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Analysis of Load Frequency Control in Power System with GA Computational data to Fuzzy Logic Controller

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***Abstract*— This paper will gives analysis and automatic load frequency control of two area power system using Fuzzy Logic Controller (FLC) and also with new generation of set of data from Genetic Algorithm (GA). Change in frequency is used as parental data for getting new generation set of data. Inputs for FLC are obtained from the process of Genetic Algorithm computational set of data. With improved generation set of data, FLC inputs are properly and carefully taken for obtaining control vector from defuzzified output of FLC. The tuning of FLC is necessary to get an output for both dynamic and static performance. The output of self tuned FLC is found reasonably well over these conventional controllers. This paper is concentrated for developing the algorithm to load frequency control and tie line power of two area test system.**

***Index Terms*— Load Frequency Control, Interconnected Power System, Fuzzy Logic Controller and Genetic Algorithm.**

NOMENCLATURE

P_G, P_D	**Generator, load powers**
ΔP_{G1} - ΔP_{D1}	**Net Surplus Power**
ΔP_{tie-1}, ΔP_{tie-1}	**Incremental Tie line power in area-1, 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**
R_1,R_2	**Feedback gains control area-1,2**
B_1, B_2	**Load damping parameters**
H_1,H_2	**Inertia Constant generator-1,2**
u	**Control vector from output of FLC**
x_{ik}	**New generation set of data**
f(x)	**Fitness function**
n	**Value of data point at instant**
p	**Previous data set point**
k_{max}, k_{min}	**User defined constant**
C	**Scaling factor according to fitness function**
ε_i	**Decreasing sequence of real numbers**

I. INTRODUCTION

Big importance is giving to control of power generation and transmission for obtaining smooth operation of power system. The modern power systems with industrial and commercial loads need to operate at constant frequency [15] with reliable power. 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.

Fuzzy [25] base type of controller adds better results in system control and also to reducing the steady 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[1], also propose work result gives better performances of dynamic responses.

The 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 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 and tie line power according to the system dynamics. Both conventional and fuzzy are similar in the sense that these two techniques are population based heuristic search methods and they approach for the optimal solution by latest updates.

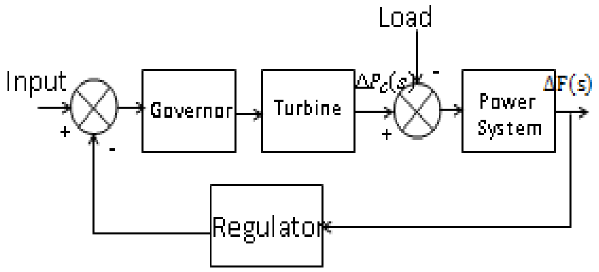

Figure 1. Block Diagram of test Power System

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

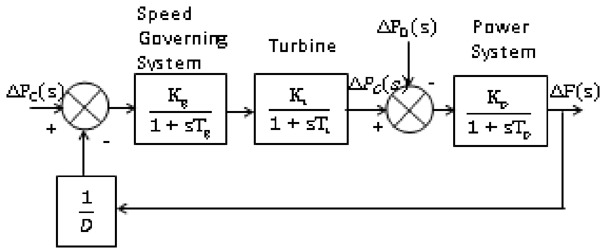

Figure 2. Mathematical Modelling of Block Diagram of test Power System

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In order to analyse the load frequency control[4] of power system with mathematical modelling, the needful transfer functions[15] of model are

Transfer function of Speed Governor

$$\frac{K_g}{1+sT_g} \qquad (1)$$

Transfer function of Turbine

$$\frac{K_t}{1+sT_t} \qquad (2)$$

Transfer function of Power System

$$\frac{K_p}{1+sT_p} \qquad (3)$$

A. GENERATOR-LOAD MODEL

Mathematical model of Generator which supply power to load

$$\Delta P_G - \Delta P_D = \left(\frac{2H}{f_0}\frac{d}{dt}\Delta f\right) + (B\Delta f) \qquad (4)$$

$$\Delta F(s) = \frac{\Delta P_G(s) - \Delta P_D(s)}{B + \frac{2H}{f_0}s} \qquad (5)$$

$$\Delta F(s) = [\Delta P_G(s) - \Delta P_D(s)] \times \frac{K_p}{1+sT_p} \qquad (6)$$

And we can represent block diagram in figure 3.

