy logic controllers considering generation constraints”, In Proceeding of 6th Int Conf on Advances in Power System Control Operation and managements” Hong Kong, 2003.
18. Ozkop Emre, H Ismail. Altas, M Adel. Sharaf. 2010. Load Frequency Control in Four Area Power Systems Using Fuzzy Logic PI Controller , 16th National Power Systems Conference, 15th-17th December, Department of Electrical Engineering, Univ. College of Engg., Osmania University, Hyderabad, A.P, India page No,233-236
19. Panna-Ram, Jha A.N. 2010. Automatic Generation control of interconnected hydro-thermal system in deregulated environment considering generation rate constraints, International Conference on Industrial Electronics, Control and Robotics, pp 148-158.
20. Shayeghi H., Shayanfar H. A., Jalili A. 2009. Load frequency control strategies: A state-of-the- art survey for the researcher, Energy Conversion and Management 50, pp 344-353, ELSEVIER.
21. Kundur, P., Power System Stability and Control, McGraw – Hill Book Company, New York, 1994.
22. Saadat, H., Power system Analysis, McGraw – Hill Book Company, New York, 1999.
23. Pan, C. I., and Liaw L.M. “AN Adaptive Controller for Power System Load – Frequency Control”, IEEE on Power System. Vol. 4, No. 1, Feb. 1989, Pp 122 – 128.
24. Dyukanovic, M., “Two-Area Load Frequency Control with Neural Networks,: Proc. 1993. North American Power Symposium, Pp. 161 – 169.
25. Brich, A. P, et.al, “Neural Network Assisted Load Frequency Control”, 28th University Power Engineering Conf. Proc. Vol. 2, 1993, Pp. 518 – 521.
26. Hsu, Y., and Cheng, C., “Load Frequency Control using Fuzzy Logic,” Int. Conf. on High Technology in the Power Industry, 1991, Pp. 32 – 38.
27. Indulka, C. S., and Raj, B., “Application of Fuzzy Controller to Automatic Generation Control,” Electric Machines and Power Systems, Vol. 23, No. 2, Mar- Apr. 1995, pp. 209 – 220. Fuzzy Logic Toolbox user’s Guide.
28. Cirstea N., Dinu A., Khor J.G., McCormick M., “Neural and fuzzy logic control of drives and power systems”, Oxford,Newnes, 2002.
29. Masiala M., Ghnbi M., Kaddouri A. 2004. An Adaptive Fuzzy Controller Gain Scheduling for Power System Load-Frequency Control, IEEE International Conference on Industrial Technology, (ICIT).pp.1515-1520.Mines J. N. 1997.
30. Bose B. K., “Expert system, fuzzy logic, and neural network applications in power electronics and motion control”, Proceedings of the IEEE, vol. 82, NO. 8,pp, 1303-1321, August 1994.
31. Dadios Elmer P., “Fuzzy logic – controls, concepts, theories and applications”, Croatia, InTech, ISBN 978-953-51-0396-7.
32. Aldeen M., “A Fresh Approach to the LQR Problems with Application to Power Systems”, Proc. of Int. Power Engineering Conf., Singapore Vol. 1, 1993, Pp. 374 – 379.
33. Randy L. Haupt Sue Ellen Haupt, “Practical Genetic Algorithms”, Second Edition, John Wiley & Sons, 2004.
34. Simoes, M.G. Bose, B.K. Spiegel, R.J., “Design and performance evaluation of a fuzzy-logic-based variable speed wind generation system” IEEE Trans. On Industry Applications, Vol. 33, no. 4, pp. 956 – 965, July-Aug.1997.
35. Bor-Sen Chen, Chung-Shi Tseng, Huey-Jian Uang, “Robustness Design of Nonlinear Dynamic Systems via Fuzzy Linear Control,” IEEE Fuzzy Systems, vol. 7, no. 5, pp. 571-585, Oct. 1999.

AUTHOR PROFILE

Dr. K. Harinadha Reddy, was born in India on july 02, 1974. He received B.E. degree in Electrical and Electronics Engineering from K.U. in 1997. He completed M.Tech degree in Electrical Power Systems Emphasis High Voltage Engineering from J. N. T. University - Kakinada Campus in 2006. He obtained Ph. D degree in Electrical Power Systems from Andhra University Campus in the year 2012. At present he is working as Professor in Electrical and Electronics Engineering department at LBR College of Engineering (Autonomous). His research interests include power transmission using FACT controllers, AI techniques and their applications to power system operation, stability and control.

Published By:
Blue Eyes Intelligence Engineering and Sciences Publication (BEIESP)