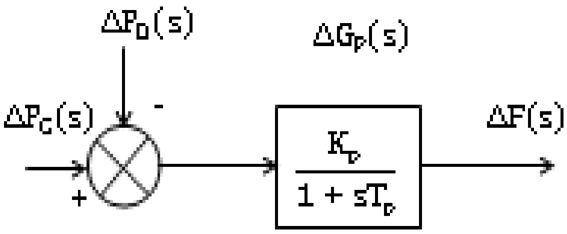


Figure 3. Block diagram of Generator-Load Model

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

$$\Delta F(s) = \frac{-K_p \times \Delta P_D(s)}{(1+sT_p) + \left[\frac{K_g K_t K_p}{(1+sT_g)(1+sT_t)}\right]} \qquad (7)$$

B. INTERCONNECTED POWER SYSTEM

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

$$P_{tie-1} = \frac{|V_1||V_2|}{X_{12}} \operatorname{Sin}(\delta_1^0 - \delta_2^0) \qquad (8)$$

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

Incremental frequency,

$$\Delta f = \frac{1}{2\pi}\frac{d}{dt}(\Delta\delta) \qquad (9)$$

$\Delta\delta$ – Phase angle deviation

Incremental tie line power in Area-1, 2

$$\Delta P_{tie-1} = 2\pi T_{12}\left[\int \Delta f_1\, dt - \int \Delta f_2\, dt\right] \text{p.u.} \quad (10)$$

$$\Delta P_{tie-2} = 2\pi T_{21}\left[\int \Delta f_2\, dt - \int \Delta f_1\, dt\right] \text{p.u.} \quad (11)$$

Net Surplus Power

$$\Delta P_{G1} - \Delta P_{D1} = \frac{2H_1}{f}\frac{d}{dt}(\Delta f_1) + B_1\Delta f_1 + \Delta P_{tie-1} \qquad (12)$$

Laplace transform of above equation

$$[\Delta P_{G1}(s) - \Delta P_{D1}(s) - \Delta P_{tie-1}]G_{p1}(s) = \Delta F_1(s) \qquad (13)$$

Block diagram of system is depicted in figure 4.

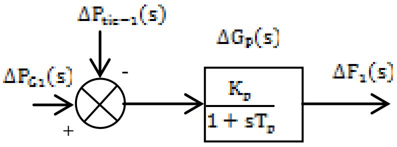


Figure 4. Mathematical of Model of Interconnected Power System block diagram

III.DESIGN OF PROPOSED CONTROLLER FOR TEST SAMPLE OF POWER SYSTEM

Simulation of test system can be done with all defined transfer functions of block diagram shown in figure 1 and figure 2. Original values of data set are change in frequencies $\Delta F(s)$ and $\Delta \dot{F}(s)$. In many available solutions, GA plays crucial role to generate[26] new set of data accordance survival of fitness. The evaluation process with development algorithmatic steps goes in natural way of related GA theory and concepts.

To achieve the better set of generation from test data for solution has to complete main stages of

i) Parent Selection and Reproduction
ii) Crossover
iii) Mutation

For getting new generation quietly good and fit for all possible test conditions of system environment, the process of all stages said above has to be complete with most care and systematically. Mathematical representation of data mapping and constant for sealing at any instant

$$k_i = \sum_{i=1,2,3\ldots n}^{p=1,2,3\ldots m}\left[k_{min} + \frac{n}{2^p - 1}\left(k_{max(i)} - k_{min(i)}\right)\right] \qquad (14)$$

n – Value of data point at instant
p – Previous data set point
k_{max}, k_{min} – User defined constant

Normal line fit equation

$y = x(k_1) + k_2$

Data set for new generation was considered $\Delta_{F=}\Delta\dot{F}$ as equalent terms of x and $\dot{x}$. Sample test also shown Table 1 and 2 respectively

For finite number solutions

$$x_i = \sum_{i=1,2,3\ldots n}\frac{2i-1}{k} + \varepsilon_i \qquad (15)$$

ε_i - Decreasing sequence of real numbers

$$f(x) = C - \sum_{i=1,2,3\ldots n}\left[y_i^r - y_i^{r-1}\right] \qquad (16)$$

‘C’ can be taken accordance to fitness function scaling.

Generate set of x with count ‘kth ‘ instant

$$x_{ik} = \frac{mx+k}{f(x)} = \frac{f}{f(x)} \qquad (17)$$

Where f = mx+k

m - data scaling factor with moderation value ‘k’

New set of data for updation

$$x_{ik}^{r+1} = \sum_{i=1,2,3..n}^{k=1,2,3...m} \left[\frac{f(y_{ik})}{f(x_i)} \times x_i \right] \qquad (18)$$

A. GENETIC ALGORITHM FOR REGENERATION OF NEW DATA SET

The sequential steps for searching optimal solution for change frequency using GA as shown in figure 5.

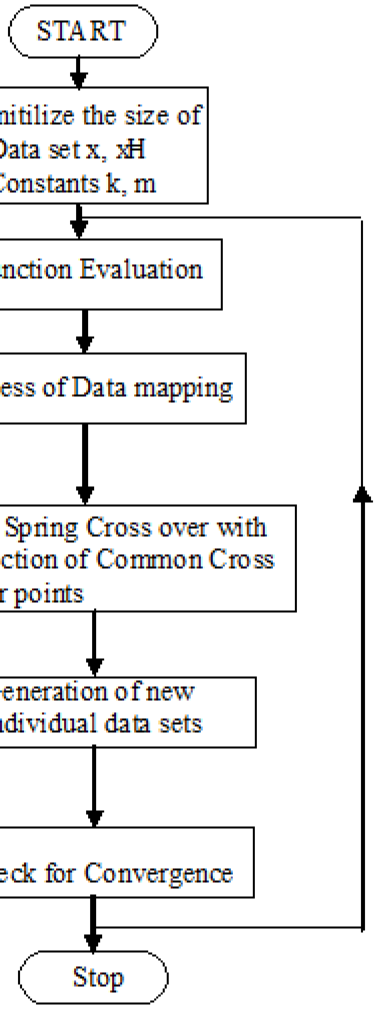


Figure 5. Flow chart of GA Process

The following algorithm describes the use of GA for determining the values of new generation of data sets.
(i) Select a set of data points from the test system i.e. change in frequency of plants.
(ii) Evaluate the Performance to fit the data in given range of input to FLC.
(iii) With proper selection, off spring crossover and mutation, new set of generation of data can obtained.
(iv) After obtaining the Generation of new individual datasets, can be normalized.
(v) The optimum integral feedback controller gain of case(i) and case(ii) at nominal condition.
The change values of frequencies $\Delta F(s)$ and $\Delta F^{*}(s)$ can be reproduced with following step by step algorithm.After Evaluation process the new data set of generation is tabulated in Table 1.

Data No.	Evaluation Function	C_1	C_2	Y_1	Y_2	f(x)	$f(x^*)$
5	1.8	-3	2	-6	-2	-0.6	1.33
7	3.2	-2	-3	4	5	1.1	1.12
16	2.32	-6	2	4	3	1.2	1.81
25	1.93	-1	3	4	-2	0.48	1.21
31	2.12	3	-1	2	6	0.72	1.91
46	1.62	1	4	3	-1	0.61	1.82
53	1.11	2	-1	-1	1	0.52	1.18
60	3.02	6	5	1	-1	0.92	1.20
73	2.83	4	-2	7	8	-1.2	1.62
82	1.06	4	1	-1	1	0.29	1.90
94	1.8	1	4	-1	1	1.81	1.02

Table 1. Sampled data and Evalution of fitness function, f(x). Sampled data for reproduction can fit in particular range and determine from evaluation function using equation 15,16. Two cross over point[22] used to get new generation. New generation set of data is shown in figures 6, 7 for 100 and 200 iterations

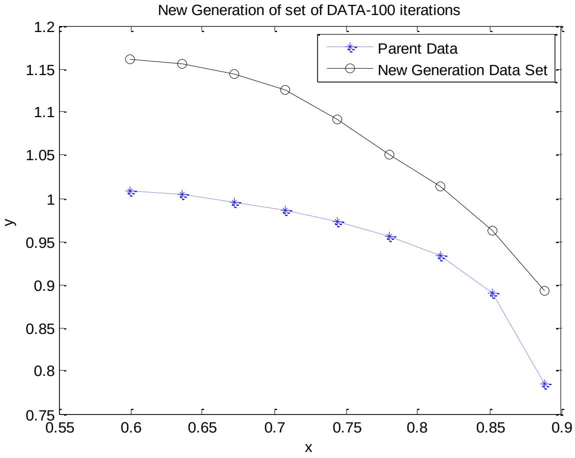


Figure 6. New generation set of data-100 iterations

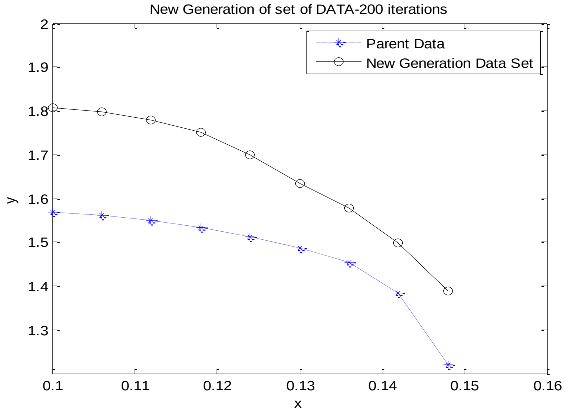


Figure 7. New generation set of data-200 iterations

B. FUZZY LOGIC CONTROLLER WITH GA REPRODUCED INPUTS

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

- Fuzzification,
- Rule base,
- Inference engine and
- 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 gives very good results like this application. Inputs for fuzzy logic controller are used from new generation set of data as obtained from GA process.

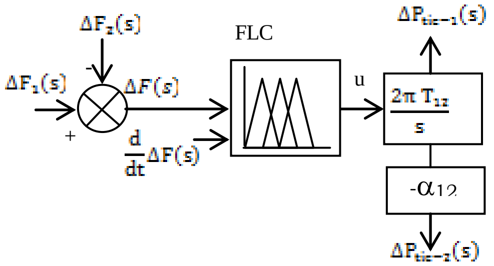


Figure 8. Fuzzy Logic Controller with New generation set of data as input

Inputs to a fuzzy logic controller are usually an error ‘e’ and a change of error ‘Δe’. Here the two inputs for fuzzy logic controller are $\Delta F(s)$ and $\Delta F'(s)$. The values that indicate input variables change of frequency and derivative of change in frequency. Linguistic terms used for the membership functions such that are terms 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 9 and Figure 10. Membership function of output of control vector is shown in Figure 11. 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 to the actual value.

That means the output values such 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 some amount of 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.

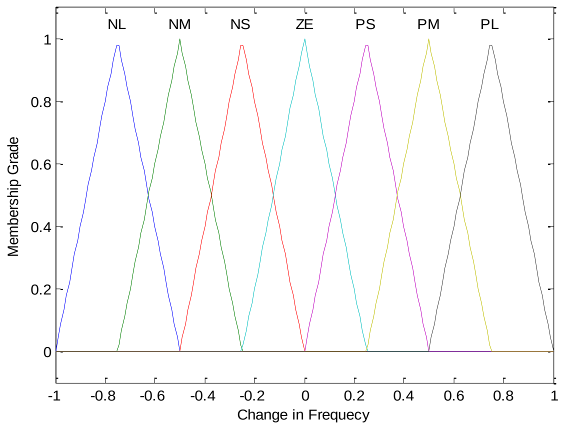


Figure 9. 1^{st} Input membership functions, $\Delta F(s)$

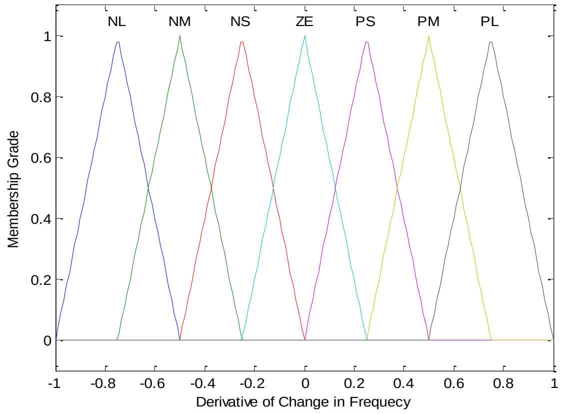


Figure 10. 2^{nd} Input membership functions, $\Delta F'(s)$

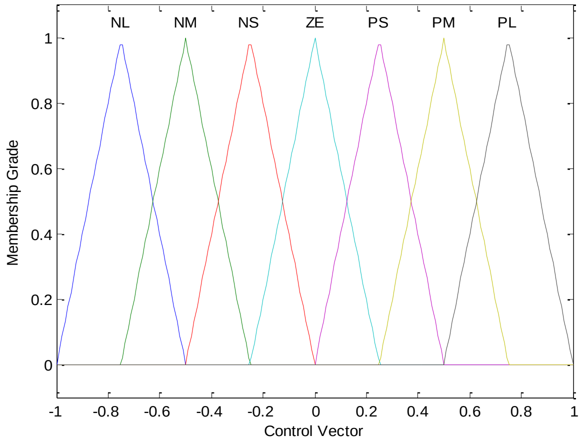


Figure 11. Output Membership Function, u

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 as 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 $\Delta F'(s)$). Fig. 9, 10 and 11 shows the membership functions for the ΔF , $\Delta F'(s)$ and the control output u. The input signals 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).

$\Delta F(s)$	$\Delta \dot{F}(s)$						
	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

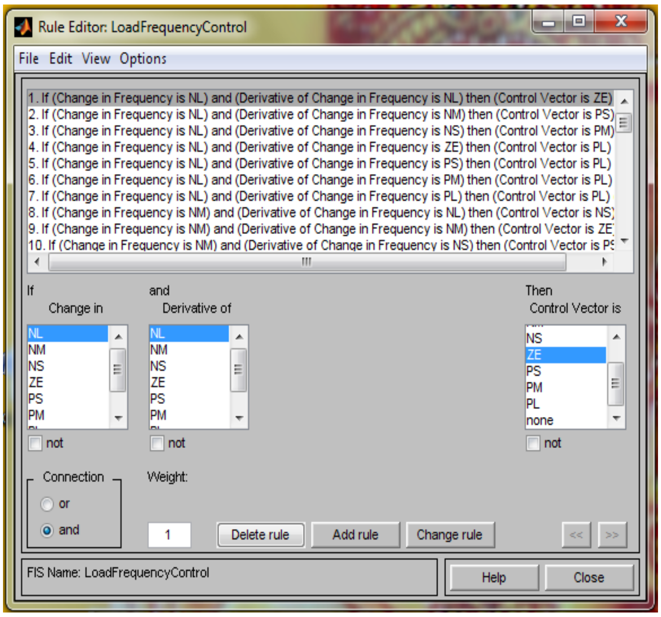
Table 2: Decision table of 7×7 rule base

Table 2 shows a set of decision rules[9], also expressed in linguistic variables relating input signals to the control signal.

The rules interpreted as follows:

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

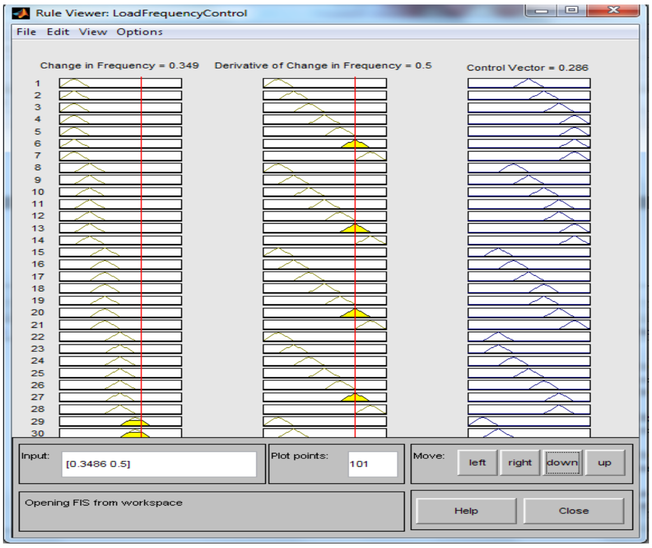
Similarly remaining all rows of decision table will be written as 'IF' and 'THEN' propositions. Propositions (IF, THEN) with all 49 rules are used to develop programming code in MATLAB. After developing rule base in matlab, the following figure 12 show all rules [6] in MATLAB window. Figure 12 interpretation of some sample of rules with input 1 is 0.349 and input 2 is 0.50 and also evaluation of these two inputs to obtain control output vector. The value of control vector, u is determined as 0.266 from simulation of two inputs



1. If (Change in Frequency is NL) and (Derivative of Change in Frequency is NL) then (Control Vector is ZE)
2. If (Change in Frequency is NL) and (Derivative of Change in Frequency is NM) then (Control Vector is PS)
3. If (Change in Frequency is NL) and (Derivative of Change in Frequency is NS) then (Control Vector is PM)
4. If (Change in Frequency is NL) and (Derivative of Change in Frequency is ZE) then (Control Vector is PL)
5. If (Change in Frequency is NL) and (Derivative of Change in Frequency is PS) then (Control Vector is PL)
6. If (Change in Frequency is NL) and (Derivative of Change in Frequency is PM) then (Control Vector is PL)
7. If (Change in Frequency is NL) and (Derivative of Change in Frequency is PL) then (Control Vector is PL)
8. If (Change in Frequency is NM) and (Derivative of Change in Frequency is NL) then (Control Vector is NS
9. If (Change in Frequency is NM) and (Derivative of Change in Frequency is NM) then (Control Vector is ZE
10. If (Change in Frequency is NM) and (Derivative of Change in Frequency is NS) then (Control Vector is P

FIS Name: LoadFrequencyControl

Figure 12. Rule base in Matlab window



Change in Frequency = 0.349
Derivative of Change in Frequency = 0.5
Control Vector = 0.286

Input: [0.3486 0.5]
Plot points: 101

Opening FIS from workspace

Figure 13. Excution of fuzzy rules in Matlab.

After developing rule base in matlab, the following figure 13 gives show the how rules will excute the two inputs to all propositions.

IV.SIMULATION OF TEST SYSTEM AND RESULTS

Simulation is carried for two area test power system. Each area is represented by governor, turbine and plant; also two areas are combined with tie line. MATLAB simulink is used for development of test system and shown in figure 14.

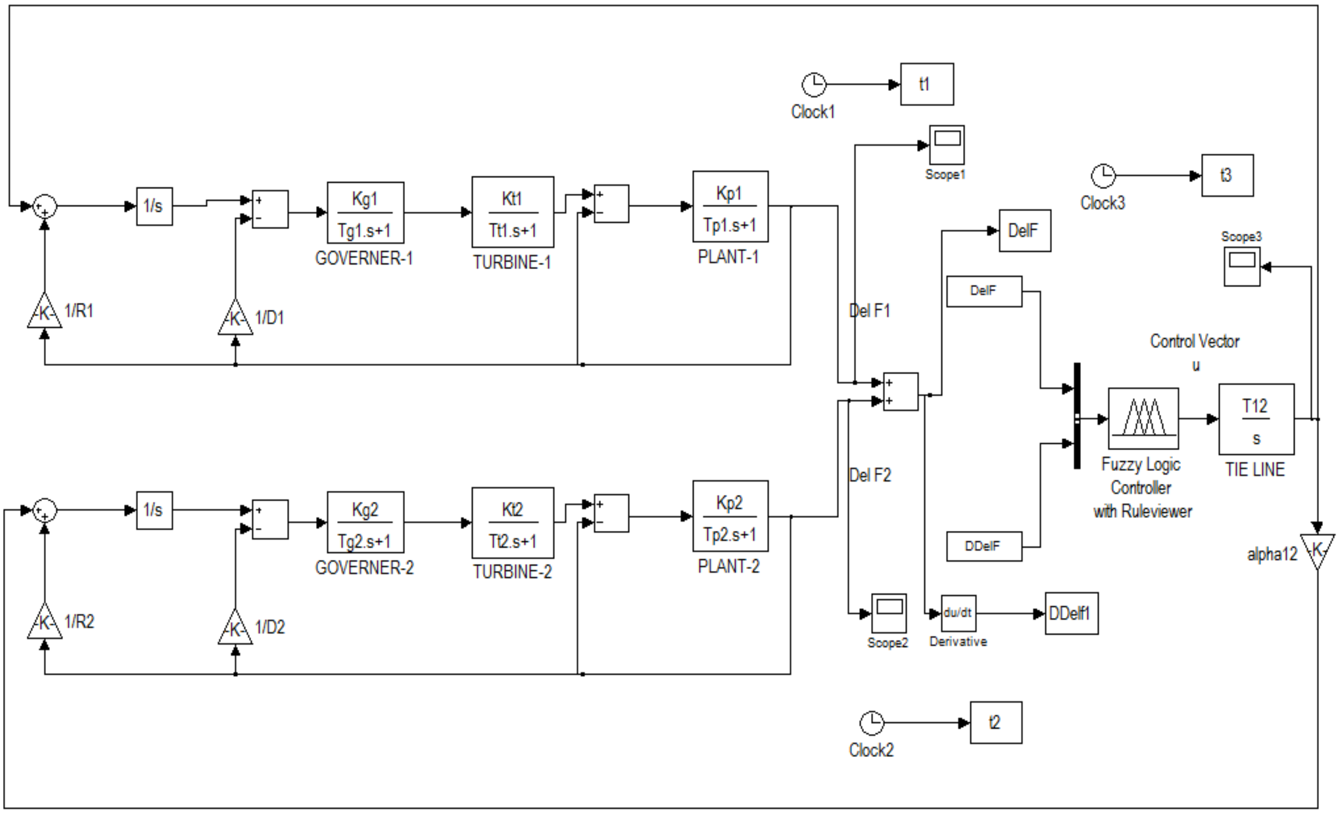


Figure 14. Matlab Simulink model of two area power system.

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. To test power system transfer function blocks are used in simulation model. Obtained transient response of ΔF_1, ΔF_2 are

shown figures 15, 16 for simulated test system. Output response of tie line power is shown in figure 17.

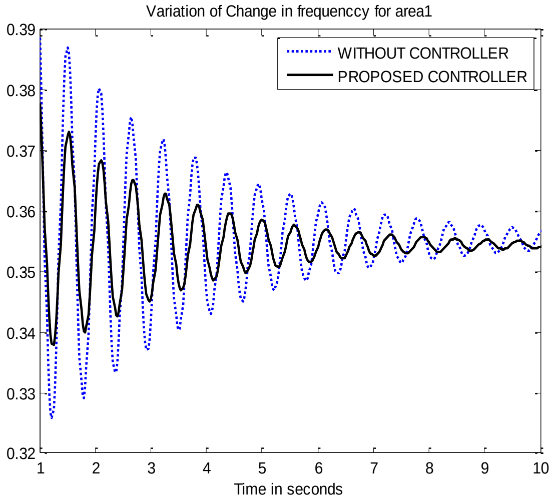


Figure 15. Frequency deviation in area-1, ΔF_1

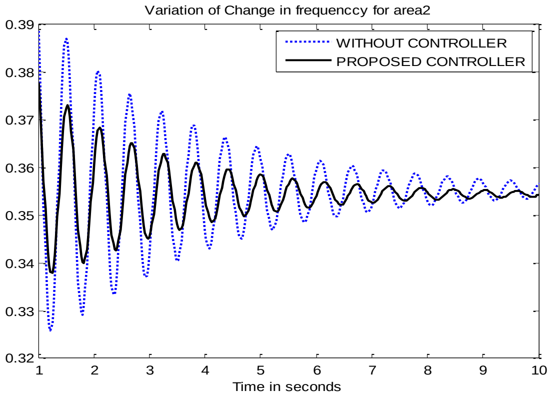


Figure 16. Frequency deviation in area-2, ΔF_2

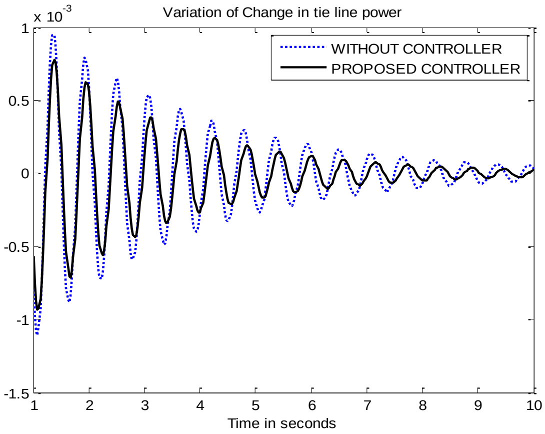


Figure 17. Change in tie line power, ΔP_{tie}

Simulation carried out for response of load variation (1-2%) and shown in figures 18 to 23.

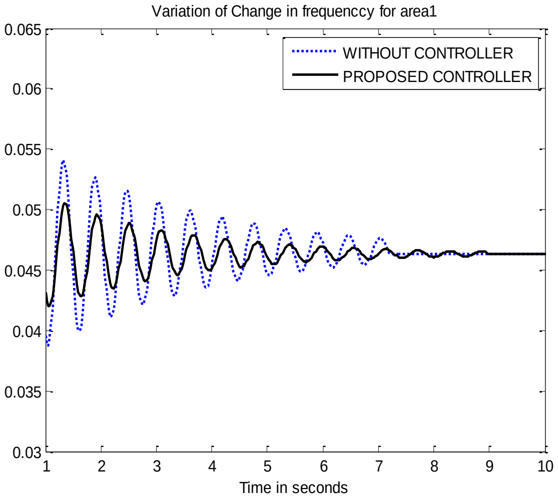


Figure 18. Response of ΔF_1 for 1% load variation

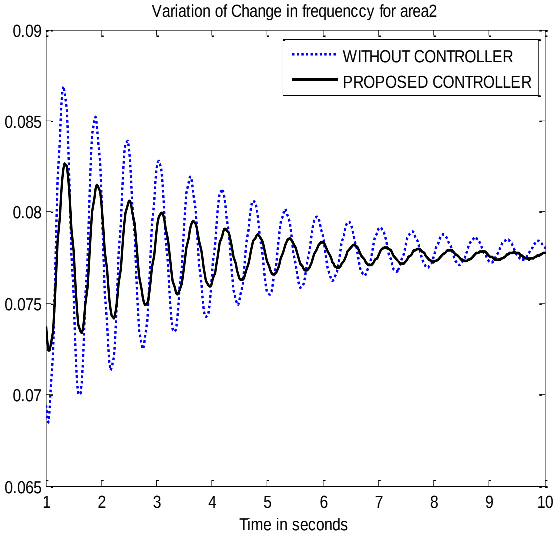


Figure 19. Response of ΔF_2 for 1% load variation

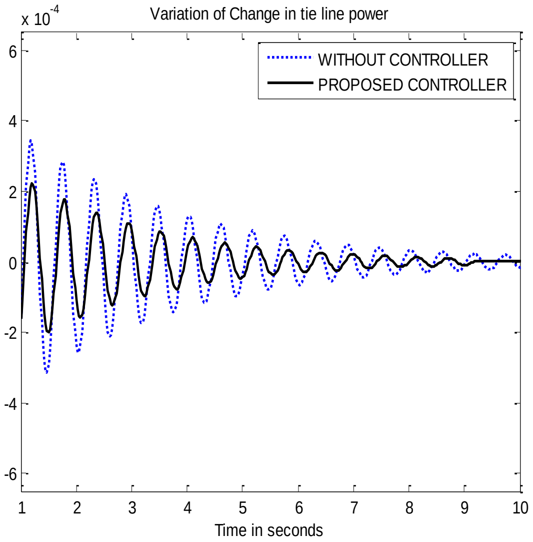


Figure 20. Response of ΔP_{tie} for 1% load variation

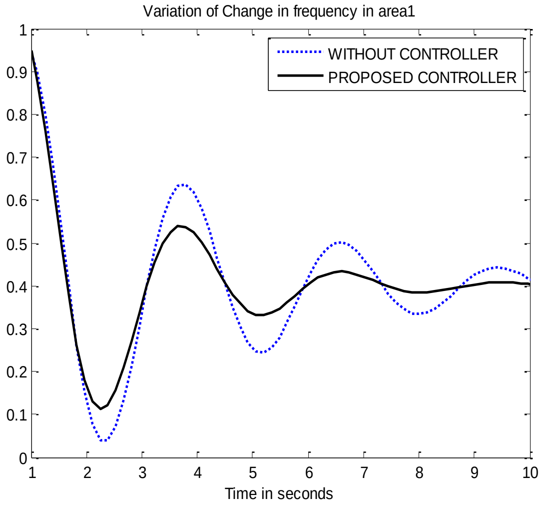


Figure 21. Response of ΔF_1 for 2% load variation

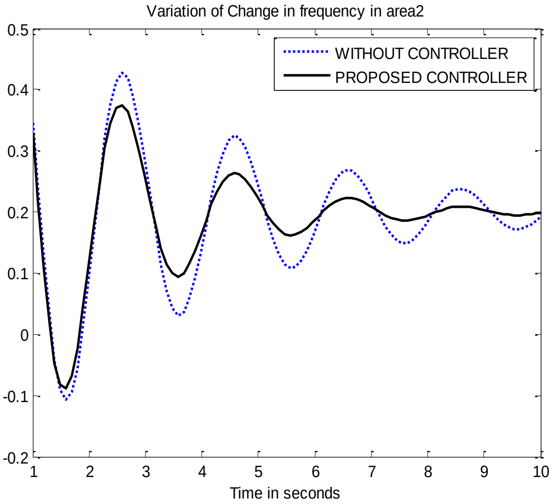


Figure 22. Response of ΔF_2 for 2% load variation

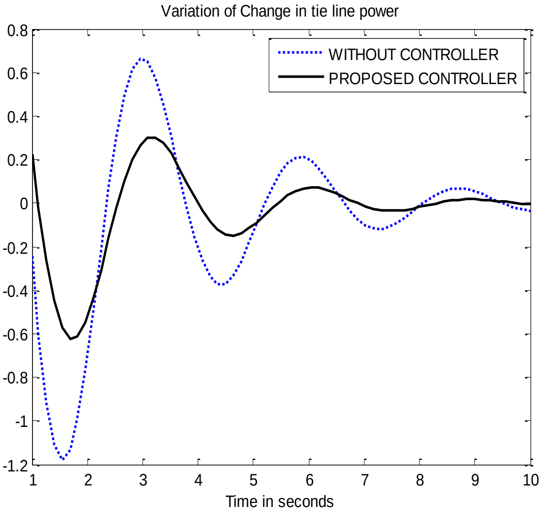


Figure 23. Response of ΔP_{tie} for 2% load variation

Comparative study of output response (Change in frequenciesΔF_1, ΔF_2 and change in tie line power ΔP_{Tie}) is 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 1 to 2% load variation also shown in table 3 and is shown in table 4.

		ΔF-Area1 (Sec)	ΔF-Area2 (Sec)	ΔP_{Tie} (Sec)
Without Controller	Without load variation	10	9	9
	1% load variation	13	8	10
	2% load variation	9	11	11
Proposed Controller	Without load variation	9	7.5	8
	1% load variation	8	7	8
	2% load variation	7.2	10	9

Table 3. Results Comparison-Settling time

		ΔF-Area1 (p.u)	ΔF-Area2 (p.u.)	ΔP_{Tie} (p.u.)
Without Controller	Without load variation	0.385	0.388	0.0009
	1% load variation	0.95	0.35	-1.2
	2% load variation	0.055	0.0875	3.2×10^{-4}
Proposed Controller	Without load variation	0.371	0.371	0.00065
	1% load variation	0.81	0.30	-0.6
	2% load variation	0.05	0.0825	2.1×10^{-4}

Table 4. Results Comparison – Overshoot

V. CONCLUSION

This paper has presented a control strategy for improving performance and stability of two area power system based on FLC and new generation set of data calculated from Genetic Algorithm process. In proposed work the inputs to FLC are calculated from fitness function of genetic algorithm. Frequency deviation in each control area and tie line power deviation of test system has been considerably increased with proposed method. The simulation studies show that proposed method can able to reduce the 1-2% load variations of two area test system.

APPENDIX

Base and rated values of Generator are as follows
Base frequency, f_{base} - 50Hz
Base voltage, V_{base} - 550V
Base MVA, S_{base} - 5MW
Base angular frequency, ω_{base} - 2π rad /sec
Stator resistance - 0.021 p.u.
Rotor resistance - 0.015 p.u.
Rated Voltage - 0.39 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

$T_{g1}=0.02$, $T_{t1}=0.09$, $H_1=0.132$, $R_1=2.1$, $D_1=0.0069$, $T_{12}=0.52$. $K_{g1}=5$, $K_{t1}= 0.5$, $K_{p1}=20$.

Typical values transfer function parameters of Control area-2 are

$T_{g1}=0.013$, $T_{t1}=0.05$, $H_1=0.52$, $R_1=1.0$, $D_1=0.021$, $T_{12}=0.31$. $K_{g1}=4$, $K_{t1}= 1.8$, $K_{p1}=10$.

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